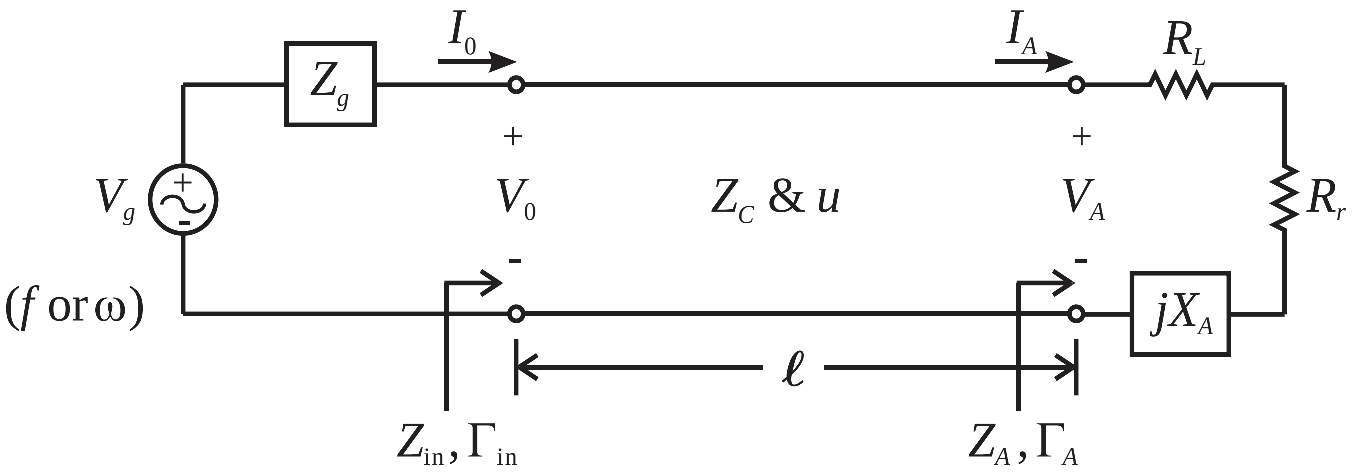
Chapter 1 - Antennas

1.1 Introduction

Definition - That part of a transmitting or receiving system that is designed to radiate or to receive electromagnetic waves. (IEEE Std. 145-1993).

Transmitting antenna equivalent circuit



Where: $Z_c \equiv$ Characteristic impedance of feeding transmission line

$Z_A \equiv$ Load impedance represented by antenna
$= (R_L + R_r) + j X_A$

$R_L \equiv$ Resistance representing conduction (ohmic losses) and/or dielectric losses of antenna

$R_r \equiv$ Radiation resistance, represents power radiated by antenna that is "lost"

$X_A \equiv$ Antenna reactance, represents energy/power stored in EM fields near antenna

- Ideally, we want to radiate all power from source (all goes into R_r).
- Practically, we have losses R_L, impedance mismatches, internal impedance of source, and lossy transmission lines. So, maximum power is delivered when the antenna is complex conjugate matched, i.e., $Z_{\text{in}} = Z_g^*$ (mentioned in Chapter 2).

1.2 Types of Antennas

Wire Antennas:

- Cheap, Reliable

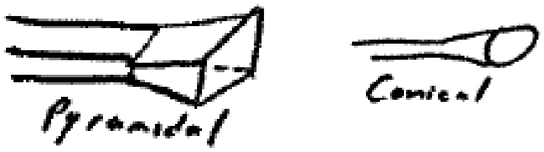
Car (whip/monopole)

TV [Loop (UHF) + "bunny ears"/dipole (VHF))

Helix
(Space communications)

Aperture Antennas:

- Rugged, High Gains

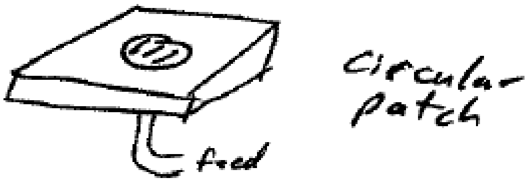


Horns (Dish Feeds)

