UESTC4004
Digital Communications

Link Budget Calculation

Goals

距离

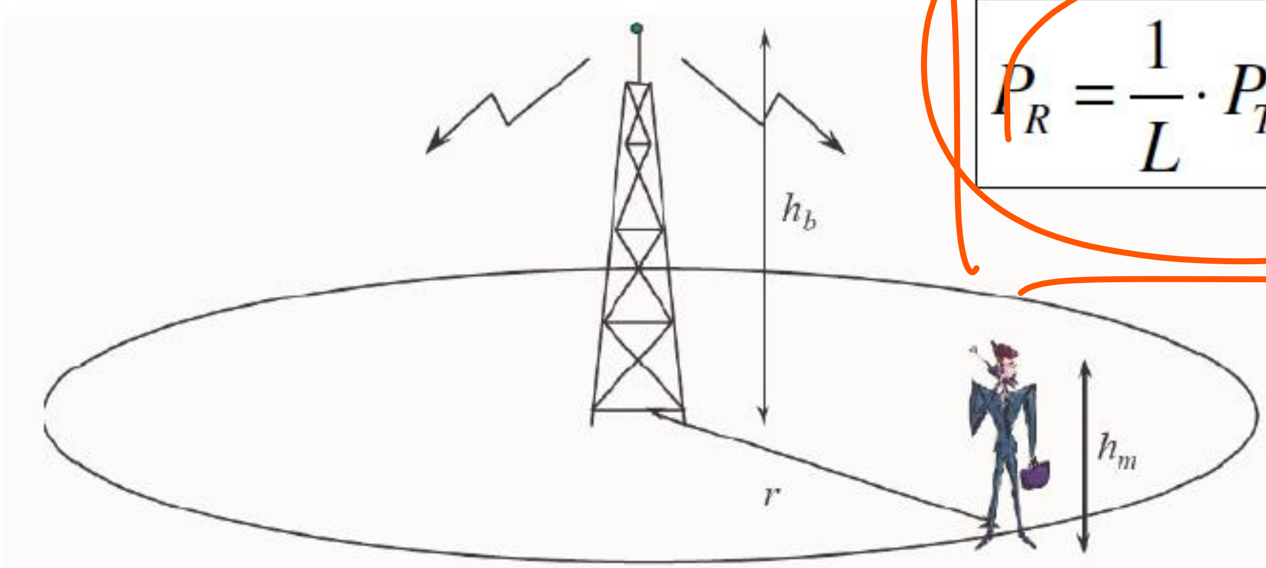
- To be able to calculate how far we can go with the equipment we have
- To understand why we need high poles for long links

基站

Cell Coverage

传输
能耗损

- A Base Station (BS) is designed to cover a designated area or cell. We are interested in the power loss involved in transmission between the BS and the mobile (path loss). A general path loss model:



$$P_R = \frac{1}{L} \cdot P_T = f\left(h_m, h_b, r, f_c\right)$$

P_R : Power received at the Mobile
P_T : BS transmitted power
r: Distance between BS and mobile

f_c :Frequency of operation
h_b : BS antenna height
h_m : Mobile antenna height

University of Glasgow

Link Path Loss

- **Path Loss** is the ratio of the transmitted to the received power (it can be expressed in dB). It includes all of the possible environmental elements of loss associated with interactions between the propagating wave and any objects between the transmit and receive antennas.

- In order to define the path loss correctly, the losses and gains in the communication system must be considered.

- The above losses and gains can be considered through a link budget (Path loss could be the same for different Tx Power or different antenna gains).

