Introduction to the Technological, Pedagogical and Content Knowledge TPACK) Curriculum

The TPACK curriculum developed by Teaching Learning Centre, Indian Institute of Technology-Madras (IIT Madras), is funded by Ministry of Human Resource Development (MHRD) under the scheme of Pandit Madan Mohan Malaviya National Mission on Teachers and Teaching (PMMMNMTT). This curriculum is designed based on principles of constructive alignment to promote and achieve outcome-based education in engineering. The curriculum has been developed by using the topics from the current syllabus used at Indian Institute of Technology-Madras and other universities like the Anna University and the National Institute of Technology (NIT's).

The objective of this curriculum is to design course learning outcomes (CO's)- using higher levels in the Bloom's Taxonomy and based on the specific observable and measurable Learning Outcomes (LO's). We propose specific teaching learning activities and specific examples of assessments designed to measure the LO. The pedagogy suggested here is just as an example by the TLC team and hence, when used at other colleges it can be modified relevant to the context where it is going to be implemented.

The curriculum has been reviewed by the faculties at IIT- Madras and this being the first attempt this is open for feedback to modify for future iterations. The feedback will also be incorporated to develop other Engineering courses in India.

For any queries/feedback kindly contact : tlc@smail.iitm.ac.in

Acknowledgement

We express our sincere thanks and appreciation to, **Dr.Balaji Srinivasan,** Professor, Department of Electrical Engineering, Indian Institute of Technology Madras for sharing the questions, spending his valuable time in reviewing the document and for the valuable comments during the preparation of this document.

Course Plan

1. Course Information

Course title	Electromagnetics for Engineering
Department	Electrical Engineering
Course type	Core
Program level	B.Tech
Year and semester	II and III
Contact hours	45
Facilities required	Classroom with Black/White/Green Board, Projector and Screen, Computer/ Laptop/Tablet, Internet or Wi-Fi, Mobile Phone (optional)
Syllabus	Refer Appendix- EE1

2. Prerequisites

Calculus:

(i) Apply vector calculus to analyze simple electrostatic and magneto static fields, and are able to perform calculations involving various differential operators as well as line, surface and multiple integrals relating to electromagnetic problems.

Engineering Physics:

(i) Able to describe the basic concepts of electromagnetism and electrostatics: electric charge, Coulomb's law, electric structure of matter; conductors and dielectrics. Concepts of electrostatic field and potential, electrostatic energy. Electric currents, magnetic fields and Ampere's law. Magnetic materials. Time-varying fields and Faraday's law of induction. Basic electric circuits. Electromagnetic waves and Maxwell's equations.

(ii) Also able to apply the above concepts to solve engineering electromagnetic problems.

3. Course Outcomes

*CO1. **Apply** math and physics concepts to **compute** distributed transmission line (Two- wire / twisted pair, Coaxial and Parallel Plate) parameters.*

Model Instructional strategy to accomplish the CO1:

S.No.	Learning Outcome	Pedagogical Decision	Brief Description	Sample Technology
1	**Calculate / Find**	Problem Solving in Group with hard or Soft scaffolding technique	Students can study the work sheets, solve the problem, find the key ideas and produce the results by working with their peer groups and also with the guidance of the teacher. (The teacher can observe how the teams and the team member works in group, evaluate and if needed must provide proper assistance to the students to proceed further.)	• Online Worksheets / Google Forms • Problem Sheets (through Moodle)
2	**Review**	Think – Pair - Share	Review previous class topics using the activity **Think-Pair-Share**. It may be helpful to have them turn in their summaries on index cards for a minor grade, to discourage tardiness (especially in students who are trying to avoid this activity).	• Index card • Problem Sheets / worksheets/ handouts

<u>Additional Resources:</u>

http://www.amanogawa.com/archive/LineImpedance/LineImpedance.html

http://www.amanogawa.com/archive/InputImpedance/InputImpedance.html

http://www.amanogawa.com/archive/StandingWavePattern1/StandingWavePattern1.html

http://www.amanogawa.com/archive/TwoWire/TwoWire.html

http://www.amanogawa.com/archive/Coaxial/Coaxial.html

http://www.amanogawa.com/archive/Stripline/Stripline.html

http://www.amanogawa.com/archive/Microstrip/Microstrip.html

ASSESSMENT PLAN

Type of assessment	**Frequency of assessment**	**Delivery from the learner**	**Data collection**	**Learning Verification**	**Decision making**
Formative	Every class (50 Min. each) (Number of classes = 10)	a) Solve problems through group work	a) Online through Moodle	a) (i) Learner see the correct answer in the feedback given; (ii) Class performance will be analyzed by Moodle	
	Weekly	b) Solve assignments	b) Hard copy submission	b) Evaluate the hard copy; determine class average; give back the answer sheets to the class and discuss the mistakes	
Summative	End of 16 and 45 no. of classes	TEST PAPER I	Hard copy	Evaluate the hard copy and grade Weightage for this portion: 12.5 %	

A few examples of questions (from previous year GATE papers), which can be given for in class activities and surprise or short quiz, are given below:

1. The input impedance of a λ/8 section of a lossless transmission line of characteristic impedance 50 Ω is found to be real when the other end is terminated by a load $Z_L = R + jX$. If X is 30 Ω, the value of R is ______.
    a) 40 Ω
    b) 20 Ω
    c) 80 Ω
    d) 10 Ω
2. The capacitance per unit length and the characteristic impedance of a lossless transmission line are C and Z_0 respectively. The velocity of a travelling wave on the transmission line is
    a) Z_oC
    b) Z_o/ C
    c) $1/(Z_oC)$
    d) C/ Z_o
3. When analyzing a transmission line, its inductance and capacitance are considered to be:
    a) lumped

    b) distributed
    c) equal reactance's
    d) ideal elements
4. The effect of frequency on the resistance of a wire is called:
    a) I^2R loss
    b) the Ohmic effect
    c) the skin effect
    d) there is no such effect
5. A transmission line has a characteristic impedance of 50Ω and a resistance of 0.1 Ω/m. If the line is distortion less, the attenuation constant (in Np/m) is
    a) 500
    b) 0.014
    c) 5
    d) 0.002
6. In which of the following transmission lines, there is a mismatch in phase velocity during transmission?
    a) Coaxial transmission lines
    b) Strip lines
    c) Micro strip lines
    d) Parallel plate transmission lines

7. A very low-loss coaxial transmission line has 30 pF /ft. of distributed capacitance and 75nH / ft. of inductance. What is its characteristic impedance?
    a) 75 Ω
    b) 100 Ω
    c) 72.5 Ω
    d) 50 Ω

A few examples for the test paper and assignment questions are given below:

1. A lossless communication line between a submarine and ground station has characteristic impedance of 50 Ω and phase constant of 2 rad/m at 200MHz. Calculate the inductance per meter and the capacitance per meter of the line.

   (Hint: $Z_0 = R_0 = \sqrt{\frac{L}{C}}, \beta = \omega\sqrt{LC}\ , L = R_0^2\mathrm{C}, C = \frac{\beta}{\omega\, R_0}$)
2. A PCB trace can be treated as a distortion less transmission line (RC = GL). One such trace has a characteristic impedance of 70 Ω, attenuation constant of 0.03 Np/m, phase velocity of 0.5c, where c is the speed of light in vacuum. Find R, L, G, C and λ at 150 MHz. Note: the phase velocity is given by the ratio of angular velocity and phase constant.

