Electromagnetism Practical, Session 1
Transmission Lines

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March 29, 2016

Contents

Assignment 1: Transmission Lines in Frequency Domain

Part 1: Standing Waves in Waveguide

1.

The laboratory equipment setup is checked in agreement with the block-diagram as shown in the practicum manual [1], before proceeding with the measurements.

The standing wave is the sum of the generated wave and the reflected wave due to a load, integrated over time. By adjusting the distance of the detector from the wave generator the wavelength of the standing wave can be determined. By finding two zero voltage points next to eachother, the half wavelength of the EM wave can be obtained. The resulting wavelength of then calculated by multiplying the difference between the first found zero voltage point $d_{v0,1}$ and the second one $d_{v0,2}$, by a factor of 2. Such that,

$$\lambda = 2 \cdot \lambda_{1/2} = 2 \cdot |(d_{v0,1} - d_{v0,2})| \tag{1}$$

Using the above equation the resulting standing wavelength λ is 4.4 cm.

The phase velocity is determined using equation 2,

$$v_p = \lambda f \tag{2}$$

Where λ the wavelength and f is the frequency of the wave. Substituting the calculated value for $\lambda = 4.4$ cm and the given frequency of $f = 9.475$ GHz into equation 2, yields a phase velocity v_p of $1.39c$. The phase velocity can indeed be greater than the speed of light. This does not mean the group velocity is greater than the speed of light and information cannot travel faster than it.

2.

The voltage-standing-wave ratio (VSWR) of different loads is calculated by determining the minimum and maximum voltage. The VSWR can be obtained using the following equation,

$$VSWR = \rho = \frac{E_{max}}{E_{min}} \tag{3}$$

Where E_{max} is the maximum voltage and E_{min} the minimum voltage.

Using the VSWR the absolute value of the reflection coefficient can be obtained,

$$|\Gamma| = \frac{\rho - 1}{\rho + 1} \tag{4}$$

The results of the VSWR, reflection coefficient and power of different loads can be seen in the table below (Table 1). The equation for the power delivered to the load is displayed in equation 5.

Load	$\boldsymbol{E_{min}}$ (mV)	$\boldsymbol{E_{max}}$ (mV)	**VSWR**	$\boldsymbol{\lvert\Gamma\rvert}$	**Power** (W)
Open waveguide	44.3	49.0	1.11	0.052	$1.20 \cdot 10^{-3}/Z_0$
Short circuits	0.02	80	4.0×10^3	1	0
Matched load	45.4	50.3	1.11	0.052	$1.27 \cdot 10^{-3}/Z_0$
Horn antenna	45.2	51.1	1.13	0.061	$1.31 \cdot 10^{-3}/Z_0$

Table 1: Results for different loads

$$P_{abs} = \frac{(V_0^+)^2}{2Z_0}(1 - |\Gamma|^2) \tag{5}$$

3.

There is no shift in antinodes in our measurement regarding the two short-circuits. This is not surprising as the difference between the 33 mm and the 55 mm short-circuit is exactly 22 mm which is half of the wavelength.

