14/04/2021

Line of Sight (LOS) | RF | wireless link

$$\boxed{\underset{(W)}{P_r} = \underset{(W)}{P_t}\, G_t\, G_r \left(\frac{\lambda}{4\pi R}\right)^2} \quad \text{— (A)}$$

↳ Friis' formula for free space LOS | RF link

$P_r \propto \frac{1}{R^2}$; $P_r \propto \lambda^2 \left(= \frac{c^2}{f^2}\right)$

($1/R^2$ decay) $\propto \frac{1}{f^2}$

Recall : Transmission line (coaxial cable)

power $\propto e^{-2\alpha R}$ (exponential decay)

In (A), $P_t G_t = EIRP$

$P_t G_t$ (W) → no units

$EIRP$ (W) → $\boxed{\text{Effective Isotropic Radiated Power}}$

$$EIRP\Big|_{dBm} = P_t(dBm) + G_t(dB)$$

In (A), $\left(\dfrac{\lambda}{4\pi R}\right)^2$ = free space path loss (FSPL)

Another form of Friis' eqn. (A) :-

(A) : $P_r = \dfrac{P_t G_t G_r}{(4\pi)^2 R^2} \dfrac{c^2}{f^2}$

$\Rightarrow \underset{(W)}{P_r} = P_t G_t G_r \left[\dfrac{(3\times10^8 \ m/s)^2}{158 \times (10^3)^2 R^2 \times (10^6)^2 f^2} \right]$

where $(4\pi)^2 = 158$;

$R^2 \times (10^3)^2 = R\,(km)$; $(10^6)^2 \times f^2 \rightarrow MHz$

$\hookrightarrow 1km = 10^3$ m $\quad$ 1MHz = 10^6 Hz

$$\Rightarrow \underset{(W)}{P_r} = \underset{(W)}{P_t} G_t G_r \left[\frac{0.057 \times 10^{-2}}{f^2 R^2} \right]$$

where f is in MHz, R is in km

$$\Rightarrow \frac{P_r}{P_t} = G_t G_r \left[\frac{0.057 \times 10^{-2}}{f^2 R^2} \right]$$

$$\Rightarrow P_r(dBm) - P_t(dBm) = G_t(dB) + G_r(dB) + 10\log(0.057 \times 10^{-2}) - 10\log(f^2) - 10\log(R^2)$$

B

$$\boxed{\Rightarrow P_r(dBm) - P_t(dBm) = G_t(dB) + G_r(dB) - [32.5 + 20\log f + 20\log R]}$$

In (dB)

$$L_p = 32.5 + 20\log(f) + 20\log(R)$$

(dB)

↳ free space path loss (FSPL)

↳ $20\log d$ or $20\log R$ law

↳ distance

Example

Let distance between antennas is 50km $f = 6000$ MHz

then $L_p = 32.4 + 20\log(6000) + 20\log(50)$

$= 32.4 + 75.6 + 34$

$$\boxed{L_p = 142 \text{ dB}}$$

In same literature,

$$L_p = 92.4 + 20\log f + 20\log R$$

$R = 1cm$

$f = GHz \; (10^9)$

$$\begin{array}{r} 32.4 \text{ dB} \\ +\,60.0 \text{ dB} \\ \hline 92.4 \text{ dB} \end{array}$$

Common, $f = MHz \; (10^3)$

$(10^3)^2$

$= 10^6$

$= 60 dB$

Problem Geosynchronous Satellite

orbiting at 36,900 km above earth's surface $= R$, $P_t = 2W$ (33 dBm), $G_t = 37\ dB$

$G_r = 45.8\ dB$, $f = 20\ GHz$

(saturation)

$P_r = ?$ (free space conditions) convert to

$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi R}\right)^2 , \quad G_t = \text{factor}, \; G_r = \text{factor}, \; \lambda = c/f$$

Or, $P_r(dBm) = P_t(dBm) + G_t(dB) + G_r(dB) - [32.4 + 20\log(20,000) + 20\log(36,900)]$

