Reflection Experiment

EV6 - Hardware Implementation

van Iterson, Arne
Student Nr: 1798423

Selier, Tom
Student Nr: 1808444

April 12, 2024

Abstract

This document describes the process of, and measurements taken during the reflection experiment; Part of the EV6 Hardware Implementation course at the University of applied sciences Utrecht.

---

1 Introduction

Signals travel over transmission lines, these lines can be as simple as a wire or as complex as a PCB trace. Any transmission line has a characteristic impedance, when the line is not terminated properly, reflections will occur. These reflections can cause signal integrity issues, and can even damage the transmission hardware. However, the effect can also be used to our advantage, by putting a pulse on the line and measuring the time it takes for the reflection to return, we can roughly calculate the length of the transmission line or a fault in the cable.

Different termination methods and values have different effects on the reflections.

1.1 Objective

The purpose of the experiment is to learn the importance of proper termination of transmission lines. The results should include the effects of various different termination methods and the estimated length of an un-terminated transmission line of unknown length.

2 Methodology

The experiment requires a pulse to be generated on the line and a way to measure any reflections, the equipment and settings used are as follows:

- Rigol DG 2041A Function/Arbitrary Waveform Generator
  - Setup according to the method described in the lab manual:
    - Pulse 0 to 5 Volts
    - Frequency 1 kHz
    - Pulse width 12 ns, edge time 5 ns
    - Output impedance 50 Ω
- DPO 2012 Oscilloscope
  - Using default settings
- Multiple 1 meter BNC cables with a characteristic impedance of 50 Ω
  - One for trigger output, three for the experiment itself
- BNC cable of unknown length with a characteristic impedance of 75 Ω
- Various BNC accessories
  - Short circuit terminator
  - 50 Ω terminator
  - T-connectors
  - Male to male connectors

2.1 Measurements to be taken

The following scenarios will be tested:

- Open termination
- Short termination
- Matched termination

For each scenario, the full dataset of the oscilloscope will be saved to CSV and analysed at a later moment using Python.

2.2 Setup

All measurements will be taken using the setup in Figure 1.

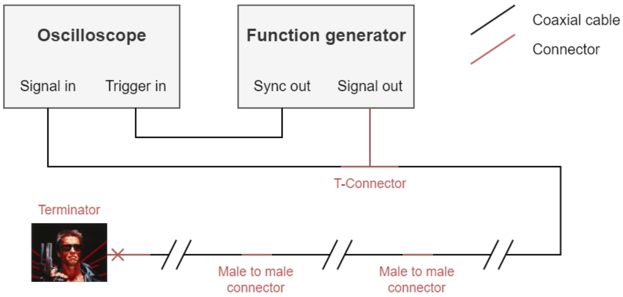

Figure 1: Measurement setup

In initial tests, it was found that using a single BNC cable between the terminator and the function generator would produce a reflection, however it would overlap with the original signal, making it difficult to take any measurements. Therefore the setup was built using three cables instead of one in order to delay the reflection to a point where it can be measured. The cables were connected using BNC male to male connectors, making the total cable length about 3 meters.

3 Expected results

We expect the following results for the different termination methods:

Open termination The reflected signal will be equal in amplitude to the input signal.

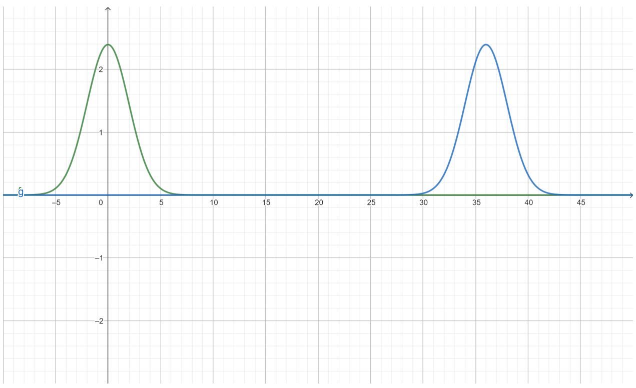

Figure 2: Expectation for open termination

Short termination The reflected signal will be equal in amplitude to the input signal, but inverted.

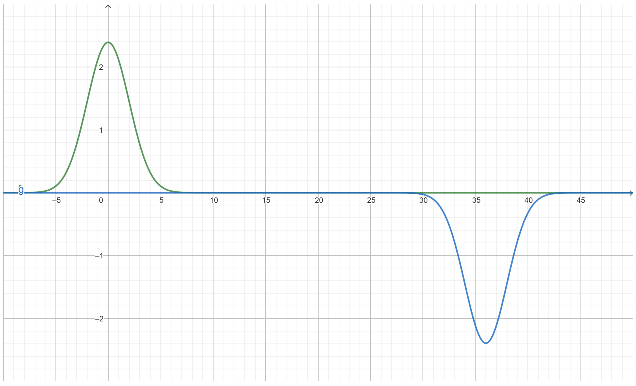

Figure 3: Expectation for short termination

Matched termination The reflected signal will not exist.