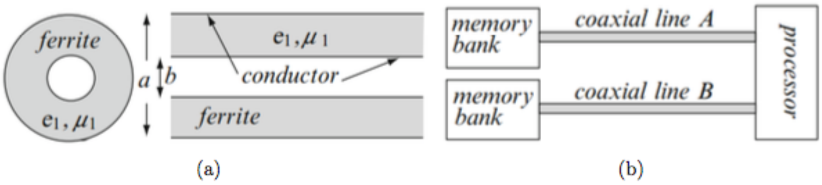
   (Hint: $uZ_0 = \frac{1}{C}\,, \lambda = \frac{v}{f}$)
3. Suppose the Ethernet cable used to connect your PC to the Internet has R = 0.3 Ω/m, L = 0.2 μH/m, G = 0 θ/m, C = 10 pF/m at an operating frequency of 1.5 GHz.

   a)What is the propagation constant of the cable?

   b) Calculate the characteristic impedance of the cable.

   (Hint: $\gamma = \alpha + j\beta$, $Z_0 = \sqrt{\frac{L}{C}}$)
4. Coaxial Line and Delay on the Line: A coaxial transmission line is made of two circular conductors as shown in Figure (a) below. The inner conductor has diameter b and the outer conductor diameter a. The conductors are perfect conductors and are separated by a lossless ferrite (a material with finite permeability, finite permittivity, and zero

conductivity). Given: ε_0 = 8.85 X10^{-12} [F/m], $\mu 0$ = 4π x 10^{-7} [H/m], ε_1 = $9\varepsilon_0$ [F/m], $\mu 1$ = $100\mu_0$ [H/m], a = 8 mm, b = 1 mm.



a)Calculate the characteristic impedance and the phase velocity on the line.

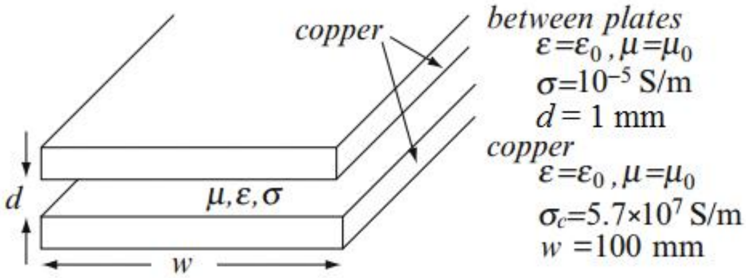
b) Two coaxial transmission lines connect two memory banks to a processor as shown in Figure above. Line A is the same as calculated in part (a). Line B has the same dimensions, but the ferrite is replaced with free space. What must be the minimum execution cycle of the processor if the two memory signals must reach the processor within one execution cycle? Assume the length of each cable is d = 100 mm.

(Hint: $Z_0 = \sqrt{\frac{L}{C}}$, $v_p = \frac{1}{\sqrt{LC}}$,

a) For a Coaxial Line,
$L = \frac{\mu_1}{2\pi} \ln\frac{r_o}{r_i}$, $C = \frac{2\pi\varepsilon_1}{\ln\frac{r_o}{r_i}}$

b) Execution Cycle of the processor is defined by slower of the two signals. Therefore, Execution Cycle = d/v_{pA})

5. Parallel plate line: A parallel plate line to be used in a PCB is made as shown in the figure below. Material properties and dimensions are also given in the figure. The line, 10 cm long, is intended to transmit signals from an oscillator at 1000 MHz to an amplifier section.



a) Find the characteristic impedance, attenuation, phase and propagation constants and wavelength.

b) Suppose the oscillator generates signals of peak amplitude 5 V. What is the peak amplitude of the signals reaching the input end of the amplifier?

c) What is the total accumulated phase shift by the wave for the case described above?

Hint: (a) $z_0 = \sqrt{\frac{R+j\omega L}{G+j\omega C}}$, $\gamma = \sqrt{(R + j\omega L)(G + j\omega C)}$, $\lambda = 2\pi / \beta$)

(b) V_{amp} = V $e^{-\alpha l}$

(c) $\Delta\phi = \beta l$

*CO2. **Analyze** and **Evaluate** transmission line parameters, characteristic impedance, reflections, load impedance and power transfer. **Apply** the concept to find impedance matching devices for maximum power transfer.*

Model Instructional strategy to accomplish the CO2:

S.No.	Learning Outcome	Pedagogical Decision	Brief Description	Sample Technology
1	**Realize** **Compare**	Inquiry Based Guided Learning with Peer Led Discussion	Student can work with their peer groups and also with the guidance of the teacher. The teacher can observe how the teams and the team member works in-group, evaluate and if needed must provide proper assistance to the students to proceed further. By random picking up of the cooperative group, the students can come and explain their findings about the activity to the entire class and the whole class discussion helps to clarify their doubts if any about the particular topic.	• Google Forms • Interactive applets • Moodle
2	**Calculate** **Find** **Determine**	Problem Solving in Group with scaffolding technique	Students can study the work sheets, solve the problem, find the key ideas and produce the results by working with their peer groups and also with the guidance of the teacher. (The teacher can observe how the teams and the team member works in group, evaluate and if needed must provide proper assistance to the students to proceed further.)	• Online Worksheets / Google Forms • Problem Sheets (through Moodle)
3	**Suggest** **Justify** **Evaluate**	Team Based Learning	Divide students into teams, define rules and procedures for teamwork, develop team contract, and deal with dysfunctional teams, peer rating through rubrics and peer evaluation forms. The teacher can evolve an auto rating system for an individual based on the peer evaluation score.	Online Worksheets / Problem Sheets (through Moodle) / Simulation tools For Peer Evaluation, (a) Rubrics (Hard copy or soft copy through Moodle or Edmodo or Google forms or spread sheet submission etc.) (b) Peer Evaluation Form

				(Hard copy or soft copy through Moodle or Edmodo or Google forms or spreadsheet submission etc.)
4	**Review**	Clickers	It is an individual response device (remote control), which allows the students to quickly and anonymously respond to questions (mostly MCQ) asked by the teacher either orally or through PPT or with clicker software. The system instantly collects, tabulates the results and display it as histogram on the screen.	• Clicker device

Additional Resources:

http://www.amanogawa.com/archive/SingleStub/SingleStub.html
http://www.amanogawa.com/archive/DoubleStub/DoubleStub.html
http://www.amanogawa.com/archive/ShortStub/ShortStub.html
http://www.amanogawa.com/archive/OpenStub/OpenStub.html

ASSESSMENT PLAN

Type of assessment	**Frequency of assessment**	**Delivery from the learner**	**Data collection**	**Learning Verification**	**Decision making**
Formative	Every class (50 Min. each) (Number of classes = 10)	a) Solve problems through group work	a) Online through Moodle / Edmodo	1. (i) Learner see the correct answer in the feedback given; (ii) Class performance will be analyzed by Moodle / Edmodo	
	Weekly	b) Solve assignments	b) Hard copy submission	2. Evaluate the hard copy; determine class average; give back the answer sheets to the class and discuss the mistakes	
	Semester	c) Mini Project	c) Hardware Submission or Simulation using software tools	3. Evaluate the Project (involve TAs) using Rubrics, Peer Assessment and provide the feedback /	

				scope for improvement through Moodle/Edmodo	
Summative	End of 16 (Partial), 36 (full) and 40 (full) no. of classes	TEST PAPER I	Hard copy	Evaluate the hard copy and grade Weightage for this portion: 25 %	

A few examples of questions(from previous year GATE papers), which can be given for in class activities and surprise or short quiz, are given below.

