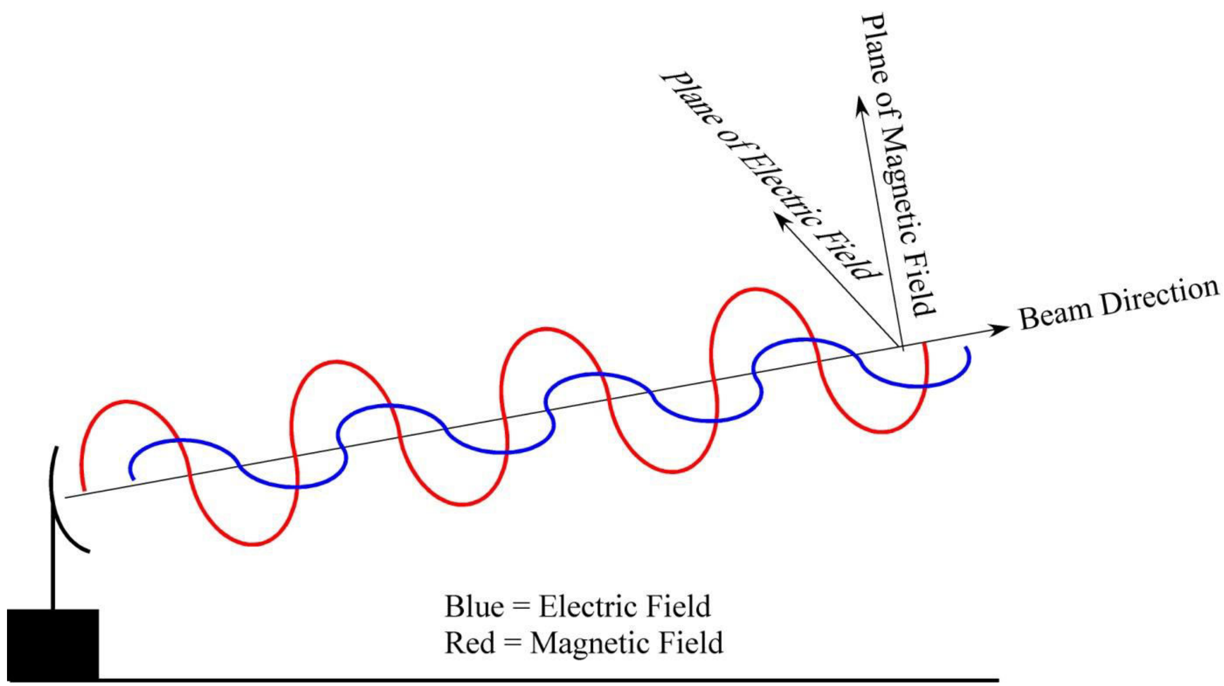
ANTENNA AND WAVE PROPAGATION

Electromagnetic Waves and Their Propagation Through the Atmosphere



ELECTRIC FIELD

An Electric field exists in the presence of a charged body

ELECTRIC FIELD INTENSITY (*E*)

A vector quantity: magnitude and direction (Volts/meter)

MAGNITUDE OF *E*: Proportional to the force acting on a unit positive charge at a point in the field

DIRECTION OF *E*: The direction that the force acts

The **Electric Field (E)** is represented by drawing the **Electric Displacement Vector (D)**, which takes into account the characteristics of the medium within which the Electric Field exists.

$$D\left(coul\ m^{-2}\right) = \varepsilon E$$

ε, the **Electric Conductive Capacity** or **Permittivity**, is related to the ability of a medium, such as air to store electrical potential energy.

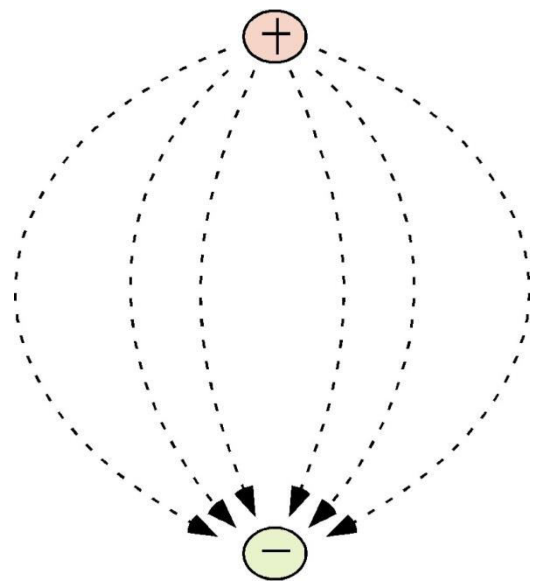
Vacuum: $$\varepsilon_0 = 8.850 \times 10^{-12}\ coul^2\ \ joule^{-1}\ m^{-1}$$

Air: $$\varepsilon_1 = 8.876 \times 10^{-12}\ coul^2\ \ joule^{-1}\ m^{-1}$$

Ratio: $$\frac{\varepsilon_1}{\varepsilon_0} = 1.003$$

The **Electric Displacement Vector**, D, is used to draw **lines of force**.

Units of D: $coul\ m^{-2}$



MAGNETIC FIELD

A Magnetic field exists in the presence of a current

MAGNETIC FIELD INTENSITY (*H*)

A vector quantity: magnitude and direction (amps/meter)

MAGNITUDE OF *H*: Proportional to the current

DIRECTION OF *H*: The direction that a compass needle points in a magnetic field

The **Magnetic Field (H)** is represented by drawing the **Magnetic Induction Vector (B)**, which takes into account the characteristics of the medium within which the current flows.

$$B = \mu H$$

μ, the **Magnetic Inductive Capacity**, or **Permeability**, is related to the ability of a medium, such as air, to store magnetic potential energy.

