Why study electromagnetic waves and transmission?

The big picture:

Circuit theory (CMPE 306) makes two major assumptions

(1) Electrical energy must be transmitted through wires

(2) Transmission from source to load is instantaneous

Assumption (1) fails in any wireless transmission

- Radio, radar
- Free space transmission

Assumption (2) fails in high-speed transmission

- Traditional analog circuits (> 3 GHz)
- High-speed digital circuits (components at 2 GHz and above)

Why? *The finite speed of light!*

= The maximum speed of any energy transmission

- $c = 3\times10^8$ m/sec in air, vaccum
- $c = 2\times10^8$ m/sec in glass, some transmission lines

UMBC
AN HONORS UNIVERSITY IN MARYLAND

Why study electromagnetic waves and transmission?

Rule of thumb (R. Schmitt: *Understanding Electromagnetics*)

$d > c/20R$ implies that circuit theory is inadequate

d = dimension of object, c = speed of light
R = maximum rate (For a digital signal; rise or fall time
= maximum Fourier component)

Example:

$R = 2$ GHz $= 2 \times 10^9$ sec^{-1}, $c = 2 \times 10^8$ m/sec
$d = 5 \times 10^{-3}$ m = 5 mm, which is smaller than many circuit boards!

UMBC
AN HONORS UNIVERSITY IN MARYLAND

Why study electromagnetic waves and transmission?

Electromagnetic theory is often considered difficult. Why?

One must study the behavior of electric and magnetic fields

$\mathbf{E}(\mathbf{r},t)$ = electric field; generated by charges
$\mathbf{H}(\mathbf{r},t)$ = magnetic field; generated by currents*

and their interaction! One must also account for the fluxes

$$\mathbf{D}(\mathbf{r},t) = \varepsilon\,\mathbf{E}(\mathbf{r},t);\quad \mathbf{B}(\mathbf{r},t) = \mu\,\mathbf{H}(\mathbf{r},t)$$

Thus, there are 12 quantities to track as a function of space.

Consequences
- Not every computer engineers learns electromagnetic theory
- Those who do have a big advantage!

UMBC
AN HONORS UNIVERSITY IN MARYLAND

*Note: It is **B** and not **H** that is fundamental (directly determined by the currents)

Why study electromagnetic waves and transmission?

*"Why Johnny Can't Design a High-Speed Digital System"**
H. W. Johnson, DesignCon Presentation

See also: *"Why Digital Engineers Don't Believe in EMC"**
H. W. Johnson, IEEE EMC Society Newsletter, Spring 1998

- **Digital engineers don't believe current flows in loops**
  — look at typical logic design diagrams
- **Digital engineers don't believe in the H-field**
- **Digital engineers don't believe that gates are *differential* amplifiers**
  — as if the reference pin has a straight connection to ground
- **Digital engineers don't believe in electromagnetic waves**
  — as if radio waves didn't exist… or couldn't exist outside radio sets
- **Digital engineers don't believe that they need to know E&M**
  — that is why INTEL is screaming for people who do!

UMBC
AN HONORS UNIVERSITY IN MARYLAND

*Papers available on course URL

Basic Course Information

For course information, go to WEB site
http://blackboard.umbc.edu

INSTRUCTOR OF RECORD: Professor Curtis R. Menyuk

Office: ITE-304 Phone: 410-455-8418 (cannot leave messages at this number)
Other office: TRC-201A
Phone: 410-455-3501 (can leave messages)
or leave messages with Ms. Cindy Lamothe at x/56505
E-mail: menyuk@umbc.edu

CLASS LOCATION: Sondheim – 202 (lecture); Sondheim – 202 (discussion)
CLASS TIME: Tu, Th 10:00 – 11:15
DISCUSSION: 11:30 – 12:20 (quizzes + problem-solving)
OFFICE HOURS: Tu, Th 1:30 – 2:30 (Other times by appointment)

