3.7. Time Domain Reflectometer (TDR)

3.7.1: TDR Measurements and Calibration Techniques

TDR (time domain reflectometer) measurements meet ideally the needs of modeling components with geometric extension. This type of devices include packages, connectors, strip lines on PC boards (printed circuit) etc. The advantage of TDR measurements is that the individual components of the DUT appear at separate time slots in a direct relation to their location. The NWA dilemma, namely that all sub-components of the DUT add basically to the 'turning to the right' of the Smith chart, and thus overlay each other's effect, is easily avoided by this method.

Basically, a TDR is a very fast GHz oscilloscope including a fast pulse generator in the picoseconds range. This fast pulse with an amplitude of usually 400mV is applied to the DUT, and the backreflections of that voltage are displayed on the oscilloscope. Therefore, the time axis on that plot corresponds to the physical location of the event on/in the DUT.

For example, when an OPEN ended line is connected to the TDR output, the resulting oscilloscope reading shows a 200mV amplitude (voltage divider: 50Ω internal resistance and 50Ω characteristic impedance of the line), as long as the impulse is present in the line. Once the open end is reached, there is a jump to 400mV. Otherwise, if the line is SHORTed at its end, the impulse again sees a 50Ω characteristic impedance (while still in the line), yet disintegrates to 0V when hitting the SHORT at the end of the line.

If there is a capacitor between two 50Ω lines, the reflected signal with its level of 200mV (in line 1 in fig.1) will briefly drop down to 0V, 'seeing' the capacitor as a SHORT for the first moment, and then ascend back to 200mV (line 2) with an exponential rise that is proportional to the capacitance value. In case there is an inductor instead of the capacitor, the reflected signal will jump to a full 400mV (because the inductor behaves like an OPEN in the first moment) to once again come back to the 200mV level of line 2.

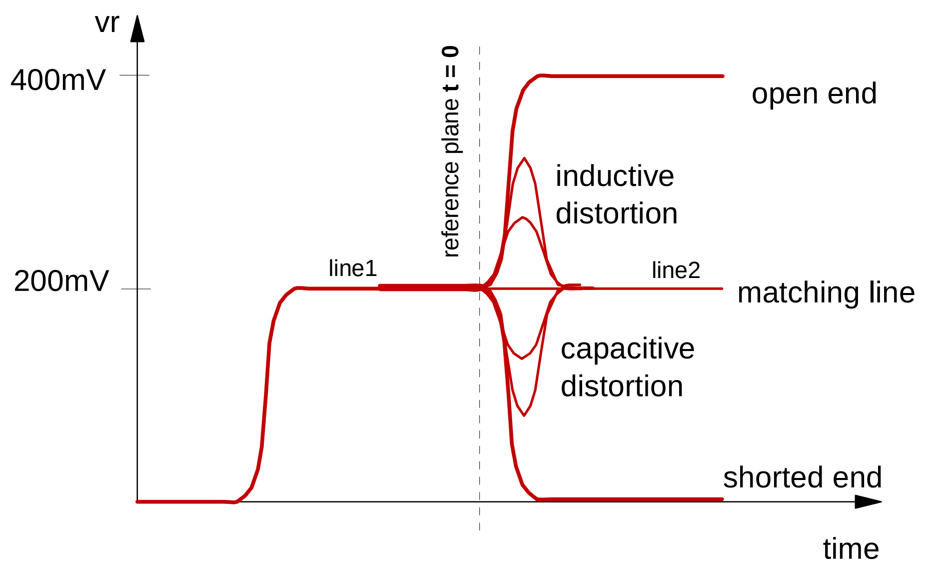

Fig. 1: time domain reflectometry (TDR)

A connector between two lines is commonly seen by a TDR like a short overshoot followed by a short undershoot. We now know what this would mean for modeling: the overshooting represents an inductor L, while the undershooting hints to a capacitor C. Fig. 2 shows such a TDR measurement.

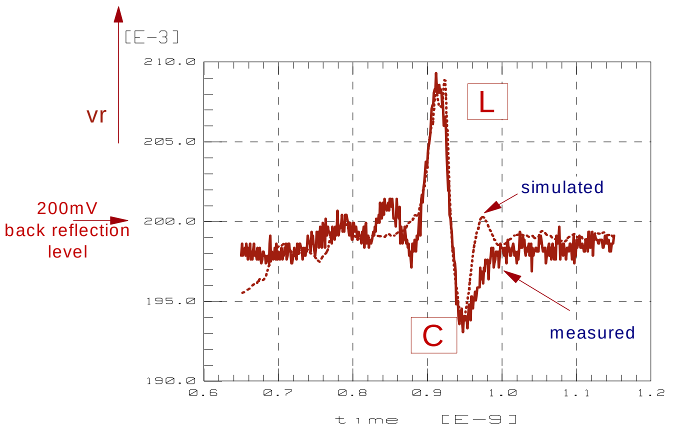

Fig. 2: TDR measurement of a connector.

