COMMUNICATION ELECTRONICS

By
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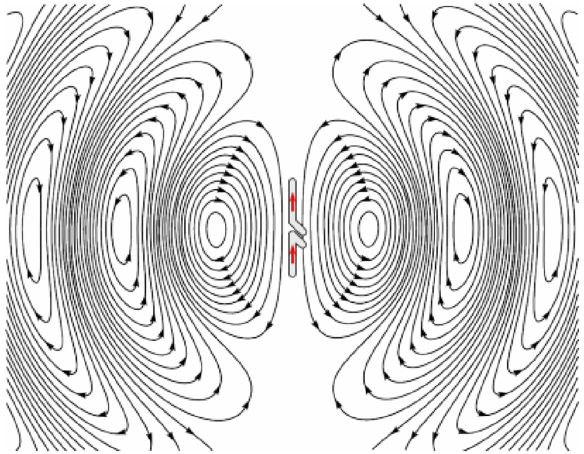
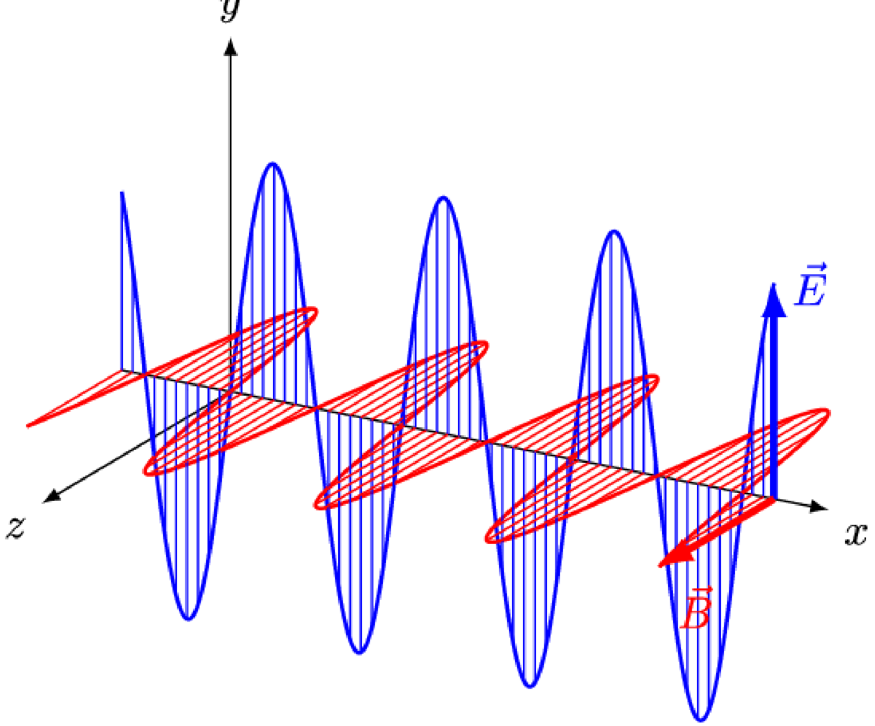
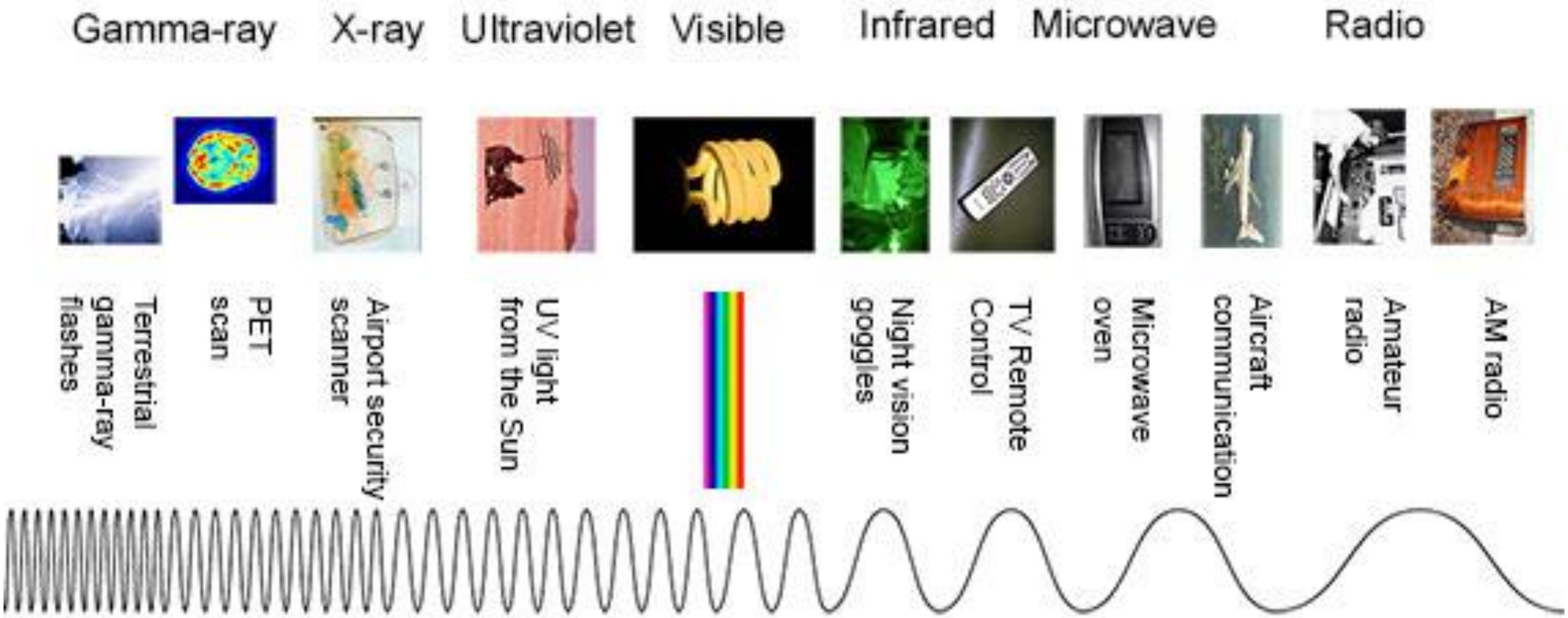
Radio Waves





- **Radio waves** are a type of electromagnetic radiation with wavelengths in the electromagnetic spectrum longer than infrared light.
- **Radio waves** have frequencies as high as 300 gigahertz (GHz) to as low as 30 hertz (Hz). At 300 GHz, the corresponding wavelength is 1 mm, and at 30 Hz is 10,000 km.

EM Spectrum



Gamma-ray
X-ray
Ultraviolet
Visible
Infrared
Microwave
Radio
Terrestrial gamma-ray flashes
PET scan
Airport security scanner
UV light from the Sun
Night vision goggles
TV Remote Control
Microwave oven
Aircraft communication
Amateur radio
AM radio

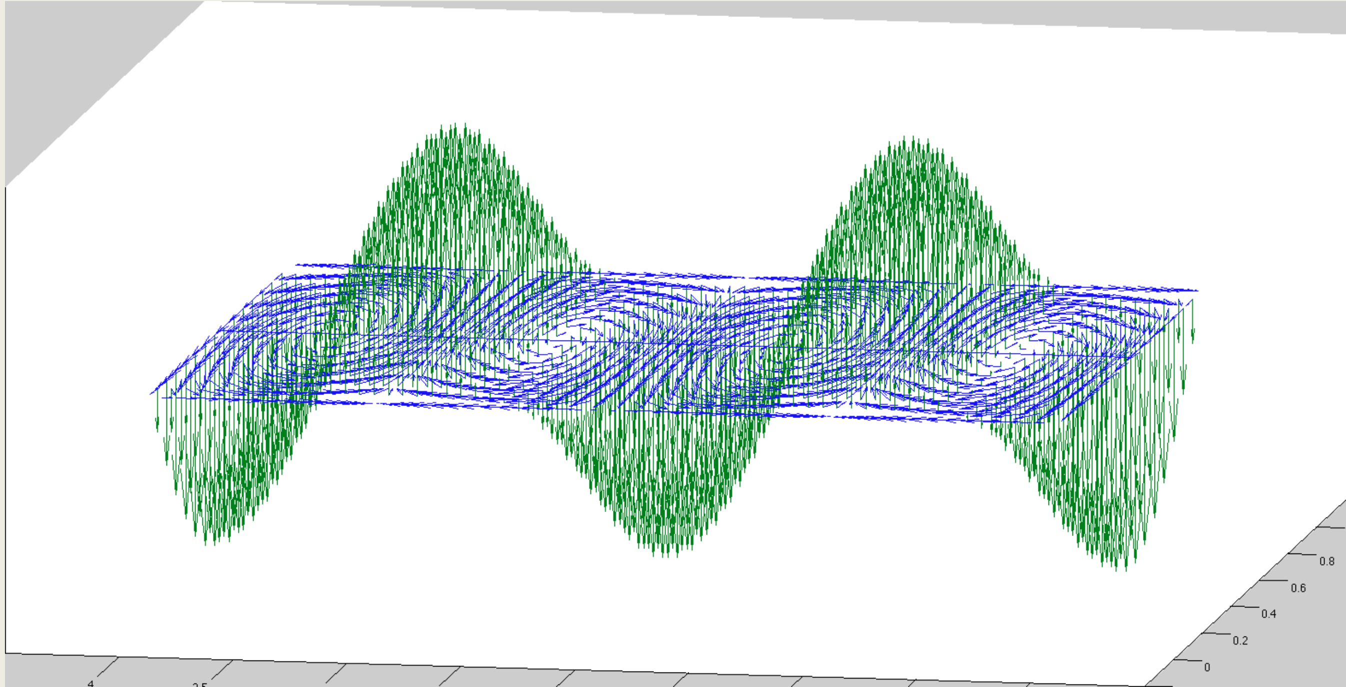
Radio Spectrum

f	λ	Band	Description
30–300 Hz	10^4–10^3 km	ELF	Extremely low frequency
300–3000 Hz	10^3–10^2 km	VF	Voice frequency
3–30 kHz	100–10 km	VLF	Very low frequency
30–300 kHz	10–1 km	LF	Low frequency
0.3–3 MHz	1–0.1 km	MF	Medium frequency
3–30 MHz	100–10 m	HF	High frequency
30–300 MHz	10–1 m	VHF	Very high frequency
300–3000 MHz	100–10 cm	UHF	Ultra-high frequency
3–30 GHz	10–1 cm	SHF	Superhigh frequency
30–300 GHz	10–1 mm	EHF	Extremely high frequency (millimeter waves)

