Chapter (4)

Radio Wave Propagation

A signal travelling between an Earth Station and a satellite must pass through the Earth's atmosphere with all its upper layers.

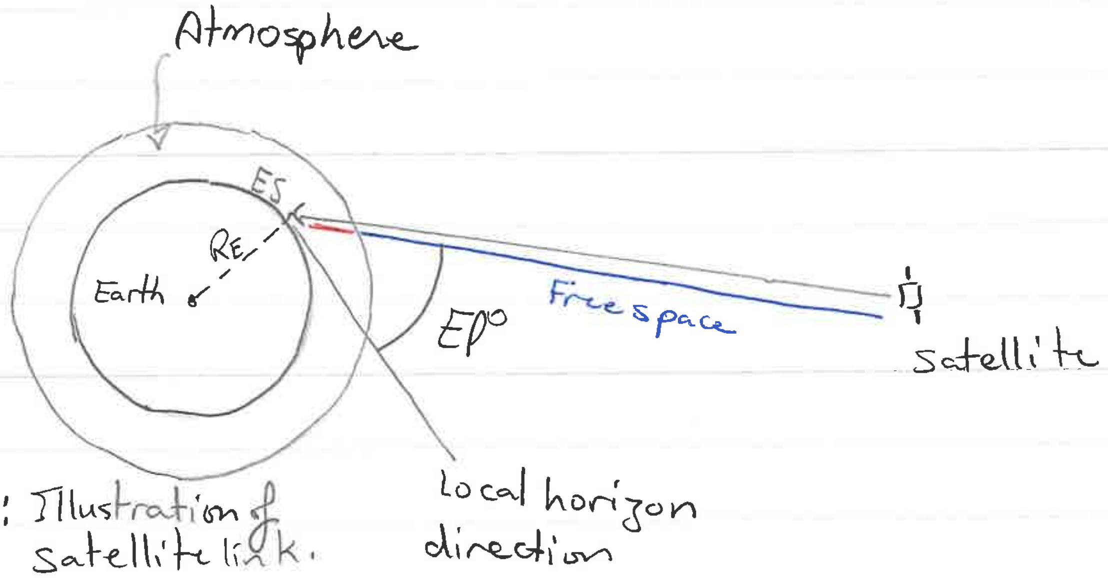


Fig.(1): Illustration of satellite link.

The propagation path is divided into two parts. Part in the atmosphere and the other part is in free space. Each of these two parts is studied seperately.

4.1. Free space loss:

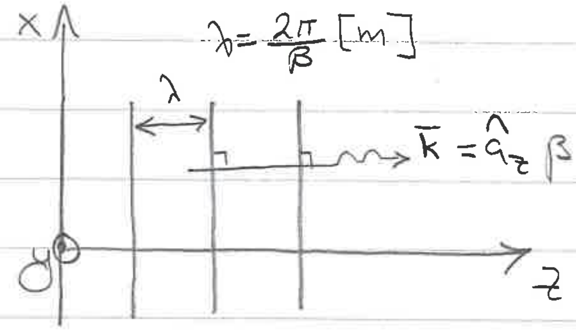
It is important to stress on the fact that the free space is not lossy by any means. Free space is a perfect dielectric with zero conductivity and zero loss tangent. A uniform plane wave propagates in free space with absolute zero attenuation.

Recall from CME 341 Electro II class;

Assume a uniform plane wave is propagating in the +ve z-direction in free space.

The associated Electric Field can be written as:

$$\bar{E} = \hat{a}_x E_o e^{j(\omega t - \beta z)}$$



where $\beta = \omega \sqrt{\mu_o \epsilon_o}$

$$= \frac{\omega}{c} = \frac{2\pi f}{c}$$

$$c = 3 \times 10^8 \text{ m/s}$$

The magnitude of the field, E_o, remains as is with no attenuation even after infinite no. of Kms. The power density associated with the field is