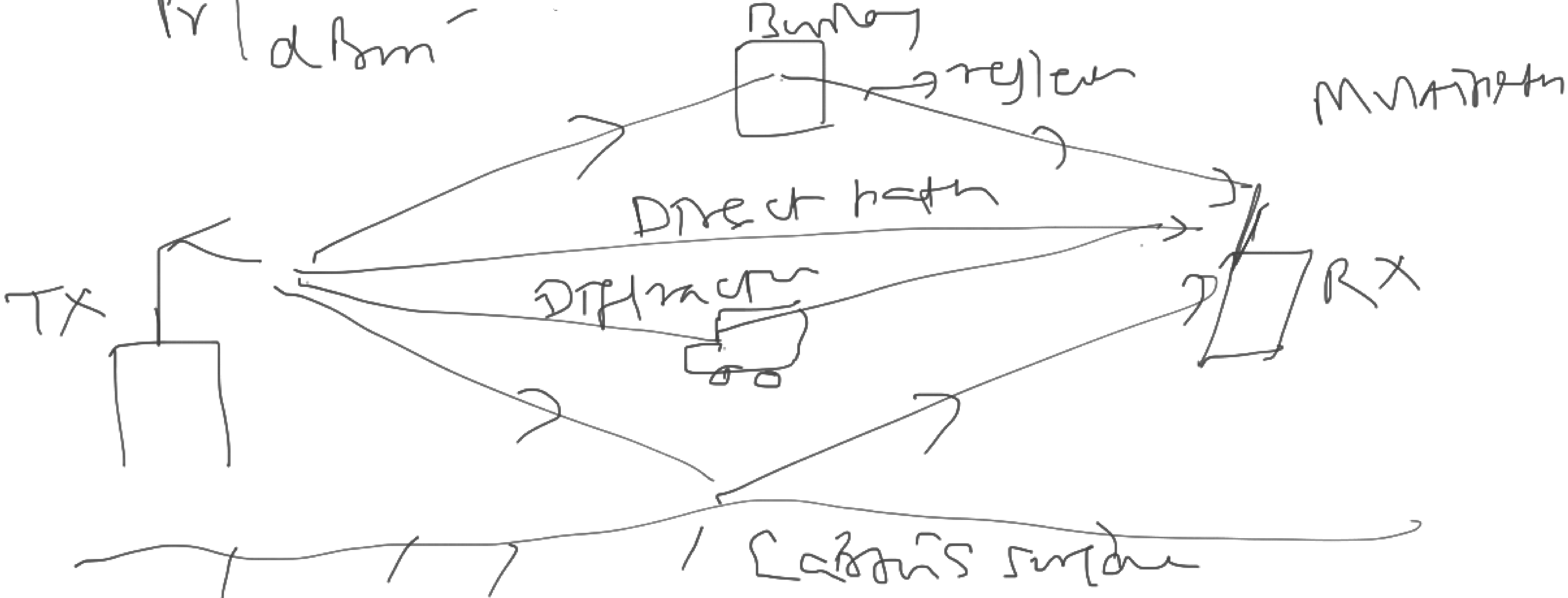
$= 33 + 37 + 45.8 - \underbrace{209.8}_{L_p\,(FSPL)\text{ in dB}}$

$\Rightarrow P_r = -94\,dBm$

or, $P_r = 3.98 \times 10^{-13}\,W$ [in Ⓐ]

$= 3.98 \times 10^{-10}\,mW$

$P_r\big|_{dBm} = -94\,dBm.$



Fade Margin (FM) → (dB)

$$FM = 30\log(D) + 10\log(6ABf) - 10\log(1-R) - 70$$

(dB)

D = distance (km)

f = freq (GHz)

R = reliability factor (99.99% = 0.9999)

A = roughness factor of terrain

- 4 over water or a very smooth surface
- 1 over average terrain
- 0.25 over a very rough, mountainous region

B = weather conditions

$$B = \begin{cases} 1 & \text{for very wet conditions} \\ 0.5 & \text{for humid areas} \\ 0.25 & \text{for average land area} \\ 0.125 & \text{for dry areas} \end{cases}$$

Example: $D = 40\,\text{km}$, $f = 1.8\,\text{GHz}$; $FM = ?$
$R = 99.99\%$
humid climate & smooth terrain

$B = 0.5$ $\qquad$ $A = 4$

$$FM\,(dB) = 20\log(40) + 10\log(6 \times 4 \times 0.5 \times 1.8) - 10\log(1 - 0.9999) - 70$$

$$= 48.06 + 13.34 - (-40) - 70 = 31.4\ \text{dB}$$

ANTENNAS (Radiators)

- → Radiator (transmits | receive e.m energy)
- → Sensor (RF)
- → transducer (converts RF to em energy & vice-versa)
- → impedance matching device

$$\left(Z_0 = \sqrt{\frac{\mu_0}{\epsilon_0}} = 120\pi \text{ or } 377\,\Omega \right)$$

