# LAB GUIDE
# TEM TRANSMISSION LINE – PART #2
# (REFLECTION AND TRANSMISSION)

- Complete the pre-test in your TL Lab Workbook #2 before you start working on the lab exercises.
- The TL Lab Workbook #2 must be submitted to the TA for marking at the end of the 3-hour session. Late submissions are unacceptable.
- This Guide will help you work with the software (MEFiSTo-2D Classic).

## Experiment #1: Reflection of a Gaussian Pulse by a Short Circuit

In this experiment, you will study the total reflection of a pulse from an electric, i.e., metallic, wall (or a short circuit). This boundary condition is characterized by a reflection coefficient $\Gamma = -1$, i.e., the reflected electric field wave has the same magnitude as the incident wave at the boundary but opposite polarity. This should be the case indeed at a metallic boundary since the total tangential electric field at such a boundary must vanish. Equivalently, the total voltage at a short circuit must be zero.

<u>Step 1: Set Up Electric-Wall Termination of Transmission Line</u>

Open the file `tline.tlm`. Replace the matched load by an **Electric Wall**. To do so, proceed as follows.

1) Reset the Simulator with .
2) Select **View** $\rightarrow$ **Draw**.
3) Right-click and select **Reflection Wall**. This is the green line at the right end of the computational domain. Re-draw this line to delete it.
4) Right-click and select **Electric Wall**. Draw the electric-wall line exactly where the reflection-wall was. You should see a red line terminating the computational region.

***Answer Questions 1 to 3 in the Workbook.***

<u>Step 2: Observing the Incident and Reflected Pulses</u>

First, set up your source. From the **Source Waveform** menu select **Gaussian (f)**. Select its characteristics as follows: Magnitude: <u>0.707</u>, Bandwidth [GHz]: <u>40</u>, Gaussian-Modulated Carrier: <u>Constant</u>. Click **OK**. Set the number of time steps to **400** and the update interval to **1** in the **Simulation Control Data** window.

Set **Sampling Mode** as Vy (voltage wave) and start the simulation in **Field/3D** view.

Reset simulation. Set **Sampling Mode** as Iz = = −Hx (current wave) and start the simulation in **Field/3D** view.

***Answer Questions 4 to 7 in the Workbook.***

Step 3: Measuring the Distance from Probe 1 to the Short Circuit

You can find the distance from Probe 1 to the short circuit by measuring the time delay between the maxima of the incident and the reflected pulses. You can easily make this measurement by viewing the **V(t)** output of Probe 1. It is best if you set **Sampling Mode** as Vy. You will need the discrete time step $\Delta t$, which you can check in the **Simulation Control Data** window. You will also need the velocity, which you can determine knowing that the medium constitutive parameters are $\varepsilon_r = 1$, $\mu_r = 1$, and $\sigma = 0$. You can compare your result with the actual distance from Probe 1 to the electric-wall termination, which you can determine using the **(Z-X)** Coordinate Window in the **Draw** view (select **View**$\rightarrow$**Draw**).

***Complete TABLE 1 in the Workbook and answer Question 8.***

## Experiment #2: Reflection of a Gaussian Pulse by an Open Circuit

In this experiment, you will study the total reflection of a pulse from a magnetic wall, which represents an open circuit. A magnetic wall is the place where the total magnetic field, or equivalently the total current, become zero. This boundary condition is characterized by a reflection coefficient $\Gamma = +1$, i.e., the reflected electric field wave has the same magnitude as the incident wave at the boundary and the same polarity.

Step 1: Set Up Magnetic-Wall Termination of Transmission Line

In the **Draw** window, delete the **Electric Wall** termination and draw in its place a **Magnetic Wall** termination. The steps are analogous to those in Step 1 of Experiment #1.

***Answer Questions 9 to 11 in the Workbook.***

Step 2: Observing the Incident and Reflected Pulses

Select **View/Field** and **Field/3D** and run the simulation first in **Sampling Mode** as Vy = Ey (voltage wave) and then in **Sampling Mode** as Iz = −Hx (current wave).

***Answer Questions 12 to 15 in the Workbook.***

## Experiment #3: Partial Reflection of a Gaussian Pulse

In this experiment, you will study the reflection of a pulse from a partially matched load. The reflection coefficient will be set to $\Gamma = 0.5$, which means that the magnitude of the reflected voltage pulse is half that of the incident pulse and its polarity at the boundary is the same as that of the incident pulse.

