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

- Submit for marking at the end of the 3-hour session!
- Write your name and student ID on each page (see top of page)!

PRETEST

(Write answers immediately below respective questions.)

1. What is the formula for the intrinsic impedance Z_w of a TEM wave in a medium characterized by permittivity ε and permeability μ?

2. Express the characteristic impedance of a TEM line in terms of its capacitance per unit length C_1 and its inductance per unit length L_1.

3. Express the phase velocity of a TEM line in terms of its capacitance per unit length and its inductance per unit length.

4. A transmission line of characteristics impedances Z_{c1} is connected to a second line of impedance Z_{c2}. If the reflection coefficient at the joint of the two lines is Γ, find the ratio Z_{c2} / Z_{c1} in terms of Γ.

5. What is the relation between the *SWR* and the reflection coefficient Γ?

6. What is the relation between Γ and *T*?

7. What is the formula to the calculation of the reflection coefficient Γ in terms of the intrinsic impedances of two media for a TEM wave normally incident at the interface between the two media? How do we calculate Γ for a wave in a transmission line, which impedance changes from Z_{c_1} to Z_{c_2}?

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8. Write the characteristic impedance of a parallel-plate line in terms of the width of the plates w, the distance between the plates h, and the constitutive parameters of the medium sandwiched between the plates.

9. If a TEM transmission line is quarter-wave long at the operating frequency, and it connects a generator of real impedance Z_g to a load of real impedance Z_L, what is the characteristic impedance of the line Z_c for which maximum power transfer will be realized.

10. What are the reasons for signal power loss along a transmission line? Explain their nature.

11. Which of the transmission lines you know is best protected from EM interference?

ADDITIONAL NOTES AND COMMENTS:

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PRACTICE AND EXPERIMENTS

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

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

Q1: The physical equivalent of an "electric-wall" termination is:

(a) open circuit
(b) short circuit
(c) matched load
(d) 50-Ω load

Q2: What is the reflection coefficient at an "electric-wall" termination?

(a) +1
(b) 0
(c) -1
(d) 0.5

Q3: Which of the following statements about the total voltage magnitude V_{Tm} and the total current magnitude I_{Tm} is correct at the "electric-wall" termination?

(a) V_{Tm} is zero, I_{Tm} is maximum
(b) V_{Tm} is maximum, I_{Tm} is maximum
(c) V_{Tm} is zero, I_{Tm} is zero
(d) V_{Tm} is maximum, I_{Tm} is zero

Step 2: Observing the Incident and Reflected Pulses

Q4: What is the polarity of the reflected voltage pulse compared to that of the incident one?

(a) same
(b) opposite

Q5: What is the magnitude of the reflected voltage pulse compared to that of the incident one?

(a) same
(b) different

Q6: What is the polarity of the reflected current pulse compared to that of the incident one?

(a) same
(b) opposite

Q7: What is the magnitude of the reflected current pulse compared to that of the incident one?

(a) same
(b) different

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

TABLE 1: DISTANCE FROM PROBE 1 TO THE ELECTRIC WALL

Time step of incident pulse peak	
Time step of reflected pulse peak	
Time delay in time steps	
Time step Δt in pico-seconds	
Time delay in pico-seconds	
Velocity, m/s	
Distance Probe 1 – Electric Wall, m	
Distance Probe 1 – Electric Wall, m (measured from layout)	

Q8: How did you calculate the distance from Probe 1 to the Electric Wall from the time delay between the incident and the reflected pulses?

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

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

Q9: The physical equivalent of a "magnetic-wall" termination is:

(a) open circuit
(b) short circuit
(c) matched load
(d) 50-Ω load

Q10: What is the reflection coefficient at a "magnetic-wall" termination?

(a) +1
(b) 0
(c) -1
(d) 0.5

Q11: Which of the following statements about the total voltage magnitude V_{Tm} and the total current magnitude I_{Tm} is correct at the "magnetic-wall" termination?

(a) V_{Tm} is zero, I_{Tm} is maximum
(b) V_{Tm} is maximum, I_{Tm} is maximum
(c) V_{Tm} is zero, I_{Tm} is zero
(d) V_{Tm} is maximum, I_{Tm} is zero

Step 2: Observing the Incident and Reflected Pulses

Q12: What is the polarity of the reflected voltage pulse compared to that of the incident one?

(a) same
(b) opposite

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Q13: What is the magnitude of the reflected voltage pulse compared to that of the incident one?