Vacuum: $$\mu_0 = 1.260 \times 10^{-6} \ joule \ amp^{-2} \ m^{-1}$$

Air: $$\mu_1 = 1.260 \times 10^{-6} \ joule \ amp^{-2} \ m^{-1}$$

Ratio: $$\frac{\mu_1}{\mu_0} = 1.000$$

Magnetic Fields:

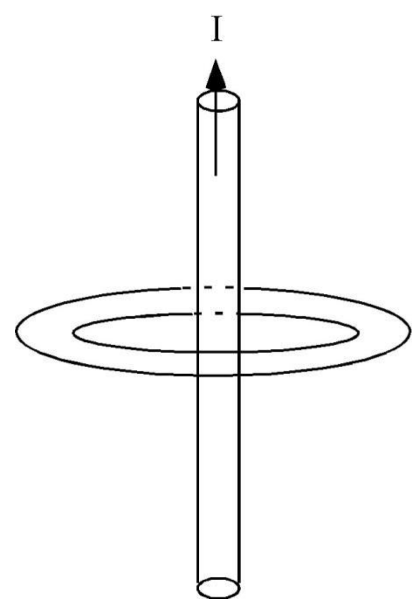
Magnetic fields associated with moving charges (electric currents)

$$Force = I \times B$$

I: Current $\left(coul\ s^{-1}\ or\ amps\right)$

B: Magnetic Induction $\left(joule\ amp^{-1}\ m^{-2}\right)$

Magnetic Field Lines are closed loops surrounding the currents that produce them



Maxwell's Equations for time varying electric and magnetic fields in free space

Simple interpretation

$$\nabla \bullet E = \frac{\rho}{\varepsilon_0}$$

Divergence of electric field is a function of charge density

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

A closed loop of E field lines will exist when the magnetic field varies with time

$$\nabla \bullet B = 0$$

Divergence of magnetic field =0 (closed loops)

$$\nabla \times B = \mu_0 I + \varepsilon_0 \mu_0 \frac{\partial E}{\partial t}$$

A closed loop of B field lines will exist in The presence of a current and/or time varying electric field

(where ρ is the charge density)

Electromagnetic Waves: A solution to Maxwell's Equations

Electric and Magnetic Force Fields

Propagate through a vacuum at the speed of light:

$$c = 3\times10^{8}\ m\ s^{-1}$$

Electric and Magnetic Fields propagate as waves:

$$E(r,\theta,\phi,t) = \frac{A(\theta,\phi)}{r}\exp\left(i2\pi f\left(t-\frac{r}{c}\right)+i\Psi\right)$$

or:

$$E(r,\theta,\phi,t) = \frac{A(\theta,\phi)}{r}\cos\left(2\pi f\left(t-\frac{r}{c}\right)+\Psi\right)$$

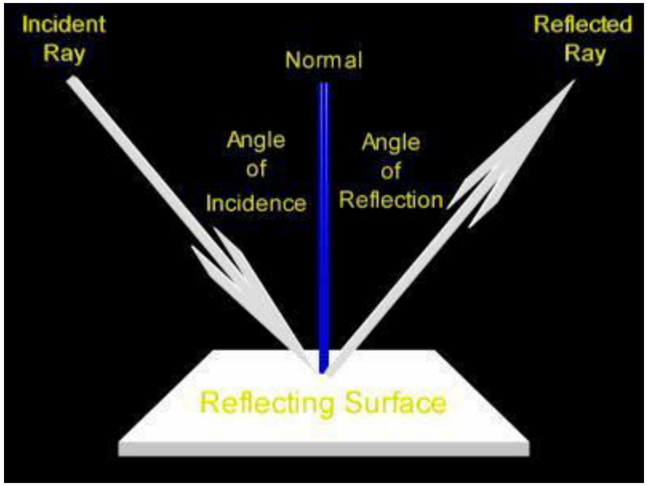
where: $$\exp(ix) = \cos(x) + i\sin(x)$$

r, θ, ϕ are coordinates, A is an amplitude factor, f is the frequency and Ψ is an arbitrary phase

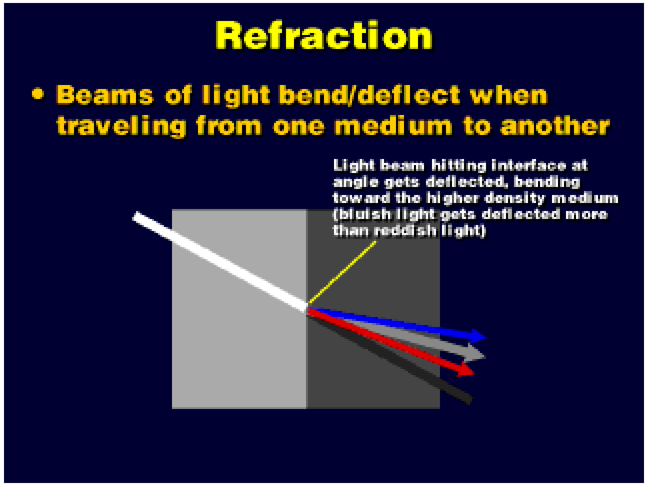
Electromagnetic waves:

Interact with matter in four ways:

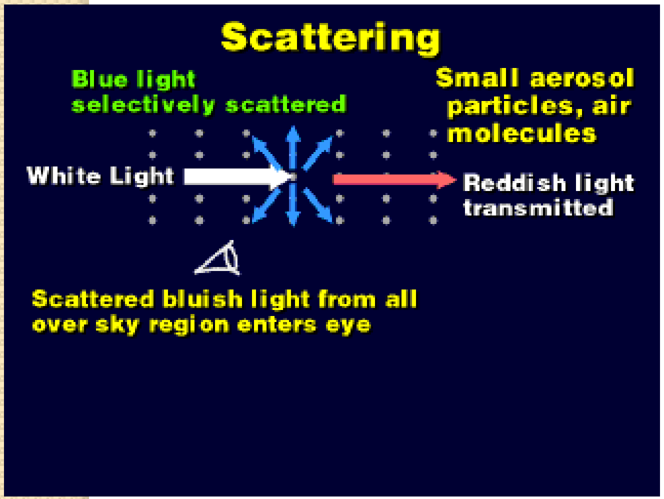
Reflection:



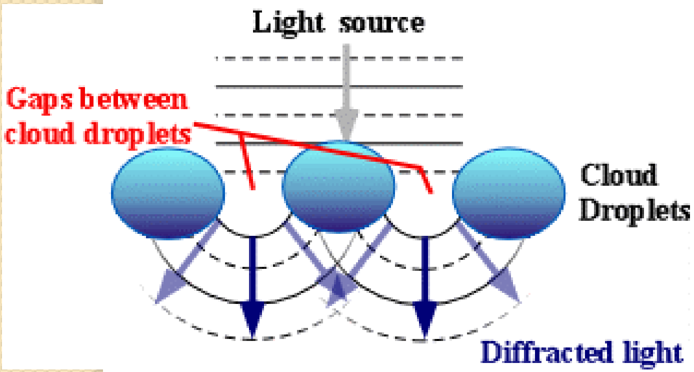
Refraction:

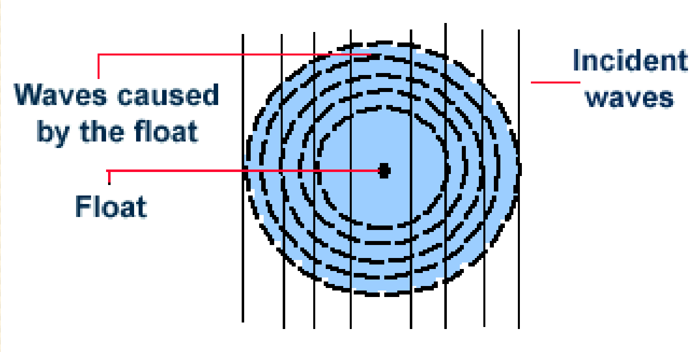


Scattering:



Diffraction:



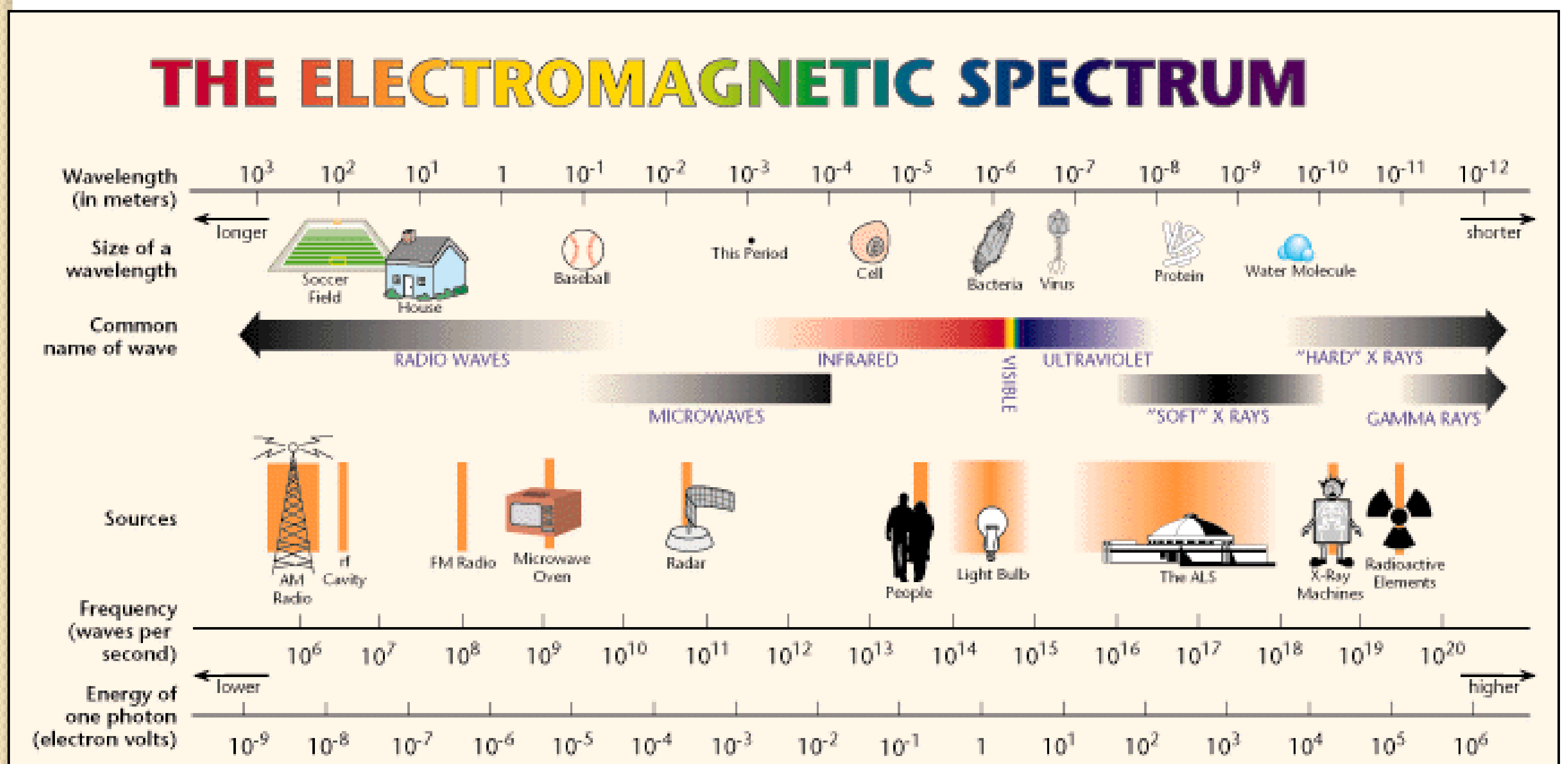


Electromagnetic Waves are characterized by:

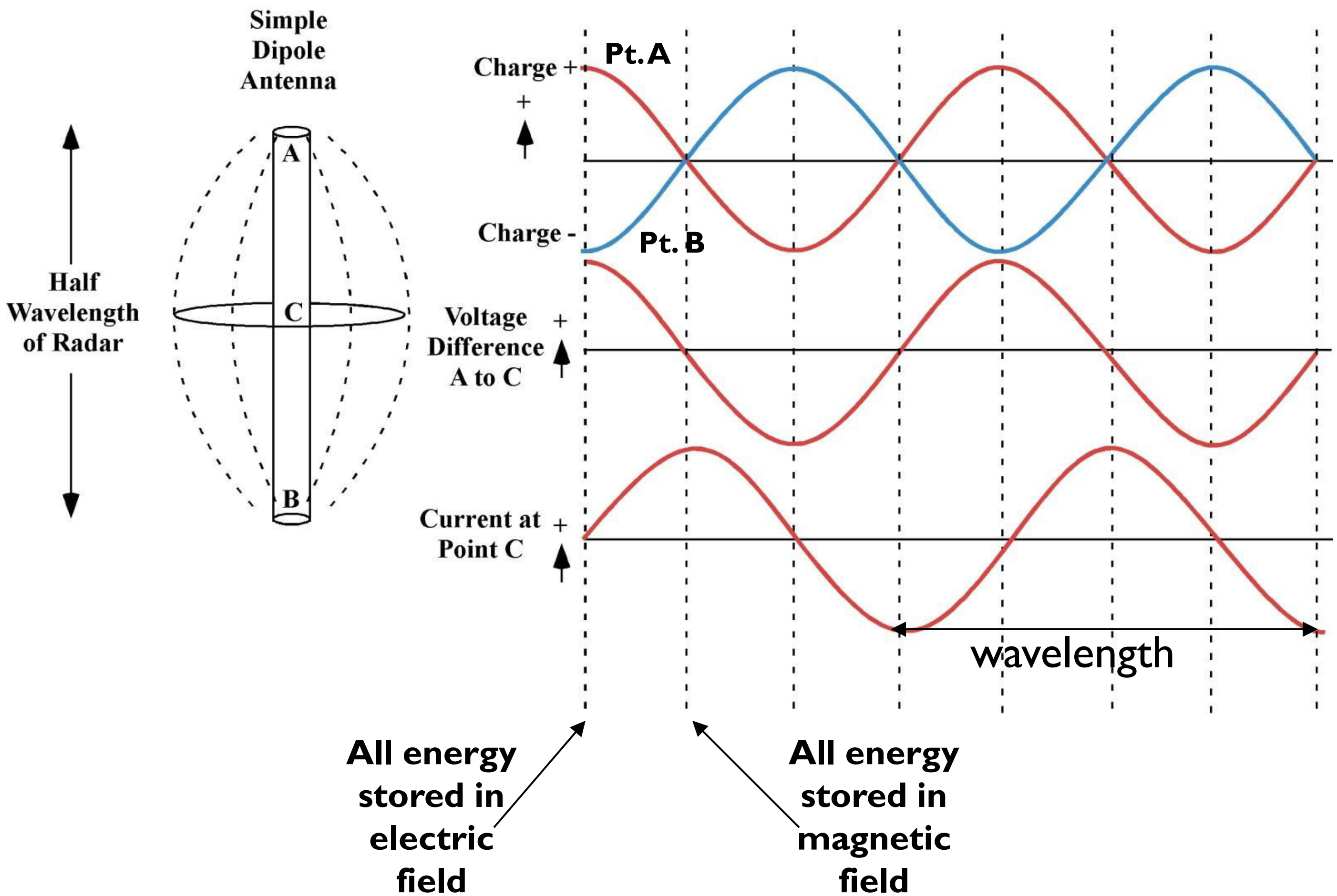
Wavelength, λ [m, cm, mm, μm etc]

