

EE1002: Part 2



香港城市大學
City University of Hong Kong

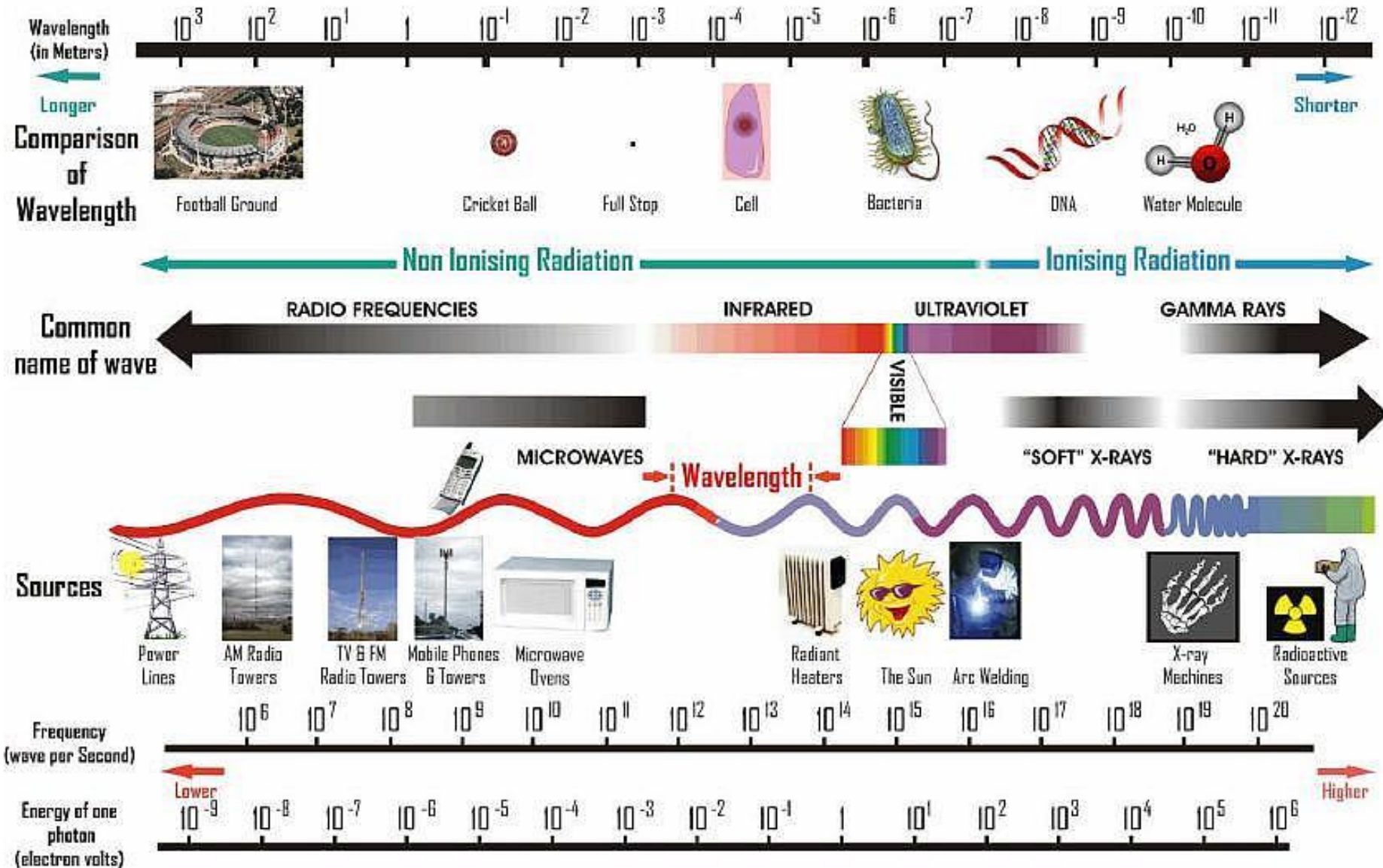
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Lecture 2

- Electromagnetic spectrum and applications
- Structure of the atmosphere
- Propagation of radio waves
- Radio transmission
- AM modulation
- FM modulation

Lecturer: Prof. K. S. Chiang, Room G6515, Tel: 3442 9605, E-mail: EEKSC@cityu.edu.hk

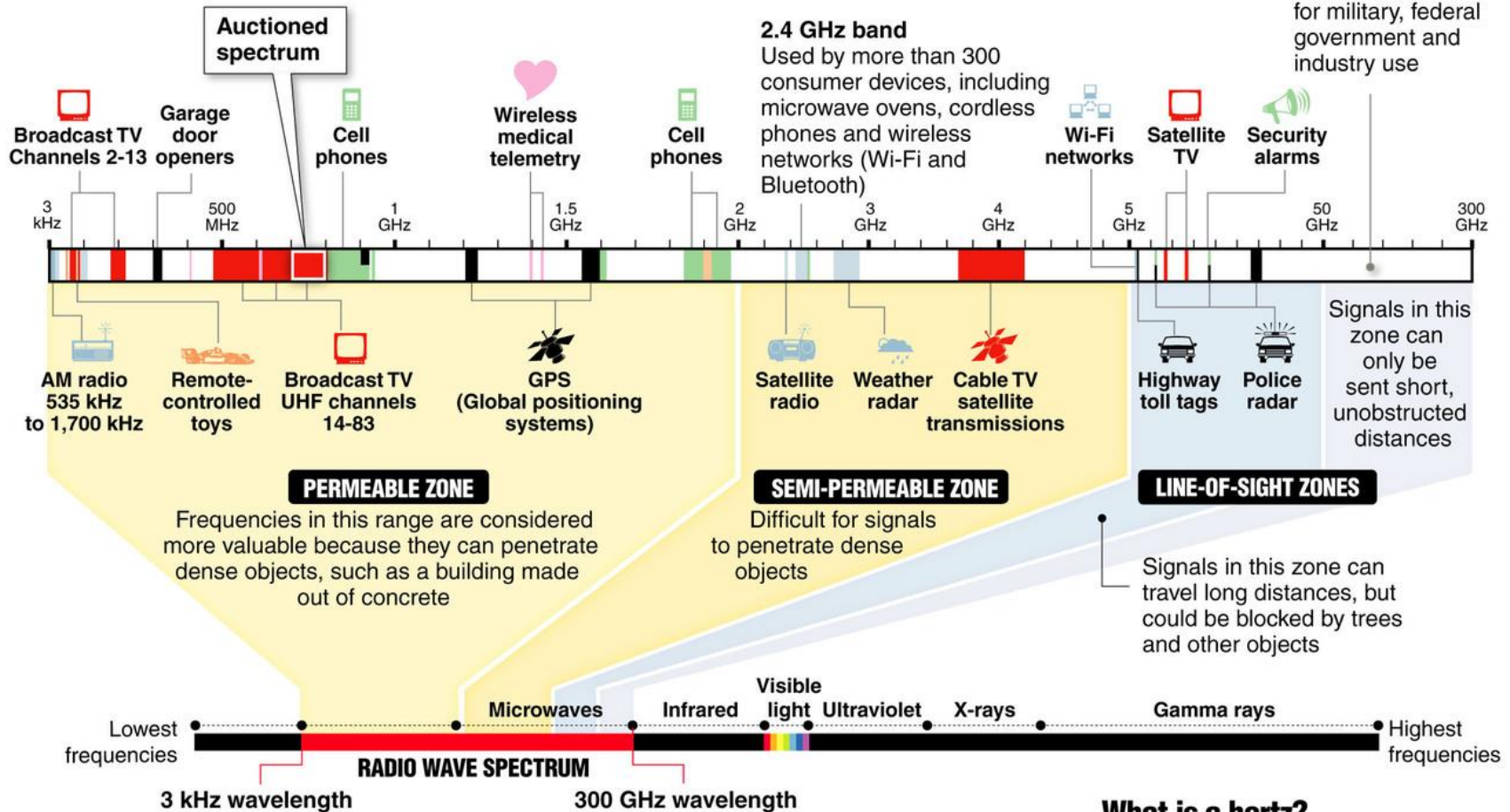
THE ELECTROMAGNETIC SPECTRUM



Inside the radio wave spectrum

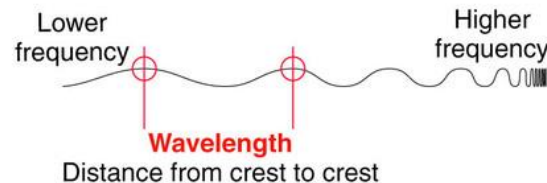
Almost every wireless technology – from cell phones to garage door openers – uses radio waves to communicate. Some services, such as TV and radio broadcasts, have exclusive use of their frequency within a geographic area. But many devices share frequencies, which can cause interference. Examples of radio waves used by everyday devices:

Most of the white areas on this chart are reserved for military, federal government and industry use



The electromagnetic spectrum

Radio waves occupy part of the electromagnetic spectrum, a range of electric and magnetic waves of different lengths that travel at the speed of light; other parts of the spectrum include visible light and x-rays; the shortest wavelengths have the highest frequency, measured in hertz



What is a hertz?

