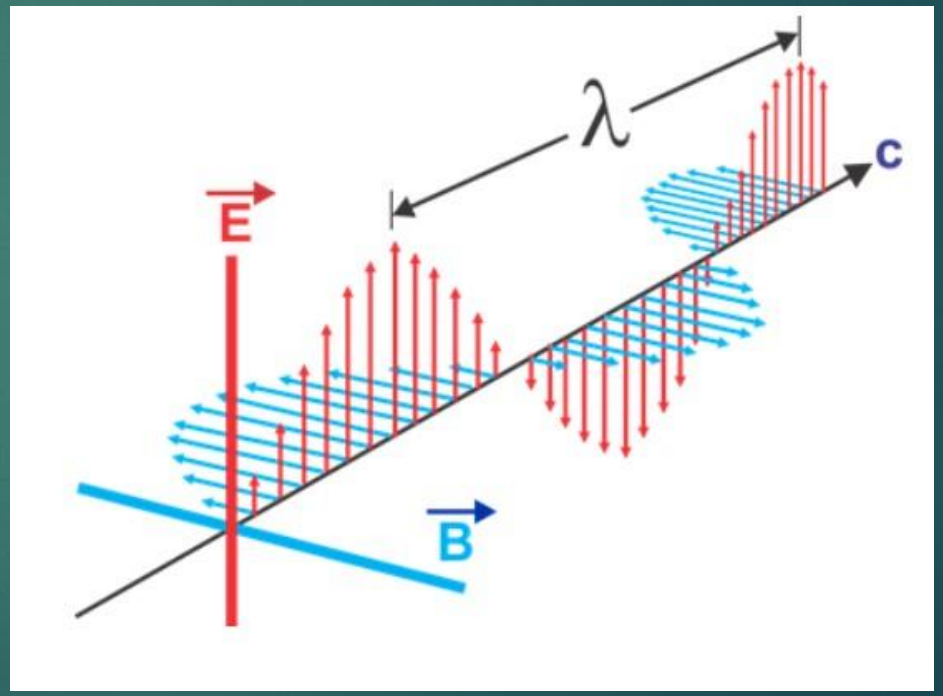
The Electromagnetic Spectrum & Radio Frequencies for Wireless Communication

SPECTRUMX
An NSF Spectrum Innovation Center

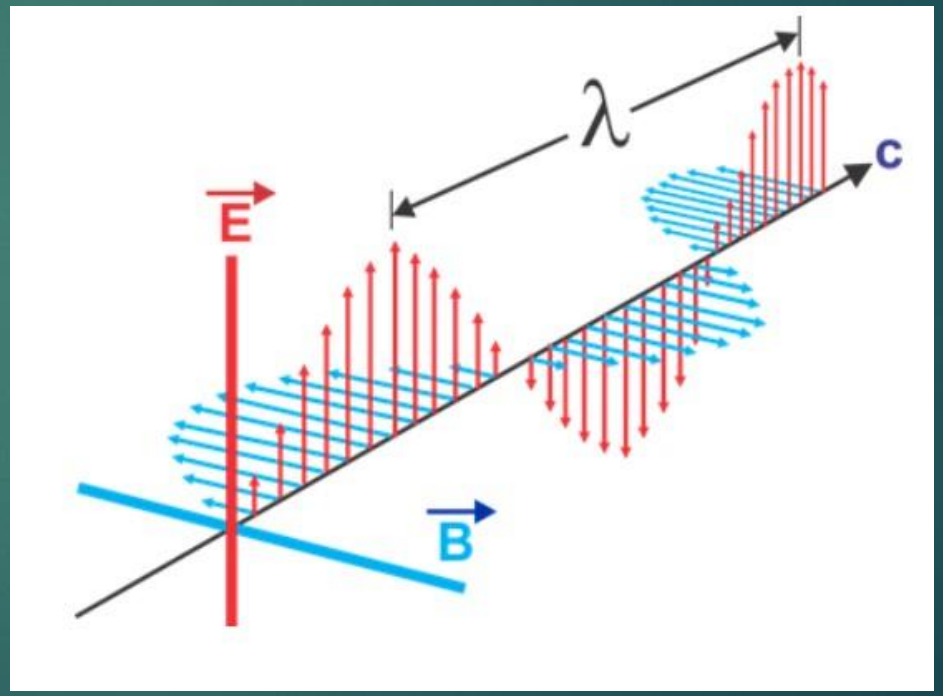
Electromagnetic waves

- The **electromagnetic** (**EM**) waves consist of electric ($\vec{E}$) and magnetic fields ($\vec{B}$) oscillating perpendicular to each other, and at the same time, both are perpendicular to the direction of propagation.



