# LE200 Electromagnetic Theory
## Class Agreements

- Homework:
  - group of no more than 3 persons.
  - turn in by due dates before class begins.
  - graded by your efforts and <u>your presentations</u>.
- Exams : Midterm (one 2-page handwritten A4 note allowed), Midterm #2 (open), Final (two A4 notes allowed)
- Class notes : *mostly* follow the textbook; please print them yourselves; ideally go through them before each class.
- Check updates on class webpage regularly.

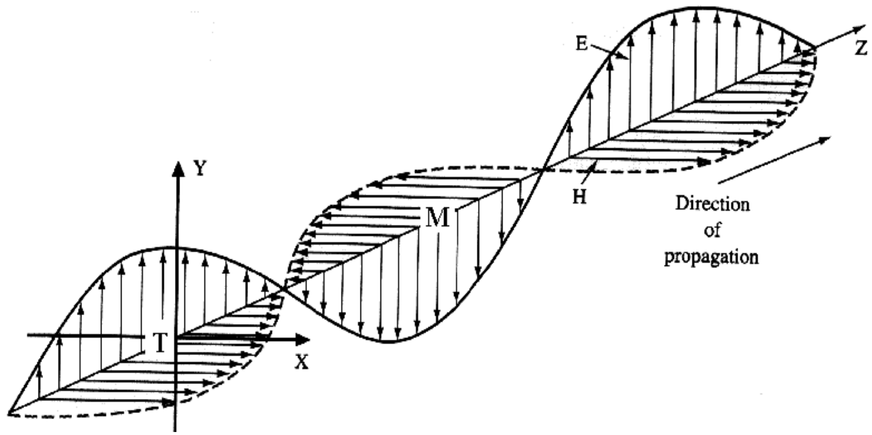
# Important Things to learn

- Vector Analysis.
- Electrostatics or “static” electric field.
- Steady Current, namely DC.
- Magnetostatics or “static” magnetic field.
- Electromagnetics or Time-varying field.
  - Maxwell’s equations
  - Electromagnetic (EM) waves

# Electromagnetics (EM)

- Electromagnetics = Electrics + Magnetics
- Electromagnetic (EM) waves occur when there exist both electric and magnetic fields simultaneously and they are coupled to each other.
- How is it important ?

➢ When considering radiation, we cannot radiate either only electric field or only magnetic field, thus both fields exist and are related as shown in the figure below.



# Technological Applications

- Wireless Communications
  - Cordless telephone
  - Mobile (Cellular) telephone
  - Mobile data transfer (e.g., wireless LAN)
  - Satellite Communication (e.g., broadcast, long-distance telephone)
  - Global Navigation/Positioning System (e.g., GPS)

# Technological Applications (con’d)

- Special Wireless Services
  - Radar Systems (e.g., airborne, surveillance)
  - Radio Astronomy
  - Electromagnetic Sensors
- “Wired” Technology
  - Cable Communications
  - Digital and Analog Electronics
  - Power Generation and Supply
  - Electro-mechanical Devices and Machinery

# Technological Applications (con’d)

- Photonics and Optics
  - Optical communication
  - Optical sensor
- “Household” Appliance
  - Remote Control
  - Speaker
  - Camera, Video Camera
  - Magnetic-type memory (e.g., hard drive)
  - Display monitor
  - Microwave Oven

# Communication Model

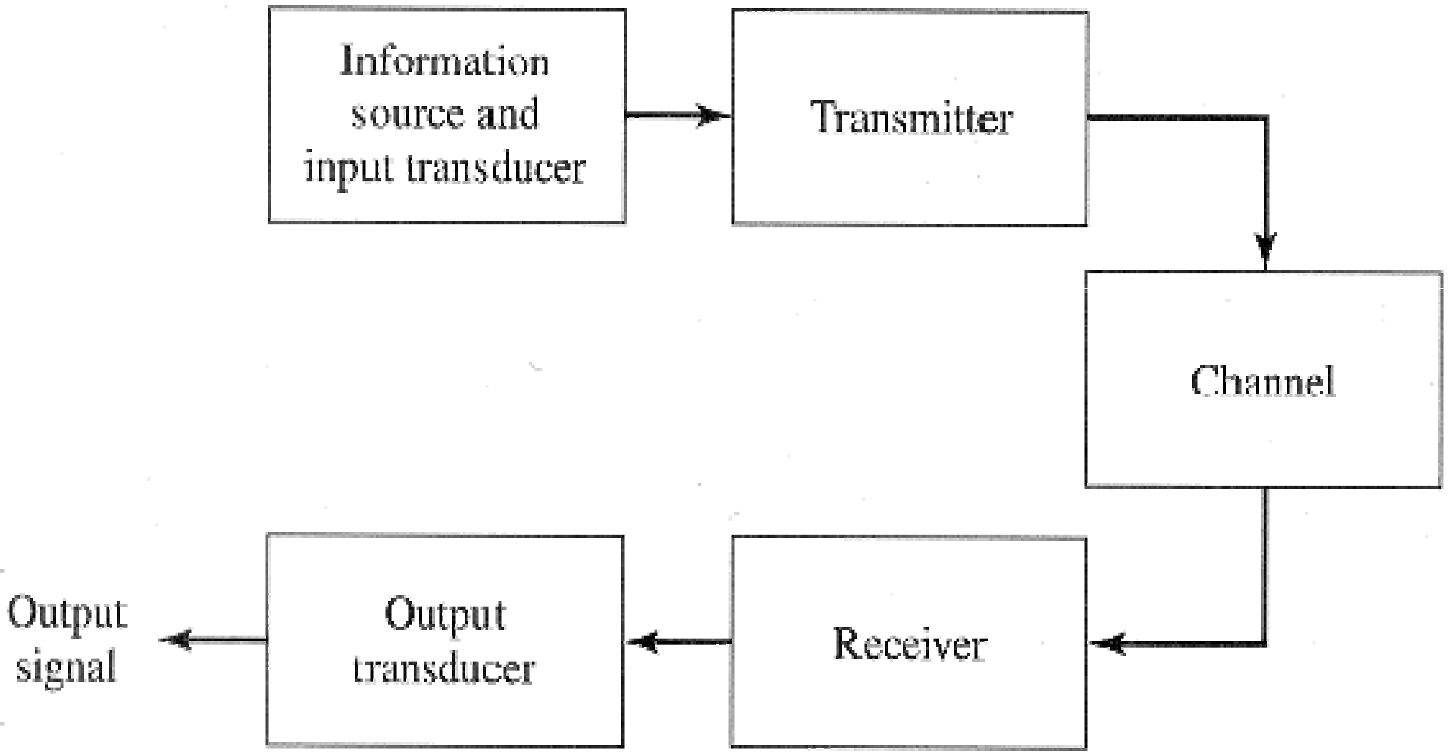
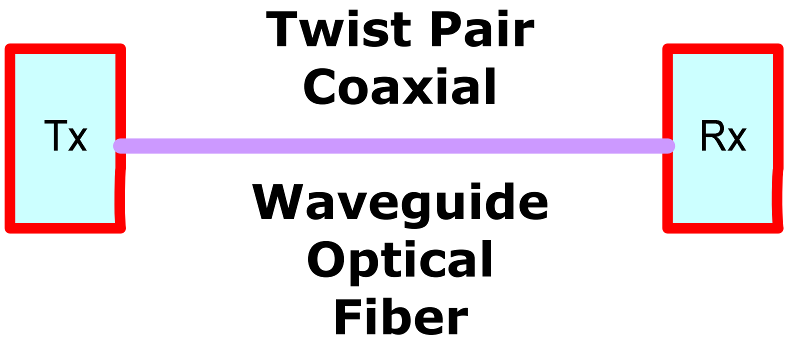



