Lect09: Propagation Models-I

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Propagation models

- Use transmitter-receiver & propagation mechanisms parameters.
- Useful to calculate the range of a wireless comm. system.
- They vary from simple (ideal) models to more complicated (more realistic) models.
- Based on type classifications:

✓ Basic models: *path loss, free-space path loss, two-ray (earth plane) reflection*.

✓Diffraction models *(Knife-edge) : obstructions block signals (for terrestrial links).*

✓Macrocells modesl: *Empirical (measurement + curve fitting) models (e.g. Clutter factor, Okumara-Hata,…), Physical (e.g. Allsebrook, Ikegami,..) , ITU-R models,…*

✓Shadowing.

✓Models for Microcells.

✓Models for Piccells.

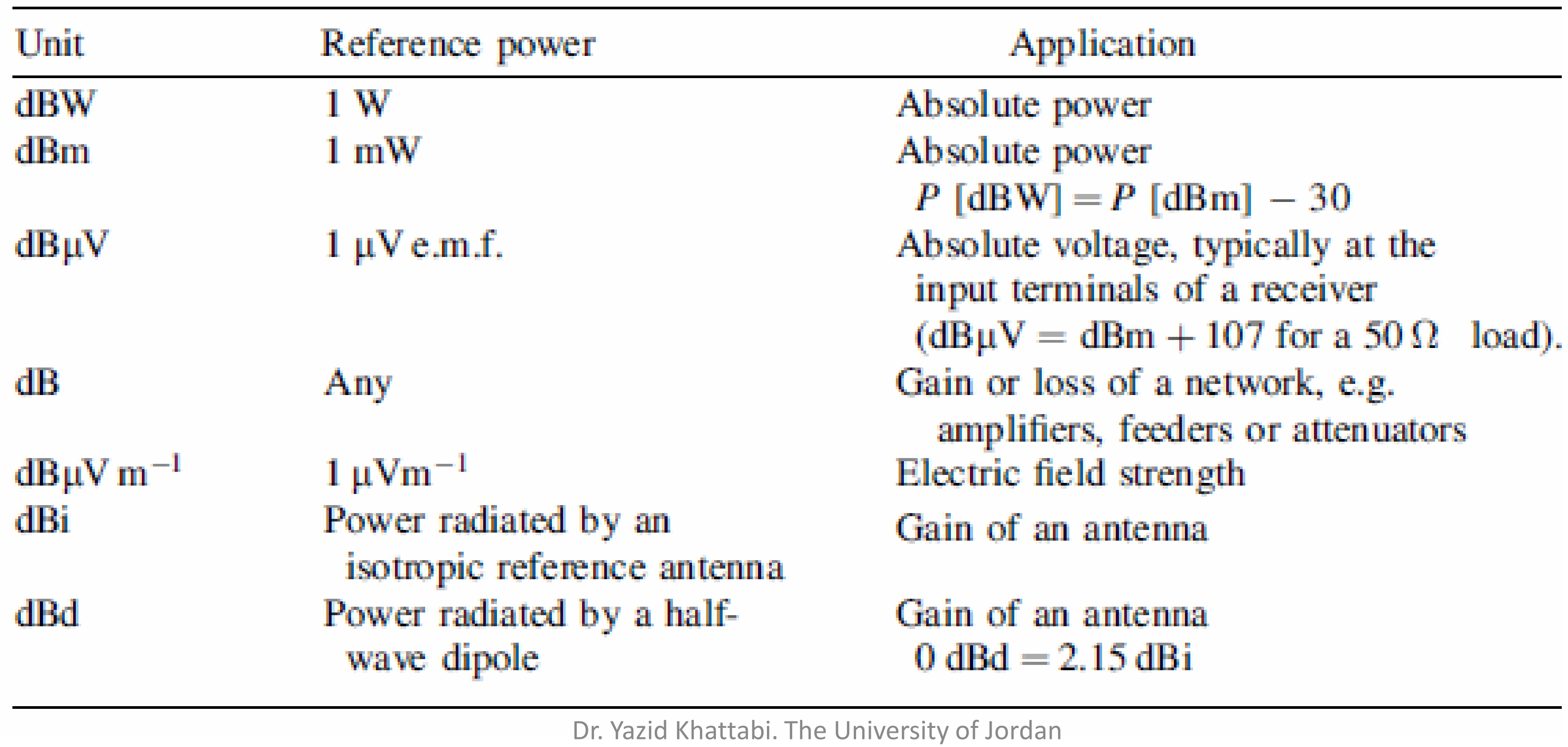
Propagation models

❑Note on decibls:

$$\text{Power ratio in decibels} = 10\log\left(\frac{P}{P_{\text{ref}}}\right)$$

$$\text{Voltage ratio in decibels} = 20\log\left(\frac{V}{V_{\text{ref}}}\right)$$

$$\text{Field strength ratio in decibels} = 20\log\left(\frac{E}{E_{\text{ref}}}\right) \text{ or } 20\log\left(\frac{H}{H_{\text{ref}}}\right)$$