1. A transmission line of 50-Ω characteristic impedance is terminated with a 100-Ω resistance. The minimum impedance measured on the line is equal to
(a) 0 Ω (b) 50 Ω (c) 25 Ω (d) 100 Ω

2. A transmission line of characteristic impedance 50Ω is terminated by a 50Ω load. When excited by a sinusoidal voltage source at 10 GHz, the phase difference between two points spaced 2 mm apart on the line is found to be π/4 radians. The phase velocity of the wave along the line is
(a) 0.8×10^8 m/s (b) 1.6×10^8 m/s (c) 1.2×10^8 m/s (d) 3×10^8 m/s

3. How many cycles of a 1-MHz wave can a 6-mile transmission line accommodate?
a) 16.67 cycles b) 32.26 cycles c) 6 cycles d) 60 cycles

4. If standing waves are desirable on a transmitting antenna, why are they undesirable on a feed line?
a) it decreases the length b) it limits the life of the antenna
c) it increases power loss d) it shortens the feeding life

5. The return loss of a device is found to be 20 dB. The voltage standing wave ratio (VSWR) and magnitude of reflection coefficient are respectively
(a) 1.22 and 0.1 (b) -1.22 and 0.1 (c) 0.8 and 0.1 (d) 2.44 and 0.2

6. The VSWR can have any value between
(a) 0 and 1 (b) – 1 and + 1 (c) 0 and ∞ (d) 1 and ∞

7. Find the reflection coefficient of the wave passing through two media having intrinsic impedances of 4 and 9 respectively.
(a) 0.5 (b) 1 (c) 0.38 (d) 0.1

8. Find the power reflected in a transmission line, when the reflection coefficient and input power are 0.45 and 18V respectively.
a) 3.645 b) 6.453 c) 4.563 d) 5.463

9. In series stub matching, if the normalized impedance at a point on the transmission line to be matched is 1+j1.33. Then the reactance of the series stub used for matching is:
a) 1 Ω b) -1.33 Ω c) -1 Ω d) 1.33 Ω

10. Shunt stubs are preferred for:
    a) Strip and micro strip lines
    b) Coplanar waveguides
    c) Circular waveguide
    d) Circulators

A few examples for the test paper and assignment questions are given below:

1. You have been asked to design a lossless parallel plate transmission line of characteristic impedance Z0 and length l, to be realized on a PCB, which is intended to connect the output of a high frequency sinusoidal source to an amplifier section.

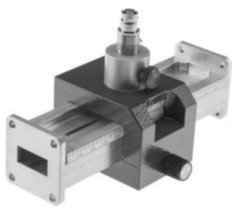
   (a) After fabrication of the board, just before terminating the line to the amplifier section, you connect an impedance analyzer at the input end of the line. What would be the impedance you would have measured?
   (b)Your friend offers to help in soldering the amplifier section to the line, but ends up shorting the line. Now if you connect the impedance analyzer at the input end of the line, what reading would you get?
   (c) Say, the open and short circuit impedances measured at the input terminals of the line are j54.6 Ω and j103Ω respectively. Assume length of the line as 1.5 m, which is less than a quarter wave length. (i) Find the characteristic impedance and propagation constant of the line. (ii) Without changing the operating frequency, find the input impedance of the short- circuited line, which is twice the given length. (iii) Can a short-circuited line appear as an open circuit at the input terminals? Justify.

   (Hint: (a) Without load $Z_L = \infty$, $Z_{in} = Z_0 \left[\frac{Z_L + jZ_0 \tan \beta l}{Z_0 + jZ_L \tan \beta l}\right]$, hence find Z_{oc}
   (b) $Z_L = 0$, hence find Z_{sc}
   (c) Given Zoc = j54.6Ω, Zsc = j103ΩΩ, l = 1.5m
   (i) we know that Z_{oc} x Z_{sc} = Z_0^2, find Z_0, β and hence γ
   (ii) $Z'_{sc} = jZ_0 \tan \beta(2l)$
   (iii) Yes, when tanβl becomes ∞)

2. In a printed circuit board, an inductance of 1 μH needs to be realized at 10 MHz using a section of shorted transmission line. Find the length of the transmission line of characteristic impedance of 50Ω required for realizing this under the following considerations.
   a) If the wavelength = 10 cm, is this realizable. How?
   b) Will your answer change if the wavelength is changed (say =10m)?

   (Hint: $Z_{in} = Z_{sc} = jZ_0 \tan \beta l$)

3. A slotted line is a device used in measurement of impedance of an unknown load at high frequencies. It consists of a section of a lossless transmission line, with a slot and probe along its length. The probe measures the voltage value along the length of the line. A 50Ω slotted line is terminated to a load with unknown impedance. The standing wave ratio on the line is ρ= 2.4 and



a voltage maximum occurs at a distance $\frac{\lambda}{8}$ from the load.

(a) Determine the load impedance.

(b) How far is the first minimum from the load?

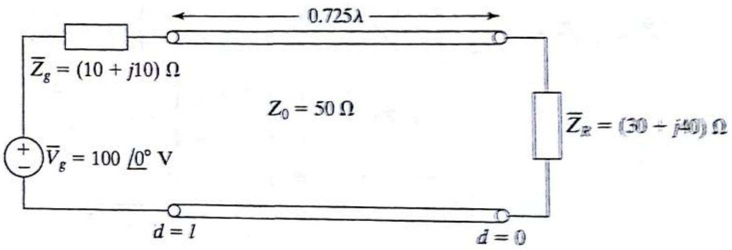
(Hint: $|\Gamma| = \frac{\rho-1}{\rho+1}$, first voltage maximum at (λ/8) from the load.
At Vmax, $\phi_\Gamma - 2\beta l = -2m\pi$, m= 0,1,2,3….
For m=0, $\phi_\Gamma = 2\beta l = \pi/2$
(a) $Z_L = Z_0 \left[\frac{1+\Gamma}{1-\Gamma}\right]$ (b) Position of first minimum = (λ/8)+ (λ/4) from load.)

4. An engineer is trying to connect a microwave source to a horn antenna through a lossless transmission line. Measurements at the antenna gave SWR = 5 and Zo = 50Ω. To identify the conditions on the line, three measurements are made by sliding a voltmeter along the line.
   (a) The first maximum from the load is found at a distance of 0.25 m from the antenna.
   (b) The next maximum is found at 0.75 m from the antenna.
   (c) V_L = 100V. Calculate the load impedance Z_L, V_+, V, I_+ and I.