Step 1: Set up Termination

Reset the simulator and return to **Draw** mode. Terminate the structure by a **Reflection Wall** of a reflection coefficient $\Gamma = 0.5$ (**TEM Wave Reflection Coefficient** has to be set to **0.5**). Set **Sampling Mode** as Vy = Ey.

***Answer Question 16 in the Workbook.***

Step 2: Measurement of the Reflection Coefficient

Run the simulation once observing the field animation in **Field/3D** mode, and a second time, in **Graph/Probe responses** mode. Inspect closely the time response of Probe 1. Compare the peaks of the incident and the reflected pulses. ***Complete TABLE 2 in the Workbook***.

## Experiment #4: Total Reflection of a Sine Wave

Step 1: Set up Electric-Wall Termination and Sinusoidal Excitation

Initialize the simulation. Enter the **Draw** mode and terminate the structure by an **Electric Wall** at the right end of the transmission line.

From **Source Waveform** select **Sin (f).** Set its characteristics as follows: Magnitude = 0.707, Frequency [GHz] = 6.

In **Simulation Control**$\rightarrow$**Control Data**, set the number of time steps to **2000** and the update interval to **1**. Make sure **Sampling Mode** is set to Vy = Ey. You are now ready to start the simulation in the **Field/3D** animation mode.

Step 2: Standing Wave Observation and *SWR* Measurement

Observe the sine wave propagating and being reflected by the short circuit (in a **Field/3D** mode). The incident and the reflected sine waves superimpose to produce a standing wave.

To measure the *SWR*, you will have to observe the standing wave envelope in the **Field/2D** mode. Reset the solver, go to **View/Field** (or right click and choose **Field**) and choose **Field**$\rightarrow$**2D**. Make sure the **Show Signal Envelope** button  is switched off before you start the simulation. Start the simulation and wait until the standing wave is well defined along the whole line. Then click on  to see the envelope of the standing wave. (Note: You can always reset the envelope plot by pressing .) Measure the maximum and the minimum value of the signal envelope and calculate the *SWR*. ***Record your findings in TABLE 3 and answer Questions 17 and 18 in the Workbook***.

Change the **Sampling Mode** to Iz = −Hx. Reset and re-run the simulation. You may need to adjust the **Graph Display Attributes** (right-click) Ymax and Ymin. ***Answer Question 19 in the Workbook***.

Step 3: Standing Wave in a Transmission Line Terminated by a Magnetic Wall

Reset the simulator. Return to the **Draw** window. Delete the **Electric Wall** termination (red line) and replace it with a **Magnetic Wall** (blue line). Start the simulation and observe the **Field/2D** animation. Observe both the voltage standing wave (**Sampling Mode** Vy = Ey) and the current standing wave (**Sampling Mode** Iz = −Hx). ***Answer Questions 20 to 23 in the Workbook***.

## Experiment #5: Partial Reflection of a Sine Wave by a Resistive Load

Terminate the structure by a **Reflection Wall** at the right end where the **TEM Wave Reflection Coefficient** is **0.5** ( $\Gamma = 0.5$ ). Set **Sampling Mode** as Vy = Ey.

Step 1: Mixed Wave Observation and *SWR* Measurement

Start the simulation and observe the field animation in **Field/3D** and **Field/2D** modes. When in **Field/2D** mode, measure the *SWR* of the mixed wave. ***Fill in TABLE 4 and answer Question 24 in the Workbook***. Close the project `tline.tlm`.

## Experiment #6: Scattering of a Gaussian Pulse at a Dielectric Discontinuity

Step 1: Project Set-up: ( $\varepsilon_{r1} < \varepsilon_{r2}$ )

Open the project (**File/Open**) `tline_diel.tlm`. This layout looks very similar to the one in `tline.tlm`. However, there are three differences:

- The total line length is larger. ***You have to measure it and write it down in TABLE 5 in the Workbook***.
- There are two regions: region 1 of $\varepsilon_{r1} = 1$, $\sigma_1 = 0$ (the left one) and region 2 of $\varepsilon_{r2} = 4$, $\sigma_2 = 0$ (the right one). To clearly distinguish them, you will have to select one of them, so that it changes its colour. Right click and select **Select Element**. Click anywhere inside the transmission-line rectangle. One region is now clearly visible. ***Measure the location of the dielectric interface and write it down in TABLE 5***.
- Finally, you should have already noticed that there are only two probes in this project. Probe 1 is in region 1, and Probe 2 is in region 2. Both probes are the same distance away from the dielectric discontinuity. ***Measure their distances from the interface and mark them down in TABLE 5***.

