CHAPTER 5 THE RF LINK

- In satellite communication systems, there are two types of power calculations. Those are transmitting power and receiving power calculations. In general, these calculations are called as **Link budget calculations**. The unit of power is **decibel**.

- First, let us discuss the basic terminology used in Link Budget and then we will move onto explain Link Budget calculations.

Basic Terminology:

- An **isotropic radiator** (antenna) radiates equally in all directions. But it doesn't exist practically. It is just a theoretical antenna. We can compare the performance of all real (practical) antennas with respect to this antenna.

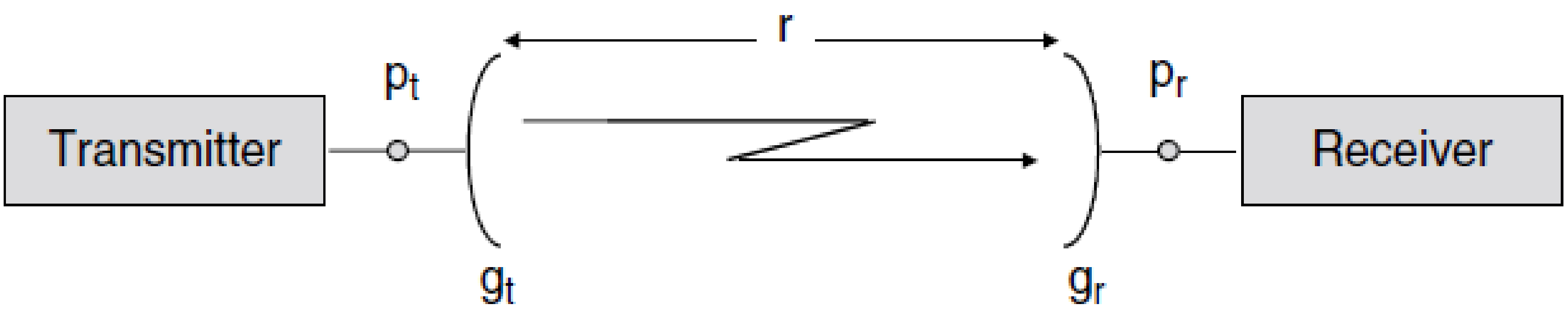


Figure 5.1 Basic communications link

The basic parameters of the link are

p_t = transmitted power (watts);
p_r = received power (watts);
g_t = transmit antenna gain;
g_r = receive antenna gain;
r = path distance (meters).

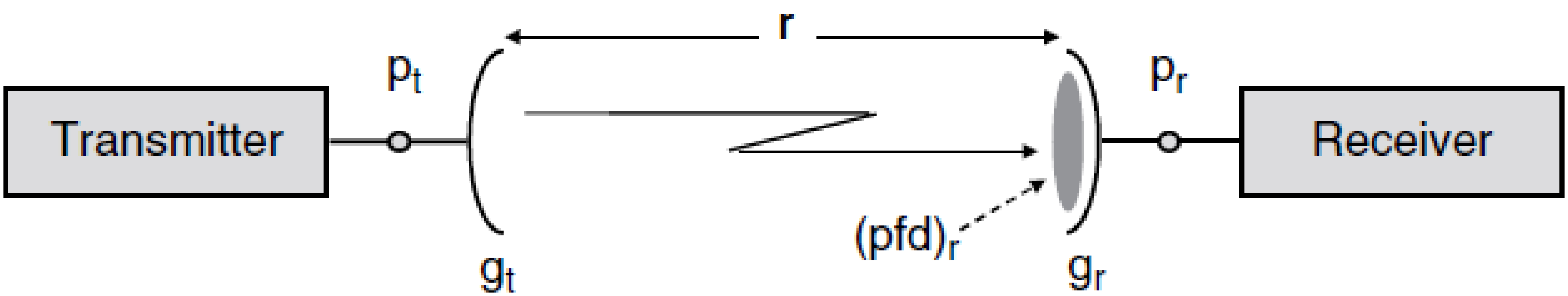


FIGURE 5.2 POWER FLUX DENSITY

5.1 Power Flux Density (pfd): The power flux density is the ratio of power flow and unit area.

The power density, in watts/m², at the distance r from the transmit antenna with a gain g_t, is defined as the *power flux density* (pfd)$_r$

