Teaching Electromagnetic Waves in Effective and Enjoyable Fashion

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Abstract

Today there is hardly any electrical gadget around us in which principles of electromagnetism are not used. Electromagnetics therefore is a core subject in electrical engineering in almost all the institutes across the world. The course is generally taught at sophomore or junior level. In spite of its importance in foundation of electrical engineering, the students invariably take the subject as a burden and therefore develop dislike for it. What is the reason for this dislike? Here we investigate some of the aspects of the subject and its development to make the teaching-learning process effective and enjoyable.

A course is liked by the students when it meets some or all the criteria like, (1) inherent interest in the course, (2) skills of the students match with that required by the course (3) the course finds wide applications in contemporary sense (4) the course is high scoring in exams (5) the course enhances employability (6) the course is taught in an inspiring manner etc. It is the responsibility of the teacher to make the electromagnetics course qualify on these criteria. It is important that a teacher builds positive bias about the course among the students and kindles their curiosity in the subject.

Electromagnetics is a subject founded on the experimental laws that have been captured with vector calculus. It has been observed however, that invariably the physical concept of the subject is not well presented by a teacher and the course reduces to mere manipulation of equations. In absence of proper understanding of the physics behind the equations the students develop dislike for the subject. Today with excellent computing facilities, the physical aspect of electromagnetics can be demonstrated very effectively by simulations and numerical modelling. A visual representation of the EM phenomenon then not only makes the subject interesting but also creates a long lasting impression on the students' minds. Also showing the applications of the concepts in the systems in our day to day life like, electrical machines, telephone lines, microwave ovens, radio and TV, satellite, fibre optic and mobile communication etc., make the subject exciting and relevant for the students.

Abstract (cont'd)

In electrical engineering curriculum, students develop a good understanding of electrical circuits and circuital laws that deal with voltages and currents. A sudden exposure of the time varying electric and magnetic fields that is dealt with in electromagnetics, creates a disconnect between the circuit theory and the field theory. The circuit theory deals with scalar quantities in frequency and time, whereas the field theory deals with vector quantities in frequency, time and space. To reduce the disconnect, the 'space' can be brought in circuit analysis through the introduction of transmission lines. If transmission lines are taught before the time varying fields, the abrupt change from the circuit theory to the field theory is reduced and the circuit theory appears as a limiting case of the field theory. The transmission line still deals with the scalar quantities like voltage and current, but develops concepts of EM waves in one dimension. Extension of the concepts in three dimension with vector fields, then becomes more manageable for the students.

It has been observed from the students' feedback that, a logical development of electromagnetics supported by relevant mathematics (in that order) makes the subject more enjoyable for the students. It is also observed that a proper examination system that tests the conceptual understanding of the subject rather than just her/his algebraic manipulation skills, plays an important role in enhancing students' involvement in the course.

In an electrical engineering curriculum, electromagnetics is a subject that has maximum number of concepts relative to any other subject. It is therefore important that this conceptual nature of the subject is highlighted with due analytical skills while conduct of the course.

Keywords: Teaching electromagnetics, effective teaching, enjoying electromagnetics

Biography

Professor Shevgaonkar has been an active researcher in the area of Optical communication, Image processing, Antennas, Microwaves, Radio astronomy etc. He was involved in commissioning the Decameter wave radio telescope at Indian Institute of Astrophysics and Raman Research Institute, Bangalore. He established Fibre Optics lab and founded the Centre for Distance education at IIT Bombay. He was Director of IIT Delhi and Vice Chancellor University of Pune. He has published more than 175 papers in international journals and conferences, and two books with McGraw Hill Education namely 'Electromagnetic Waves' and 'Transmission lines' for Electrical Engineers. He has guided 18 PhDs and more than 30 M.Tech. dissertations. His video and web lectures on Transmission Lines and Electromagnetic Waves, and Advanced Optical communication are used worldwide through YouTube.

Professor Shevgaonkar is a recipient of IEEE Undergraduate Teaching award 2011, IETE award for his outstanding contribution to Optical communication, and the 'Excellence in Teaching' award of IIT Bombay. He has received the Education Leadership Award 2012 from Headlines Today, New Delhi. He is also a recipient of VASVIK Award (2009) in the category of Information & Communication Technology, IETE – Ram Lal Wadhwa Award (2013) and IEEE William E. Sayle Award for Achievement in Education (2014). He is Fellow of IEEE, Fellow of Indian National Academy of Engineering, Fellow of National Academy of Science, India, Fellow of Institution of Electronics and Telecommunication Engineers, Fellow of Optical Society of India, Fellow of Institution of Engineers, Fellow of Maharashtra Academy of Sciences, and Member of International Astronomical Union and Astronomical Society of India. He has been a member of many international and national research and educational committees.