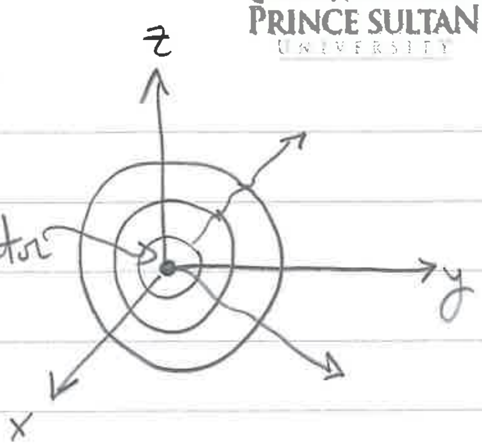
$P = \frac{1}{2} \frac{E_o^2}{\eta}$ [W/m^2] and doesnot decrease with the distance.

If that is the case, then what do we mean by free space loss?

What happens is that the sources used to produce signals are always localized sources in the form of antennas.

A point radiator produces a spherical wave not a plane wave. The field associated with a spherical wave can be written as: (for example)

$$\bar{E} = \hat{a}_\theta \, E_0 \, \frac{e^{j(\omega t - \bar{k}\cdot\bar{r})}}{|\bar{r}|}$$



where $|\bar{k}| = \beta = \omega\sqrt{\mu_0\epsilon_0}$

$= \frac{\omega}{c}$ [rad/m]

& $|\bar{r}| = r$ is the distance from the point source.

The magnitude of the field is $\frac{E_0}{r}$ which decreases as r increases.

Accordingly, the power density associated with the wave decreases with r^2

we can write

$$P_t = \frac{W_t}{4\pi r^2} \quad [W/m^2]$$ where

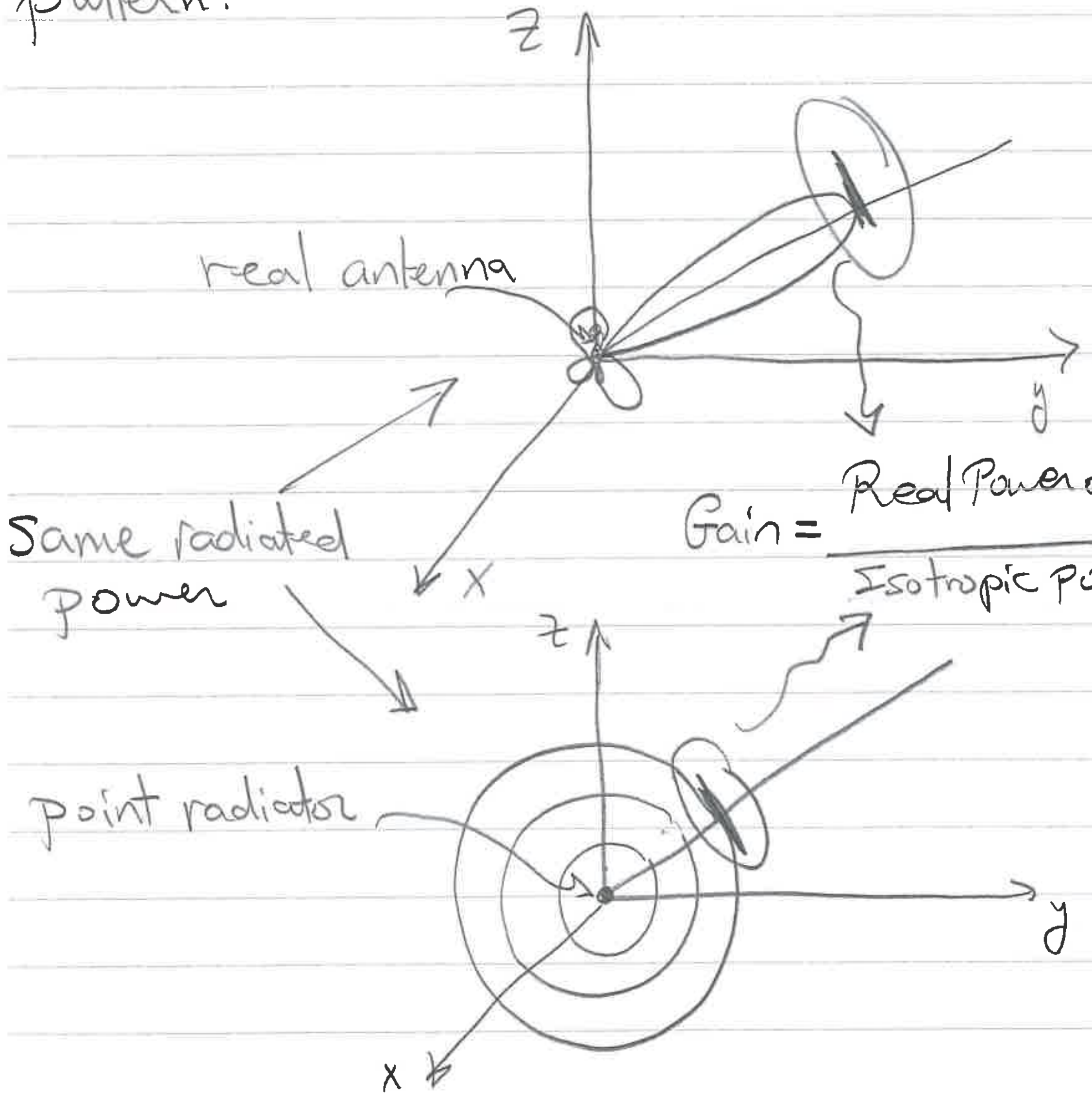
P_t is the transmitted power density $[W/m^2]$

