How does an antenna that only generates a magnetic field, generate an electromagnetic (EM) wave?

Electromagnetic (EM) Wave

- Made up of <u>two</u> time varying components:
  - Electric field (E)
  - Magnetic field (B)
- Electric and magnetic fields
  - Orthogonal and in phase
  - ***<u>Are tightly coupled to each other</u>***
  - Propagate through space at the speed of light
  - How do we know this: Maxwell' equations
- Greatest physicists all time:
  1. Newton (F= ma)
  2. Einstein ($E= mc^2$)
  3. ?

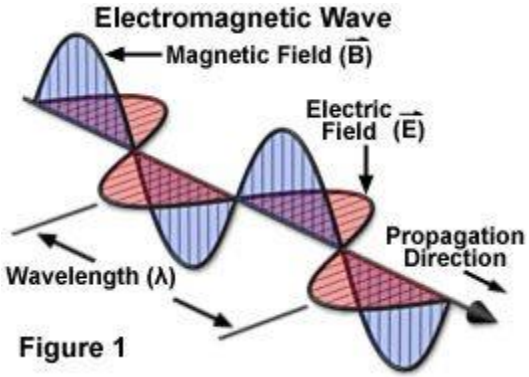

Figure 1

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- Greatest physicists all time:
  1. Newton (F= ma)
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  3. Maxwell (Maxwell's equations)

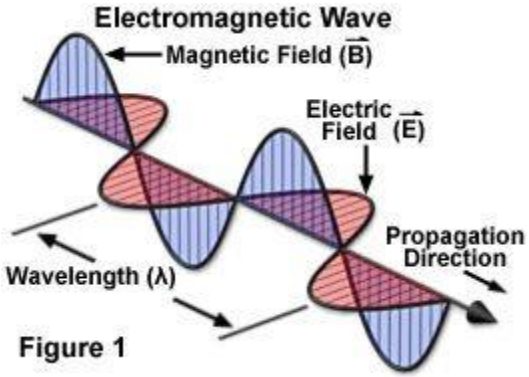


Figure 1

Force Fields & EM Waves

- Charged particle: free electron (which has a negative charge)
- Constant electric field is produced by a stationary charged particle
  - Example: a capacitor with a DC charge
- Constant magnetic field is produced by a moving charged
  - Important point: charges are moving at a constant velocity
  - Example: a DC current flowing thru a conductor
- An EM wave is produced by an accelerating charged particle
  - Examples:
    - Particle accelerator
    - **AC current flowing thru a conductor of sufficient length**

Maxwell's Equations

$$\oiint_S \vec{\mathbf{E}} \cdot \hat{\mathbf{n}}\, dA = \frac{1}{\varepsilon_0} \iiint_V \rho\, dV \qquad \text{(Gauss's Law)}$$

$$\oiint_S \vec{\mathbf{B}} \cdot \hat{\mathbf{n}}\, dA = 0 \qquad \text{(Magnetic Gauss's Law)}$$

$$\oint_C \vec{\mathbf{E}} \cdot d\vec{\mathbf{s}} = -\frac{d}{dt} \iint_S \vec{\mathbf{B}} \cdot \hat{\mathbf{n}}\, dA \qquad \text{(Faraday's Law)}$$

$$\oint_C \vec{\mathbf{B}} \cdot d\vec{\mathbf{s}} = \mu_0 \iint_S \vec{\mathbf{J}} \cdot \hat{\mathbf{n}}\, dA + \mu_0 \varepsilon_0 \frac{d}{dt} \iint_S \vec{\mathbf{E}} \cdot \hat{\mathbf{n}}\, dA \qquad \text{(Maxwell - Ampere's Law)}$$

