Lecture 1: Applications of High Power Electromagnetic Systems

Low Power (not covered in this class)
- EM sensors
- Radio communications and broadcast
- Cellular communications

High Power
- High power microwaves
- X-ray generation and applications
- Electron beam applications
- Ion beam applications
- Plasma devices and applications

High Power Microwaves

Radar

Range determined by power

\[ R \propto P^{\frac{1}{4}} \]

Resolution determined by pulse length

\[ \delta = \frac{cT}{2} \]

- First developed in 1904, initially for detection, and then ranging
- Extensive development leading up to WWII, and extensive use during the war
- Basic principles
  - Send out a short burst of RF
  - Wave reflects off of object
  - Sense returning wave
  - Use timing to find range

Might be solid state

Almost always vacuum electronics
Power Beaming

+ Means of moving power from a remote power facility
+ Of current interest for space based solar power
+ Could also be used to deliver power from a stationary source to a moving device - space propulsion

Friis transmission formula can be used to find transfer efficiency

$$\frac{P_r}{P_t} = G_r G_t \left( \frac{\lambda}{4\pi R} \right)^2$$

where

$$G = \frac{4\pi \eta A}{\lambda^2}$$

Directed Energy Weapons

+ Use HPM to disable or destroy electronics
+ At high frequencies (10s to 100s GHz) can produce pain in humans without lasting physical damage
+ Blink opposition radar and communications
X-ray generation and applications

High energy electron beam
+ High voltage for energetic x-ray
+ High current for high brightness

High Z-number target, like W

Produces X-rays

Typical bremsstrahlung spectrum

The beam energy is related to the beam voltage
\[ E_b = eV_b \]

The efficiency of conversion of beam energy to X-ray also depends on beam energy and target Z
\[ \eta \propto E_b \times Z \]

X-ray applications:
+ Imaging and radiography: all familiar with medical x-rays, also used to view interiors of machines. Resolution is better with higher energy photons
+ Disinfections: x-ray generators can be used to disinfect and sterilize. Because high beam-xray efficiencies mean less wasted power, high energy brems is usually used.

Electron beam applications

We have talked about a couple of electron beam applications, but there are more that use the electron beam directly

+ Electron beam disinfection - here, and electron beam impinges on a target, killing microbes. The penetrating power of the electron beam is related to the electron beam energy. Range (R) is dependent on electron energy in a power law, where n is between 1 and 2
\[ R \propto E^n \]
Polymer cross-linking - electron beams are used to help non- or partially-polymerized materials form bonds between polymer chains. The materials then change properties, often becoming stronger and more rugged.

**Ion beam applications**

Much like electron beams, accelerated ion beams have a number of interesting and useful applications.

**Ion implantation**

- Ions are accelerated to high energies to increase their range in solid materials.
- Ions lodge in the crystal lattice of a semiconductor, producing donor and acceptor energy levels.

Space propulsion

- Ions are electrically accelerated to produce thrust.
- Spacecraft momentum.
- Ion momentum.
- $T = M_{ion} \frac{I_b}{q_{ion}} \sqrt{\frac{2E_b}{M_{ion}}}$
Plasma applications

Electron cyclotron resonance heating

\[ \phi = \pi/2 \quad \rightarrow \quad \text{RCP field components sync} \]

\[ \phi = 0 \quad \uparrow \quad \text{with electron motion} \]

\[ \phi = 3\pi/2 \]

Electrons revolve around magnetic field at the cyclotron frequency

\[ \omega_c = eB/m_e \]

\[ \phi = \pi \]

+ a righthand circularly polarized wave at the cyclotron frequency is in phase with the electron motion, accelerating the electron
+ for many magnetized plasma devices, this frequency is a few GHz
+ can be used to heat the plasma - especially important in magnetic fusion reactors
+ there are other resonances in plasmas, where EM waves couple directly to plasma particle motion

Z-pinch

\[ \vec{F} = \vec{J} \times \vec{B} \]

+ A current carrying plasma column produces a B-field as shown
+ The plasma feels a force radially, which compresses and heats the plasma
+ Used by Z-machine to produce 100 TW pulses of xrays
Conceptual map of this course

Electrical energy is stored and then released

Electrical energy is then stored in another form - beam energy or plasma current

The secondary stored energy is then put to some good use - generating microwaves, making x-rays, generating fusion power