**Figure 1.1** Functional block diagram of a communication system.

# Communication Systems by medium

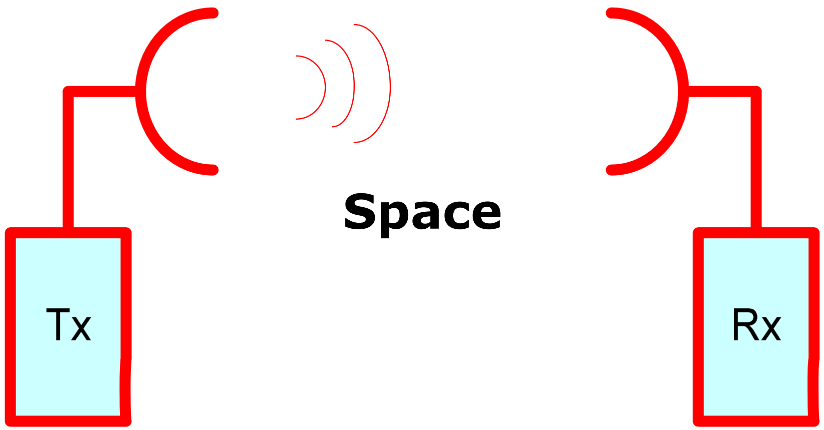
## 1. Cable Communication (Wire, or Guided)