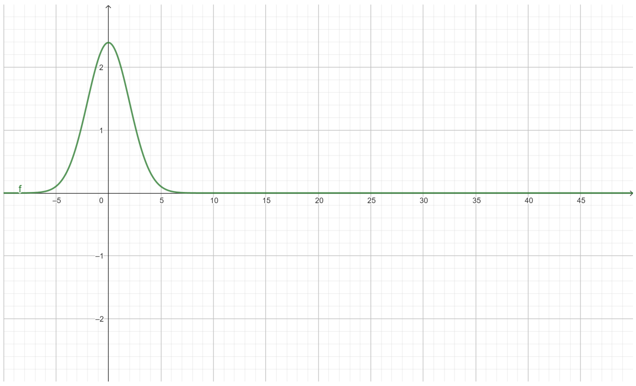

Figure 4: Expectation for matched termination

4 Results

First, the pulse itself was measured without any cable to ensure that the pulse matched the settings of the function generator.

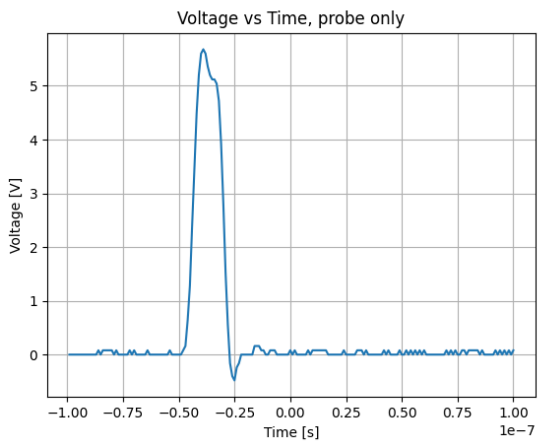

Figure 5: Pulse measurement, no cable

The resulting pulse is as described in section 2, and within tolerances.

4.1 Termination results

4.1.1 Open termination

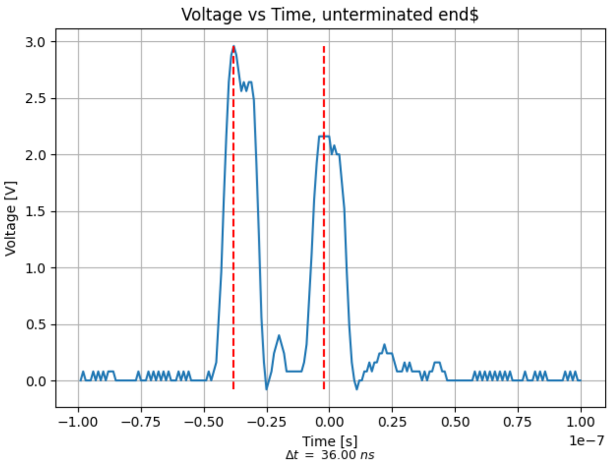

Figure 6: Result for open termination

The open termination results in a reflection of roughly equal amplitude to the original signal. There is 36 ns between the original pulse and the reflection.

4.1.2 Short termination

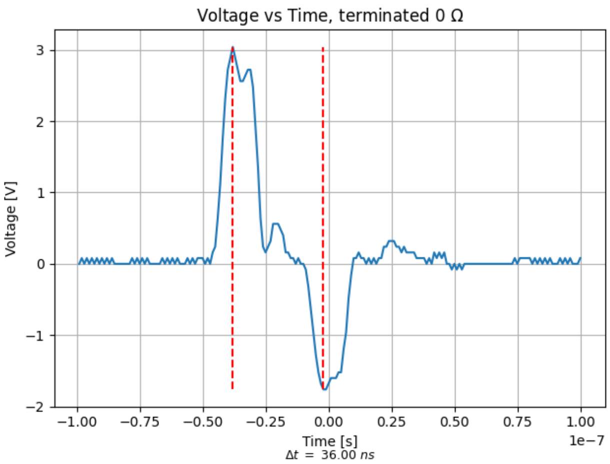

Figure 7: Result for short termination

The short termination results in a reflection of the original signal, but inverted. The reflection is also of lower amplitude than the original signal. Interestingly, the time between the original pulse and the reflection is 36 ns exactly, which is identical as the open termination result.