UMBC
AN HONORS UNIVERSITY IN MARYLAND

Year 2015 course information is also at:
http://blackboard.umbc.edu

1.5

Basic Course Information

For course information, go to WEB site
http://blackboard.umbc.edu

TEACHING ASSISTANT: Mr. Qi Zhen
Office: TRC-203
Phone: 410-455-6507
E-mail: zhenqi1@umbc.edu
OFFICE HOURS: TBD

GRADER: Mr. Patrick Sykes
Office: TRC-203
Phone: 410-455-6507
E-mail: psykes1@umbc.edu
OFFICE HOURS: TBD

UMBC
AN HONORS UNIVERSITY IN MARYLAND

Year 2015 course information is also at:
http://blackboard.umbc.edu

1.6

Basic Course Information

For detailed instructor bio, go to WEB site
http://blackboard.umbc.edu

Some highlights
- Have been at UMBC since 1986
- Founded electrical engineering program
- Former UMBC Presidential Research Professor
- Fellow of APS, OSA, IEEE
- Winner of the 2013 IEEE Photonics Society Willam Streifer Award
- Winner of 2015 – 2016 Humboldt Award
- Have worked in industry and government (DoD)

Regarding students
- Graduate: Two former IEEE-LEOS award winners; numerous other awards (best paper awards at meetings)
- Undergraduates: Published papers; have gone on to excellent graduate schools; one former student is a professor at Dartmouth

UMBC
AN HONORS UNIVERSITY IN MARYLAND

1.7

Basic Course Information

Detailed syllabus is on the WEB site
http://blackboard.umbc.edu

Summary schedule
- Introduction [complex numbers; waves] (4 lectures)
- Transmission lines (5 lectures)
- Mid-Term 1 (1 lecture)
- Vector Analysis (3 lectures)
- Classic E&M experiments (1 lecture)
- Static fields (6 lectures)
- Mid-Term 2 (1 lecture)
- Time-varying fields (4 lectures)
- Wave propagation (5 lectures)
- Final

QUIZZES: Math/physics quizzes (5–10 minutes)
Exercise/review quizzes (up to 30 minutes)
will be given in discussion section

UMBC
AN HONORS UNIVERSITY IN MARYLAND

1.8

Basic Course Information

Detailed syllabus is on the WEB site
http://blackboard.umbc.edu

Grading
- 2 writing/project assignments [including motor-generator project] (20%)
- 2 mid-term exams (20%) [including exercise quizzes]
- final exam (20%)
- 9 problem sets (40%) [including math/physics quizzes]

Changes (in response to student suggestions/comments)
- introduction of quizzes
- ***introduction of motor/generator project (2014)***

Your suggestions are very important!

UMBC
AN HONORS UNIVERSITY IN MARYLAND

Why Quizzes?

+ You cannot succeed without following the examples that are presented in class on a weekly basis
  AND
  Knowing the values of the fundamental constants [$\pi, \sqrt{2}, \sin(\pi/6)\ldots$]
  AND
  Knowing how to use geometric series, Taylor series…

– You need to keep up with the work on a weekly basis.

But it requires memorization… Isn't that bad?

Memorization is a critical skill for engineers!

…and has long term benefits. See:
"In Praise of Memorization: 10 Proven Brain Benefits"
"Save Rote Memorization" (J. Matthews)

on the course URL

UMBC
AN HONORS UNIVERSITY IN MARYLAND

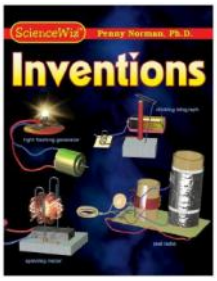
Basic Course Information

MOTOR/GENERATOR PROJECT

- Electrical motors and generators are ubiquitous
- Their development was one of the great triumphs of 19-th century electrical engineering
- The need for green solutions has revitalized this area of technology

Inexpensive kits (< $30) are available for partial credit:

- Thames and Kosmos, Motors and Generators
- ScienceWiz, Inventions Kit



UMBC
AN HONORS UNIVERSITY IN MARYLAND

1.11

Basic Course Information

For full credit, build your own: Some ideas from YouTube

MOTOR:

- http://www.youtube.com/watch?v=Ux-QGhbjOA0
- http://www.youtube.com/watch?v=elFUJNodXps
- http://www.youtube.com/watch?v=19oW0G8sYng

GENERATOR:

- https://www.youtube.com/watch?v=DKmhfWY86MM
- http://www.youtube.com/watch?v=k7Sz8oT8ou0&list=PLDCA11625D0FCB35B

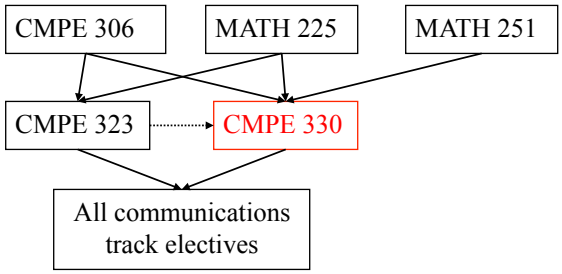
Sophistication of the design, motor/generator reciprocity, and quality of your explanation will all count. More details will be decided later.

UMBC
AN HONORS UNIVERSITY IN MARYLAND

1.12

Basic Course Information

Where this course fits in the syllabus



Other courses that this course complements

- PHYS 122: Introductory Physics II
- CMPE 314: Principles of Electronic Circuits

UMBC
AN HONORS UNIVERSITY IN MARYLAND

Basic Course Information

Textbook: (More information on URL)

Principal text: Ulaby, et al., *Fundamentals of Applied Electromagnetics*

- Transmission lines first; additional demos and solved problems
  - — ***See WEB site:*** ***http://em7e.eecs.umich.edu***
  - — 2015 now available ; should be used

Additional text: Clayton R. Paul, *Electromagnetics for Engineers*

- Will not be used much; is not required; available in the library

Comments on the textbook — or potential alternatives — are appreciated!

UMBC
AN HONORS UNIVERSITY IN MARYLAND

Basic Course Information

Other textbooks

- Almost all "real" problems must be solved computationally
- We will cover basics, not computational methods
- We will present examples that use computational results
  — particularly the FDTD (with thanks to Prof. Allen Taflove - NWU)

Textbooks that discuss computational methods

FDTD methods: A. Taflove and S. C. Hagness, *Computational Electrodynamics: The Finite-Difference Time Domain Method*

General methods: M. N. O. Sadiku, *Numerical Techniques in Electromagnetics*

UMBC
AN HONORS UNIVERSITY IN MARYLAND

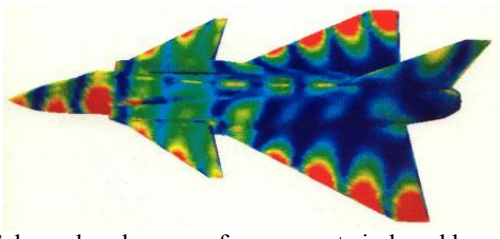
MATLAB

fdtd1D.m, fdtd2D.m, fdtd3D.m — Sue Hagness

Applications: Taflove

See: A. E. Taflove, *Why Study Electromagnetics: The First Unit in an Undergraduate Electromagnetics Course* (available on course URL)

Military: Radar on a jet fighter plane



Calculated using FDTD methods

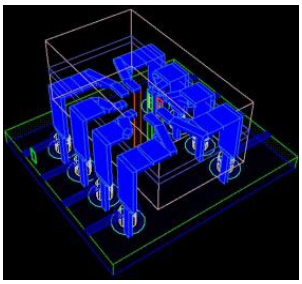
— False color shows surface currents induced by radar beam at 100 MHz

