TDR Analysis using Agilent ADS

Objective:

How to perform Single Ended and Differential TDR analysis using Agilent ADS
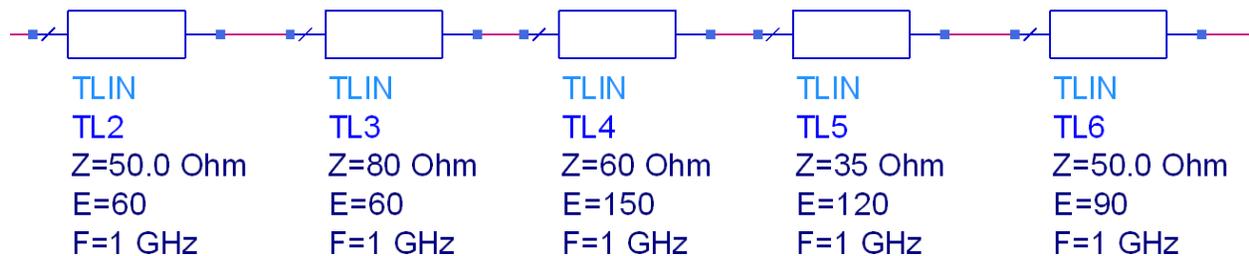
Introduction:

Time Domain Reflectometry (TDR) is one of the most frequently used analysis by Signal Integrity engineers to study the impedance offered by various sections of the Device **or** Design under Test (DUT). This analysis provides clear idea to designers where the main cause of impedance discontinuities in their structure and then take suitable actions to correct them.

With higher signal rates i.e. high frequency data transfer in modern day serial interfaces smallest of impedance mismatch can cause serious degradation to signal response in terms of Signal Integrity hence TDR is a valuable analysis which can be performed by designers to check their designs.
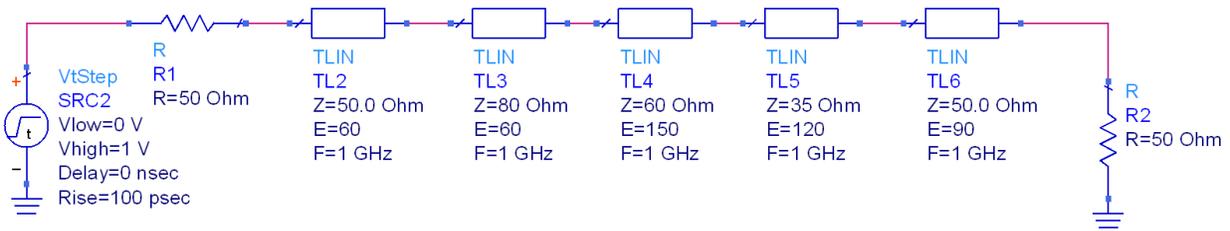
In the present technical note we shall look at methods of performing Single-ended and Differential TDR simulations using ADS Transient simulator

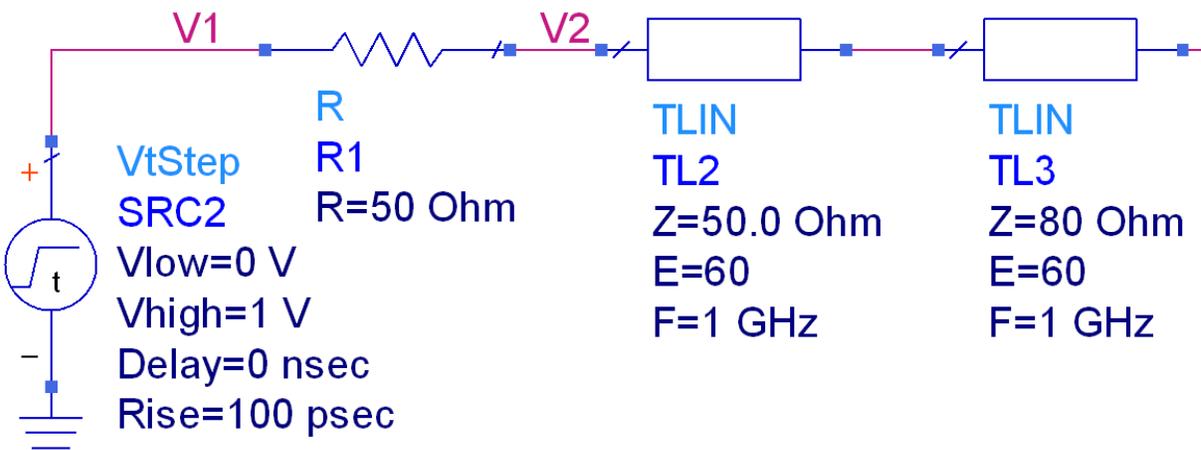## Case Study 1: Single Ended TDR Response