=

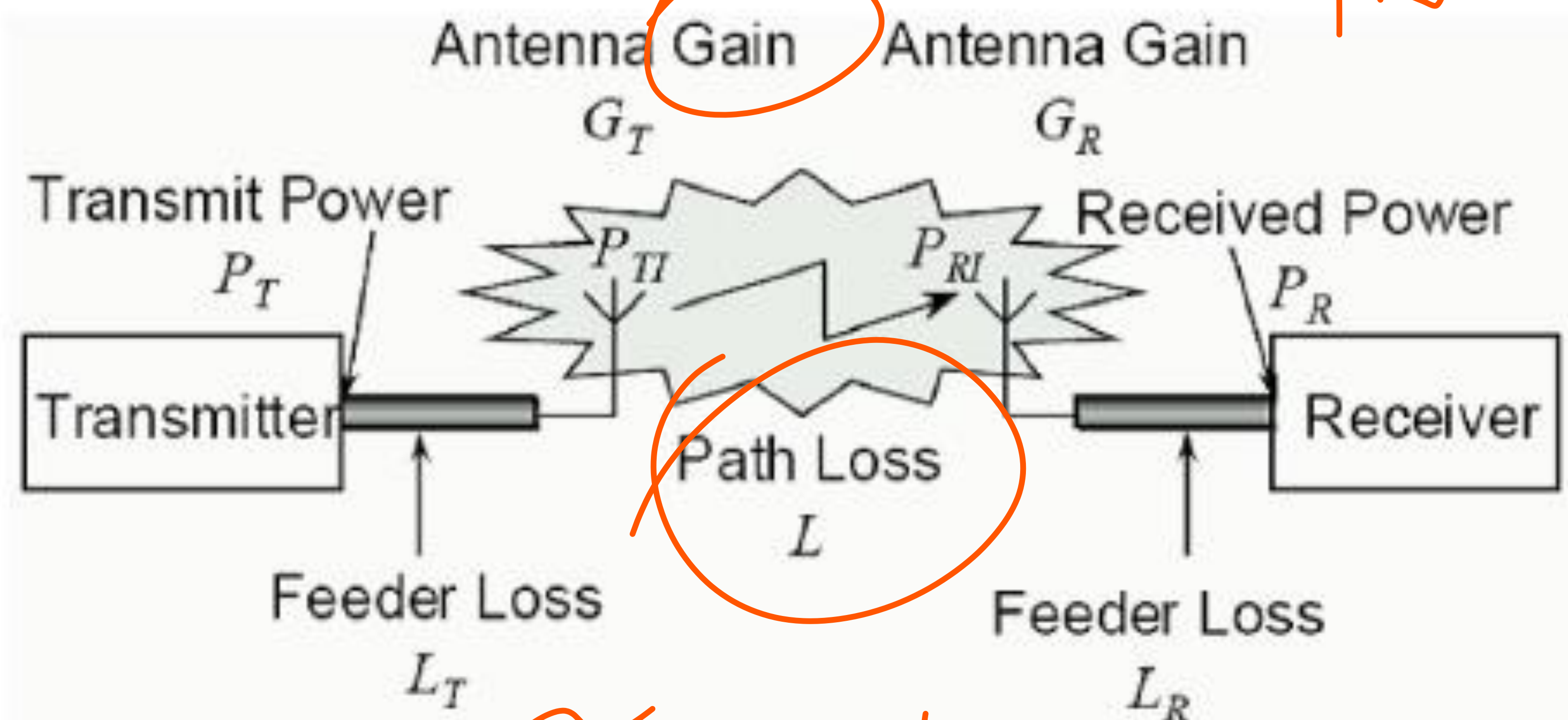
增益
&
损耗

链路预算 用来考虑

Link Budgets

- Elements of a simple wireless link:

$P_R = P_T \cdot \frac{G_T G_R}{L_T L L_R}$



上增

$$\boxed{P_R = \frac{P_T G_T G_R}{L_T L L_R}}$$

下损

Gains and losses are expressed as power ratio and **power in watts**

University of Glasgow

EIRP

- Antenna gains, G_T, G_R, are expressed with reference to an isotropic antenna (radiates equally in all directions)

- Effective Isotropic Radiated Transmit Power (EIRP) is given by:

有效各向同性

$$\boxed{EIRP = \frac{P_T G_T}{L_T} = P_{TI}}$$

Transmit

辐射传输能量

Propagation loss

有效各向同性辐射接收能量

- Similarly, the Effective Isotropic Radiated Received Power is given by:

$$\boxed{P_{RI} = \frac{P_R L_R}{G_R}}$$

- Advantage of expressing the powers in terms of *EIRP* is that the path loss, *L*, can be expressed independently of the system parameters, as a ratio between the transmitted and received *EIRP*.

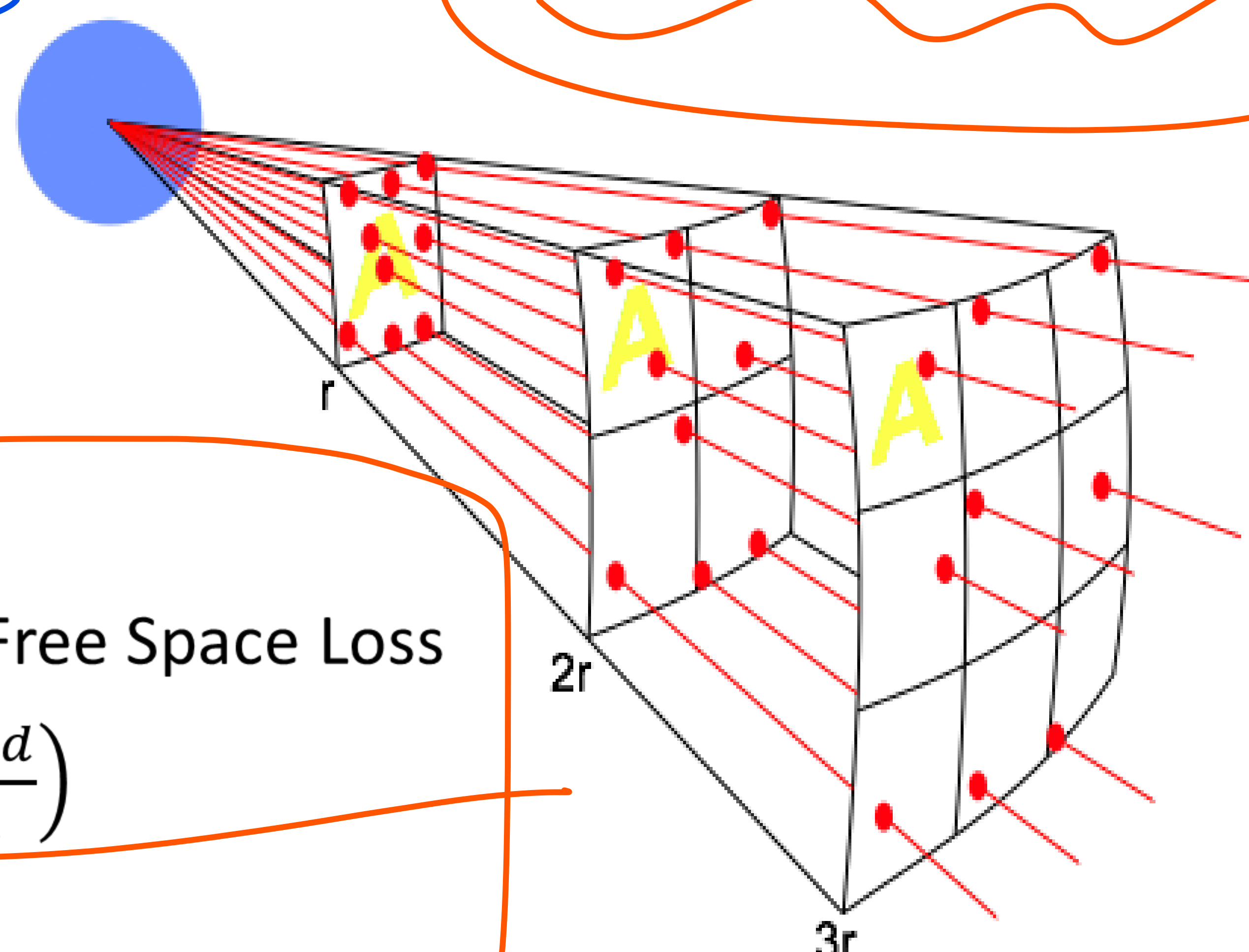
- Propagation loss ➡ $$\boxed{L = \frac{P_{TI}}{P_{RI}} = \frac{P_T G_T G_R}{P_R L_T L_R}}$$