Frequency, f [s^{-1}, hertz (hz), megahertz (Mhz), gigahertz (Ghz)

where: $c = \lambda f$



Time variations in charge, voltage and current in a simple Dipole Antenna

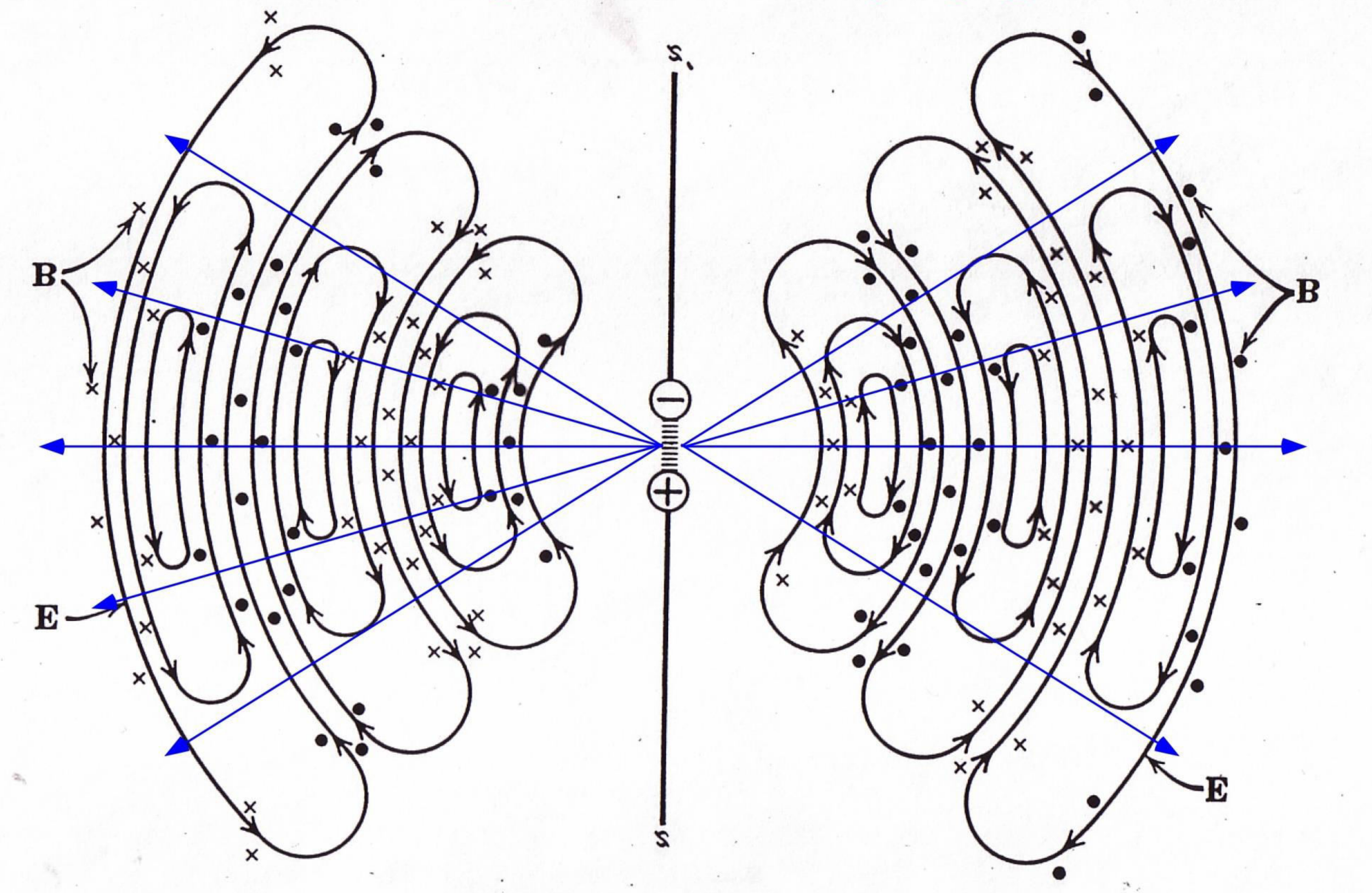


Energy is 1) stored in E, B fields, 2) radiated as EM waves, 3) Dissipated as heat in ant

Near antenna: **Energy stored in induction fields (E, B fields) >> energy radi**

More than a few λ from antenna: **Energy radiated >> energy stored in induction fields**