Communication network and Transmission Lines

Optical Communication

## 2. Radio Communication (Wireless)



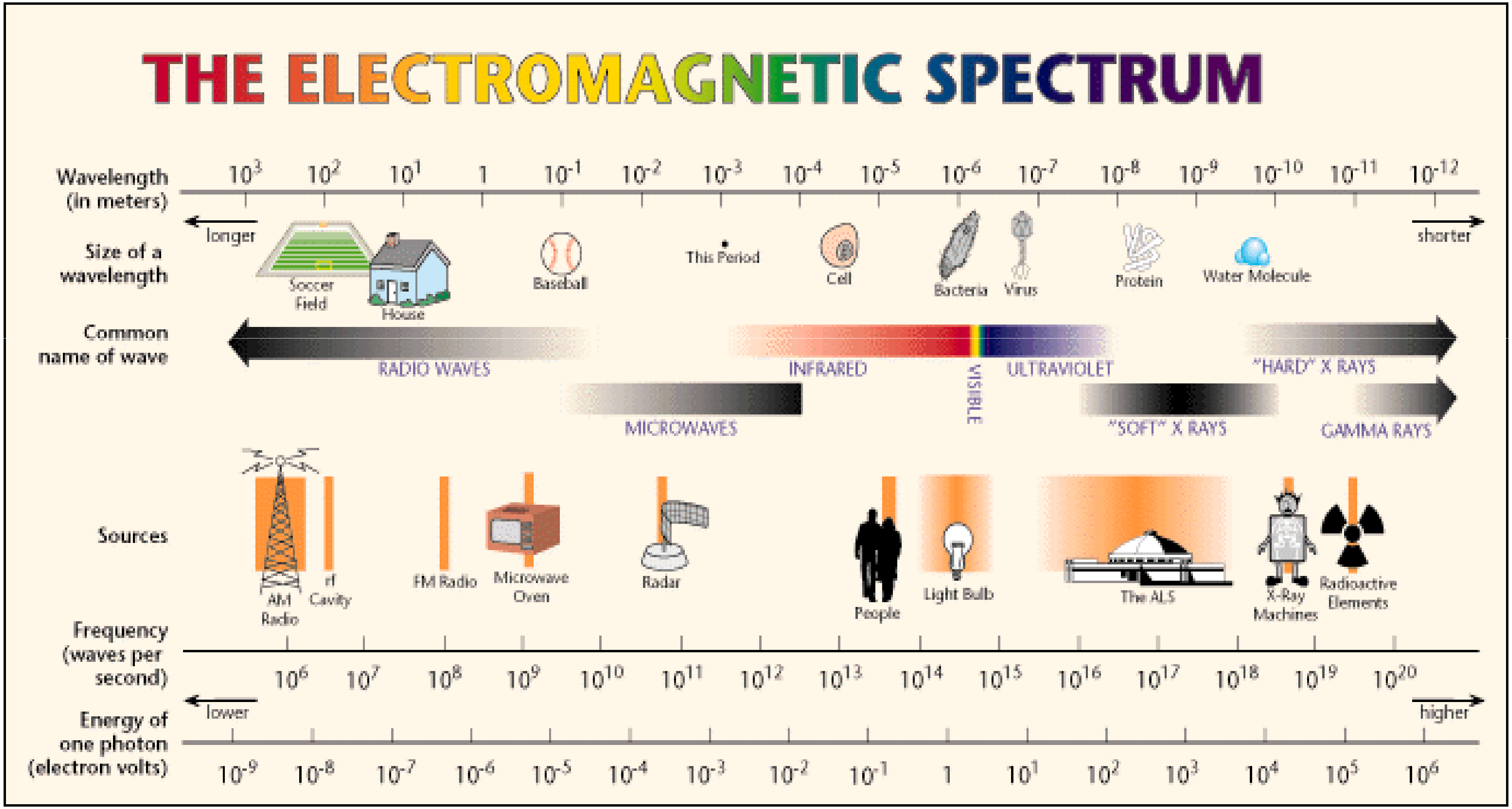

Radio Engineering

Mobile Telecommunication

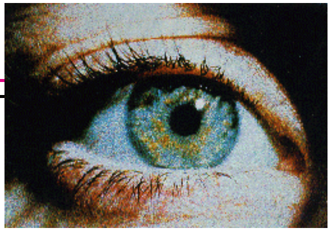
Antenna Engineering

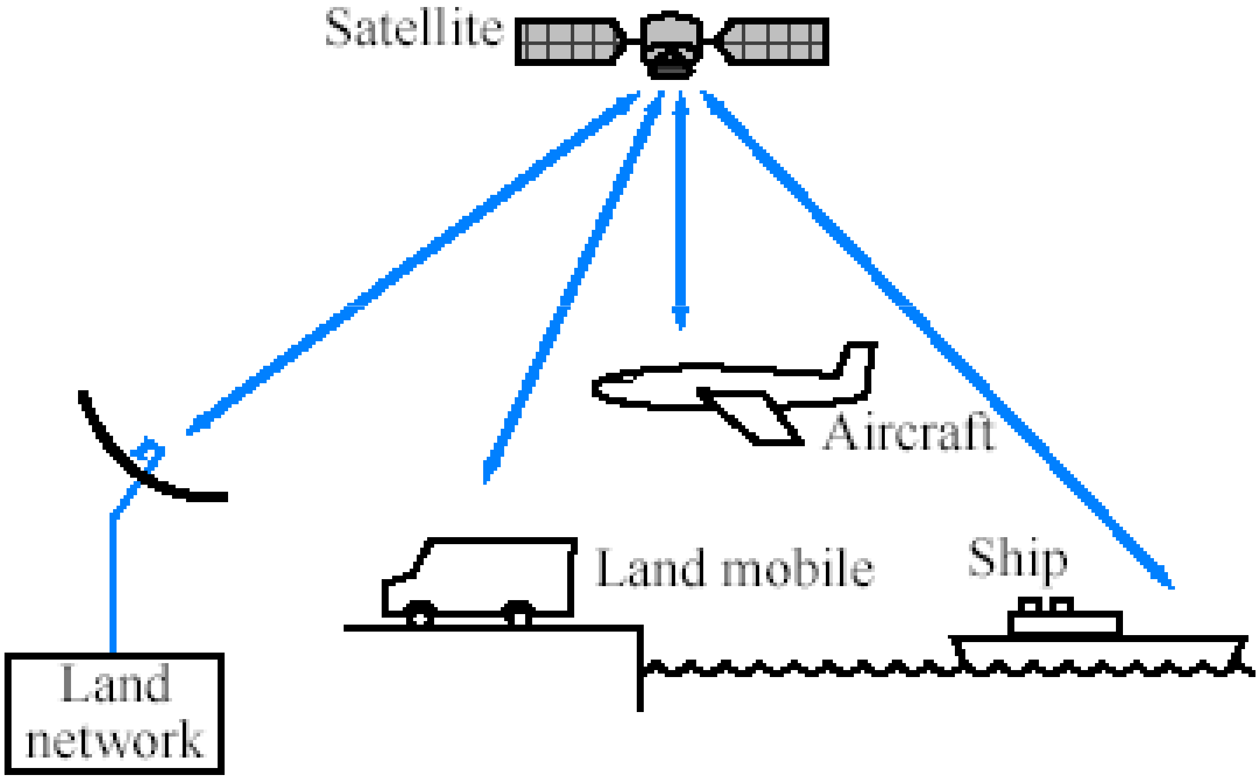
Radio Wave Propagation

# Electromagnetics

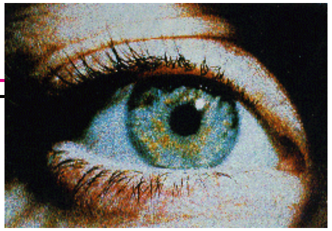


# Satellite Communication





# Satellite Communication System



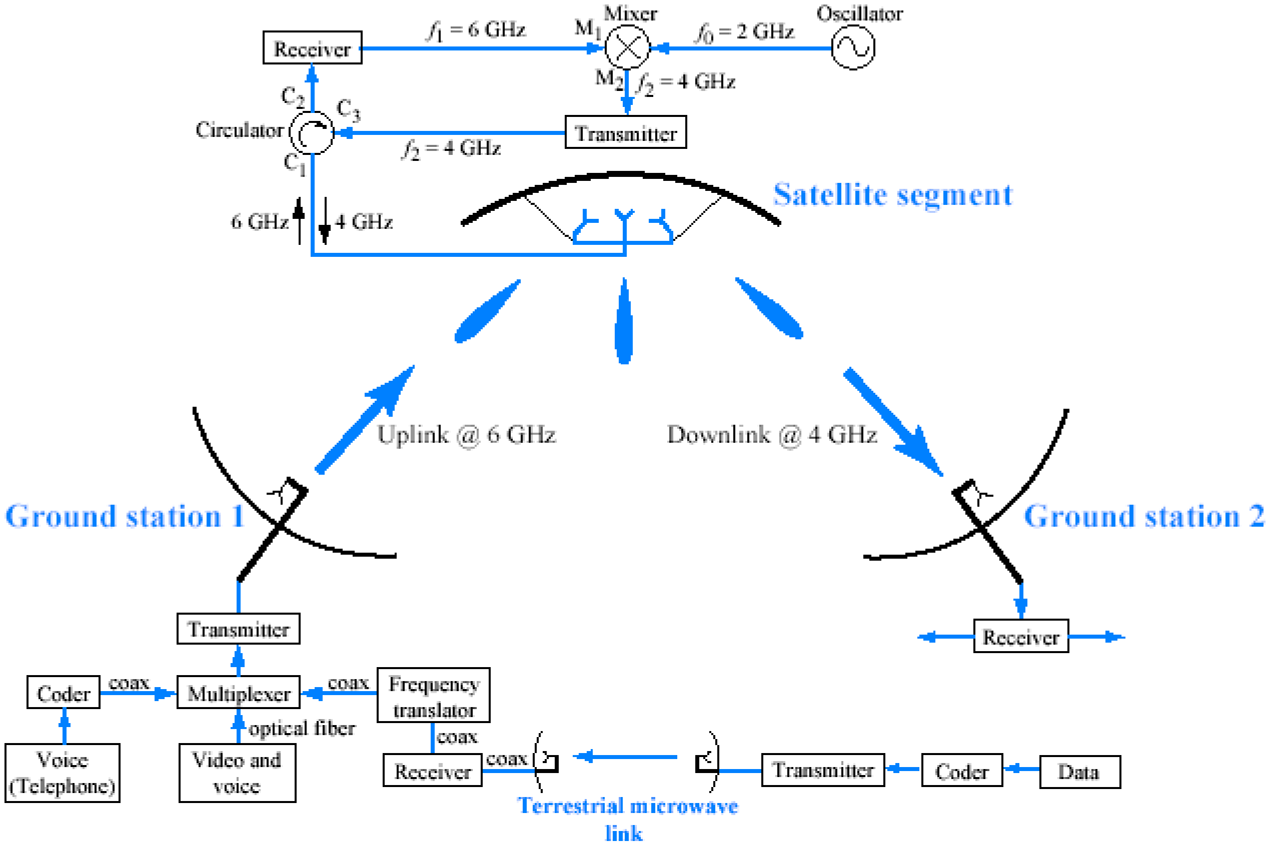



Figure 1.1

# Radio frequency spectrum

The band designations shown below are made by the International Radio Consultative Committee (Commite' Consultatif Internanational de Radiodiffusion - CCIR)

| Band No. | Freq. Range | Designation | Application |
|---|---|---|---|
| 2 | 30Hz – 300Hz | Extremely Low Freq. (ELF) | Ac power |
| 3 | 0.3kHz – 3kHz | Voice Freq. (VF) | Voice |
| 4 | 3kHz – 30kHz | Very Low Freq. (VLF) | Submarine |
| 5 | 30kHz – 300kHz | Low Freq. (LF) | Marine navigation |
| 6 | 0.3MHz – 3MHz | Medium Frequency (MF) | AM radio broadcast |
| 7 | 3MHz – 30MHz | High Frequency(HF) | SW broadcast, CB |
| 8 | 30MHz – 300MHz | Very High Frequency (VHF) | FM, TV broadcast |
| 9 | 300MHz – 3GHz | Ultrahigh Frequency (UHF) | TV,cellphone,radar,satelite |
| 10 | 3GHz – 30GHz | Superhigh Frequrncy (SHF) | Microwave links,satellite |
| 11 | 30GHz – 300GHz | Extremely High Frequency (EHF) | Sophisticated application |
| 12 | 0.3Tera-3TeraHz | Infrared light | Electromagnetic radiation concerning heat, heat seeking, photo, astronomy |