代值

Free space loss

- Signal power is diminished by geometric spreading of the wavefront, commonly known as ***Free Space Loss***.
- The power of the signal is spread over a wave front, the area of which increases as the distance from the transmitter increases. Therefore, the power density diminishes.

$10\log\left(\frac{4\pi d}{\lambda}\right)^2$



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

$$\left[\frac{P_{TI}}{P_{RI}}\right] = \left[\frac{4\pi d}{\lambda}\right]^2 \text{ = Free Space Loss}$$

$$\text{FSL} = 20\log_{10}\left(\frac{4\pi d}{\lambda}\right)$$

Figure from *http://en.wikipedia.org/wiki/Inverse_square*

Free Space Loss (any frequency)

- Using decibels to express the loss and using a generic frequency f, the equation for the Free Space Loss is:

一般的

$$L_{fs} = 92.4 + 20*\log_{10}(D) + 20*\log_{10}(f)$$

- ...where ***L_{fs}*** is expressed in dB, ***D*** is in kilometers and **f** is in GHz.

km

$$L_{fs}(\text{或}FSL) = 20\log_{10}\left(\frac{4\pi d}{\lambda}\right)$$

(一般空间表达)

Free Space Loss (@2.4 GHz)

Loss与f成正比.

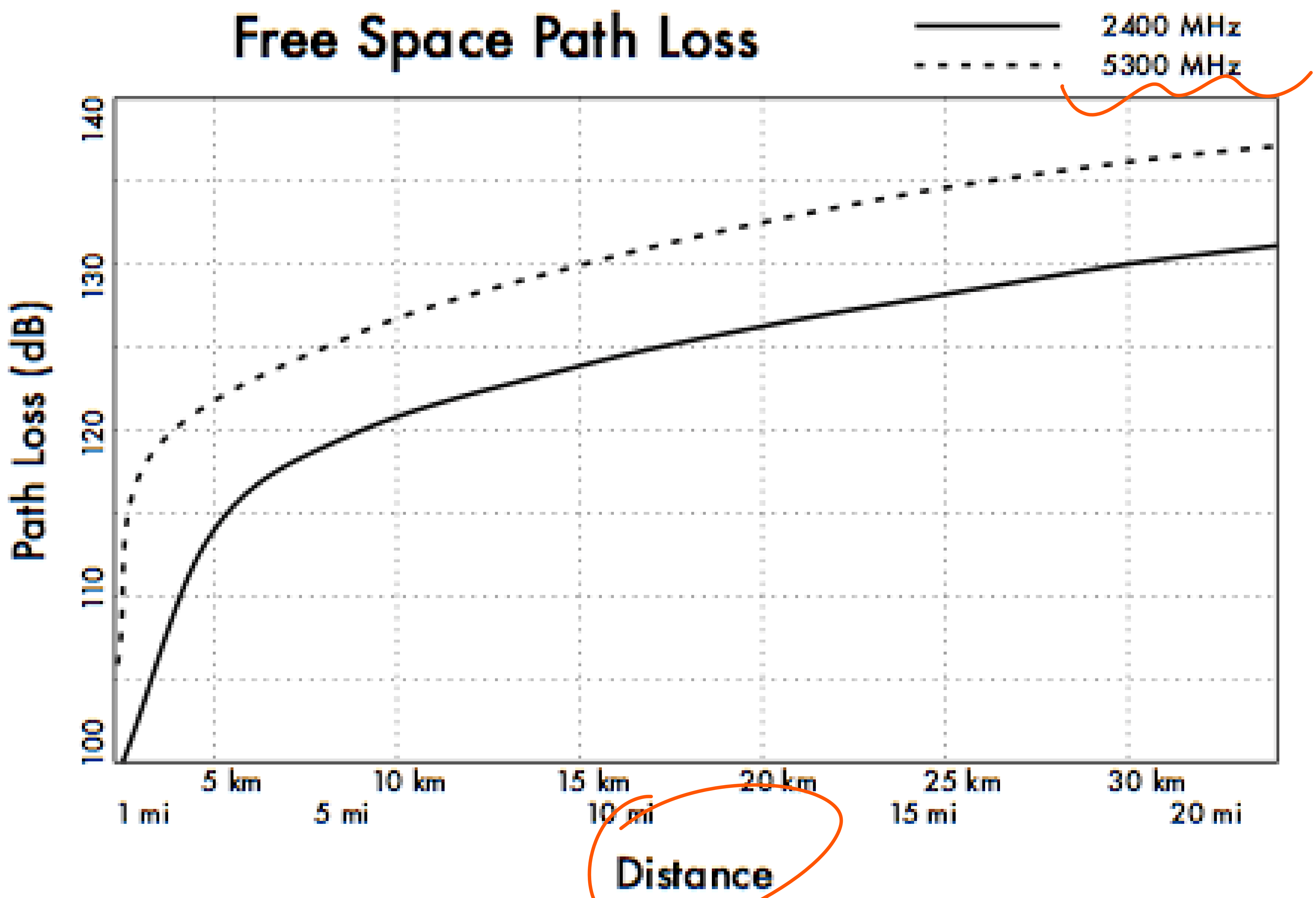
- Using decibels to express the loss and using 2.4 GHz as the signal frequency, the equation for the Free Space Loss is:

$20\log_{10}(2.4)$

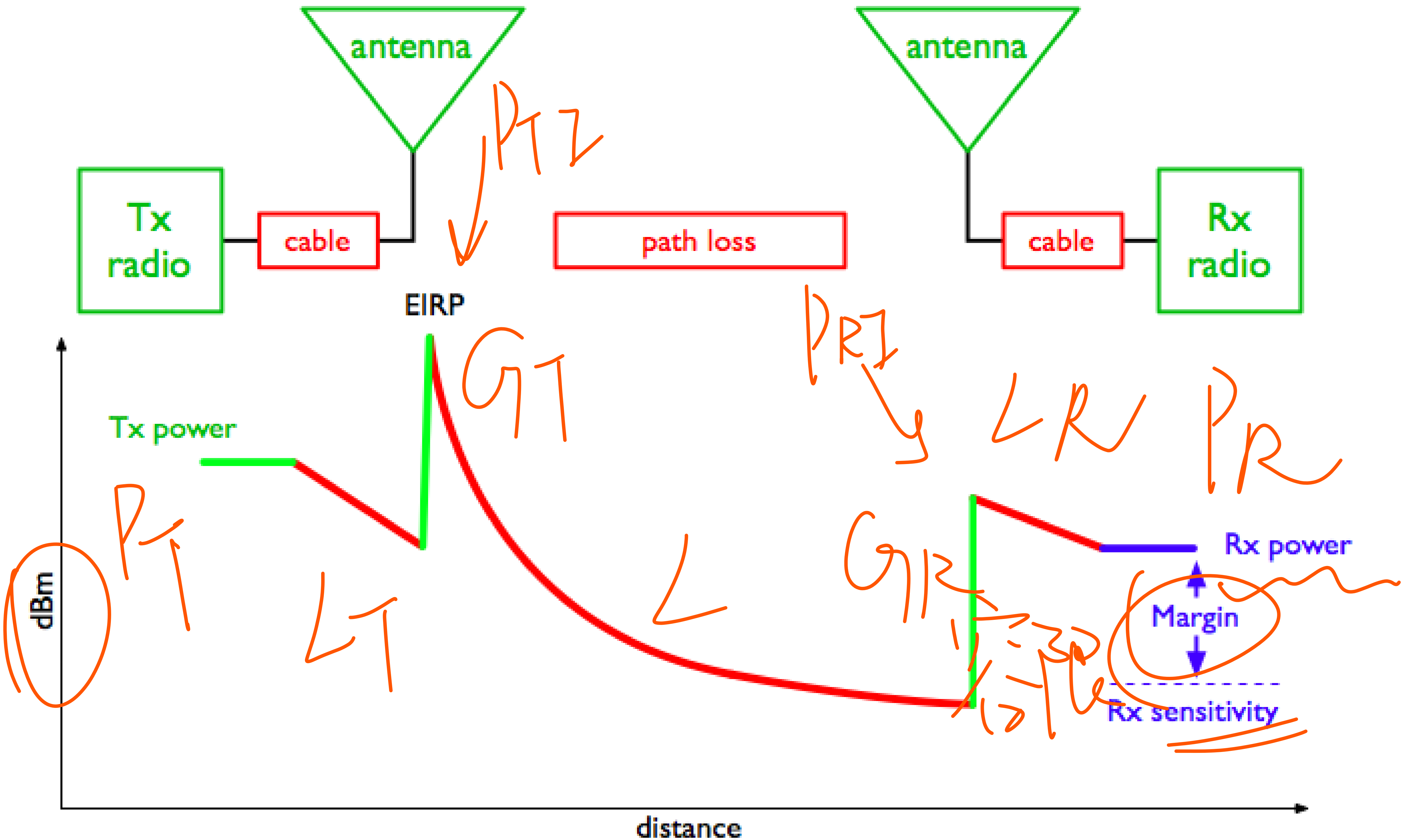
$$L_{fs} = 100 + 20*\log_{10}(D)$$

- ...where $\boldsymbol{L_{fs}}$ is expressed in dB and ***D*** is in kilometers.