Propagation of Radio waves

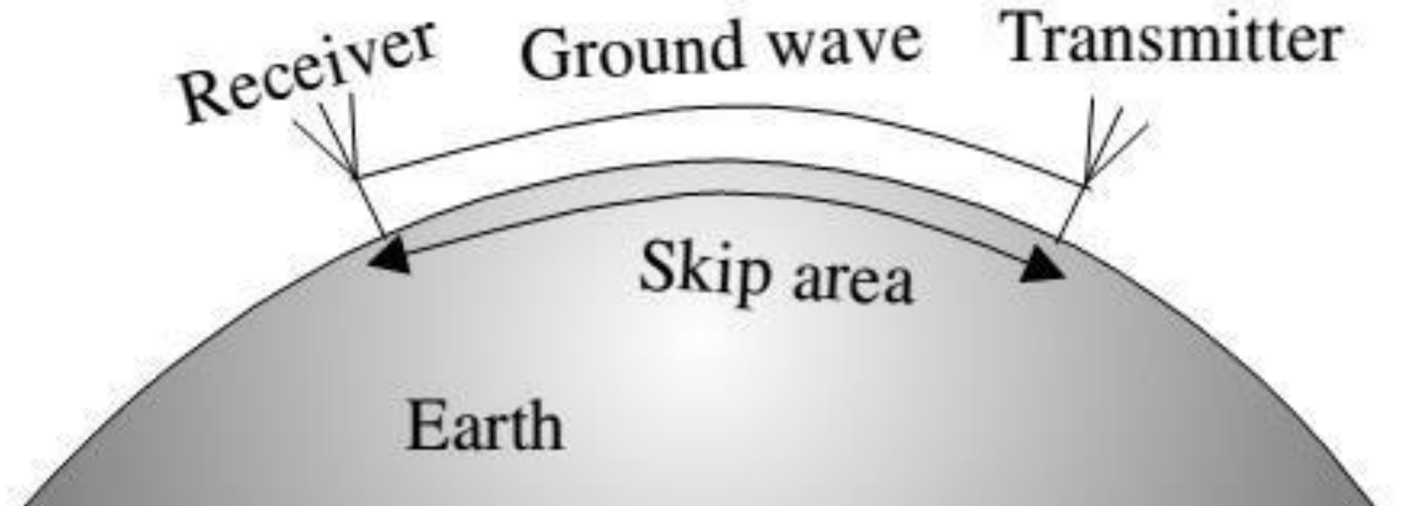
Radio propagation is the behavior of **radio waves** as they travel, or are propagated, from one point to another, or into various parts of the atmosphere

- Ground Wave
- Space Wave
- Sky Wave

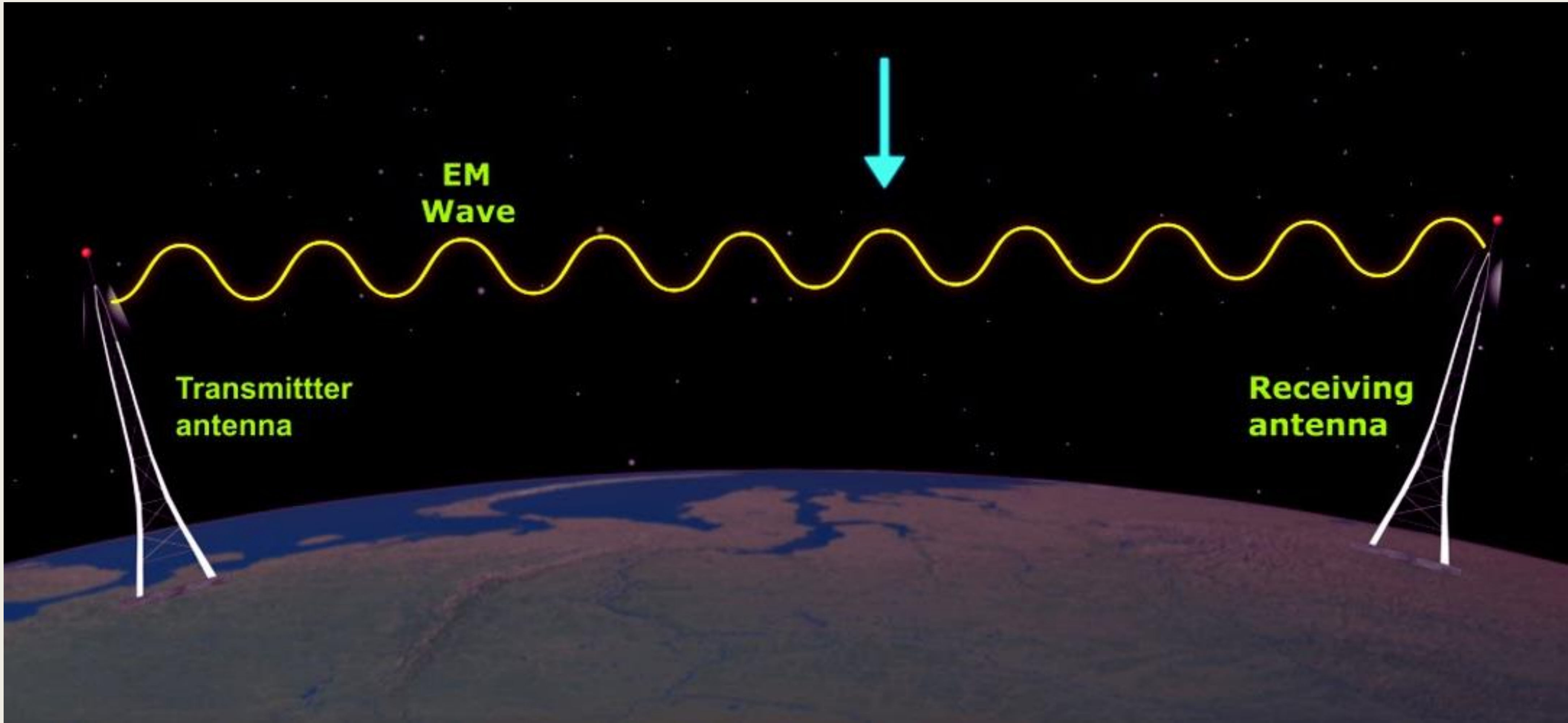


Ground Wave

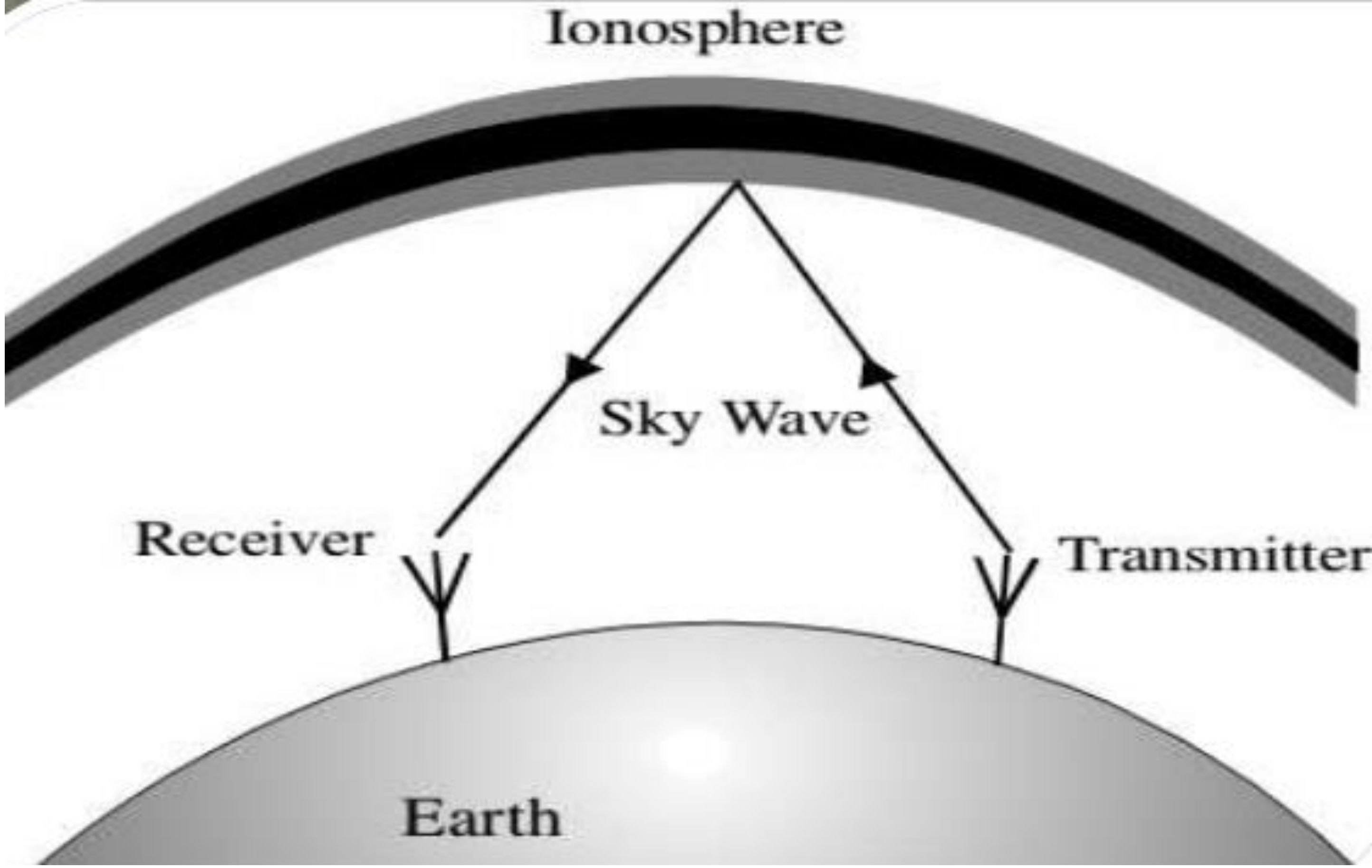
- In the VLF, LF and MF bands the propagation of waves, also called as **ground waves** follow the curvature of the earth.
- The maximum transmission ranges of these waves are of the order of a few hundred kilometers.
- They are used for low bandwidth transmissions such as Amplitude Modulation (AM) radio broadcasting.