4.1.3 Matched termination

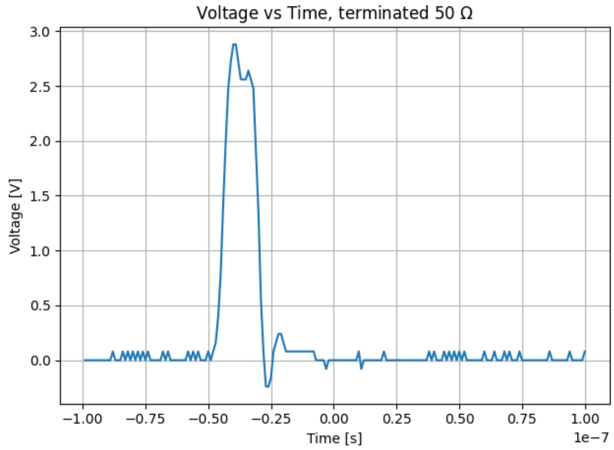

Figure 8: Result for matched termination

As expected, the matched termination results in no reflection at all.

4.2 Cable length determination

By measuring the difference in time between the original pulse and the reflection, we can calculate the length of the cable using the speed formula:

$$v = \frac{s}{t}$$
$$s = v \cdot t$$

The speed of light in a cable is roughly 2/3 of the speed of light in a vacuum. Good quality cables include this value exactly, but unfortunately, we do not have this information for the cables used in this experiment.

$$\begin{aligned} c &= 299792458 && [ms^{-1}] \\ v &= \frac{2}{3} \cdot c && \\ &= 199861638,\overline{66} && [ms^{-1}] \\ t &= 36 && [ns] \\ &= 36 \cdot 10^{-9} && [s] \\ \frac{1}{2}t &= 18 \cdot 10^{-9} && [s] \end{aligned}$$

Time has to be divided by 2 since the reflection has to travel the same distance twice, once to the end of the cable and once back.

$$\begin{aligned} s &= 1199861638,\overline{66} \cdot (18 \cdot 10^{-9}) && \\ &= 3,5975094959 && [m] \end{aligned}$$

$$s \approx 3,6 \qquad [m]$$

The actual length of the cable is 3 meters, so the result is somewhat off, there are several possible reasons for this:

1. The speed of light in the cable and the male to male connectors is not exactly 66% of the speed of light in a vacuum. Each percent difference yields a difference of about 5 cm in this case.
2. The cables are not exactly 1 meter long
3. The length of the male to male connectors is not taken into account

4.2.1 Unknown 75 Ohm cable

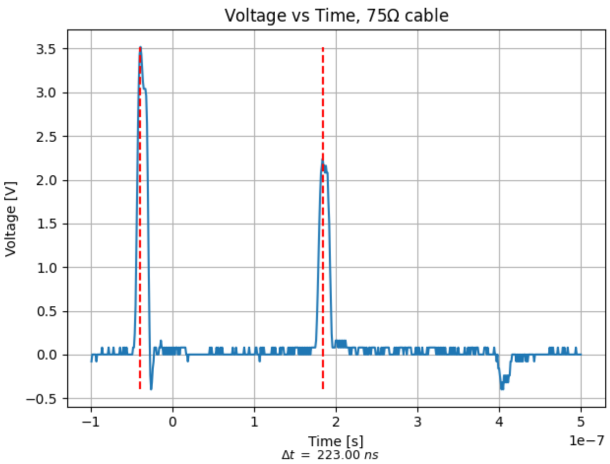

Figure 9: Result for unknown cable

The cable with an unknown length is a 75 Ohm cable made by Belden. It has part number 9248 printed on the sheath of the cable. According to the data sheet of the cable, the propagation delay is 82 %[1].

Furthermore, the initial pulse shown in figure 9 is 3.5 V instead of 2.5 V. This is because the cable is a 75 Ohm cable, and thus creates a different voltage division. However, this does not affect the results of the experiment, since the pulse does not change position with respect to time.

Using the same equations as in section 4.2, the length of the cable can be calculated.

$$
\begin{aligned}
c &= 299792458 && [ms^{-1}] \\
v &= 0.82 \cdot c \\
&= 245829815,56 && [ms^{-1}] \\
t &= 223 && [ns] \\
&= 223 \cdot 10^{-9} && [s] \\
\frac{1}{2}t &= 116,5 \cdot 10^{-9} && [s] \\
s &= 245829815,56 \cdot (116,5 \cdot 10^{-9}) \\
&= 27,4100243725 && [m] \\
\hline
s &\approx 27,4 && [m]
\end{aligned}
$$

5 Conclusion

Reflections can be used to measure distance in case of a faulty cable. However, an accurate propagation delay of the cable should be known. Otherwise, depending on the length of the cable, the measurement could be off by several meters to kilometres.

In conclusion, a reflection in a transmission line can be manipulated by its termination. A matched impedance will result in no reflections, whilst a mismatched reflection will cause reflections, either positive or negative.

[1] Belden, "Part Number: 9248", 9248 data sheet, 2019