[redacted]

Skywave propogation (2 to 30 MHz).

- It has practical importance at medium & high frequencies for very long distance radio communications.
- In this mode of propogation electromagnetic waves reach the receiving point after reflection from the ionized region in the upper atmosphere called inosphere.
- Inosphere acts like a reflecting surface and is able to reflect back the EM waves of frequencies between 2 to 30 MHz. EM waves of frequency more than 30 MHz are not reflected back from the inosphere rather they penetrate it.
- It is also called short wave propogation.
- It is also called inospheric propogation.

Critical Frequency : f_0 (or) f_c.

The critical frequency of an ionized layer of the ionosphere is defined as the highest frequency which can be reflected by a particular layer of ionosphere at vertical incidance. This highest frequency is called critical frequency for that particular layer and it is different for different layers.

The critical frequency of the particular layer is proportional to the square root of the maximum electron density.

We know that the expression for refractive index in ionosphere

$$\mu = \sqrt{1 - \frac{81N}{f^2}} = \frac{\sin i}{\sin r}$$

For vertical incidance $i = 0$, then $f = f_c$, $N = N_{max}$

$$\frac{\sin 0}{\sin r} = \sqrt{1 - \frac{81 N_{max}}{f_c^2}} \Rightarrow 1 - \frac{81 N_{max}}{f_c^2} = 0$$

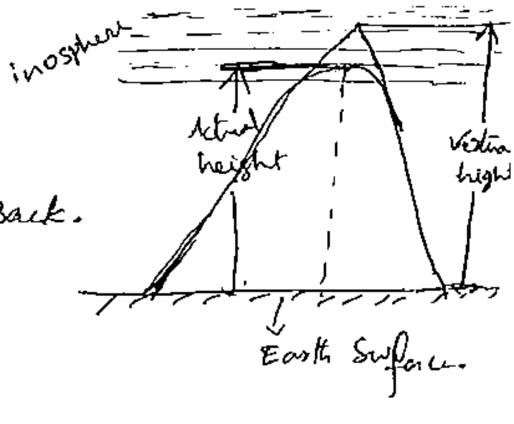
$$\frac{81 N_{max}}{f_c^2} = 1 \Rightarrow 81 N_{max} = f_c^2$$

$$\therefore \boxed{f_c = 9\sqrt{N_{max}}}$$ where N_m is max electron density.

Virtual height: It is defined as the height to which a short pulse of energy sent vertically upward and travelling with the speed of light would reach taking the same two-way travel time as does the actual pulse reflected from the ionospheric layer.

Virtual height $h = CT/2$

where 'T' is time taken by EM wave to travel to Ionosphere and return back.



The value of virtual height always greater than Actual height.

Maximum usable Frequency (MUF)

The maximum possible value of the frequency for which reflection takes place for a given distance of propagation is called the maximum usable frequency for that distance.

ie It is a highest frequency which can be reflected back to earth but this time some specific angle of incidence rather than vertical.

For a sky wave to return earth, the angle of refraction $r = 90°$, which implies $N = N_{max}$, $f = f_{max}$. ie the max. frequency

Then $\mu = \dfrac{\sin i}{\sin 90°} = \sqrt{1 - \dfrac{81 N_{max}}{f^2_{MUF}}}$

$= \sin i = \sqrt{1 - \dfrac{81 N_{max}}{f^2_{MUF}}}$ But $81 N_{max} = f_c^2$

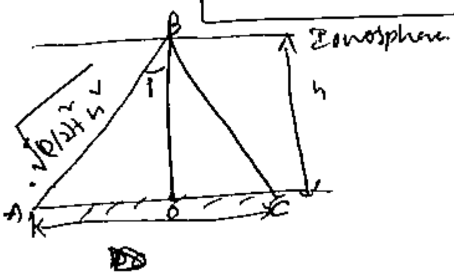
$\sin i = \sqrt{1 - \dfrac{f_c^2}{f^2_{MUF}}} \Rightarrow 1 - \dfrac{f_c^2}{f^2_{MUF}} = \sin^2 i$

$\dfrac{f_c^2}{f^2_{MUF}} = 1 - \sin^2 i \Rightarrow f^2_{MUF} = \dfrac{1}{\cos^2 i} \cdot f_c^2$

$$\boxed{f_{MUF} = \sec i \cdot f_c}$$

Calculation of MUF

(1) For a flat earth.