Assignment 2: Transmission Lines in Time Domain

Part 1: Time Domain Reflectometry: estimate the loads impedance

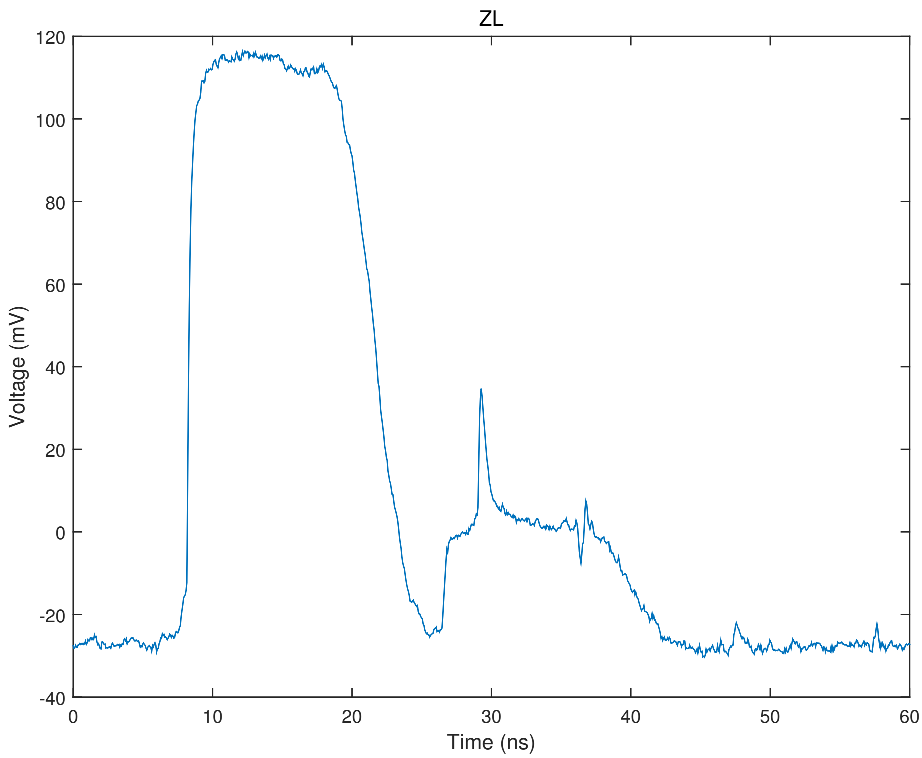


Figure 1: Recording with ZL as load

As seen in Figure 1, the incident signal ranges from around -30 to 120 mV and the reflected signal -30 to 0 mV.
By increasing the values by 30, the values of $E_i \approx 150mV$ and $E_r \approx 30mV$ can be found.

$$\Gamma = E_r/E_i = 0.2 \tag{6}$$

Z_l can be determined with equation 7 with $Z_0 = 50\Omega$

$$\Gamma = \frac{Z_l - Z_0}{Z_l + Z_0} \tag{7}$$

$$Z_l = -\frac{\rho + 1}{\rho - 1} \cdot Z_0 = 75\Omega \tag{8}$$

Part 2: Dielectric in Coaxial Cable: the Estimation of the Propagation Speed and Relative Permittivity

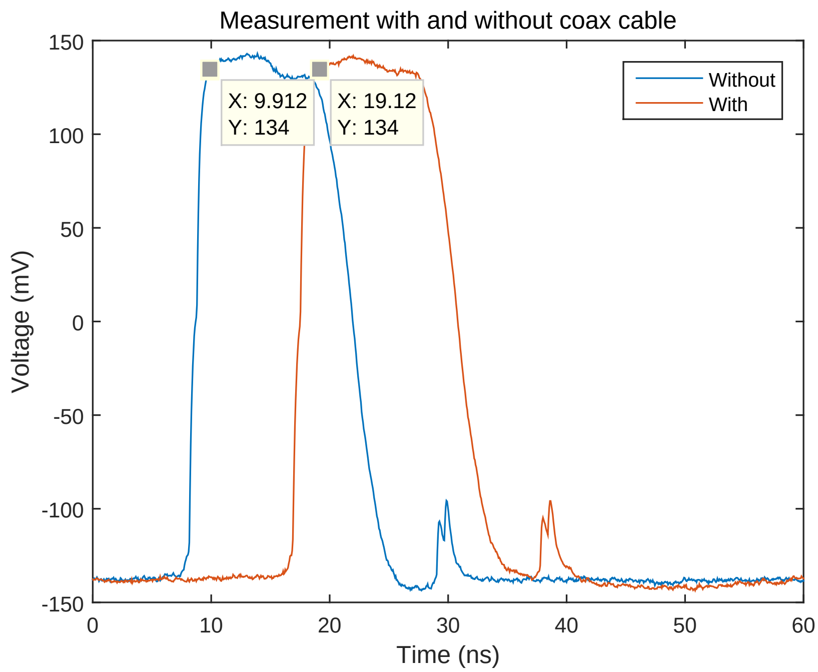


Figure 2: Recording with and without coaxial cable

By measuring the time the signal is delayed after the 2 meter long coaxial cable is connected, the propagation velocity can be calculated. As seen in Figure 2, the time difference is 9.2 ns. The propagation velocity can now be calculated:

$$v = s/t = 2.17 * 10^8 m/s = 0.72 * c \tag{9}$$

From the reflections the propagation velocity turned out to be $0.72c$, which is slightly less than the 0.77c, stated by the datasheet of the cable [2]. Using equation 10 the relative permittivity ϵ_r can be calculated.

$$v = \frac{c}{\sqrt{\epsilon_r}} = 0.72c \tag{10}$$

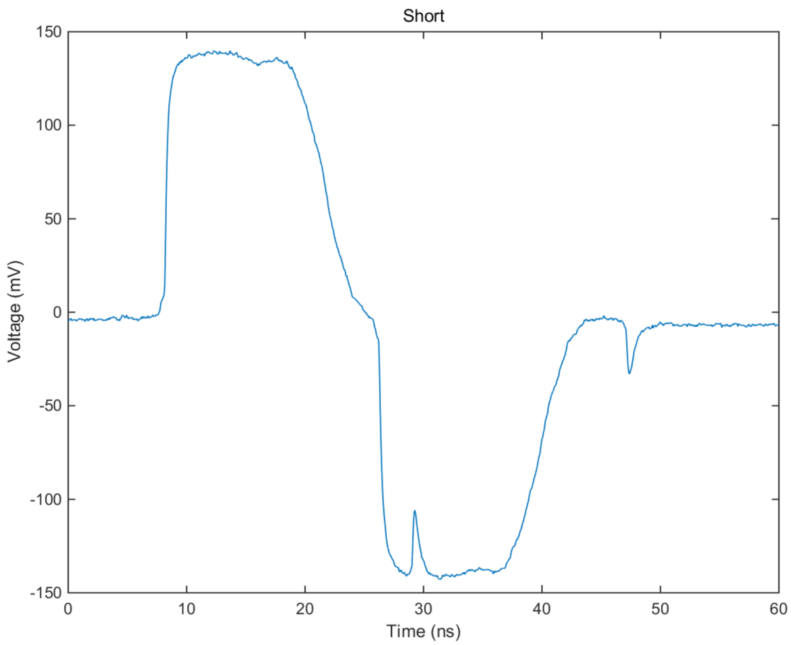
$$\epsilon_r = (\frac{c}{v})^2 = 1.91 \tag{11}$$