One hertz is one cycle per second. For radio waves, a cycle is the distance from wave crest to crest

1 kilohertz (kHz) = 1,000 hertz

1 megahertz (MHz) = 1 million hertz

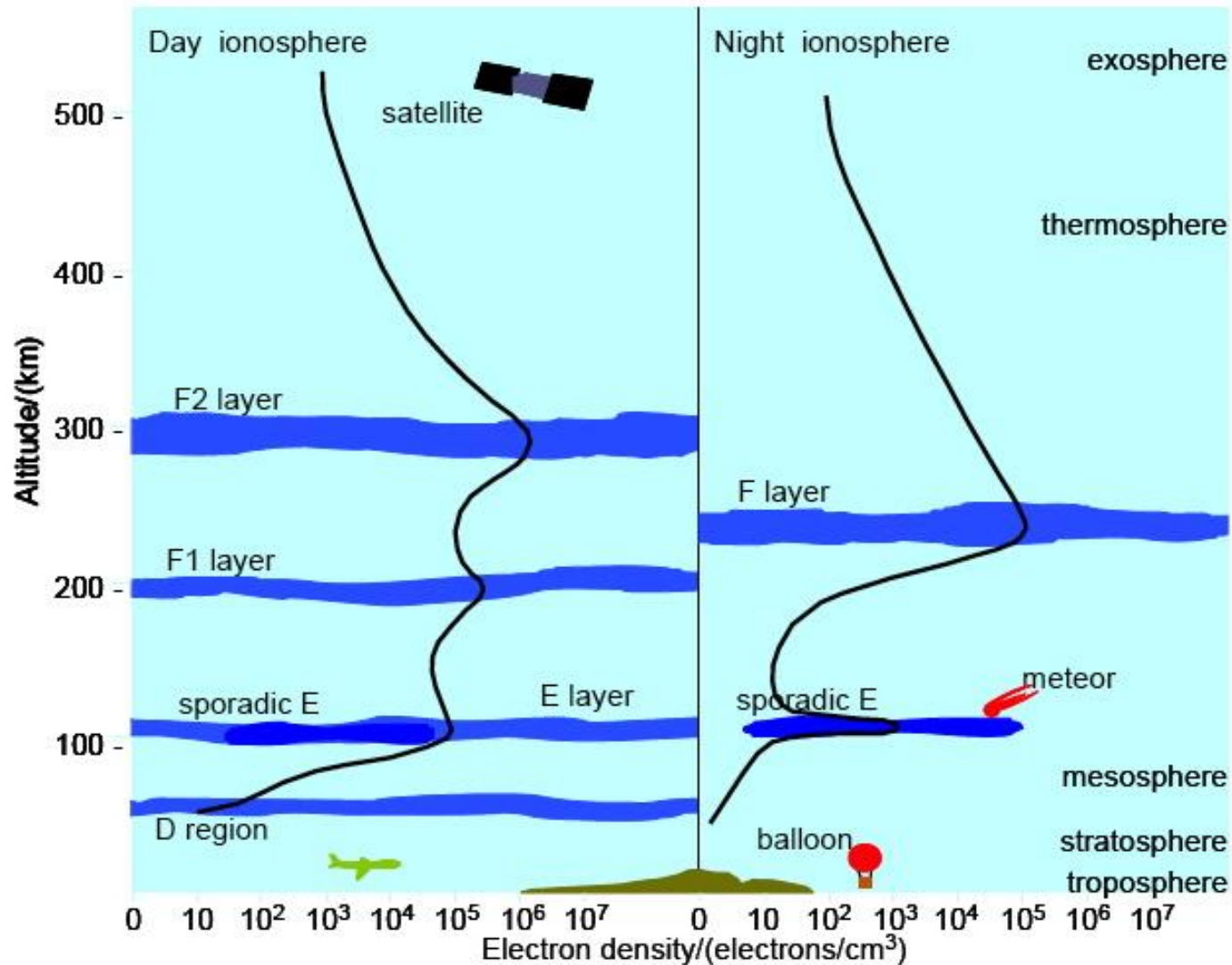
1 gigahertz (GHz) = 1 billion hertz

CLASS	FREQUENCY	WLENGTH	ENERGY
Y	300 EHz	1 pm	1.24 MeV
HX	30 EHz	10 pm	124 keV
SX	3 EHz	100 pm	12.4 keV
SX	300 PHz	1 nm	1.24 keV
EUV	30 PHz	10 nm	124 eV
NUV	3 PHz	100 nm	12.4 eV
NIR	300 THz	1 μ m	1.24 eV
MIR	30 THz	10 μ m	124 meV
FIR	3 THz	100 μ m	12.4 meV
EHF	300 GHz	1 mm	1.24 meV
SHF	30 GHz	1 cm	124 μ eV
UHF	3 GHz	1 dm	12.4 μ eV
VHF	300 MHz	1 m	1.24 μ eV
HF	30 MHz	10 m	124 neV
MF	3 MHz	100 m	12.4 neV
LF	300 kHz	1 km	1.24 neV
VLF	30 kHz	10 km	124 peV
VF/ULF	3 kHz	100 km	12.4 peV
SLF	300 Hz	1 Mm	1.24 peV
ELF	30 Hz	10 Mm	124 feV
	3 Hz	100 Mm	12.4 feV

http://www.bbc.co.uk/bitesize/standard/physics/health_physics/using_the_spectrum/revision/1/

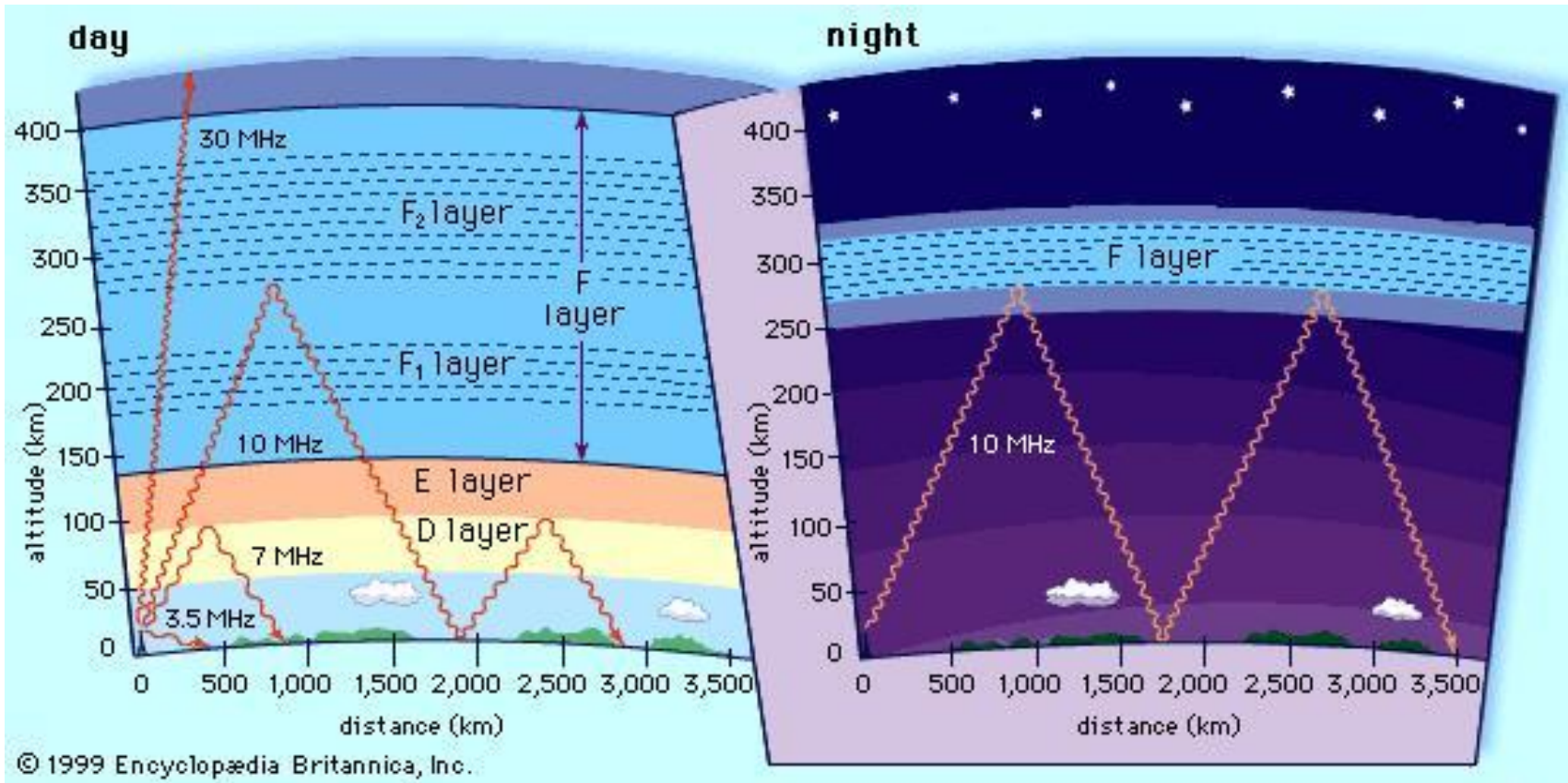
Low Frequency Long Wavelength	Type of wave	Typical source	Example of detector	Approximate wavelength	Typical users	Dangers of over exposure
	Radio: LW MW VHF	electronic circuits, cool objects	aerial and electronic circuit	1km 100m 1m	communications, radio, TV	safe (unless very concentrated)
	Microwaves	electronic circuits, cool objects	aerial and electronic circuit	1cm (10^{-2} m)	communications satellites, telephony, heating water and food	burning, if concentrated
	Infra-red (ir)	electronic devices, warm objects, sun	electronic detectors, special film, blackened thermometer	0.1mm (10^{-4} m)	magic eyes in security lighting, remote control (e.g. TV)	burning, if concentrated
	Light Red Orange Yellow Green Blue Indigo Violet	electronic devices(LED), hot objects, sun	eye, film, electronic devices (e.g.LDR)	0.001mm (10^{-6} m)	seeing, photography	burning, blindness, if concentrated
	Ultra-violet (uv)	gas discharge, very hot objects, amps, sun	film	0.00001mm (10^{-8} m)	sun-tan lamp, making ions, making Vitamin D	sunburn, skin cancer
	X-rays	very fast electrons hitting a metal target	film	10^{-10} m	imaging defects in bones, hidden devices	cell destruction, cell mutation, cancer
	Gamma rays (γ)	radioactive nuclei decaying	film, GM tube	10^{-12} m	medical tracers, killing cancerous cells, steralisation	cell destruction, cell mutation, cancer
						4
High Frequency Short Wavelength						