When a Subject Appears Interesting?

- Inherent liking for the subject
- Positively biased towards the subject
- Subject requirements match with your skills
- See wide applications in present context
- Makes it more employable
- Scoring subject in exams
- Subject appears more a fun than burden
- When presented in an exciting fashion

How does Electromagnetics Qualify on This Matrix?

- The course is the foundation for most of the modern gadgets and systems
- Has very wide applications
- Makes people employable in hardware industry (ONLY)
- Very Scoring/Losing in exams like mathematics
- Subject is exciting if presented properly - Responsibility of Teacher
- Today it appears more demanding and less rewarding

What is Required for Effective Teaching?

- First get self excited. Read Lecture series by Feynman and listen to exciting lectures.
- Teach the subject without a bias. Assure students that it is not a difficult subject.
- Use a quality text book and not some solution keys
- Define the objective of the course clearly and tell its application in contemporary sense.
- Emphasize on physical concepts and NOT only manipulation of equations
- Note that an Image creates far more lasting impression than an equation or text

Electromagnetics is a Conceptual Course

- Origin of EM is Experimental
- First explain the physical concepts
- Derive Maxwell's equations from the physical laws
- Use mathematics to get quantitative answers for the qualitative understanding of the concepts
- Avoid unnecessary and repetitive algebra. It is not an algebra course.
- Avoid unnecessary numerical complications

Contd..

- Electromagnetics phenomenon is abstract. Ask students to imagine. Give mechanical analogies.
- Use computer simulations if possible to visualize things better
- Refine exam system to test concepts and understanding rather than usage of formulae
- Do not set unnecessarily difficult assignments and exams
- Give practical demonstrations if possible
- At the end of every lecture pose a question to kindle students curiosity

First Discuss Transmission Lines Why?

- Transmission lines is a bridge between circuits and fields.
- Circuits use frequency-time analysis. Show how the analysis is incomplete without bringing 'space' into consideration.
- In TL, circuit parameters are retained but size of the circuit is brought into analysis.
- TL approach is inevitable in high speed circuits.
- TL can create foundation of EM waves in 1-D.

Core Concepts of Transmission Lines

- Signals always travel with a finite speed on a power carrying structure. Concept of distributed elements
- Time varying fields always exist in the form of waves: Traveling or Standing
- Every structure has a unique impedance associated with it: Characteristic Impedance (Z_0)
- Reflections occur if the impedances are NOT equal to Z_0.
- Impedance transformation is an inherent property of a TL. Give extreme examples to make it charismatic.
- NOT absolute, but impedances relative to Z_0 matter in a distributed circuit analysis

Maxwell's Equations

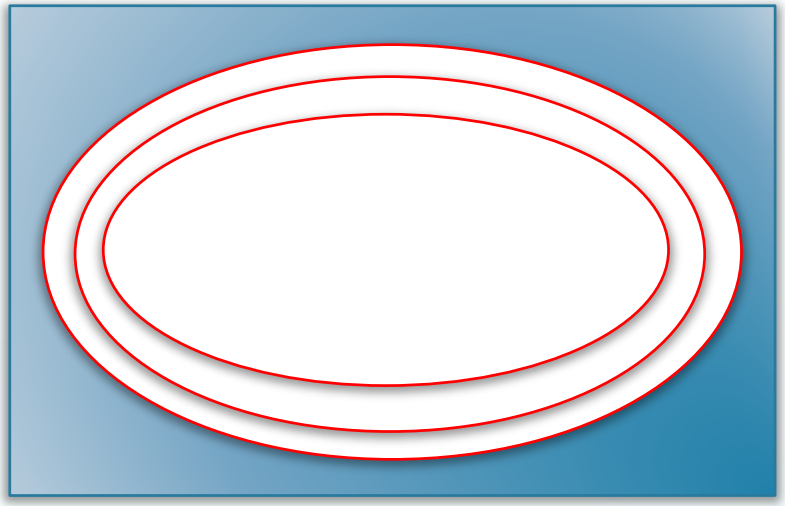
- First introduce basics of vector calculus and important theorems.
- Give physical feel for Divergence and Curl with examples of fluids/water
- Derive Maxwell's equations from the basic laws: Gauss, Faraday, Ampere
  - Integral form
  - Differential form
- Remember that EM laws are experimental with vector representation. GO SLOW (Every thing need not be understood on day one)
- Derive Boundary Conditions from integral form

