EE3P11 - EM Practicum, 2015-2016 Q3

Session I TRANSMISSION LINES

Weeks 3.3 – 3.5

Reports: One report per group. Deadline for report submission: March 29 (week 3.8)

The first Session of the EE3P11 EM Practicum includes two assignments, related to effects and phenomena, which take place during the propagation of the EM waves (microwaves) in two types of standard transmission lines – coaxial cables and waveguides. These assignments include the measurements in time and frequency domains.

According to Wikipedia, the **time domain** is the analysis of mathematical functions or physical signals with respect to time. In the time domain, the signal or function's value is known for all real numbers, for the case of continuous time, or at various separate instants in the case of discrete time. An oscilloscope is a tool commonly used to visualize real-world signals in the time domain. In microwave frequency bands (1 – 100 GHz) the measurements of signals in time domain even with modern progress in technology can be quite difficult and costly.

The **frequency domain** refers to the analysis of mathematical functions or signals with respect to frequency, rather than time.

Put simply, a time-domain graph shows how a signal changes over time, whereas a frequency-domain graph shows how much of the signal lies within each given frequency band over a range of frequencies. A frequency-domain representation also includes information on the phase shift that must be applied to each sinusoid in order to be able to recombine the frequency components to recover the original time signal.

A given function or signal can be converted between the *time* and *frequency domains* with a pair of mathematical operators called a *transform*. An example is the Fourier transform, which converts the time function into a sum of sine waves of different frequencies, each of which represents a frequency component. The *'spectrum'* of frequency components is the *frequency domain representation* of the signal. The inverse Fourier transform converts the frequency domain function back to a time function. A *spectrum analyser* is the tool commonly used to visualize real-world signals in the frequency domain. A *network analyser* can work in both domains.

Short theoretical overview

Chapters 2, 3, 6.1 and 7.1-7.7 of A.L. Lance *Introduction to Microwave Theory and Measurements*. McGraw-Hill Co. (scanned book chapters on the blackboard's practicum page)

Assignment 1. Transmission Lines in Frequency Domain. 45 min

For this assignment we do not use any equipment, which can resolve the temporal structure of the EM waves.

Part 1: Standing Waves in Waveguide

In this experiment, you will use the oscilloscope and the slotted line to examine the standing-wave pattern caused by various loads. The measurements you will be making are un-calibrated measurements. In order to correct for this, the first step is to measure the standing-wave pattern for a known load to use as a reference. The reference load that will be used is the short termination since we know the standing wave pattern that should be produced by the short termination. By measuring the slotted line terminated with various loads and calibrating against the reference measurement, the standing wave pattern of the loads can be determined.

The slotted line consists of a piece of metal tubing (which is a WR-90 rectangular waveguide – operational frequency band from 8.2 to 12.4, size 22.86 x 10.16 mm), a probe, and a detector. The probe measures the electric field present in the line and uses a detector to convert the measured field to a voltage. The probe and the detector are housed on a mount which can slide down the line. On the side of the mount is a scale that can be used to measure the position of the probe. The slotted waveguide is show in Figure 1.

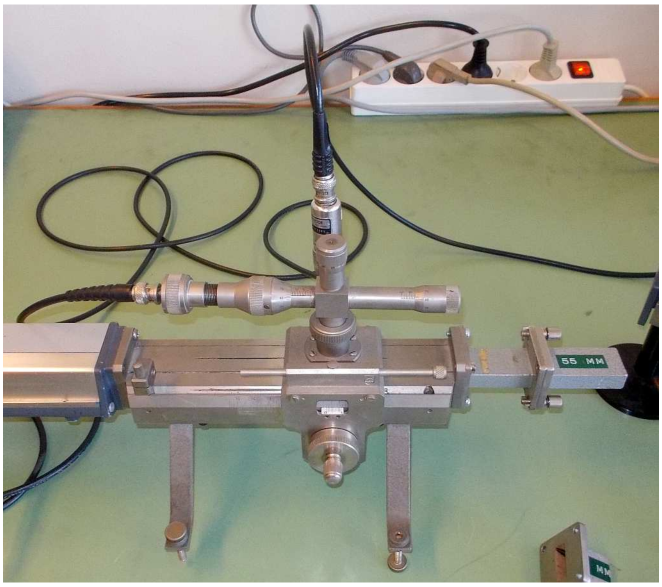


Figure 1: The slotted line

Note: The wavelength of the EM wave in a waveguide is different in comparison with free space. For the mode, which is used in this experiment, it can be defined as