(Hint: $|\Gamma| = \frac{\rho-1}{\rho+1}$, first voltage maximum at 0.25m from load, second voltage maximum at 0.55m from load, therefore, λ/2 = 0.75 -0.25 = 0.5m, i.e., λ = 1m.
At first maximum, $\phi_\Gamma - 2\beta l = -2m\pi$, m= 0,1,2,3….
For m=0, $\phi_\Gamma = 2\beta l = \pi$
$\Gamma = |\Gamma| e^{j\pi}$, $Z_L = Z_0 \left[\frac{1+\Gamma}{1-\Gamma}\right]$, $V(l) = V^+ e^{j\beta l} + \Gamma_L V^+ e^{-j\beta l}$
At load end, l=0;

5. Burial grade coaxial line is used for underground cable TV transmission over long distances. Somewhere along the buried section, due to a fault in the cable, water is leaking into it causing a short. The test engineers would like to detect the location of the fault. For this, a matched signal generator is connected to the cable input and the frequency is increased/decreased until a maximum / minimum in voltage (or current) is detected by the measuring instrument. The engineers observe successive minima at frequencies of 50 MHz and 60 MHz.
   (a) At what distance from the input end of the cable is water leaking?
   (b) Is it possible to determine the fault location if the engineers had measured maxima?

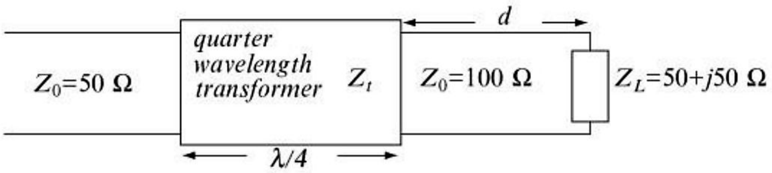
6. Let us consider the system shown in the figure below:



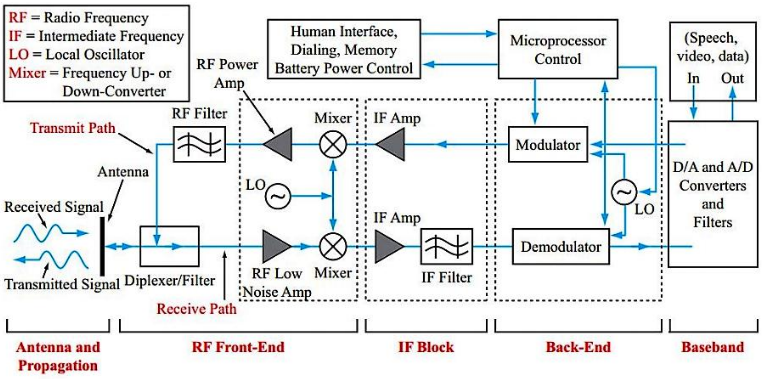
   (a) Compute the reflection coefficient at the load and at the input end (i.e. d = l)
   (b) Find the input impedance

(c) Evaluate the current drawn from the generator and the corresponding voltage across the input impedance
(d) Find the time-averaged power delivered to the input, and hence to the load
(e) Evaluate the power transfer efficiency and mention the favorable techniques to enhance transformer efficiency.

7. A transmission line is given as shown in the figure below. If the characteristic impedance of the quarter-wavelength transformer must be real, find the location of the transformer (distance d in the figure) and the intrinsic impedance of the transformer Zt



8. A block diagram of typical cell phone which uses 1800 MHz for transmit is shown in the figure below. It is necessary to match the diplexer/filter to the 40-Ω antenna. Using the principles of quarter-wave transformer, design the impedance matching section if the output impedance of the diplexer/filter is 1 KΩ .



9. A two-wire transmission line has characteristic impedance of 300 Ω and connects to an antenna. The line is long; the antenna has an equivalent impedance of 200 Ω and operates at a wavelength of 3.8 m. To match the line and load, a quarter-wavelength transformer is connected on the line, but the location at which the transformer may be connected is 10 m from antenna or larger. Calculate:
(a) The closed location at which the transformer may be connected.
(b) For the result in (a), calculate the characteristic impedance of the transformer section. (c) Calculate the standing wave ratios on the section of the line:
1. Between the transformer and antenna and
2. Between the transformer and generator.

10. A cable TV operator is laying cable between customer's set-top box and the dish antenna. Both the set-top box and dish have impedance of 75 Ω each (75 Ω is standardized for these equipment's), but he has only 50-Ω cable with him. After connecting the cable, he finds the reception of 700 MHz signal is not optimal.
(a) Why do you think that the signal reception is poor?
(b) Suggest and appropriate scheme to improve the reception quality with his existing cable (Use velocity= 0.5c).

CO3. ***Apply*** *Maxwell's equation and* ***analyze*** *EM wave propagation in different unbounded (free space) media, its characteristics, polarization and power flow.*

Model Instructional strategy to accomplish the CO3:

S.No.	Learning Outcome	Pedagogical Decision	Brief Description	Sample Technology
1	**Compare**	Inquiry Based Guided Learning with Peer Led Discussion	Student can work with their peer groups and also with the guidance of the teacher. The teacher can observe how the teams and the team member works in-group, evaluate and if needed must provide proper assistance to the students to proceed further. By random picking up of the cooperative group, the students can come and explain their findings about the activity to the entire class and the whole class discussion helps to clarify their doubts if any about the particular topic.	• Google Forms • Interactive applets • Moodle
2	**Calculate** **Obtain** **Find** **Determine** **Verify**	Problem Solving in Group with scaffolding technique	Students can study the work sheets, solve the problem, find the key ideas and produce the results by working with their peer groups and also with the guidance of the teacher. (The teacher can observe how the teams and the team member works in group, evaluate and if needed must provide proper assistance to the students to proceed further.)	* Online Worksheets / Problem Sheets (through Moodle)
3	**Identify** **Discuss**	Active Cooperative Learning	Prepare worksheets for the group task. Give clear instruction to avoid ambiguity. Set some simple rules if necessary to ensure participation. Assign roles (Ex. Team Leader, Spokes person, Reader, Researcher.. etc.,) for group members. Monitor and Guide as and when needed. Evaluate the team performance through whole class discussion / short Quiz / Debate / Brainstorming.	• Online Worksheets / Problem Sheets (through Moodle) • Interactive Applets / Simulation tools
4	**Review**	Polling	It is almost similar to clicker. It uses stand web technology, integrates well with PPT and students can use a vast array of	• Poll Everywhere • Poll daddy • Flisti

			mobile technology to communicate in the classroom system.	• Micropoll • Plickers • Kahoot • Socrative • Google doc or form

Additional Resources:

http://www.amanogawa.com/archive/PlaneWave/PlaneWave.html
http://www.amanogawa.com/archive/Polarization2/Polarization2.html
http://www.amanogawa.com/archive/Polarization/Polarization.html

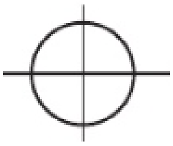
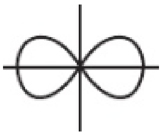
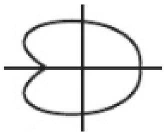
ASSESSMENT PLAN