Structure of the Atmosphere



<http://www.amateur-radio-wiki.net/index.php?title=Propagation>

Propagation of Radio Waves

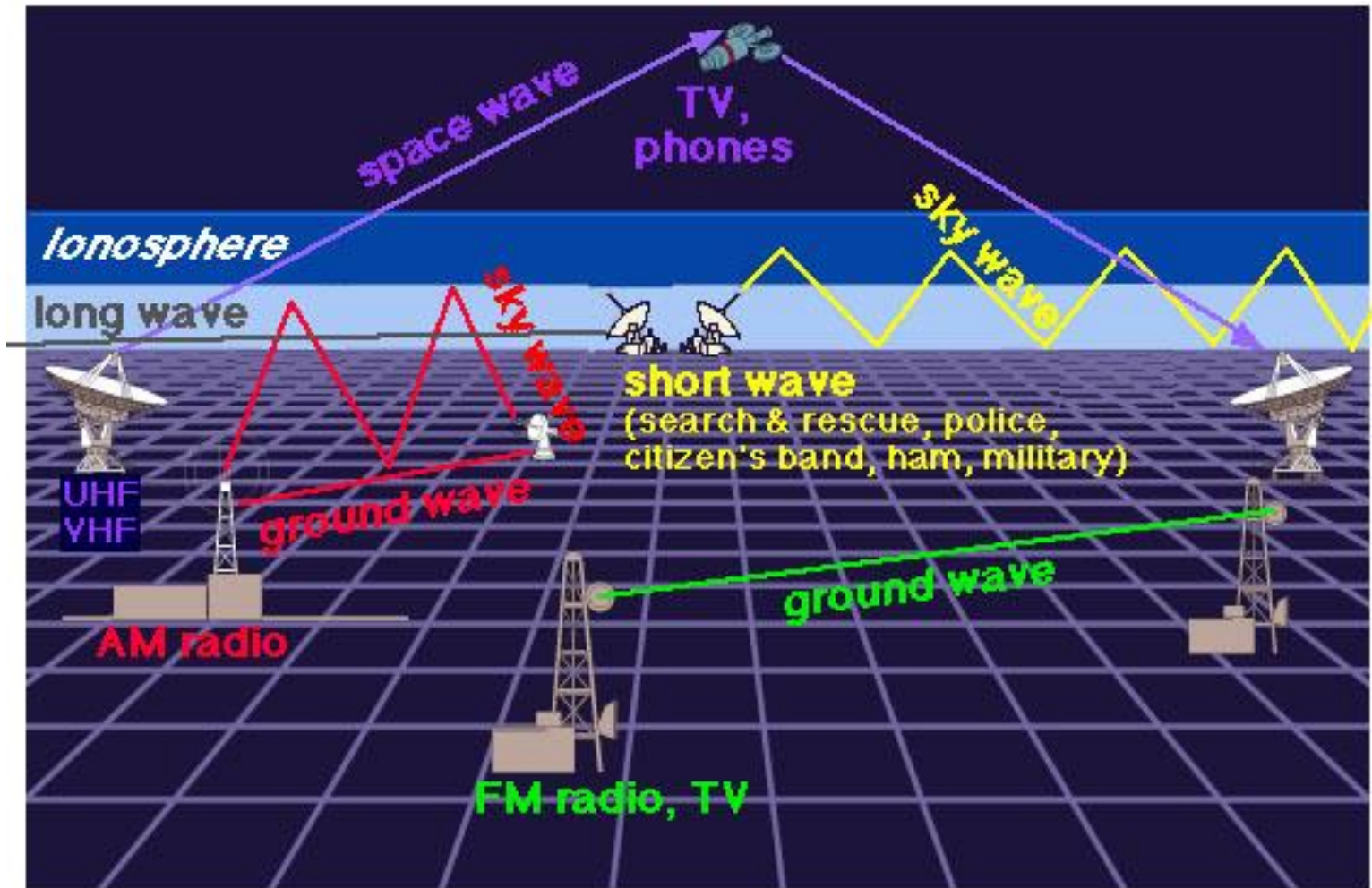


<http://www.britannica.com/science/radio-wave/images-videos>

Propagation of Radio Waves

Radio Band		Frequency	Propagation Via
VLF	Very Low Frequency	3 - 30 kHz	- Guided between the earth and the ionosphere
LF	Low Frequency	30 - 300 kHz	- Guided between the earth and the ionosphere - Ground Waves
MF	Medium Frequency	300 - 3000 kHz	- Ground wave during the day - E layer ionospheric reflection at night
HF	High Frequency (Short Wave)	3 - 30 MHz	- E layer ionospheric reflection - F layer ionospheric reflection
VHF	Very High Frequency	30 - 300 MHz	- Line-of-sight - Es layer ionospheric reflection
UHF	Ultra High Frequency	300 - 3000 MHz	- Line-of-sight

Propagation of Radio Waves



<http://www.yaesu.org.uk/5.html>

Propagation of Radio Waves

Radio propagation categories

There are a number of categories into which different types of radio propagation can be placed. These relate to the effects of the media through which the signals propagate.

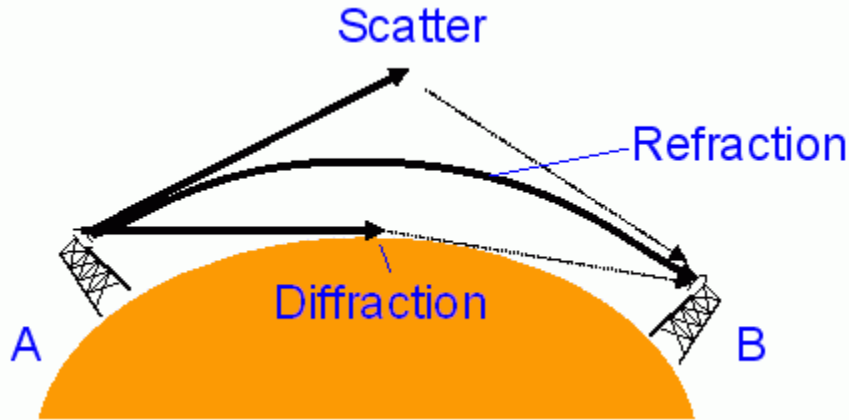
Free space propagation: The radio signals travel in free space, or away from other objects which influence the way in which they travel. It is only the distance from the source which affects the way in which the field strength reduces. This type of radio propagation is encountered with signals travelling to and from satellites.

Ground wave propagation (Surface wave): When signals travel via the ground wave they are modified by the ground or terrain over which they travel. They also tend to follow the earth's curvature. Signals heard on the medium wave band during the day use this form of propagation.

Ionospheric propagation (Sky wave): The radio signals are modified and influenced by the action of the free electrons in the upper reaches of the earth's atmosphere called the ionosphere. This form of radio propagation is used by stations on the short wave bands for their signals to be heard around the globe.