$$\lambda_w = \frac{\lambda_0}{\sqrt{1-\left(\frac{\lambda_0}{2a}\right)^2}}$$

where λ_0 - wavelength in free space, $\lambda_0 = c/f$, c - speed of light in free space, f - frequency, a - size of long side of waveguide (22.86 mm in our case)). The phase velocity of wave equals to

$$v_p = \lambda f$$

The voltage-standing-wave ratio (VSWR) defined as

$$VSWR = \rho = \frac{E_{\max}}{E_{\min}} = \frac{1+\Gamma}{1-\Gamma}$$

The reflection coefficient

$$\Gamma = \frac{\rho - 1}{\rho + 1}$$

Experiment Setup

This experiment uses an RF signal source, a waveform generator and amplifier to modulate the amplitude of the RF signal, an oscilloscope and digital voltmeter as indicators, and various loads and cables.

Setup the experiment as shown in Figure 2.

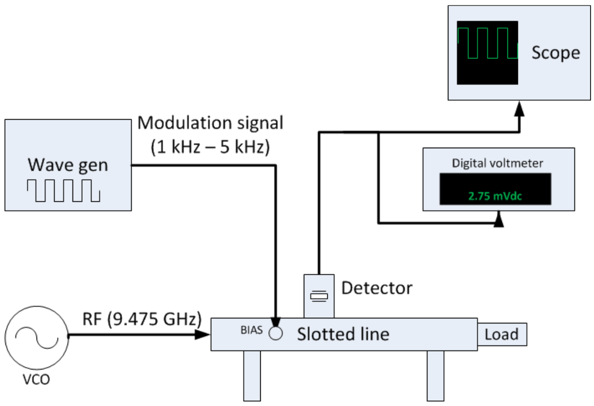


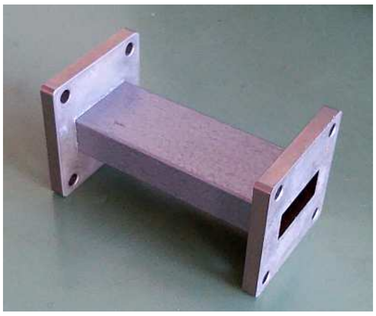
Figure 2: Setup for slotted line experiment

- Check that the laboratory equipment setup is in agreement with block-diagram, presented in Figure 2.

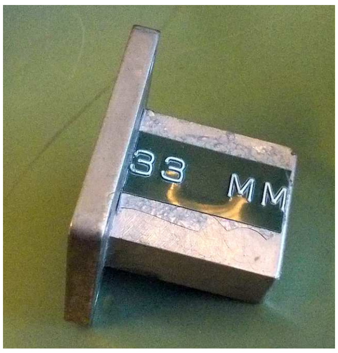
Figure 3: Waveform generator output

Experiments

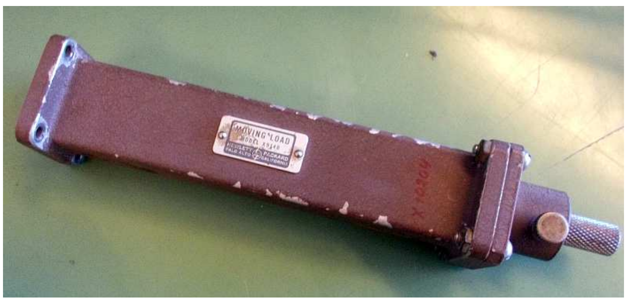
1. Measure the wavelength of the EM wave in waveguide.
   What is the phase velocity of the EM waves in waveguide? Explain this result.
2. Measure the voltage-standing-wave ratio (VSWR) of different loads:
   a. Open waveguide



   b. Short circuits



   c. Matched load



d. Horn antenna

Calculate the absolute value of the reflection coefficients for every loads and power, which is delivered into this load.