Type of assessment	Frequency of assessment	Delivery from the learner	Data collection	Learning Verification	Decision making
Formative	Every class (50 Min. each) (Number of classes = 10)	a) Solve problems through group work b) Index Card / Minute Paper	a) Online through Moodle / Edmodo b) Hard Copy	1. (i) Learner see the correct answer in the feedback given; (ii)Class performance will be analyzed by Moodle / Edmodo 2. Evaluate the hard copy; determine class average; give back the answer sheets to the class and discuss the mistakes	
	Weekly	c) Solve Assignments d) Surprise test / short tests (using Multiple Choice Questions) e) Individual / Group Activity through Mobile ready open source interactive applets with or without worksheets.	c) Hard copy submission d) Test paper (Hard copy) or Online through Moodle/ any LMS (Soft Copy) e) Hard copy (in case of Worksheets) or online submission through any LMS (soft copy).		
Summative	End of 36 and 45 no. of classes	TEST PAPER I	Hard copy	Evaluate the hard copy and grade Weightage for this portion: 25 %	

A few examples of questions (from previous year GATE papers), which can be given for in class activities and surprise or short quiz, are given below:

1. If for the transmission of a parallel-polarized wave from a dielectric medium of permittivity ε_1 into a dielectric medium of permittivity ε_2, there exist a value of the angle of incidence θ_p for which the reflection coefficient is zero, then
   a) $\tanh \theta p = \sqrt{\varepsilon_1/\varepsilon_2}$
   b) $\tan \theta p = \sqrt{\varepsilon_1/\varepsilon_2}$
   c) $\tan \theta p = \sqrt{\varepsilon_2/\varepsilon_1}$
   d) $\tanh \theta p = \sqrt{\varepsilon_2/\varepsilon_1}$

2. Match List-I (Antennas) with List-II (Radiation Patterns) and select the correct answer:

List I	List II	
A. Simple dipole	1.	
B. Omni directional antenna	2.	
C. Loop antenna	3.	

Codes:

	A	B	C
a)	1	2	3
b)	2	1	1
c)	3	2	1
d)	1	1	2

3. Consider the following statements regarding a plane wave propagating through free space:
   The direction of field
   1. 'E' is perpendicular to the direction of propagation
   2. 'H' is perpendicular to the direction of propagation
   3. 'E' is perpendicular to the direction of field 'H'
   Which of these statements are correct?
   a) 1 and 2
   b) 2 and 3
   c) 1 and 3
   d) 1, 2 and 3

4. A radio communication link is to be established via the ionosphere. The virtual height at the mid-point of the path is 300 km and the critical frequency is 9 MHz. The maximum usable frequency for the link between the stations of distance 800 km assuming flat earth is
    a) 1.25 MHz
    b) 12 MHz
    c) 15 MHz
    d) 25.5 MHz
5. Which one of the following statements is NOT correct for a plane wave with $H = 0.5\, e^{-0.1x} \cos(10^6\, t - 2x)\, \widehat{a_z}$ A/m
    a) The wave frequency is 10^6 r.p.s
    b) The wave length is 3.14 m
    c) The wave travels along +x direction
    d) The wave is polarized in the z direction.
6. Assertion (A): For an E.M. wave normally incident on a conductor surface the magnetic on a conductor surface the magnetic field H undergoes a 180° phase reversal and the phase of electric field E remains same.

   Reason (R): The direction of propagation of incident wave will reverse after striking a conductor surface.
    a) Both A and R are true and R is the correct explanation of A
    b) Both A and R are true but R is NOT the correct explanation of A
    c) A is true but R is false
    d) A is false but R is true

7. Match List I (Nature of Polarization) with List II (Relationship Between X and Y Components) for a propagating wave having cross-section in the XY plane and propagating along Z -direction and select the correct answer:

List I	List II
A. Linear	1. X and Y components are in same phase
B. Left circular	2. X and Y components have arbitrary phase
C. Right circular	3. X component leads Y by 90°
D. Elliptical	4. X component lags behind Y by 90°

Codes :

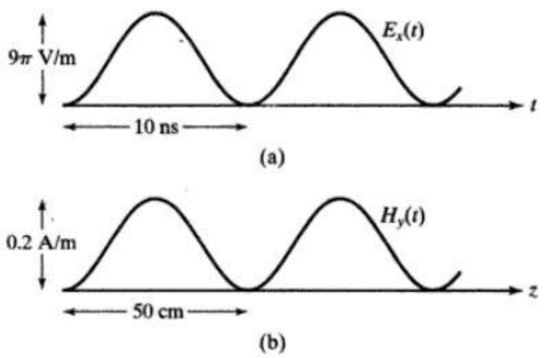
	A	B	C	D
a)	1	4	2	3
b)	4	1	2	3
c)	1	4	3	2
d)	4	1	3	2

8. For seawater with σ =5 mho/m and ε_r = 80, what is the distance for which radio signal can be transmitted with 90% attenuation at 25 kHz?
    a) 0.322 m
    b) 3.22 m
    c) 32.2 m

d) 322 m

A few examples for the test paper and assignment questions are given below:

1. Consider a 50MHz uniform plane wave in free space having electric field amplitude 10V/m. The wave propagates in x-y plane with an angle of 60° from the x-axis and is left circularly polarized. Write down the wave equation for the field and identify the parallel and the perpendicular polarization components.
2. Suppose we wish to communicate with a submarine using a conventional communication system at 1 MHz (in the AM radio range). Properties of sea water are $\varepsilon = 81\varepsilon_0$, $\mu = \mu 0$ and σ =4 S/m. Assume that a magnetic field intensity of 10,000 A/m can be generated at the surface of the ocean and that the receiver in the submarine can receive magnetic fields as low as 1 μA/m.
   a) Calculate the approximate range of frequencies over which seawater may be assumed to be a good conductor, assuming permittivity remains constant. (Assume the required ratio to be 10)
   b) Calculate the maximum range for this communication system.
   c) Suppose the frequency is lowered to 100 Hz, what is the range now?
   d) Suppose the antenna on the submarine must be one half wave length long. Calculate the required antenna lengths in (b) and (c).
3. A uniform plane wave propagating in a medium has
   $\vec{E} = 2e^{-\alpha(0.6y-0.8z)}(x + i0.4y + i0.3z)e^{i(\omega t+0.6y-0.8z)}$ V/m. If the medium is characterized by $\varepsilon_r = 1, \mu_r = 20$ and $\sigma = 3$ S/m,
   (a) Find α, β and $\vec{H}$
   (b) Find the time average power flow per unit area normal to the direction of wave propagation at y=1, z=1.
4. For a uniform plane wave having $\vec{E} = E_x(z,t)\widehat{a_x}$ and $\vec{H} = H_y(z,t)\widehat{a_y}$ and propagating in the +z direction in a perfect dielectric medium, the time variation of E_x in a constant z-plane and distance variation of H_y for a fixed time are observed to be periodic, as shown in figure below. Find the relative permeability and relative permittivity of the medium.