W_t is the total transmitted or radiated power by the point radiator [W]

& $4\pi r^2$ is the surface area of a sphere with radius r centered at the point source.

In reality, there is no perfect point source.

Any antenna produces a group of spherical waves instead of one. Those waves add up in certain directions and cancel out in other directions giving the shape of the antenna radiation pattern.



$$\text{Gain} = \frac{\text{Real Power density}}{\text{Isotropic power density}}$$

Usually, the direction of maximum gain of a given antenna is directed towards the receiver.

Thus, the power density at a receiver at a distance r from the transmitting ant. in the direction of its maximum gain is given by:

$$P_r = G_{Tx} \cdot P_t \quad , \quad G_{Tx} \text{ is max gain of trans. ant.}$$

$$= \frac{G_{tx} W_t}{4\pi r^2} \quad [W/m^2]$$

& the total received power is:

$$W_r = P_r \cdot A_{eff.} \quad , \text{ where}$$

A_{eff} is the effective area of the receiving antenna.

Recall from Antenna Class: $\boxed{A_{eff} = \frac{\lambda^2}{4\pi} G}$

$$\Rightarrow \quad W_r = G_{tx} \cdot \frac{W_t}{4\pi r^2} \cdot \frac{\lambda^2}{4\pi} G_{RX}$$

$$= \left(\frac{\lambda}{4\pi r}\right)^2 G_{RX}\, G_{tx}\, W_t \quad [W]$$

The quantity $G_{tx} W_t$ is usually called the effective isotropic radiated power (EIRP)

The free space loss is usually defined as

$$FSL = \left(\frac{4\pi r}{\lambda}\right)^2 = \left(\frac{4\pi r}{c} \cdot f\right)^2$$

$$FSL_{dB} = 20 \log\left(\frac{4\pi r}{\lambda}\right) \quad dB$$

From the above eqn, one can erroneously conclude that the free space loss depends on the frequency and that higher frequencies suffer more losses in free space channels.