Electromagnetic waves

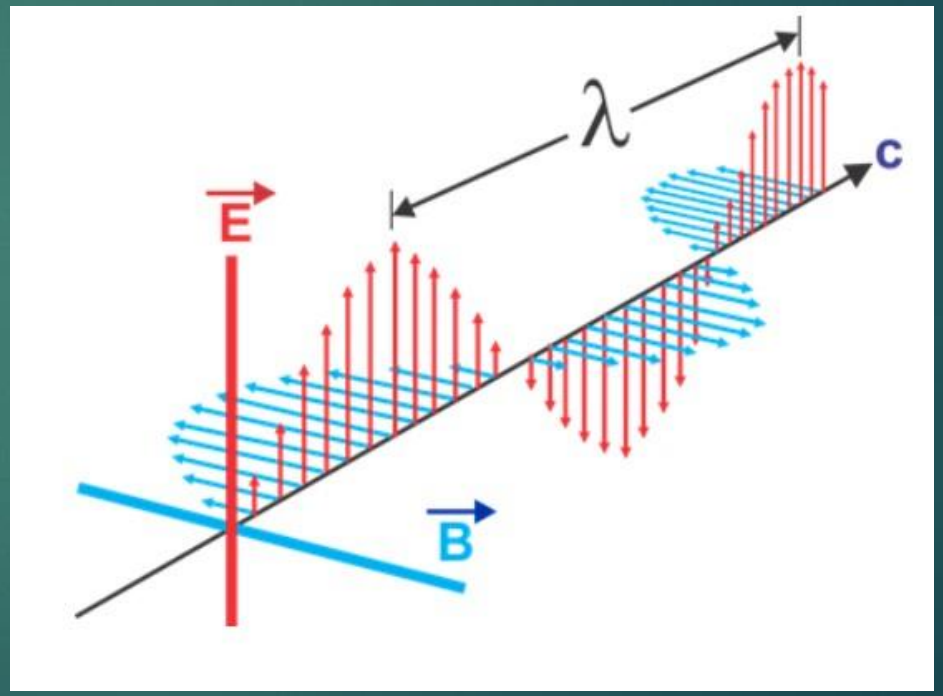
- The distance from crest to crest is the wavelength λ, measured in meters $[m]$.
- The number of cycles per unit of time is the frequency f of the EM wave, measured in Hertz $[Hz]$.
- The electromagnetic waves traves at the speed of light $c = 3.00 \times 10^8 \frac{m}{s}$.



Electromagnetic waves

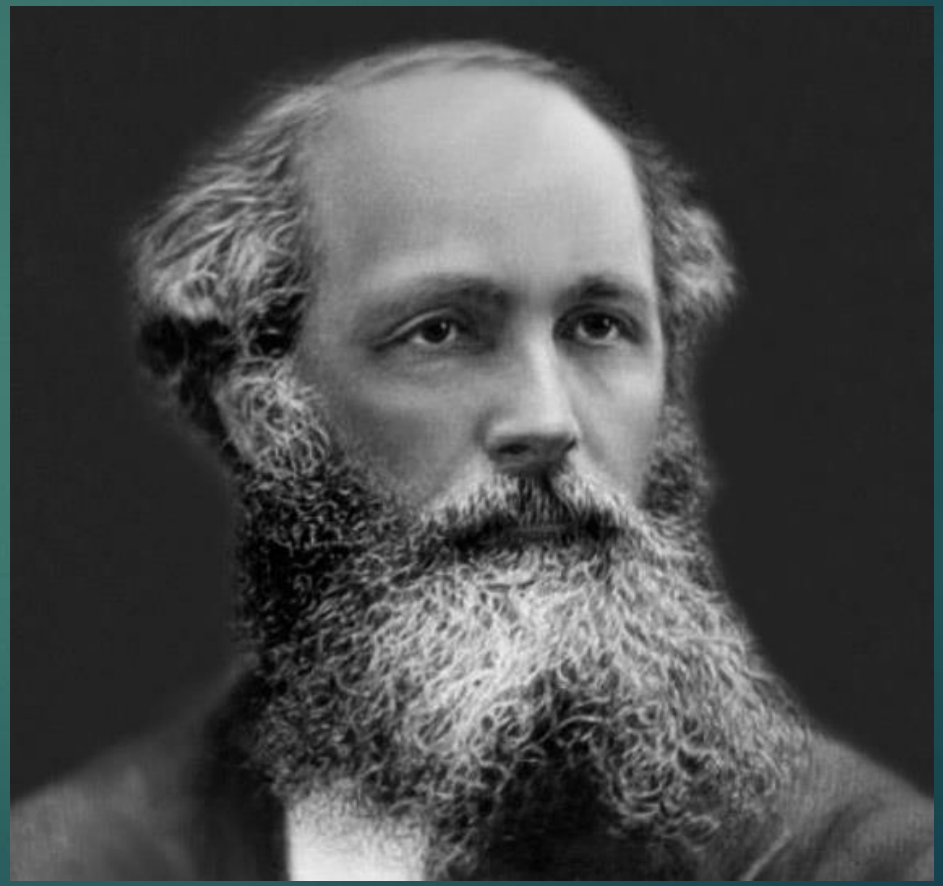
- Analogous to mechanical waves, the product of the wavelength times the frequency gives the speed of the wave, in this case, EM waves:

$$c = \lambda f$$

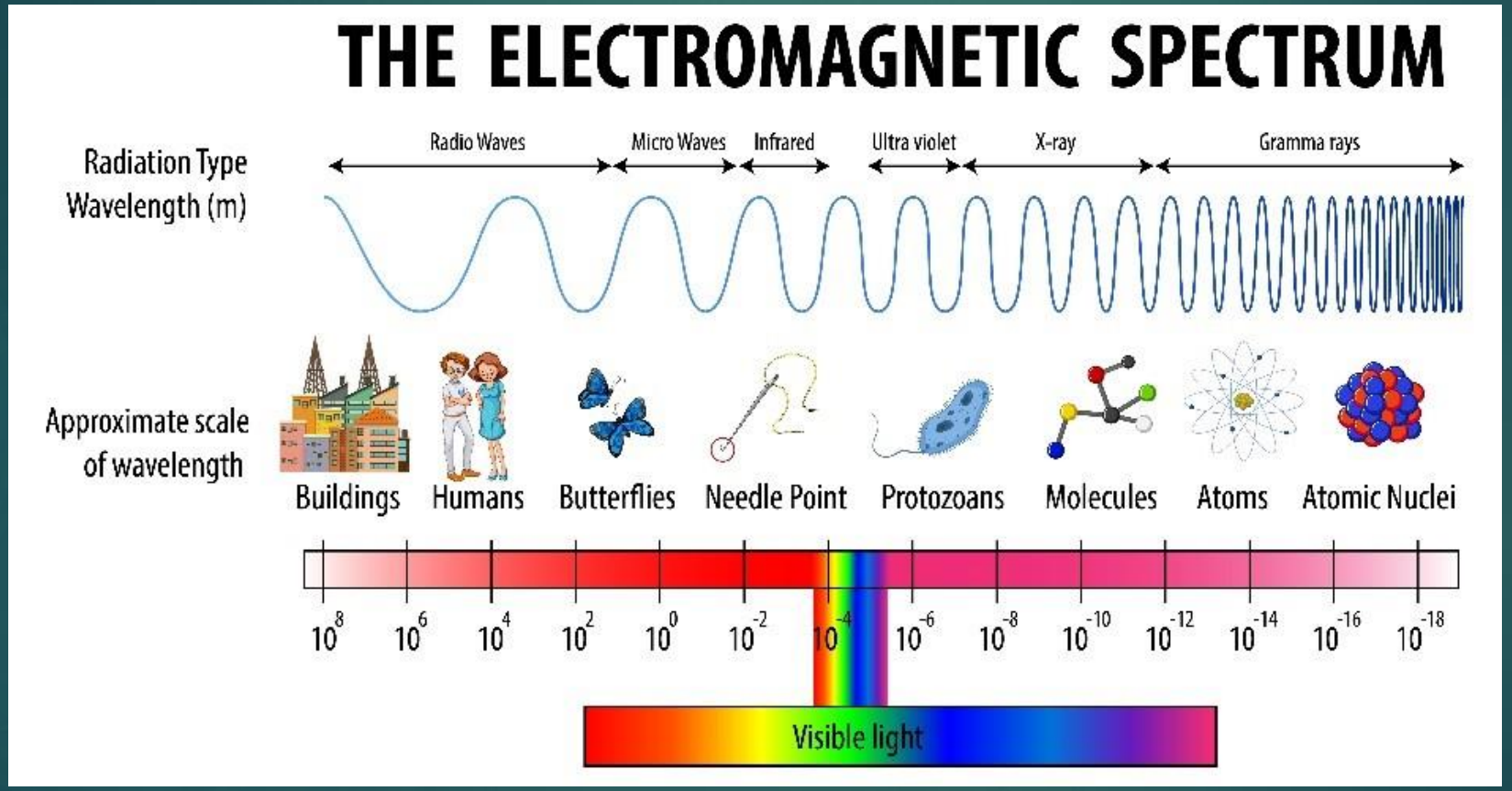


Electromagnetic waves

- The EM waves were discovered by the Scottish physicist James Clerk Maxwell (1831-1879), who unified electric and magnetic phenomena in a single theory.



The Electromagnetic Spectrum



The Electromagnetic Spectrum

Gamma rays (γ rays)

- About $100\ pm$ in wavelength, or shorter.
- Frequencies corresponds to above $30\ EHZ$.
- Very high energetic electromagnetic waves.
- Gamma rays are used in medicine to destroy cancer cells.

Note: $p = 10^{-12}$ (pico) and $E = 10^{18}$ (Exa).

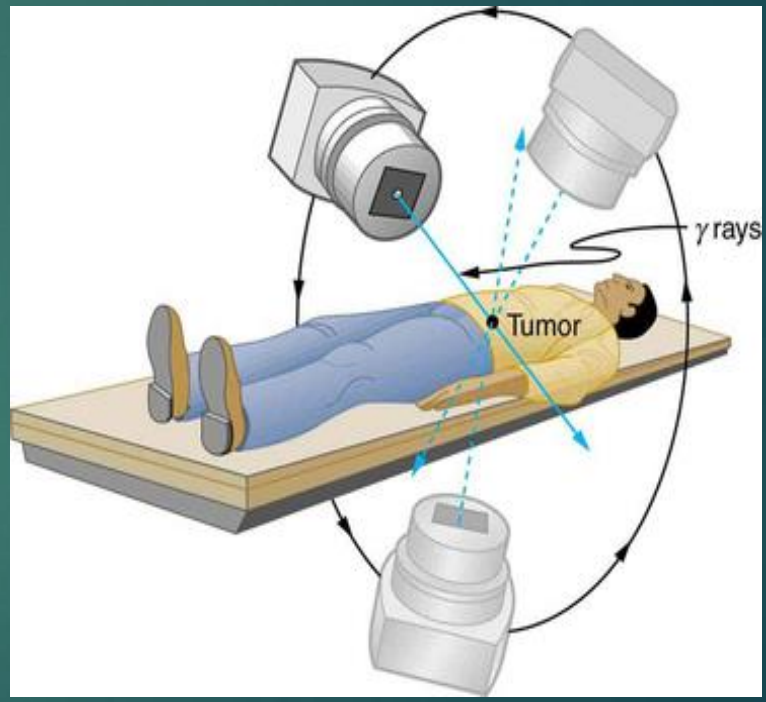


Image courtesy of https://clipart-library.com/clipart/1724115.htm

The Electromagnetic Spectrum

X rays

- $0.01\ nm$ to $10\ nm$ wavelengths.
- corresponding frequencies of $30PHz$ to $30\ EHz$.
- X rays EM waves are used in dentistry and medicine because it penetrates the flesh and interacts with the bones structures.

Note: $P = 10^{15}$ $(Peta)$ and $E = 10^{18}$ (Exa).

Image courtesy of the National Cancer Institute on Unsplash

The Electromagnetic Spectrum

Ultraviolet (UV)

- The UV ranges from about $400\ nm$ to $10\ nm$ in wavelength.
- Corresponding frequencies from $750\ THz$ to $30\ PHz$.
- Humans cannot see in the UV range, but animals like the bees can see this part of the spectrum (see the right hand photo with a sensitive UV camera).

