1.1 Radiation mechanism - single wire, two wire and current distribution

Module:1 EM Radiation and Antenna Parameters

Course: BECE305L – Antenna and Microwave Engineering

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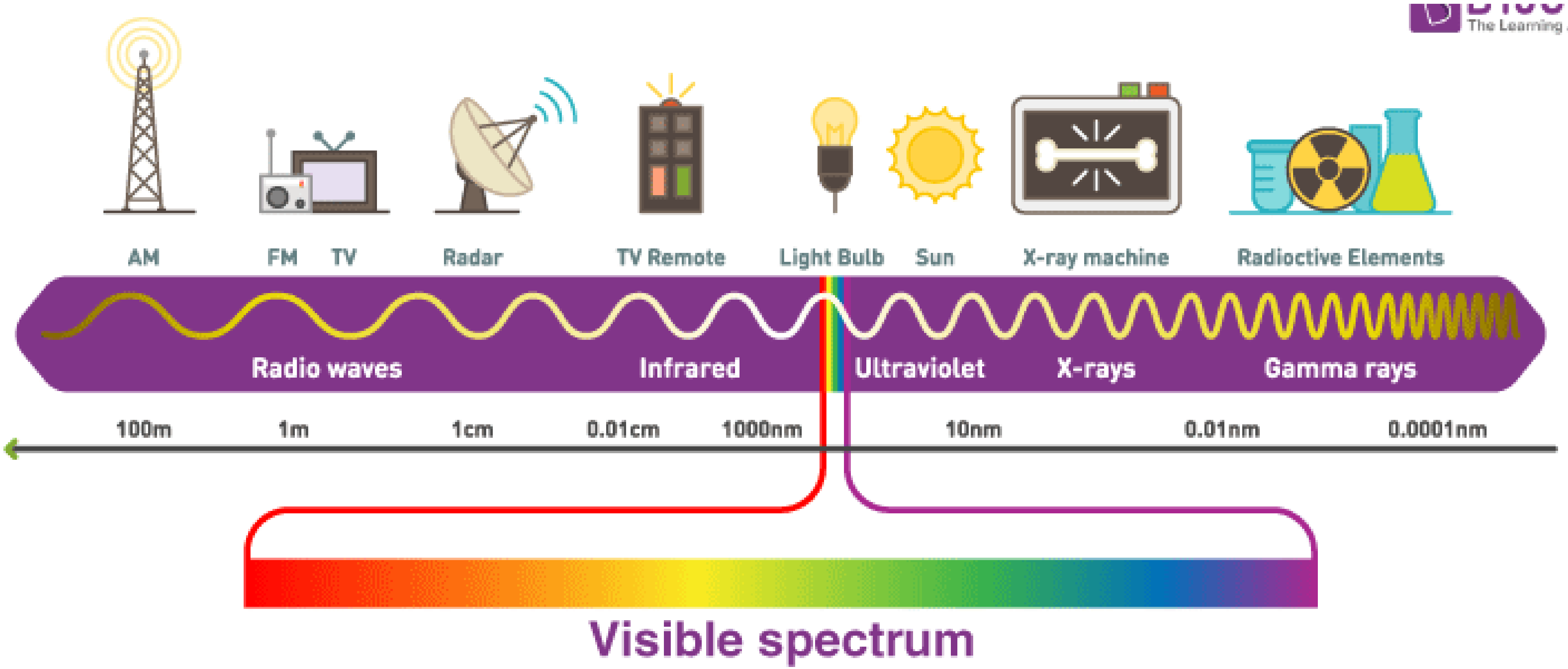
(Deemed to be University under section 3 of UGC Act, 1956)
CHENNAI

Module:1 EM Radiation and Antenna Parameters

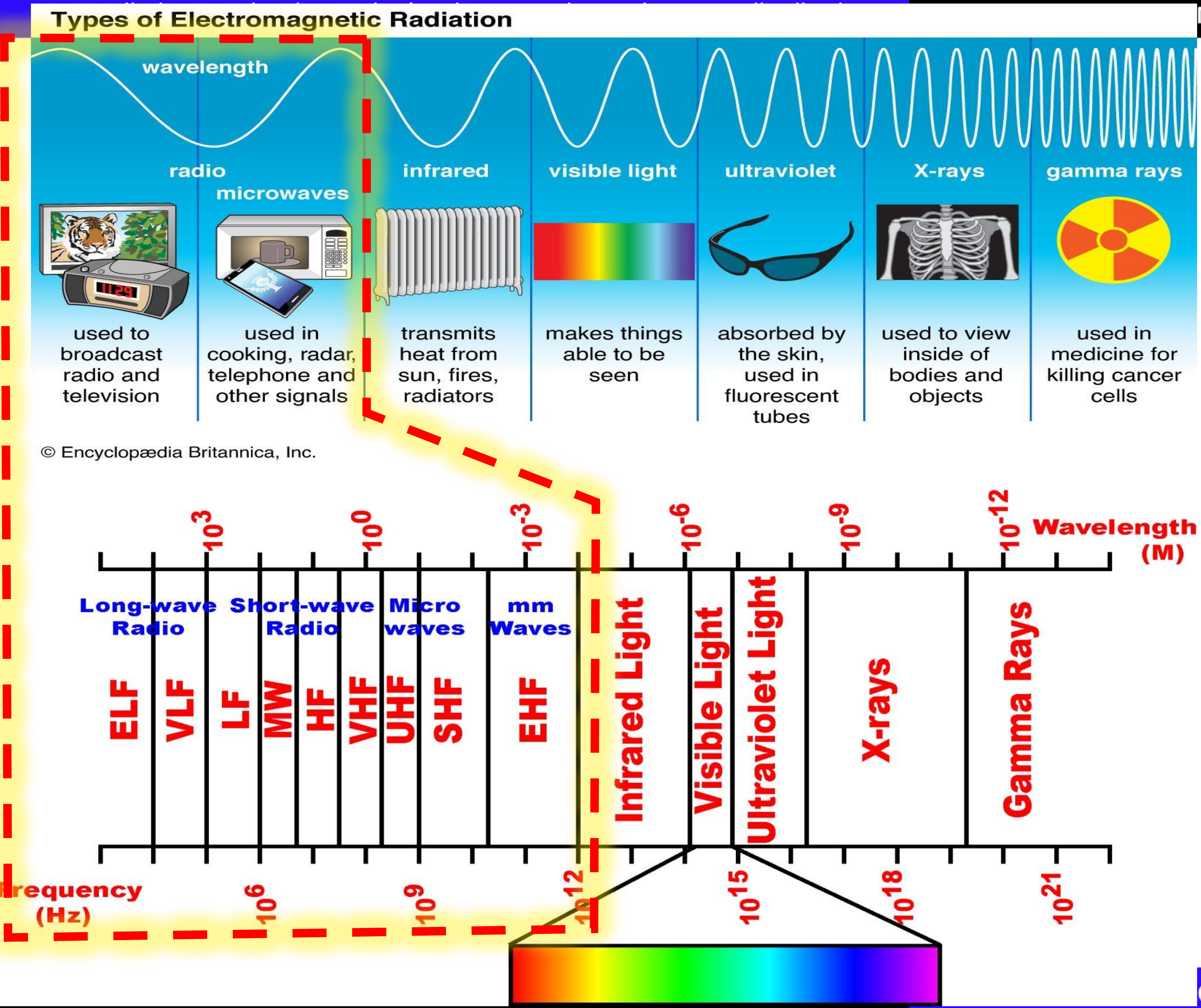
- **Radiation mechanism - single wire, two wire and current distribution**, Hertzian dipole, Dipole and monopole - Radiation pattern, beam width, field regions, radiation power density, radiation intensity, directivity and gain, bandwidth, polarization, input impedance, efficiency, antenna effective length and area, antenna temperature. Friis transmission equation, Radar range equation

- Source of the contents: Constantine A. Balanis - Antenna theory analysis and design (2016)

Applications at various frequencies



https://byjus.com/physics/electromagnetic-spectrum-radio-waves/



- RADIO FREQUENCIES

https://www.britannica.com/science/electromagnetic-spectrum
https://linxtechnologies.com/wp/ufaqs/what-is-radio-frequency-rf-how-is-it-measured/

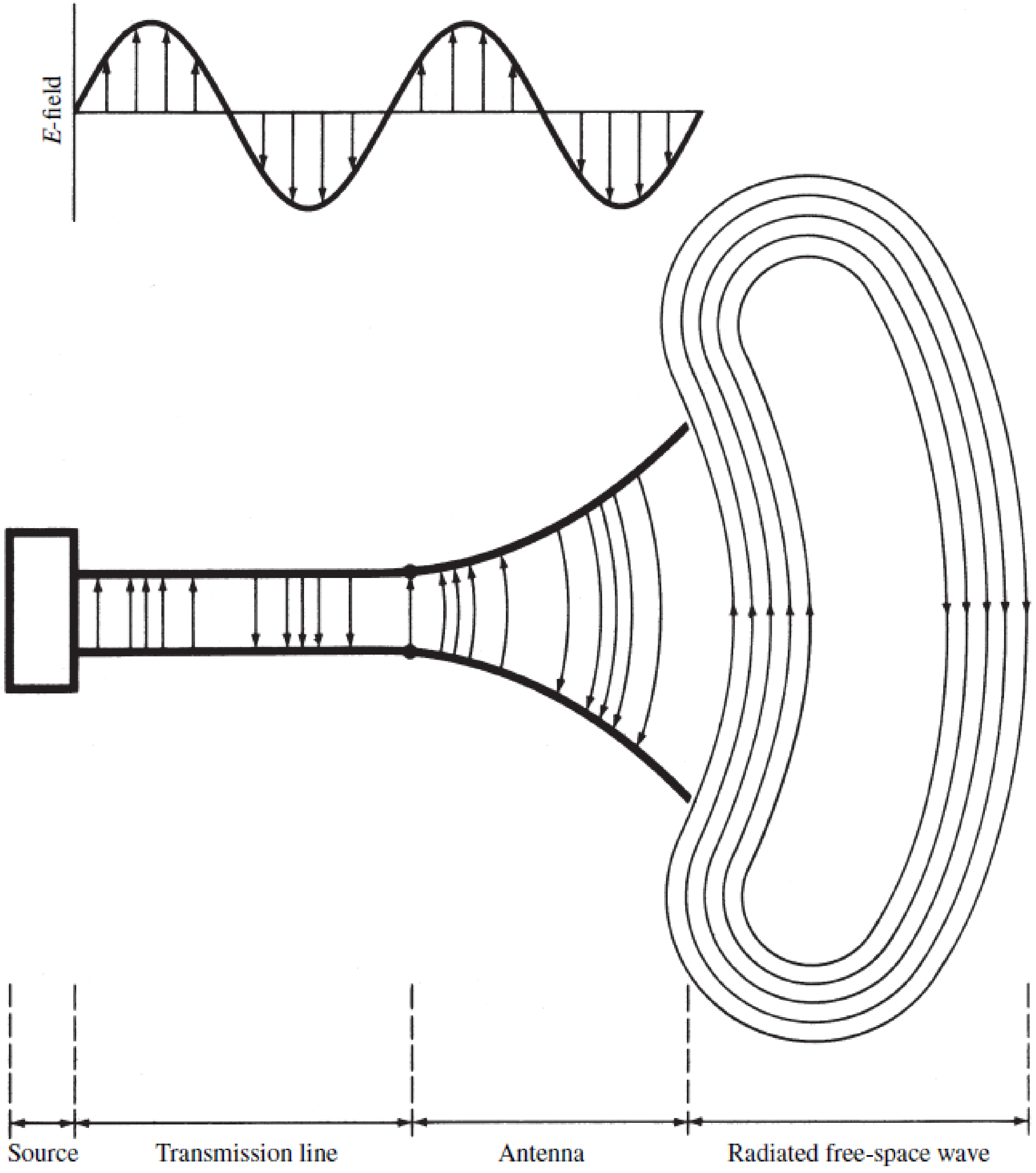
1. Introduction

- **An antenna** is defined by Webster's Dictionary as "*a usually metallic device (as a rod or wire) for radiating or receiving radio waves*."
- The *IEEE Standard Definitions of Terms for Antennas* (IEEE Std 145–1983) defines the antenna or aerial as