Effect of Distance and Frequency



Power in a wireless system



Link budget 链路

- The performance of any communication link depends on the quality of the equipment being used.
- ***Link budget*** is a way of quantifying the link performance.

  PR

- The received power in an 802.11 link is determined by three factors: ***transmit power***, ***transmitting antenna gain***, and ***receiving antenna gain***.

  PT Lfs GT GR

- If that power, minus the ***free space loss*** of the link path, is greater than the ***minimum received signal level*** of the receiving radio, then a link is possible.
- The difference between the minimum received signal level and the actual received power is called the ***link margin***. 容限
- The link margin must be positive, and should be maximized (should be at least 10dB or more for reliable links).

University of Glasgow

Applying dB to Power

用dB作为计算的数值.

$$\boxed{\begin{aligned} P_{dBm} &= 10 \cdot \log_{10}\left(\frac{P}{1mW}\right) \\ P_{dBW} &= 10 \cdot \log_{10}\left(\frac{P}{1W}\right) \\ P_{dBm} &= P_{dBW} + \underline{\underline{30}} \end{aligned}}$$

$(\log_{10}\frac{P}{1W}10^3)$

$= (\log_{10}\frac{P}{1W} + \log_{10}10^3)$

$= (\log_{10}\frac{P}{1W} + 3)$

$P_{dB} = P_{dBW} + 30$

dBW ± dB = dBW

dBm ± dB = dBm

dBW - dBW= dB

dBm - dBm= dB

30被减

Applying dB to Power (2)

$$10\log_{10}\left(\frac{P}{X}\right)$$

dBW = dB relative to 1W
dBm = dB relative to 1mW

$$X = \begin{cases} 1\text{mW} \\ 1\text{W} \\ \vdots \end{cases}$$

1W →	0dBW	→ +30 dBm
10W →	+10dBW	→ +40 dBm
100W →	+20dBW	→ +50 dBm
0.1W →	-10dBW	→ +20 dBm
0.01W →	-20dBW	→ +10 dBm
0.001W →	-30dBW	→ 0 dBm

<u>n.b. dBW = dBm -30dB</u> ✓

nota bene.

Example link budget calculation

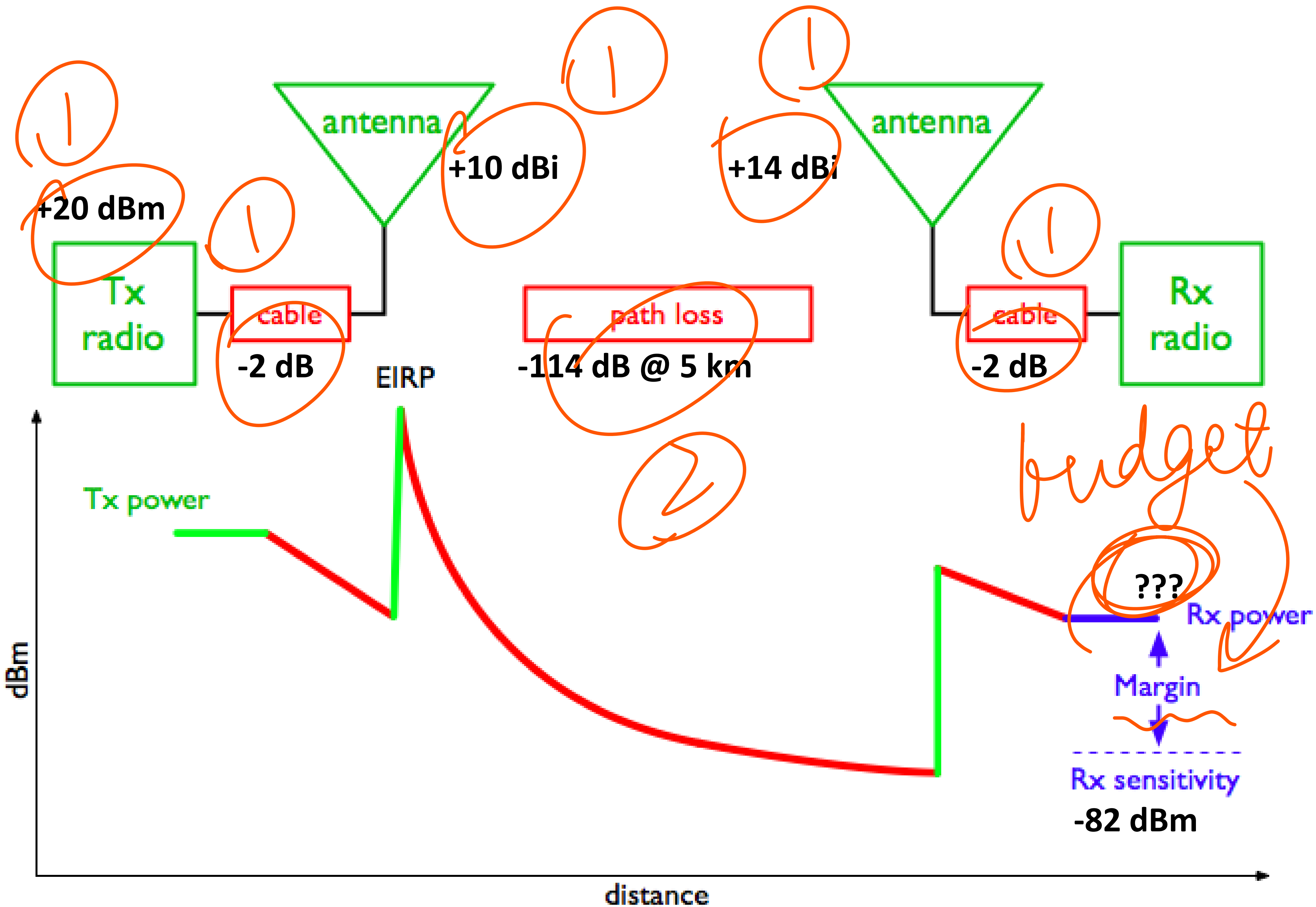
Let's estimate the feasibility of a **5 km** link, with one access point and one client radio.