Tropospheric propagation: The signals are influenced by the variations of refractive index in the troposphere just above the earth's surface. Tropospheric radio propagation is often the means by which signals at VHF and above are heard over extended distances

Propagation of Radio Waves



At higher altitudes of the sky, the pressures and the temperatures are lower. As a result, the refractive index of the atmosphere usually falls with height. Radio waves get bent downwards by **refraction** and thus propagate beyond the geometric horizon, which extends the range of propagation.

Radio waves can get bent around obstacles by **diffraction**. The effects are significant when the wavelength of the waves is similar to the size of the diffracting object.

Radio waves can be **reflected** from the ground surface of the Earth, which may cause multipath interference to the signals.

Radio signals may be **scattered** to receivers beyond the horizon by eddies and turbulences in the Troposphere. This mechanism is the dominant mode for long-range VHF/UHF propagation.

Propagation of Radio Waves

Definition of **decibel (dB)**

$$\text{Power ratio in dB} = 10 \log \frac{P_2}{P_1}$$

where P_1 and P_2 are the powers to be compared.

Power ratio (P_2/P_1)	dB
10^3	30
10	10
5	7.0
2	3.0
1	0
0.5	- 3.0
0.2	- 7.0
0.1	- 10
10^{-5}	- 50

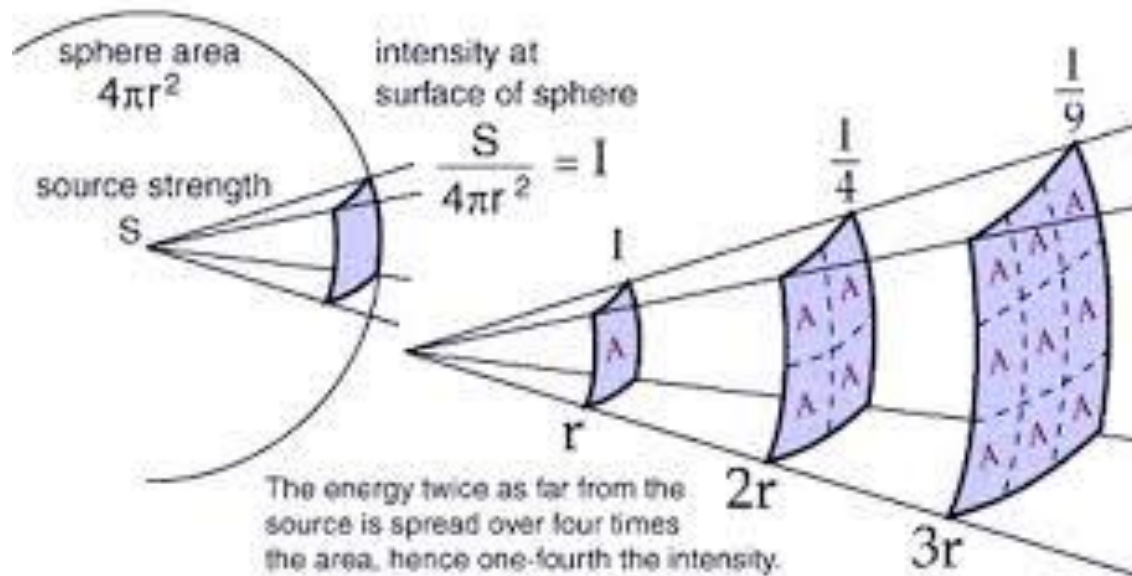
Also $P \text{ in dBm} = 10 \log \frac{P \text{ (in mW)}}{1 \text{ mW}}$ $P \text{ in dBW} = 10 \log \frac{P \text{ (in W)}}{1 \text{ W}}$

Propagation of Radio Waves

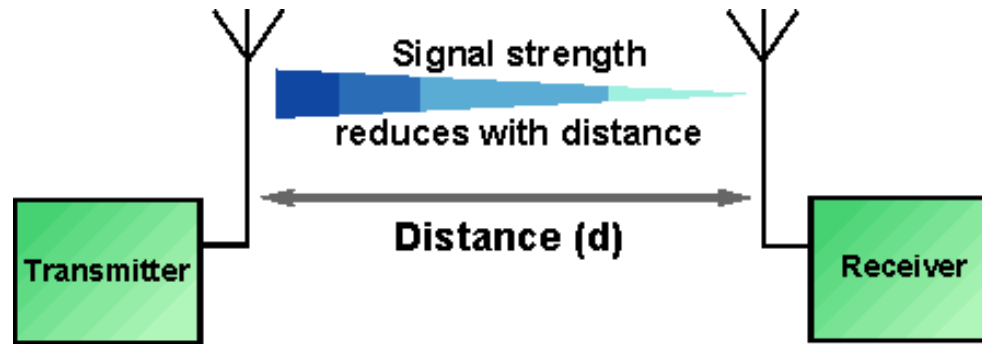
A radio wave launched from a point in any given direction propagates outwards from that point at the speed of light. The intensity at a receiving point, defined as the rate of flow of wave energy (i.e., power) per unit area in W/m^2 , is given by

$$\text{Intensity } I = \frac{\text{Transmitted power}}{\text{Surface area of a sphere of radius } r} = \frac{S}{4\pi r^2}$$

where r is the distance between the receiving point and the emitting point.



Propagation of Radio Waves



The **free space path loss (FSPL)** of radio waves, defined as the ratio of the received power to the transmitted power for an isotropic receiving antenna, is given by

$$\text{Free Space Path Loss} = \frac{4\pi d^2}{A_{eff}} = \frac{4\pi d^2}{\lambda^2/4\pi} = \left(\frac{4\pi df}{c}\right)^2$$

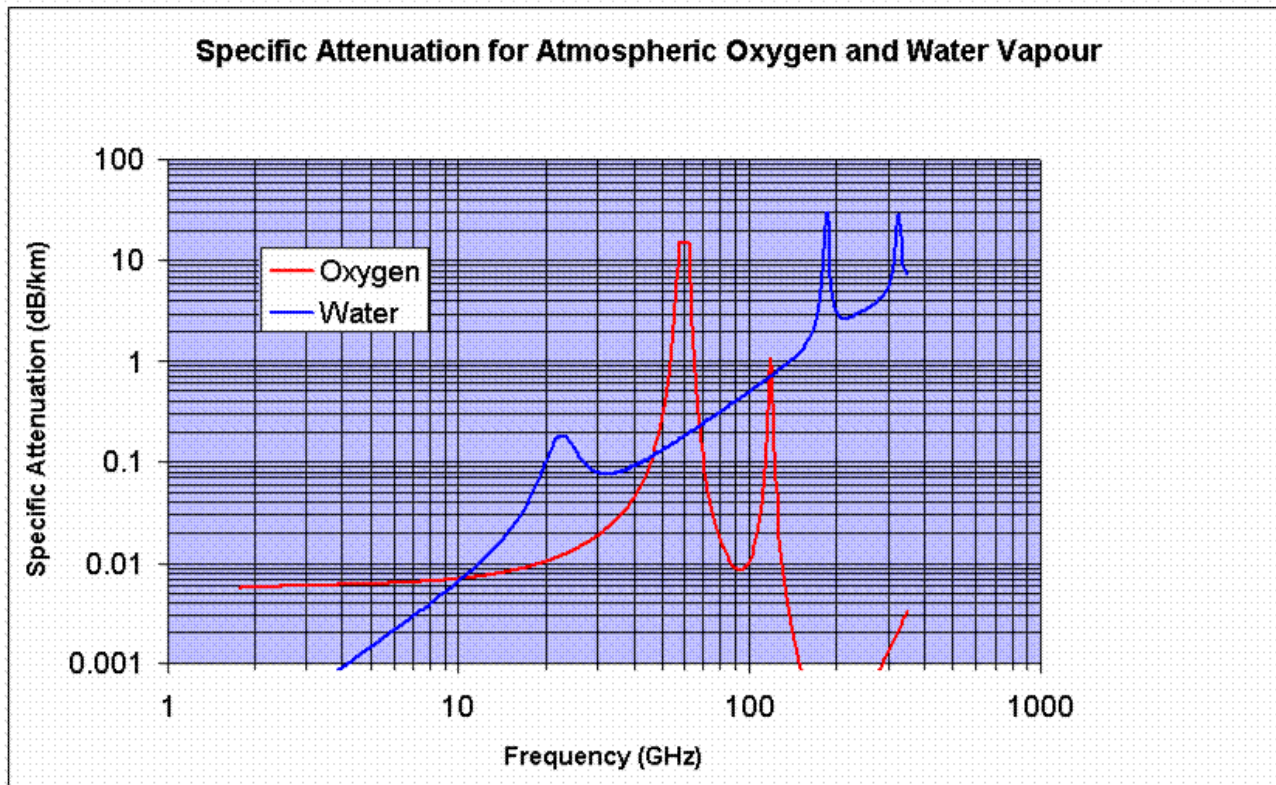
$$\text{Free Space Path Loss} = 32.45 + 20\log(d) + 20\log(f) \quad \text{in dB}$$

where d (in km) is the distance between the receiver and the transmitter, f (in MHz) is the radio frequency, and A_{eff} is the effective area of the isotropic antenna.

