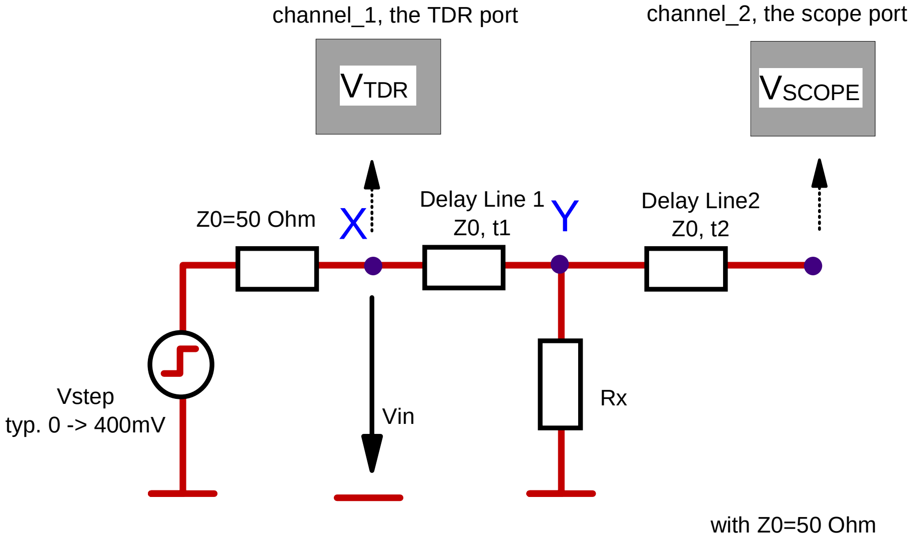
3.7.2.1: Basics of TDR Measurements

This chapter is intended to make you familiar with TDR measurements and the interpretation of TDR plots.

Let's commence with some basic TDR theory:
Assuming we have the following measurement, an unknown resistor Zx to ground between two 50 Ohm delay lines



At any point within the tested device, there is a backreflected and an on-going voltage:

$$v_{refl} = v_{in} \frac{Z - Z_0}{Z + Z_0} \qquad (1) \qquad\qquad v_{thru} = v_{in} \frac{2 * Z}{Z + Z_0} \qquad (2)$$

with Z : impedance seen in forward direction at the actual location.

Example:
Be `Vstep = 1` (normalized), then `Vin = 0.5` when the step hits the location **X** at t=0.
At location **Y** , we have after time t1 and with `Rx = 50 Ohm` using equ.(1):

$$Vrefl = \frac{1}{2} * \frac{25 - 50}{25 + 50} = - \frac{1}{6} \qquad (3)$$

This voltage Vrefl is reflected back to the TDR port and seen there after time `2 * t1` overlaying the on-going Vin=0.5 as

$$VTDR = Vin + Vrefl \overset{(3)}{=} \frac{1}{2} - \frac{1}{6} = \frac{1}{3} \qquad (4)$$

The ongoing propagating wave beyond location **Y** is then

```
          (2)   1       2 * 50       1
Vthru      =   --- *  ---------  =  ---
                2     50 + 25        3
```

what is observed with the scope input at the open end at the time `t1 + t2` as

```
                                              2
VSCOPE = Vopen_end  =  2 * Vthru  =  ---
                                              3
```

Where factor 2 comes from equation (2) for Z = infinite (open end).

As another example, we can calculate the
impedance Z at any location of the backreflected TDR graph:

From (1), we obtain

$$\frac{V_{refl}}{V_{in}} = \frac{Z - Z_0}{Z + Z_0}$$

or solved for Z:

$$Z = Z_0 \frac{V_{in} + V_{refl}}{V_{in} - V_{refl}} \qquad (5)$$

It is

$$V_{step} = (V_{in} + V_{ref}) + (V_{in} - V_{ref}) \overset{(4)}{=} V_{TDR} + (V_{in} - V_{ref})$$

and solved for

$$(V_{in} - V_{ref}) = V_{step} - V_{TDR} \qquad (6)$$

Introducing (6) into (5) gives finally the local impedance along the TDR measurement