  "a means for radiating or receiving radio waves."
- An antenna in an advanced wireless system is usually required to optimize or accentuate the radiation energy in some directions and suppress it in others.
- Thus the antenna must also serve as a directional device in addition to a probing device.

1. Introduction

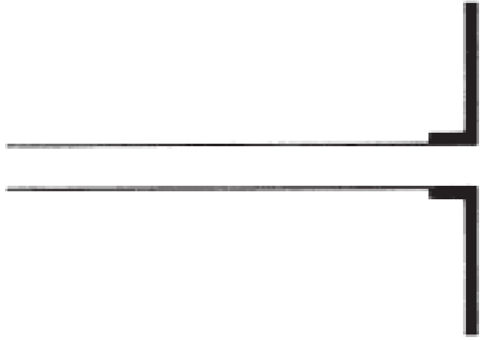
- Antenna is the **transitional structure** between free-space and a guiding device
- The guiding device or transmission line: a coaxial line or a hollow pipe (waveguide),
  Used to transport electromagnetic energy from the transmitting source to the antenna, or from the antenna to the receiver.
- In the former case, we have a *transmitting* antenna and in the latter a *receiving* antenna



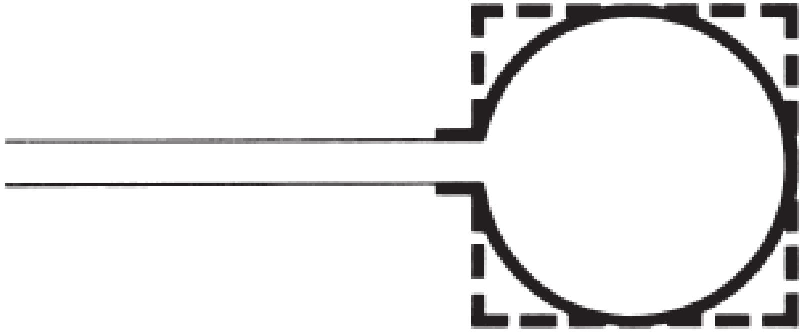
2. Types of antenna

2.1 Wire antennas

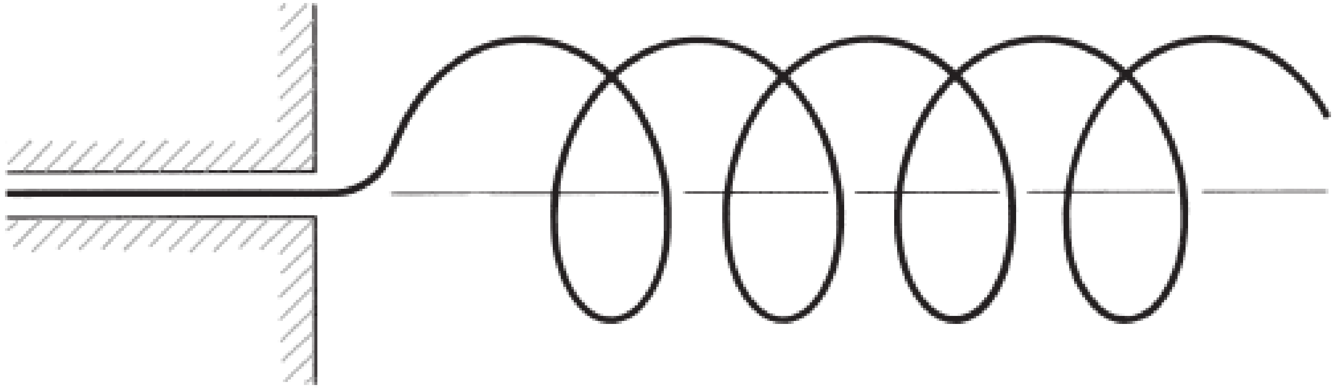
- on automobiles, buildings, ships, aircraft, spacecraft, and so on.



(a) Dipole



(b) Circular (square) loop

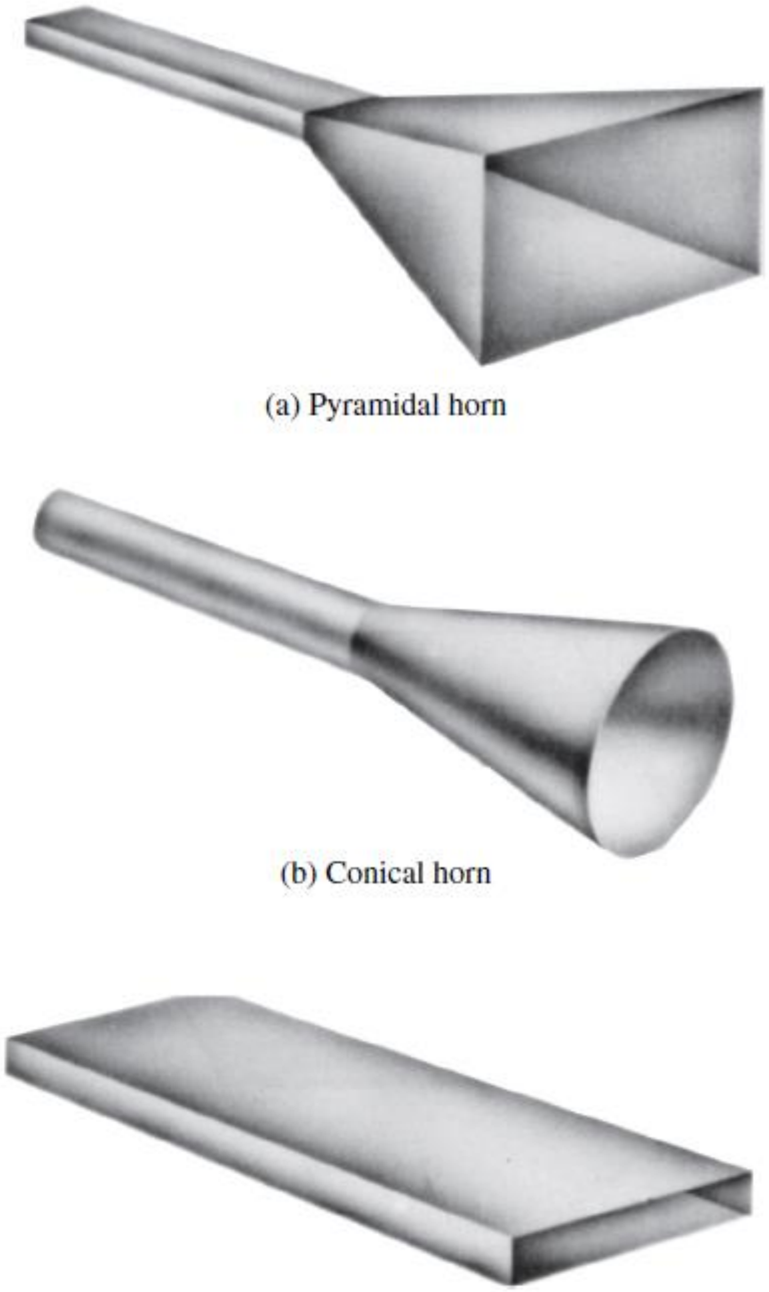


(c) Helix

2. Types of antenna

2.2 Aperture antennas

- very useful for aircraft and spacecraft applications, because they can be very conveniently flush-mounted on the skin of the aircraft or spacecraft.