$\cos i = \dfrac{OB}{AB} = \dfrac{h}{\sqrt{(D/2)^2 + h^2}}$

h → height of layer

D → propagation distance (AC).

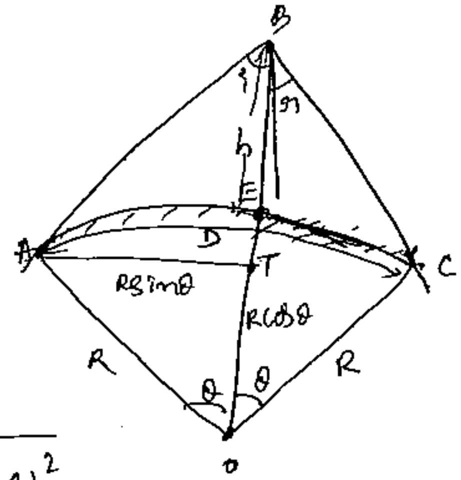
$$\therefore \boxed{f_{MUF} = f_c \cdot \sqrt{1 + \left(\frac{D}{2h}\right)^2}}$$

$\cos i = \dfrac{h}{\sqrt{\dfrac{D^2}{4} + h^2}} = \dfrac{h}{h\sqrt{\dfrac{D^2}{4h^2} + 1}}$

$\cos i = \dfrac{1}{\sqrt{\left(\dfrac{D}{2h}\right)^2 + 1}}$

$\sec i = \sqrt{1 + (D/2h)^2}$

For Curved earth MUF Calculation



$$\text{Angle} = \frac{\text{Arc}}{\text{Radius}}$$

$\therefore 2\theta = D/R \Rightarrow \boxed{D = 2R\theta}$ — (1)

$AT = R\sin\theta$, $OT = R\cos\theta$.

$BT = OE + EB - OT$

$= R + h - R\cos\theta$.

$$AB = \sqrt{AT^2 + BT^2} = \sqrt{(R\sin\theta)^2 + (h + R - R\cos\theta)^2}$$

$$\cos i = \frac{BT}{AB} = \frac{h + R - R\cos\theta}{\sqrt{(R\sin\theta)^2 + (h + R - R\cos\theta)^2}}$$

$$\therefore \cos^2 i = \frac{(h + R - R\cos\theta)^2}{(R\sin\theta)^2 + (h + R - R\cos\theta)^2} \quad \text{— (2)}$$

D is skip distance

But $\cos\theta = \frac{OA}{OB} = \frac{R}{R+h}$.

$$\cos\theta = \frac{R}{R(1 + \frac{h}{R})} = \frac{1}{(1 + \frac{h}{R})} = \left(1 + \frac{h}{R}\right)^{-1}$$

$$\cos\theta = 1 - \frac{h}{R} + \cdots \quad \left(\because \frac{h}{R} << 1.\right)$$

from (1) $1 - \theta^2/2 = 1 - h/R \Rightarrow \theta^2 = \frac{2h}{R}$

$$D^2 = 4R^2\theta^2 \Rightarrow D^2 = 4R^2 \times \frac{2h}{R} \Rightarrow$$

$$D^2 = 8hR.$$

$$\boxed{h = D^2/8R} \quad \text{— (3)}$$

$$\cos\theta = \left(1 - \frac{D^2}{8R^2}\right).$$

$$\sin\theta = \theta = D/2R.$$

$$\therefore \cos^2 i = \frac{f_c^2}{f_{MUF}^2} = \frac{\left\{h + R - R\left(1 - \frac{D^2}{8R^2}\right)\right\}^2}{\left\{R^2 \frac{D^2}{4R^2} + \left[h + R - R\left(1 - \frac{D^2}{8R^2}\right)\right]\right\}^2} = \frac{\left(h + \frac{D^2}{8R}\right)^2}{\frac{D^2}{4} + \left(h + \frac{D^2}{8R}\right)^2}$$

Optimum frequency

The Frequency at which there is optimum return of wave energy is called optimum frequency. It is also called Called Optimum working frequency. (OWF).

The Optimum freq which is 15% less than the MUF is used for Ionosphere propagation.

MUF changes at a perticular location with factors such as with time of the days (hour to hour), from season to season. & from months to months & accordingly optimum working frequency also follow similar variations. However, in practice it is not possible to change the freq. of Comm. from hour to hour. Therfore, for continuous Communication, it is necessary to use atleast two frequencies, one for day and other for night. Even, some times a third frequency for transition period is also used.