$$(pfd)_r = \frac{p_t \, g_t}{4\pi r^2} \; w/m^2$$

OR
IN TERMS OF EIRP (EFFECTIVE ISOTROPIC RADIATED POWER)

$$(\text{pfd})_r = \frac{\text{eirp}}{4\pi r^2} \text{ w/m}^2$$

The power flux density expressed in dB, will be

$$(\text{PFD})_r = 10\log\left(\frac{p_t\, g_t}{4\pi r^2}\right)$$

$$= 10\log(p_t) + 10\log(g_t) - 20\ \log(r) - 10\log(4\pi)$$

With r in meters,

$$(\text{PFD})_r = P_t + G_t - 20\log(r) - 10.99$$

$$(\text{PFD})_r = \text{EIRP} - 20\log(r) - 10.99$$

5.2 Calculation of System Noise Temperature for satellite receiver, noise power calculation:

Already discussed in Unit 4

5.3 FREE-SPACE PATH LOSS:

The power Receive P_r intercepted by the receiving antenna will be

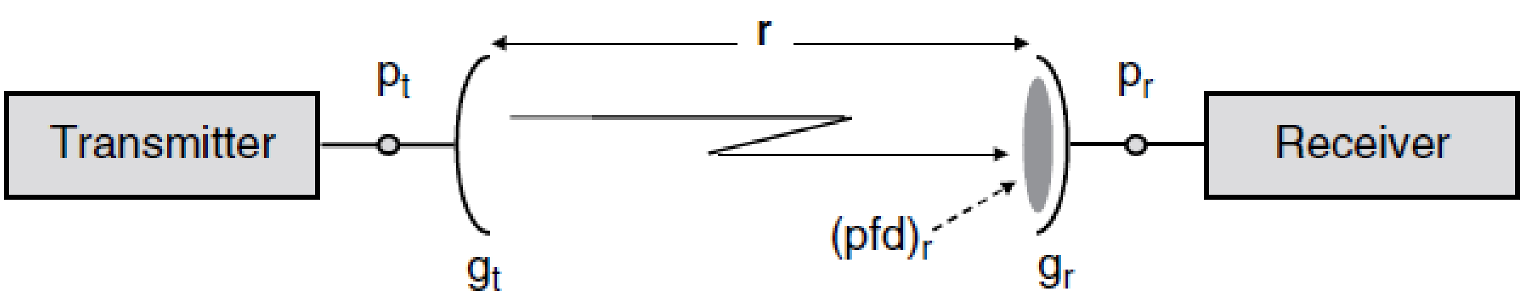
$$p_r = (pfd)_r A_e = \frac{p_t g_t}{4\pi r^2} A_e, \text{ watts}$$

Where $A_e = \dfrac{g\lambda^2}{4\pi}$ **Is the effective aperture**

p_t Transmitter power in watts

g_t Transmitter antenna gain

Then $p_r = \dfrac{p_t g_t}{4\pi d^2} \dfrac{g_r \lambda^2}{4\pi}$



$$p_r = \left[\frac{p_t g_t}{4\pi r^2}\right] g_r \left[\frac{\lambda^2}{4\pi}\right]$$

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Power Flux Density (pfd) in w/m^2 — **Spreading Loss** s in m^2

$$s = \frac{\lambda^2}{4\pi} = \frac{0.00716}{f^2}$$

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

$$S(dB) = -20\log(f) - 21.45$$

Rearranging Equation in a slightly different form, We have Received Power.

$$p_r = p_t\, g_t\, g_r \left[\left(\frac{\lambda}{4\pi r}\right)^2\right]$$

Friis transmission Equation

inverse square loss

FREE SPACE PATH LOSS IS RECIPROCAL OF INVERSE SQUARE LOSS:

$$l_{FS} = \left(\frac{4\pi r}{\lambda}\right)^2$$

$$L_{FS}(dB) = 20\log\left(\frac{4\pi r}{\lambda}\right)$$ Free space Path Loss

$$l_{FS} = \left(\frac{4\pi\, r}{\lambda}\right)^2 = \left(\frac{4\pi\, r\, f}{c}\right)^2$$ **Where** $\lambda = \frac{c}{f}$