Why Are Maxwell's Equations Important

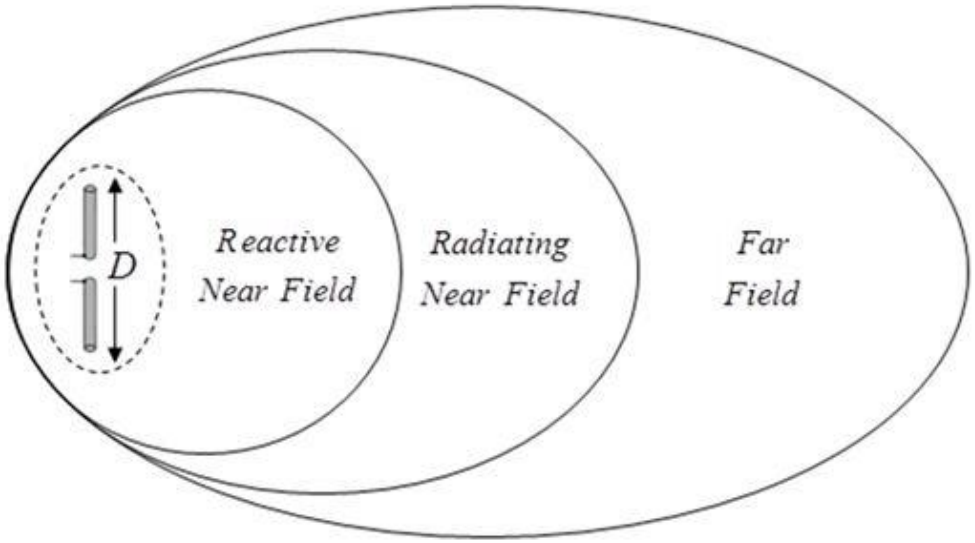
- Show the link between electricity, magnetism and light
  - Show that light is a form of EM radiation
- Break down under some conditions
  - Led Einstein to Theory of Relativity
- **Mathematical description of how EM waves are generated** and altered

How Does An EM Wave Get Generated

- From Maxwell's equations:
  - ***A time varying electric field induces a time varying magnetic field***
  - ***A time varying magnetic field induces a time varying electric field***
  - ***This interplay between induced electric and induced magnetic fields leads to propagating electromagnetic waves***
- Most antennas do not launch an EM wave
  - They generate either a time varying electric field or a time varying magnetic field

Spatial Fields (Distance From An Antenna)

- Pure EM waves only exist in the Far Field



Reactive Near Field : $r < 0.62\sqrt{D^3/\lambda}$

Radiating Near Field : $0.62\sqrt{D^3/\lambda} < r < 2D^2/\lambda$

Far Field : $r > 2D^2/\lambda$

Spatial Fields (Distance From An Antenna)

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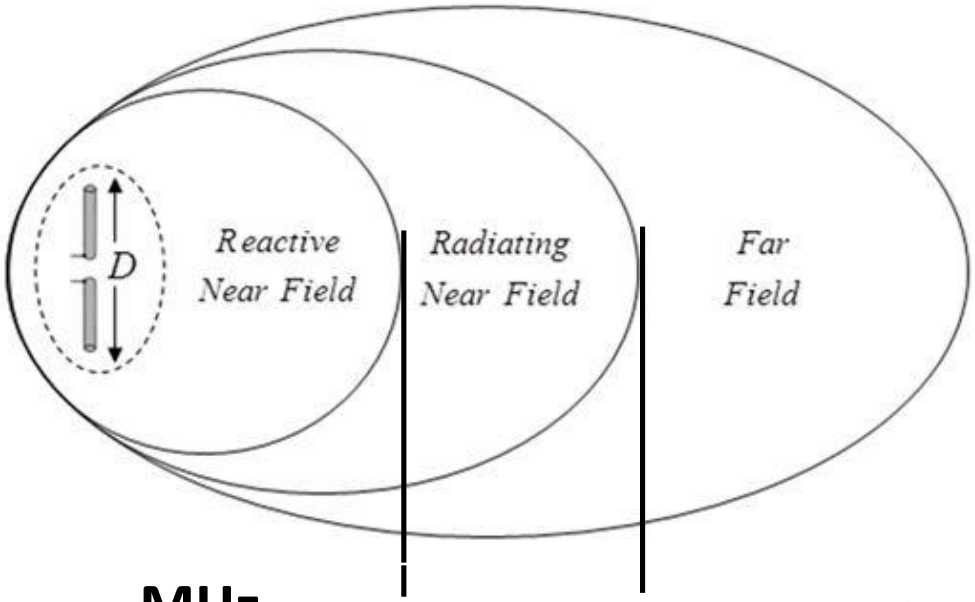