Ground wave



Sky Wave

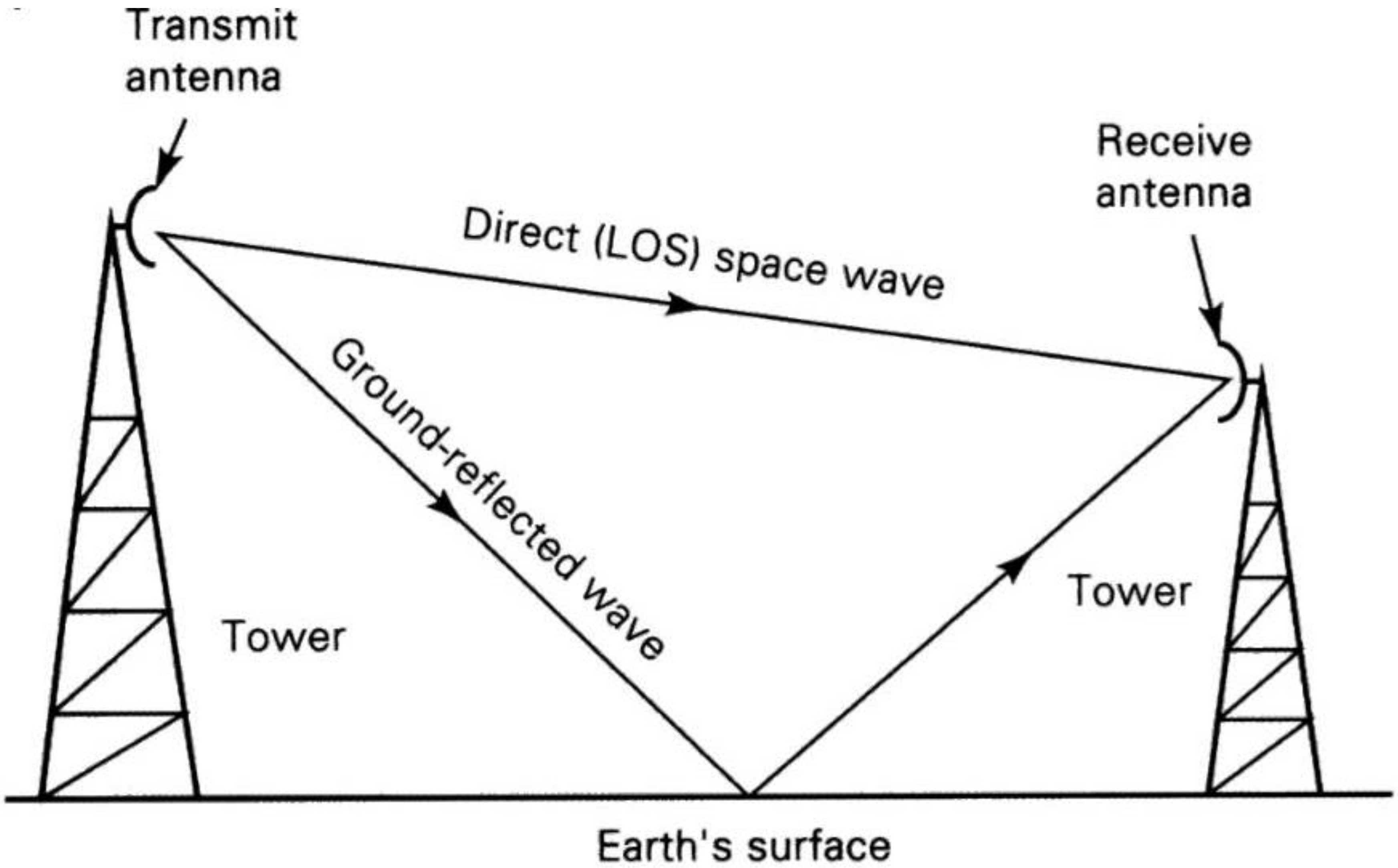


- *The sky waves are the radiowaves of frequency between 2 MHz to 30 MHz.*
- *These radio waves can propagate through atmosphere and are reflected back by the ionosphere of earth's atmosphere.*
- *Since these waves go from transmitter antenna to receiver antenna while traveling through sky, hence their propagation is known as sky wave propagation*
- *Used in military use and Amateur radio*

Space Wave

- *The space waves are the radio waves of very high frequency (i.e. between 30 MHz to 300 MHz or more).*
- *The space waves can travel through atmosphere from transmitter antenna to receiver antenna either directly or after reflection from ground in the earth's troposphere region.*
- *That is why the space wave propagation is also called as tropospherical propagation*
- *The space wave propagation is utilized in very high frequency (VHF) bands (between 30 MHz to 300 MHz), ultra high frequency (UHF) bands and microwaves.*
- *The line of sight distance is the distance between transmitting antenna and receiving antenna at which they can see each other*
- *The space wave propagation is utilized in television communication, radar communication etc*

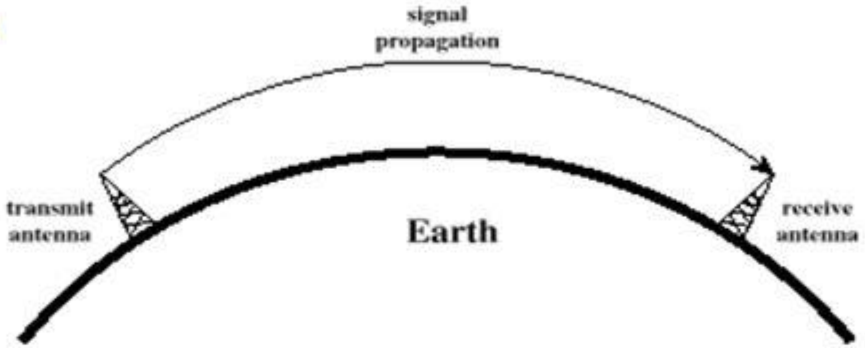
Space Wave

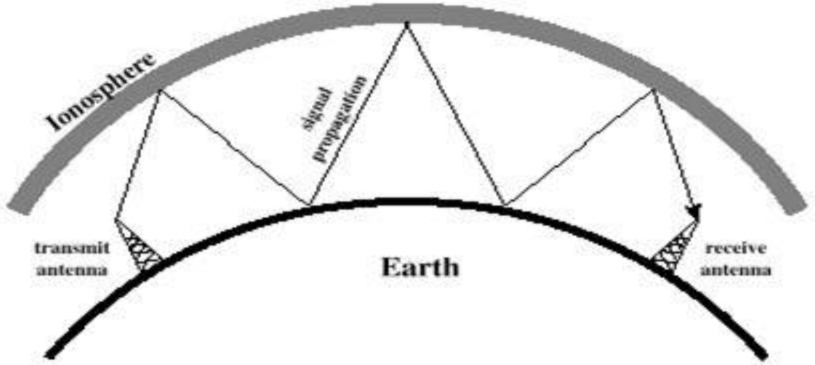


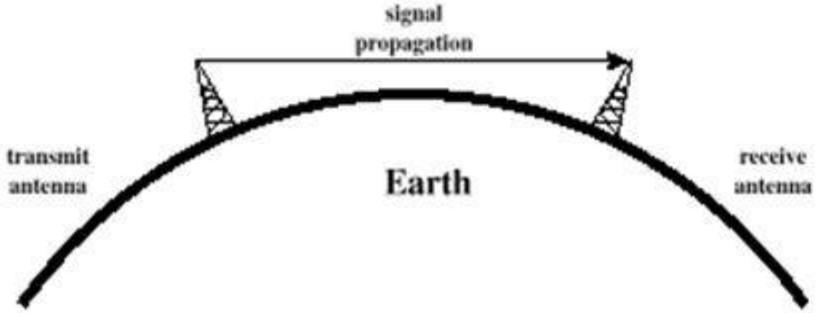
Transmit antenna
Receive antenna
Direct (LOS) space wave
Ground-reflected wave
Tower
Tower
Earth's surface