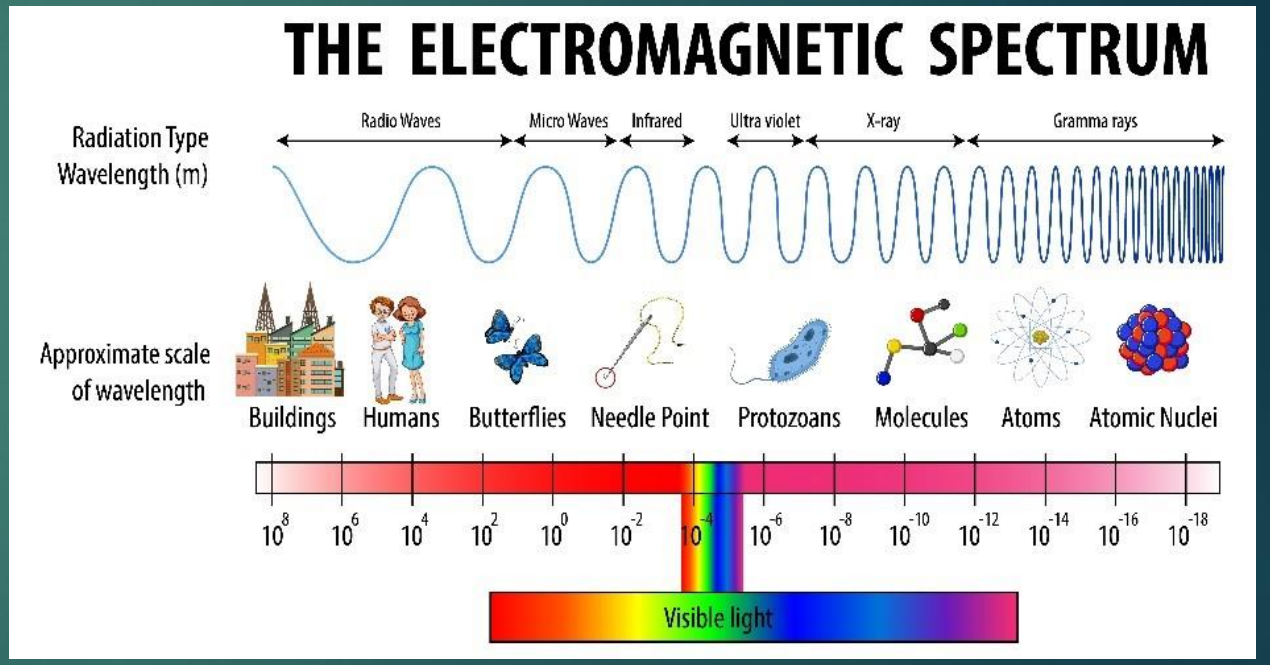
Note: $T = 10^{12}\ \ (Tera)$ and $\ P = 10^{15}\ \ (Peta)$.

https://brilliantstarmagazine.org/articles/bees

The Electromagnetic Spectrum

Visible spectrum (Visible light)

- Goes from about 380 to 750 nm (nanometers) in wavelength.
- The corresponding frequencies are from about 790 to 400 THz (Tera-Hertz)
- The branch of physics that study the visible light waves of the EM spectrum is called **optics**.



Note: $n = 10^{-9}$ (nano) and $T = 10^{12}$ $(Tera)$.

The Electromagnetic Spectrum

Microwaves

- Typical wavelengths range from 30 centimeters (cm) to 1 millimeter (mm).
- Heating food with microwaves is the most popular application. Water and fat absorb these EM waves.
- Microwave cosmic background radiation is studied in astronomy as a residual from the Big Bang.

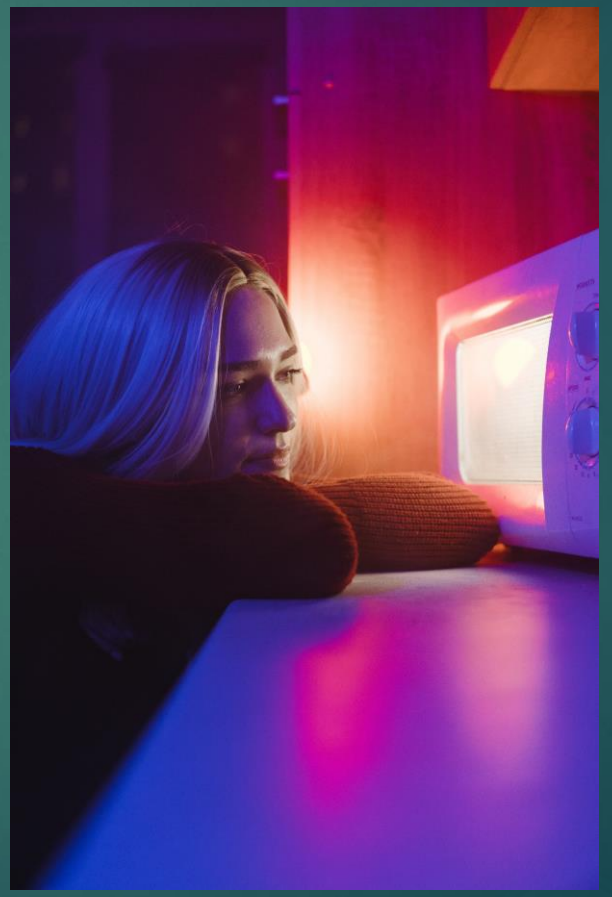


Photo by Stepan Kulyk on Unsplash

The Electromagnetic Spectrum

Infrared

- ranges typically from less than $700\ nm$ to about $1\ mm$.
- Corresponding frequencies range from about $300\ GHz$ to $400\ THz$.
- Human bare eyes cannot perceive infrared EM waves.
- Specialized equipment can create images (thermal cameras for example).
- Some animals, like the snake, can see in the infrared range of the spectrum.