5. Determine the polarization of the waves for the given electric fields.

   a) $E(t,y) = E_0\cos(\omega t - \beta y)\hat{z} + 2E_0\cos(\omega t - \beta y)\hat{x}$
   b) $E(t,y) = E_0\cos(\omega t - \beta y)\hat{z} + iE_0\cos(\omega t - \beta y)\hat{x}$

c) $E(t,y) = E_0 \cos(\omega t - \beta y)\hat{z} + 2E_0 \sin(\omega t - \beta y)\hat{x}$

d) $E(t,y) = -2E_0 \sin(\omega t + \beta y)\hat{z} + E_0 \cos(\omega t + \beta y)\,\hat{x}$

e) $E(t,y) = -E_0 \sin(\omega t - \beta y + \pi/4)\hat{z} + E_0 \cos(\omega t - \beta y)\,\hat{x}$

f) $E(t,y,z) = 10(i0.4\hat{y} + i0.3\hat{z})e^{i(\omega t+0.6y-0.8z)}$

6. Consider a plane wave generated from a satellite antenna which has a electric field intensity E = 1000cos(ωt - kz) yˆ V/m with f = 300MHz. Assume loss less propagation in free space.
   (b) Calculate instantaneous and time averaged power densities of the wave.
   (c) Suppose a receiving dish antenna is 1m in diameter. How much of the power is received by the receiving antenna if the surface of the dish is perpendicular to the direction of propagation if the wave.
7. A satellite in geosynchronous orbit is used for communication generates electric field $E = 10\ (\hat{x} + i0.4\hat{y} + i0.3\hat{z})e^{i(\omega t+0.6y-0.8z)}$
   a) Determine the frequency and direction of propagation of the wave.
   b) Obtain the associated magnetic field intensity.
   c) Verify whether the Electric and Magnetic fields are perpendicular to the direction of wave propagation.
   d) Discuss the polarization of the wave.
   e) Find the time average power flow per unit area normal to the direction of wave propagation.
8. A uniform plane wave with $E = E_x\hat{x}$ propagates in a lossless medium ($\varepsilon_r = 4$, $\mu_r = 1$, $\sigma=0$) in the +z direction. Assume that E_x is sinusoidal with a frequency 100 MHz and has a maximum value of 10^{-4} V/m at t=0 and z=1/8m
   (a) Write the instantaneous expression for E for any t and z.
   (b) Write the instantaneous expression for H.
   (c) Determine the location where E_x is a positive maximum when t=10^{-8} s.
9. A satellite in geosynchronous orbit (37,000km above the equator) issued for communication at 30 GHz. The atmosphere is 15 km thick. Assume plane wave propagation and free space above the atmosphere. Properties of the atmosphere are $\varepsilon=1.05\varepsilon_0$, $\mu = \mu_0$, and $\sigma= 10^{-6}$ S/m. Calculate:
   (a) the phase velocity in atmosphere and in free space
   (b) the attenuation and phase constants in atmosphere and in free space
   (c) the intrinsic impedance in atmosphere and in free space
   (d) If the minimum electric field intensity required for reception is 10 mV/m, what must be the minimum amplitude of electric field at the transmitter? Assume that the satellite does not amplify the signal but only reflects it, and both transmitter and receiver are on earth.

CO4. ***Apply*** *Maxwell's equation to find the reflection / transmission characteristics for uniform plane wave at interface between two different media.*

Model Instructional strategy to accomplish the CO4:

S.No.	Learning Outcome	Pedagogical Decision	Brief Description	Sample Technology
1	**Calculate** **Find** **Obtain**	Think-aloud-Pair – Problem solving (TAPPS)	This is the most suitable approach for analytical courses. The teacher will give a set of complex problems to the students and give few minutes to think about it individually. Then ask the students to pair with their neighbor and allow them to discuss the problem and methodology to solve it. Here, the teacher should instruct the students that one student to be problem solver who explains the methodology to solve a problem, while the partner will listen to it and give suggestions or clarifying the doubts if any and later for the next problem the students have to switch their role and solve the problem in the same fashion.	• Online Worksheets / Problem Sheets (through Moodle) • Interactive applets
2	**Review**	Minute Paper	Finish the class period with a **Minute Paper** activity to be turned in on an index card: "What are the two questions that you still have on today's topic?" The teacher will review the most representative of these in the last lecture segment of the next class.	• Index Card • Google Form • Today's Meet • Feedback forms through Moodle, Edmodo etc.,

Additional Resources:

http://www.amanogawa.com/archive/ObliqueLossy/ObliqueLossy.html
http://www.amanogawa.com/archive/Oblique/Oblique.html

ASSESSMENT PLAN

Type of assessment	Frequency of assessment	Delivery from the learner	Data collection	Learning Verification	Decision making

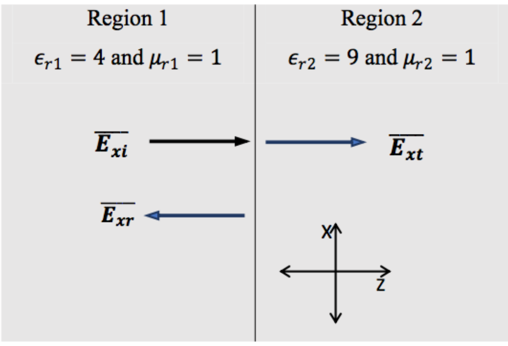
Formative	Every class (50 Min. each) (Number of classes = 5)	a) Solve problems through group work	1. Online through Moodle / Edmodo	(i) Learner see the correct answer in the feedback given; (ii) Class performance will be analyzed by Moodle / Edmodo	
	Weekly	b) Solve assignments	2. Hard copy submission	Evaluate the hard copy; determine class average; give back the answer sheets to the class and discuss the mistakes	
Summative	End of 36 (partial) and 45 no. of classes	TEST PAPER I	Hard copy	Evaluate the hard copy and grade Weightage for this portion: 12.5 %	

A few examples of questions (from previous year GATE papers), which can be given for in class activities and surprise or short quiz, are given below:

1. A wave incident on a surface at an angle 60 degree is having field intensity of 6 units. The reflected wave is at an angle of 30 degree. Find the field intensity after reflection.
   a) 9.4
   b) 8.4
   c) 10.4
   d) 7.4
2. The phase velocity of a wave having a phase constant of 4 units and a frequency of 2.5×10^9 radian/sec is (in 10^8 order)
   a) 3.25
   b) 3.75
   c) 6.25
   d) 6.75
3. The group velocity of a wave with a phase velocity of 60 x 109 is (in 106 order)
   a) 1.5
   b) 2
   c) 2.5
   d) 3
4. If the magnetic field component of a plane wave in a lossless dielectric is
   $H = 50 \sin (2\pi \times 10^6 t - 6x)\, a_z$ mA/m, what will be the wave velocity?
   a) 1.047×10^6 m/s
   b) 1.257×10^6 m/s
   c) 2.50×10^6 m/s
   d) 3×10^6 m/s
5. For a critical angle of 60 degree and the refractive index of the first medium is 1.732, the refractive index of the second medium is
   a) 1
   b) 1.5
   c) 2
   d) 1.66

A few examples for the test paper and assignment questions are given below:

1. A uniform plane wave propagating in x-z plane with electric field given by
   $E_t = E_0(\widehat{a_x} - \widehat{a_z})\cos\left(6\pi\ X\ 10^8 t - \sqrt{2}\,\pi(x+z)\right)$
   is incident on an interface along the y-z plane between air and a dielectric medium with $\varepsilon = 1.5\varepsilon_0$ and $\mu = \mu_0$ .Find the expression for the transmitted and the reflected electric fields.
2. A uniform plane wave with electric field given by
   $E_t = E_0\left(\frac{\sqrt{3}}{2}\widehat{a_x} - \frac{1}{2}\widehat{a_z}\right)\cos\left(6\pi\ X\ 10^9 t - 10\,\pi\left(x+\sqrt{3}z\right)\right) + E_0\widehat{a_y}\sin\left(6\pi\ X\ 10^9 t - 10\,\pi\left(x+\sqrt{3}z\right)\right)$
   is incident on an interface along y-z plane between free space and a dielectric medium of permittivity ε_2 and permeability μ_0.
   (a) Find the value of ε_2 for which the reflected wave is linearly polarized.
   (b) Using the value found in part (a), obtain the expression for electric field of the transmitted and reflected waves.
3. A plane wave having peak electric field of 25V/m is incident at an air and dielectric interface with perpendicular polarization. The dielectric constant of the medium is 2.4 and angle of incidence is 30°.
   (a) Find the power densities of incident, reflected and transmitted waves.
   (b) Verify the energy conservation relation.
4. Consider a 100V/m, 3GHz wave that is propagating in a dielectric material having $\varepsilon_{r1} = 4$ and $\mu_{r1} = 1$. The wave is normally incident on another dielectric material having $\varepsilon_{r2} = 9$ and $\mu_{r2} = 1$ as shown in the figure below. Find out the locations of maxima and minima of the electric field and the standing wave ratio in the Region 1.



CO5. ***Apply*** *Maxwell's equation to calculate the wave propagation characteristics in different modes for different types of waveguides.* ***Analyze*** *and* ***Evaluate*** *wave propagation in bounded media.*

Model Instructional strategy to accomplish the CO5:

S.No.	Learning Outcome	Pedagogical Decision	Brief Description	Sample Technology
1	**Calculate**	Cooperative Learning	Students can study the work sheets, solve the problem, find the key ideas,	Online Worksheets / Problem Sheets

	Find **Determine**	with Scaffolding technique	develop their own design, simulate and produce the results by working with their peer groups and also with the guidance of the teacher. (The teacher can observe how the teams and the team member works in group, evaluate and if needed must provide proper assistance to the students)	(through Moodle) / Simulation tools
2	**Compare** **Justify** **Suggest**	Team Based Learning	Divide students into teams, define rules and procedures for teamwork, develop team contract, and deal with dysfunctional teams, peer rating through rubrics and peer evaluation forms. The teacher can evolve an auto rating system for an individual based on the peer evaluation score.	Online Worksheets / Problem Sheets (through Moodle) / Simulation tools For Peer Evaluation, (a) Rubrics (Hard copy or soft copy through Moodle or Edmodo or Google forms or spread sheet submission etc.) (b) Peer Evaluation Form (Hard copy or soft copy through Moodle or Edmodo or Google forms or spreadsheet submission etc.)
3	**Review**	Memory Matrix	The teacher should prepare the memory matrix based on the lecture / course content for the students to fill either inside or outside the class for verifying their understanding and recalling ability on key concepts. Then, the teacher should give the corrective feedback to individual student through LMS or whole class through in class discussion / interaction, by adding up correct and incorrect responses in each cell.	• Memory Matrix Worksheet (as Hard Copy) or Memory Matrix Spreadsheets (in case of Moodle / any LMS) • Google forms

Additional Resources:

http://www.amanogawa.com/archive/ParallelWaveGuide/ParallelWaveGuide.html
http://www.amanogawa.com/archive/DielectricWaveGuide/DielectricWaveGuide.html
http://www.amanogawa.com/archive/RectWaveGuide/RectWaveGuide.html

ASSESSMENT PLAN

Type of assessment	**Frequency of assessment**	**Delivery from the learner**	**Data collection**	**Learning Verification**	**Decision making**
Formative	Every class (50 Min. each) (Number of classes = 10)	a) Solve problems through group work b) Index Card / Minute Paper	a) Online through Moodle / Edmodo b) Hard Copy	(i) Learner see the correct answer in the feedback given; (ii) Class performance will be analyzed by Moodle / Edmodo	
	Weekly	c) Surprise test / short tests (using Multiple Choice Questions)	Test paper (Hard copy) or Online through Moodle/ any LMS (Soft Copy)		
		d) Memory Matrix	Hard copy or soft copy (online submission through any LMS)		
		e) Solve assignments	Hard copy submission	Evaluate the hard copy; determine class average; give back the answer sheets to the class and discuss the mistakes	
Summative	End of 45 no. of classes	TEST PAPER I	Hard copy	Evaluate the hard copy and grade Weightage for this portion: 12.5 %	

A few examples of questions (from previous year GATE papers), which can be given for in class activities and surprise or short quiz, are given below:

1. The cut-off frequency in a waveguide signifies:
   a) longer wave will not propagate significantly
   b) the frequency at which no transmission takes place
   c) the dimension of the waveguide
   d) all of the above
2. In TE mode of wave propagation in a rectangular waveguide, what is the equation that has to be satisfied?
   a) $(\partial^2/ \partial x^2 + \partial^2/ \partial y^2 + kC^2)$. HZ (x, y) =0
   b) $(\partial^2/ \partial x^2 + \partial^2/ \partial y^2 + kC^2)$. HZ (x, y) =0
   c) $(\partial^2/ \partial x^2 + \partial^2/ \partial y^2 + kC^2)$. HZ (x, y) =0
   d) None of the mentioned

3. If a waveguide is filled with a lossless material of relative permeability 2, then the wave impedance in the TEM mode is:
   a) 188.5 Ω
   b) 170 Ω
   c) 123 Ω
   d) 345 Ω
4. If ρ=0.3 and the wave number of air in TM mode is 16, then the intrinsic impedance of air in TM mode given wave number is 125 is:
   a) 1 Ω
   b) 0.9 Ω
   c) 0.8 Ω
   d) 2 Ω
5. If a waveguide is filled with a lossy material then the expression for ε for that material is:
   a) $\varepsilon=\varepsilon_o\varepsilon_r(1\text{-j}\tan\delta)$
   b) $\varepsilon= \varepsilon_o\varepsilon_r$ ((1/ j tanδ)
   c) $\varepsilon= \varepsilon_o\varepsilon_r /(1+ j \tan\delta)$
   d) $\varepsilon= \varepsilon_o\varepsilon_r /(1\text{-j} \tan\delta)$
6. For TM_2 mode, if the distance between two parallel plates of a waveguide are 40 mm, then the cut off wavelength for TM_2 mode is:
   a) 20 mm
   b) 80 mm
   c) 40 mm
   d) 60 mm
7. Given that the wave number of a circular cavity resonator is 151 (TE_{011} mode), and the length of the cavity is twice the radius of the cavity, the radius of the circular cavity operating at 5GHz frequency is:
   a) 2.1 cm
   b) 1.7 cm
   c) 2.84 cm
   d) insufficient data
8. For TE_{10} mode, if the waveguide is filled with air and the broader dimension of the waveguide is 2 cm, then the cutoff frequency is:
   a) 5 MHz
   b) 7.5 MHz
   c) 7.5 GHz
   d) 5 GHz
9. For dominant mode propagation in TE mode, if the rectangular waveguide has a broader dimension of 31.14 mm , then the cutoff wave number:
   a) 100
   b) 500
   c) 50
   d) 1000
10. In TE_{10} mode of wave propagation in a rectangular waveguide, if the broader dimension of the waveguide is 40 cm, then the cutoff wavelength for that mode is:
    a) 8 cm
    b) 6 cm
    c) 4 cm
    d) 2 cm