Slotted Waveguides
(Flush Mounted - military)

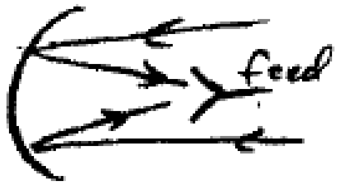
Microstrip Antennas:

- Cheap + easy to manufacture

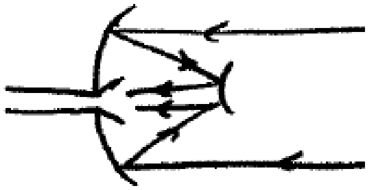


Reflector Antennas

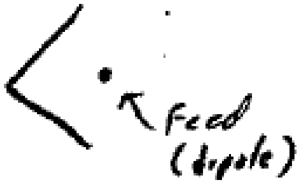
- Very common for space applications
- Fed by another antenna
- Can achieve very large gains



Parabolic Dish



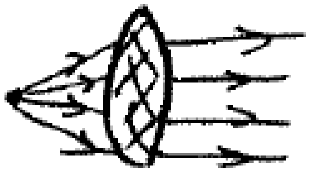
w/ Cassegrain feed



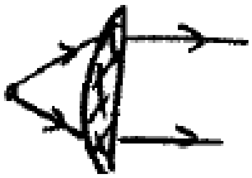
Corner reflector
(side view)

Lens Antennas

- Not very common



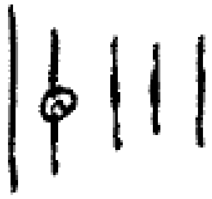
Convex-convex



Convex-plane

Arrays

- Use more than one antenna to achieve design goal
- More flexibility to get desired radiation pattern, beam steering…



Yagi-Uda Array

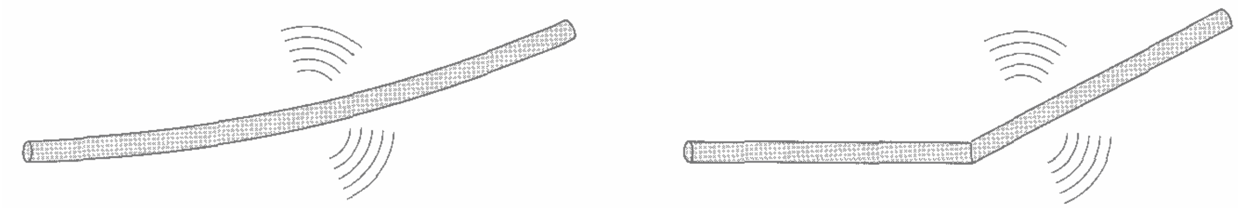
Slotted Waveguide

1.3 Radiation Mechanism

How is radiation accomplished? I.e., How do we take a confined wave/field in a transmission line or waveguide and "detach" it to form a wave propagating in free space?

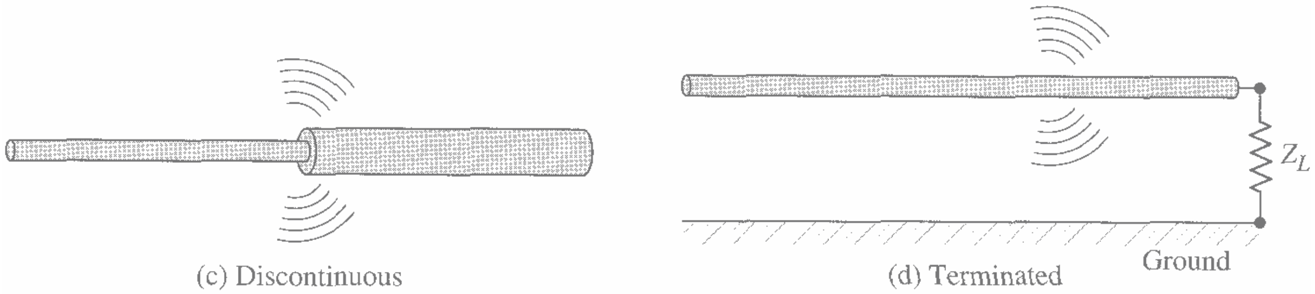
For radiation to occur, we must have a time-varying current or an acceleration (deceleration) of charge.