Note: $n = 10^{-9}$ (nano), $m = 10^{-3}$ (mili), $G = 10^{9}$ (Giga) and $T = 10^{12}$ (Tera).

https://www.optica-opn.org/home/newsroom/2020/october/illuminating_the_infrared_vision_of_snakes/

James Webb Infrared Telescope

Image courtesy of NASA

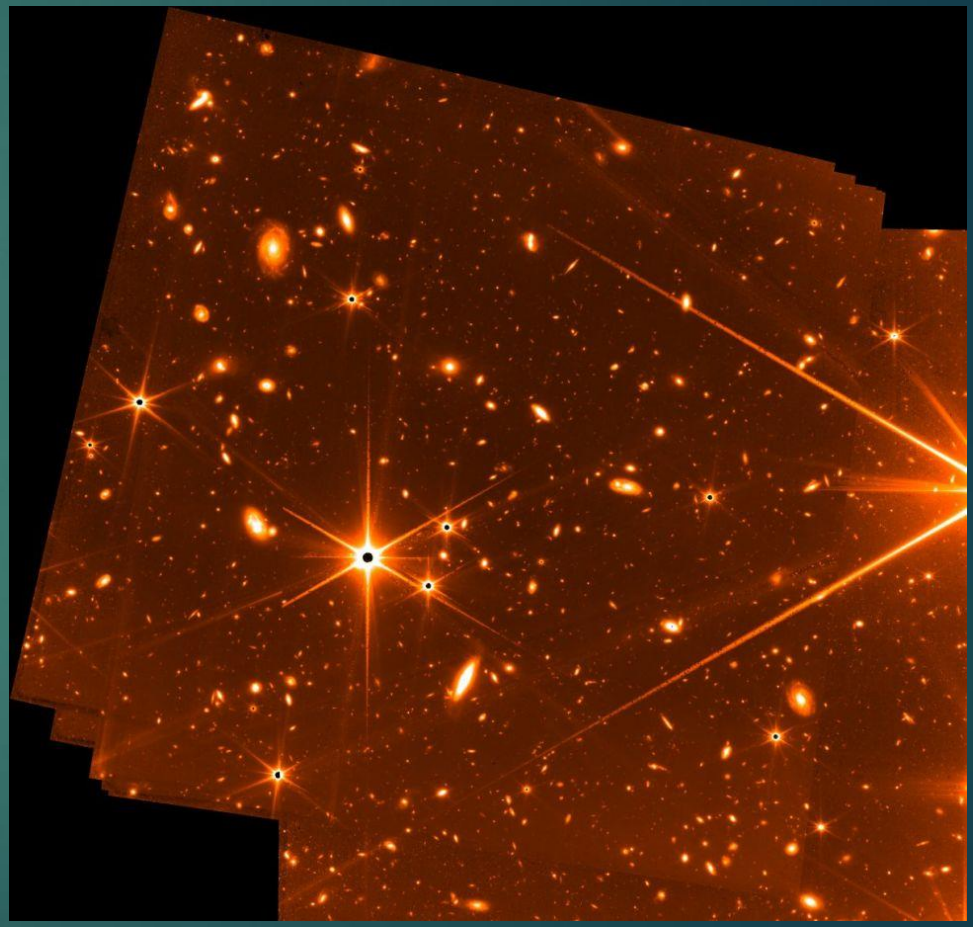


Image courtesy of NASA/ CSA and FGS team/Flickr (CC BY 2.0)

The Electromagnetic Spectrum

Radio waves

- Range from around $10^4 m$ to about $30\ cm$ in wavelength.
- Frequencies correspond to about $3\ Hz$ to GHz.
- Less energetic EM waves and longest wavelengths.

Photo courtesy of NRAO

The Electromagnetic Spectrum

Radio waves

- Radio, TV and wireless communication lies in this range of EM spectrum.
- Essential for global communication.

Photo by Jorge Salvador on Unsplash

Radio Waves

- Discovered by the German physicist Heinrich Hertz (1857-1894) in late 1880's.
- The first to create the radio wireless communication is credited to Guglielmo Marconi (1874-1937), Italian inventor and electric engineer.

Heinrich Hertz

Guglielmo Marconi

Radio Waves

Radio waves applications

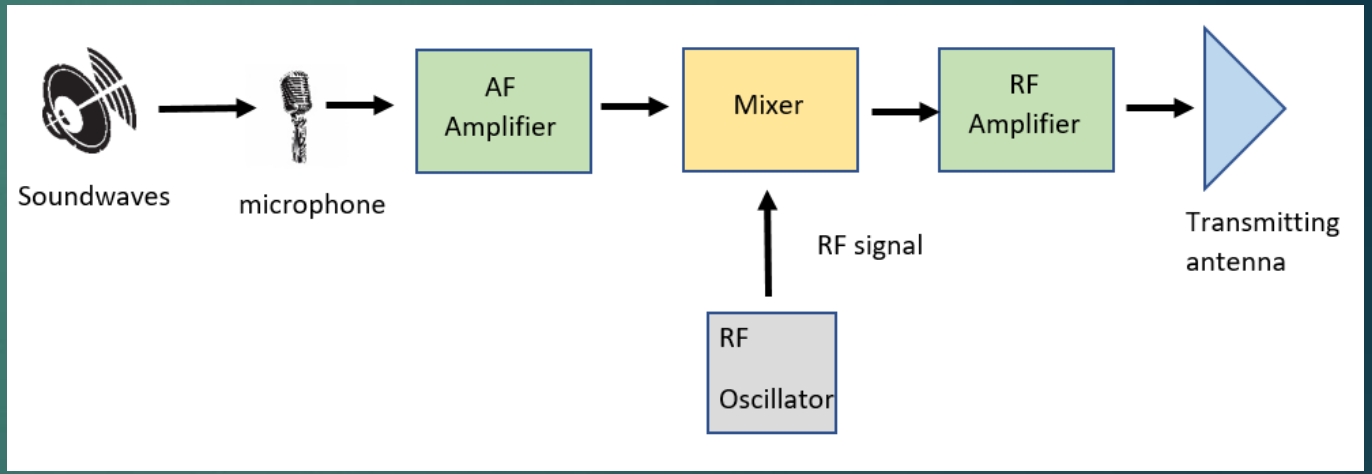
- TV
- Radio Broadcasting AM and FM
- Mobile phones
- Ham radio
- Satellites
- Military communication
- Cellphones
- Bluetooth
- Keyless remote
- Others

Radio Waves

Radio Transmission

The process by which radio station transmit RF waves signals (words or music) is outlined in the image.