In the night time the vertical height of Ionosphere increases than in the day time and so the skip distance increases.

Problems

① A communication link is to be established b/w points which are 400km apart from the Ionosphere layer which 250 km above the surface of the earth. If the critical frequency is 11MHz. determine the frequency of EM wave that is highly to return back to the surface of Earth

Sol D skip = 400km

$h = 250km$

$f_c = 11MHz$

$$F_{MUF} = f_c \sqrt{\left[\frac{D_{skip}}{2h}\right]^2 + 1}$$

(P) If ... are 1500 km apart, the $f_{muf} = 37.95$ MHz, the Ionosphere layer is at 250 km. calculate the Critical freq. in MHz. If the earth is assumed to be flat.

$$f_{muf} = f_c \cdot \sqrt{1 + \left(\frac{D}{2h}\right)^2}$$

(A)

(P) Calculate the critical freq. & M.U.F for E-layer having electron density of 10^{12} per cubic met. & angle of incidence is 20°.

Sol

$f_c = 9\sqrt{N_{max}}$ $\quad f_c = 9$ MHz.

$F_{MUF} = f_c \sec i$

$= 9 \times 10^6 \times \sec 20$

$= 22.05$ MHz

(P) Assume that the reflection takes place at a height of 400 km and max. density in Ionosphere corresponds to 0.9 Refractive index at 10 MHz. what will be the skip distance for which MUF is 10 MHz.

Sol

$$n = \sqrt{1 - \frac{81N}{f^2}}$$

at $n = 0.9$, $N = N_{max}$

$$0.9 = \sqrt{1 - \frac{81 N_{max}}{(10 \times 10^6)^2}} \Rightarrow N_{max} = 0.23 \times 10^{12}$$

$\therefore f_c = 9\sqrt{N_{max}} = 4.31$ MHz

$$D_{skip} = 2h\sqrt{\left(\frac{F_{muf}}{f_c}\right)^2 - 1}$$

$$= 2 \times 400 \sqrt{\frac{(10 \times 10^6)^2}{(4.3 \times 10^6)^2} - 1} \Rightarrow D_{skip} = 1674.73 \text{ km}$$

(P) Determine the change in electron density in E-layer when critical freq. changes from 4.5 MHz to 1.5 MHz. b/w midway & sunset positions.

Sol

$f_{c_1} = 4.5\text{ MHz} = 9\sqrt{N_{max1}}$ — (1) ; $f_{c_2} = 1.5\text{ MHz} = 9\sqrt{N_{max2}}$ — (2)

Add (1) & (2) 6 MHz = $9\left[\sqrt{N_{max1}} + \sqrt{N_{max2}}\right]$ — (3)

(P) ... the tr. antenna is 10ft & Receiving antenna in 50ft.

Ans. $D_{max} = 4.12\left[\sqrt{h_t} + \sqrt{h_r}\right]$ km.

(Q) Discuss the Following :—
(1) Ionosphere storms (2) Sudden Ionospheric disturbances.

(A) Ionospheric storms are the disturbances which occur with the rapid and excessive fluctuations associated with the magnetic storms in Ionosphere. These disturbances are dependent on the magnetic storms that occur in earth's magnetic field.

Ionospheric storms causes the absorption of sky waves and change in critical frequency of F2 and E layers. These Ionospheric storms occur throughout the day and night and may extend upto two or more days.

During the ionospheric storms, the ionosphere looses its layered structure. In order to establish communication in this situation, we have to lower the working frequency.

The virtual height of F2 layer increases because of sudden decrease in critical frequency due to ionospheric storm.

Ionospheric storm caused by α & β ray particals that are emitted from Sun.

The Ionospheric storm effect decreases as one moves from poles to equator.

⇒ Sudden Ionospheric Disturbances (SID) (Mongel - Dellinger effect)

SID is caused due to appearance of bright spots on solar disc suddenly. These bright spots due to large emission of hydrogen from Sun. The X-rays along with bright spot causes tremendous increase in the ionization density till the D-layer. This causes increase in absorption, reflection and atmospheric noise. Hence the value of LUF increases and exceeds MUF, causing complete blackout of skywave communication over ionosphere. This blackout effect is known as sudden ionospheric disturbance.

SID is high at noon and at equator position. SID does not occur during the nights. SID takes place for a very less duration. It does not effect E, F1, F2 layers.