Key Concepts to Always Remember from Maxwell's Equations

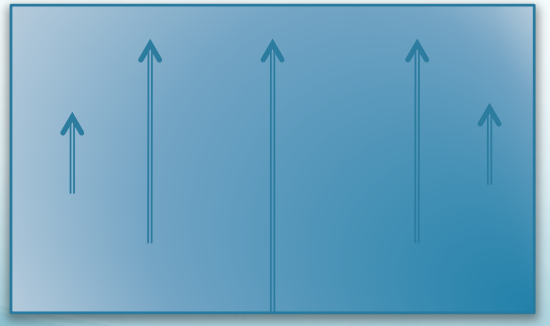
- Conservation of charge
- Time Varying Electric and Magnetic fields are always coupled
- E and H are perpendicular to each other
- Electric field originates or terminates on a charge or at infinity
- Magnetic filed line always closes on itself or extends to infinity
- Reliable BCs are: Continuity of tangential component of E and normal component of B
- BC on a conducting surface: Tangential component of E and normal component of B is ZERO

Can I see Modal Field Pattern Coming from These Key Concepts?

- Transverse Magnetic Fields
  - (1,1)



- Transverse Electric Fields
  - (1,0)



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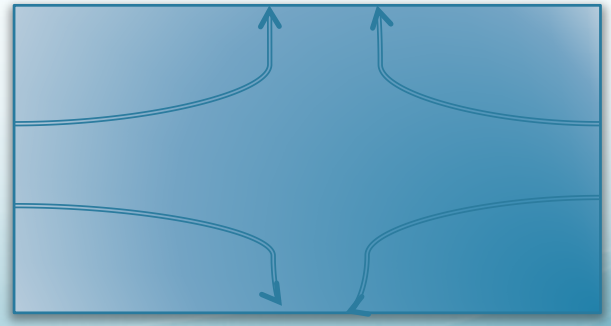
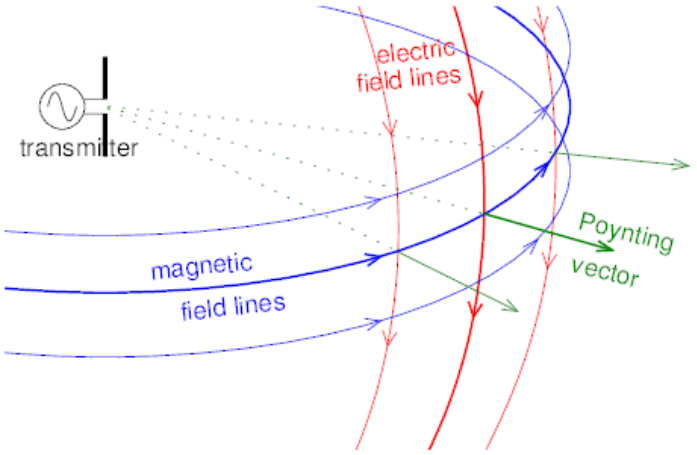


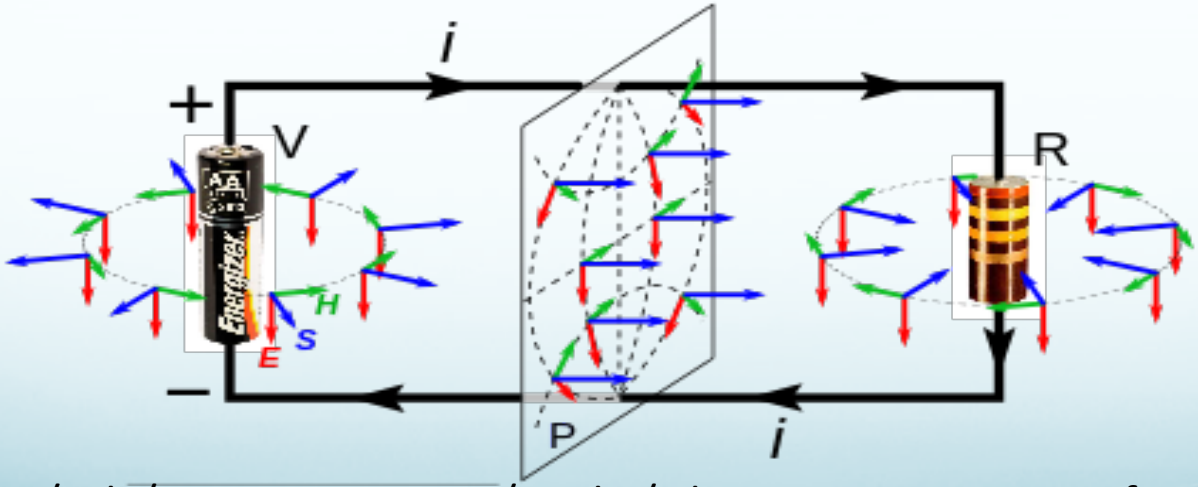
Modal Propagation

- Why uniform field distributions cannot survive?
- Modal propagation: Definite field distributions
  - Transverse Electromagnetic (TEM)
  - Transverse Electric (TE)
  - Transverse Magnetic (TM)
  - Hybrid
- Cut-off frequency
- Propagation constant and guided wavelength
- Dispersion (For each Mode)
- Phase Velocity and Group Velocity
- Signal distortion

