Phys 2426   2007-07-26   Lec 14

From Oscillations to Waves

Osc: $x = x_{max} \sin(2\pi f t + \phi)$

Waves are many coupled oscillators.
The oscillators stay in place (on average).

The speed of a wave is the speed of the disturbance or energy.

Wave type	Disturbance	Speed
Light	$\vec{E}, \vec{B}$	$c = 3\times10^{8}$ m/s
Sound	pressure, velocity, displacement	340 m/s
Earthquake	displacement	
String	displacement	$v = \sqrt{F_T/\mu}$
Water	displacement	

Repetition in time → space

Wavelength (λ) is length of one cycle.

$$v = \frac{\lambda}{T} = f\lambda$$

Generally, when one oscillation stimulates another, the frequency is copied.

Exception: Doppler Effect

- Frequency shift due to relative motion between source, medium, & observer. (Note: Light has no medium.)
- Easy version: only source & observer. Only motion toward & away matters.

$$\frac{\Delta f}{f_s} = \frac{V_{rel}}{V_{wave}}$$

Δf = freq. shift
f_s = source freq
V_{rel} = relative v
V_{wave} = wave v

Ex: car horn

$$\frac{192\ \text{Hz}}{4705\ \text{Hz}} = \frac{V_{rel}}{340\ \text{m/s}}$$

$$V_{rel} = 13.9\ \text{m/s} = 31\ \text{mph}$$

Works well for $\Delta f / f < 0.1$ or 0.2

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Doppler Radar - Doppler shift happens twice.

$$\frac{\Delta f}{f} = 2\,\frac{V_{rel}}{V_{wave}}$$

Ex: Police Radar @ 5 GHz
Car moving 30 m/s

$$(5\times10^9\,Hz)\frac{\Delta f}{f} = 2\,\frac{30\,m/s}{3\times10^8\,m/s}$$

$$\Delta f = 1000\ Hz$$

Received freq is 5 000 001 000 Hz

Energy, Power, Intensity, and decibel Levels

Power is rate of energy flow:

$$P = \frac{\Delta Energy}{\Delta t}$$

Waves tend to spread out.
Intensity describes loudness, brightness.

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

Ex: $I = 1368 \, W/m^2$ for ISS.
Solar panel area $= 2500 \, m^2$

$$\text{Power Arriving} = (1368 \, W/m^2)(2500 \, m^2)$$
$$= 3.42 \, MW \text{ of light.}$$

<u>Point Source</u> - wave spreads spherically

$$I = \frac{P}{4\pi R^2}$$

$$\text{Sun's Power} = (1368 \, W/m^2) 4\pi (150 \times 10^9 \, m)^2$$
$$= 4 \times 10^{26} \, W$$

US Electrical Peak: $800 \times 10^9 \, W$
Cell phone Signal: $10^{-14} \, W$

Decibels – quantity is called a "Level"

- Levels are <u>always</u> relative.
- Reference values are used to "anchor" the meaning of Levels.
- 0 dB means "the same".
  - 0 dB increase = no change
  - 0 dB level = reference intensity
- Sound

$$I_{ref} = 10^{-12}\ W/m^2$$

- dB values are exponents.
  They correspond to ratios or factors.

Level (dB)	Ratio
0	$10^{0} = 1$
3	$10^{0.3} = 2$
5	$10^{0.5} \approx 3$ $(\sqrt{10})$
7	$10^{0.7} = 5$
10	$10^{1.0} = 10$
β	$10^{\beta/10}$

- As energy is mult or divided, dB Levels are ⊕ or ⊖.

Ex: $86\ dB = 10^{8.6} = 10^{8}(+3dB)(+3dB)$
$= 4 \times 10^{8}$

If sound: $I = I_0 (4 \times 10^{8}) = 4 \times 10^{-4}\ W/m^2$

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How Intense is a signal from Mars as compared to from ISS?

Dist to Mars 50×10^6 km
Dist to ISS 400 km

Mars is $\frac{50 \times 10^6}{400} = 125000$ times further

Intensity $\propto \frac{1}{R^2}$

I Ratio is $(125000)^2 = 15.6$ billion times

~ 102 dB

$15.6 \times 10^9 = 10^{\beta/10}$

$\log(15.6 \times 10^9) = 10.2 = \beta/10$

$102 = \beta$

Common decibel-derived units:

Sound Level Ref is 10^{-12} W/m^2

Power Level in a wire
dBm Ref is 1 mW

Ex: −110 dBm is $10^{11.0}$ times less than 1 mW

$$P = (10^{-3} W)/(10^{11}) = 10^{-14} W$$

What about dBmV?

- Describes a signal whose <u>power</u> is related to a 1 mV signal.

1 mV in 1 Ω makes 1 mA flow
$P = (1 mV)(1 mA) = 1 \mu W$
2 mV in 1 Ω makes 2 mA flow
$P =$ 4 μW
10 mV → 10 mA → 100 μW

A 10x increase in voltage increased power by 100x, which is 20 dB.

$\beta = 20 \log\left(\frac{V}{1 mV}\right)$ for dBmV only