Double-check whether the **Source Waveform** is set as **Gaussian (f)**, with a magnitude of 0.707, a bandwidth of 40 GHz and a constant carrier.

***Answer Questions 25 and 26 in the Workbook***.

Step 2: Observation of the Reflection and Transmission Coefficients ( $\varepsilon_{r1} < \varepsilon_{r2}$ )

Start the simulation and observe the scattering (reflection and transmission) of the pulse at the air-dielectric interface in a **Field/3D** mode. ***Answer Questions 27 and 28 in the Workbook***.

Step 3: Measurement of the Reflection and Transmission Coefficients ($\varepsilon_{r1} < \varepsilon_{r2}$)

Using the peak values of the incident, the reflected and the transmitted pulses, calculate the reflection coefficient $\Gamma$ and the transmission coefficient $T$. Measure accurately the peak values of the pulses in the **Graph** mode: go to **View**$\rightarrow$**Graph** and select **Graph**$\rightarrow$**Probe 1**$\rightarrow$**V(t)**. Probe 1 will provide you with the information about the incident and the reflected pulses. To measure the peak of the transmitted pulse, go to **Graph**$\rightarrow$**Probe 2**$\rightarrow$**V(t)**. Compare your results with your analytical calculations. ***Fill in all data in TABLE 6 in your Workbook and answer Questions 29 to 32***. Close the project `tline_diel.tlm`.

Step 4: Observation of the Reflection and Transmission Coefficients ($\varepsilon_{r1} > \varepsilon_{r2}$)

Open the project `tline_diel_inv.tlm`. In this project line segments 1 and 2 are exchanged, i.e., now $\varepsilon_{r1} = 4$ and $\varepsilon_{r2} = 1$. All other settings are the same as in `tline_diel.tlm`. Observe the field propagation in **Field/3D** view and in **Graph/Probe Responses** view. ***Fill in TABLE 7 in your Workbook and answer Question 33***. Close `tline_diel_inv.tlm`.

## Experiment #7: Scattering of a Sine Wave at a Step Discontinuity

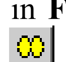
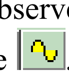
Step 1: Project Description

Close the current project file. Open `tline_step.tlm`. View the outline in the **View/Draw** window. ***Perform all necessary measurements to fill in TABLE 8 in your Workbook***. ***Answer Question 34***.

Step 2: Observation of the Sine Wave in Both Line Segments

Start the simulation and observe the wave in a **Field/3D** mode. ***Answer Questions 35 to 37 in your Workbook***.

Step 3: Measurement of Standing Wave Ratio in Both Segments

Change the Animation Region to a region whose width is only 1 cell so that you can observe the wave envelope along the whole line in **Field/2D** mode. Re-run the simulation and observe the wave envelope in both regions using . If you need to re-set the envelope curve, use . ***Fill in TABLE 9 in your Workbook and answer Questions 38 and 39***.

## Experiment #8: Quarter-wavelength Impedance Transformer

Step 1: Project Description

Close the current project file. Open `tline_3segments.tlm`. ***Perform all necessary measurements to fill in TABLE 10 in your Workbook***. To find the constitutive parameters assigned to a computational region, enter the **Draw** mode, right-click and select **Select Element**, click anywhere within the region of interest so that it changes color, right-click and select **Property**. After recording the assigned value, click **OK**. Do not change the assigned parameters. ***Answer Questions 40 to 42***.

Step 2: Observation of the Sine Wave Propagation

Start the simulation and observe the wave propagation first in **Field/3D** mode and then in **Field/2D** mode. Switch on the envelope  to see whether there are maxima and minima in its values along segment 1 and segment 3 of the line. ***Answer Questions 43 to 46 in your Workbook***.

Step 3: Observation of the 10-GHz Sine Wave Propagation

Re-set the simulator and change its **Source Waveform** frequency to 10 GHz. Run the simulation and observe the envelope in **Field/2D** view. ***Answer Questions 47 to 49***.

***Submit your Workbook to the TA now!***