Electric and Magnetic Field with propagation vectors

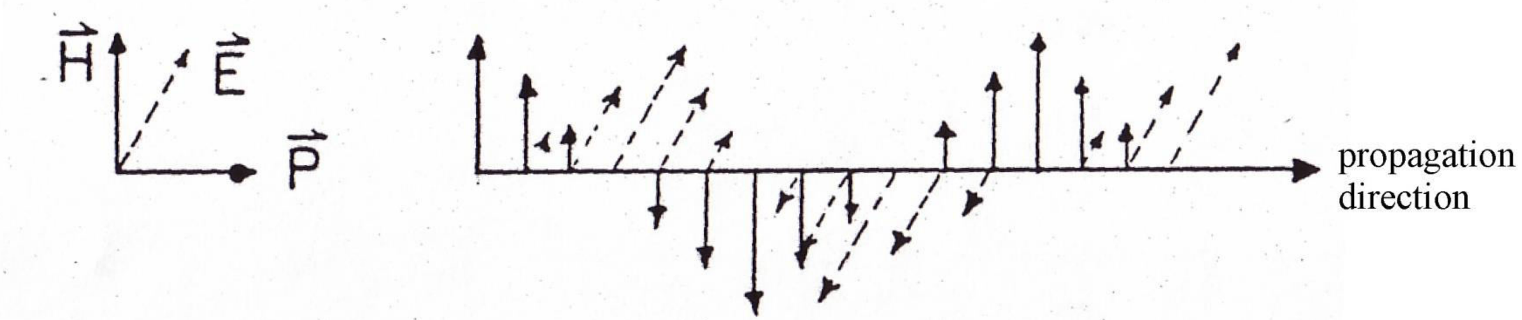


Polarization of electromagnetic waves

The polarization is specified by the orientation of the electromagnetic field.

The plane containing the electric field is called the plane of polarization.

A polarized wave: E field and H field each oscillate in a single plane

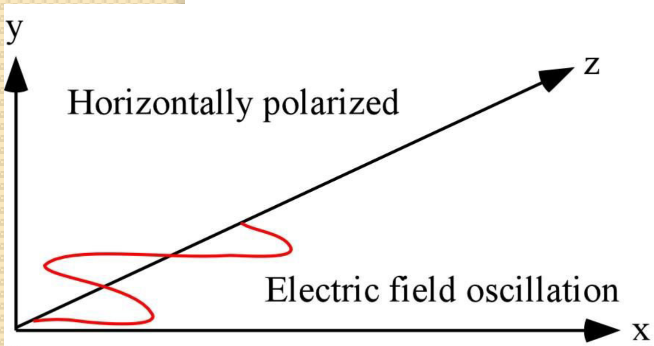


Electric field will oscillate in the x,y plane with z as the propagation directi

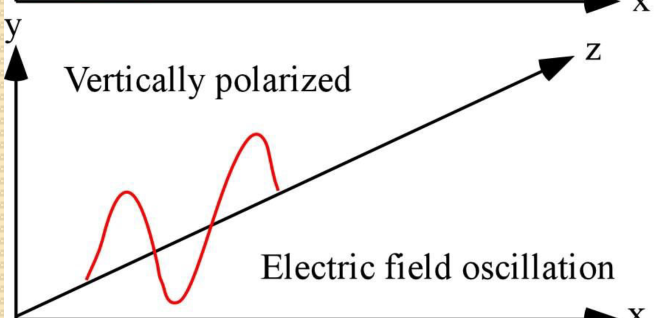
For a monochromatic wave:

$$E_x = E_{xm} \cos(2\pi f t)$$
$$E_y = E_{ym} \cos(2\pi f t + \delta)$$

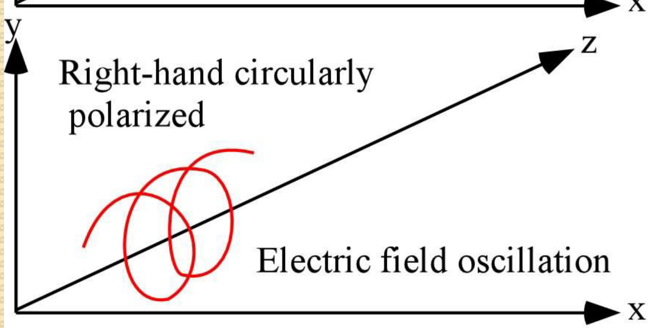
where f is the frequency and δ is the phase difference between E_{xm} and E_{ym} and the coordinate x is parallel to the horizon, y normal to x, and z in the direction of propagation.



If E_{ym} = 0, Electric field oscillates in the x direction and wave is said to be "horizontally polarized"



If E_{xm} = 0, Electric field oscillates in the y direction and wave is said to be "vertically polarized"



If $E_{xm} = E_{ym}$, and $\delta = \pi/2$ or $-\pi/2$, electric field vector rotates in a circle and wave is circularly polarized

All other situations: E field rotates as an ellipse

Propagation of electromagnetic waves in the atmosphere

Speed of light in a vacuum:

$$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$$

Speed of light in air:

$$v = \frac{1}{\sqrt{\varepsilon_1 \mu_1}}$$

Refractive index:

$$n = \frac{c}{v} = \frac{\sqrt{\varepsilon_0 \mu_0}}{\sqrt{\varepsilon_1 \mu_1}}$$

At sea level: n = 1.003
In space: n = 1.000

Radio refractivity:

$$N = (n-1) \times 10^6$$

At sea level: N = 3000
In space: N = 0

The **Refractive Index** is related to:

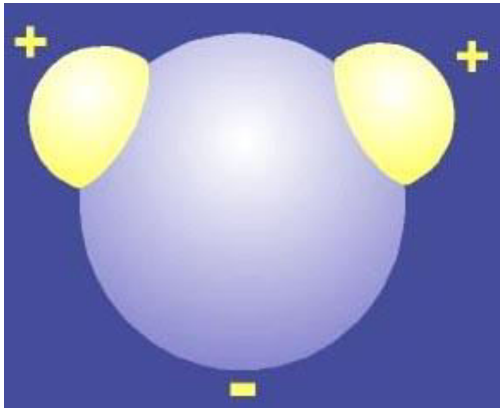
$$n = 1 + 7.76\times10^{-5} K\ mb^{-1}\left(\frac{P_d}{T}\right) - 5.6\times10^{-6} K\ mb^{-1}\left(\frac{e}{T}\right) + 0.375 K^2 mb^{-1}\left(\frac{e}{T^2}\right)$$