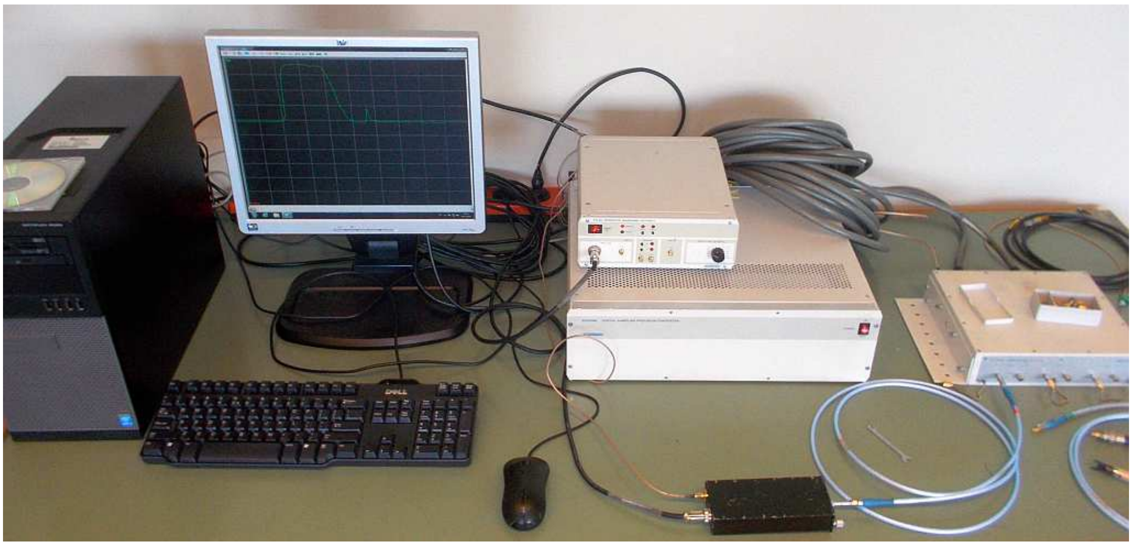
3. Compare patterns of standing waves for two short circuits of different lengths. Explain the shift of standing waves antinodes?

Additional tasks for the report:

- Determine and plot the theoretical dependence of phase velocity inside the X-band waveguide as function of frequency from 8 GHz to 12 GHz and compare with measurement results.
- What other parameters of waveguide and loads can be estimated from your measurements?

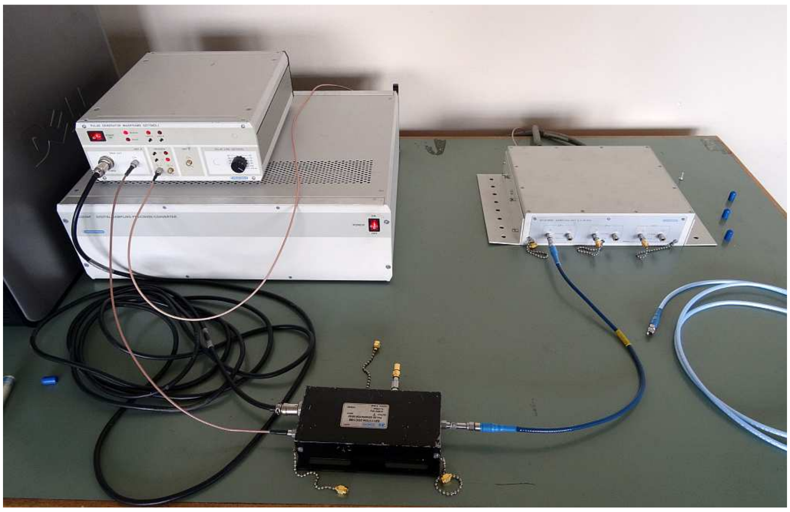
Assignment 2. Transmission Lines in Time Domain. 45 min