SID caused due to UV and X-rays ... from Sun ...

NOTE

for curved earth the skip distance is defined by

$$D_{skip} = 2\left[h + \frac{D^2}{8R}\right]\sqrt{\left[\frac{f_{MUF}}{f_{cr}}\right]^2 - 1}$$

where $D = 1651.16\,km$, $R = 6370\,km$ } curved earth.

$$= 2\left[400 + \frac{(1651.16)^2}{8 \times 6370}\right]\left[\sqrt{\left[\frac{10}{4.31}\right]^2 - 1}\right]$$

$$D_{skip} = 1898.91\,km$$

* A short wave broadcasting service is to be established covering a distance of 6000km in 3 hops each each hop of 2000km. Assume that reflection takes place at a height of 250km and electron density is $5 \times 10^{11}\,cm^3$. What is the freq of operation and angle incidence that should be ...

By definition $D_{skip} = 2h\sqrt{\left[\frac{f_{MUF}}{f_{cr}}\right]^2 - 1}$ → (1)

But $f_{cr} = 9\sqrt{N_{max}}$

$= 9\sqrt{5 \times 10^{11}}$

∴ $f_{cr} = 6.363\,MHz$ → (2)

$$2000 = 2(250)\sqrt{\frac{(f_{MUF})^2}{(6.36)^2} - 1}$$

$$\frac{2000}{500} = \sqrt{\frac{(f_{MUF})^2}{(6.31)^2} - 1}$$

$f_{MUF} = 10.3\,MHz$

The actual freq that is used for communication is optimal working freq which is 85% HUF

∴ Optimal working freq 85% of HUF

$= 10.3 \times \frac{85}{100}$

$= 20.93\,MHz$.

By def $f_{MUF} = f_{cr}\sec\theta_i$

$$\sec^{-1}\left[\frac{f_{MUF}}{f_{cr}}\right] = \theta_i$$

$$\sec^{-1}\left[\frac{10.3}{6.36}\right] = \theta_i$$

$$\theta_i = 51.8$$

① Effect of Ionosphere on skywave propagation

$E = E_m \sin\omega t$

$i_D = \omega k_0 E_m \cos$

$i_I = \frac{N e^2}{m\omega} E_m$

We know that as we move higher into Ionosphere the electron density increases. These electrons are not stationary but are getting displaced under the influence of air density and windspeed. This displacement will result in current flow which will always be capacitive in nature because of which the displacement current lags the applied voltage by 90°.

This displacement current is quantified as

$$(i_D)_C = \omega k_0 E_m \cos\omega t$$

This happens when the electromagnetic wave is of the nature $E = E_m \sin\omega t$.

When the EM wave enters the Ionosphere with electric field intensity $E = E_m \sin\omega t$ the lines of forces associated with this E field will strike the electron density and make the electrons vibrate sinusoidally. This vibration of electrons will contribute to a current which will inductive in nature because of which the inductive

Current lead the Voltage by 90°

The inductive current is quantified as

$$(i_I)_i = \left[-\frac{Ne^2}{mw}\right] E_m \cos wt$$

At any point of time the current flowing through Ionosphere will be sum of displacement and inductive current

$$i = (i_D)_c + (i_I)_I$$

$$= wk_0 E_m \cos wt - \frac{Ne^2}{mw} E_m \cos wt$$

$$= w\left[k_0 - \frac{Ne^2}{mw^2}\right] E_m \cos wt$$

In eq(1) k_0 represents the dielectric constant of Ionosphere in the absence of electrons

In eq(3) $k_0 - \frac{Ne^2}{mw^2}$ represents the dielectric constant of Ionosphere in presence of electron density

From eq(1) & (3)

We infer that the presence of electron density decreases the dielectric constant of Ionosphere & because of this decreasing wav. values the EM wave gets refracted back to the surface of earth

* Effect of Earths magnetic field on sky wave propagation

The effect of earth's magnetic field is to exert a deflecting force on the electron density present in Ionosphere.

The magnitude of this deflecting force is equal to the product of the instantaneous velocity of vibration of electrons that takes place when EM wave strikes them and magnitude of earth M-field that acts as right angle to the velocity of vibration. Because of this the resultant polarization of EM wave gets transformed to elliptical polarization

At high frequencies the elliptically polarised em wave will exhibit a very narrow elliptical path. If the freque is brought down the amplitude of vibration increases because of which the electrical path exhibits a wide minor axis and narrow major axis. At a particular val of frequency the elliptical path will now transform to a spiral path of increasing radius. At this path cyclotron resonance is said to happen and usually occurs at a frequency of 1400 KHz.