| 13 | 3THz – 30THz | Infrared light | |
| 14 | 30THZ – 300THz | Infrared light | |
| 15 | 0.3Peta-3PetaHz | Visible light | Optical fiber system |
| 16 | 3PHz – 30PHz | Ultraviolet light | |
| 17 | 30PHz – 300PHz | X-rays | Very little application to communications |
| 18 | 0.3Exa-3ExzaHz | Gamma rays | |
| 19 | 3EHz – 30EHz | Cosmic rays | |

$10^0$ hertz (Hz), $10^3$ kilohertz (kHz), $10^6$ Megahertz (MHz), $10^9$ Giga hertz (GHz), $10^{12}$ Tetrahertz (THz), $10^{15}$ Petahertz (PHz), $10^{18}$ Exahertz (EHz),

In the United States, freq. Assignments for free-space radio propagation are assigned by the Federal Communications Commission (FCC)

The electromagnetic field splits into two independent parts:

$\boxed{\text{Statics}}$

Electrostatics: $(q, \mathbf{E})$ ← Static charge (not a function of time)

Magnetostatics: $(I, \mathbf{H})$ ← Steady current

$\boxed{\text{Time-varying}}$ Electromagnetics: $(\mathbf{E}, \mathbf{H})$ ← Time-varying (accelerated) current

Static Fields --> Electric and magnetic fields not related to each other.

Time-varying Fields --> Electric and magnetic fields related by Maxwell's Equations.

The following areas rely upon static field theory:

- circuit theory
- electronics
- power engineering

Static field

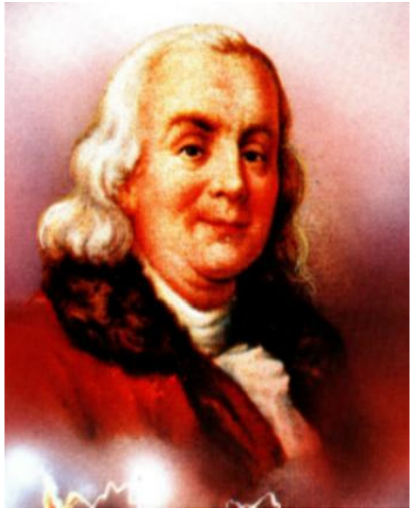
The following areas rely upon Time-Varying field theory:

- antennas
- transmission lines
- microwaves

Time-Varying field

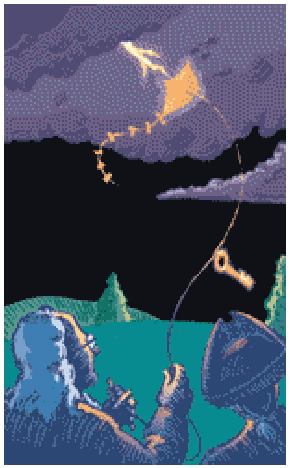
# Introduction
# A Brief History of Electromagnetic Fields and Wave