1. Sound waves are converted into electric signals of the same frequency. Usually, a microphone is used, but other equipment like lasers may be used.

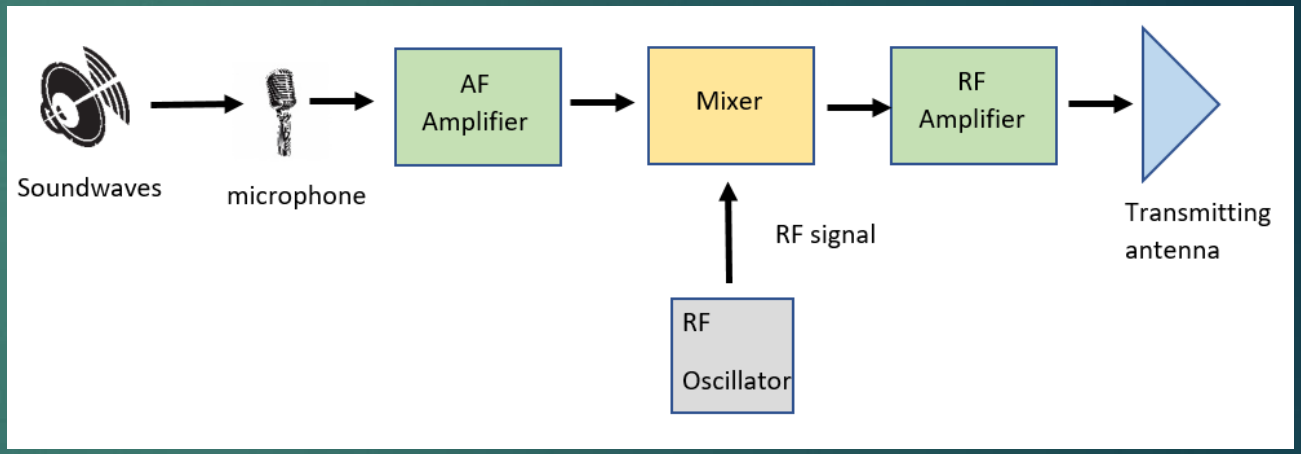


Radio Waves

Radio Transmission

2. The electric signal is called audio-frequency (AF) signal because its frequencies are in the audio range, from about $20\ Hz$ to $20{,}000$ Hz.

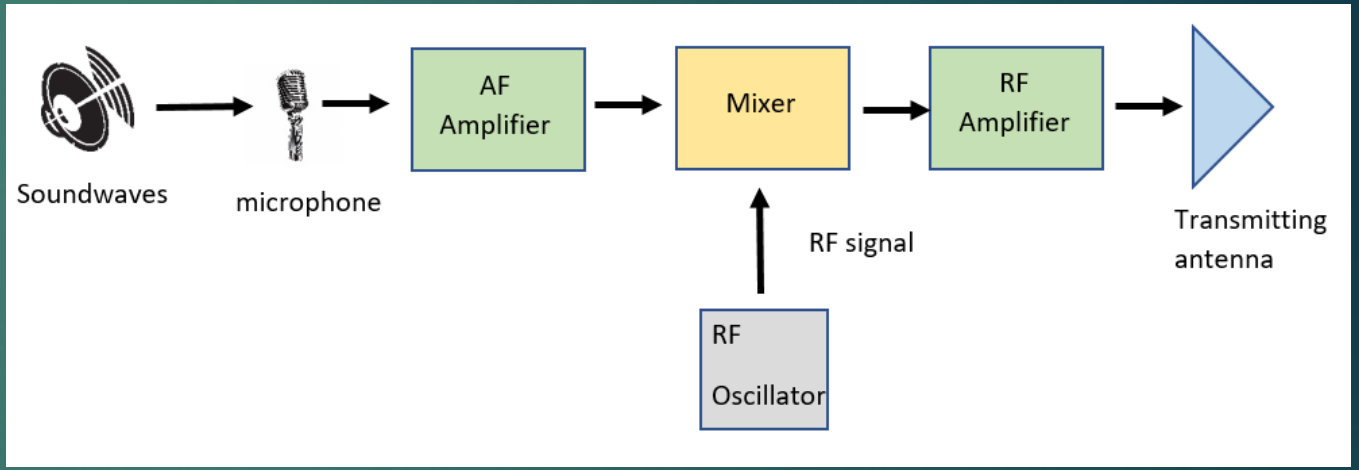
3. The signal is amplified electronically and then mixed with radio frequency (RF) signal, called carrier frequency. The carrier signal could be in AM or FM, which will be explained.