Propagation of Radio Waves

Gaseous Attenuation

Air is made up of Nitrogen (N_2) 78%; Oxygen (O_2) 21%; Argon (Ar) 0.9%; Carbon dioxide (CO_2) 0.1% Neon, Helium, Krypton 0.0001%; Water vapor (H_2O) 0-2%, and trace quantities of Methane (CH_4), Sulphur dioxide (SO_2), Ozone (O_3), Nitrogen oxide (NO), Nitrogen Dioxide (NO_2), etc. The gas molecules may absorb radio waves.



Propagation of Radio Waves

Radio link power budget calculation:

Received power = Transmitted power (isotropic source) - Path Loss
+ Receiver antenna gain

Path loss = Free space path loss + Gas loss + Additional path loss

* An isotropic antenna has a 0-dB antenna gain, i.e., no gain.

Example:

Handheld radio operating at 448 MHz

Transmitted power = 0.25 W = -6 dBW

Antenna gain = 3 dB

1 km line of sight path:

Free space path loss = $32.45 + 20\log(1) + 20\log(448) = 85$ dB

Received power = -6 dBW - 85 dB + 3 dB = -88 dBW = 1.6×10^{-9} W
or 1.6 nW (ignoring all other losses)

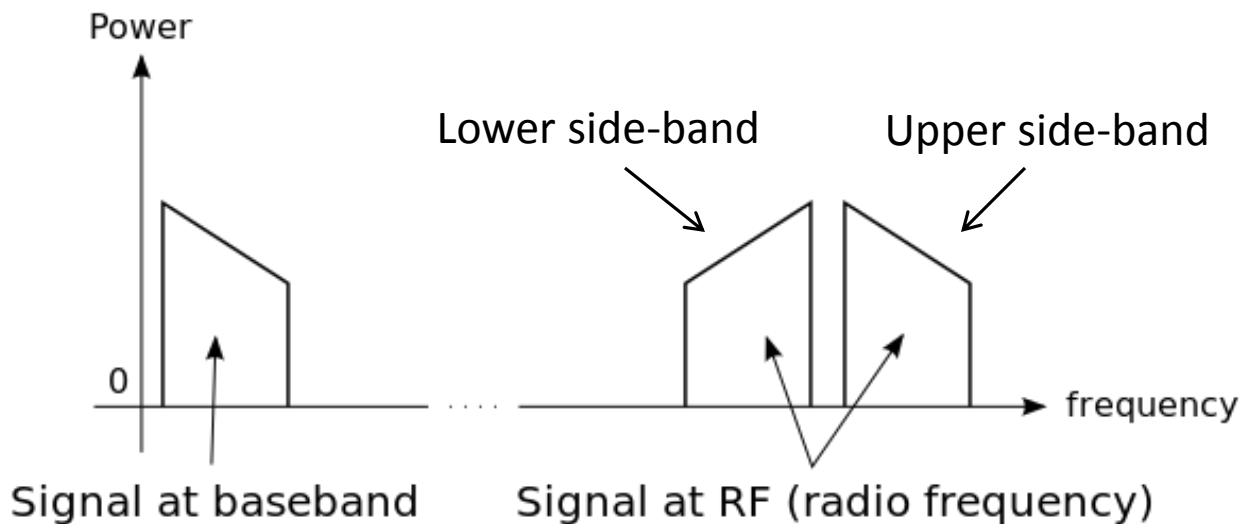
Why Radio?

Whereas telephone signals can be transmitted at audio frequencies, the same is not really a practical proposition for radio transmissions. The main reason for this is that the optimum length of a radio antenna is a half or a quarter of a wavelength. Since a typical audio frequency of 3,000 hertz has a wavelength of approximately 100 kilometres, the antenna would need to have a length of 25 kilometres to be effective - not a realistic proposition. By comparison, a radio frequency of 100 megahertz would have a wavelength of approximately 3 metres, and could use an antenna 80 centimetres long. It becomes necessary, therefore, to use a radio frequency carrier signal in order to transmit audio signals, which are used to modulate the carrier waveform.

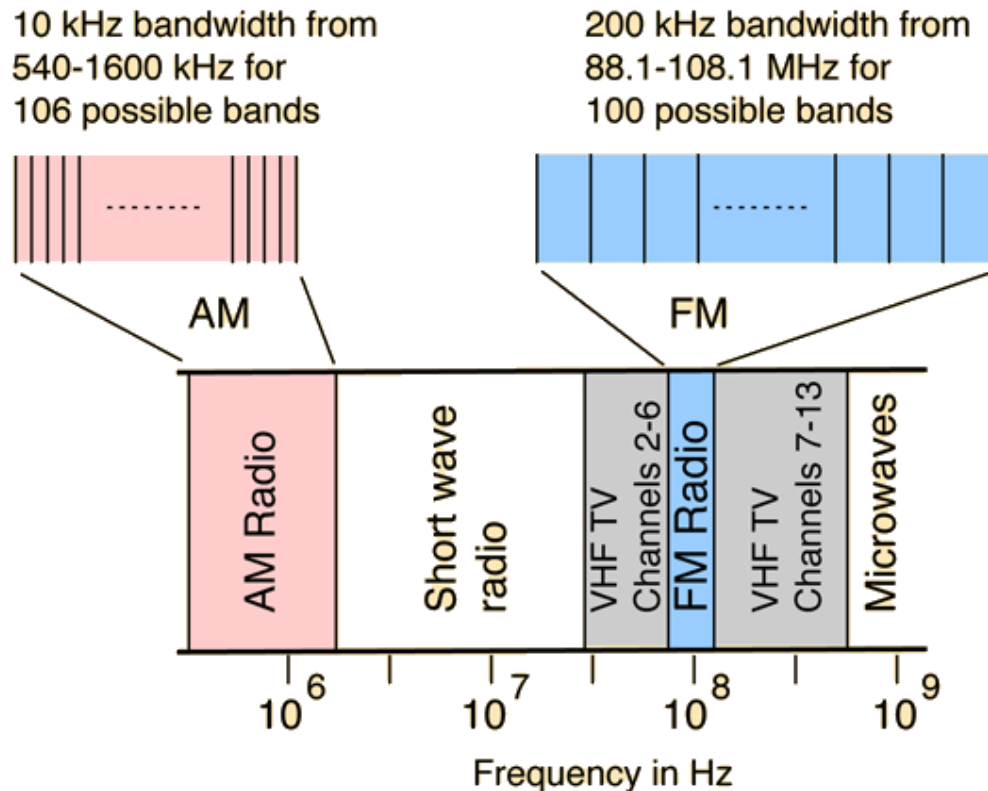


Modulation

The original frequency range of a transmission signal, which is referred to as the **baseband signal**, is converted, or modulated, to a much higher frequency range. For example, an audio signal, which has a baseband range from 20 to 20,000 Hz, may be transmitted on a radio frequency (**carrier signal**) and modulated to a much higher, inaudible, frequency range.



Radio Frequency Bands



Amplitude modulated (AM) radio is limited to 5kHz maximum frequency by the width of the AM bands. Music transmission by AM radio is limited in fidelity.

Frequency modulated (FM) radio is limited to 15kHz for music transmission, which allows high fidelity signal transmission. The operational bandwidth is limited to 150 kHz, with 25 kHz on each side of that for guard bands.

Amplitude Modulation (AM)

Amplitude modulation (AM) is a modulation technique in which the amplitude of a high frequency sine wave (the carrier) is varied in direct proportion to that of a modulating signal (baseband signal). The modulating signal carries the required information and often consists of audio data, as in the case of AM radio broadcasts or two-way radio communications.

$$A(t) = [1 + M(t)]A_0 \sin(2\pi f_c t)$$

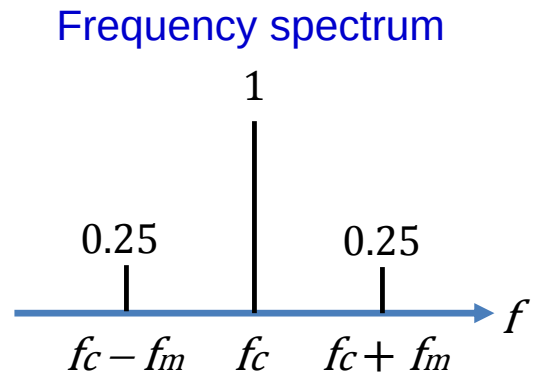
f_c : Carrier frequency

$$|M(t)| \leq 1$$

f_m : Modulation frequency

Example:

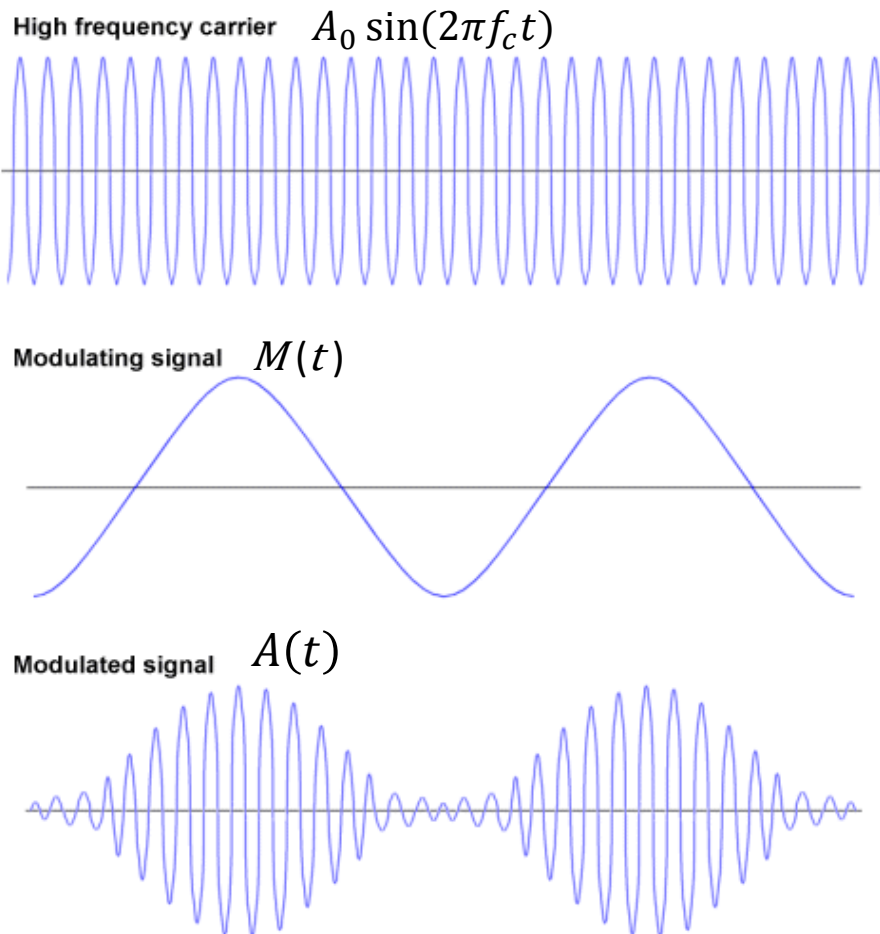
With $M(t) = 0.5 \cos(2\pi f_m t)$, we have



$$\begin{aligned} A(t) &= [1 + 0.5 \cos(2\pi f_m t)]A_0 \sin(2\pi f_c t) \\ &= A_0 \{ \sin(2\pi f_c t) + 0.25 \sin [2\pi(f_c + f_m)t] + 0.25 \sin [2\pi(f_c - f_m)t] \} \end{aligned}$$

There are three frequency components in the modulated signal, $f_c + f_m$, f_c , $f_c - f_m$, and the **bandwidth** of the signal is $2f_m$.

Amplitude Modulation (AM)

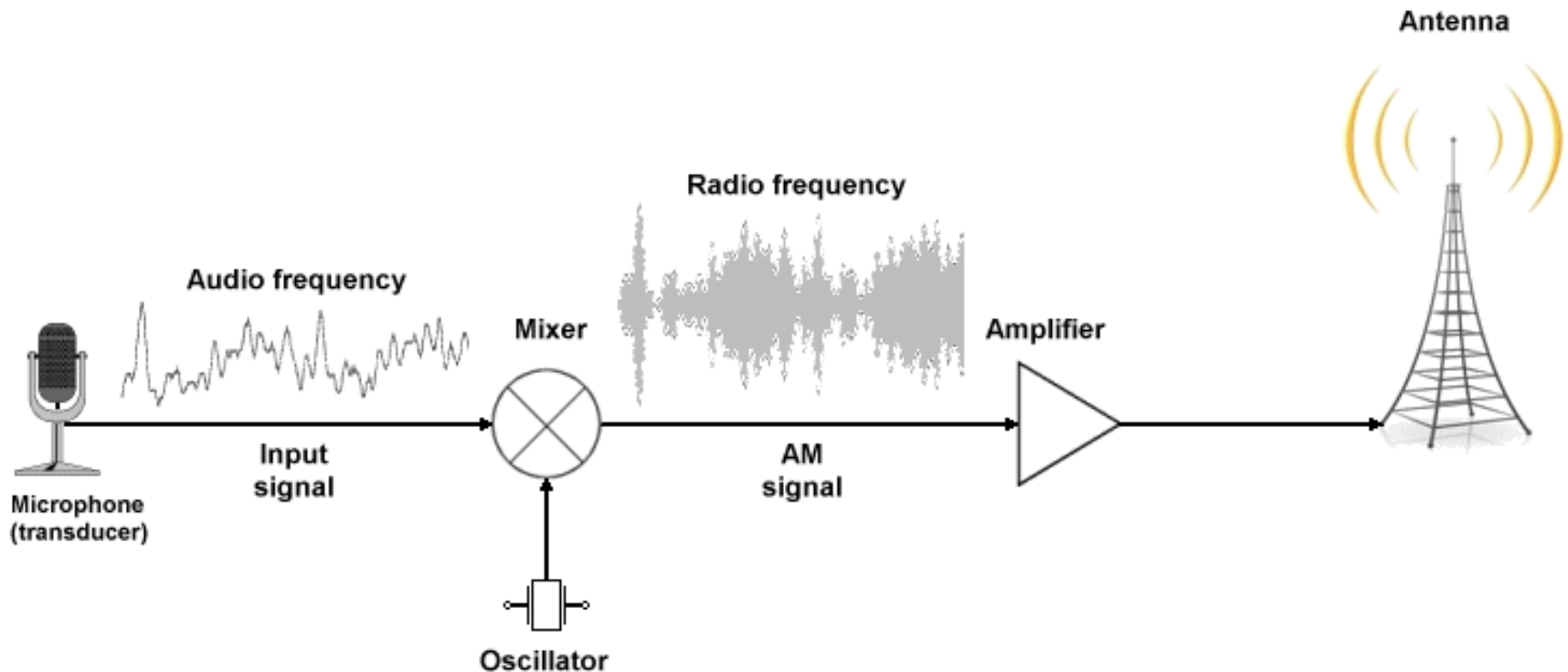


http://www.technologyuk.net/telecommunications/telecom_principles/amplitude_modulation.shtml

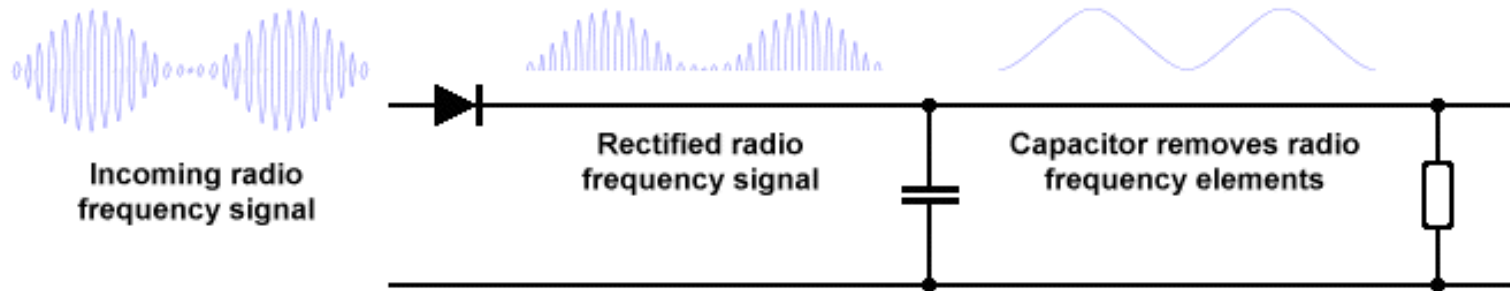
The highest frequency in the baseband signal determines the bandwidth of the modulated signal. Or, the bandwidth allocated to an RF channel limits the bandwidth of the baseband signal it can carry.