## <u>Electrics</u>



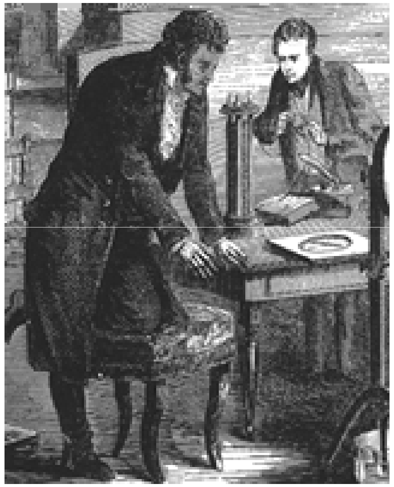
❑ $6^{th}$ century B.C. - Static electricity was discovered in Greece.

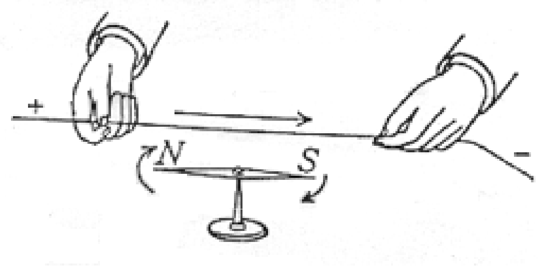
❑ 1752 Benjamin Frankin suspected that electric charges in sky caused lightning and thundering. He used a kite to prove that lightning is really a stream of electrified air, known today as plasma and also invented a lightning rod.



# Magnetics

**1820 : Hans Christian Oersted proved that electric current affects polarity of a compass needle.**





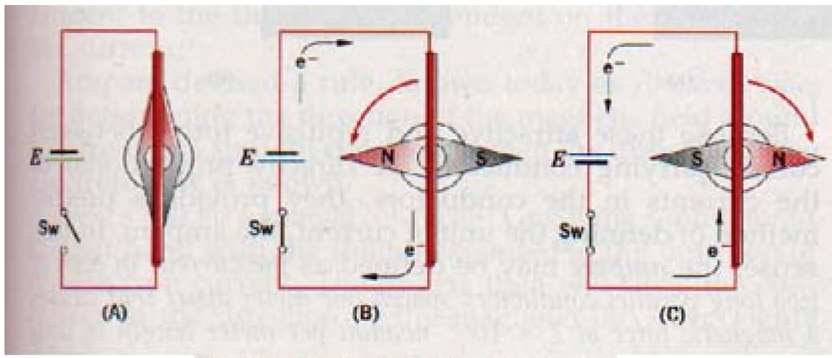
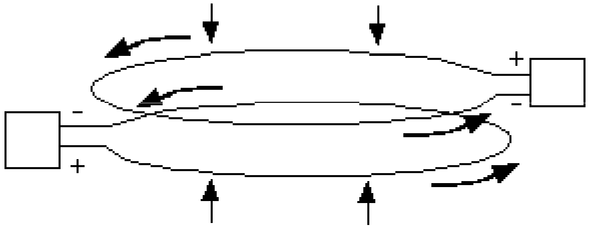




Figure 19-19. The Oersted experiment as viewed from above. In each diagram the compass needle is located below the conductor.

Shortly after Oersted's discovery,

André-Marie Ampére studied the magnetic field due to electric currents flowing through electric conductors.

$I_1 I_2 L_1 L_2 / R^2$




Parallel currents in two loops also attract

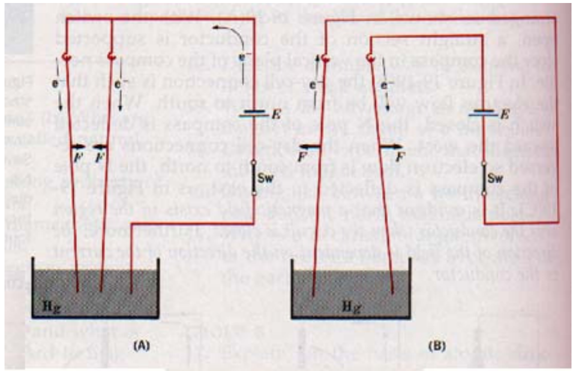
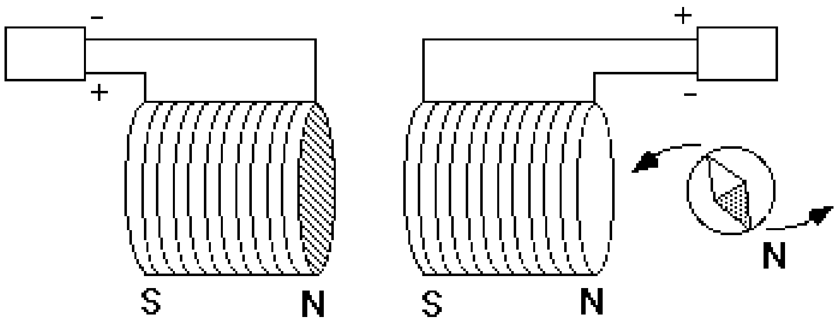



Figure 19-21. Forces between parallel currents (A) in the same direction and (B) in opposite directions.




Two coils of many parallel loops, with currents in the same direction, attract each other and act like magnets

Michael Faraday believed that “if currents create magnetic field, then reciprocally magnetic field should also create electric currents.”

1831 : Faraday discovered the induced current.



**Figure 20-1.** A current is induced in a closed conducting loop when the magnetic flux linked through the circuit is changing.