(a) Pyramidal horn

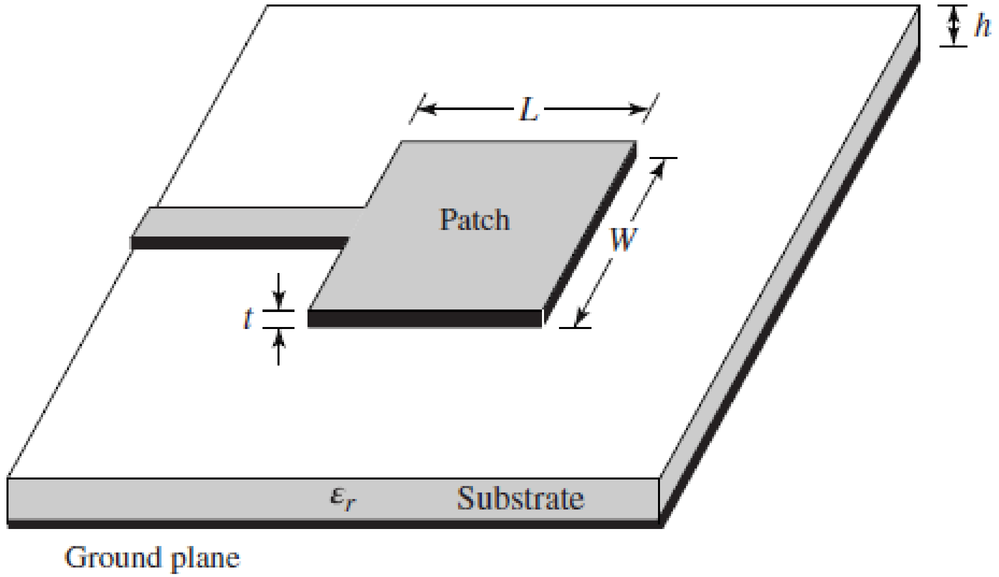
(b) Conical horn

(c) Rectangular waveguide

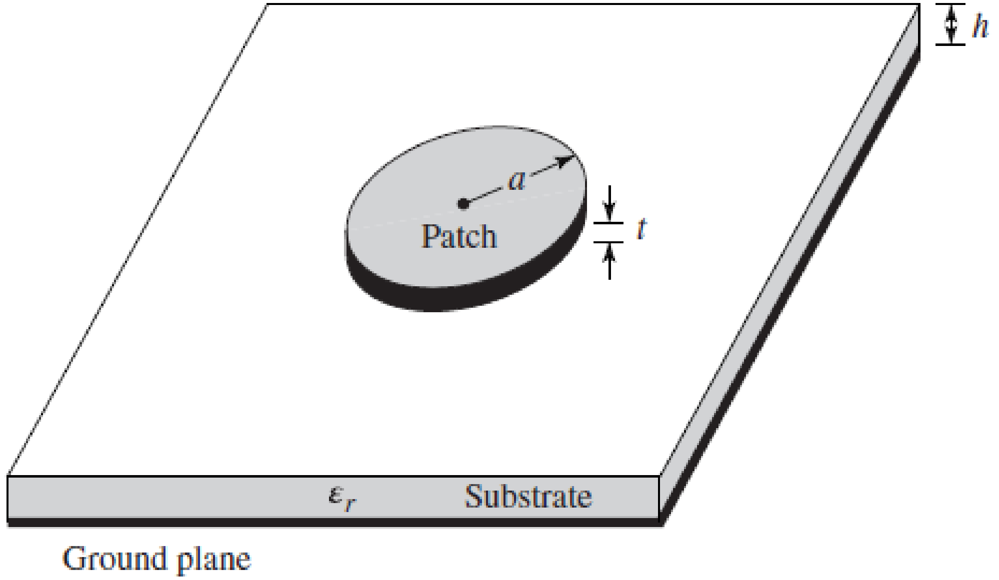
2. Types of antenna

2.3 Microstrip antennas

- Consist of a metallic patch on a grounded substrate
- most popular : ease of analysis and fabrication, and their attractive radiation characteristics, low cross-polarization radiation, low profile, conformable to planar and nonplanar surfaces, simple and inexpensive to fabricate using modern printed-circuit technology, mechanically robust when mounted on rigid surfaces, compatible with MMIC designs, and very versatile in terms of resonant frequency, polarization, pattern, and impedance
- mounted on the surface of high-performance aircraft, spacecraft, satellites, missiles, cars, and even mobile devices



(a) Rectangular

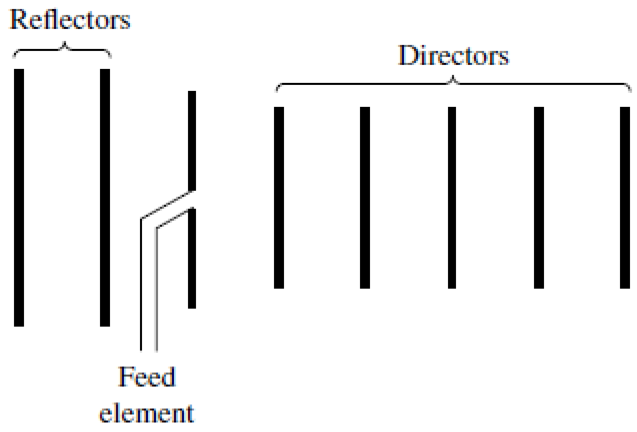


(b) Circular

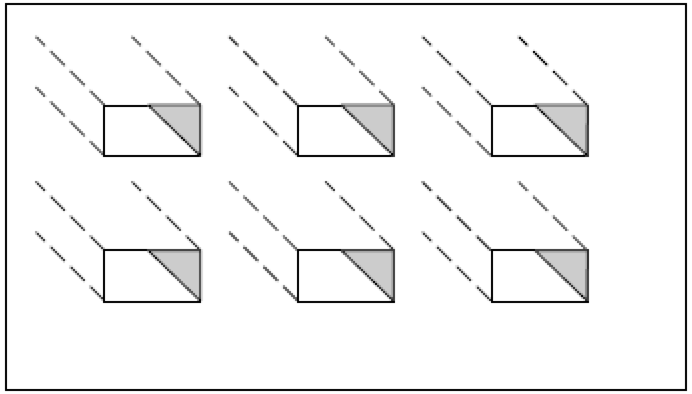
2. Types of antenna

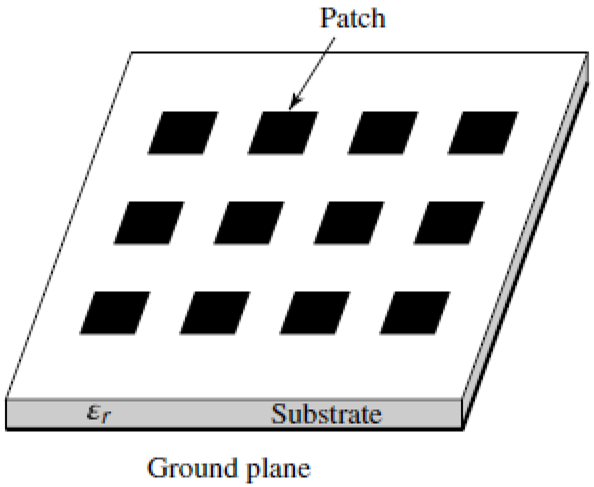
2.4 Array Antennas

- applications require radiation characteristics that may not be achievable by a single element.
- An aggregate of radiating elements in an electrical and geometrical arrangement (*an array*) will result in the desired radiation characteristics
- radiation from the elements adds up to give a radiation maximum in a particular direction or directions, minimum in others.

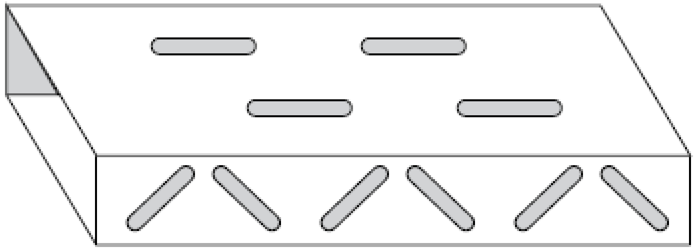


(a) Yagi-Uda array


(b) Aperture array



(c) Microstrip patch array

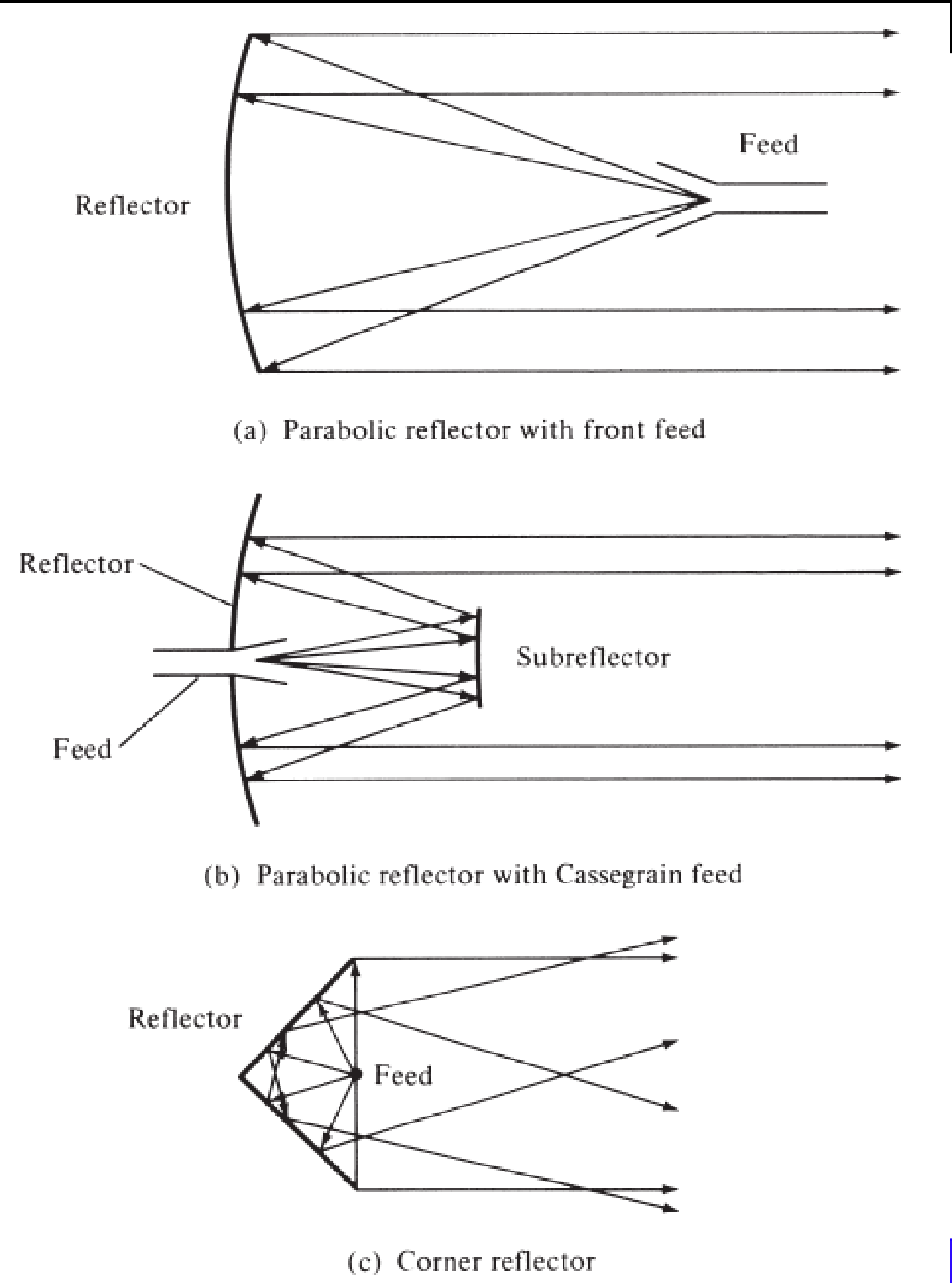

(d) Slotted-waveguide array

2. Types of antenna

2.5 Reflector antenna

To communicate over greater distances (Millions of miles), parabolic reflector.

