① Phys 2426 2015-11-12 Lec 23

How do we quantify Energy in waves?

Packets, bundles, Localized energy:

Energy in J

Energy spread in a line, surface, volume:

Energy Density in J/m, J/m^2, J/m^3

Continuous flow of energy in a wire:

P in $J/s = W$ can be $P = \text{Density} \cdot v$

$J/s = J/m \cdot m/s$

Continuous surface waves

$\text{Intensity} = \text{Density} \cdot v$

$W/m = J/(m \cdot s) = J/m^2 \cdot m/s$

Sound & Light Waves

$\text{Intensity} = \text{Density} \cdot v$

$W/m^2 = J/m^3 \cdot m/s$

$$I = \frac{P}{A}$$

Point Source Approx

$$\frac{P}{4\pi r^2} = I \quad \text{Uniform emission}$$

$$I \propto \frac{P}{r^2} \quad \text{General Far-field}$$

Ex: $I = 50\ \mu W/m^2$, go 2X further

$$I_2 = \frac{1}{4}(I_0) = 12.5\ \mu W/m^2$$

- Our eyes/ears have a HUGE range of allowed intensities.

  $10^{-12}\ W/m^2$ Quietest Sound
  $1\ W/m^2$ Painfully Loud

- Filters and inefficiencies tend to multiply the intensity.
- We interpret steps in intensity by the ratio, not the delta.
  We can hear a factor of $5/4$ just barely.
- We use a logarithmic scale.

Definitions: $\frac{I}{I_0} = 10^{\beta/10}$ ← β: decibel level

$\frac{I}{I_0}$: ratio of intensity vs. reference

$$\beta = 10 \log(I/I_0)$$

As intensity is <u>multiplied</u>, dB levels <u>add</u>.

dB	ratio
10 dB	10
20 dB	100
30 dB	1000
3 dB	$10^{0.3} = 2$
5 dB	$10^{0.5} = \sim 3$
7 dB	$10^{0.7} = 5$
1 dB	$10^{0.1} \approx 1.25$
−3 dB	0.5
0 dB	1.0

Reference Sound $I_0 = 10^{-12}\ W/m^2$

60 dB = conversation $I = 10^{-6}\ W/m^2$
100 dB = power tools
180 dB = hearing loss

(4)

In a radio, we care about the energy flow on a wire. P in W

$0 \text{ dBm} = 1 \text{ mW}$

$-70 \text{ dBm} = 10^{-10} \text{ W}$ Lowest useful Wifi signal

If A sound is 80 dB @ 1.0 m, how loud is it @ 30 m?

$I \propto \frac{1}{r^2}$ $r \uparrow 30X$ $I \downarrow 30^2 X$

ratio = 900

$\log(900) = 2.9$

$\beta = 29 \text{ dB}$

New sound = 51 dB

$30^2 = 3^2 \cdot 10^2$

$-(5 \text{ dB} + 5 \text{ dB} + 20 \text{ dB})$

New sound = 50 dB

Transverse waves have oscillations that are perpendicular to the velocity. Describing the direction is polarization.

For a horizontally-moving wave:

- Pure Vertical
- Pure Horizontal
- Circular
- Diagonal
- Random

A polarizer absorbs "undesired" waves. It also polarizes the waves.

Incoming unpolarized: $I_{out} = I_{in} (1/2)$

Incoming polarized: $I_{out} = I_{in} \cos^2 \theta$

mismatch ↗ (θ)

The polarization is actually rotated.