1. Create a new workspace in ADS
2. Open a new schematic design and place following components from TLines-Ideal library palette and define their parameters as shown here. We are using ideal transmission lines for our case study so that we can check accuracy of our TDR analysis without any unnecessary doubt about impedance values seen during our simulations

TLIN	TLIN	TLIN	TLIN	TLIN
TL2	TL3	TL4	TL5	TL6
Z=50.0 Ohm	Z=80 Ohm	Z=60 Ohm	Z=35 Ohm	Z=50.0 Ohm
E=60	E=60	E=150	E=120	E=90
F=1 GHz	F=1 GHz	F=1 GHz	F=1 GHz	F=1 GHz

3. Connect two 50 ohm resistors on either side of the Design Under Test (DUT) and place a Step Voltage Source from Sources-Time Domain library palette as shown here. Define the Rise time = 100 psec in the Step Voltage source

The circuit consists of a VtStep source SRC2 (Vlow=0 V, Vhigh=1 V, Delay=0 nsec, Rise=100 psec) in series with R1 (R=50 Ohm), followed by transmission lines:
- TLIN TL2: Z=50.0 Ohm, E=60, F=1 GHz
- TLIN TL3: Z=80 Ohm, E=60, F=1 GHz
- TLIN TL4: Z=60 Ohm, E=150, F=1 GHz
- TLIN TL5: Z=35 Ohm, E=120, F=1 GHz
- TLIN TL6: Z=50.0 Ohm, E=90, F=1 GHz

terminated by R2 (R=50 Ohm).

4. Click on Wire label icon [NAME] and provide wire label as V1 and V2 as shown here

5. From Simulation-Transient library palette, place a Transient Controller and MeasEqn block and set their parameters as shown here. Time step used here is Trise/5 and same is recommend for proper resolution of the time domain response.
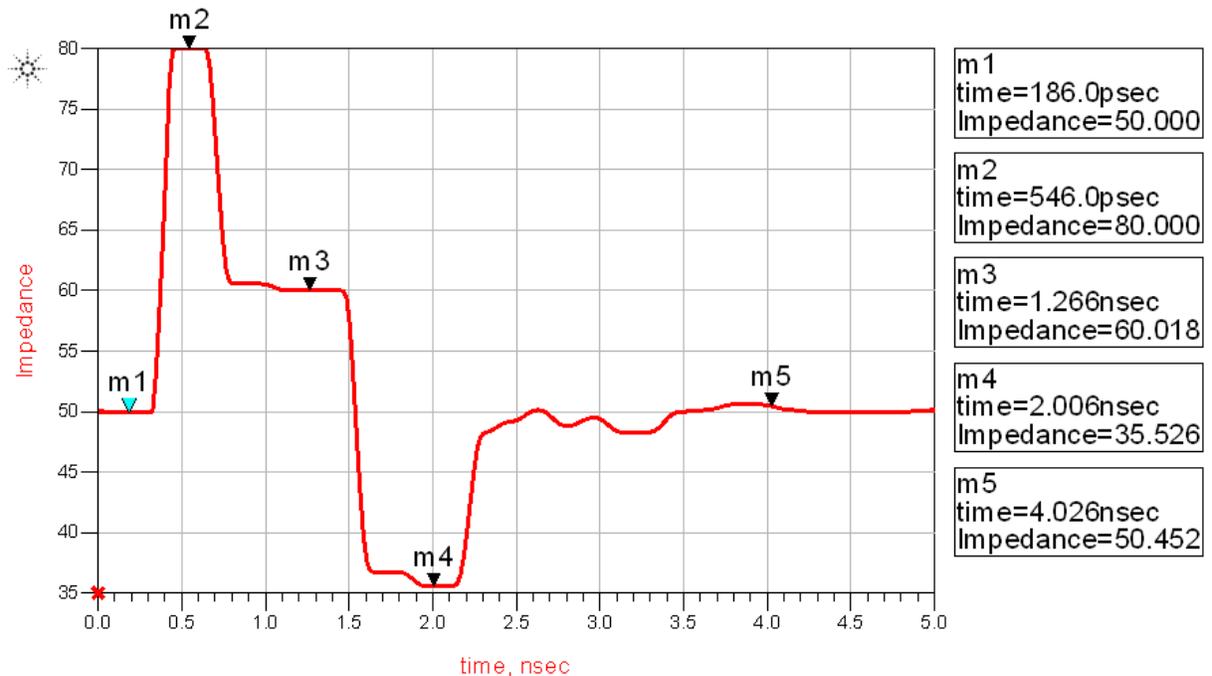