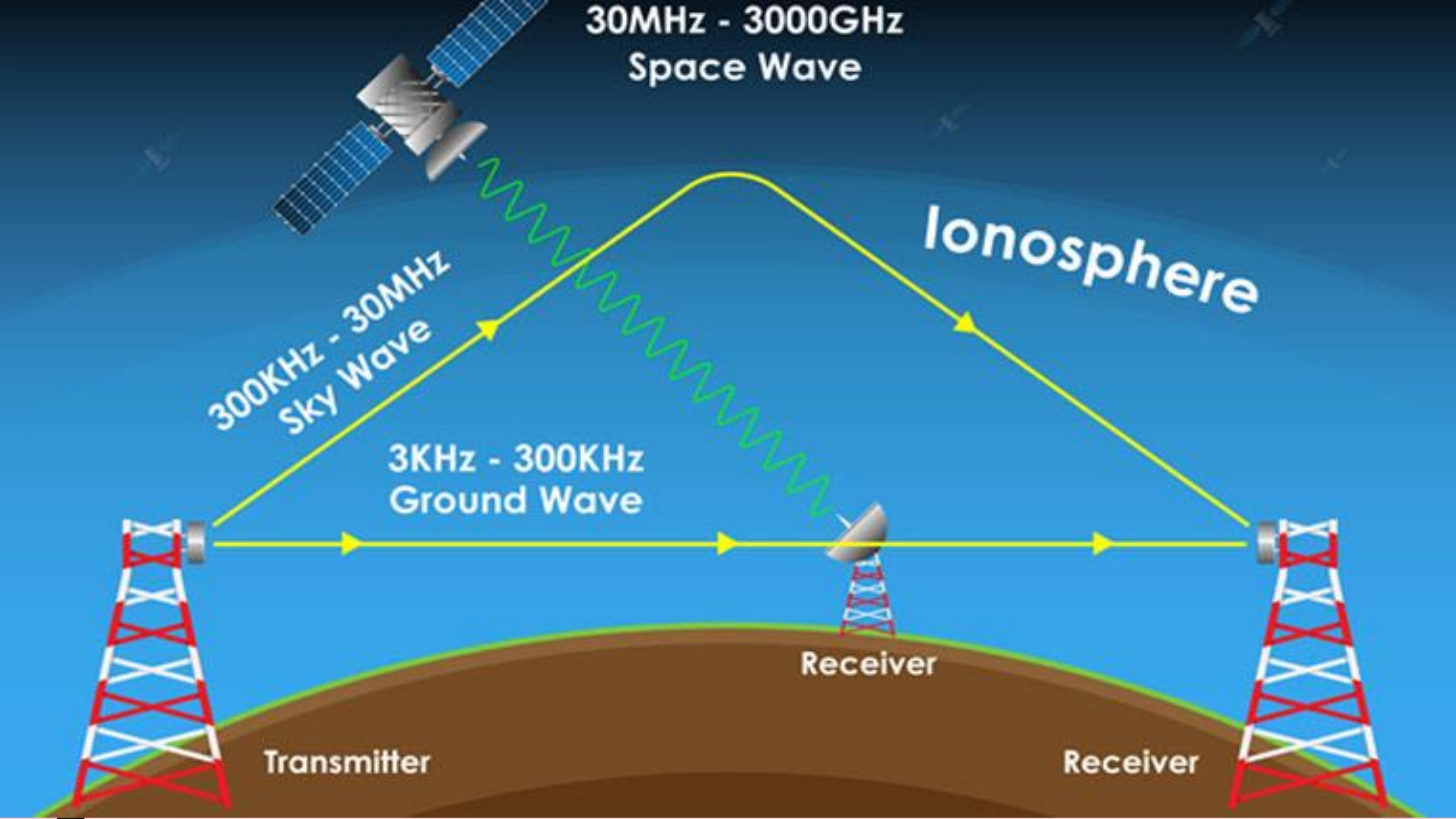
Propagation Modes

- Radio signal behaves like light in free space
- Ground Wave
  - Frequencies up to 2 MHz
  - Follows contour of the earth
  - Example: AM Radio
- Sky Wave
  - Signal reflected from ionosphere and earth's surface
  - Can travel thousands of kilometers
  - Frequency: 2-30MHz
  - Amateur Radio, Military Comm.
- Line of Sight
  - Transmitting and receiving antennas must be within line of sight
  - Frequency: More then 30MHz
  - TV, satellite, optical comm.

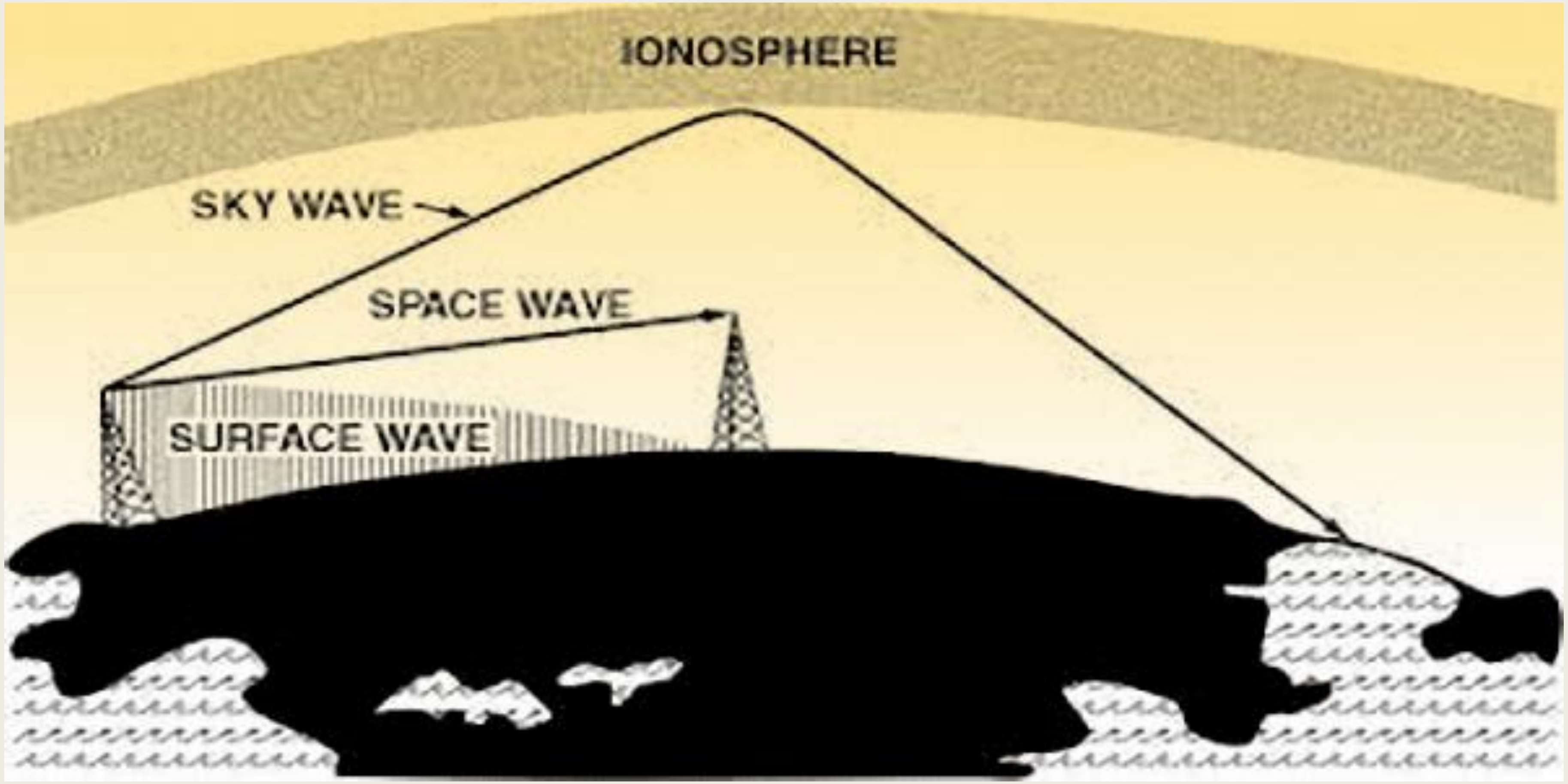




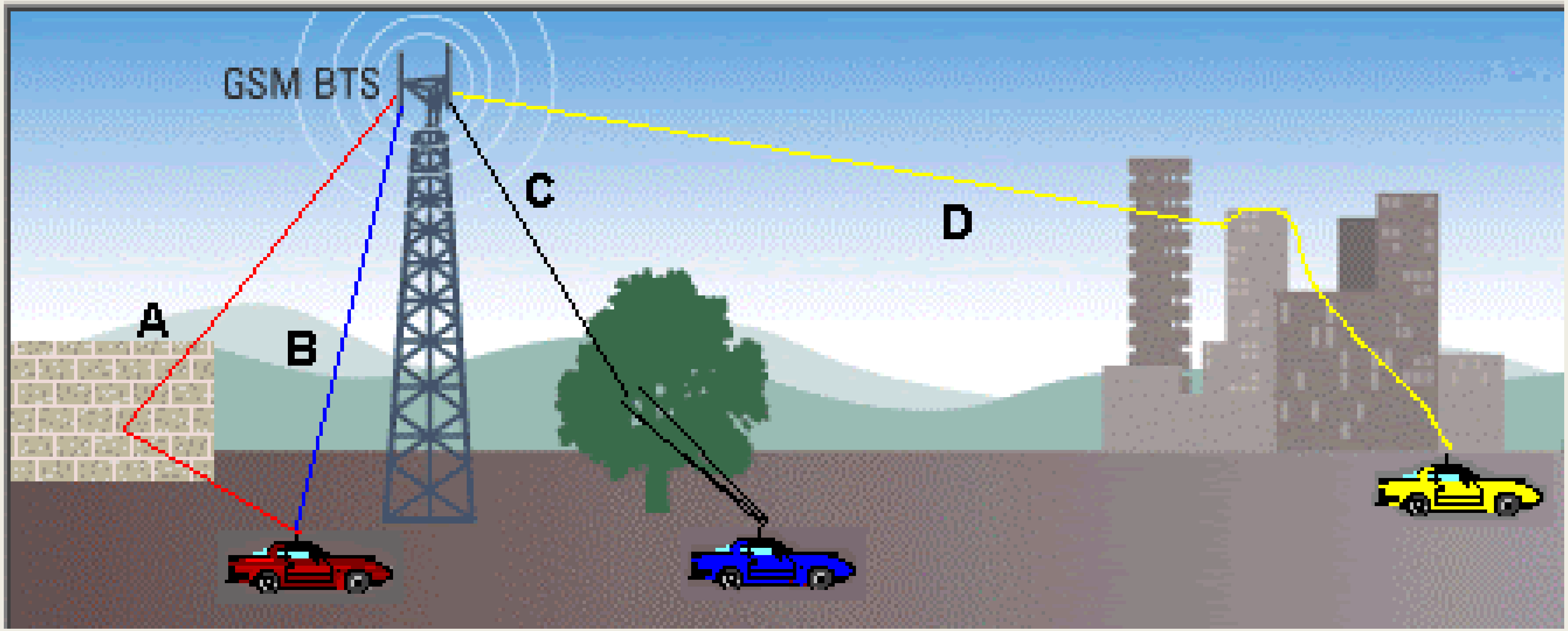




30MHz - 3000GHz
Space Wave
Ionosphere
300KHz - 30MHz
Sky Wave
3KHz - 300KHz
Ground Wave
Receiver
Transmitter
Receiver