Other applications: EMP; Radar on a missile radome

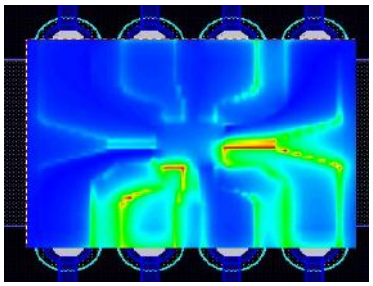
UMBC
AN HONORS UNIVERSITY IN MARYLAND

Applications: Taflove

High-Speed Electronics: Logic pulse on a microchip



Layout of dual in-line integrated-circuit package



Visualization of coupling and crosstalk of logic pulse

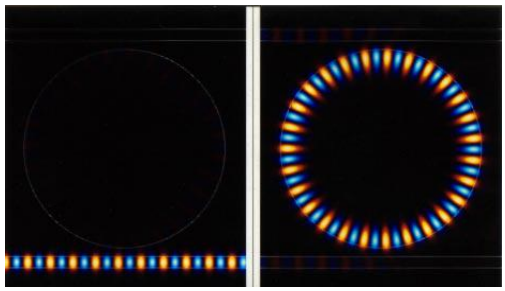
UMBC AN HONORS UNIVERSITY IN MARYLAND

The signal is not confined to the metal circuit path; it couples to all adjacent paths!

1.17

Applications: Taflove

High-Speed Photonic Devices: GaAlAs Microdisk Resonator



Off resonance On resonance

Other applications: Microcavity lasers, glass

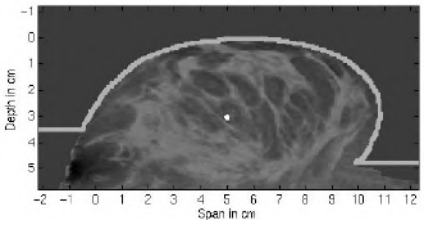
UMBC AN HONORS UNIVERSITY IN MARYLAND

— See also the Mohammed, et al. paper

1.18

Applications: Taflove

Medical Imaging: Detecting breast cancer



MRI Image

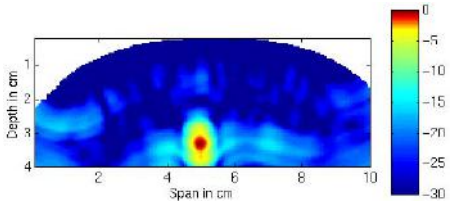


Image reconstruction of tumor

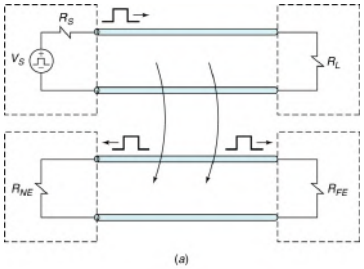
(Taflove acknowledges: S. Davis, et al., *Electromagnetic Waves and Applications*)

UMBC
AN HONORS UNIVERSITY IN MARYLAND

Applications: Paul

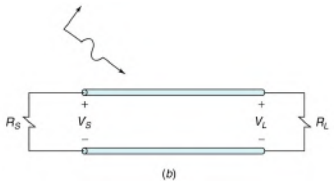
See: C. R. Paul, Section 1.5

Electromagnetic Interference: Possible problems



Crosstalk between two transmission lines

[Paul, Fig. 1-9, p. 18]



Electromagnetic radiation incident on a transmission line

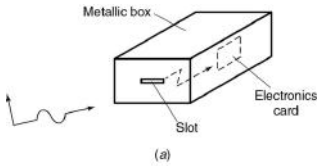
UMBC
AN HONORS UNIVERSITY IN MARYLAND

- A "hidden schematic" leads to improper operation
- Correct design to avoid these E&M problems is required

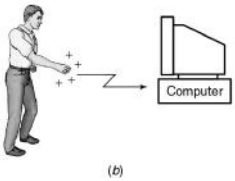
Applications: Paul

See: C. R. Paul, Section 1.5

Electromagnetic Interference: More possible problems



Even with shielding, radiation can penetrate through slots



Electrostatic discharge can damage or destroy computer equipment

[Paul, Fig. 1-11, p. 21]

Applications: Ulaby, et al.