Radio Waves

Radio Transmission

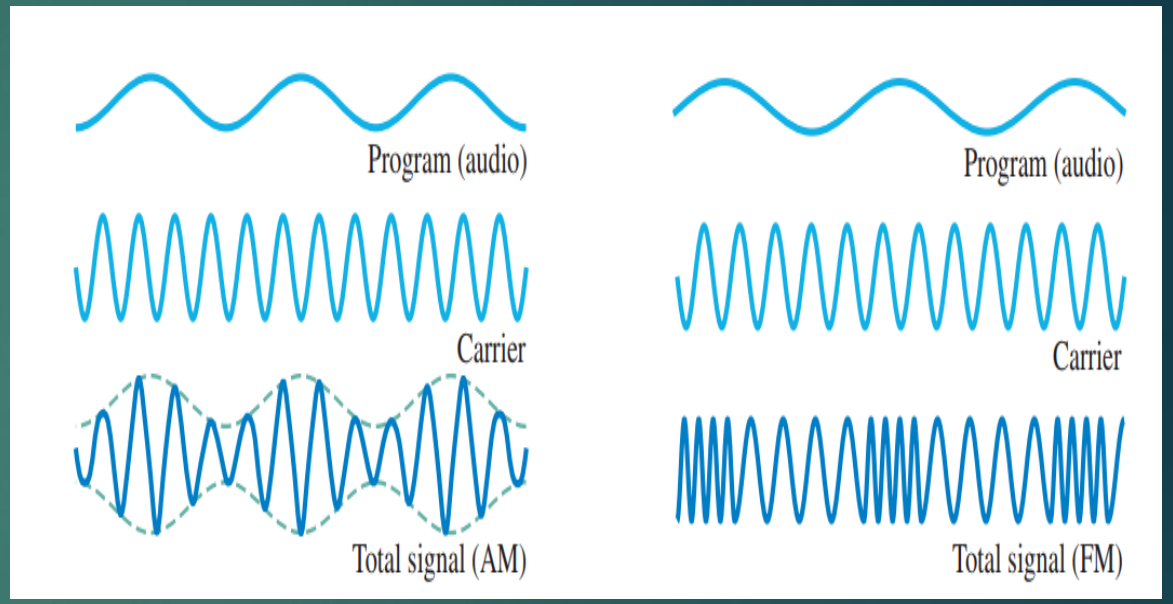
4. The RF wave is amplified and is transmitted via the Transmitting antenna.



Radio Waves

Amplitude modulation (AM)

- Amplitude modulation means that the carrier RF wave amplitude is made to vary according to the audio amplitude (see left case in image).
- Wavelength (distance from peak to peak λ) remains the same, and so its frequency.
- In AM, the carrier frequencies are about $530\ kHz$ to $1700\ kHz$.

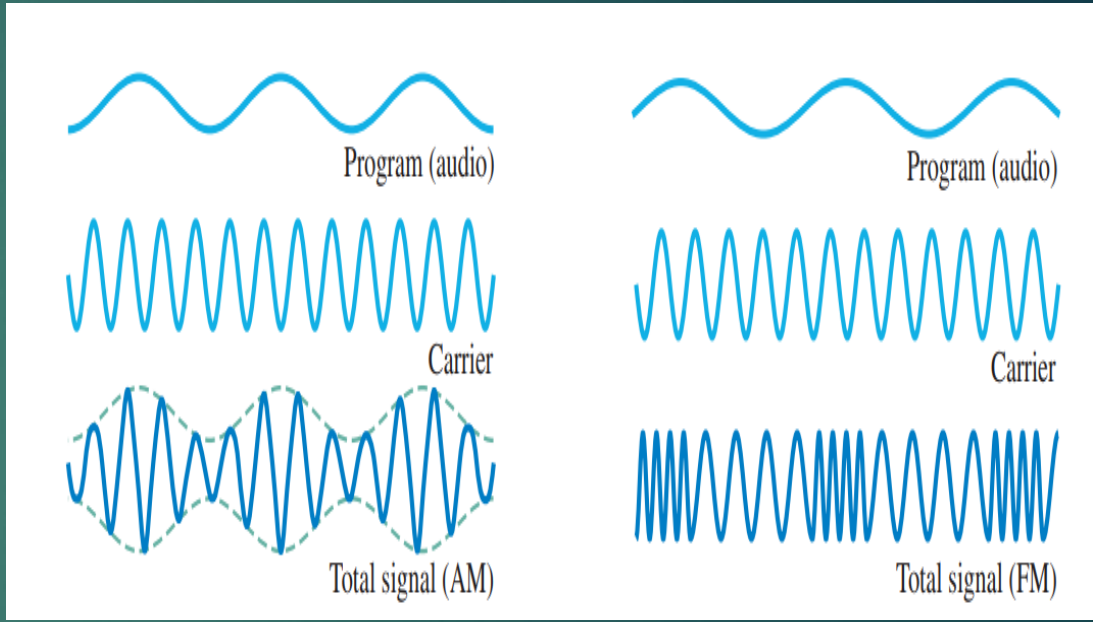


Physics for Scientists and Engineers with Modern Physics, 4th edition; D. Giancoli; Pearson Prentice Hall.

Radio Waves

Frequency modulation (FM)

- In frequency modulation, the carrier frequency is made to vary according to the audio amplitude.
- In FM, is ranges from about $88MHz$ to about $108MHz$.



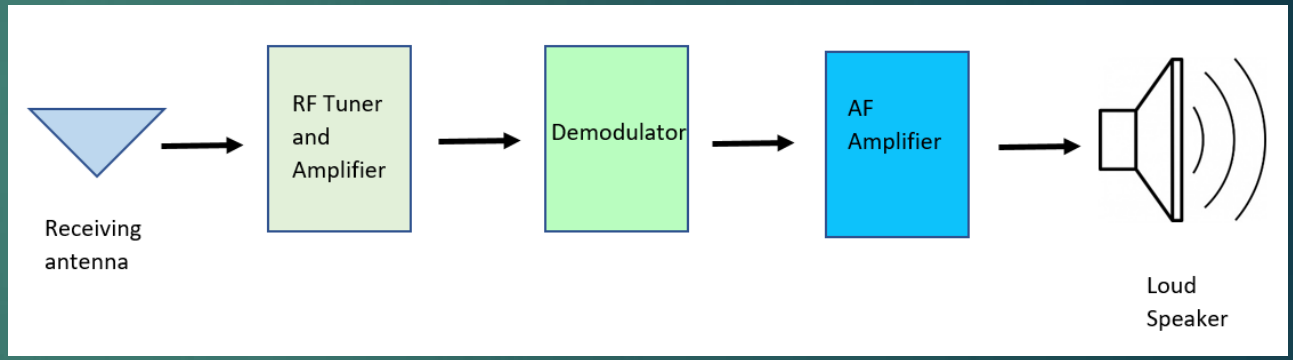
Physics for Scientists and Engineers with Modern Physics, 4th edition; D. Giancoli; Pearson Prentice Hall.