IONOSPHERE
SKY WAVE
SPACE WAVE
SURFACE WAVE

Fading



Fading

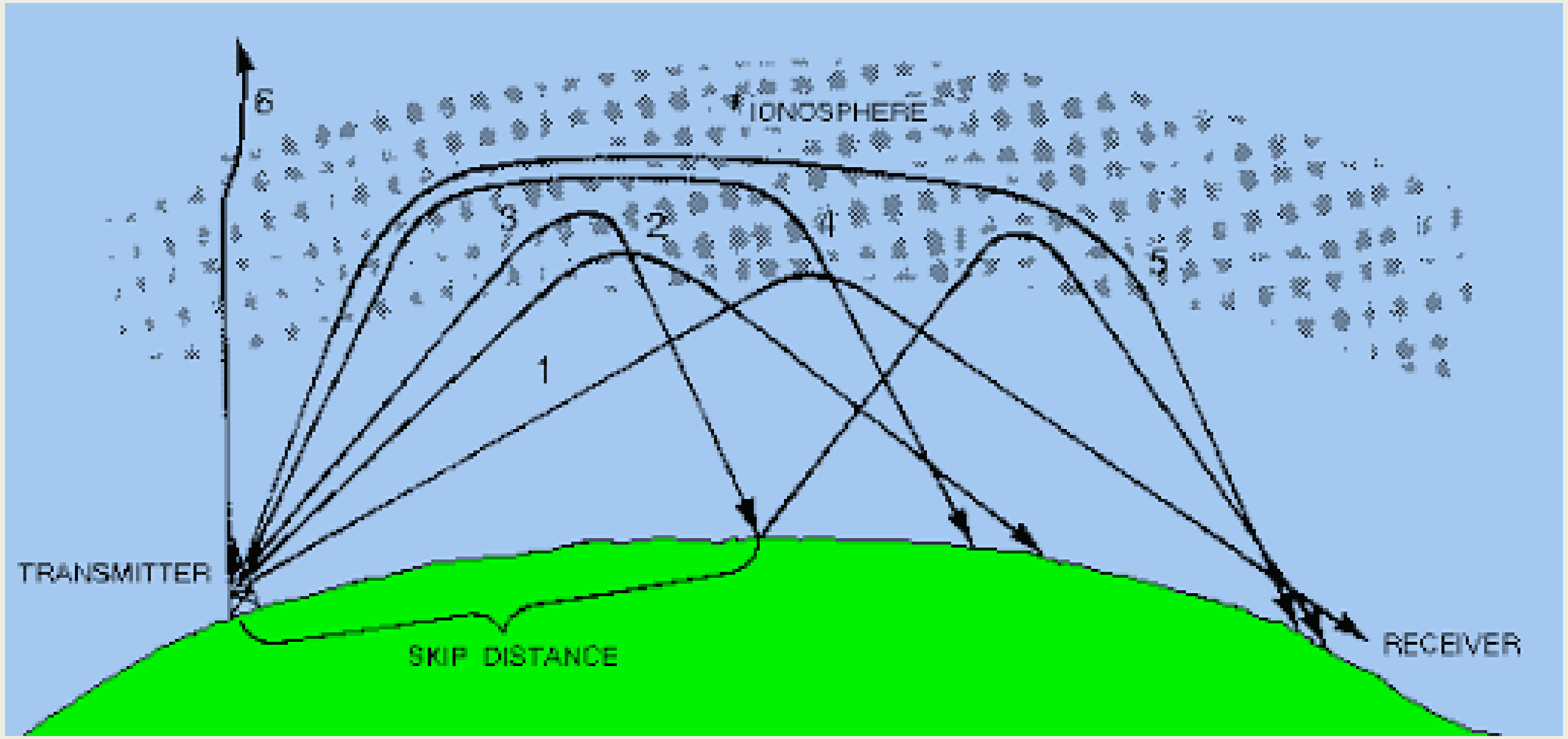
- In **wireless communications**, **fading** is variation of the attenuation of a signal with various variables. These variables include time, geographical position, and radio frequency.
- Fading signal occur due to reflections from ground and surrounding buildings as well as scattered signal from trees, people tower etc..

How to avoid fading

- Frequency Diversity
- Modulate the signal through L different carriers
- The separation between the carriers should be at least the coherent bandwidth, not effective over frequency-flat channel
- Only one antenna is needed

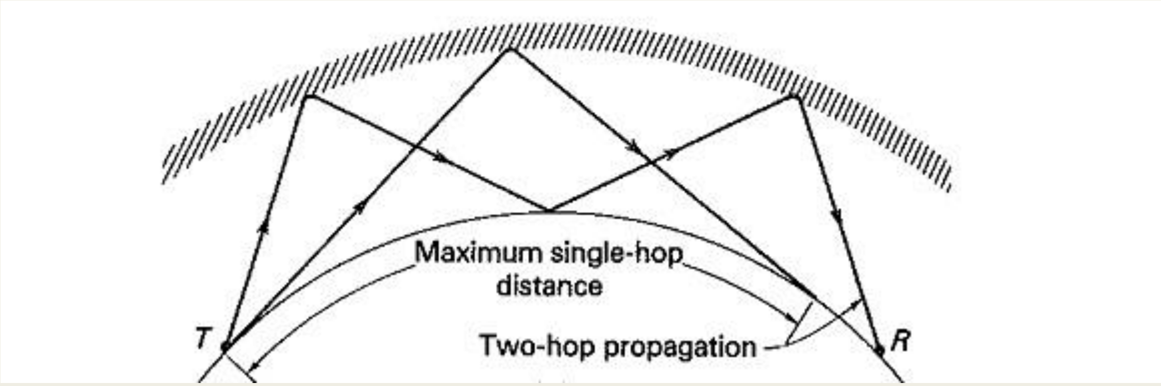
Skip Distance

- The minimum distance along the earth's surface between the position of a short-wave transmitter and the region where its signal is received after one reflection from the ionosphere

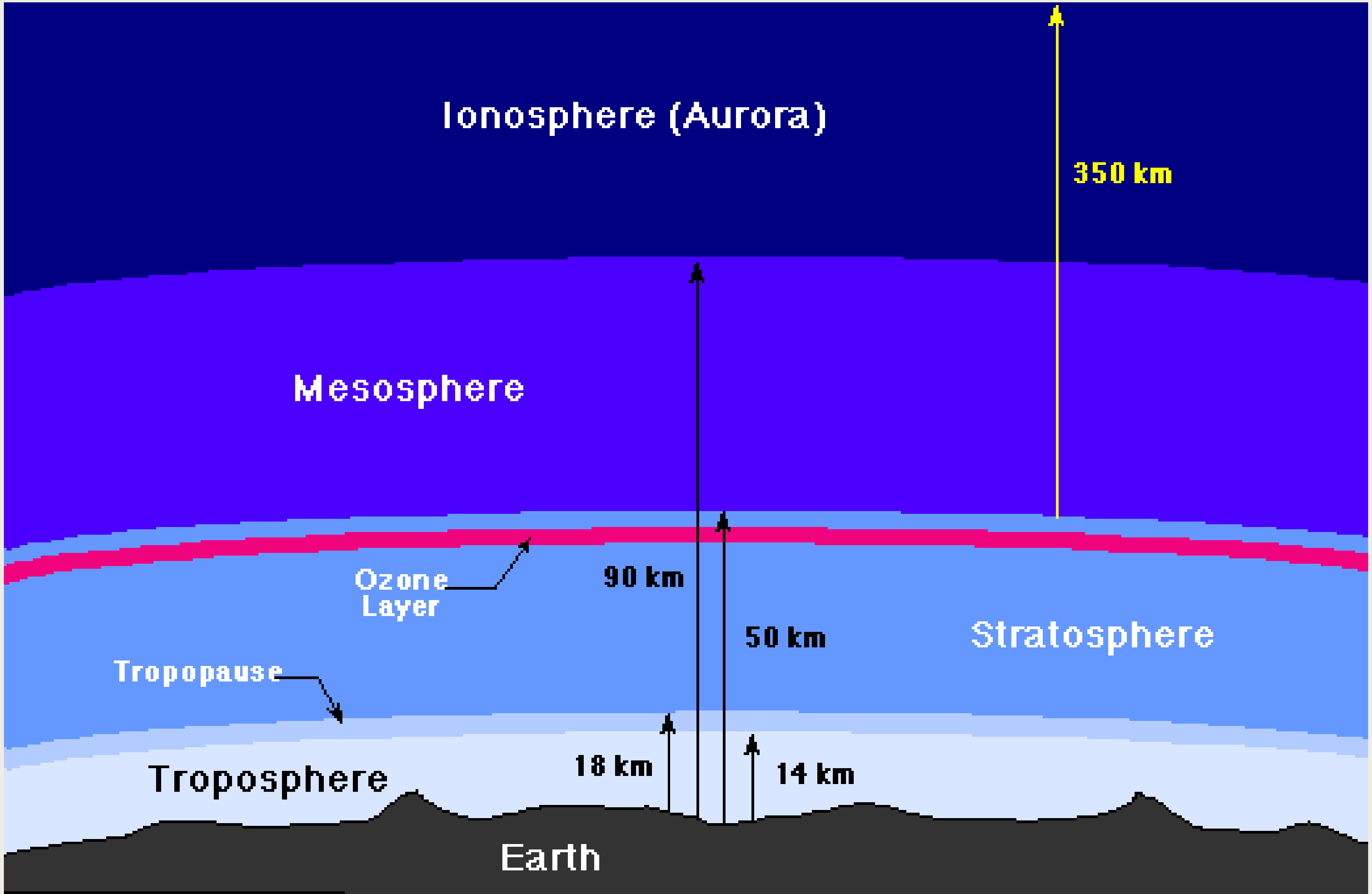


Single hop and Multihop Transmission

- Radio waves can be reflected by the ionosphere and the earth's surface and propagate long distance from the transmitter to the receiver with several **hops**, which is also called sky wave **propagation**