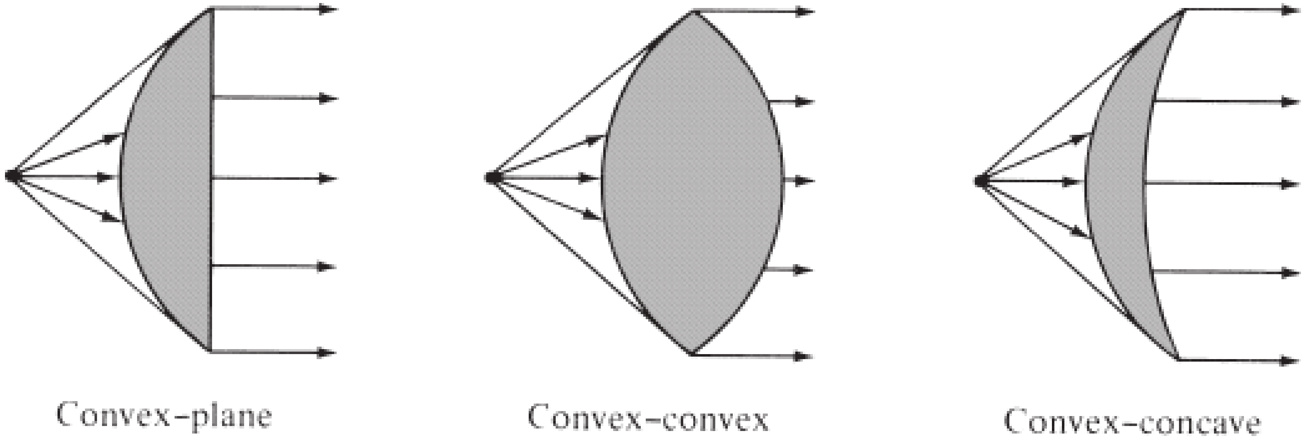
We have 305m diameter parabolic dish too.



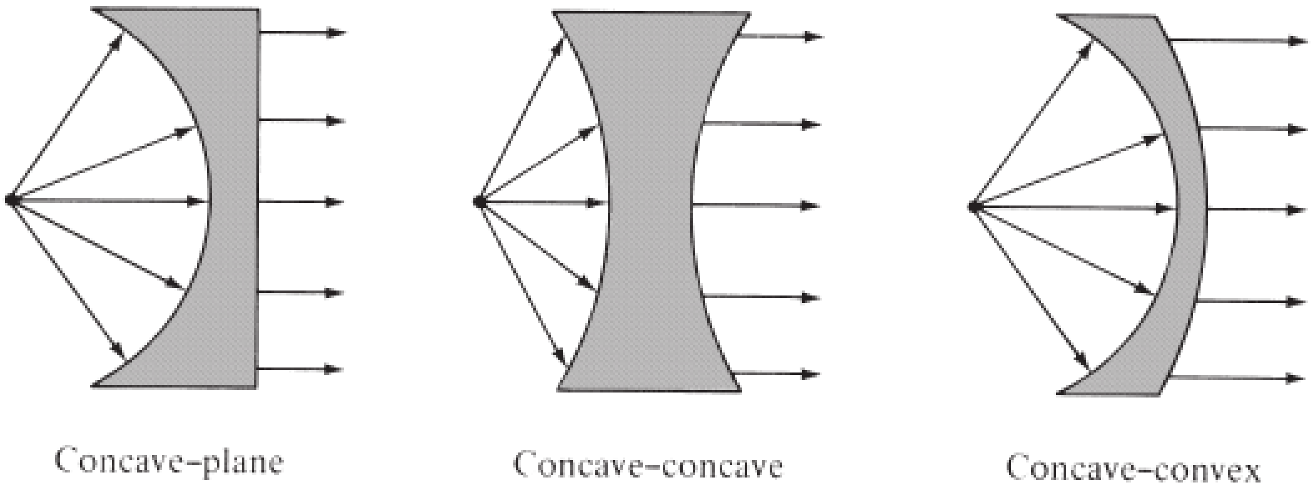
2. Types of antenna

2.6 Lens antenna

To collimate incident divergent energy to prevent it from spreading in undesire directions



(a) Lens antennas with index of refraction $n > 1$



(b) Lens antennas with index of refraction $n < 1$

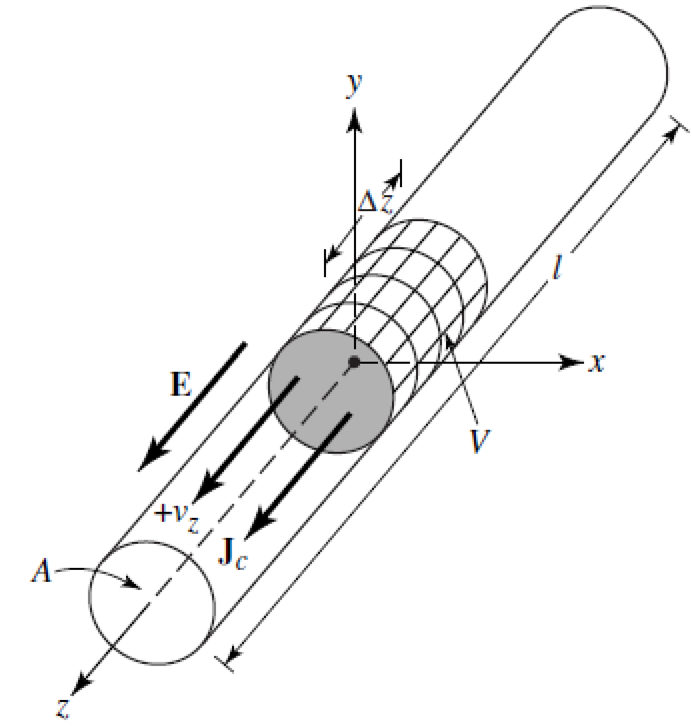
3. Radiation mechanism

- To study how **radiation is accomplished**.
- How the **electromagnetic fields are generated by the source**, **contained and guided within transmission line and antenna**, and **finally detached from antenna to form a free-space wave**.
- This will be studied with
  Single wire, two wire and current distributions

4. Single wire

- Electric **volume charge density** q_v (coulombs /m^3) is distributed uniformly in a circular wire of cross sectional area A and volume V.
- **Total charge** within volume V is **moving in z direction with uniform velocity** $\boldsymbol{v_z}$ (meters/sec)

Current density J_z (amperes /m^2)$= q_v v_z$

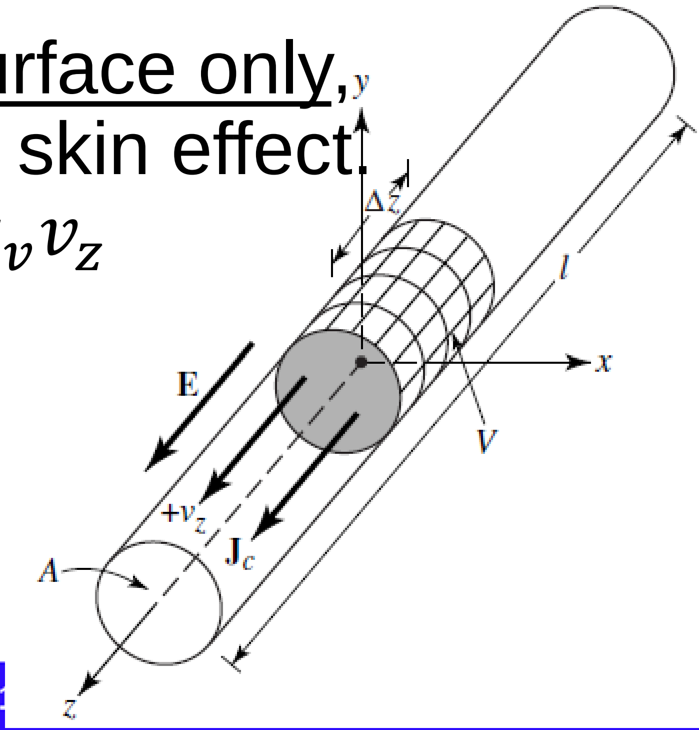


4. Single wire

- Electric volume charge density q_v (coulombs /m^3) is distributed uniformly in a circular wire of cross sectional area A and volume V.
- Total charge within volume V is moving in z direction with uniform velocity v_z (meters/sec)

  Current density J_z (amperes /m^2)$= q_v v_z$

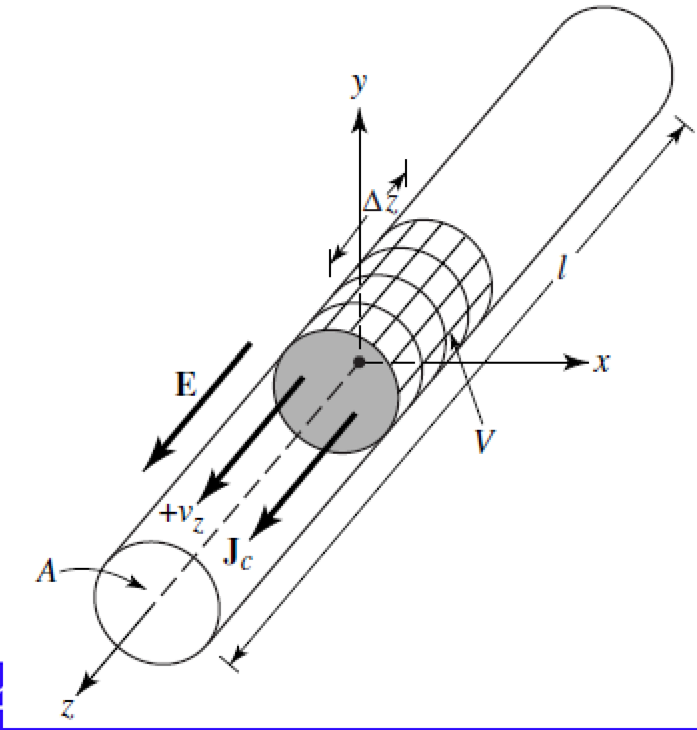
- <u>Ideal electric conductor has charges traveling along surface only</u>, with **surface charge density** q_s (coulombs/m^2) due to skin effect. Current density on surface of wire: J_s (amperes/m) $= q_v v_z$
- <u>**If thin wire (ideally zero radius)**</u>, then current in wire: $I_z = q_l v_z$ where charge per unit length is q_l (coulombs /m)



4. Single wire

- Consider **thin wire case** (ideally zero radius), $I_z = q_l v_z$ where charge per unit length is q_l (coulombs /m)
- For time varying current, derivative of current

$$\frac{dI_z}{dt} = q_l \frac{dv_z}{dt} = q_l a_z$$ with a_z being acceleration.