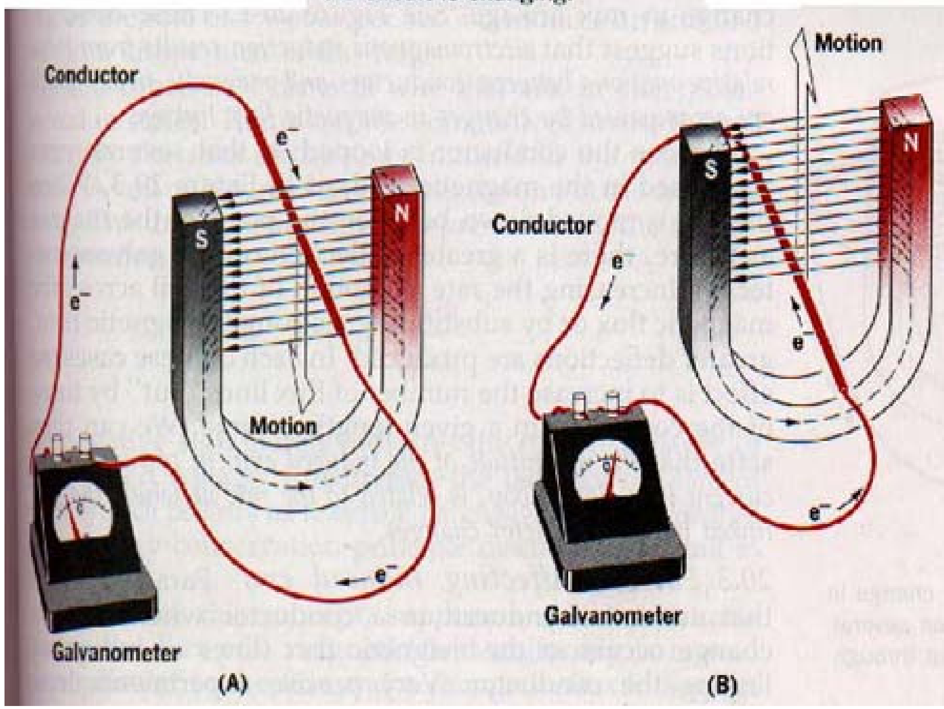


Figure 20-2. An emf is induced in a conductor when there is a change of flux linked by the conductor.

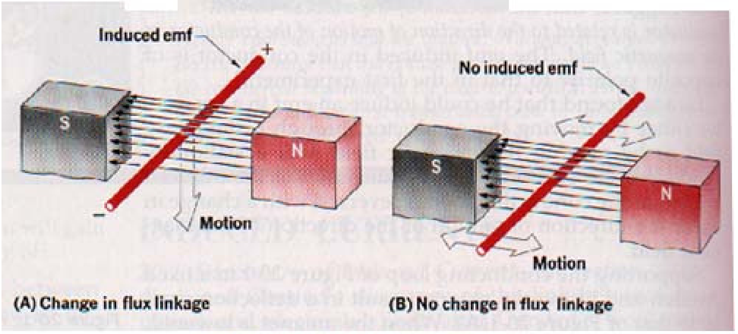
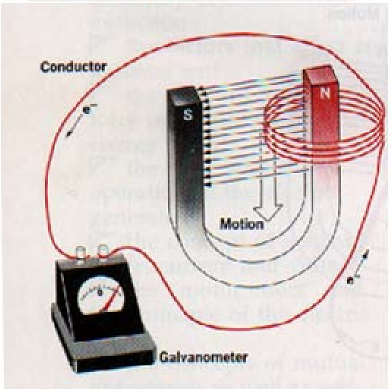



Figure 20-3. A greater change in flux linkage occurs when several turns of a conductor cut through the magnetic flux.



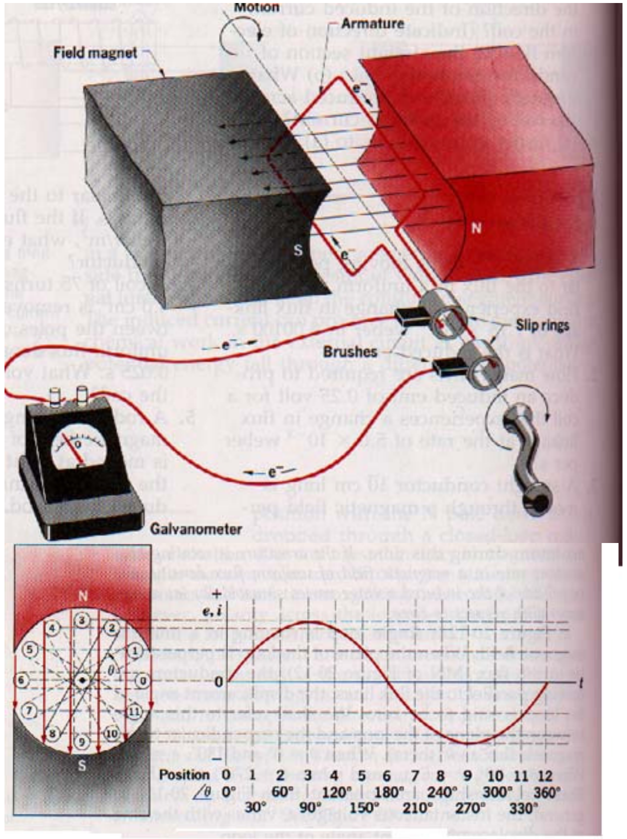




Figure 20-14. A sine curve representing current or voltage generated by a single-loop armature rotating at a constant rate in a uniform magnetic field. Positions 0 through 12 on the graph correspond to positions of the rotating armature in the magnetic field, as shown to the left.