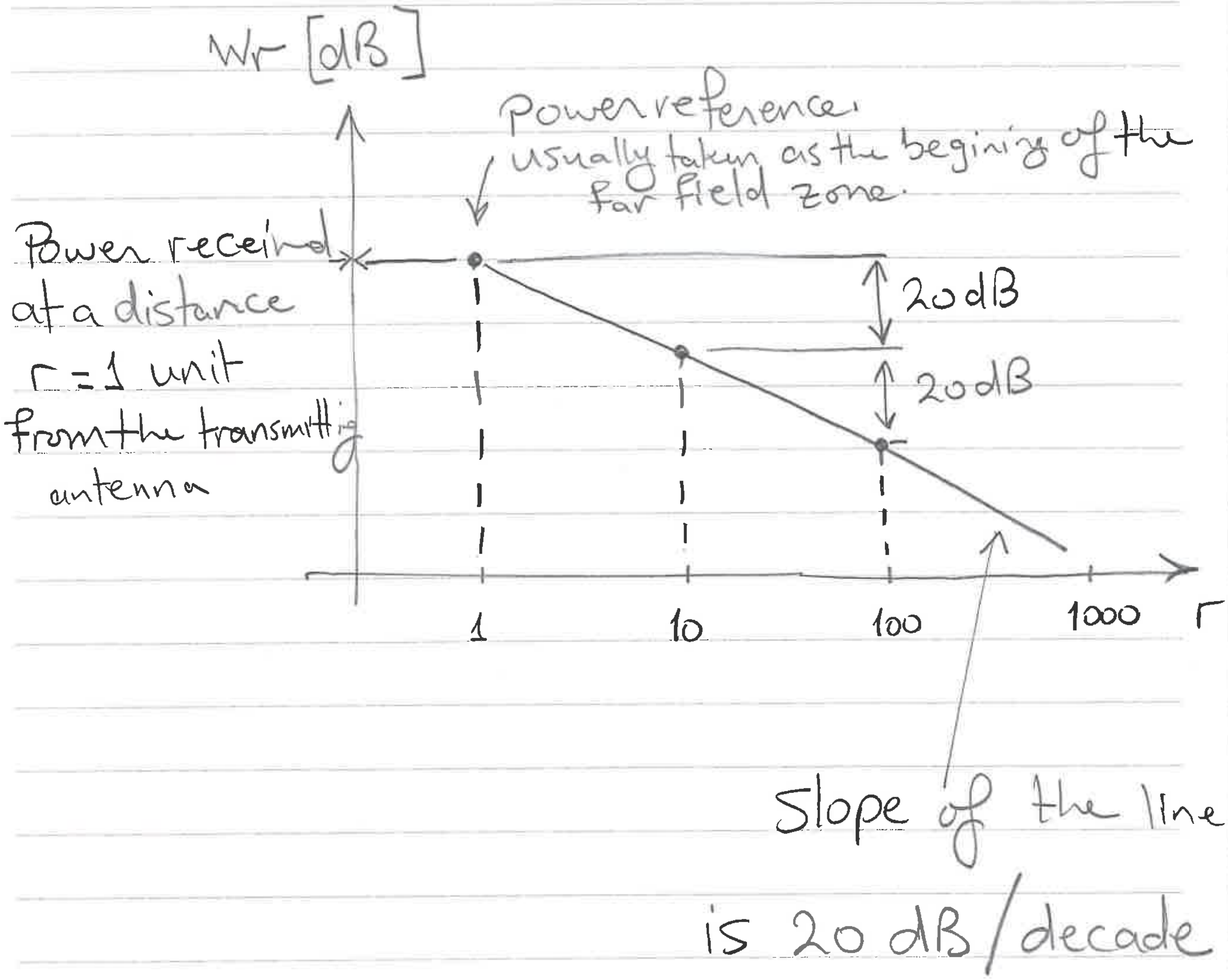
In fact, what brought the frequency into the picture is this equation:

$$A_{eff} = \frac{\lambda^2}{4\pi} G$$

which tells us that the antenna gain is function in frequency. Therefore if you change the frequency in the equation of the received power, you should change also G_{tx} & G_{Rx}.

Thus, the right conclusion is that for localized sources (real transmitting & receiving antennas) the free space loss increases with the square of the distance and the rate of increase is 20 dB per decade (decade means when you increase r 10 times the free space loss increases by 20 dB)

This can be illustrated graphically as :



This is a fixed rate for any free space channel and it does NOT depend on frequency

4.2 Atmospheric Loss:

This loss appears in the part of the path that passes through the atmosphere. (which is the red segment in fig. 1).