Note: The basic principles of understanding TDR measurements are summarized in the chapter entitled 'Interpreting TDR Measurements'.

CALIBRATION TECHNIQUES

When measuring and modeling a packaged device in the GHz region, it must be placed in a test fixture. Therefore, when using a TDR, we have to do a calibration of the reflected signal first. This is done by the following two steps:

1.) model the step impulse of the TDR
(either using the SPICE step function with the parameters slope, start and end value, or more accurately, using a sum of PWL function (piecewise linear) of the simulator)

2.) determine the length of the connection cable
(modeled using a delay line)

After that, we connect the cable to the test fixture, model it and, finally, model the component itself. Fig. 3 illustrates these steps.

Because of the sequence of modeling steps, it is always very easy to determine the part of the equivalent schematic related to the test fixture or the DUT itself.

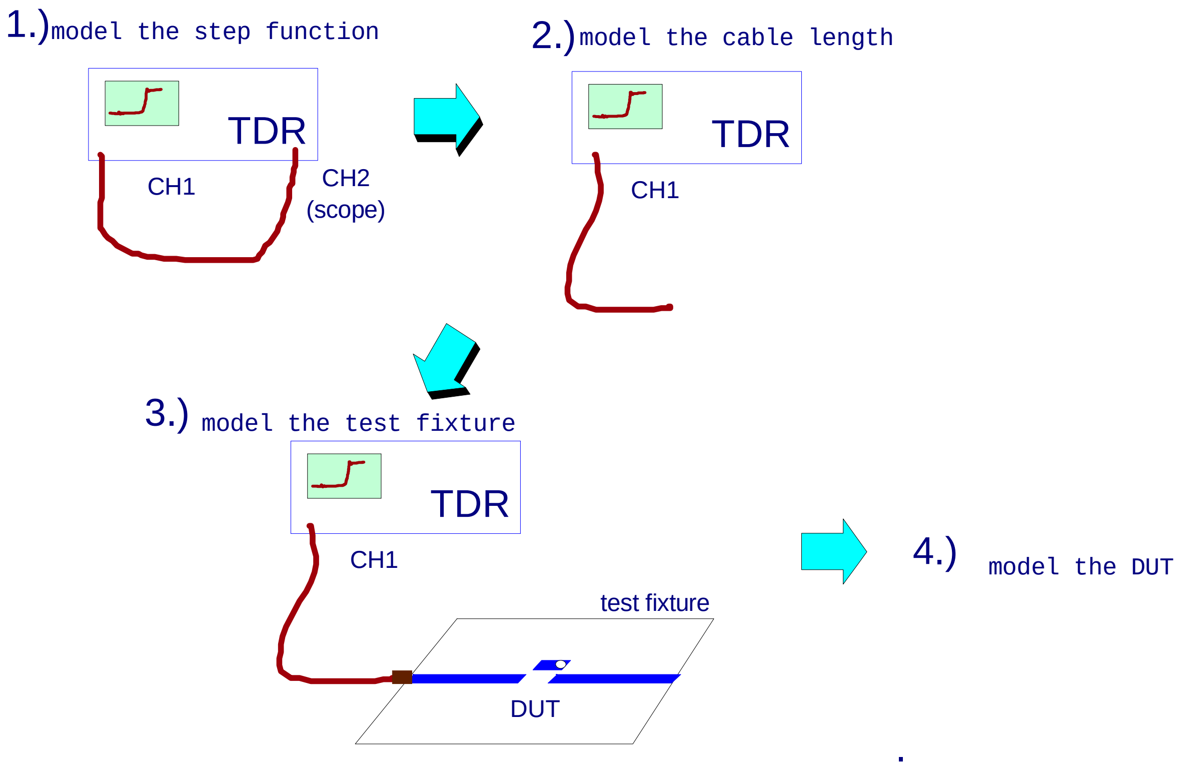

Fig. 3: the individual steps to calibrate a TDR and to perform modeling measurements

<u>TDR CALIBRATION UNDER IC-CAP:</u>
examples about how to calibrate the TDR step function and the test cable in IC-CAP, can be found in the following IC-CAP model file
$ICCAP_ROOT/examples/demo_features/4extraction/specific_PEL_routines/tdr_cal.mdl

Publications:

Advanced TDR techniques, Hewlett-Packard Application Note 62-3,
Publication HP5952-1141, April 1990.

Evaluating Microstrip with Time Domain Reflectometry,
Hewlett-Packard Application Note 1304-1, Publication HP5968-0007E, August 1998

Time Domain Reflectometry Theory,
Hewlett-Packard Application Note 1304-2, Publication HP5966-4855E, May 1998