$$\boxed{Z = Z_0 \frac{V_{TDR}}{V_{step} - V_{TDRl}}}$$

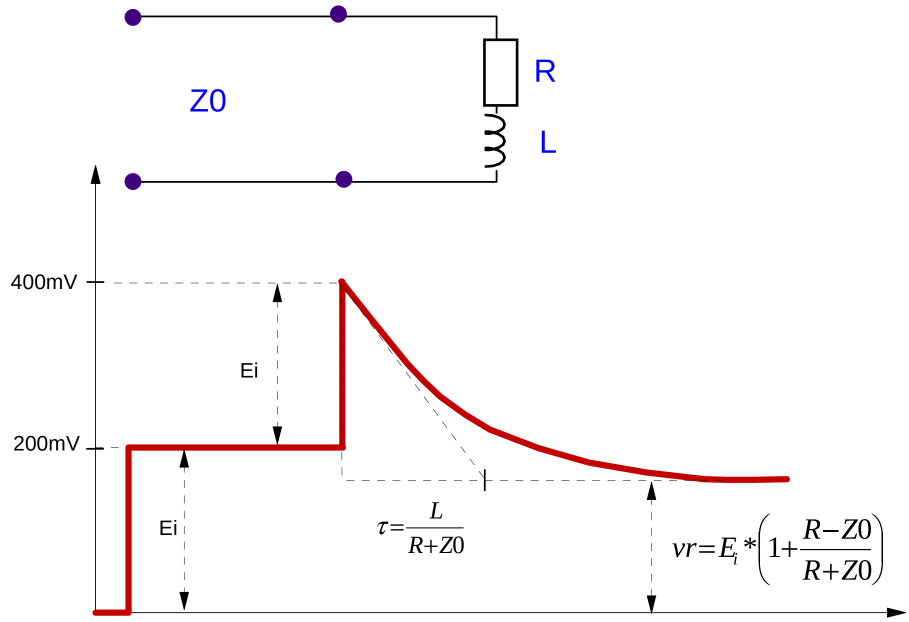
with V_{step} typically 400mV

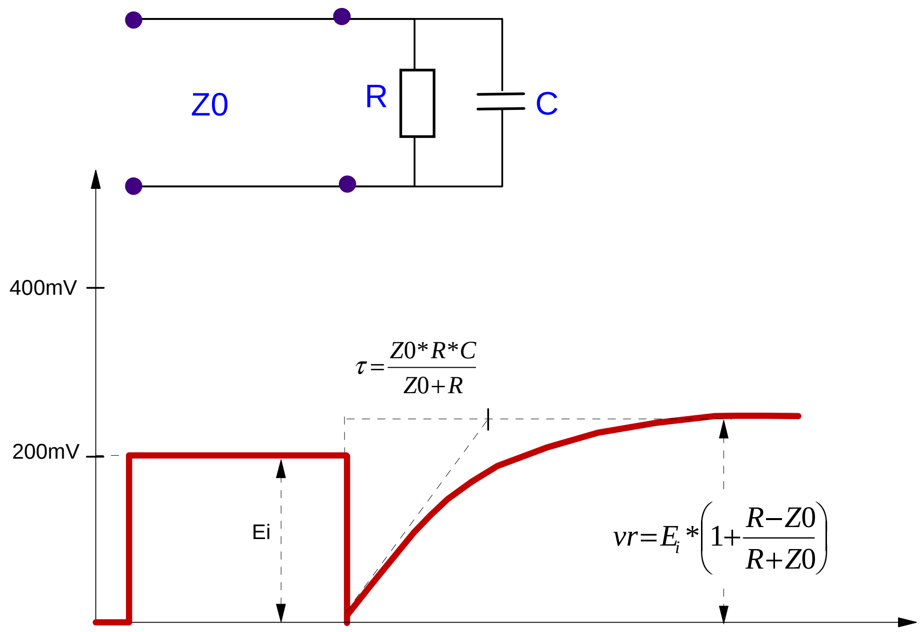
and $0 < V_{TDR} < V_{step}$

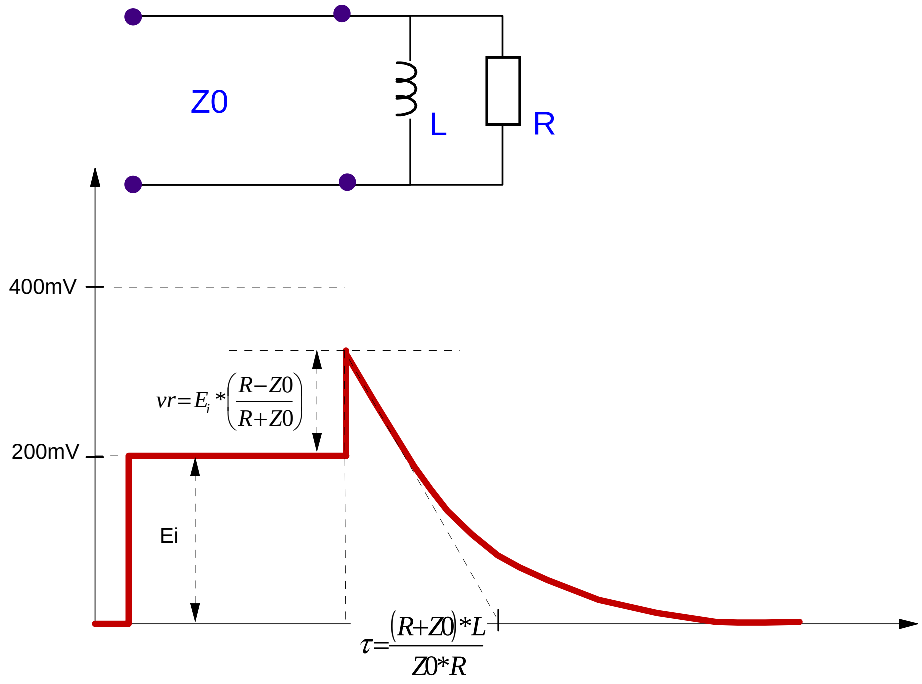
MODELING THE COMPLEX LOAD OUT OF TDR PLOTS:

Equations for ideal TDR response to complex loads can be derived, allowing to determine R, L, and C values of a circuit. Response time constant and final value, resp. incremental step, are usually the most important factors for such calculations. Some typical TDR responses can be seen in figure 1 below. Its sketches are from the HP application note 62-3 'Advanced TDR techniques'.

For example, with a series RL circuit, with a measured time constant τ of 20ps, and a final value of 150mV from a 200mV input Ei: R=30 Ohm, and L=1.6nH.