1. Density of air (a function of dry air pressure (P_d), temperature (T), vapor pressure (e)

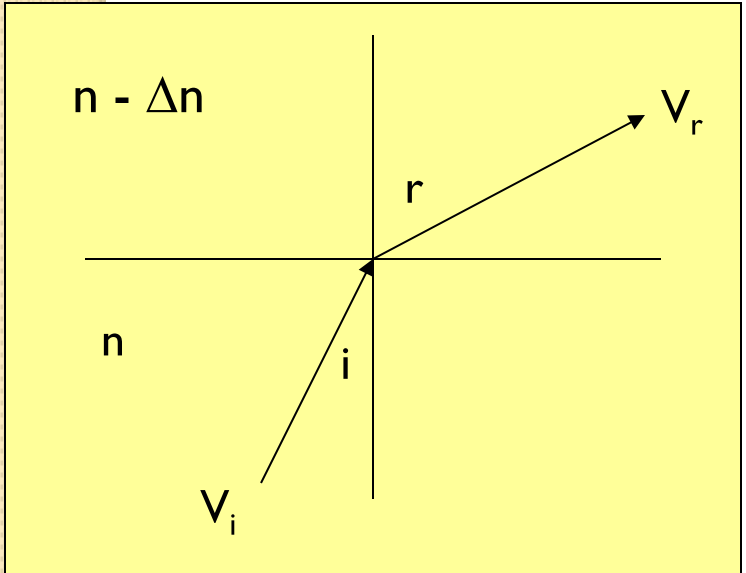
2. The polarization of molecules in the air

   (molecules that produce their own electric field in the absence of external forces)

The water molecule consists of three atoms, one O and two H. Each H donates an electron to the O so that each H carries one positive charge and the O carries two negative charges, creating a polar molecule – one side of the molecule is negative and the other positive.



Snell's law:



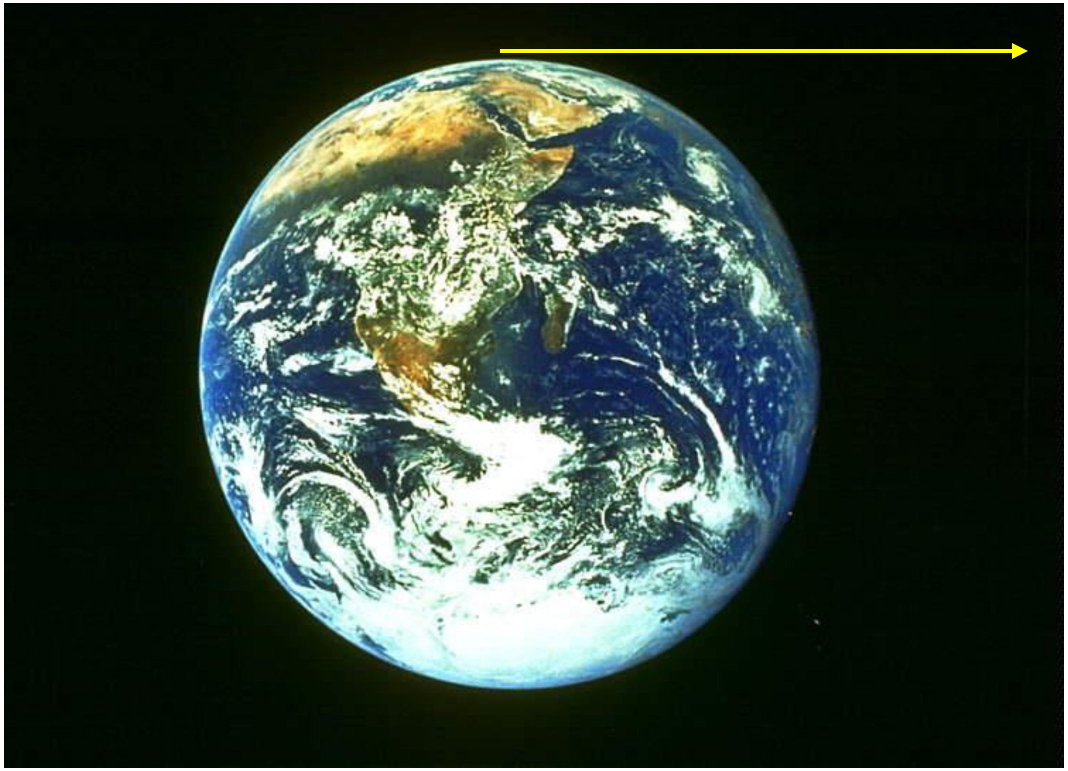
$$\frac{n-\Delta n}{n}=\frac{\sin i}{\sin r}=\frac{V_i}{V_r}$$

Where: i is the angle of incidence
r is the angle of refraction
V_i is the velocity of light in medium n
V_r is the velocity of light in medium n - Δn

In the atmosphere, n normally decreases continuously with height…

Therefore: <u>due to refraction</u>, electromagnetic rays propagating upward away from a radar will bend toward the earth's surface

Earth curvature



Electromagnetic ray propagating away from the radar will rise above the earth's surface due to the earth's curvature.

Equation governing the path of a ray in the earth's atmosphere:

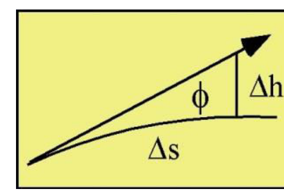
$$\frac{d^2h}{ds^2} - \left(\frac{2}{R+h} + \frac{1}{n}\frac{dn}{dh}\right)\left(\frac{dh}{ds}\right)^2 - \left(\frac{R+h}{R}\right)^2\left(\frac{1}{R+h} + \frac{1}{n}\frac{dn}{dh}\right) = 0$$

where R is the radius of the earth, h is the height of the beam above the earth's surface, and s is distance along the earth's surface.

To simplify this equation we will make three approximations

1. Large earth approximation $$R + h \approx R$$

2. Small angle approximation $$\frac{dh}{ds} = \tan\phi \approx \phi << 1$$



3. Refractive index ~ 1 in term: $$\frac{1}{n}$$

1 1/R 1

$$\frac{d^2h}{ds^2} - \left(\cancel{\frac{2}{R+h}} + \cancel{\frac{1}{n}\frac{dn}{dh}}\right)\cancel{\left(\frac{dh}{ds}\right)^2} - \left(\cancel{\frac{R+h}{R}}\right)^2\left(\cancel{\frac{1}{R+h}} + \cancel{\frac{1}{n}}\frac{dn}{dh}\right) = 0$$