The atmospheric loss is given by:

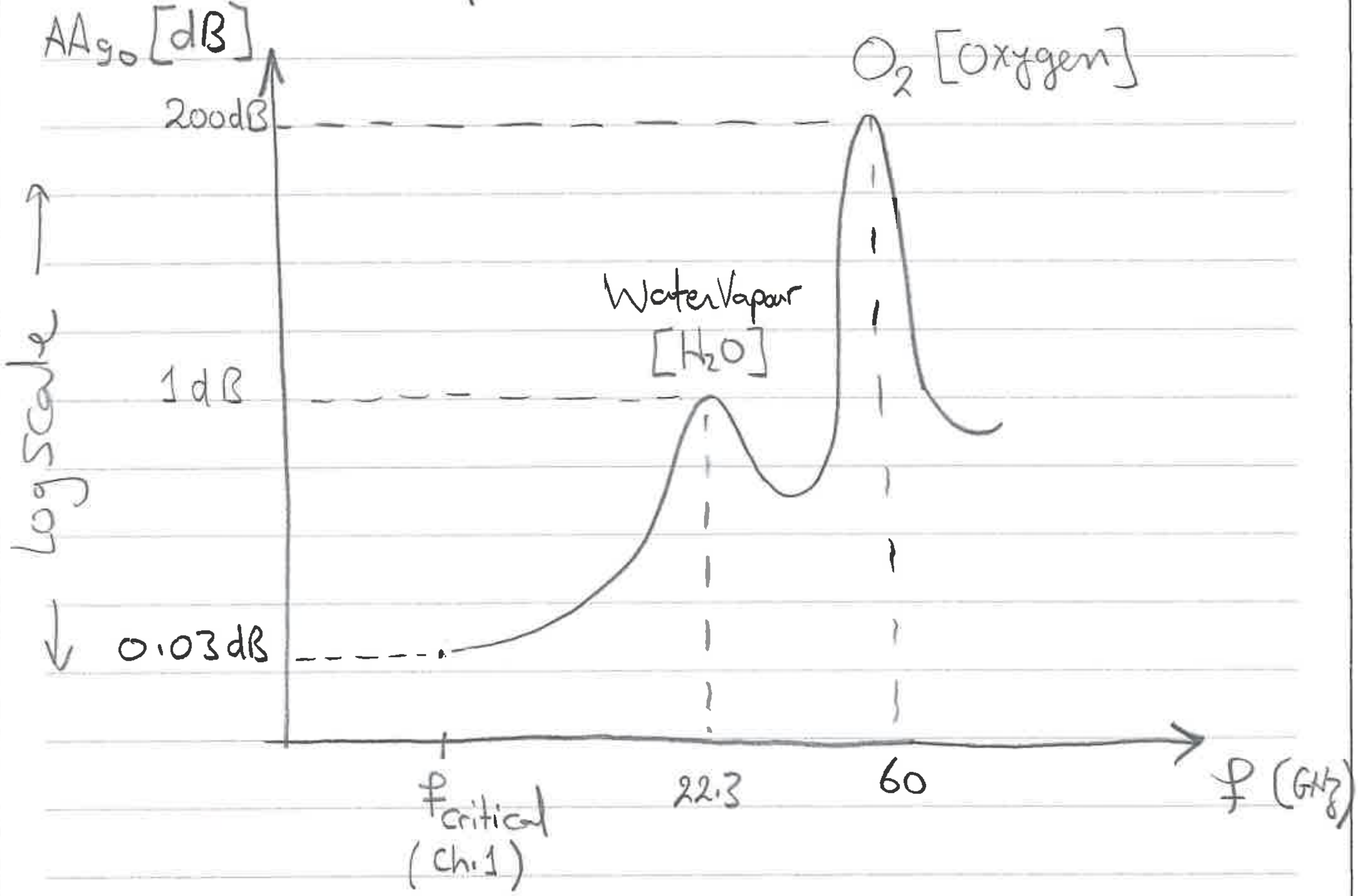
$$AA = AA_{90} \operatorname{cosec}(El^\circ)$$

$$= \frac{AA_{90}}{\sin(El^\circ)}$$

where El° is the elevation angle of the Earth station antenna.

AA_{90} is the value of the loss for $El^\circ = 90^\circ$ and is given in the form of graph vs. frequency.

For the whole Atmosphere



Atmospheric loss vs. frequency.