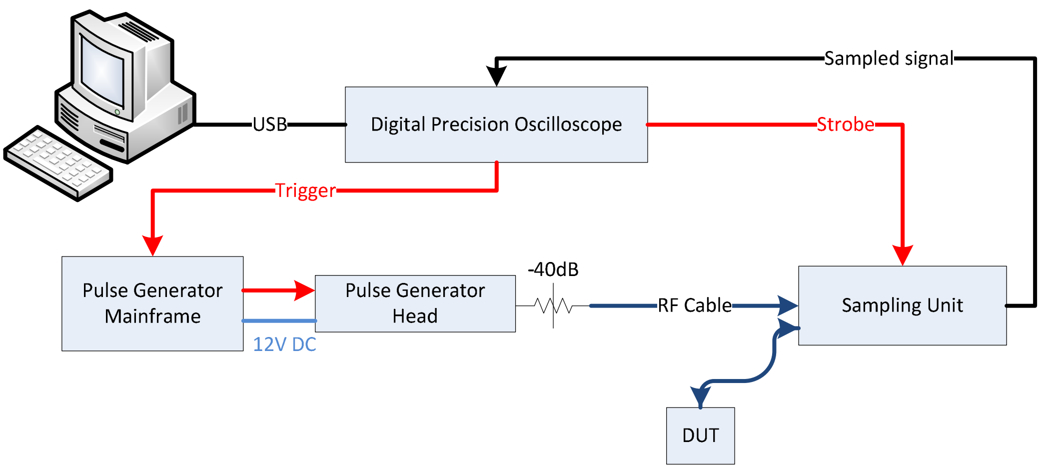
For the time domain we will use ultra wide band (UWB) pulse generator and Digital Sampling Oscilloscope.



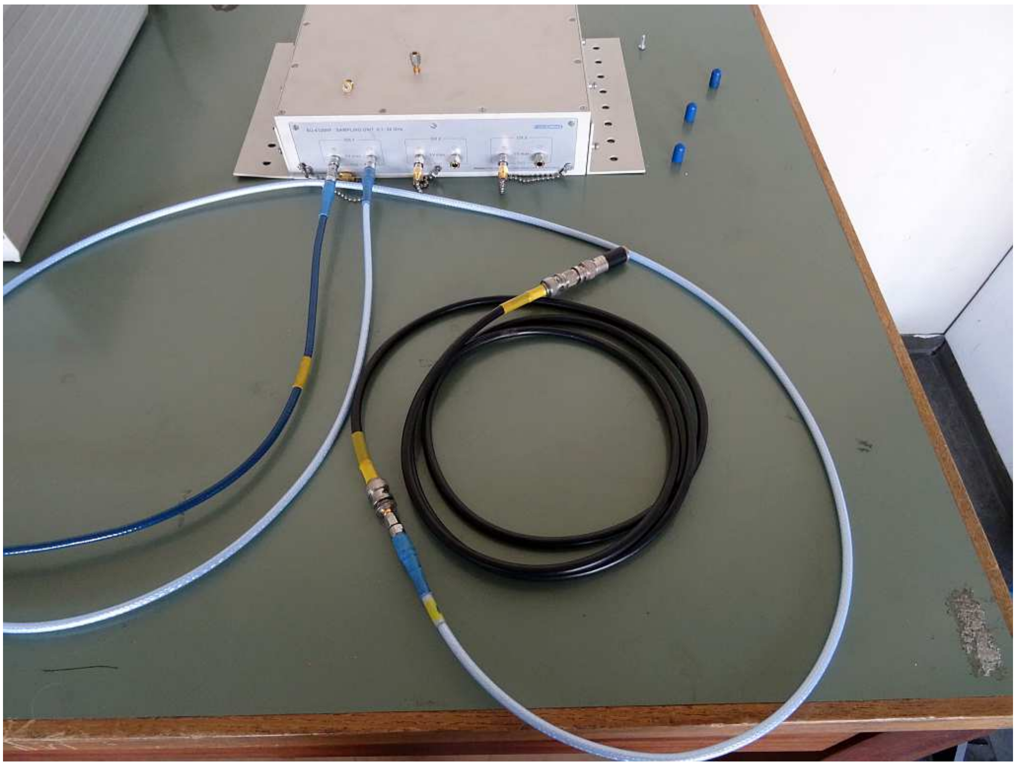
Part 1. Time Domain Reflectometry: estimate the load's impedance

Connect components for time domain reflectometry as shown on pictures:





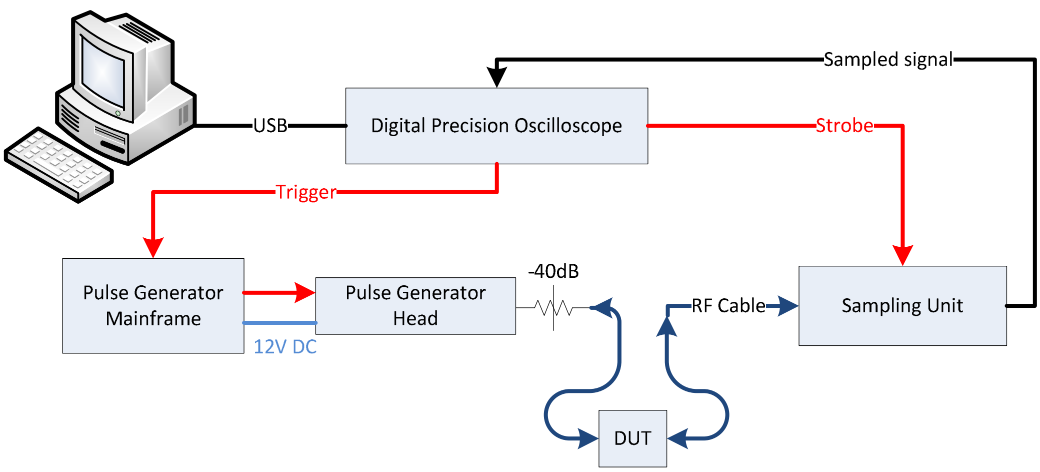
- Connect short circuit, record signal
- Connect match load, record signal
- Connect Z_l, record signal



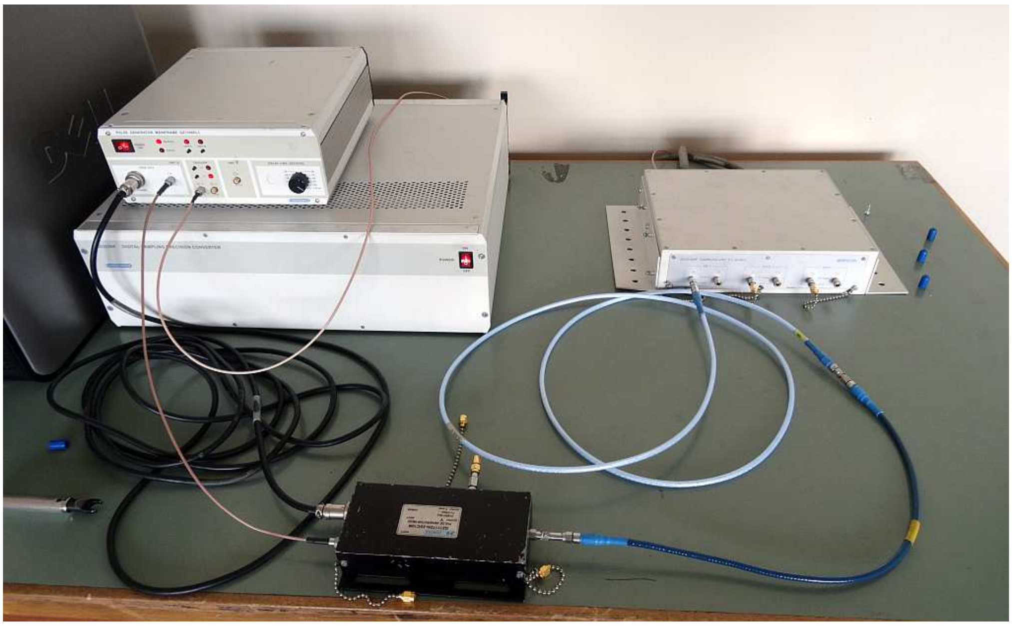
- Determine Z_l knowing Z_0 = 50 Ω. Explain the difference between measurements of load's impedance in time and frequency domains.

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

Connect components for the measurement of one-way propagation time as shown on pictures:



- Connect calibration RF cable, record signal
- Connect extra cable (under investigation), record signal



- Estimate the propagation velocity of electromagnetic wave in coaxial cable and the relative permittivity of dielectric filling of this cable.