Examples-



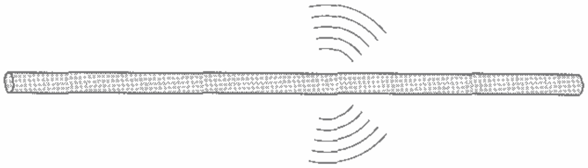
(a) Curved

(b) Bent



(c) Discontinuous

(d) Terminated



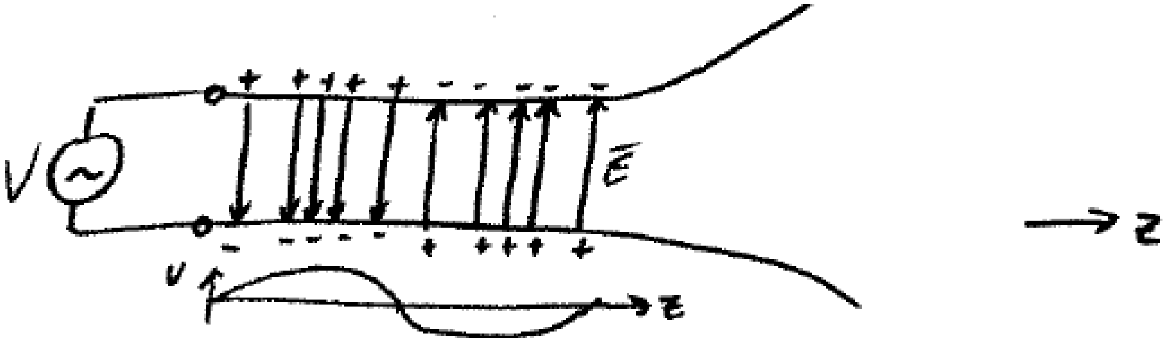
(e) Truncated

Figure 1.10 Wire configurations for radiation [Balanis, 4th edn]

Consequences

1. No charge movement → no current → no radiation
2. Uniform charge velocity (speed + direction)
   a) No radiation of wire is straight + infinitely long
   b) Radiation if above conditions met
3. If charge is oscillating (e.g. sinusoidal excitement), it radiates even if wire is straight.

Now let's consider how waves are radiated, using a two-wire example.



1) A voltage source creates an electric field between the conductors that propagates down the transmission line.

   → Electric field lines act on free electrons so that they start on + charges and end on - charges.

   → Remember electric field lines can:

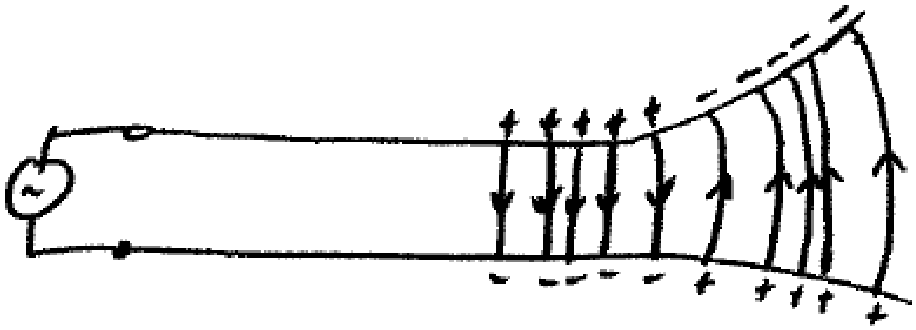
   1) Start on + charges and end on - charges.
   2) Start on + charges and end at infinity.
   3) Start at infinity and end on - charges.
   4) Form closed loops (no charges involved).