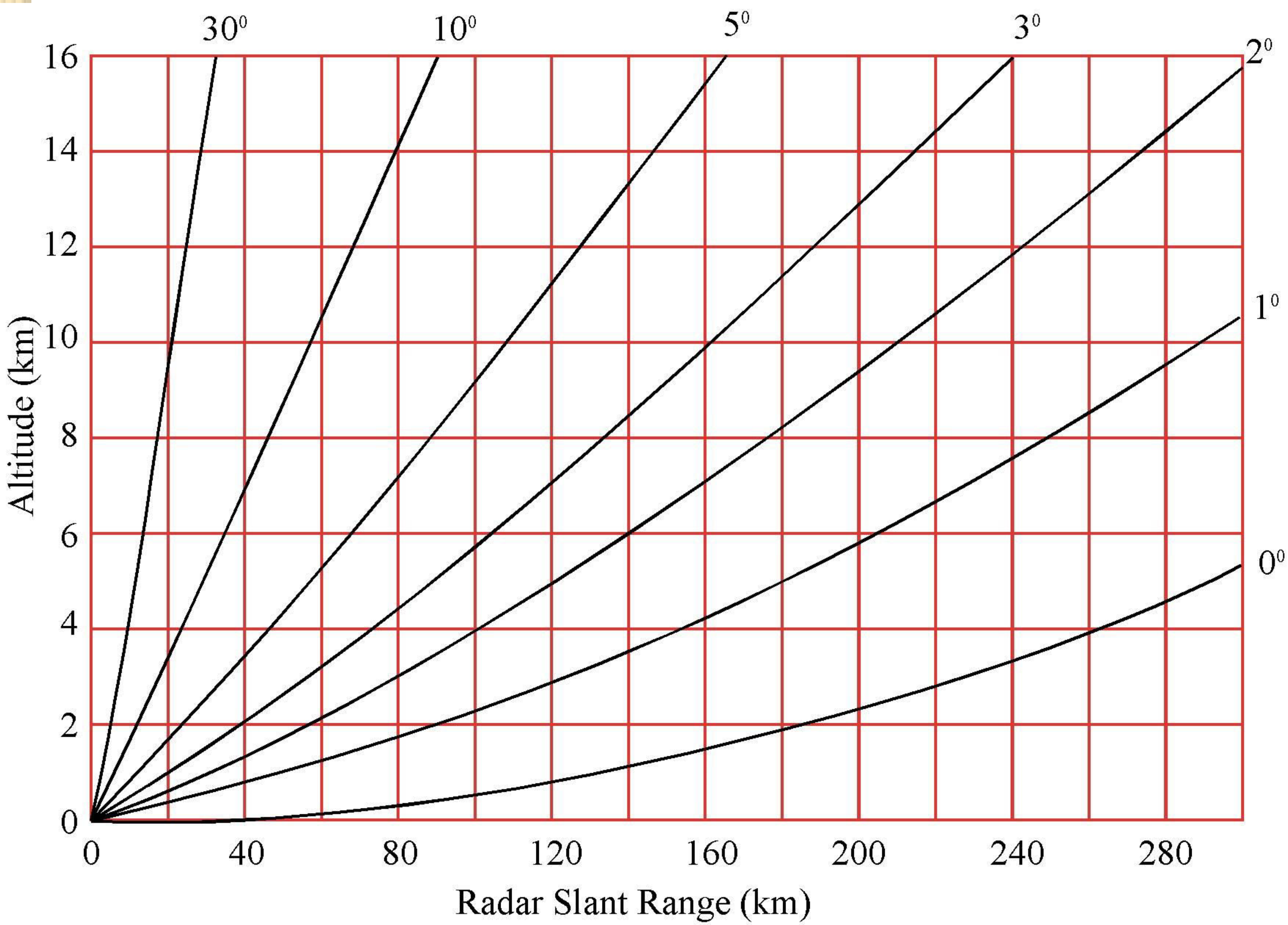
Approximate equation for the path of a ray at small angles relative to the earth's surface:

$$\boxed{\frac{d^2h}{ds^2} = \frac{1}{R} + \frac{dn}{dh}}$$

Or, in terms of the elevation angle of the beam

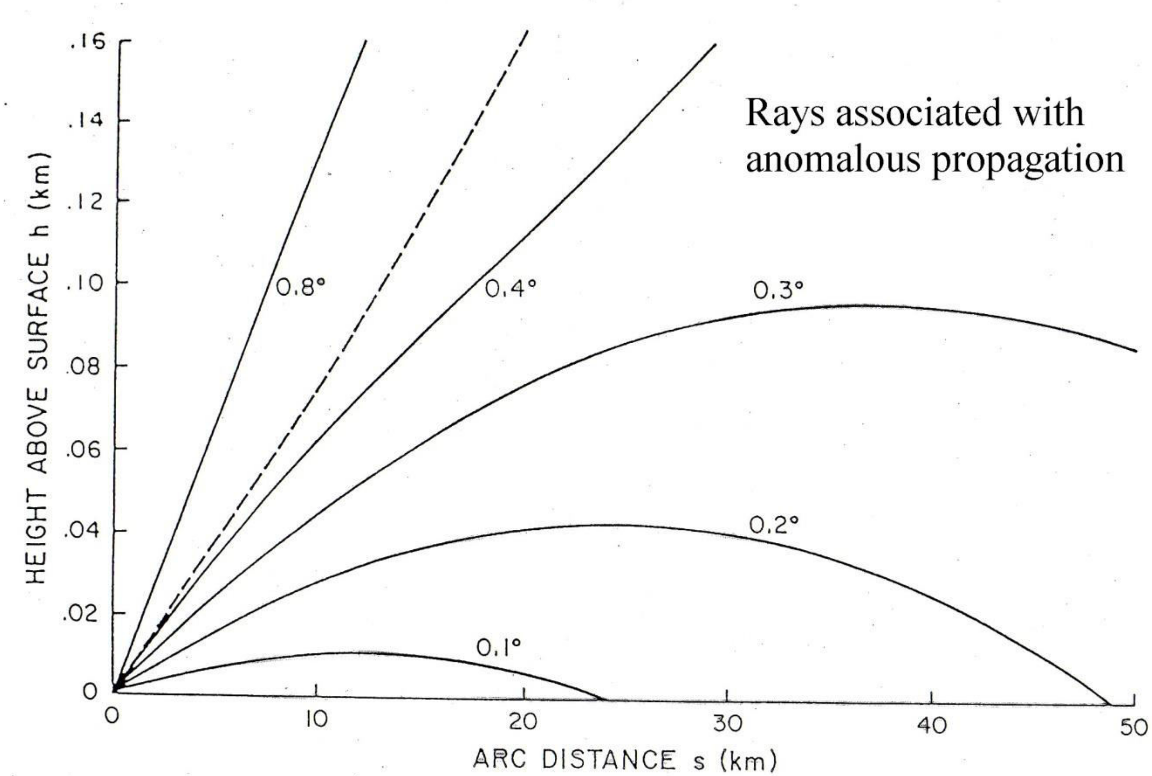
$$\boxed{\frac{d\phi}{ds} = \frac{1}{R} + \frac{dn}{dh}}$$

Height of a ray due to earth's curvature and standard atmospheric refracti



Anomalous Propagation

The propagation of a radar ray along a path other than that associated with standard atmospheric refraction