MHz		
3.5	175 ft	564 ft
144	4.3 ft	14 ft

Reactive Near Field : $r < 0.62\sqrt{D^3/\lambda}$

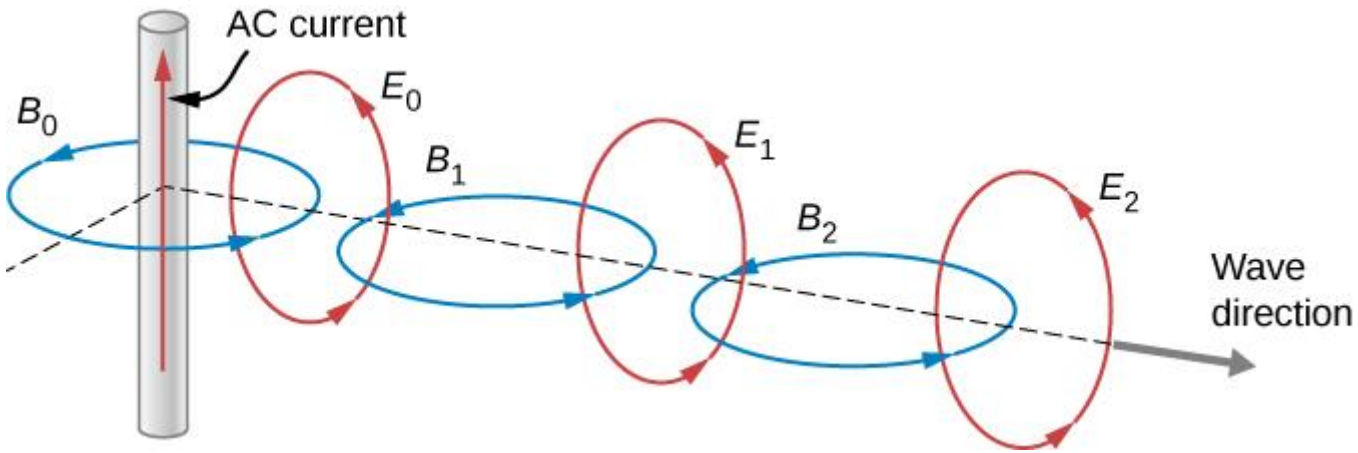
Radiating Near Field : $0.62\sqrt{D^3/\lambda} < r < 2D^2/\lambda$

Far Field : $r > 2D^2/\lambda$

EM Wave From A Magnetic Field Generator

Conductor length must be > 0.05 wavelength to radiate

(LC tank circuits don't radiate because they are << 0.05 wavelength)



Reactive Near-field

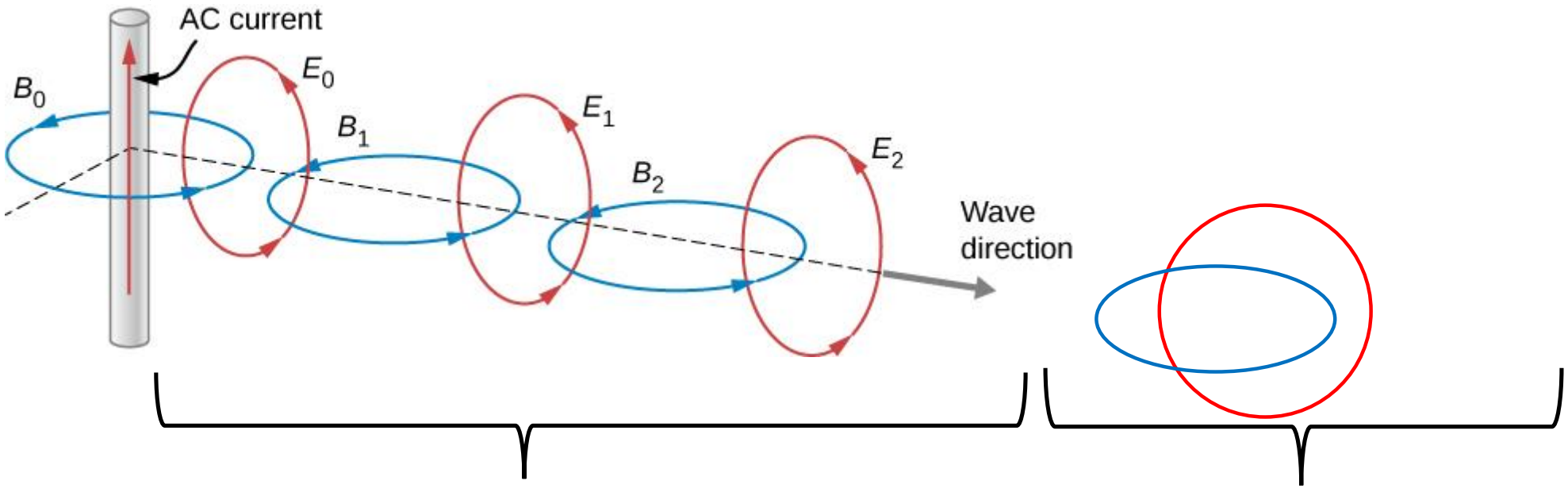
Initially:

- **E & B fields are orthogonal but 90^o <u>out</u> of phase**
- **Energy goes back and forth between E & B fields**
- **No radiation**
- **Analogous to a lossless LC tank circuit**

EM Wave From A Magnetic Field Generator

Length must be > 0.05 wavelength to start radiating

(This is why LC tank circuits don't radiate)



Reactive Near-field

Radiating Near Field

(Transition region)

EM Wave From A Magnetic Field Generator

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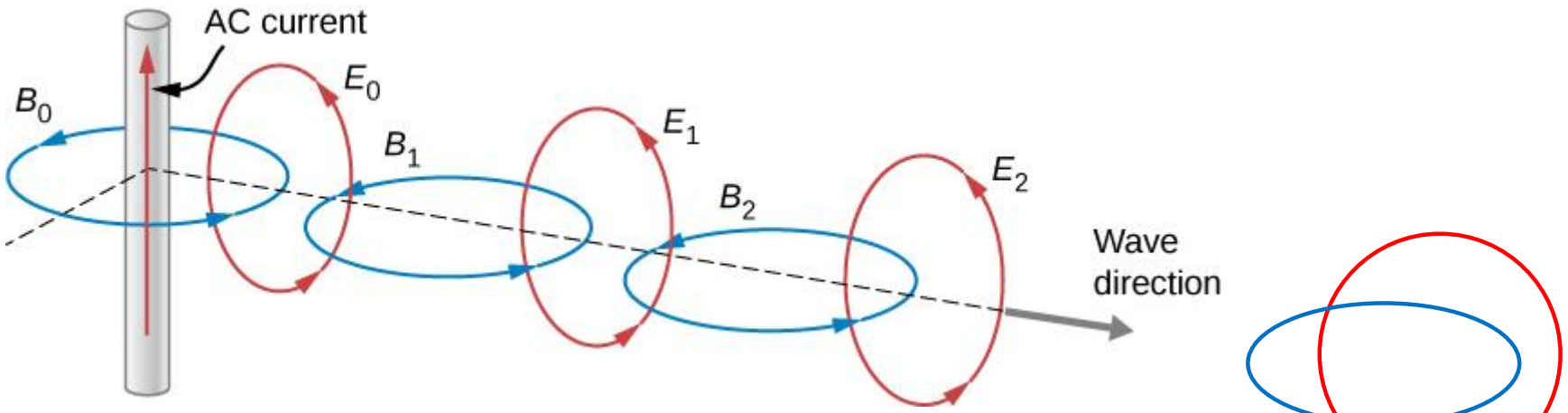
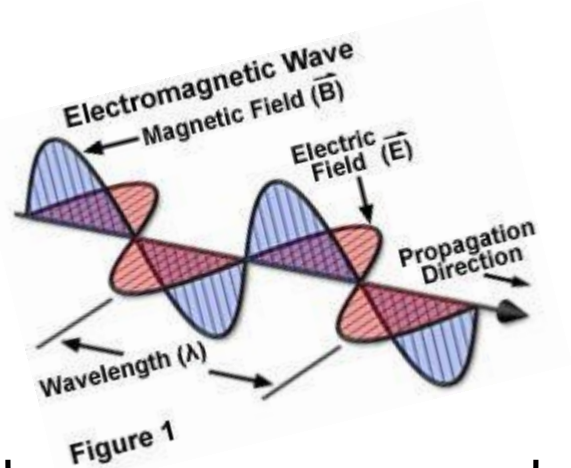
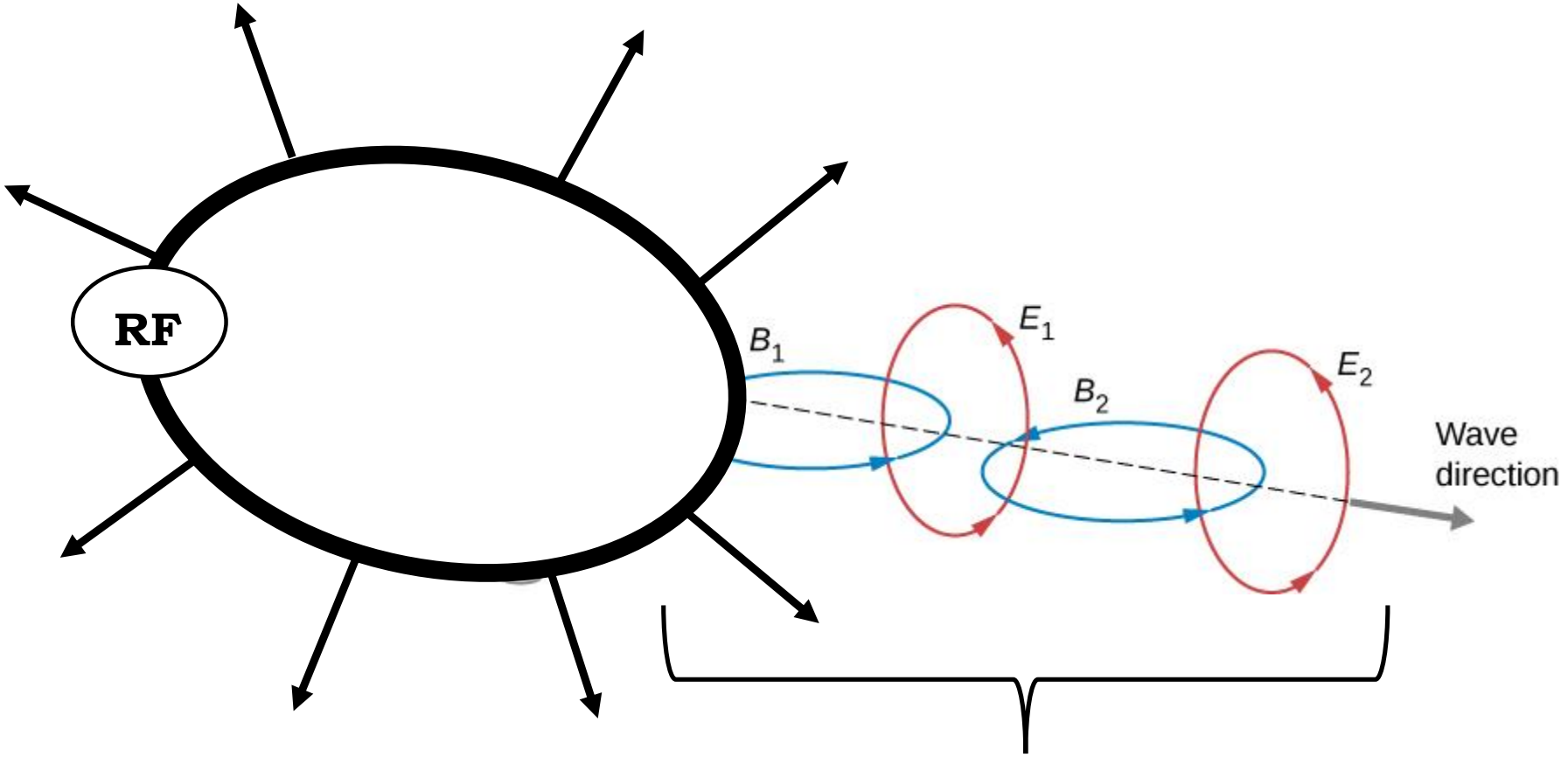