TRANSIENT

Tran
Tran1
StopTime=10.0 nsec
MaxTimeStep=20 psec

Meas Eqn
MeasEqn
Meas1
Impedance=50*V2/(V1-V2)

Note: 50 used in Impedance equation here is the desired characteristic impedance

6. Click on Simulate icon ⚙ or press F7 to start simulation. In the data display window, insert a rectangular graph and plot Impedance from the available measurement list. Place markers at appropriate places to see result similar to the one shown below and check it against the values which we used in our DUT.

m1
time=186.0psec
Impedance=50.000

m2
time=546.0psec
Impedance=80.000

m3
time=1.266nsec
Impedance=60.018

m4
time=2.006nsec
Impedance=35.526

m5
time=4.026nsec
Impedance=50.452

Note: If you have a 2 port touchstone file which is either measured on Network Analyzer or generated from some other tool, same setup will be applicable.

However, accuracy of TDR response will depend on the bandwidth available in the S-Parameter file.

Case Study 2: Effect of S-Parameter File Bandwidth on TDR response

Place the Transmission lines used in our earlier simulation on a new schematic. From Simulation-S_Param library palette, place following components:

a. 50 Ohm Terminations – 2 nos
b. S-Parameter simulation controller, set Start = 0 Hz, Stop = 5 GHz and Step = 0.01 GHz
c. SP Output, define output file name as "SingleEnded_S2P_Sim". SP Output component will generate a 2 port touchstone file under \data sub-folder of the workspace automatically from our S-Parameter simulations

Once done the overall schematic will appear as shown in next snapshot. Run Simulation by clicking Simulate icon or pressing F7.
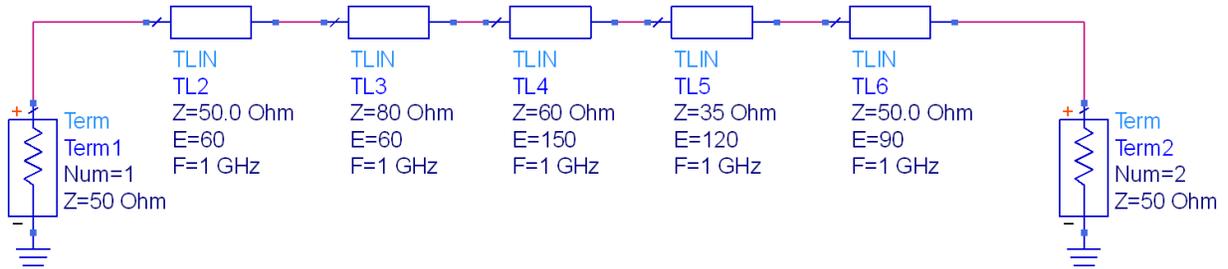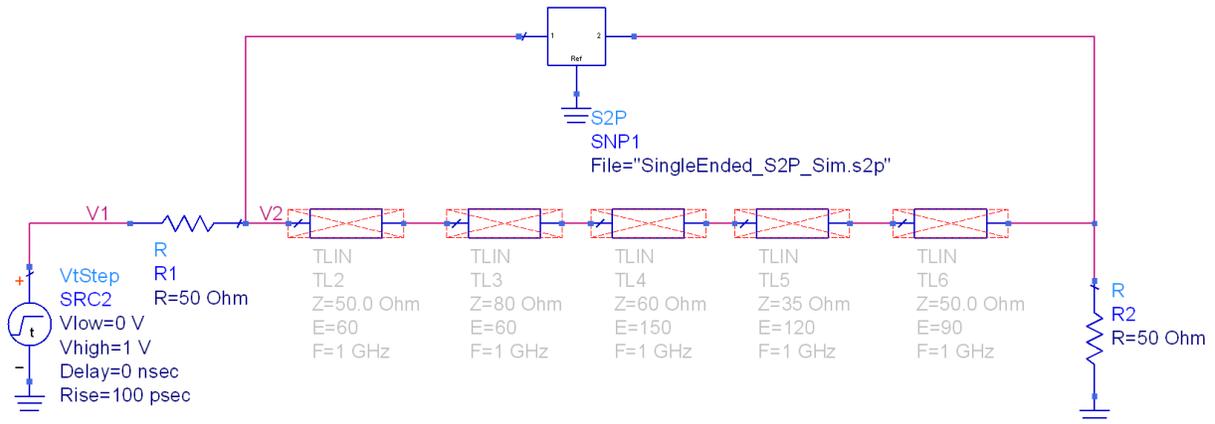
Once simulation is finished, go back to earlier Transient Simulation schematic and deactivate all the TLines component and place S2P file component from Data Items library palette.