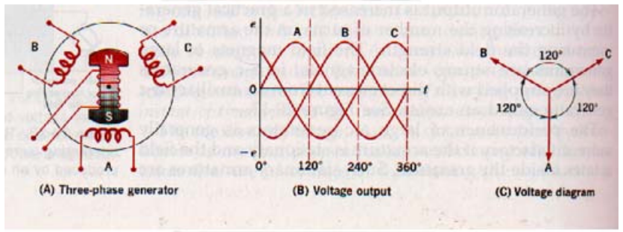
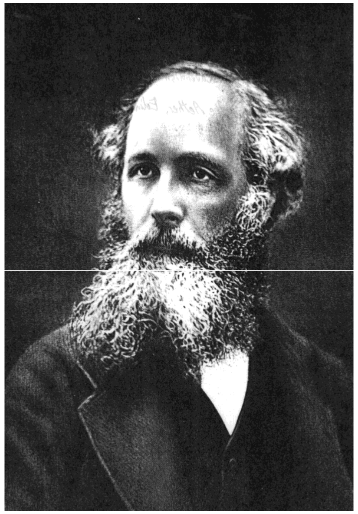
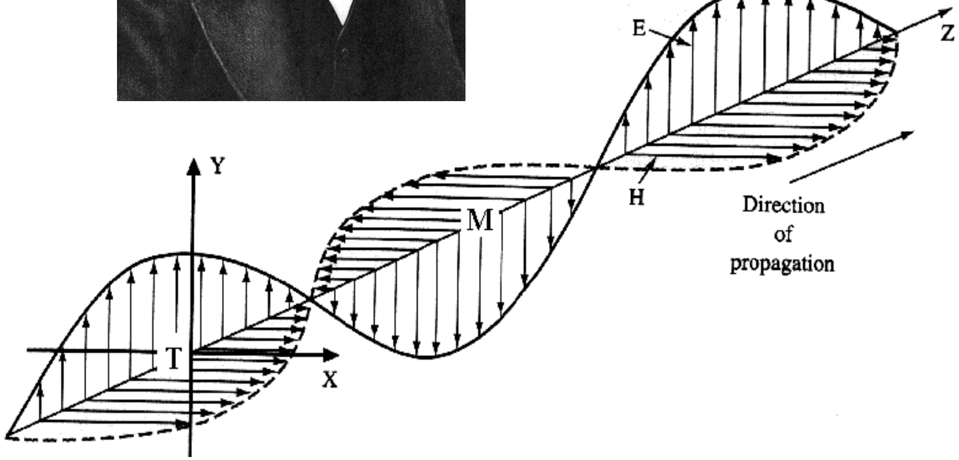


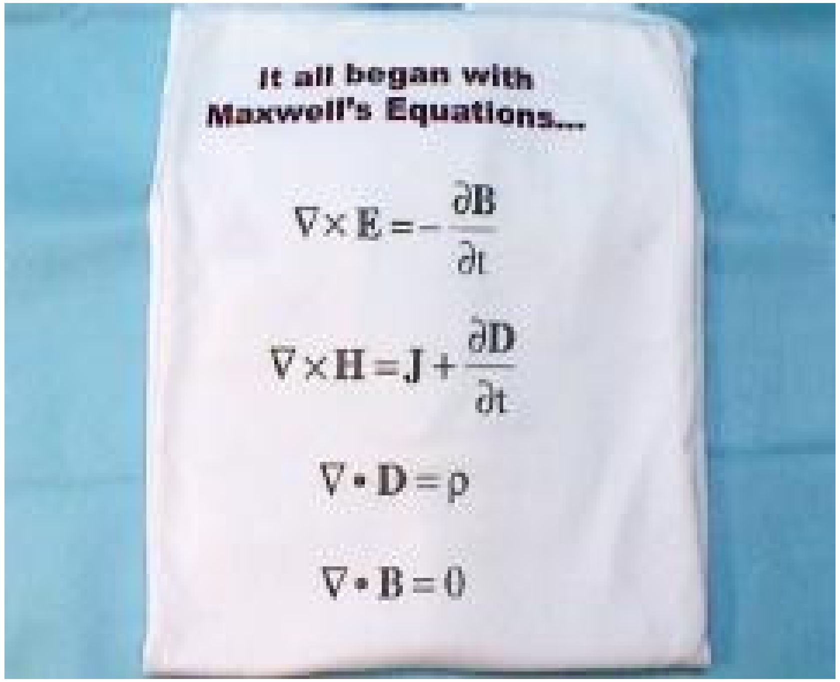

Figure 20-15. The principle of the three-phase alternator. Armature coils schematically diagrammed in (A) are spaced 120° apart and generate peak voltage output in three phases as shown in (B). In (C) the output is shown as a voltage diagram.

1864 : James Clerk Maxwell combined electric fields with magnetic Fields and proved that there existed electromagnetic waves; this is known as “Maxwell’s Equations”.