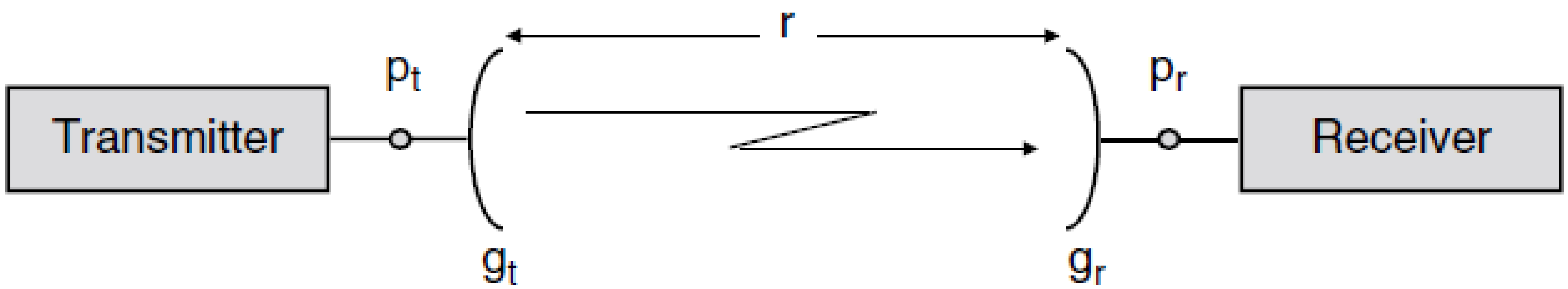
For the Range r in *meters*, and the frequency f in *GHz*

$$l_{FS} = \left(\frac{4\pi r\ (f \times 10^9)}{(3 \times 10^8)}\right)^2 = \left(\frac{40\,\pi}{3} r\, f\right)^2$$

$$L_{FS}(dB) = 20\log(f) + 20\log(r) + 20\log\left(\frac{40\,\pi}{3}\right)$$

$$L_{FS}(dB) = 20\log(f) + 20\log(r) + 32.44$$

5.4 BASIC LINK EQUATION FOR RECEIVED POWER



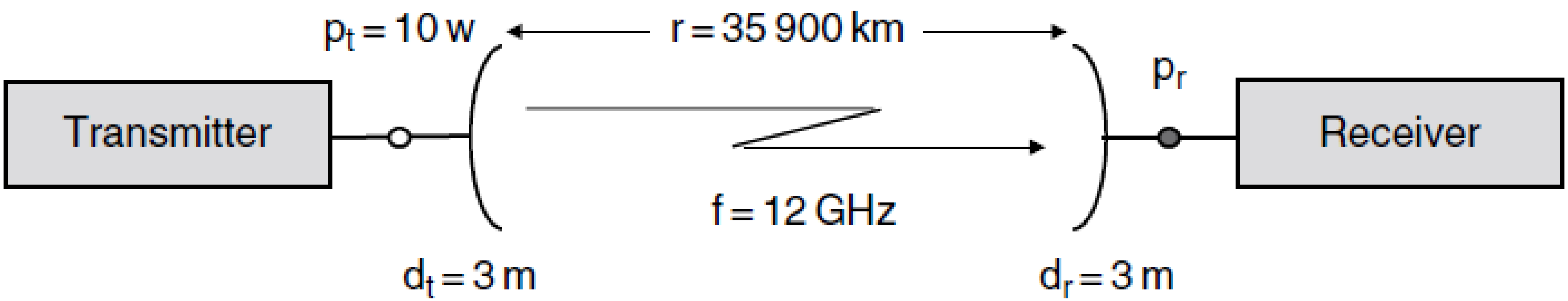
We now have all the elements necessary to define the basic link equation for determining the received power at the receiver antenna terminals for a satellite link.