Double click on S2P component and browse to the "SingleEnded_S2P_Sim" which we generated earlier. Make connections as shown below
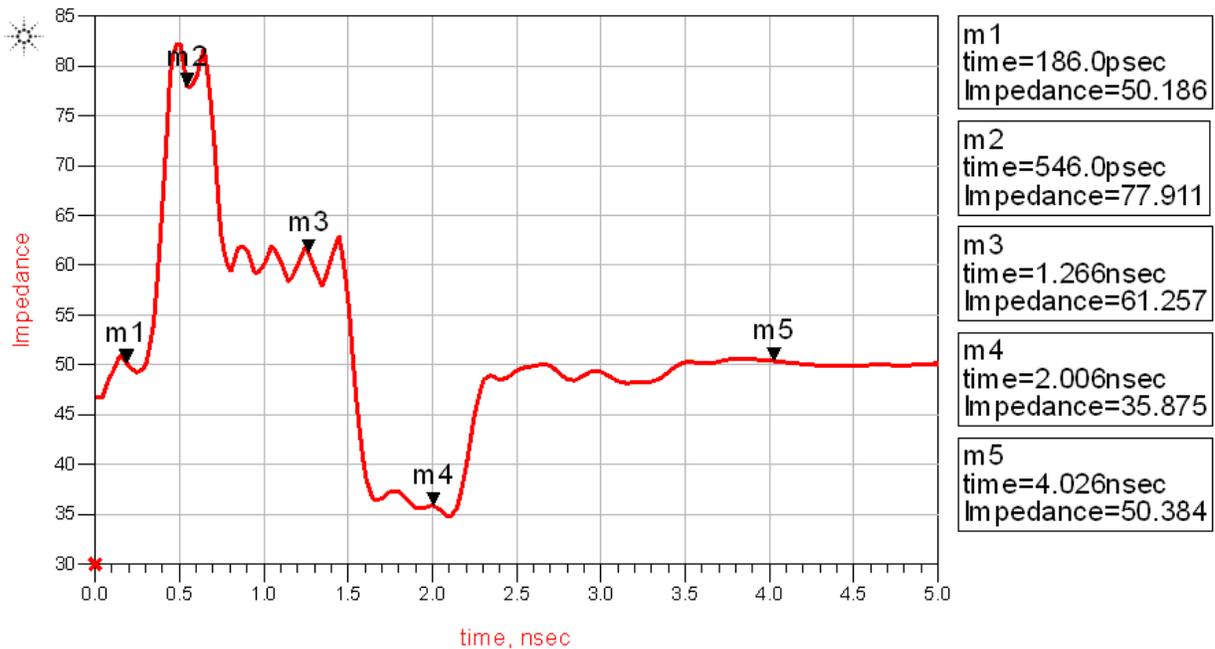
Run simulation and observe TDR response which is degraded as compared to the one we obtained earlier.