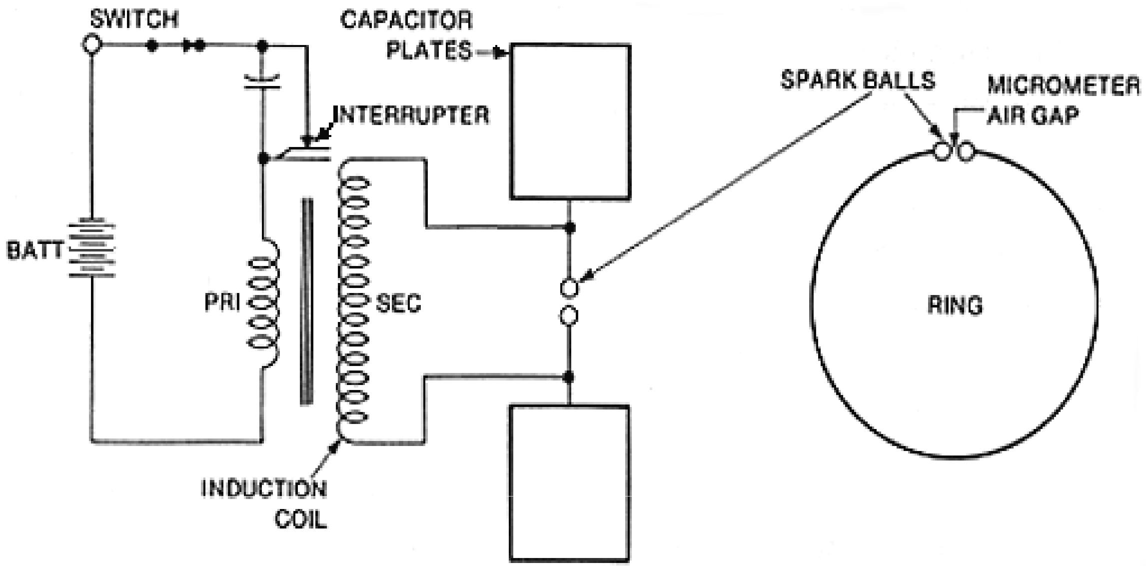


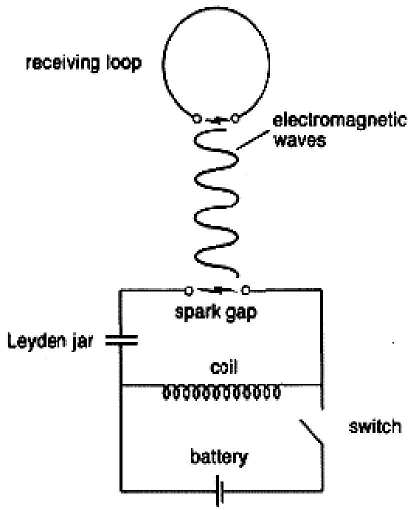


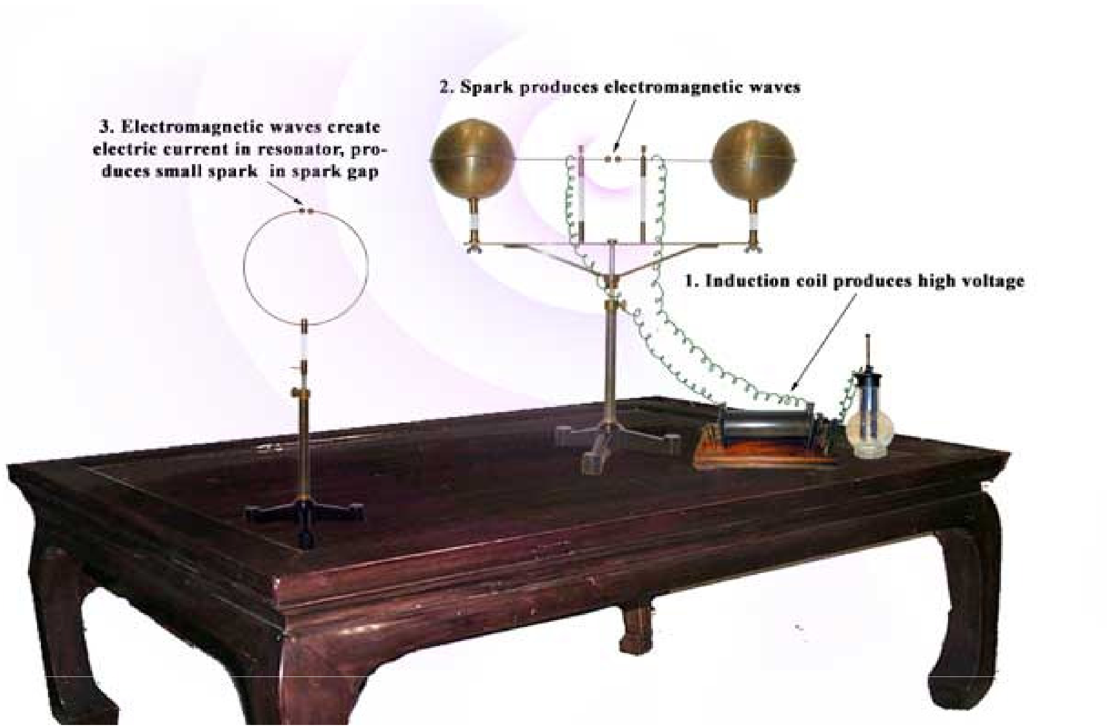

**TEM : Transverse Electromagnetic Wave**



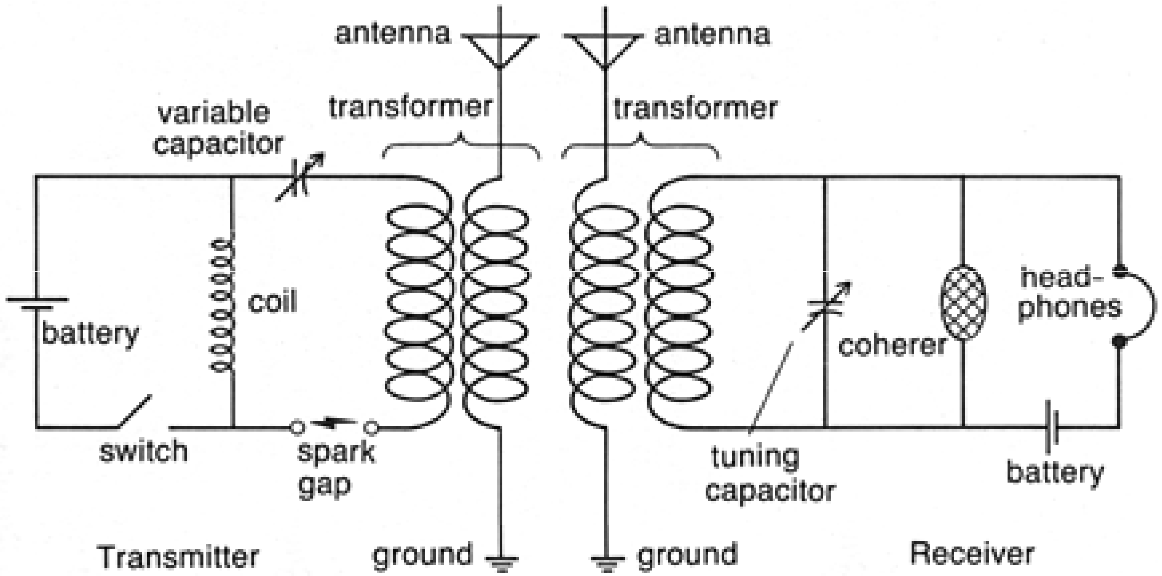
1886 : Heinrich Rudolf Hertz proved the existence of electromagnetic Waves.


2. Spark produces electromagnetic waves
3. Electromagnetic waves create electric current in resonator, produces small spark in spark gap
1. Induction coil produces high voltage

1896 : Guglielmo Marconi was the first to succeed in transmitting and receiving radio waves.




**A schematic of Marconi's 1900 wireless system**

# Then came .....

- Radio broadcast (1900s)
- Telegraph (1900s), origin of “wireless” communications
- Television broadcast (1930s)
- Satellite communication or SATCOM (1960s)
- Car phone (1980s)
- Cellular phone/Mobile phone (1990s)
- Wireless LAN or WLAN (Wi-Fi) (1990s)
- WiMAX or Worldwide Interoperability for Microwave Access (2000s)
- .....