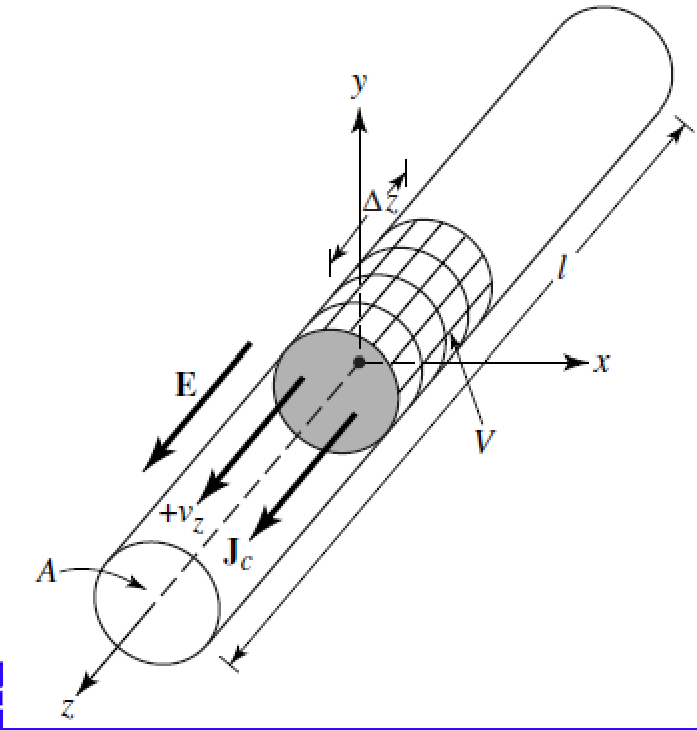
4. Single wire

- Consider **thin wire case** (ideally zero radius), $I_z = q_l v_z$ where charge per unit length is q_l (coulombs /m)
- For time varying current, derivative of current $\frac{dI_z}{dt} = q_l \frac{dv_z}{dt} = q_l a_z$ with a_z being acceleration.
- For a wire of length l, we have

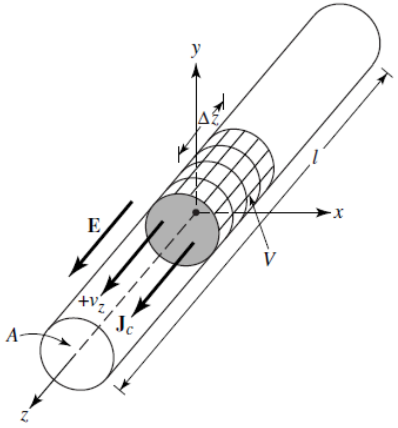
$$\boxed{l\frac{dI_z}{dt} = lq_l \frac{dv_z}{dt} = lq_l a_z}$$

This is **basic relation between current and charge**, **fundamental relation of electromagnetic radiation**.

- To produce radiation,
there must be a time varying current
or acceleration(or deceleration) of charge.



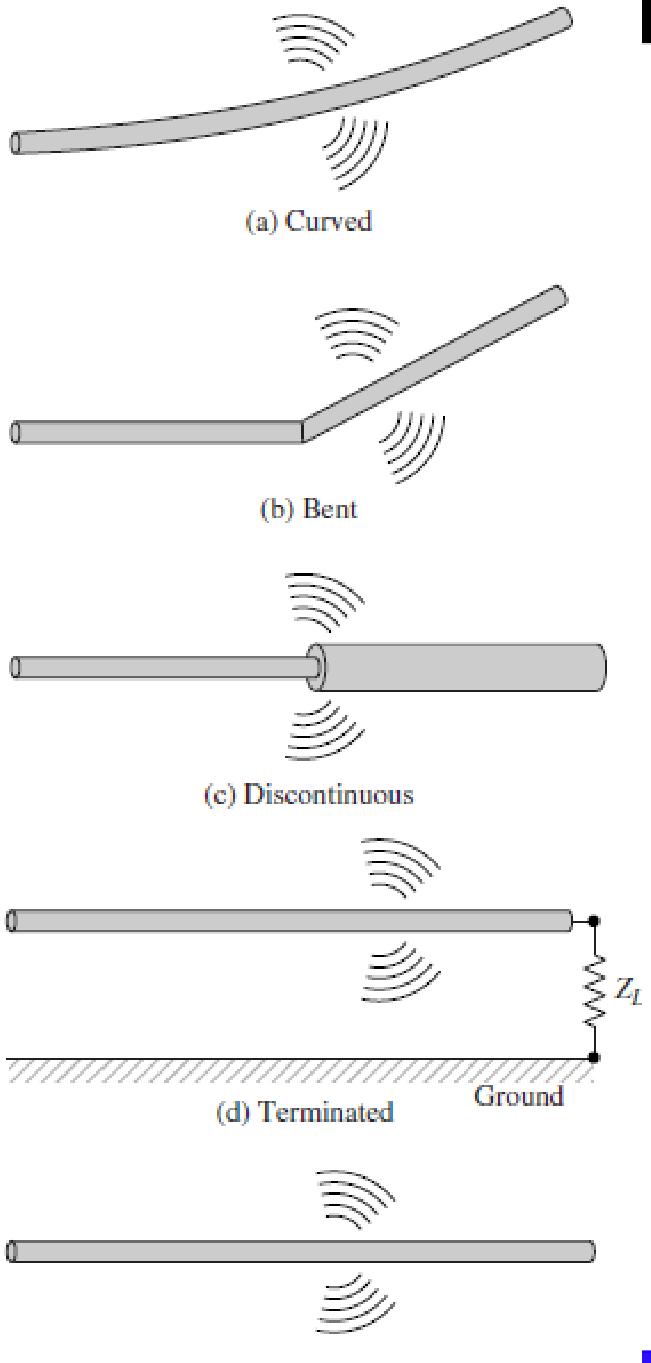
4. Single wire



- For a thin wire of length l, we have

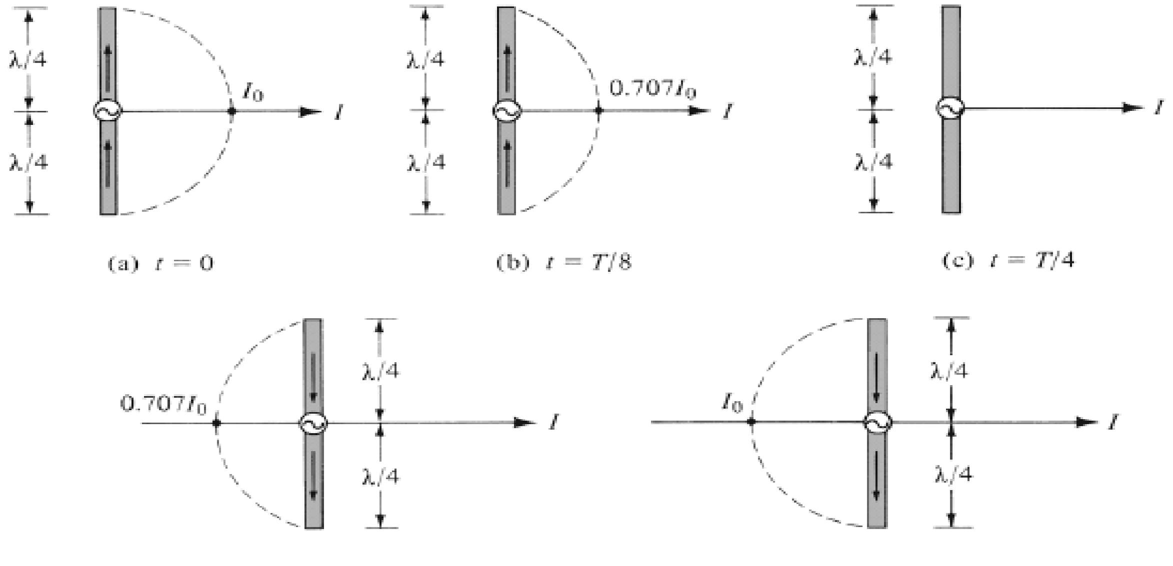
$$l\frac{dI_z}{dt} = lq_l\frac{dv_z}{dt} = lq_l a_z$$

- **For charge acceleration or deceleration**, wire must be **curved** or **bent** or **discontinuous** or **terminated**.

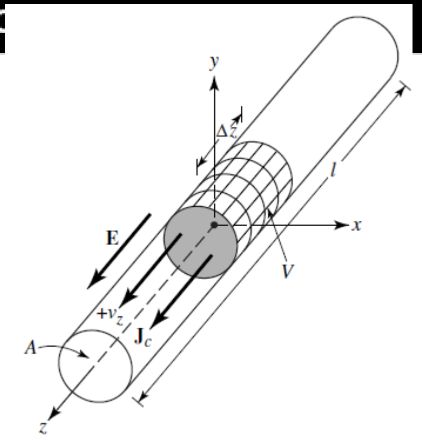


(a) Curved
(b) Bent
(c) Discontinuous
(d) Terminated
(e) Truncated

- Also, **with time harmonic motion of charge**, ***Periodic charge acceleration*** *(or deceleration) is accomplished.*



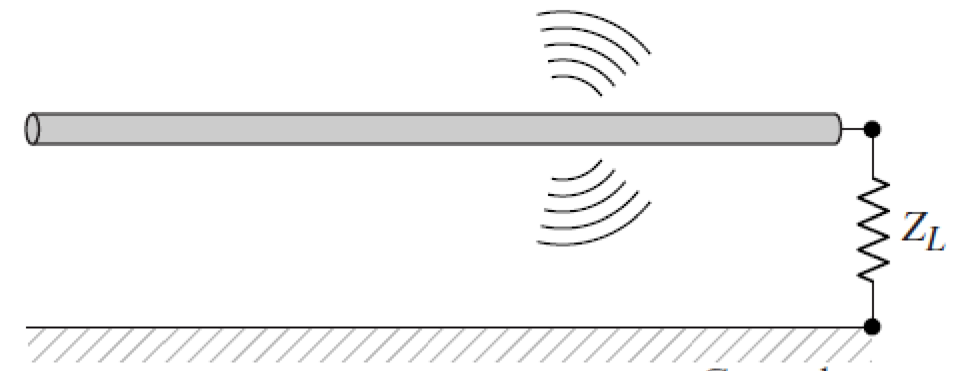
(a) $t = 0$
(b) $t = T/8$
(c) $t = T/4$
(d) $t = 3T/8$
(e) $t = T/2$



4. Single wire

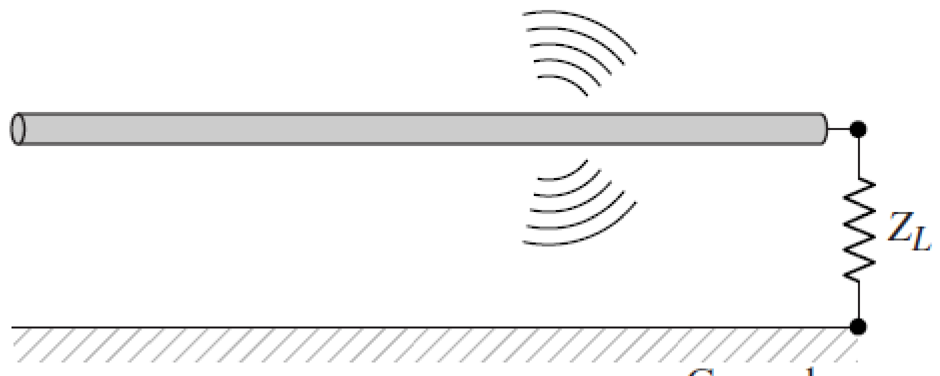
- For a thin wire of length l, we have
  $$l\frac{dI_z}{dt} = lq_l\frac{dv_z}{dt} = lq_l a_z$$
- If **charge is not moving**, **no current, no radiation**.
- If **charge is moving with uniform velocity**:
  a) there is **no radiation** if wire is straight and infinite in extent.
  b) there is **radiation** if wire is curved, bent, discontinuous, terminated or truncated.
- **If charge is oscillating** (in time motion), it radiates even if wire is straight.