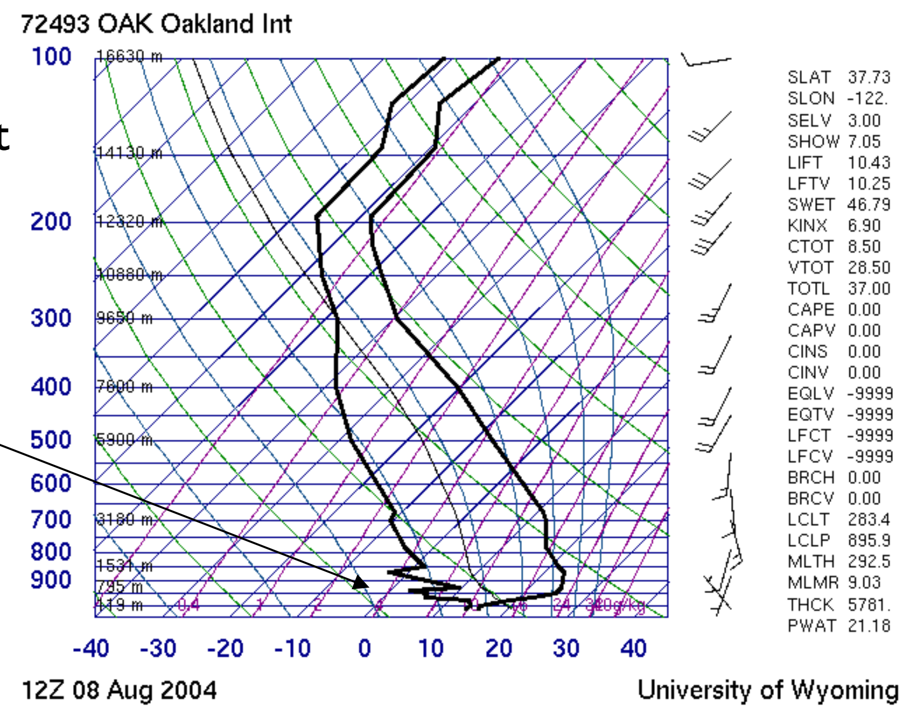


Anomalous propagation occurs when the index of refraction decreases rapidly with height in the lowest layers of the atmosphere

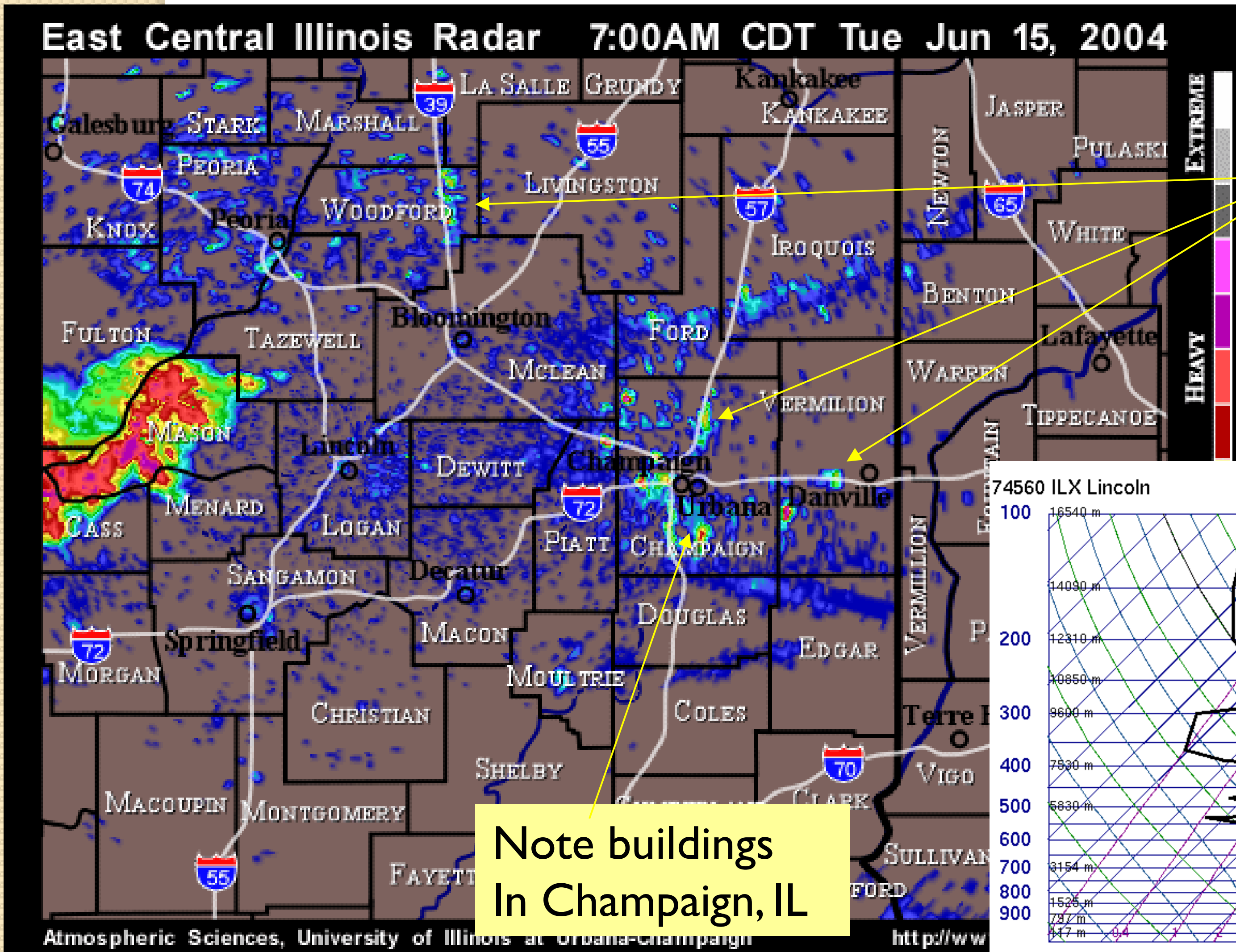
Recall that the **Refractive Index** is related to:

$$n = 1 + 7.76\times10^{-5}\,K\,mb^{-1}\left(\frac{P_d}{T}\right) - 5.6\times10^{-6}\,K\,mb^{-1}\left(\frac{e}{T}\right) + 0.375K^2mb^{-1}\left(\frac{e}{T^2}\right)$$

n decreases rapidly when *T* increases with height and/or *e* decreases with with height in the lowest layer



Effects of anomalous propagation:



Note cell towers along Interstates!

Note buildings In Champaign, IL