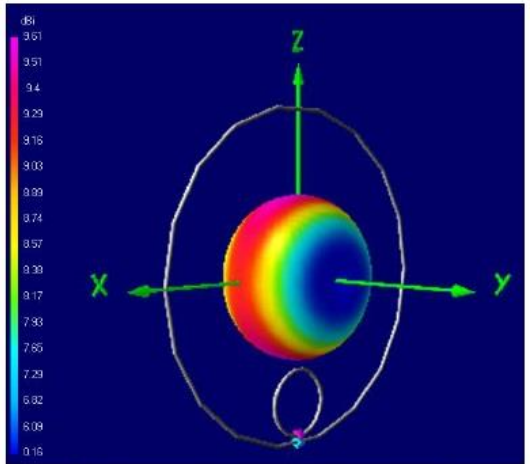
- **E & B fields in-phase**
- **Full radiation**
- **No reactive energy**

Far Field

Magnetic Loop Antenna

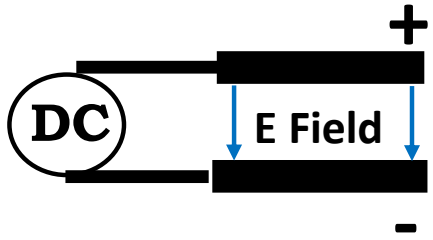


Reactive
Near-field

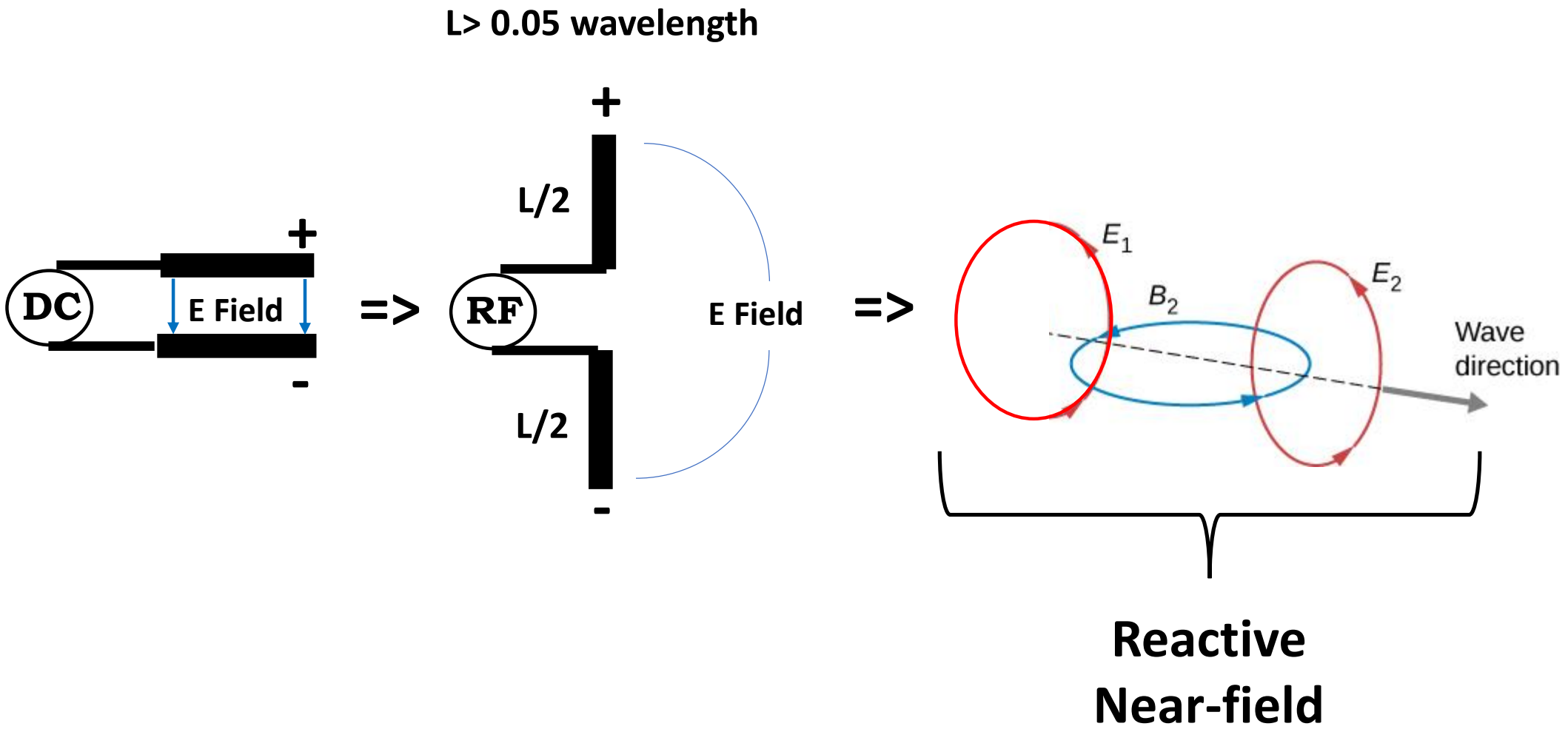


Far Field Pattern

Electric Field Antenna



Electric Field Antenna



Reactive
Near-field

Magnetic Loop Antenna

- Why is it called a Magnetic Loop antenna?
  - In the reactive near-field:
    - It generates a magnetic field on transmit and,
    - It responds primarily to the magnetic field of an EM wave when receiving
- In the far field, there is no difference between the EM wave generated from a magnetic loop or from a dipole
- Ground effects:
  - Near field: detuning and losses are minimal
  - Far field: similar to ground mounted vertical

Pseudo-Brewster angle notch-out