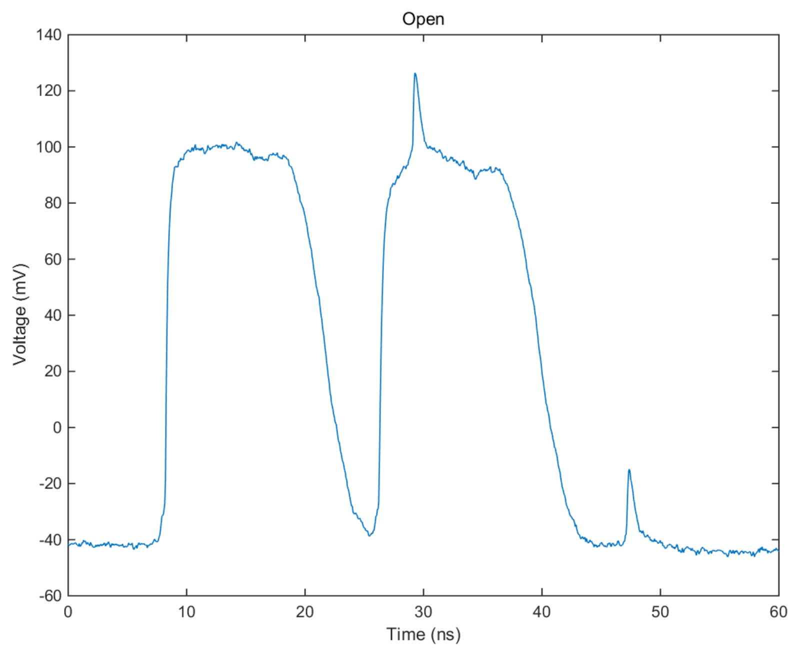
References

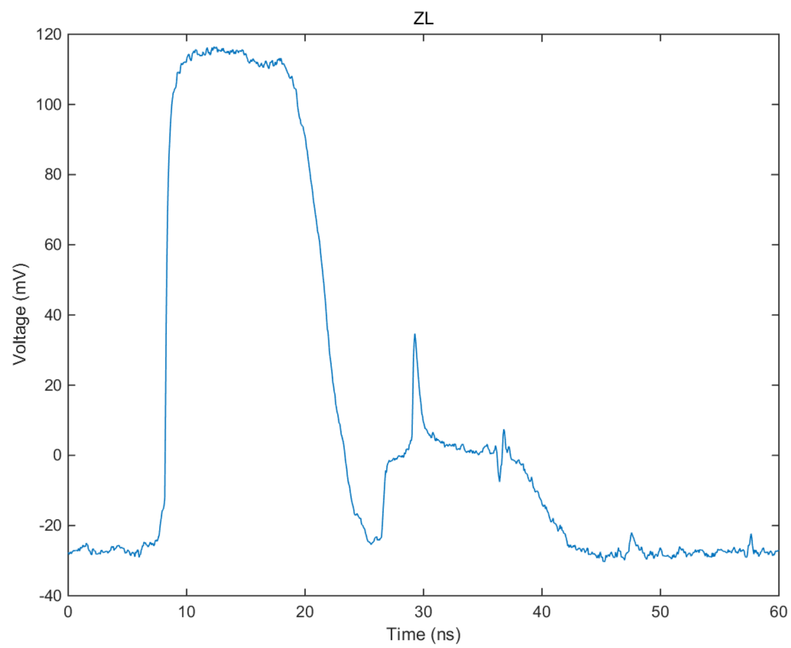
[1] *EE3P11 - EM Practicum, 2015-2016 Q3.* TU Delft, 2016.

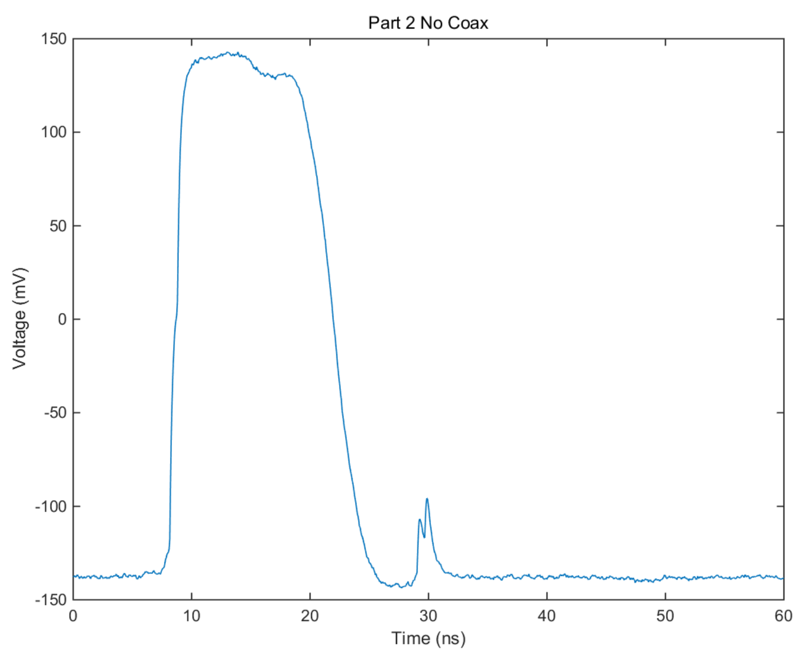
[2] Helmut Singer Elektronik. Sucofles 104. URL `http://www.helmut-singer.de/pdf/sucoflex104pb.pdf`.