(a) same (b) opposite

Q14: What is the polarity of the reflected current pulse compared to that of the incident one?

(a) same (b) opposite

Q15: What is the magnitude of the reflected current pulse compared to that of the incident one?

(a) same (b) opposite

Experiment #3: Partial Reflection of a Gaussian Pulse by a Resistive Load

Step 1: Set-up Termination

Q16: A termination wall of $\Gamma = 0.5$ represents a load at the right end Z_L, which is not matched to the characteristic impedance of the transmission line Z_{c1}. Alternatively, it may also represent another transmission line whose characteristic impedance is $Z_{c2} = Z_L$ and which is matched at the end. What is the ratio Z_L / Z_{c1} corresponding to $\Gamma = 0.5$?

Step 2: Measurement of the Reflection Coefficient

TABLE 2: REFLECTION OF A GAUSSIAN PULSE FROM $\Gamma = 0.5$ WALL

	Peak, V	Ratio: Reflected/Incident
Incident		
Reflected		

Experiment #4: Total Reflection of a Sine Wave

Step 2: Standing Wave Observation and *SWR* Measurement

TABLE 3: *SWR* MEASUREMENT, $\Gamma = -1$

	Envelope	*SWR*
V_{max}, V		
V_{min}, V		

Q17: What is the theoretical value of the *SWR* in the case of total reflection?

Q18: What is the magnitude of the voltage wave at the electric-wall end of the line?

(a) zero (b) maximum
(c) half-maximum (d) quarter-maximum

Q19: What is the magnitude of the current wave at the electric-wall end of the line?

(a) zero (b) maximum
(c) half-maximum (d) quarter-maximum

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

Q20: What is the magnitude of the voltage wave at the magnetic-wall end of the line?

(a) zero (b) maximum
(c) half-maximum (d) quarter-maximum

Q21: What is the magnitude of the current wave at the magnetic-wall end of the line?

(a) zero (b) maximum
(c) half-maximum (d) quarter-maximum

Q22: What is the distance in terms of wavelengths between two neighbouring nulls of the standing wave?

(a) one wavelength (b) two wavelengths
(c) half a wavelength (d) quarter wavelength

Q23: What is the distance in terms of wavelengths between two neighbouring maxima of the standing wave?

(a) one wavelength (b) two wavelengths
(c) half a wavelength (d) quarter wavelength

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

Step 1: Mixed Wave Observation and *SWR* Measurement

TABLE 4: *SWR* measurement, $\Gamma = 0.5$

	Envelope	*SWR*
V_{max} , V		
V_{min} , V		

Q24: What is the theoretical value of the *SWR* when $\Gamma = 0.5$?

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

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

TABLE 5: STRUCTURE DESCRIPTION OF DIELECTRIC DISCONTINUITY

Computation Domain		Transmission Line		
ΔL	1 mm		# of cells N_L	Phys. dimension= $N_L \cdot \Delta L$, mm
Δt	2.35865 ps	Width		
ε_{r1}	1	Length		
ε_{r2}	4	Interface at		
$\sigma_1 = \sigma_2$	0 S/m	Probe 1 - Interface		
# probes	2	Probe 2 - Interface		

Q25: What is the ratio Z_{c2} / Z_{c1} of the characteristic impedances of the two sections of transmission lines joined at the interface?

(a) 2
(b) 1
(c) 0.25
(d) 0.5

Q26: What is the ratio v_{p2} / v_{p1} of the phase velocities of the two sections of transmission lines joined at the interface?

(a) 2
(b) 1
(c) 0.25
(d) 0.5

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

Q27: Which pulse exits the structure first?

(a) reflected exits first to the left
(b) transmitted exits first to the right
(c) incident exits first to the left
(d) incident exits first to the right

Q28: The dielectric interface is practically equidistant from the two ends of the transmission-line structure. Based on your answer of Q27, in which region the pulse velocity is smaller?

(a) region #1 (left region)
(b) region #2 (right region)
(c) velocities in both regions are about the same
(d) there is no relation between Q27 and Q28

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

TABLE 6: REFLECTION AND TRANSMISSION COEFFICIENTS ($\varepsilon_{r1} < \varepsilon_{r2}$)

	Peak, V	Γ measured	Γ theory	T measured	T theory
Incident					
Reflected					
Transmitted					

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Q29: How did you calculate Γ measured from the measured pulse peaks?

Q30: How did you calculate T measured from the measured pulse peaks?

Q31: How did you calculate the theoretical reflection coefficient Γ ?

Q32: How did you calculate the theoretical transmission coefficient T?

