Assignment 2

Scattering Parameters and Time Domain Reflectometry (TDR)

Purpose

The purpose of this assignment is to help you understand S-parameter concatenation (cascading) and Time Domain Reflectometry (TDR).

Notes and Instructions

1. While only the answers in the Formative boxes are required for submission on the Formative platform, you are encouraged to attempt other questions.

1 Basics: Cascading S-Parameters

Figure (1) shows two 2-port networks where Network 2 is connected after Network 1. This configuration is commonly used in Signal Integrity analysis. For example, Network 1 could be a package model obtained from a full-wave simulator, and Network 2 could represent a PCB model from a vendor, measurement, or simulation. Cascading these networks enables large system analysis.

The S-parameters of the combined system are derived from basic circuit theory, and take the following

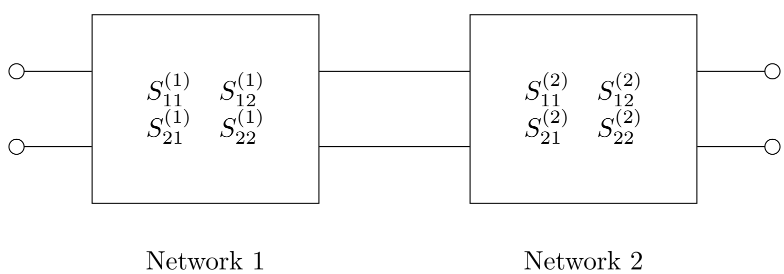


Figure 1: Cascade of two networks

forms:

$$S_{11} = S_{11}^{(1)} + \frac{\left(S_{21}^{(1)}\right)^2 S_{11}^{(2)}}{1 - S_{22}^{(1)} S_{11}^{(2)}} \tag{1}$$

$$S_{21} = \frac{S_{21}^{(1)} S_{21}^{(2)}}{1 - S_{22}^{(1)} S_{11}^{(2)}} \tag{2}$$

$$S_{12} = \frac{S_{12}^{(1)} S_{12}^{(2)}}{1 - S_{22}^{(1)} S_{11}^{(2)}} \tag{3}$$

$$S_{22} = S_{22}^{(2)} + \frac{\left(S_{12}^{(2)}\right)^2 S_{22}^{(1)}}{1 - S_{22}^{(1)} S_{11}^{(2)}} \tag{4}$$

The above equations are used to calculate the cascaded S-parameters in the function:

```
S = cascade2P_SI(S1, S2)
```

Task 1: Cascading Two S-Parameters

In this task, open the `cascade2P_SI` file and review the documentation and code.
The `cascade2P_SI` function takes two S-parameter matrices and returns the cascaded S-parameters. **Note**: the order of inputs matters.
The `sparamsxxOhm` files represent the S-parameters of transmission lines with characteristic impedances of $xx\ \Omega$.

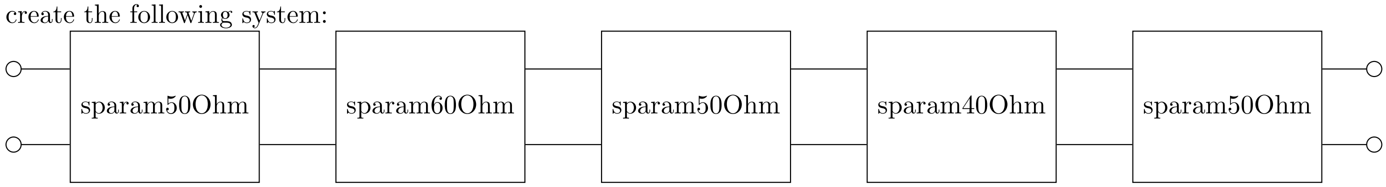
1. **Cascade** `sparam50Ohm` with `sparam60Ohm`. Plot the magnitude of S_{11} in dB (use the built-in function `db()`).
2. **Cascade** `sparam60Ohm` with `sparam50Ohm`. On the same plot, show the magnitude of S_{11} in dB.

> **Formative**
>
> Do the S_{11} values calculated above match?

Task 2: Repeated Cascade

Overview

In this task, you will build a complex system from multiple S-parameters. Use the cascade function to create the following system:



Steps:

1. **Repeatedly use the cascade function**:
2. **Plot** S_{11} and S_{22}.

Formative

Are S_{11} and S_{22} equal?

3. **Plot** S_{12} and S_{21}.

Formative

Are S_{12} and S_{21} equal?

TDR:

1.1 Overview

Time Domain Reflectometry (TDR) is a simple but powerful tool for estimating the impedance profile of an interconnect. The impedance profile represents the instantaneous impedance when a unit step input is applied (a constant voltage switched on at $t = 0$).
The function for calculating the impedance profile, or TDR, is:
`tdr_SI(freq, S11, z0)`
where z_0 is the single-ended reference impedance, typically 50 Ω.
For the S-parameters from the previous task:

1. **Apply** `tdr_SI` to calculate the TDR using S_{11}.
2. **Plot** the impedance profile versus time. The profile represents the impedance as seen from port one. Does this match your expectations?

   Formative

   Based on the impedance profile, what is the order of transmission lines?

3. **Apply** `tdr_SI` to calculate the TDR using S_{22}.
4. **Plot** on the same graph, the impedance profile versus time, representing the impedance as seen from port two. Does this match your expectations?

   Formative

   Based on the impedance profile, what is the order of transmission lines?

Observe

Note that the impedance accuracy decreases as we move further into the interconnect.

2 DEMO

Watch the demo that shows a pulse propagating inside the previously obtained interconnect. The pulse reflects when it encounters a discontinuity[1].

Formative

Do the pulse reflections correlate with the impedance profile?

[1] The impedance has been changed to increase the mismatch so reflections are clearer for viewers.