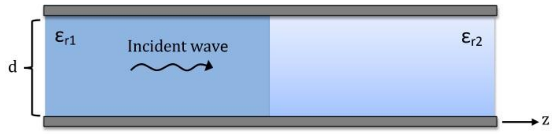
A few examples for the test paper and assignment questions are given below:

1. A parallel waveguide has a plate separation d = 1 cm, and is filled with Teflon, having dielectric constant 2.1. (a) Determine the maximum operating frequency such

that only the TEM mode will propagate. Also find the range of frequencies over which the TE_1 and TM_1 modes will propagate, and no other higher order modes. (b) Suppose the operating wavelength is 2 mm, how many waveguide modes will propagate?

2. The operating frequency of an air filled parallel plate waveguide is 20% higher than the cut-off frequency of the first order mode and plate separation is 2 cm.
   (a) Calculate the frequency of operation.
   (b) What are the modes supported by waveguide at the above frequency? Calculate the cut-off frequency of all possible modes.
   (c) If a signal is sent from one side of the waveguide then how long should the waveguide be to obtain a 10 ns delay for all possible modes?
3. A parallel plate wave-guide is partially filled with two lossless dielectrics where ε_{r1}= 4, ε_{r2}= 2.1 and d = 1 cm. At a certain frequency, it is found that the TM_1 mode propagates through the guide without suffering any reflective loss at the dielectric interface.
   (a) Find this frequency. Is the guide operating at a single TM mode at this frequency?
   (b) It is found that for some modes other than TM_1, propagating from left to right, totally reflect at the interface, so that no power is transmitted into the region of dielectric ε_{r2}. Determine the range of frequency over which this will occur.

(c) Is the answer of part (b) in any way related to the cutoff frequency for m = 1 modes in either region?



4. **Low-Frequency Waveguide Limitations:** An engineer had a bright idea: Why not use rectangular waveguides instead of the coaxial lines used in cable TV? The requirements are as follows: lowest frequency 50 MHz, and the waveguide has a ratio of a = 2b.
   (a) What must be the dimensions of the waveguide to propagate from 50 MHz and up in the TE_{10} mode?
   (b) The normal TV range in the VHF band is up to 150 MHz. Assuming each channel is 6 MHz, how many channels can be propagated in the TE_{10} mode alone?
   (c) Is this a bright idea?
5. **Tunnels as Waveguides:** A tunnel is modeled as an air-filled metallic rectangular waveguide with dimensions a = 8 m and b = 16 m. Determine, whether the tunnel will pass:
   (a) a 1.5 MHz AM broadcast signal,
   (b) a 120 MHz FM broadcast signal?
6. **Waveguide in radar:** In an air-filled rectangular waveguide used to transfer RF energy from the antenna, the cutoff frequency of a TE_{10} mode is 5 GHz, whereas that of TE_{01} mode is 12 GHz. Calculate the following:
   (a) The dimensions of the guide
   (b) The cutoff frequencies of the next three higher TE modes

(c) The cutoff frequency for TE_{11} mode if the guide is filled with a lossless material having $\varepsilon_r = 2.25$.

(d) Suppose a signal of frequency 12.5 GHz propagates in the air-filled waveguide which is 10 m long, calculate the resulting intermodal dispersion assuming that the signal gets coupled to all possible TE modes.

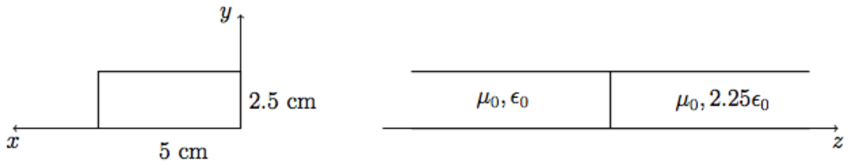
7. **Phase and group velocities:** A 1 cm x 3 cm rectangular air-filled waveguide operates in the TE12 mode at a frequency that is 20% higher than the cutoff frequency. Determine:

(a) the operating frequency,

(b) the phase and group velocities.

8. **Pulse transit time:** An air-filled hollow rectangular waveguide is 150 m long and is capped at the end with a metal plate. If a signal of frequency centered around 7.2 GHz is introduced into the input end of the guide, how long does it take the pulse to return to the input end? Assume that the cutoff frequency of the guide is 6.5 GHz.

9. **Waveguide with dielectric discontinuity:** A rectangular waveguide with cross sections shown below has a dielectric discontinuity along its length. Calculate the standing wave ratio if the guide operates at 8 GHz in the dominant mode.



10. **Parabolic dish feed:** A TE_{10} wave at 10 GHz propagates in a brass ($\sigma = 1.57 \times 10^7$) S/m rectangular waveguide, which is used to connect the feed of a parabolic dish antenna to the power amplifier. The waveguide with inner dimensions a = 1.5 cm and b = 0.6 cm, is filled with polyethylene ($\varepsilon_r = 2.25$, $\mu_r = 1$ and loss tangent = 4×10^{-4}). Determine:

(a) the phase constant.

(b) the guide wavelength.

(c) the phase velocity.

(d) the wave impedance.

(e) the attenuation constant due to loss in the guide walls.

APPENDIX – EE1

SYLLABUS

ELECTROMAGNETICS for ENGINEERING

Module I: TIME VARYING FIELDS AND TRANSMISSION LINES

Maxwell's Equation and boundary conditions – Time harmonic (sinusoidal) fields – General Wave Equation – Types of transmission lines – Equation of current and voltages – Characteristic Impedance – Power transfer on a transmission line – Loss less and low loss Propagation – Propagation constant – Wave reflection at discontinuities – Voltage Standing Wave Ratio – Transmission lines of finite length – Impedance matching by Quarter Wave Transformer, Single and Double Stub matching.

Module 2: THE UNIFORM PLANE WAVE

EM wave equation and plane wave solution – Poynting's Theorem and Wave Power – Wave propagation in loss-less and lossy media – Wave polarization – Linearly, Elliptically and Circularly polarized waves – Waves at the interface (Fresnel's Equation, Brewster's Angle, Total Internal Reflection, Skin depth).

Module 3: WAVE GUIDES

Transverse Electromagnetic (TEM) waves – Transverse Magnetic (TM) waves – Transverse Electric (TE) waves – TM and TE waves between parallel plates – TM and TE waves in Rectangular wave guides – Bessel's differential equation and Bessel function – TM and TE waves in Rectangular and Circular wave guides – Introduction to Optical Waveguides and Fiber Optics.