The access point is connected to an antenna with **10 dBi** gain, with a transmitting power of **20 dBm** and a receive sensitivity of **-89 dBm**.

The client is connected to an antenna with **14 dBi** gain, with a transmitting power of **15 dBm** and a receive sensitivity of **-82 dBm**.

The cables in both systems are short, with a loss of **2dB** at each side at the 2.4 GHz frequency of operation.

AP to Client link



Link budget: AP to Client link

注意加减符

20 dBm (TX Power AP)
+ 10 dBi (Antenna Gain AP)
- 2 dB (Cable Losses AP)
+ 14 dBi (Antenna Gain Client)
- 2 dB (Cable Losses Client)

---

40 dBm Total Gain
-114 dB (free space loss @5 km)

-74 dBm (expected received signal level)
--82 dBm (sensitivity of Client)

---

8 dB (link margin)

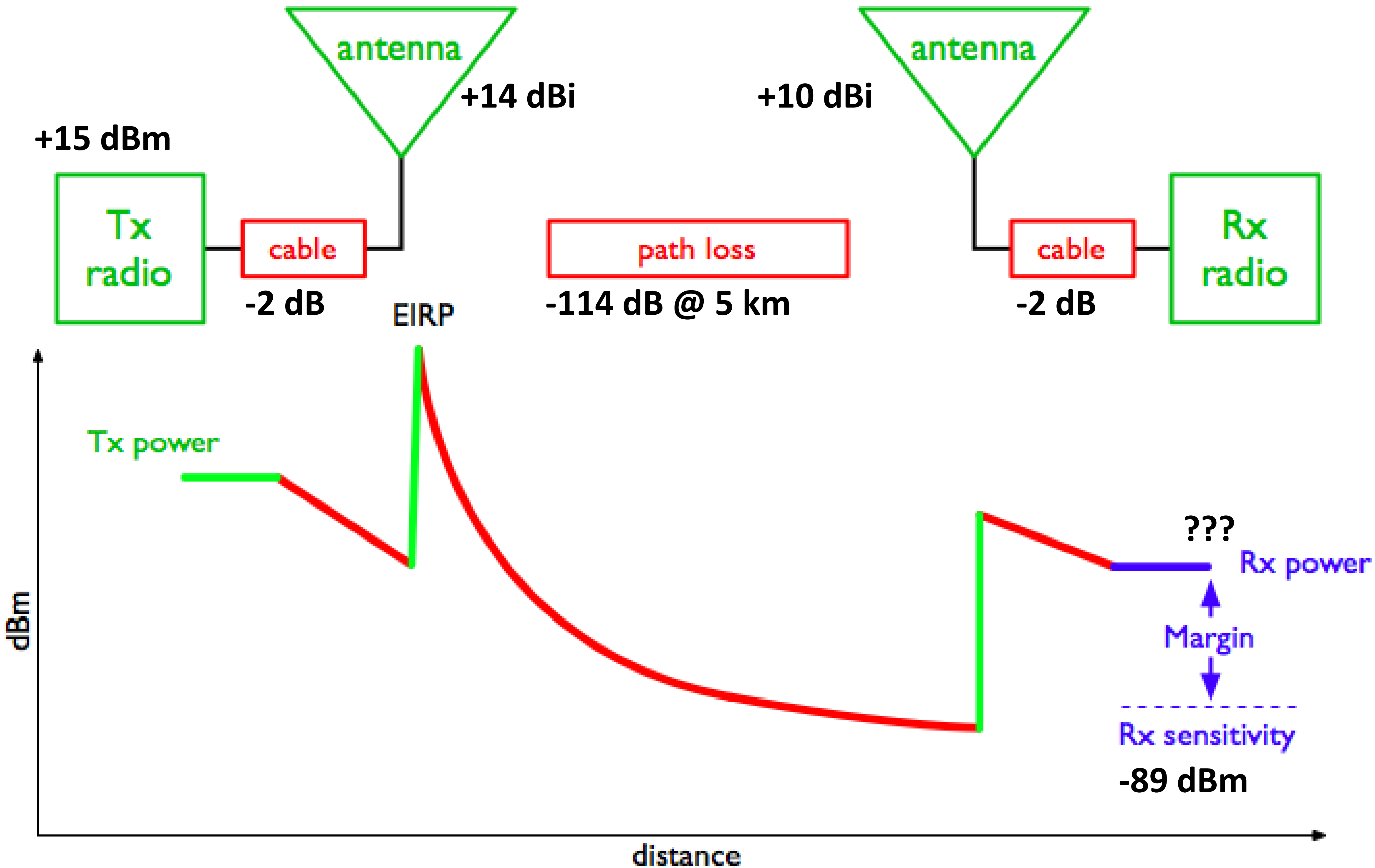
$20-30+10-2+14-2$
$=(40-30)\,\mathrm{dB}$ w
$=40\,\mathrm{dBm}$