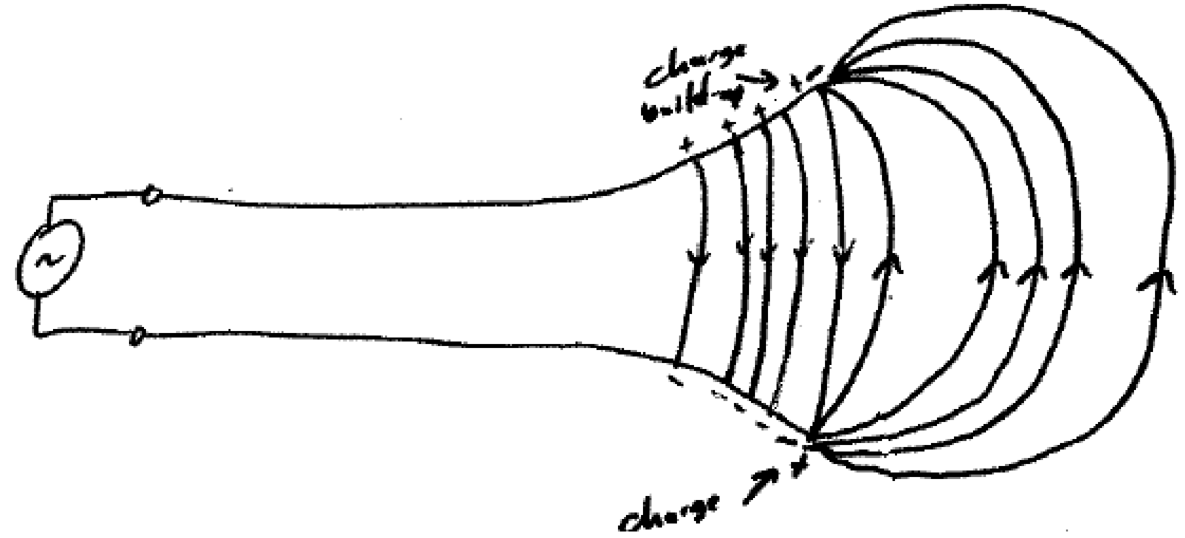
   → The movement of charges induces a magnetic field.