$$p_r = p_t \, g_t \left(\frac{1}{l_{FS}} \right) g_r$$

$$= \text{eirp} \left(\frac{1}{l_{FS}} \right) g_r$$

$$P_r(\text{dB}) = \text{EIRP} + G_r - L_{FS}$$

Sample Calculation for Ku-Band Link



$$\eta_A = 0.55$$

$$G = 10\log(109.66\, f^2\, d^2\, \eta_A)$$

$$G_t = G_r = 10\log(109.66 \times (12)^2 \times (3)^2 \times 0.55) = 48.93\,\text{dBi}$$

The effective radiated power, in db, is found as

$$\text{EIRP} = P_t + G_t$$

$$= 10\log(10) + 48.93$$

$$= 10 + 48.93 = 58.93\,\text{dBw}$$

The free space path loss, in dB is

$$L_{FS} = 20\log(f) + 20\log(r) + 32.44$$

$$= 20\log(12) + 20\log(3.59 \times 10^7) + 32.44$$

$$= 21.58 + 151.08 + 32.44 = 205.1\,\text{dB}$$

$$P_r(\text{dB}) = \text{EIRP} + G_r - L_{FS}$$

$$= 58.93 + 48.93 - 205.1$$

$$= -97.24\,\text{dBw}$$

The received power in watts can be found from the above result:

$$p_r = 10^{\frac{-97.24}{10}} = 1.89 \times 10^{-10}\,\text{watts}$$

The power flux density, in dB,

is then determined from Equation

$$(PFD)_r = EIRP - 20\log(r) - 10.99$$
$$= 58.93 - 20\log(3.59 \times 10^7) - 10.99$$
$$= 58.93 - 151.08 - 10.99$$
$$= -103.14\ dB(w/m^2)$$

Where $(PFD)_r = EIRP - 20\log(r) - 10.99$

5.5 Satellite link Budget & C/N ratio Calculation:

There are two types of link budget calculations since there are two links namely, **Uplink** and **Downlink**.

Earth Station Uplink:
It is the process in which earth is transmitting the signal to the satellite and satellite is receiving it. Its **mathematical equation** can be written as

$$\left(\frac{C}{N_0}\right)_U = [EIRP]_U + \left(\frac{G}{T}\right)_U - [LOSSES]_U - K$$

Where:

$\left[\frac{C}{N_0}\right]$ is the carrier to noise density ratio

$\left[\frac{G}{T}\right]$ is the satellite receiver G/T ratio and units is dB/K

Here, Losses represent the satellite receiver feeder losses. The losses which depend upon the frequency are all taken into the consideration.

The EIRP value should be as low as possible for effective UPLINK. And this is possible when we get a clear sky condition.

Here we have used the (subscript) notation "U", which represents the uplink phenomena.

Satellite Downlink

In this process, satellite sends the signal, and the earth station receives it. The equation is same as the satellite uplink with a difference that we use the abbreviation "D" everywhere instead of "U" to denote the downlink phenomena.

Its **mathematical** equation can be written as;

$$\left[\frac{C}{N_0}\right]_D = [EIRP]_D + \left[\frac{G}{T}\right]_D - [LOSSES]_D - K$$

Where: $\left[\frac{C}{N_0}\right]$ is the carrier to noise density ratio

$\left[\frac{G}{T}\right]$ is the earth station receiver G/T ratio and units are dB/K

Link Budget:

If we are taking ground satellite into consideration, then the free space spreading loss (FSP) should also be taken into consideration.

If antenna is not aligned properly then losses can occur. so we take **AML** (Antenna misalignment losses) into account. Similarly, when signal comes from the satellite towards earth it collides with earth surface and some of them get absorbed. These are taken care by **A**tmospheric **A**bsorption loss given by **“AA”** and measured in db.

Now, we can write the loss equation for free sky as

$$Losses = FSL + RFL + AML + AA + PL$$

Where,

- RFL stands for received feeder loss and units are db.
- PL stands for polarization mismatch loss.

Now the **decibel equation** for received power can be written as

$$P_R = EIRP + G_R + Losses$$

Where,

- P_R stands for the received power, which is measured in dBW.
- G_r is the receiver antenna gain.

The designing of downlink is more critical than the designing of uplink. Because of limitations in power required for transmitting and gain of the antenna.