$\mathrm{dBm}=\mathrm{dB}+30$

作差

$\mathrm{dBi}=\mathrm{dB}$

Opposite direction: Client to AP



Link budget: Client to AP link

[illegible]

模型不可逆

  15 dBm (TX Power Client)
+ 14 dBi (Antenna Gain Client)
- 2 dB (Cable Losses Client)
+ 10 dBi (Antenna Gain AP)
- 2 dB (Cable Losses AP)

---

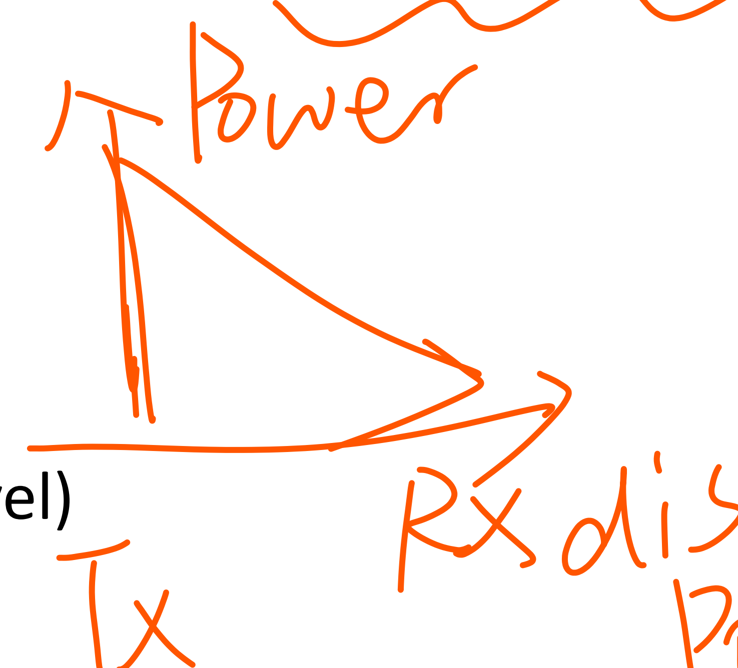
  35 dBm Total Gain
-114 dB (free space loss @5 km)

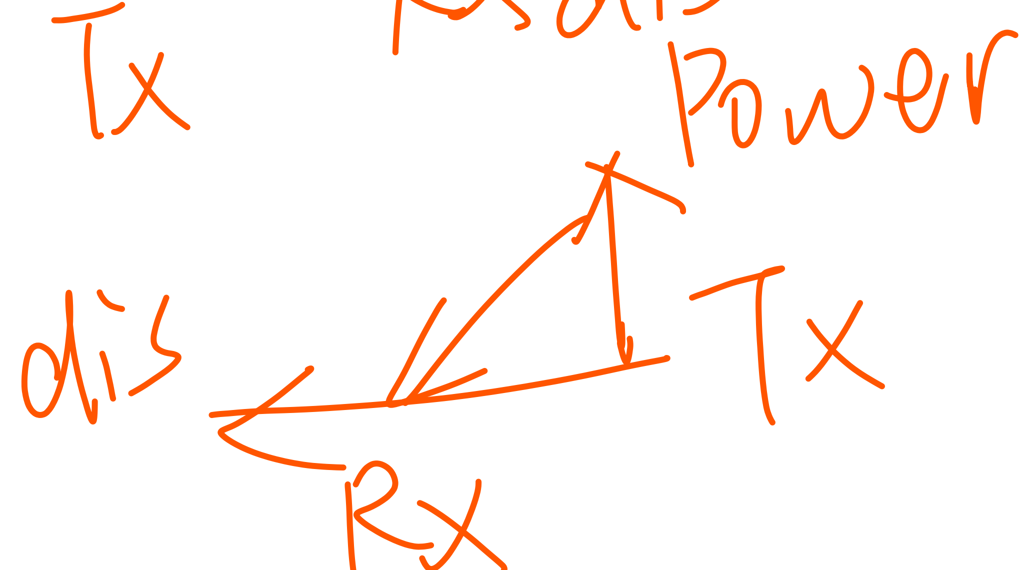
 -79 dBm (expected received signal level)
--89 dBm (sensitivity of AP)