4.3 Rain Attenuation:

Weather conditions affect the quality of the signal passing througth the atmosphere. This effect can be modelled as attenuation factor in dB, given by:

$$RA = \alpha L \quad [dB]$$

where $\alpha = a R_p^{\,b}$ [dB/km]

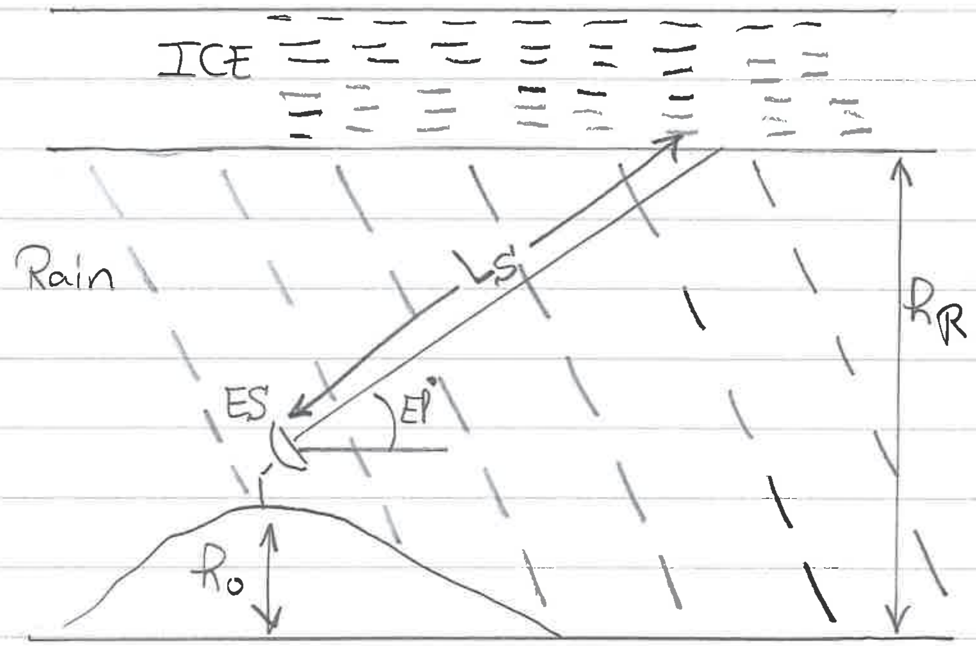
R_p is called the rain rate in mm/hr

a & b are constants given in tables for both vertical and horizontal polarizations. vs. frequency.

$$L = L_s r_p \quad [km]$$

where L_s is the total distance through the rain Layer as illustrated in the next figure.

r_p is a modification factor depending on the percentage of time R_p is exceeded.



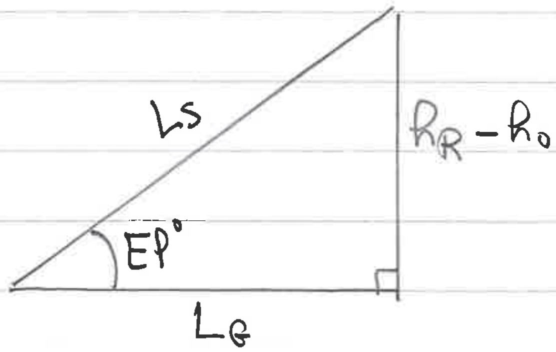


Illustration for the RA calculation

$$r_p = \begin{cases} \dfrac{10}{10+L_G}, & p = 0.001\,\% \\[2ex] \dfrac{90}{90+4L_G}, & p = 0.01\,\% \\[2ex] \dfrac{180}{180+L_G}, & p = 0.1\,\% \end{cases}$$

$$\Rightarrow \quad RA = \alpha L \quad [dB]$$

$$= a R_p^{\,b} L_s r_p \quad [dB]$$

This valued depends on frequency because a & b are function of frequency.

Note: No unit conversion is needed here because all those empirical formulas include constants measured with specific units.

Therefore, in this type of problems you need only to substitute in the right equation to calculate the value of the rain attenuation.