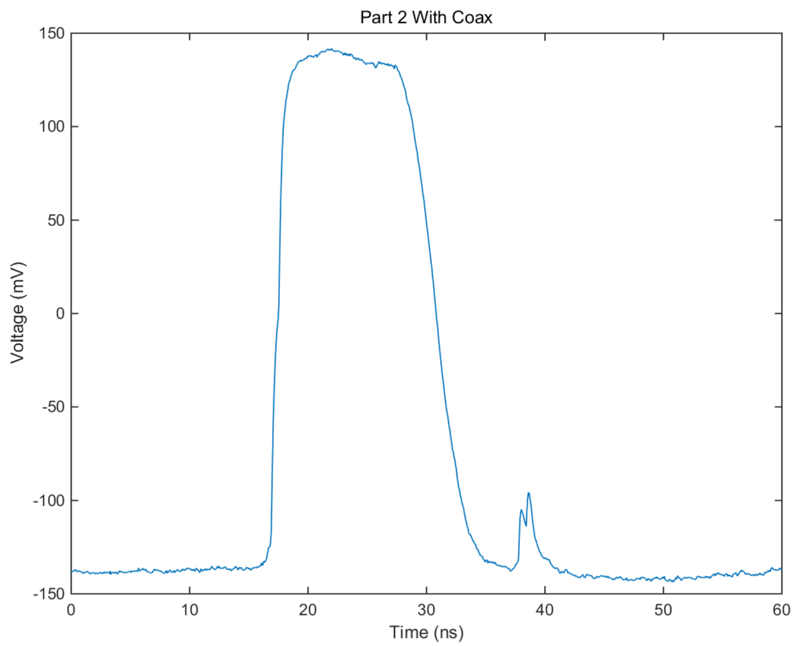
Appendix A Plots



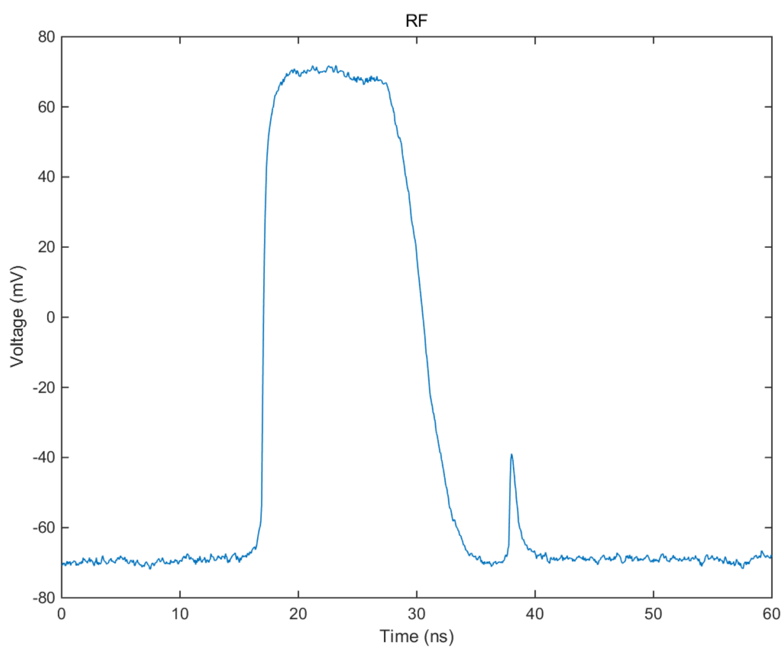



ZL
Voltage (mV)
Time (ns)
120
100
80
60
40
20
0
-20
-40
0
10
20
30
40
50
60

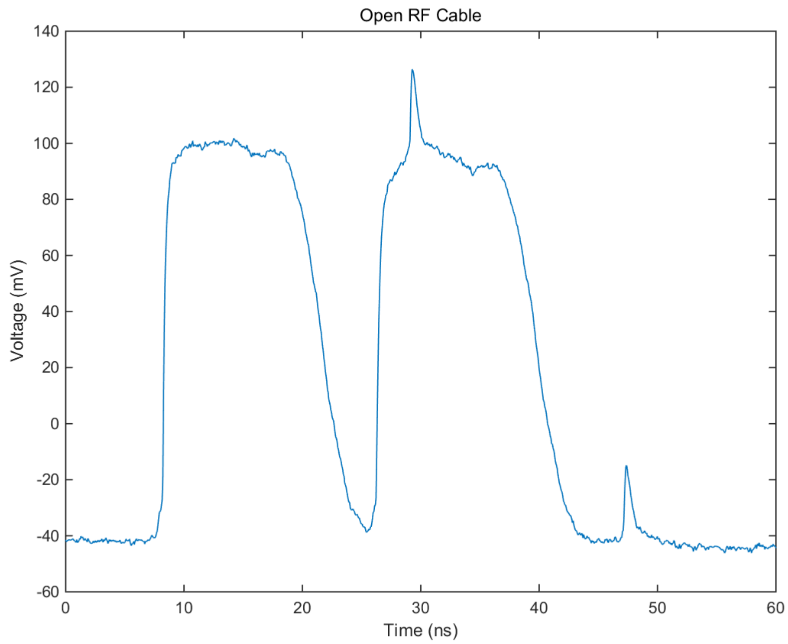

Part 2 No Coax
Voltage (mV)
Time (ns)
150
100
50
0
-50
-100
-150
0
10
20
30
40
50
60

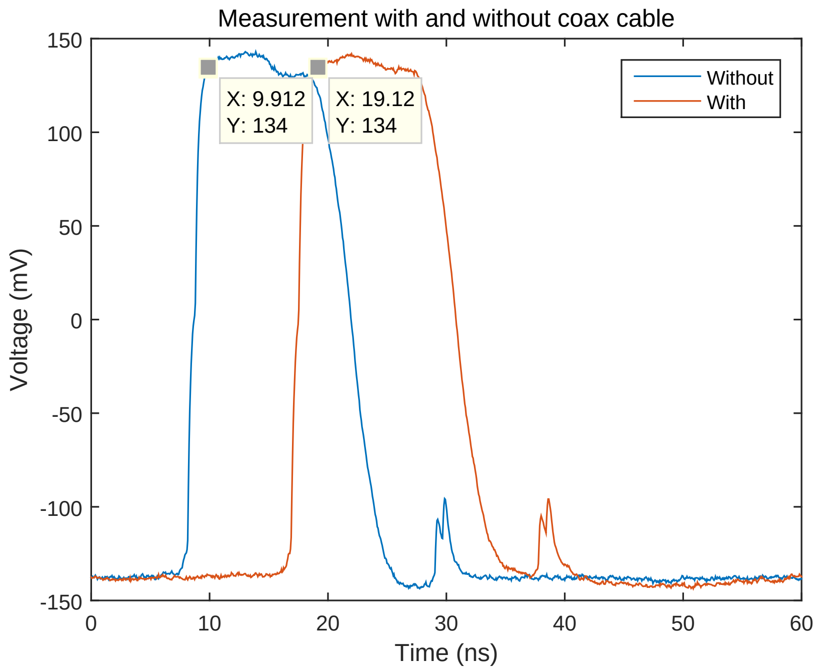


Part 2 With Coax
150
100
50
0
-50
-100
-150
Voltage (mV)
0
10
20
30
40
50
60
Time (ns)



RF
80
60
40
20
0
-20
-40
-60
-80
Voltage (mV)
0
10
20
30
40
50
60
Time (ns)


Open RF Cable
Voltage (mV)
Time (ns)
140
120
100
80
60
40
20
0
-20
-40
-60
0
10
20
30
40
50
60


Measurement with and without coax cable
Voltage (mV)
Time (ns)
Without
With
X: 9.912
Y: 134
X: 19.12
Y: 134
150
100
50
0
-50
-100
-150
0
10
20
30
40
50
60