---

 10 dB (link margin)

对 dBW ⇌ dBm





Review Questions

1. If a transmitter produces 50W of power, express the transmit power in units of (a) dBm, and (b) dBW. If 50W is applied to a unity gain antenna with 900 MHz carrier frequency, find the received power in dBm at free space distance of 100 m from the antenna. What is the received power at 10 km? Assume unit gain for the receiver antenna. [47 dBm, 17 dBW, -24.5 dBm, -64.5 dBm]

2. Consider an indoor wireless LAN with $f_c = 900\ MHz$, cells of radius 10 m, and non directional antennas. Under the free-space path loss model, what transmission power is required at the access points in order for all terminals with the cell to receive a minimum power of 10 μW? How does this change if the system frequency is 5 GHz? [1.45 W/1.61 dBW, 43.9W/16.42 dBW]

(b). $P_{dB} = P_{dBm} - 30$

(a). $P_{dBm} = 10\log_{10}\left(\frac{P}{1mW}\right)$

900×10^{-3} GHz $= 0.9$

0dBi

$L = 92.4 + 20\log_{10}(0.1) + 20\log_{10}(0.9)$

(10)

用 $\left(\frac{4\pi d}{\lambda}\right)^2$ 也等价

$L_{fs} = L = 92.4 + 20\log_{10} D + 20\log_{10} f =$

(a). 51.5dB

(b) 66.4dB

$10\mu W \Rightarrow 10\log_{10}\frac{10\mu W}{1W} = -50dBW$

University of Glasgow

Review Questions (contd)

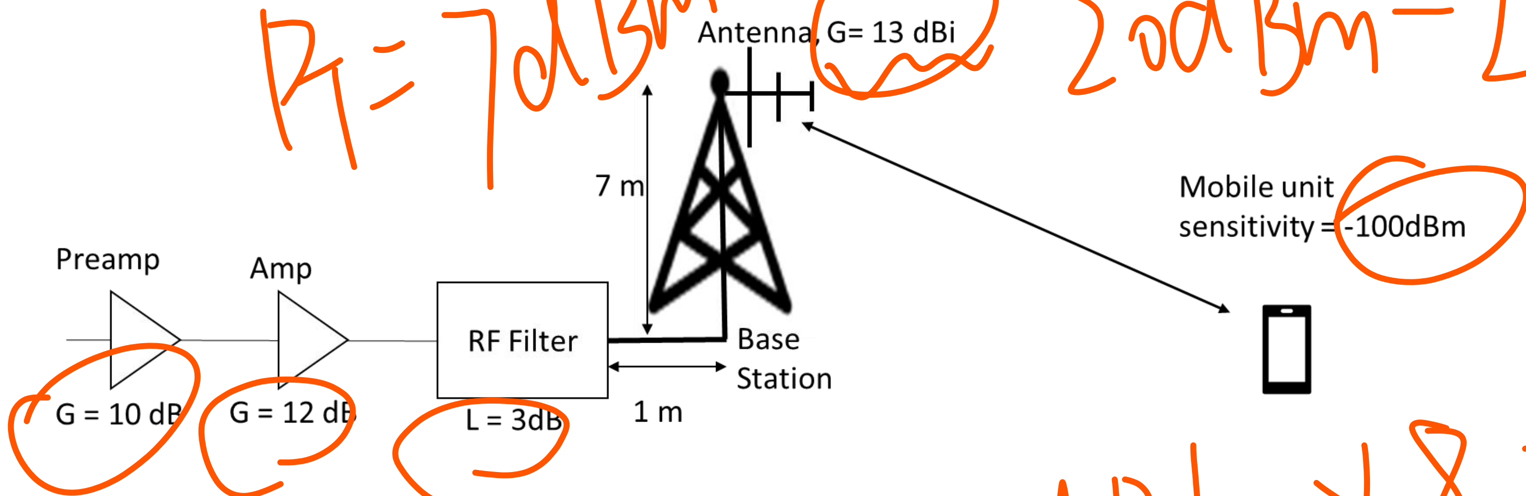
$L_{fs} < 120 \Rightarrow 2387.3$

用 $\left(\frac{4\pi d}{\lambda}\right)^2$

3. Consider a communication system with carrier frequency $f_c = 10$ GHz. The communication link between a base station and a mobile unit is described in the figure below, where G denotes gain and L loss,

$P_t = 7$ dBm

20 dBm − L_{fs} > −100 dBm



1.5 dB/m × 8 = 12 dB

Assume that

- The input power to the Preamp is 0 dBm
- The output of the filter connected to the transmitting antenna through a feeder cable having a loss of 1.5 dB per metre 1.5 dB/m
- The mobile unit's antenna has a gain of 0 dBi and its feeder loss is negligible

i. Determine the effective isotropic radiated power in watts

ii. Determine the acceptable maximum distance between the base station and the mobile unit (i.e., the coverage range).

[20 dBm, D =2387.3]

EIRP = 7 + 13 = 20 dBm