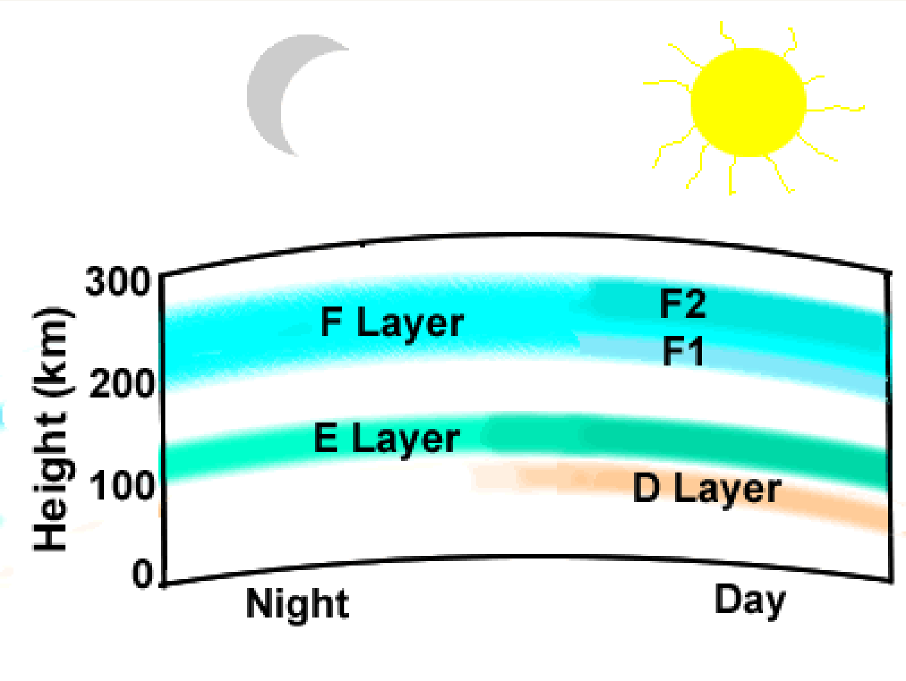


Ionosphere

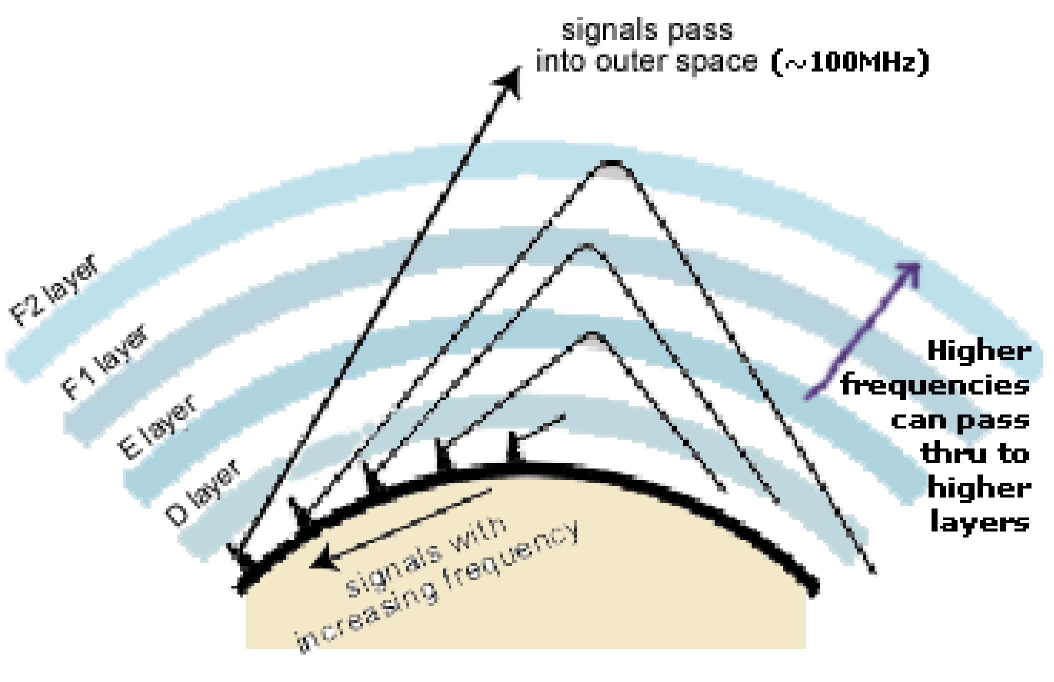


Ionosphere (Aurora)
350 km
Mesosphere
Ozone
Layer
90 km
50 km
Stratosphere
Tropopause
Troposphere
18 km
14 km
Earth

Ionosphere

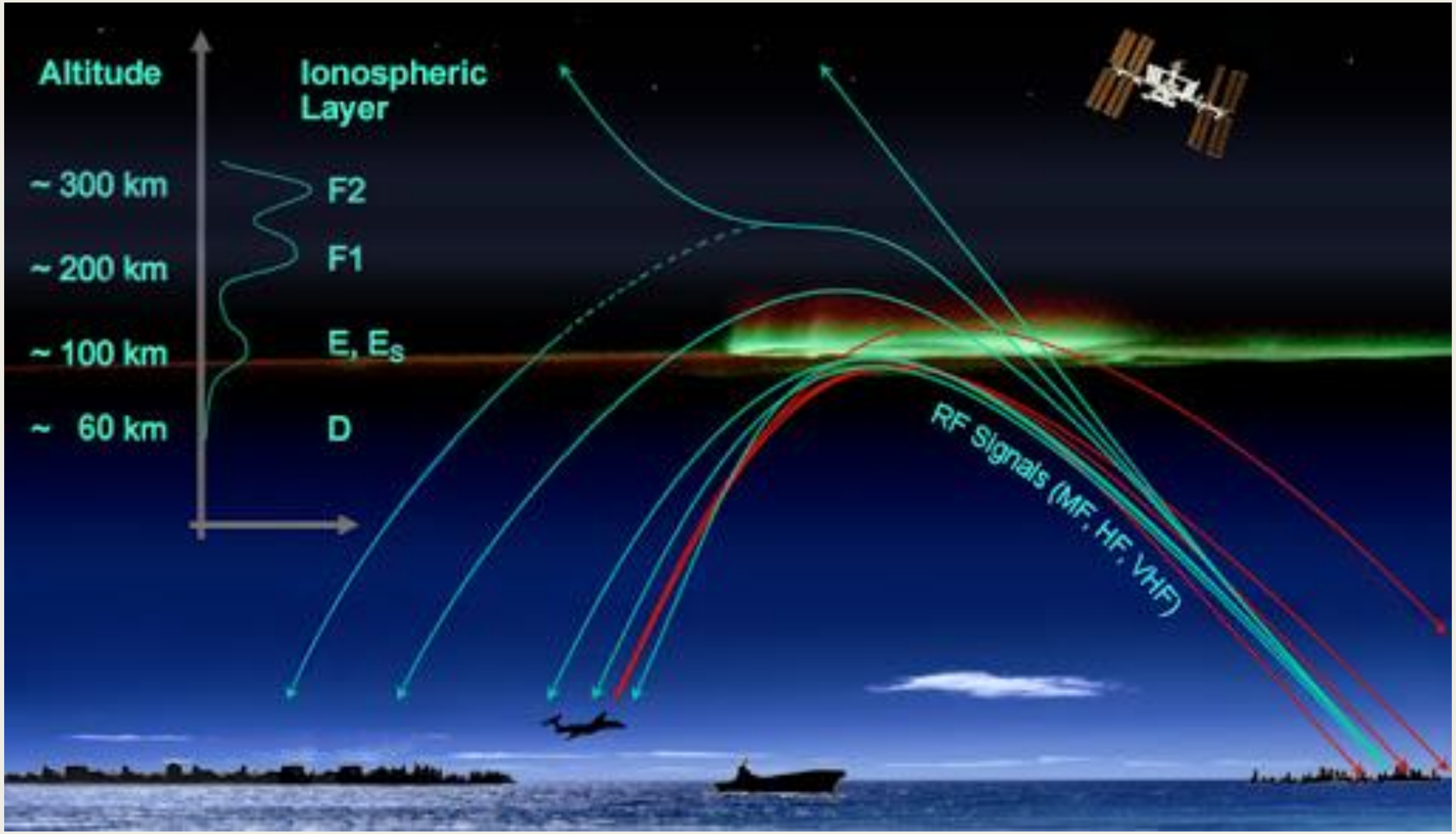


300
200
100
0
Height (km)
F Layer
F2
F1
E Layer
D Layer
Night
Day



signals pass
into outer space (~100MHz)
F2 layer
F1 layer
E layer
D layer
Higher frequencies can pass thru to higher layers
signals with increasing frequency