m1
time=186.0psec
Impedance=50.186

m2
time=546.0psec
Impedance=77.911

m3
time=1.266nsec
Impedance=61.257

m4
time=2.006nsec
Impedance=35.875

m5
time=4.026nsec
Impedance=50.384

Looking at the simulation status window, we can notice that ADS simulator is complaining about the limited bandwidth available in S2P file as compared to what is needed for proper time domain simulation:
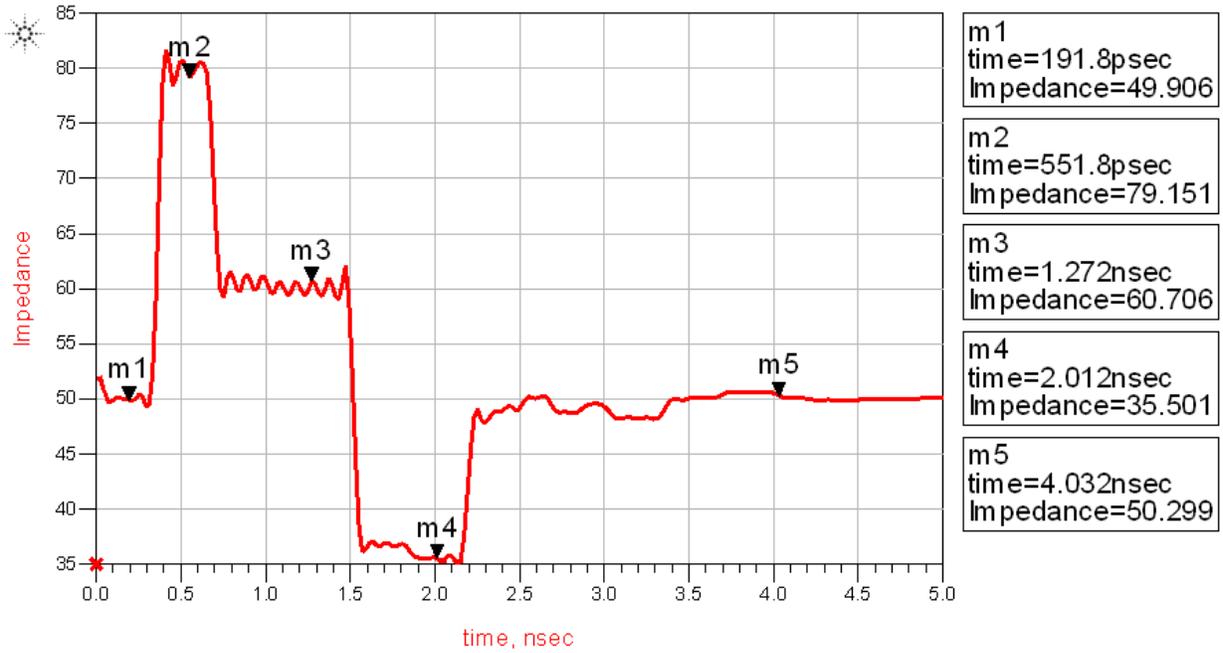
```
Warning detected by hpeesofsim during TRAN analysis `Tran1'.
    COMPONENT `SNP1.CMP1':
        Highest frequency in data is 5e+09 Hz, which is smaller than the maximum source bandwidth 1e+10 Hz.
```

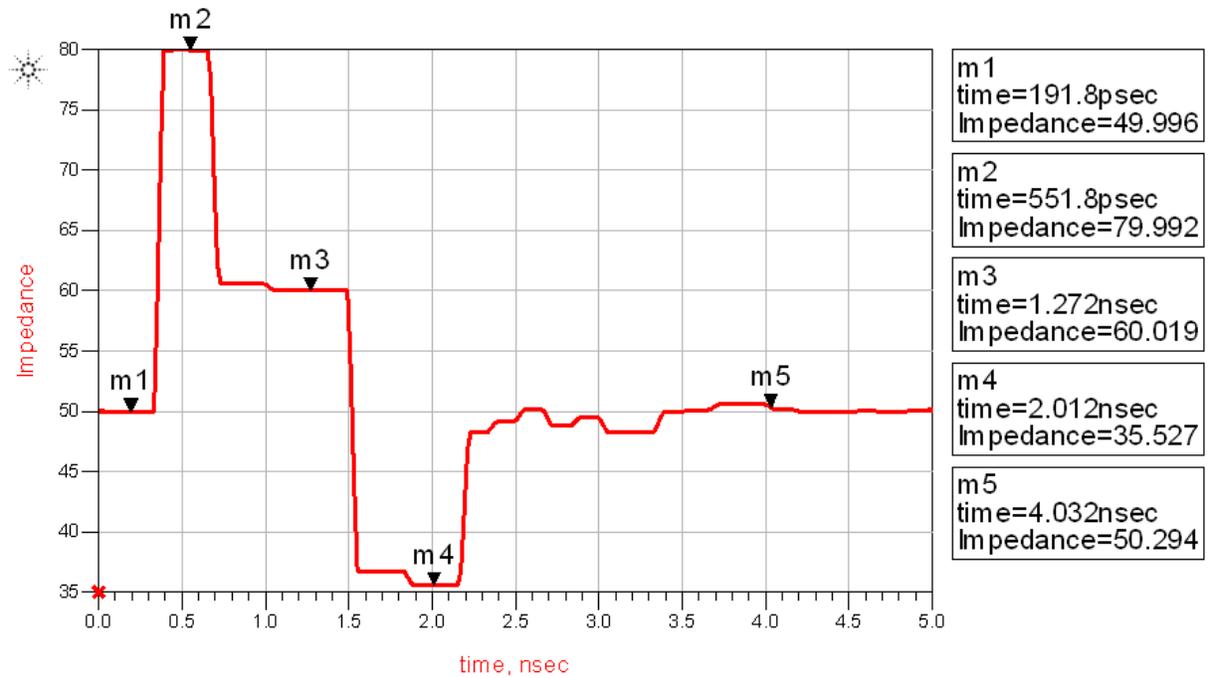*Question:* How do we arrive at requirement of 10 GHz BW requirement for this simulation?