The third effect of Earth's magnetic field is to spli into two components - Ordinary and Extraordinary components. This effect is called Magneto ionic effect. The Ordinary & Extraordinary components reach the desinations following diff path diff amt of attenuatio and absorption. This is going to cause interference effect at reception side

* Effect of Collision on sky wave propagation

We know that there is huge ionisation rate during day time under the influence of radiation from the sun. As the temp gets cooler, the electrons try to recombine and in the process they collide with the molecules already present resulting in absorption. This is going to attenuate the EM waves considerably and in some extreme case the received signal strength may fall below the noise level and cause interference effects.

* Fading

Fading can be defined as the fluctuation in the received signal strength due to variation in height and density of Ionospheric layers that depends on vagaries of the nature, because of which there would be huge attenuation of received signal and in some cases the signal may fall below noise leve and there would be complete blackout. Following a different types of fading:

1 Selective Fading

In this there is a selective fading of a modulating signal in the received EM wave. It is found that the AM signals are more suspectable to selective fading when compared to SSBSC.

2. Interference Fading

When the EM waves are broadcasted into the atmosphere, they reach the destination following dif path and different instants of time because of which there would be a phase difference resulting in reduction in amplitude of received signal. Also when EM wave travels through atmosphere they get interefered with surface & space wave present in tropospheric region. These two phenomenon would retard the signal and result in interference fading

3. Absorption Fading

The atmosphere has various absorption agents in the form of moisture, watervapour contents, humidity, temperature and gaseous contents. When EM wave travel through them, they absorb the energy and retard the received signal strength this phenomenon is called absorption fading

4. Polarisation Fading

We know that EM waves radiated from vertical antennas are always vertically polarised. When the vertical polarised EM waves strikes the electron density present in ionosphere they vibrate them sinusoidally because of which the vertical polarisation transforms to elliptical polarization. This elliptical polarisation depends on operating frequency. At high frequency the ellipt path is narrow and when the frequency is brought to a bit less value, the elliptical path exhibits different widths along major and minor axis at a particular frequency of 1400KH the elliptical path transforms to circular path mi singradius. All this processes will reduce the amplitu of received signal and result in what is called as polarisation fading

5. Skip fading

Skipdistance is the distance from transmitting antenna measured along the surface of earth at which the EM are likely to appear. This skipdistance cannot be fixed because of the volatile nature atmosphere and is likely to oscillate over certain range called skip zone. This is going to retard the received signal and result in skip fading. When the received signal strength is reasonable but has noise content. In this case automatic ga control and Automatic Volume control can be used to redu fading

* Diversity Reception

When ever the Received signal strength falls below noise level, to reduce fading and improve the quality of reception. The only solution is diversity Reception

There are two types of Diversity Reception

1. Space diversity reception
2. Frequency diversity reception

* **Space diversity**

Space diversity reception is used whenever ample space is available to install 2 or 3 antenas physically separated by a distance of 9-10 times of operating wavelength. Here the no. of receivers used equals no. of transmitting antennas and are arranged in such a way that whenever the receiver receives a strong signal by default it generates automatic gain control signal that will turn off other two receivers

* **Frequency diversity Reception**

This concept is used whenever no ample space is available for space diversity reception concept to be employed. Here a single antenna capable of operating over a wide range of frequency is used. So that whenever the frequency changes the reception is not disturbed. This concept is widely used for establishing communication link between ship to ship & ship to control station

* **Friss formula for Wireless Communication**

Consider P_t is the power transmitted by a transmitting antenna

The power received at distance r by another isotropic antenna is defined by

$$P_{received} = \frac{P_t}{4\pi r^2} \longrightarrow (1)$$

If G_t is the gain of transmitting antenna the received power is

$$P_{received} = \frac{P_t G_t}{4\pi r^2} \longrightarrow (2)$$

Consider the $(A_e)_r$ is the affective aperature of receiving antenna.