Ionosphere



Altitude
Ionospheric Layer
~ 300 km
F2
~ 200 km
F1
~ 100 km
E, E_S
~ 60 km
D
RF Signals (MF, HF, VHF)

Ionosphere Influence on radio wave

- The equation of motion of electron,

$$m \frac{dv}{dt} = -eF \cos \omega t \tag{21.1}$$

where m is the electronic mass. Integrating Eq. (21.1) with respect to t, we obtain

$$v = -\frac{eF}{m\omega} \sin \omega t + K_1 \tag{21.2}$$

where K_1 is the integration constant. Since $v = 0$, when $F = 0$, Eq. (21.2) gives $K_1 = 0$. So,

$$v = -\frac{eF}{m\omega} \sin \omega t \tag{21.3}$$

N – Concentration of electrons
F – Force
e – electron charge
m – electronic mass
ω - angular frequency

The current density produced by N electrons each of charge $-e$ and travelling with velocity v, is

$$J_e = -Nev = \frac{Ne^2}{m\omega} F \sin \omega t \tag{21.4}$$

Equation (21.4) shows that the current density lags behind the electric field by 90°. Since the ionosphere is a weakly ionized medium, its permittivity is nearly equal to that of free space. Therefore, the displacement current density is approximately given by

$$J_d = \frac{d}{dt} (\varepsilon_0 F \cos \omega t) = -\varepsilon_0 F\omega \sin \omega t. \tag{21.5}$$

where ε_0 is the permittivity of free space. Equation (21.5) shows that the displacement current leads the electric field by 90°. The total current density in the ionosphere is

$$J = J_e + J_d = -\omega \left(\varepsilon_0 - \frac{Ne^2}{m\omega^2} \right) F \sin \omega t. \tag{21.6}$$

...lacement cur-

$$J = J_e + J_d = -\omega\left(\varepsilon_0 - \frac{\quad}{m\omega^2}\right)$$

where Eqs. (21.4) and (21.5) have been used. Taking the total current as the displacement current, Eq. (21.6) predicts that the *effective* permittivity of the ionized region is less than ε_0 and is expressed by

$$\varepsilon = \varepsilon_0\left(1 - \frac{Ne^2}{m\omega^2\,\varepsilon_0}\right) \tag{21.7}$$

In SI units, used in the foregoing analysis, we have $\varepsilon_0 = 8.854 \times 10^{-12}$ F/m, $e = 1.6 \times 10^{-19}$ C, and $m = 9.1 \times 10^{-31}$ kg. Substituting these values in Eq. (21.7) gives

$$\varepsilon = \varepsilon_0\left(1 - \frac{81N}{f^2}\right), \tag{21.8}$$

where $f = \omega/(2\pi)$ is the frequency of the radiowave.

The phase velocity of plane wave propagating in a medium of permittivity ε and permeability μ is

$$v_p = \frac{1}{\sqrt{\varepsilon\mu}} \tag{21.9}$$

$= 4\pi \times 10^{-7}$ H/m. Hence the phase velocity in free

In free space, we have $\varepsilon = \varepsilon_0$ and $\mu = \mu_0 = 4\pi \times 10^{-7}$ H/m. Hence the phase velocity in free space is c (= 3×10^8 m/s), the velocity of light. In the ionized medium of concern here, $\mu = \mu_0$ but ε is less than ε_0, as predicted by Eq. (21.8). So, the phase velocity of the radio wave in the ionosphere exceeds the velocity of light. The group velocity, however, cannot be greater than c.

The refractive index of the ionized medium relative to free space is

$$n = \frac{c}{v_p} = \sqrt{\frac{\varepsilon}{\varepsilon_0}} \qquad (21.10)$$

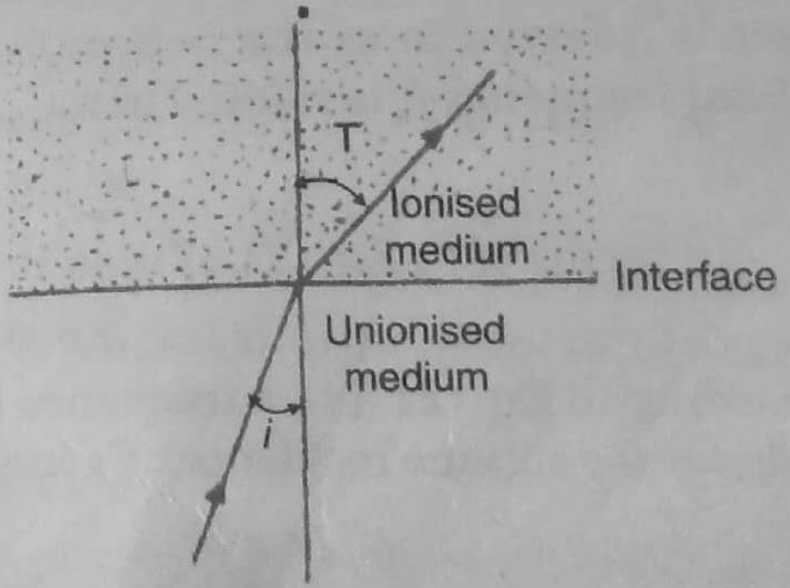


Fig. 21.6 Refraction of a radiowave at the interface between the ionosphere and free space

Let a radiowave travel into the ionosphere from the underlying unionized region. Since the phase velocity in the ionosphere is greater, the corresponding

$$n = \frac{\sin i}{\sin r} = \sqrt{\frac{\varepsilon}{\varepsilon_0}} = \left(1 - \frac{81N}{f^2}\right)^{1/2} \tag{21.11}$$

As the wave moves deeper into the layer, the electron concentration gradually increases with the consequent decrease of the refractive index n. Therefore, the angle r increases and the ray bends gradually, as indicated in Fig. 21.7. At the top point M of the ray trajectory, we have $r = 90°$. If N_r is the electron concentration at the point, Eq. (21.11) gives

$$n = \sin i = \left(1 - \frac{81N_r}{f^2}\right)^{1/2} \tag{21.12}$$

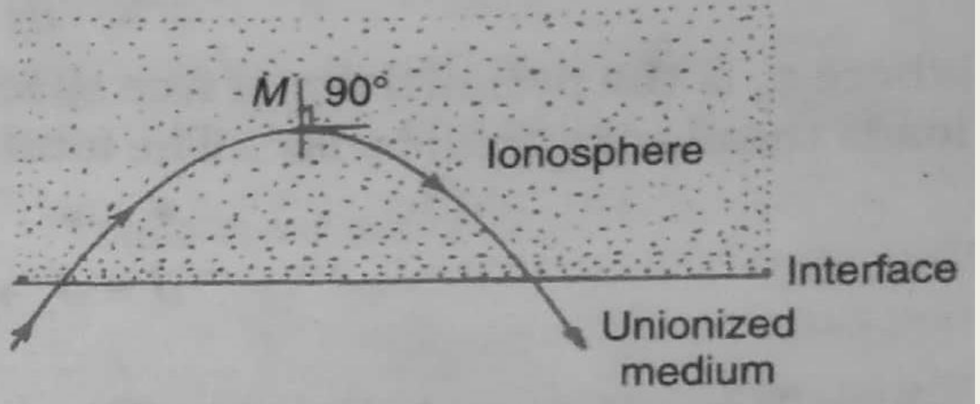
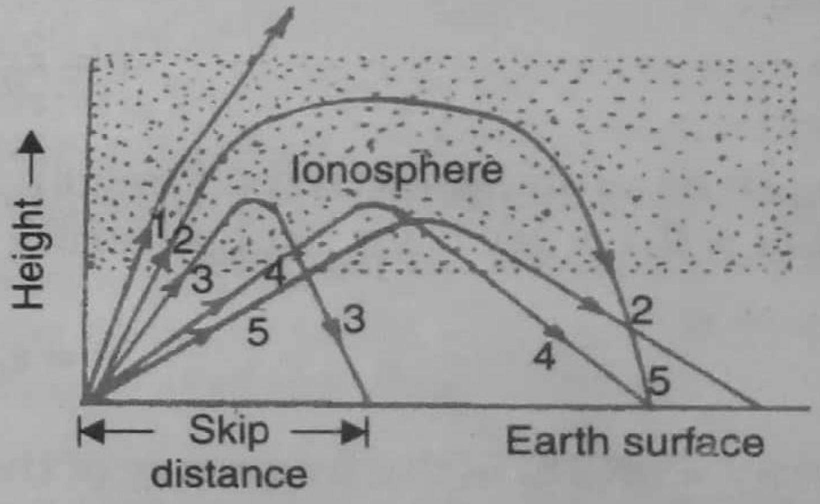


Fig. 21.7 Ray bending and reflection in the ionosphere

At the point M, the ray is parallel to the earth's surface. Thereafter, it travels downwards and returns to the earth. So, M is known as the *point of reflection*. Equation (21.12) shows that the greater the angle i, the higher is the refractive index n, and the lower is the value of N_r. So, for rays incident more obliquely, the point of reflection is lower, the electron concentration decreasing with decreasing height. The situation is illustrated in Fig. 21.8 with rays numbered 2 through 5.



For a sufficiently small angle of incidence i, Eq. (21.12) is not satisfied even with the largest value of the electron concentration in the layer. The ray then penetrates the layer and does not return to the earth. This happens for the ray labelled 1 in Fig. 21.8.