Answer: For our present case, **minimum** bandwidth required for TDR simulation using Step source of rise time of 100 psec will be 1/100e-12 = 10 GHz and this is what simulation status message shows.

While 10 GHz in this case is the minimum requirement, it is always better to have bandwidth of atleast 3 X BWmin for more accurate response (infact 5 X BWmin always works best if possible)

**TDR with 10 GHz BW in S2P file. We can notice slightly better response**

m1
time=191.8psec
Impedance=49.906

m2
time=551.8psec
Impedance=79.151

m3
time=1.272nsec
Impedance=60.706

m4
time=2.012nsec
Impedance=35.501

m5
time=4.032nsec
Impedance=50.299

TDR with 30 GHz BW (3X of BWmin) in S2P file. We can notice much better response

m1
time=191.8psec
Impedance=49.996

m2
time=551.8psec
Impedance=79.992

m3
time=1.272nsec
Impedance=60.019

m4
time=2.012nsec
Impedance=35.527

m5
time=4.032nsec
Impedance=50.294

# Case Study 3: Differential TDR Simulations

For differential TDR simulation we can use a simple setup as shown below using 4-port Balun component available under System-Passive library palette.

a. From TLine-Ideal palette, place 3 coupled line components
b. From System-Passive palette, place 2 nos of 4 port Balun components
c. Place resistors and define their values as shown here
d. Define a measurement equation as shown here and take note that 100 is the characteristic impedance for our present differential TDR
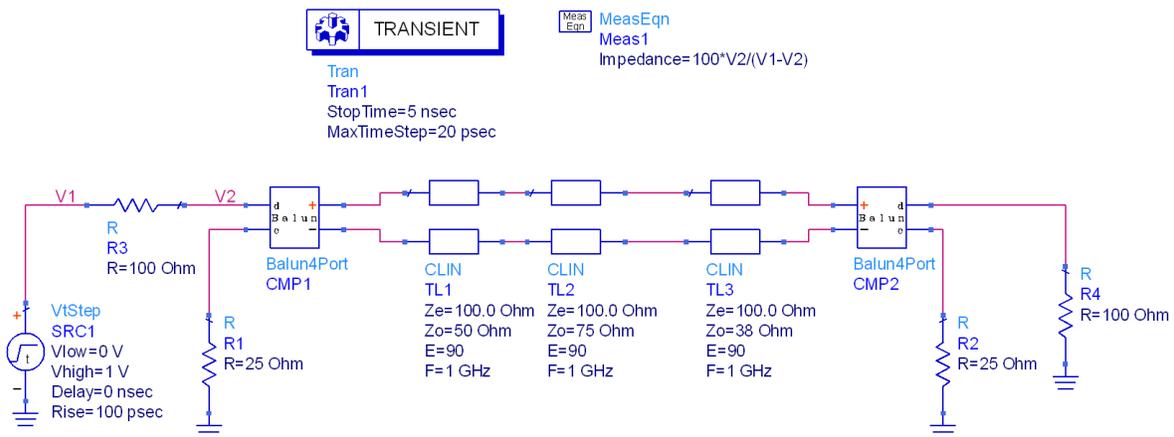
Note: Differential impedance produced by coupled lines is 2*Zo and in our case it would 100 Ohm for TL1, 150 Ohm for TL2 and 76 Ohm for TL3
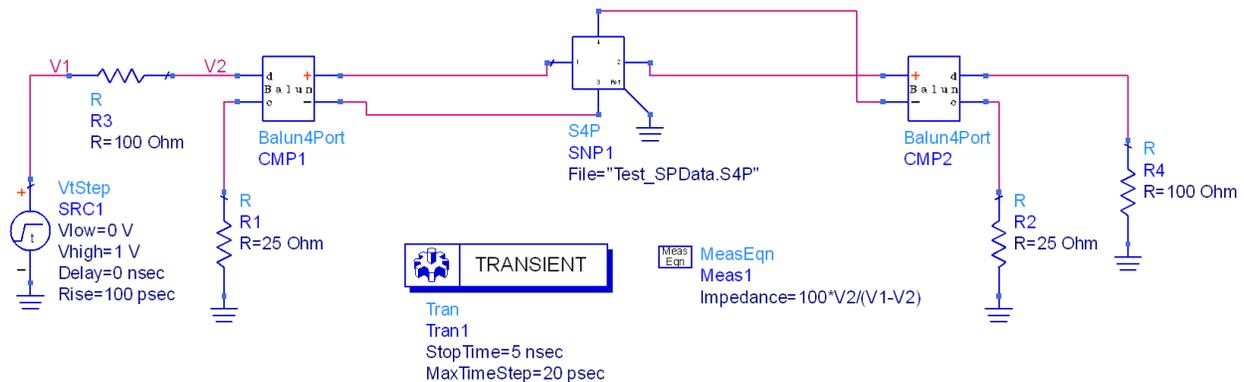
Run simulation and plot Impedance trace on a rectangular graph as shown here:
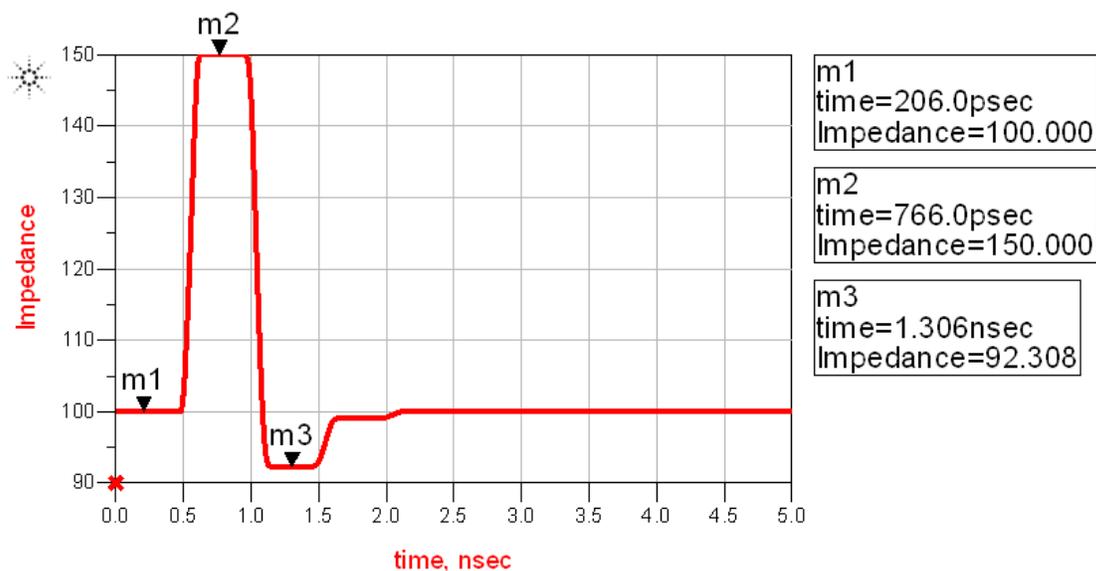
Case Study 4: Differential TDR on a measured S4P file

Let's take an example of performing TDR on a measured S4P to understand the process and also it will point a common issue which is often seen in performing TDR on measured S-Parameter files.

As for earlier single ended case, setup remains the same. As can be seen in the snapshot below we connect Port 1 & 3 of S4P file to the input side Balun terminals and Port 2 & 4 to the output side Balun.