Amplitude Modulation (AM)

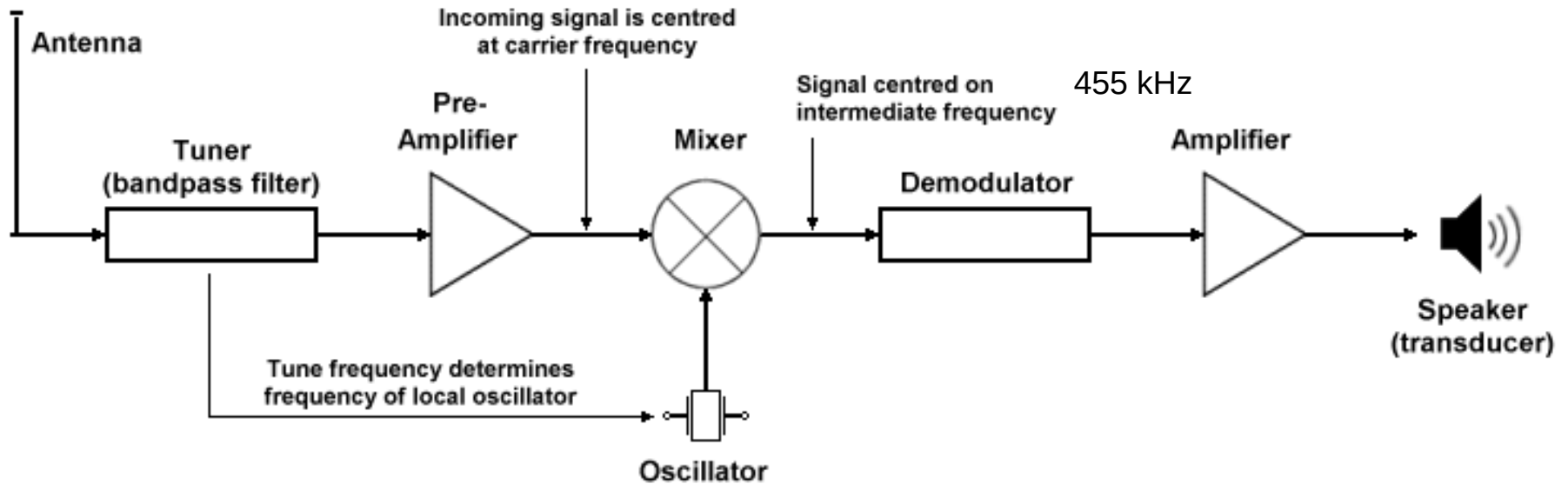
The high frequency carrier is modulated by adding the modulating signal to it in a mixer.



Amplitude Modulation (AM)



Basic diode detector circuit



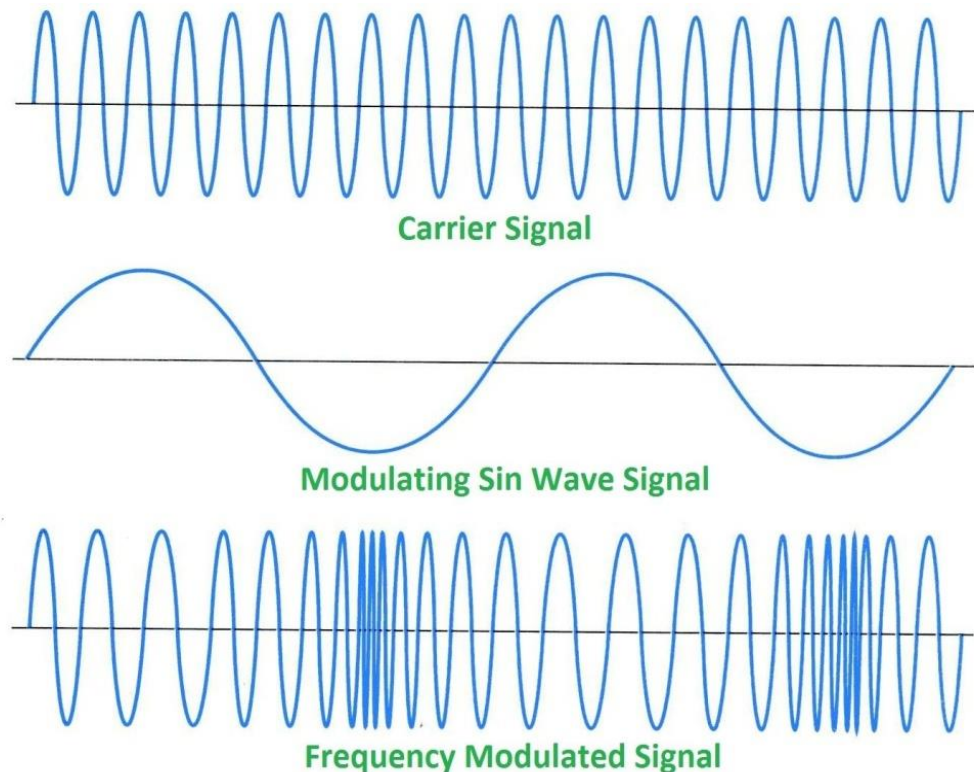
Superheterodyne AM receiver

Frequency Modulation (FM)

Frequency modulation (FM) is a modulation technique in which the instantaneous frequency of a high frequency sine wave (usually at a radio frequency) is varied in direct proportion to the amplitude of a modulating signal.

$$A(t) = A_0 \sin\left[2\pi f_c t + \frac{\Delta f}{f_m} \sin(2\pi f_m t)\right] \quad \Delta f: \text{Peak frequency deviation}$$

FM broadcasts on the VHF bands can provide exceptionally high-quality audio. It is also used for a variety of forms of two-way radio communications, especially for mobile radio communications, which is being used in taxis and many other forms of vehicle.

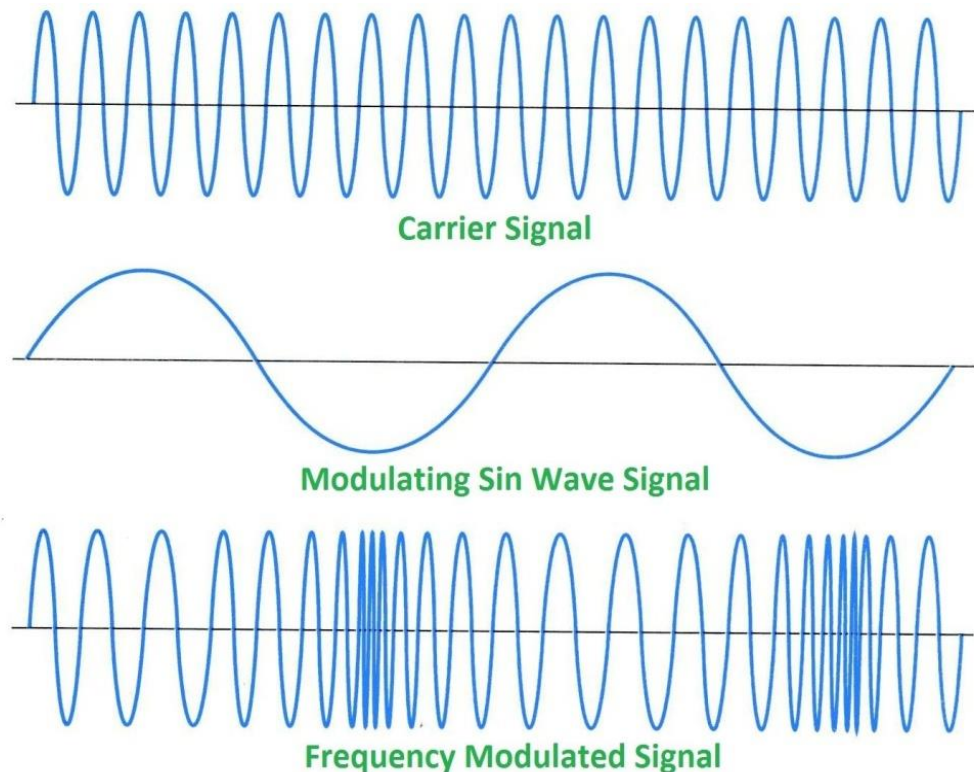


Frequency Modulation (FM)

