EM

MAXWELLS EQUATIONS

▼ Basic Quantities in Electromagnetism

1. Basic Quantities in Electromagnetism

- **Explanation**: This section introduces fundamental quantities like electric field ($\vec{E}$), magnetic field ($\vec{B}$), electric flux density ($\vec{D}$), and magnetic flux density ($\vec{H}$). It may also cover charge density (ρ) and current density ($\vec{J}$).
- **Important Formulas**:
  - **Electric field**: $\vec{E} = \frac{\vec{F}}{q}$
  - **Magnetic field**: Often defined in terms of the Lorentz force, $\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$.
  - **Electric flux density**: $\vec{D} = \epsilon\vec{E}$
  - **Magnetic flux density**: $\vec{B} = \mu\vec{H}$
- **Physical Interpretation**: These quantities describe how electric and magnetic fields interact with charges and currents. The fields can exert forces on charged particles, affecting their motion and energy.
- **Example**: The electric field between two parallel plates with a voltage applied across them, or the magnetic field created around a current-carrying wire.

▼ Basic Laws of Electromagnetism

2. Basic Laws of Electromagnetism

- **Explanation:** This section will likely cover four primary laws:
  - **Gauss's Law for Electricity**: Describes how electric flux emerges from charges.
  - **Gauss's Law for Magnetism**: States that magnetic flux lines are continuous; there are no magnetic monopoles.
  - **Faraday's Law**: Describes how a time-varying magnetic field creates an electric field.
  - **Ampère's Law (with Maxwell's correction):** Relates magnetic fields to currents and changing electric fields.
- **Important Formulas**:
  - Gauss's Law for Electricity: $\nabla \cdot \vec{D} = \rho$
  - Gauss's Law for Magnetism: $\nabla \cdot \vec{B} = 0$
  - Faraday's Law: $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$
  - Ampère's Law (Maxwell's correction): $\nabla \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t}$
- **Physical Interpretation**: These laws describe the behavior of electric and magnetic fields in space and time. They lay the groundwork for Maxwell's equations, showing how fields are generated and interact.
- **Example:** Using Faraday's Law to explain how a changing magnetic field induces current in a conductor, which is the basis for transformers and generators.

▼ Maxwell's Equations

3. Maxwell's Equations

- **Explanation**: Maxwell's equations are the cornerstone of classical electromagnetism, combining the above laws into a set of four differential equations. They unify electric and magnetic fields and describe electromagnetic wave propagation.
- **Equations:**
  1. $\nabla \cdot \vec{D} = \rho$
  2. $\nabla \cdot \vec{B} = 0$
  3. $\nabla \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$
  4. $\nabla \times \vec{H} = \vec{J} + \frac{\partial \vec{D}}{\partial t}$
- **Physical Interpretation:** Maxwell's equations link electric and magnetic fields. They predict electromagnetic waves, showing that changing electric fields generate magnetic fields and vice versa, enabling self-sustaining wave propagation.
- **Example**: Electromagnetic waves (like light) propagate by electric and magnetic fields regenerating each other through space.

▼ Surface Charge and Surface Current

4. Surface Charge and Surface Current

- **Explanation**: These concepts describe charges and currents localized on surfaces. Surface charge density (σ) and surface current density ($\vec{K}$) are essential for understanding boundary conditions at interfaces.
- **Formulas**:
  - Surface charge density: $\sigma = \frac{dQ}{dA}$
  - Surface current density: $\vec{K} = \frac{dI}{dL}$
- **Physical Interpretation**: Surface charges create discontinuities in the electric field at material boundaries, while surface currents influence the magnetic field in these regions.
- **Example**: A charged conducting plate with surface charge density σ or a thin current-carrying sheet used in waveguides.

▼ Boundary Conditions

5. Boundary Conditions

- **Explanation**: Boundary conditions determine how fields behave at the interface of two different media. They are derived from Maxwell's equations and are essential for solving practical problems involving interfaces (e.g., wave reflection and transmission).
- **Conditions**:
  - The normal component of $\vec{D}$ has a discontinuity proportional to surface charge.
  - The tangential component of $\vec{E}$ is continuous across boundaries.
  - The normal component of $\vec{B}$ is continuous across boundaries.
  - The tangential component of $\vec{H}$ has a discontinuity proportional to surface current.
- **Physical Interpretation**: These conditions ensure the correct behavior of fields across materials with different permittivity or permeability.
- **Example**: Reflection and refraction of an electromagnetic wave at the boundary between air and glass.

5. Boundary Conditions

- **Electric Field Boundary Conditions**:
  - Normal component of $\vec{D}$:

$$\vec{D}_1 \cdot \hat{n} - \vec{D}_2 \cdot \hat{n} = \sigma$$

    where σ is the surface charge density.

  - Tangential component of $\vec{E}$:

$$\vec{E}_1 \times \hat{n} = \vec{E}_2 \times \hat{n}$$

- **Magnetic Field Boundary Conditions**:
  - Normal component of $\vec{B}$:

$$\vec{B}_1 \cdot \hat{n} = \vec{B}_2 \cdot \hat{n}$$

  - Tangential component of $\vec{H}$:

$$\vec{H}_1 \times \hat{n} - \vec{H}_2 \times \hat{n} = \vec{K}$$

    where $\vec{K}$ is the surface current density.

waveguides:

Doubts:

1. d< lambda / 2 → no waves ?

✅ Ans :

- **When d<λ/2d < \lambda/2d<λ/2: Energy Loss Through Reflection or Absorption**: If you place the metal at d<λ/2d < \lambda/2d<λ/2, the field pattern is disrupted significantly because the metal no longer aligns with a natural zero of the electric field. This disruption reflects or absorbs part of the wave, which means the wave can't propagate normally beyond this point. Instead of radiating energy as an electromagnetic wave beyond this obstruction, the wave's energy is partially trapped or dissipated in the guide.
- **No Wave Propagation Means No Energy Transfer**: When we say "no energy radiated," it means that the wave can't carry energy forward along the waveguide beyond the obstruction. Instead, that energy is either reflected back along the guide, absorbed by the metal piece, or dissipated as heat. If the wave can't sustain its normal propagation mode (which requires specific boundary conditions), it loses its ability to transfer energy forward efficiently.

2. Guided Wavelength:

✅ In a waveguide, the *phase velocity* (the speed at which the wave's phase moves) can exceed the speed of light. This happens because of the wave's interactions with the walls of the waveguide, which cause it to travel in a zigzag pattern rather than straight through.

When the phase velocity is higher, it stretches the *guided wavelength* (λg\lambda_gλg), making it longer than it would be in free space. This longer wavelength is a result of the wave needing more distance within the waveguide to complete each cycle due to its altered, "zigzag" path.

So, even though the phase velocity is high, this doesn't mean the wave's energy or information is moving faster than light—just the phase. The actual flow of energy along the waveguide is still slower, constrained by the guide's structure.