Interesting visualization of Power Flow

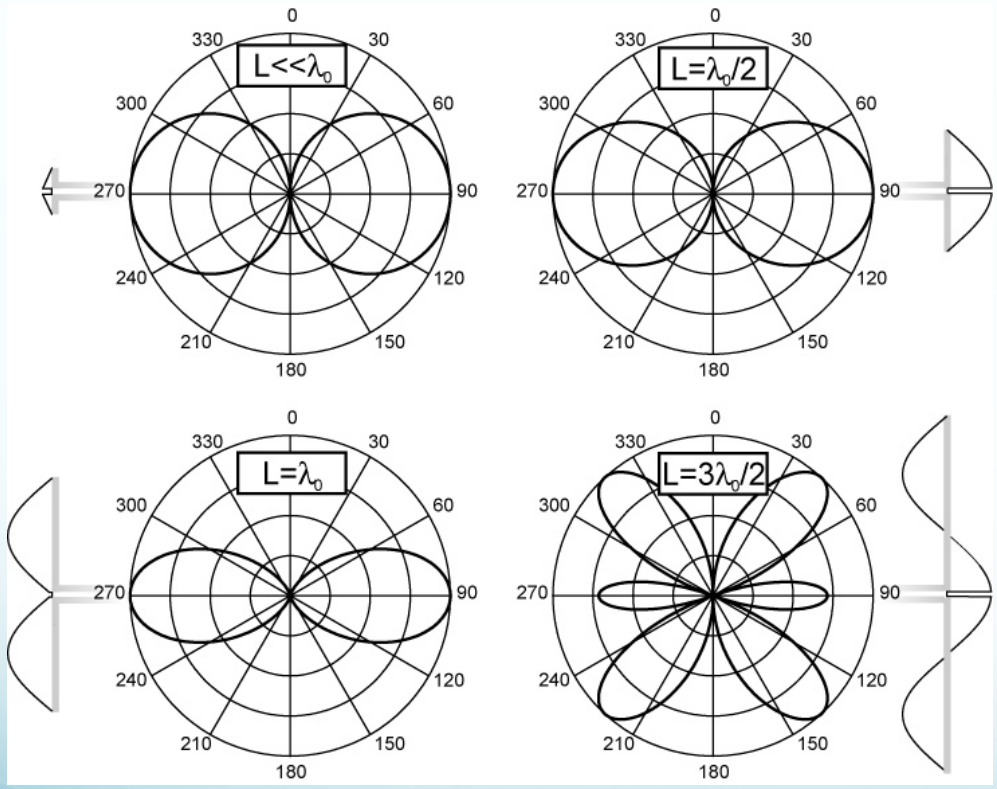


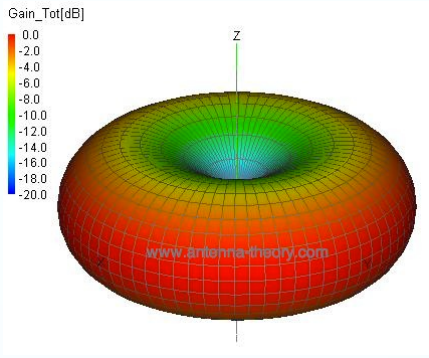
http://forum.nasaspaceflight.com/index.php?topic=36313.1420

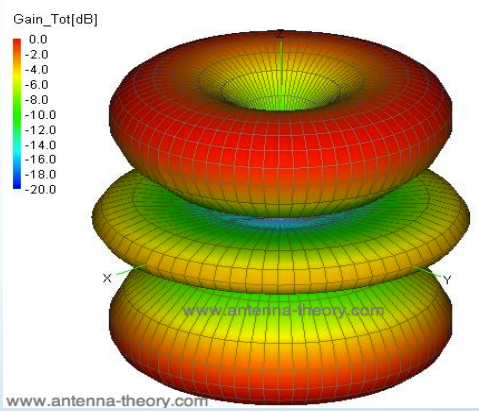


en.wikipedia.org/wiki/Poynting_vector#/media/File:Poynting_vectors_of_DC_circuit.svg

Correct Visualization of Radiation Pattern







http://www.antenna-theory.com/antennas/dipole.php

So Many Exciting Concepts

- Gradient
- Divergence
- Curl
- Displacement current
- Characteristic Impedance
- Reflections
- Impedance Transformation
- Impedance Matching
- Skin Depth
- Surface current
- Free-space Impedance
- Phase and Group velocity
- Polarization
- Total Internal Reflection
- Modal Propagation
- Poynting Vector
- Radiation Pattern
- ……

Thank you

Enjoy EM