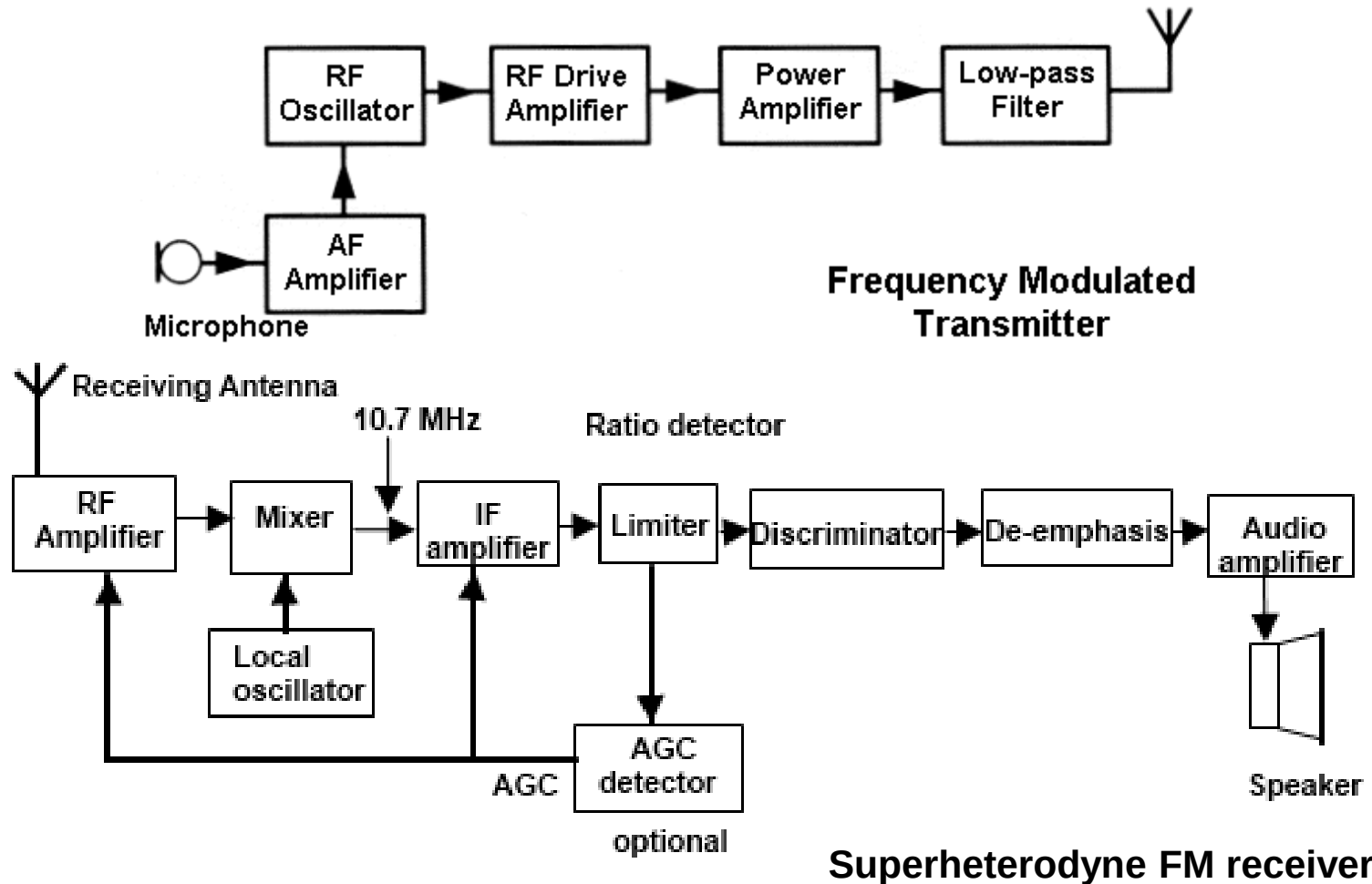
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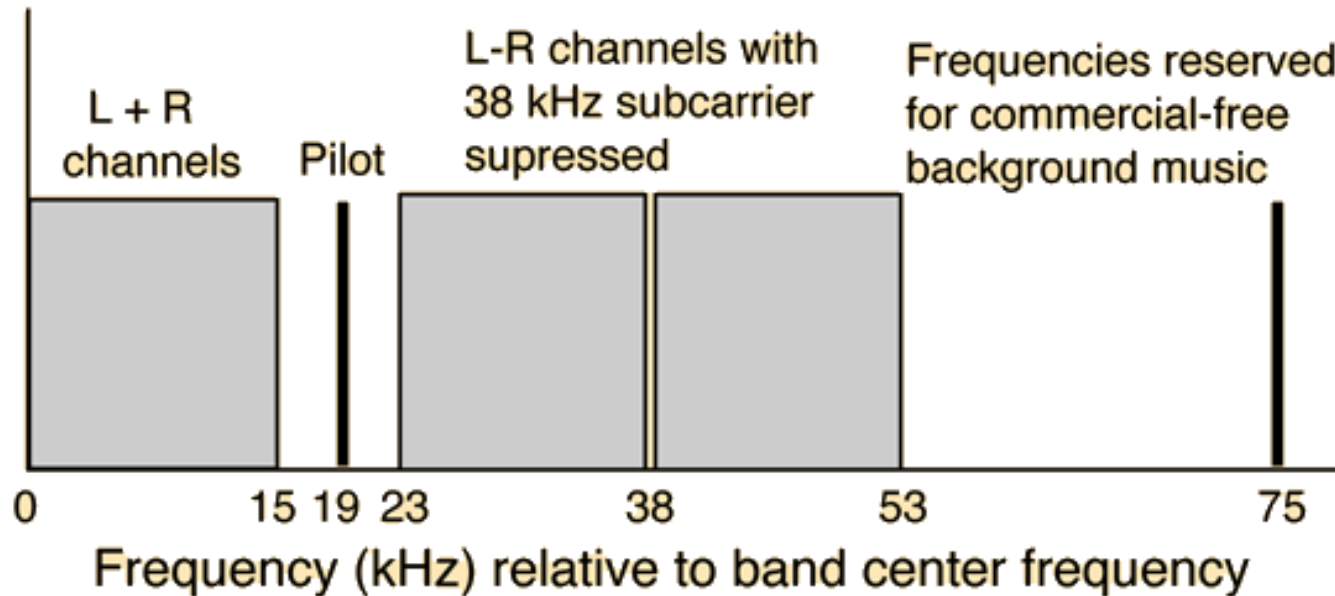


An FM discriminator is able to convert frequency changes into amplitude changes.

<http://www.daenotes.com/electronics/communication-system/superheterodyne-fm-receiver>

Frequency Modulation (FM)

FM Stereo Broadcast Band



The bandwidth assigned to each FM station is sufficiently wide to broadcast high-fidelity, stereo signals. The carrier frequency is directly modulated with the sum of the left and right channel audio signals. A 38kHz subcarrier also modulates the carrier, and that subcarrier is modulated with the difference, $L - R$, of the audio signals. The FM tuner then decodes this signal and separates the Left and Right audio channels.

Comparison Between AM and FM

	AM	FM
Origin	AM method of audio transmission was first successfully carried out in the mid 1870s.	FM radio was developed in the United states in the 1930s, mainly by Edwin Armstrong.
Pros and cons	AM has poorer sound quality compared with FM, but is cheaper and can be transmitted over long distances. It has a lower bandwidth so it can have more stations available in any frequency range.	FM is less prone to interference than AM. However, FM signals are impacted by physical barriers. FM has better sound quality due to higher bandwidth.
Frequency range	AM radio ranges from 535 to 1705 KHz	FM radio ranges in a higher spectrum from 88 to 108 MHz.
Bandwidth requirement	The modulating signal has a bandwidth of 5kHz and the bandwidth of an amplitude-modulated signal is 10kHz.	The modulating signal has a bandwidth of 15kHz and the bandwidth of an frequency-modulated signal is 150kHz.
Complexity	Transmitter and receiver are simple.	Transmitter and receiver are more complex as variation of modulating signal has to be converted and detected from corresponding variation in frequencies.
Noise	AM is more susceptible to noise because noise affects amplitude, which is where information is "stored" in an AM signal.	FM is less susceptible to noise because information in an FM signal is transmitted through varying the frequency, and not the amplitude.

http://www.diffen.com/difference/AM_vs_FM

How Does Radio Transmission Work? (8 min)

<https://www.youtube.com/watch?v=Y6G9uHeRD3w>

Exercise

1. List the following in order of frequency, lowest first: 5 GHz radar, 3 micron infrared radiation, 20 kHz sonar, 4 kHz sound in air, blue light, and 2000 m radio.
2. A radar transmitter has a 20 W power source. If the source radiates isotropically in all directions, what will the intensity be 50 m from the source expressed in mW/m^2 .
3. An amplifier has a power gain of 25 dB. For an output power of 10 W, what is the input signal power? Express the answer in both W and dBW.
4. A handheld radio operating at 448 MHz emits an equivalent isotropic power of 2.0 W. The receiving antenna has a noise power of -148 dBW and a gain of 5 dB. For an acceptable level of reception, the signal-to-noise ratio (SNR) (i.e., the ratio of the signal power to the noise power) at the receiving antenna must be at least 20 dB. Estimate the maximum line-of-sight range for the radio communication.

Exercise (Continue)

5. The commercial AM radio channels are separated by 10 kHz. What is the maximum bandwidth of the base-band signal each of these channels can carry?
6. A 1050 kHz carrier is amplitude-modulated by a voice signal whose highest frequency component is 3.4 kHz. What are the frequency range and the bandwidth of the modulated signal?
7. Which frequency components are present in the AM signal $A(t) = A_0[1 + a \sin(2\pi f_m t)] \sin(2\pi f_c t)$, where $f_m = 2.5$ kHz, $f_c = 800$ kHz, and $a = 0.08$? What are their relative strengths? Sketch the amplitude spectrum of the signal, which is a plot with the horizontal axis for the frequency and the vertical axis for the amplitude.
8. Consider the FM signal $A(t) = A_0 \sin[2\pi f_c t + \frac{\Delta f}{f_m} \sin(2\pi f_m t)]$, where $f_m = 2.5$ kHz, $f_c = 88.1$ MHz, and $\Delta f/f_m = 0.08$. Sketch the amplitude spectrum of the signal. What is the bandwidth of the signal? [Note: You may take $\sin x \cong x$ and $\cos x \cong 1$ for x (in radian) $\ll 1$.]