Radio Waves

Radio receiver

1. The RF waves sent out by stations are received by the antenna.
2. Signals of the RF received by the antenna contains different frequencies, so a LC circuit is used in the receiver so select a particular RF for a particular station.

Note: LC circuit stands for inductor (L) and capacitor (C) in electronics.

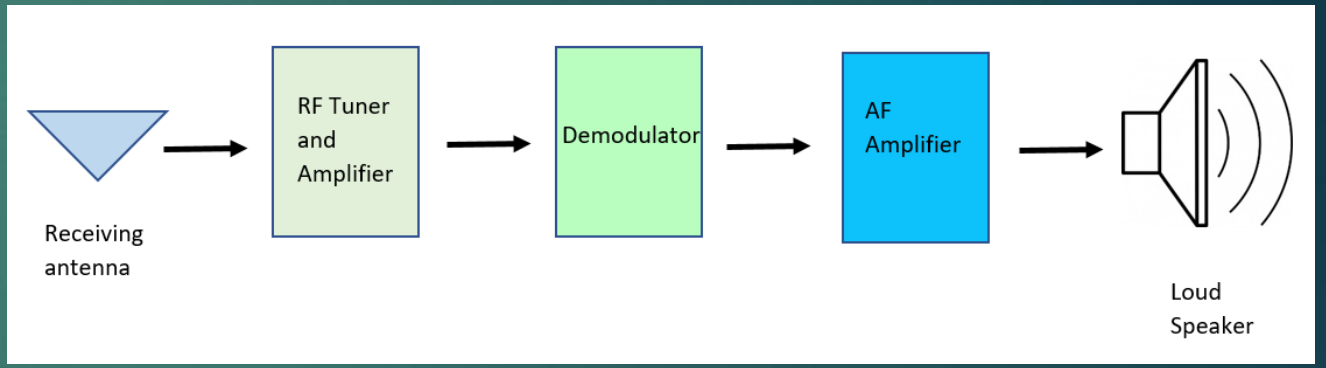


Radio Waves

When you "tune in" a particular RF station, you adjust the capacitance C and/or the inductance L, so the circuit frequency resonates (coincides) with the RF.

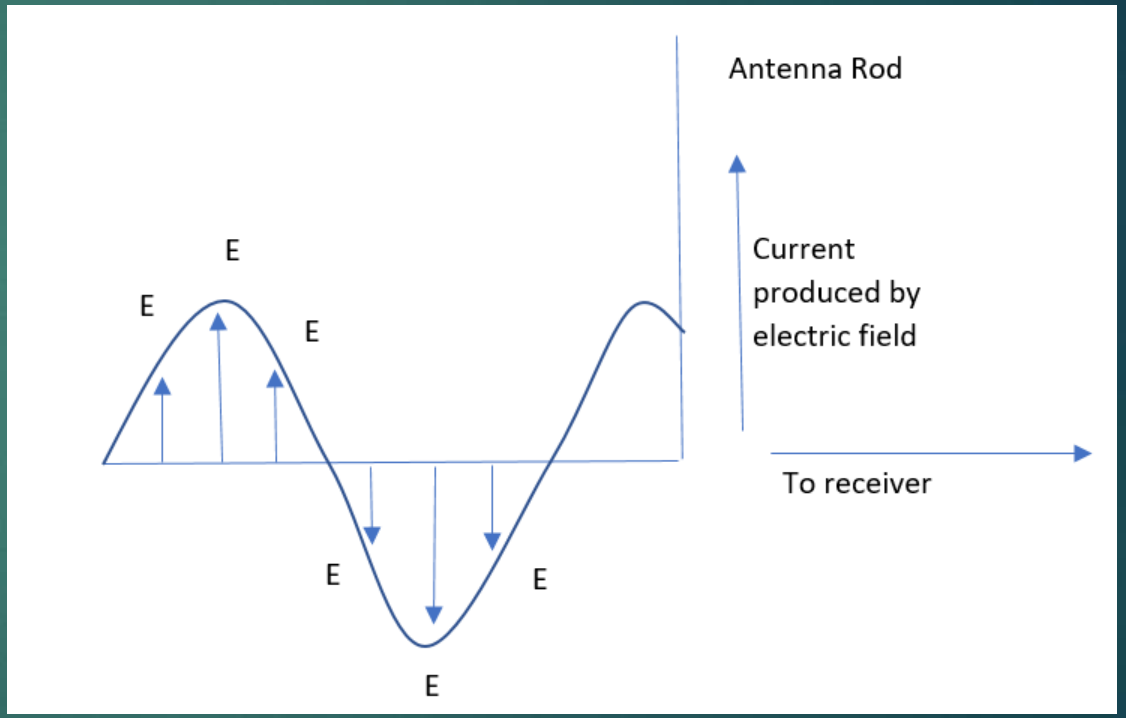
3. The RF signal then goes to the demodulator, where the audio signal is separated from the carrier.

4. Audio signal is amplified and sent to a loudspeaker.



Radio Waves

The antenna consist of a straight wire or rods that receive the EM wave, and the electric field ($\vec{E}$) induces a current (I) at the same EM wave frequency.



Radio Waves - Regulations

Federal Communications Commission (FCC)

- Administers the RF spectrum for non-Federal use.
- Use by state, local government, commercial, private internal business, and personal use.

Radio Waves - Regulations

National Telecommunications and Information Administration (NTIA)

- Administers RF spectrum for Federal use.
- Use by the Army, the FAA, and the FBI.

Radio Waves - Regulations

International Communication Union (ITU)

- Specialized agency of United Nations for information and communication technologies (ICTs).

References

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