See: Ulaby, et al., Technology Brief 1

Energy-Efficient Lighting: Light Sources

Possible Light Sources:

Ulaby, et al.
Figure TF1-1: (a) Incandescent light bulb; (b) fluorescent mercury vapor lamp; (c) white LED.

Incandescent: Light emission from a hot filament
Fluorescent: Collision induced excitation
Light-emitting diode: Electron-hole collisions in semiconductors

Applications: Ulaby, et al.

See: Ulaby, et al., Technology Brief 1

Parameter	Type of Light Bulb			
	Incandescent	Fluorescent	White LED	
			Circa 2010	Circa 2025
Luminous Efficacy (lumens/W)	~12	~40	~70	~150
Useful Lifetime (hours)	~1000	~20,000	~60,000	~100,000
Purchase Price	~$1.50	~$5	~$10	~$5
Estimated Cost over 10 Years	~$410	~$110	~$100	~$40

Ulaby, et al.
Figure TF1-7: Even though the initial purchase price of a white LED is several times greater than that of the incandescent light bulb, the total 10-year cost of using the LED is only one-fourth of the incandescent's (in 2010), and expected to decrease to one-tenth by 2025.

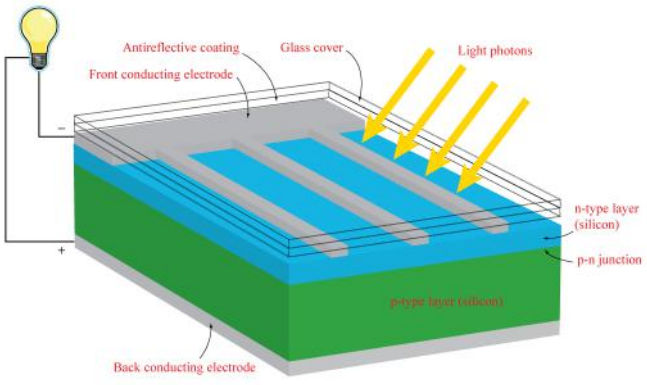
UMBC
AN HONORS UNIVERSITY IN MARYLAND

New light bulb technology is more efficient and lasts longer!

Applications: Ulaby, et al.

See: Ulaby, et al., Technology Brief 2

Collecting Solar Energy: Photovoltaic Cells



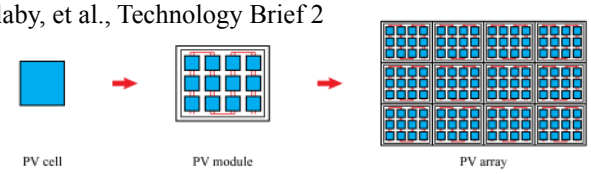
Ulaby, et al. Figure TF2-2: Basic structure of a photovoltaic cell.

UMBC
AN HONORS UNIVERSITY IN MARYLAND

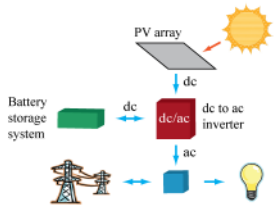
The basic structure uses p-n junctions, but…

Applications: Ulaby, et al.

See: Ulaby, et al., Technology Brief 2



Ulaby, et al. Figure TF2-4: PV cells, modules, and arrays.



Ulaby, et al. Figure TF2-5: Components of a large-scale photovoltaic system.

UMBC
AN HONORS UNIVERSITY IN MARYLAND

…a large-scale system must be created.

1.25

Assignments

Reading: Introductory materials; Ulaby, et al., Chapter 1

Writing:

- Write a two-page essay describing a particular application of electro-magnetics and waves that may be of interest to you in a future career.
- Possibilities may be found in Taflove's article, Mohammed, *et al.*'s article, and the Ulaby, et al. book.
- Everything counts: Grammar, good organization, spelling, etc.

  BUT

  I will give the highest grades for describing carefully how the application relates to your own career goals and searching the references for details on the application.

UMBC
AN HONORS UNIVERSITY IN MARYLAND

- Samples of the best, middle, and worst essays are available on the course URL

1.26