Run simulation and plot Impedance on a rectangular graph
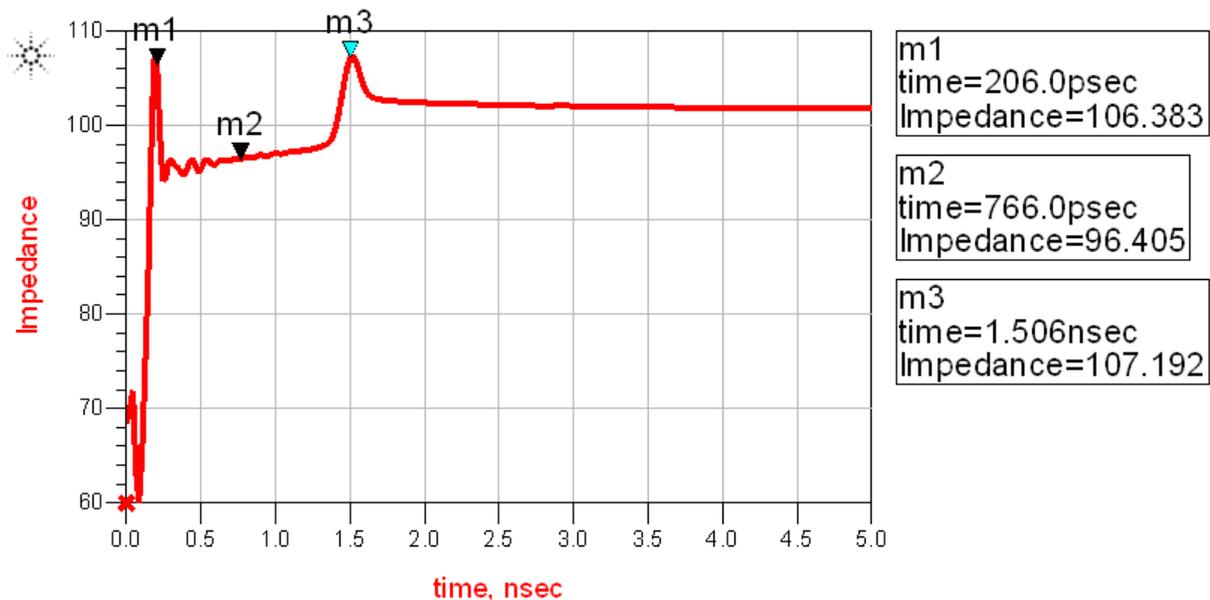
Now here the problem is at the starting of the waveform and we start at t=0 which might cause non-causal response. To compensate for this usually we apply concept of Ideal, Lossless or Lossy transmission line to apply Port extension.

Insert a coupled line from TLines-Ideal library palette and define Zo=50 Ohm so that it represents differential impedance of 100 Ohm before the S4P file as shown here
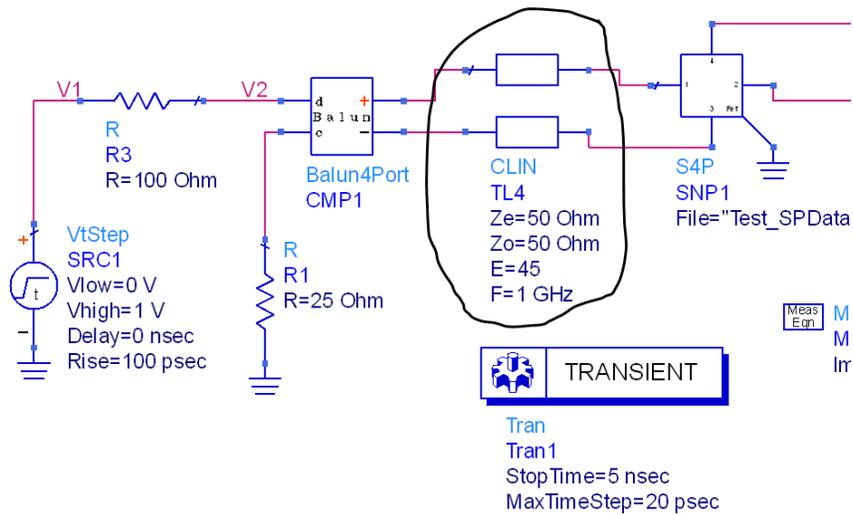
Run simulation and see the impact of this port extension in the TDR response. Notice a constant 100 Ohm impedance in the initial part which allows us to see proper TDR response for S4P file.