4. Single wire



(d) Terminated

- **Radiation mechanism with pulse source** attached to open ended conducting wire, with one end connected to ground through discrete load.
- Acceleration from source (pulse) and deceleration (negative acceleration) from load end due to reflection **results in radiated fields**.



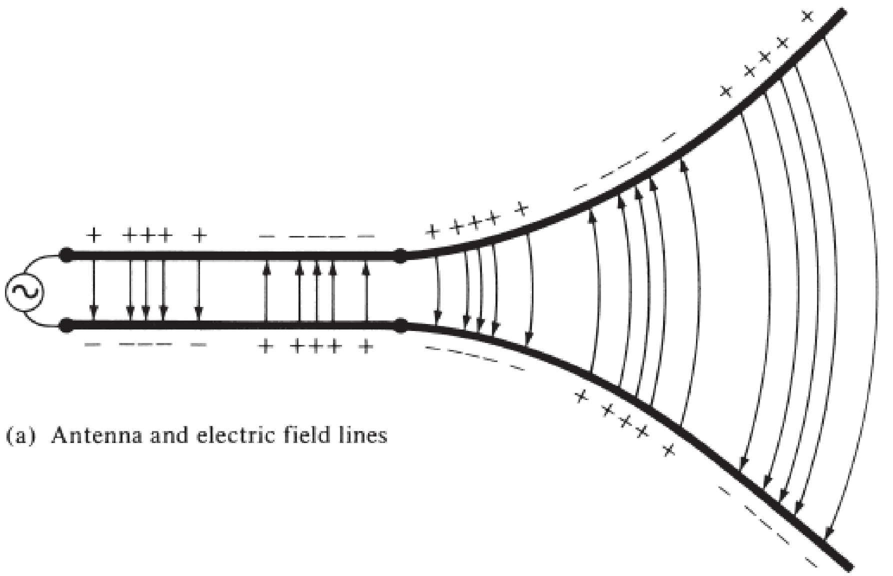
(d) Terminated

4. Single wire

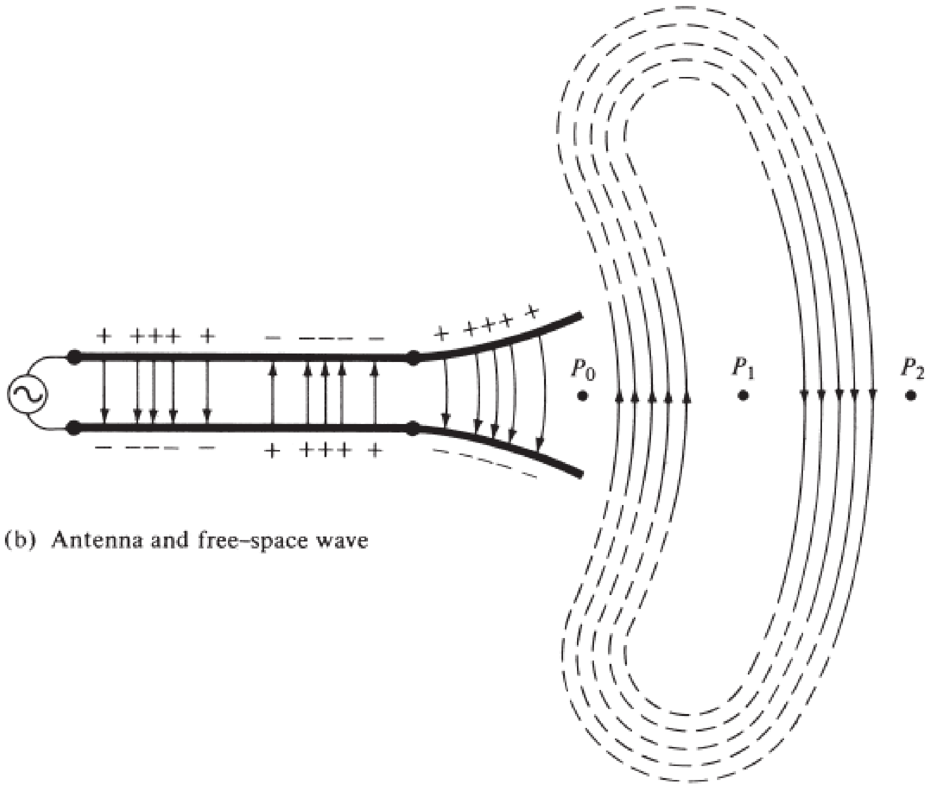
- Radiation mechanism with pulse source attached to open ended conducting wire, with one end connected to ground through discrete load.
- Acceleration from source (pulse) and deceleration (negative acceleration) from load end due to reflection results in radiated fields.
- **Short pulses (compact duration)** generate **broad frequency spectrum of radiation** (more frequencies simultaneously are generated)
- **Continuous Time harmonic oscillating charge** produces radiation of **single frequency (that of source)**
- Note: deceleration is due to build up of charge concentration at ends of wire (impedance discontinuities).

5. Two wires

- A voltage source connected to a two conductor transmission line, which is connected to an antenna.
- Applying **voltage** creates **Electric field intensity** between two conductors – **electric lines of force** which are tangent to electric field at each point – Strength of the force is proportional to electric field intensity.
- **electric lines of force** act on **free electrons of conductor** and force them to be displaced. Movement of electrons creates **changing current – creating changing magnetic field intensity** with **magnetic lines of forces** tangent to magnetic field.



(a) Antenna and electric field lines



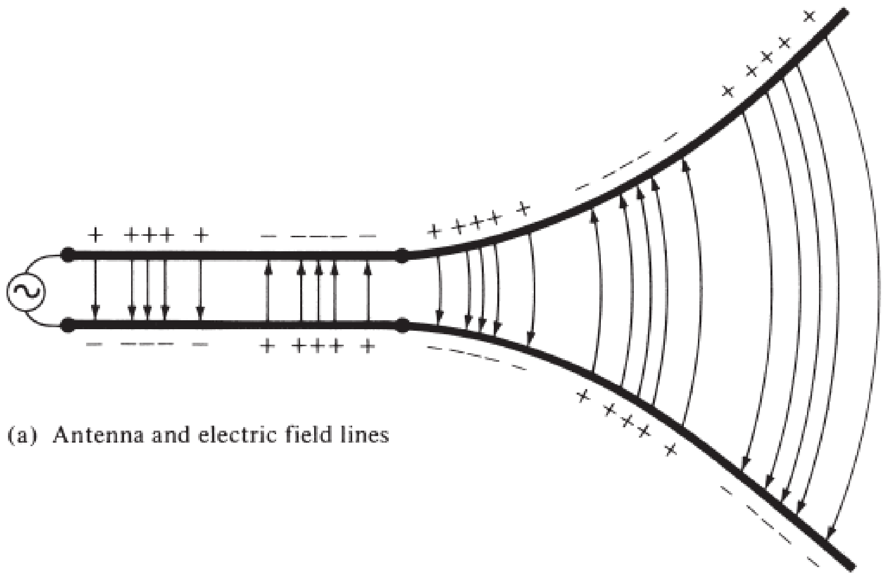
(b) Antenna and free-space wave

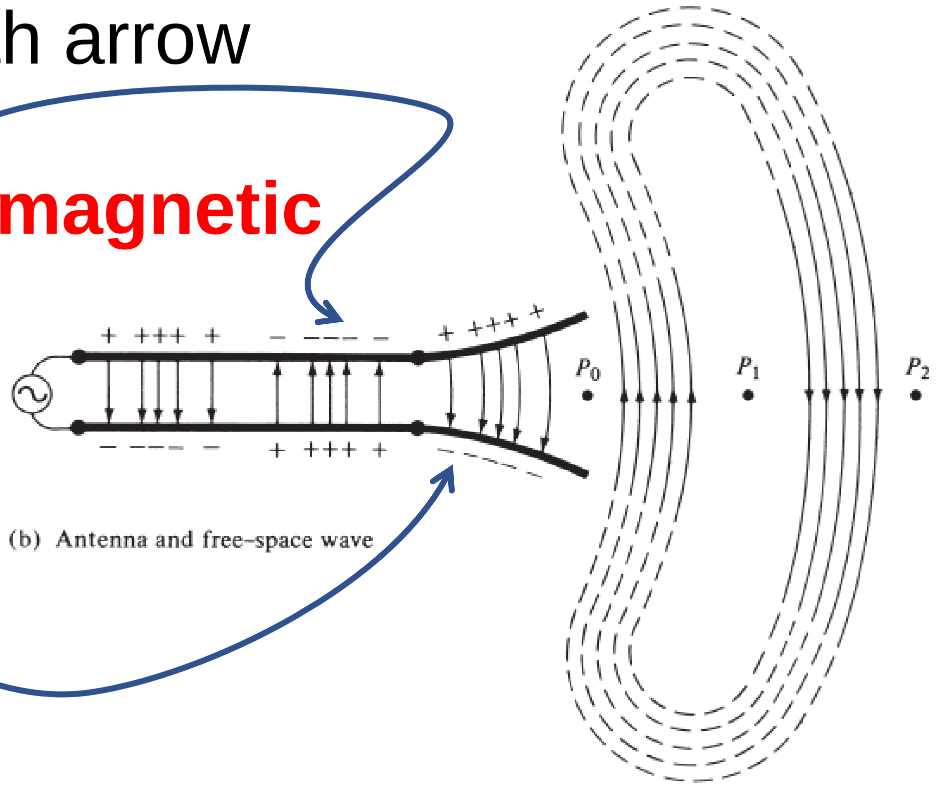
5. Two wires

- a)Electric field lines start on positive charges and end on negative charges.
  b) They can start on a positive charge and end at infinity, or
  c) Start at infinity and end on negative charge,
  d) form closed loops neither starting or ending on any charge.
- Magnetic field lines always form closed loops encircling current carrying conductors as no magnetic charges are present.
- Electric field lines drawn between two conductors help to exhibit distribution of charges.