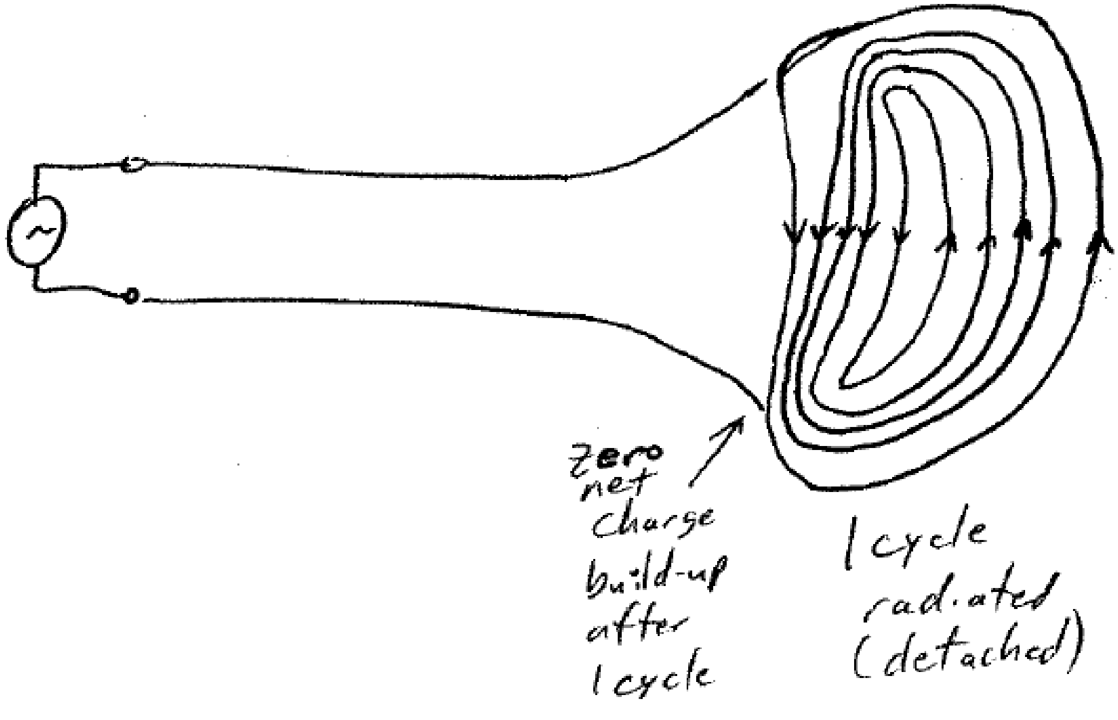
   → Magnetic field lines are always closed loops, no known physical magnetic charges. [Note: non-physical magnetic charges and current are sometimes used for mathematical convenience.]

2) Note that if the voltage source were to turn off, the electric/E and magnetic/H fields already created would continue to exist and be radiated. (Stone in pond analogy)

3) Let the electric field continue to progress down the transmission line and antenna. For clarity, only a single cycle is shown.







1.5 Abbreviated History

Maxwell → Maxwell's Equations - 1873.

→ Radiated waves are electromagnetic.

Hertz → 1886 demonstrated first <u>wireless</u> electromagnetic radiation (used spark gap generator, dipole and loop antennas).

Marconi* → 1901 achieved transatlantic <u>wireless</u> transmission to and from St, John’s, Newfoundland and Cornwall, England.

* Won Nobel Prize in Physics 1909

1900-1930's → Most antenna work focused on wire antennas up to UHF (470- 890 MHz) and related electronics.

→ Yagi-Uda antennas developed 1920’s.

WWII years → MIT Radiation Lab (huge burst of theoretical as well as practical research)

→ Aperture antennas (horns, waveguide slots, reflectors…)

→ Antenna arrays

→ High power RF/microwave sources such as klystron and magnetron developed.

Late 1940's-50's → Frequency independent antennas. E.g., equiangular spiral, log-periodic dipole array (LPDA), etc.

→ Helical antennas.

1960's-present → huge impact of computers making numerical methods practical (e.g. MoM, GTD, FEM, FDTD…)

1.5.2 Methods of Analysis

Integral Equations / Method of Moments (MoM)

→ Takes EM integrals and breaks into pieces to form simultaneous linear equations (matrices) and solves numerically).

→ Usually, single frequency solution. Can run at multiple frequencies and use inverse Fourier transform to get time-domain results.

Example- MoM is used by NEC program to solve for current (and charge distributions). Once these are known, **E**, **H**… can be calculated.

→ Best for wire antennas, small antennas (in terms of wavelengths).

Geometrical Theory of Diffraction (GTD)

→ Better suited for larger problems (many wavelengths) or high frequency problems.

→ Extension or application of optics.

Finite-Difference Time-Domain (FDTD)

→ Based on differential form of Maxwell's equations in the time-domain.

→ Extremely flexible for both geometry, materials, and signals.

→ Computationally expensive (memory and speed)

Finite Elements Method (FEM)

→ Single frequency solution. Can run at multiple frequencies and use inverse Fourier transform to get time-domain results.

→ Works best on bounded problems.

→ Starts with differential equations.