The power received by receiving antenna increases in proportion of to affective aperature of receiving an

$$= \frac{P_t G_t (A_e)_r}{4\pi r^2}$$

by definition the relationship between gain of receiving antenna (G_R) and affective aperature of receiving antenna is defined by

$$G_R = \left[\frac{4\pi}{\lambda^2}\right](A_e)_r$$

$$(A_e)_r = \frac{G_R}{\left[\frac{4\pi}{\lambda^2}\right]} \longrightarrow (4)$$

Put (4) in (3)

$$P_r = \frac{P_t G_t G_R}{\left[\frac{4\pi r}{\lambda}\right]^2}$$

This formula is called friss formula for wireless communication.

* A C-link is to be established between 2 station using half wave length antenna for maximum directive gain. The transmitting power 1kHz. The transmitting and receiving antenn distance between transmitter and receiving antenn is 100km. What is the max power received by receiver if operating frequency is 100MHz.

$f = 100MHz$

$\lambda = \frac{c}{f}$

$= \frac{3\times10^8}{100\times10^6}$

(P) A communication link has to be 2 stations which are 1500 km apart, the $f_{muf} = 37.95$ MHz, the Ionosphere layer is at 250 km. Calculate the critical freq. in MHz. If the earth is assumed to be flat. (8) 8

$f_{muf} = f_c \cdot \sqrt{1 + \left(\frac{D}{2h}\right)^2}$ D = 1500 km, h = 250 km, $f_{muf} = 37.95$ MHz

(A)

(P) Calculate the critical freq. & M.U.F for E-layer having electron density of 10^{12} per cubic met. & angle of incidence is 20°.

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$f_c = 9\sqrt{N_{max}}$ $f_c = 9$ MHz.

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Sol
$f_{c1} = 4.5\text{ MHz} = 9\sqrt{N_{max1}}$ —(1) ; $f_{c2} = 1.5\text{ MHz} = 9\sqrt{N_{max2}}$ —(2)

Add (1) & (2) $6\text{ MHz} = 9\left[\sqrt{N_{max1}} + \sqrt{N_{max2}}\right]$ —(3)   change = $N_{max1} - N_{max2}$

If earth is assumed to perfect conductor $K=1$

K is Earth constant.

$\beta = 180°$

$\therefore |E_R| = E_0 \cdot \sqrt{1+2\cos\theta+1}$

But $\theta = \alpha+\beta$

$= E_0 \sqrt{2(1+\cos\theta)}$

$\theta = \frac{4\pi h_t h_r}{d\lambda} + \pi$.

$= E_0 \sqrt{4\cos^2(\theta/2)}$

$|E_R| = 2E_0 \cos(\theta/2)$

$= 2E_0 \cos\left[\left(\frac{4\pi h_t h_r}{d\lambda} + \pi\right)/2\right]$

$= 2E_0 \cos\left[\left(\frac{2\pi h_t h_r}{d\lambda}\right) + \pi/2\right]$

$E_R = 2E_0 \sin\left(\frac{2\pi h_t h_r}{\lambda \cdot d}\right)$.

$\left(\frac{D}{2h}\right)^2 = \frac{f_{max}^2}{f_c^2} - 1$

$\frac{f_{max}^2}{f_c^2} = \left(\frac{D}{2h}\right)^2 + 1$

$f_{max} = f_c \cdot \sqrt{1+\left(\frac{D}{2h}\right)^2}$

For small angle θ, $\sin\theta \cong \theta$.

$\therefore E_R = 2E_0 \cdot \left(\frac{2\pi h_t h_r}{\lambda d}\right)$.

But E_0 is free space field strength at a unit distance is

$E_0 = \frac{7\sqrt{P}}{d}$.

$\therefore |E_R| = \frac{7\sqrt{P}}{d} \cdot \frac{4\pi h_t h_r}{\lambda d}$

$$E_R = \frac{88\sqrt{P}\, h_t h_r}{\lambda \cdot d^2} \text{ V/m}$$

(P) A T.V transmitting antenna mounted at a height of 120m radiates 15KW of power in all direction at a freq. of 50 MHz calculate.

(1) Field strength at a Receiving antenna mounted at height of 16 m at a distance of 12km

(2) Distance at which field strength reduced to 1mV/m

(3) Detect the presence of sky waves & ground waves.

(4) Max. line of sight distance

Sol

(1) $E_R = \frac{88\sqrt{P}\, h_t h_r}{\lambda d^2} = \frac{88 \cdot \sqrt{15\times10^3} \times 120 \times 16}{\lambda \times (12\times10^3)^2}$

But $\lambda = \frac{3\times10^8}{50\times10^6}$

$E_R = 0.023$ V/m