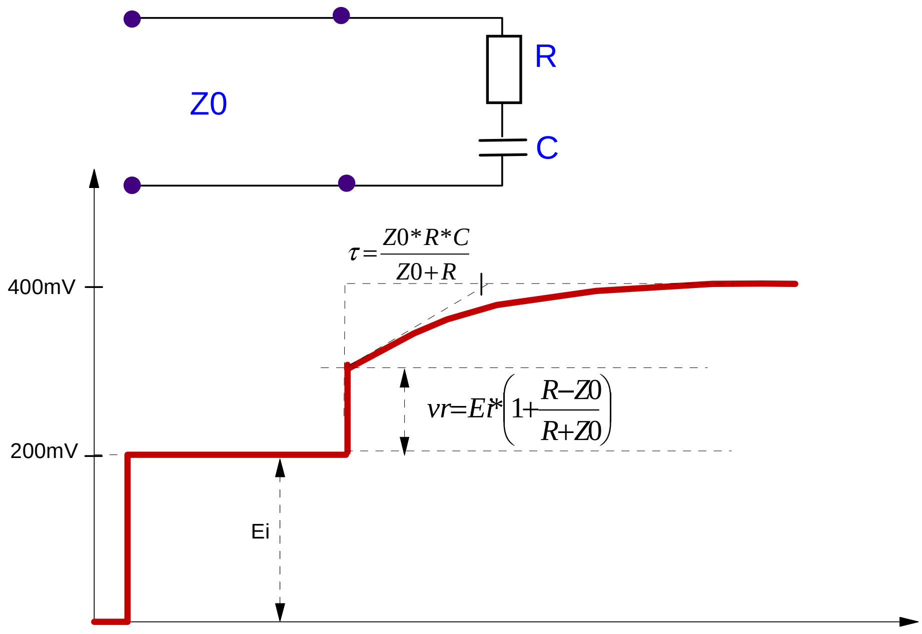


Fig.1: TDR responses to complex loads

ABOUT THE CONTEXT BETWEEN TIME AND LOCATION:

As a rule of thumb, the speed of a step function on a ceramic substrate strip line is roughly:

```
TDR-time        10ps
--------   =   -----
Distance         1mm
```

or:

```
Distance        10cm
--------   =   -----
TDR-time         1ns
```

This gives also an idea about when the connecting components between electronic devices have to be modeled too. This is necessary when the forth and back traveling impulse time is longer than the impulse rise time. This means that the still rising edge of the impulse will be interfered by the backreflection (glitches in digital signals).