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

TABLE 7: REFLECTION AND TRANSMISSION COEFFICIENTS ($\varepsilon_{r1} > \varepsilon_{r2}$)

	Peak, V	Γ measured	Γ theory	T measured	T theory
Incident					
Reflected					
Transmitted					

Q33: How do you explain the fact that the transmitted pulse peak in segment 2 is greater than that of the incident peak in segment 1? Does this mean that the transmitted power in segment 2 is greater than the incident power in segment 1?

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

Step 1: Project Description

TABLE 8: STRUCTURE DESCRIPTION OF STEP DISCONTINUITY

Computation Domain		Transmission Line		
ΔL	1 mm		# of cells N_L	Physical size= $N_L \cdot \Delta L$, mm
Δt	2.35865 ps	Width Line 1, w_1		
ε_r	1	Length Line 1, L_1		
σ	0 S/m	Width Line 2, w_2		
		Length Line 2, L_2		
# probes	2	Probe 1 z-position		
Excite	Sine, 6 GHz	Probe 2 z-position		

Q34: Based on the measured widths of the two segments of transmission lines, w_1 and w_2, calculate the ratio of the characteristics impedances Z_{c2} / Z_{c1} of the two lines. Note that the heights of the two line segments are identical.

(a) $Z_{c2} / Z_{c1} = 1$
(b) $Z_{c2} / Z_{c1} = 2$
(c) $Z_{c2} / Z_{c1} = 0.25$
(d) $Z_{c2} / Z_{c1} = 0.5$

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

Q35: From the field animation, what can you conclude about the type of wave propagating in line segment 1 (the left one)?

(a) traveling
(b) standing
(c) mixed
(d) cannot tell

Q36: From the field animation, what can you conclude about the type of wave propagating in line segment 2 (the right one)?

(a) traveling
(b) standing
(c) mixed
(d) cannot tell

Q37: From the type of wave propagating in line segment 2, what can you conclude about the matching conditions at its end?

(a) not matched
(b) matched

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Step 3: Measurement of Standing Wave Ratio in Both Segments

TABLE 9: *SWR* MEASUREMENT IN BOTH TRANSMISSION-LINE SEGMENTS

	Envelope Segment 1	Envelope Segment 2
V_{max} , V		
V_{min} , V		
SWR Measured		
Reflection Coefficient Γ Theory		
SWR Theory		

Q38: How did you calculate the theoretical reflection coefficient Γ ?

Q39: How did you calculate the theoretical *SWR*?

Experiment #8: Quarter-wavelength Impedance Transformer

Step 1: Project Description

TABLE 10: STRUCTURE DESCRIPTION OF QUARTER-WAVELENGTH IMPEDANCE TRANSFORMER

Common Parameters			
ΔL	1 mm	Permittivity Line 1, ε_{r1}	
Δt	2.35865 ps	Length Line 1, L_1 , mm	
Width	3 mm	Permittivity Line 2, ε_{r2}	
σ	0 S/m	Length Line 2, L_2	
# probes	3	Permittivity Line 3, ε_{r3}	
Excite	Sine, 2.65165 GHz	Length Line 3, L_3	

Q40: Calculate the ratio $Z_{c2} / \sqrt{Z_{c1}Z_{c3}}$ for the three transmission-line segments bearing in mind that the only thing that is different in these line segments is the permittivity of the medium.

Q41: What is the wavelength at which the middle section of the transmission line acts best as an impedance transformer?

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Q42: What frequency does this wavelength correspond to?

Step 2: Observation of the Sine Wave Propagation

Q43: What type of wave propagates in line segment 1?

(a) traveling
(b) standing
(c) mixed
(d) cannot tell

Q44: What is your conclusion about the equivalent load impedance of line segment 1?

(a) it is different from Z_{c1}
(b) it is the same as Z_{c1}

Q45: Where is the wavelength the shortest?

(a) segment 1
(b) segment 2
(c) segment 3
(d) it is the same everywhere

Q46: Why is the voltage smaller in segment 3 compared to that in segment 1?

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

Q47: What type of wave propagates in line segment 1 when $f = 10$ GHz?

(a) traveling
(b) standing
(c) mixed
(d) cannot tell

Q48: What is your conclusion about the equivalent load impedance of line segment 1 when $f = 10$ GHz?

(a) it is different from Z_{c1}
(b) it is the same as Z_{c1}

Q49: Explain the difference (if any) between the 10-GHz wave and the 2.65-GHz wave.

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