Lesson 1
Introduction

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Sec. 1-1
Basics

1. What is EM
2. Why to study EM
3. Overview
4. Analysis of different types of EM problems
What is Electromagnetism (EM)?

- The study of electric charges at rest and in motion
Why to study EM?

- To understand the natural EM phenomena
  E.g. The “blue” sky (EM wave scattering), the lightening (discharge)

- To create EM devices to facilitate (and complicate) our lives
  E.g. The compass, motors, memories, solar cells

- To be an EE alumnus(alumna)

- To appreciate the beauty of the universal laws
Overview of EM

- Electric charges establish electric fields
- Moving charges become electric currents and create magnetic fields
- Timing-varying charges and currents cause the coupling between electric and magnetic fields such that they behave like “waves”
Types of EM problems

- Lumped circuit
  - $L \ll \lambda$
  - $V_s(t)$
  - $R_1$
  - $R_2$

- Transmission line
  - $D \ll \lambda$
  - $L > \lambda$

- Waveguide (cross-section)
  - $L \gg \lambda$
  - $D > \lambda$
# Analysis of EM problems

<table>
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<tr>
<th>Conditions</th>
<th>Theory</th>
<th>Unknowns</th>
<th>Math tool</th>
<th>Description</th>
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<tr>
<td>$L &lt;&lt; \lambda$</td>
<td>Lumped circuits</td>
<td>$V(t)$, $I(t)$</td>
<td>Ordinary differential equations (ODEs)</td>
<td>All points react to the source instantly</td>
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<tr>
<td>$L &gt; \lambda$,</td>
<td>Transmission lines</td>
<td>$V(z,t)$, $I(z,t)$</td>
<td>Partial differential equations (PDEs)</td>
<td>Delay along the longitudinal ($z$) direction matters</td>
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<td>$D &lt;&lt; \lambda$</td>
<td>Kirchhoff’s laws</td>
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<td>$L &gt;&gt; \lambda$,</td>
<td>Waveguides</td>
<td>$\bar{E}(x,y,z,t)$, $\bar{H}(x,y,z,t)$</td>
<td>Full vectorial PDEs</td>
<td>Delay along the longitudinal ($z$), and transversal ($x,y$) directions matter</td>
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<td>$D &gt; \lambda$</td>
<td>Maxwell’s equations</td>
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Example: Monopole antenna

- Lumped circuit theory: it’s an “open circuit”, no current can flow.
- EM theory: it may carry spatially nonuniform current.
Sec. 1-2
EM Model

1. Methodology
2. Our approach
Methodology

- **Inductive (歸納) approach:** Starting with observations of experiments, inferring laws and theorems (from particular phenomena to general principles)

- **Deductive (演繹) approach:** Starting with fundamental postulates, deriving particular laws and theorems, which can be verified by experiments
Our approach: Deductive

1. Defining the basic quantities:

   (i) Electric charge \( q \) \( (e = 1.6 \times 10^{-19} \text{ C}) \), volume charge density \( \rho \) \( \text{C/m}^3 \)

   (ii) Current \( I \) \( \text{C/s, or A} \), volume current density \( \vec{j} \) \( \text{A/m}^2 \)

   (iii) Electric field intensity \( \vec{E} \) \( \text{V/m} \): Electric force on a unit charge

   (iv) Electric flux density \( \vec{D} \) \( \text{C/m}^2 \): Useful in studying electric field in materials

   (v) Magnetic flux density \( \vec{B} \) \( \text{T} \): Magnetic force on a charge moving with a given velocity

   (vi) Magnetic field intensity \( \vec{H} \) \( \text{A/m} \): Useful in studying magnetic field in materials
Our approach-2

2. Rules of operations:
   
   (i) Vector analysis
   
   (ii) Partial differential equations

3. Fundamental postulates: Maxwell equations and conservation of electric charges relate the source and field quantities. The solutions describe all the EM phenomena.