5. Two wires

- When voltage applied is sinusoidal, electric field lines are periodic and equal to that of applied source.
- **Relative magnitude** is described as the **density (bunching) of lines of forces** with arrow showing the direction (positive or negative).
- Creation of **Time varying electric fields and magnetic fields** forms **electromagnetic waves which travel along transmission line**.
- EM waves then enter antenna and have electric charges and corresponding currents.

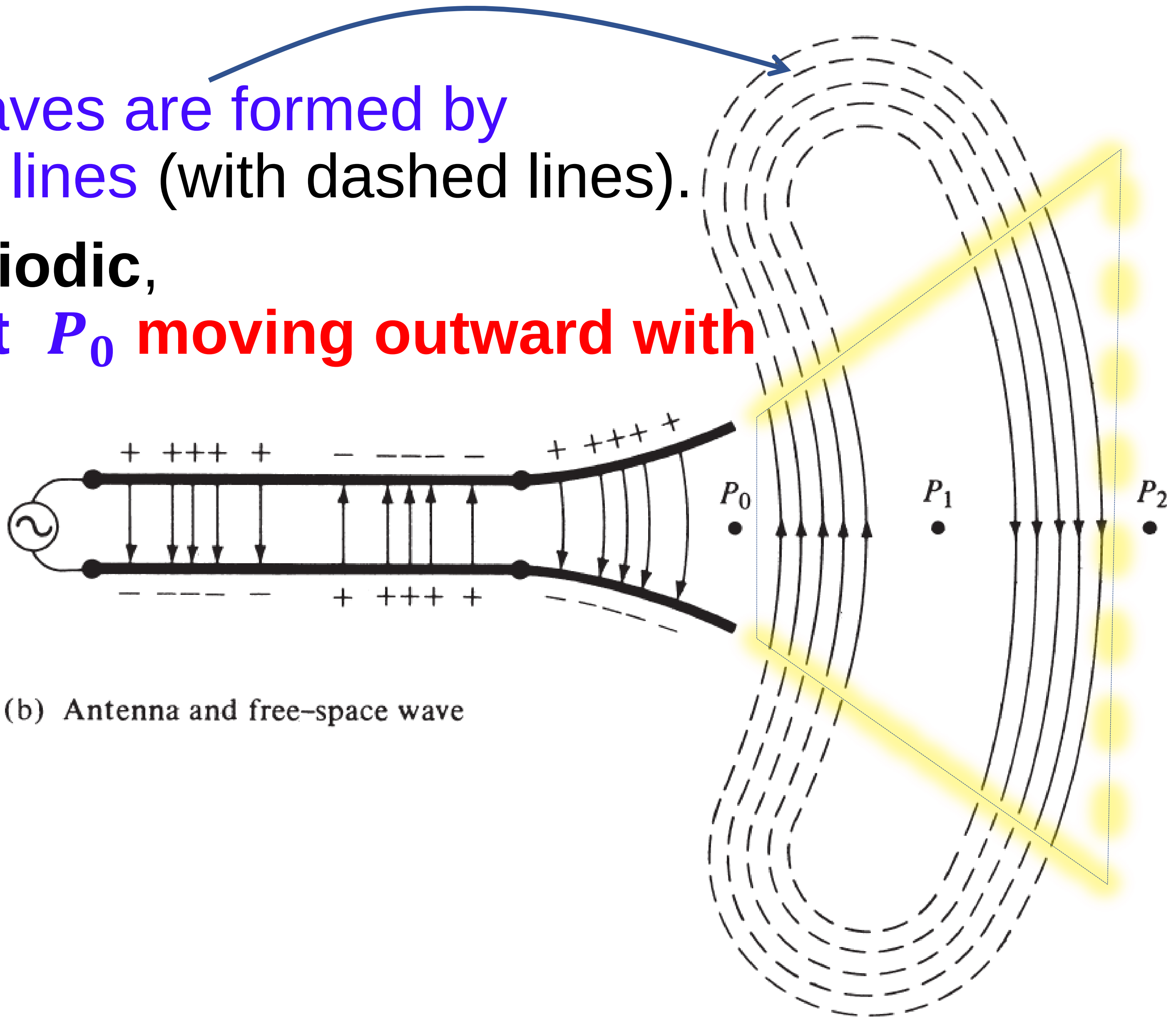

(a) Antenna and electric field lines



(b) Antenna and free-space wave

5. Two wires

- **Without antenna**, free space waves are formed by connecting open ends of electric lines (with dashed lines).
- **Free space waves are also periodic**, **has a constant phase constant P_0 moving outward with speed of light** and **travels a distance of $\lambda/2$ to P_1 in time of one half period**.

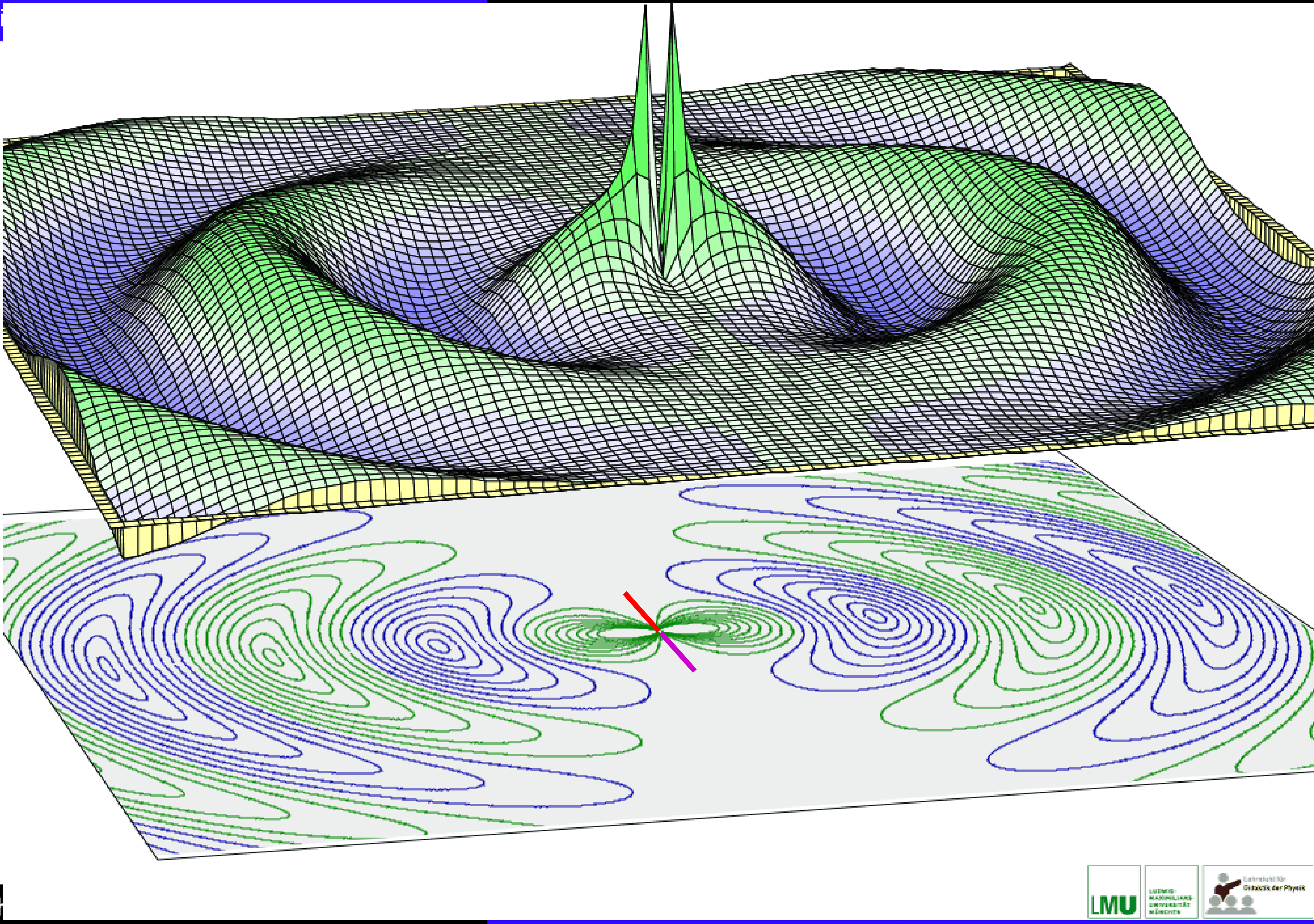


(b) Antenna and free–space wave

5. Two wires

- When we drop a pebble in calm body of water, once disturbance is initiated, the water waves begin to travel outwardly, and continue traveling even after the pebble is removed.
- If **disturbance persists**, new waves are continuously created with a lag in their travel behind others.
- If initial disturbance by source is of short duration, electromagnetic waves are created which travel inside transmission line and then into antenna and are radiated as free space waves (even after electric source is stopped) – Once launched, waves would travel.
- Similarly, **if initial electric disturbance is of continuous nature**, electromagnetic wave exists continuously and follow in their travel behind others.