$\mu_0 = 4\pi \times 10^{-7}$ H/m

$\epsilon_0 = 8.854 \times 10^{-12}$ F/m

↓

Impedance of free space

- → temperature sensing device (Tep)

Antenna Parameters

1) Antenna Impedance

$$Z_a = R_a + jX_a$$

X_a → reactive part results from fields surrounding area

$$R_a = R_i + R_r$$

R_i → losses of antenna due to conductor or dielectric losses

R_r → Radiation resistance or hypothetical resistance that would dissipate an amount of power equal to radiated power

2) Effective Aperture Area

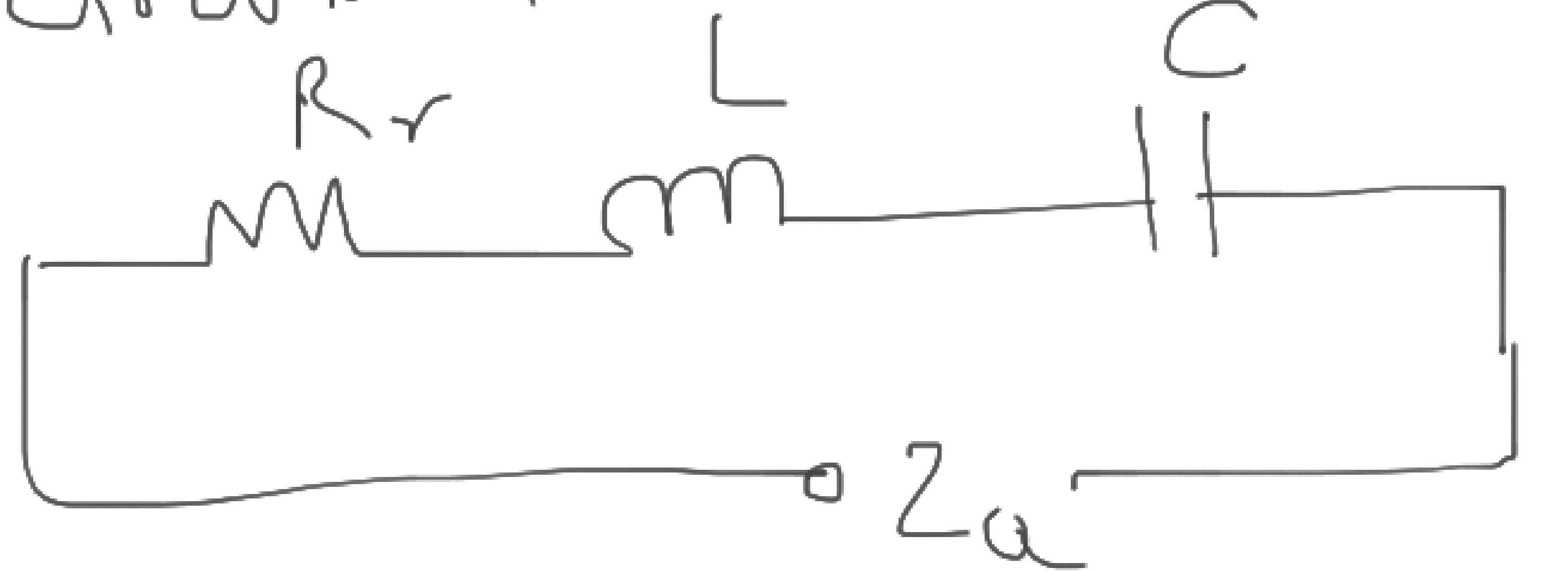
3) Gain

4) Directivity

5) Efficiency

6) Radiation pattern — Power
Voltage

7) Eqv. circuit of antenna



$$Z_a = R_a + jX_a$$

$$= R_r + j(X_L - X_C)$$

wren $X_L = j\omega L$, $X_C = \frac{-j}{\omega C} = \frac{1}{j\omega C}$

At resonance freq of antenna,

$$X_L = X_C$$

$$\Rightarrow j\omega L = \frac{1}{j\omega C} \Rightarrow \omega = 2\pi f_r = \frac{1}{\sqrt{LC}}$$

$$\Rightarrow f_r = \frac{1}{2\pi\sqrt{LC}}$$

resonant freq of antenna

R = resistance → must be maximum at resonant freq

↳ losses → non lost into free space

High Q device

$$Q = \frac{f_r}{\Delta f}, \quad \Delta f \to 0, \text{ for } Q \to \infty$$

$\to$ Bandwidth