Fig. 21.8 Ray trajectories in the ionosphere for different angles of incidence

When the radiowave is incident vertically, $i = 0$ and so $n = 0$ at the point of reflection. For vertical incidence, the maximum frequency of the wave reflected to the earth from an ionospheric layer is referred to as the *critical frequency* (f_c) of the layer. Equation (21.12) shows that the critical frequency f_c is related to the peak electron concentration N_p of the layer by

$$f_c = 9\sqrt{N_P} \tag{21.13}$$

In terms of f_c, Eq. (21.12) can be written as

$$n = \sin i = [1 - (f_c/f)^2]^{1/2}. \tag{21.14}$$

According to Eq. (21.14), a frequency higher than the critical frequency can be reflected back by the layer for oblique incidence. Equation (21.14) gives

$$\left(\frac{f_c}{f}\right)^2 = 1 - \sin^2 i = \cos^2 i$$

or,

$$f = f_c \sec i \tag{21.15}$$

This relationship is called the *secant law*. It relates the frequency f of the reflected wave for an angle of incidence i to the critical frequency f_c. When the ray is launched tangentially to the earth, the angle of incidence i attains its maximum value i_m (Fig. 21.9). If R is the radius of the earth and H is the height of the ionized layer, we write from Fig. 21.9.

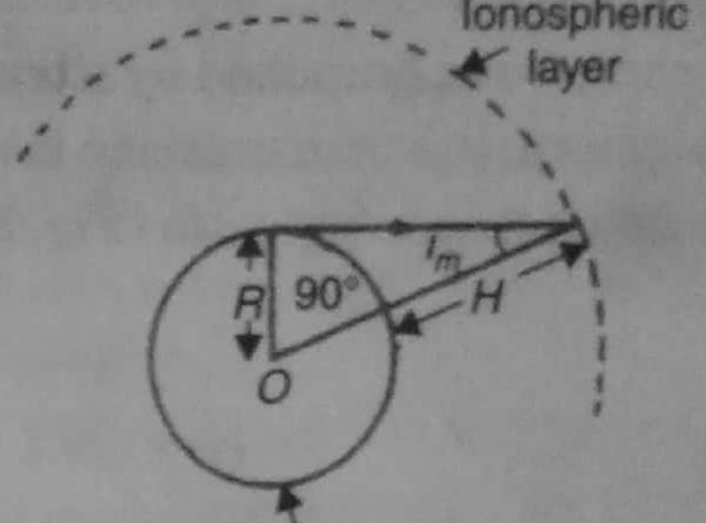


Fig. 21.9 Ray leaving the earth tangentially

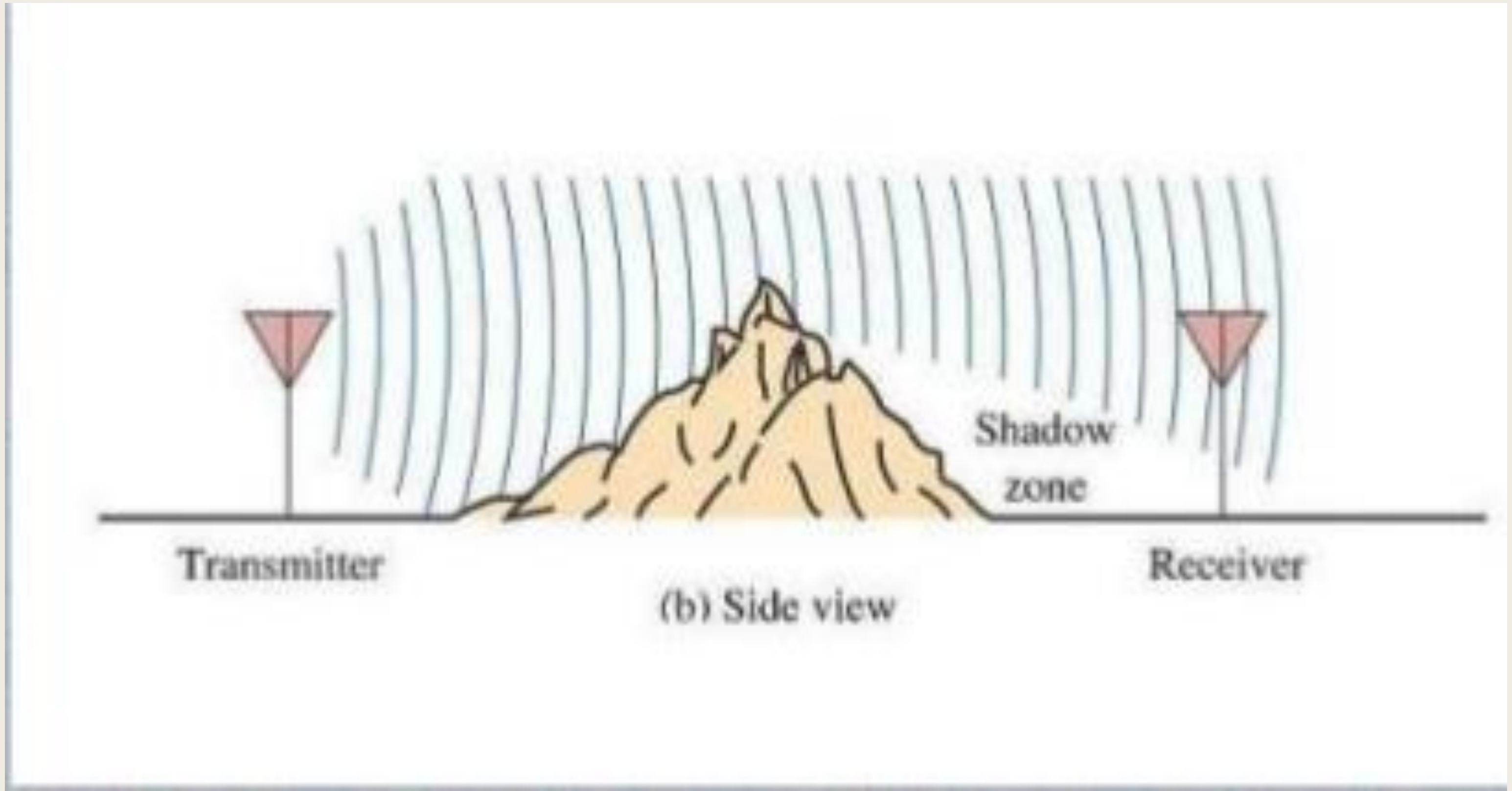
$$\sin i_m = \frac{R}{R+H}. \qquad (21.16)$$

The maximum frequency f_m corresponding to the angle i_m reflected by the layer can be obtained from Eq. (21.15).

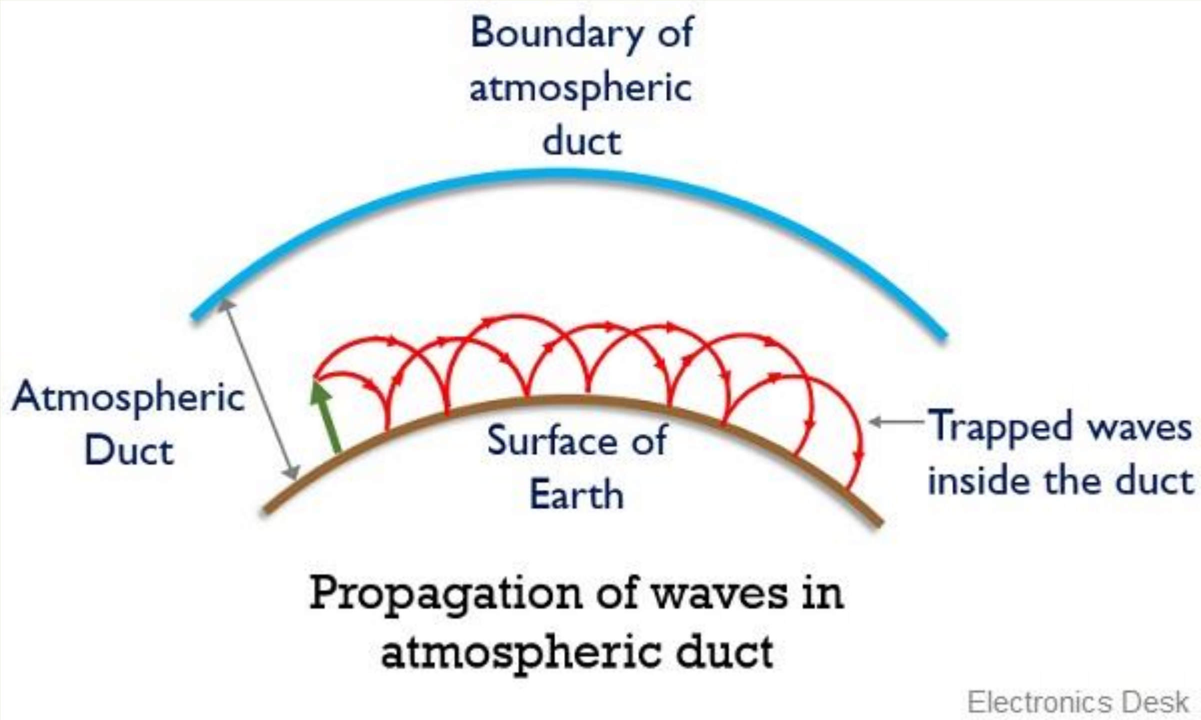
The critical frequencies for E and F layers are about 2.5 MHz and 9 MHz, respectively. The maximum frequencies f_m that can be reflected from these layers are about 12 MHz and 33 MHz, respectively. These values are variable since the heights and the peak electron concentrations of the layers are subject to diurnal, seasonal, and sun-spot cycle variations.

Shadow Zone

- The **S wave shadow zone** is the area of the Earth's surface where **S waves** are not detected following an earthquake



- **Duct propagation** - also called atmospheric **propagation** - happens in Earth's lower atmosphere when the vertical refractive index is such that electromagnetic waves (radio waves, light) are refracted and reflected against layers of less density above and are guided to follow the curvature of the Earth



Thank You