- 3d wave front is termed as prolate spheroid with $\lambda/2$ interfocal distance



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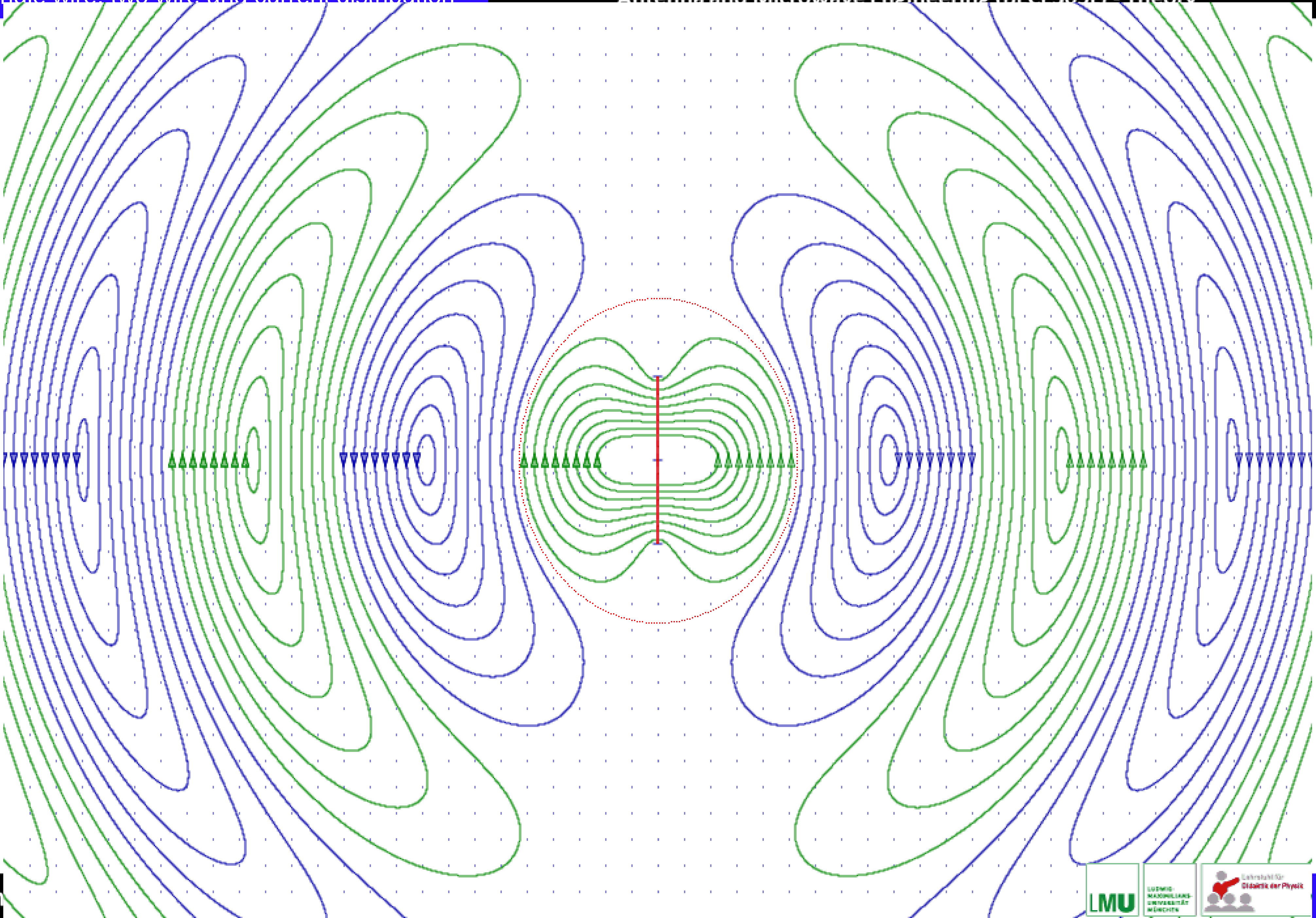
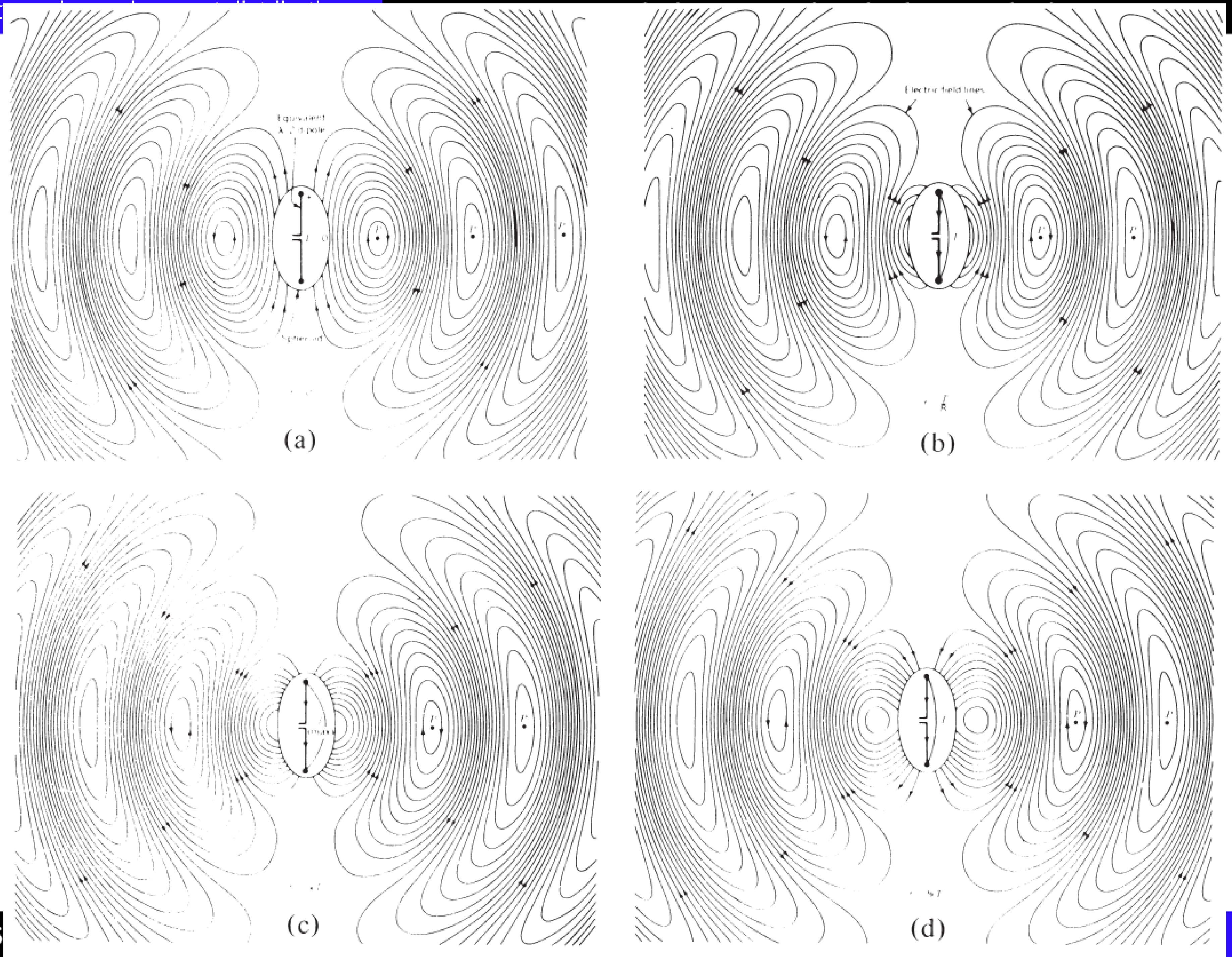


https://www.en.didaktik.physik.uni-muenchen.de/multimedia/dipolstrahlung/animated-gifs-aus-bildern/index.html

Electric field lines of free-space wave for a $\lambda/2$ antenna at $t = 0$, $T/8$, $T/4$, and $3T/8$.



- Electric charges are required to excite the fields.
- Electric charges are not needed to sustain the electric fields and electric fields may exist in their absense.

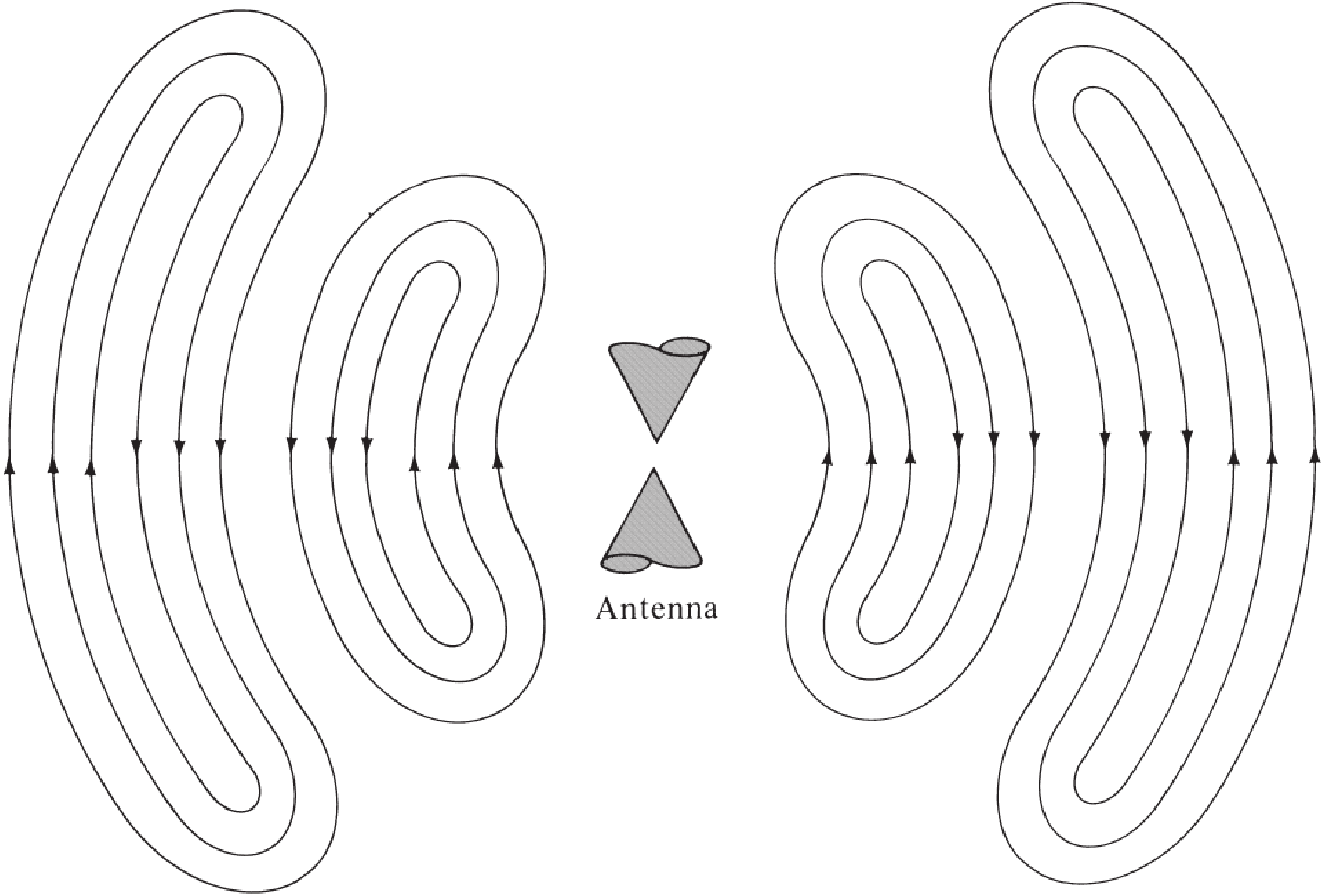


Figure 1.13 Electric field lines of free-space wave for biconical antenna.