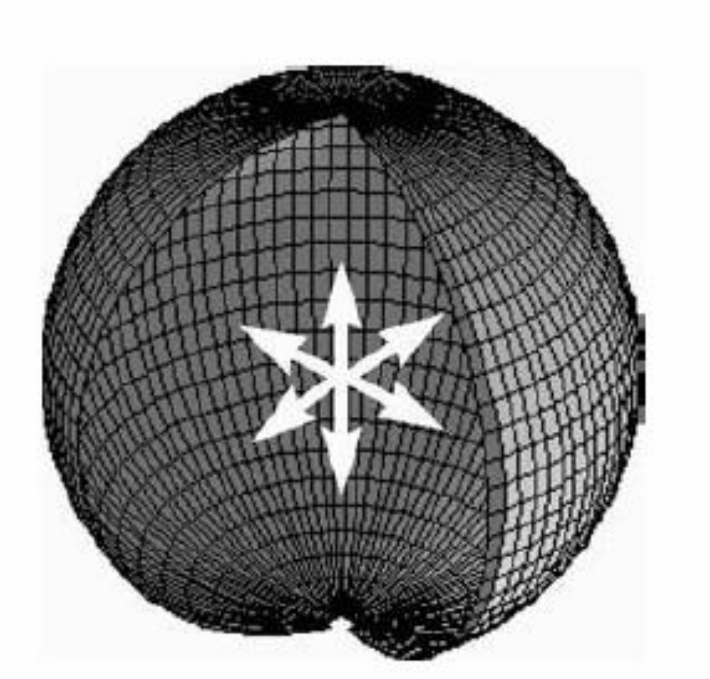


Unit	Reference power	Application
dBW	1 W	Absolute power
dBm	1 mW	Absolute power P [dBW] = P [dBm] − 30
dBμV	1 μV e.m.f.	Absolute voltage, typically at the input terminals of a receiver (dBμV = dBm + 107 for a 50 Ω load).
dB	Any	Gain or loss of a network, e.g. amplifiers, feeders or attenuators
dBμV m^{-1}	1 μVm^{-1}	Electric field strength
dBi	Power radiated by an isotropic reference antenna	Gain of an antenna
dBd	Power radiated by a half-wave dipole	Gain of an antenna 0 dBd = 2.15 dBi

Propagation models

❑Isotropic Antenna:

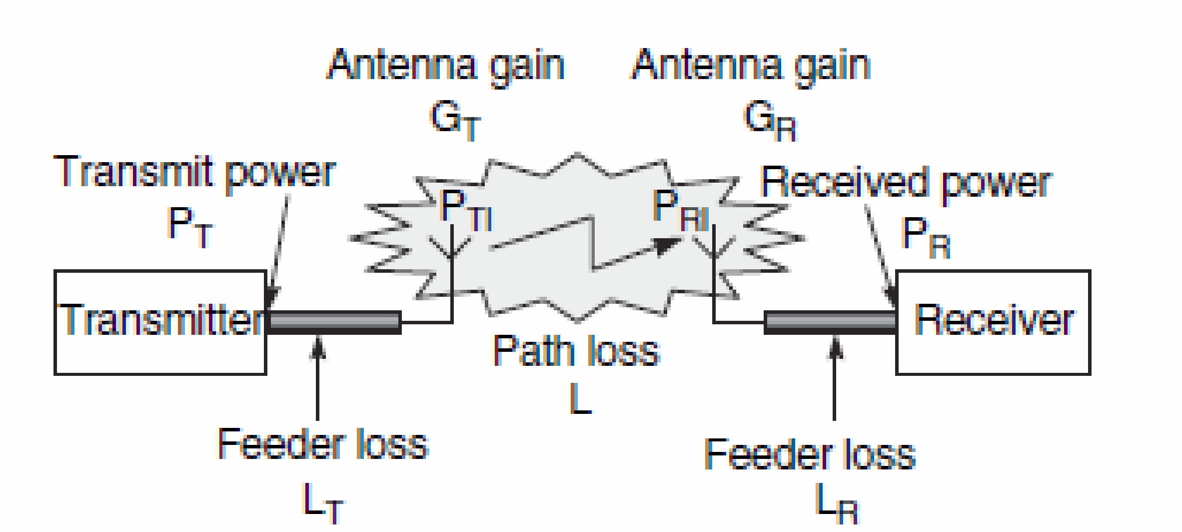
- Non real antenna used as reference.
- Spread power equally over the surface of a sphere.
- Has unit gain (0 dBi).
- Ex: Gain of half-wave dipole is 2.15 dBi.
- Ex: 12 dBd antenna has actual gain of 14.15 dBi.



Propagation models

❑Basic propagation models: 1- Path loss

- Includes all of the possible elements of loss associated with interactions between the propagating wave and any objects between Tx and Rx.
- The simplest mathematical model.
- Takes into account the main basic parameters.
- Useful for preliminary link-budget calculations.
- Ratio of EIRP (P_{TI}) to the effective received power (P_{RI}) .



Propagation models

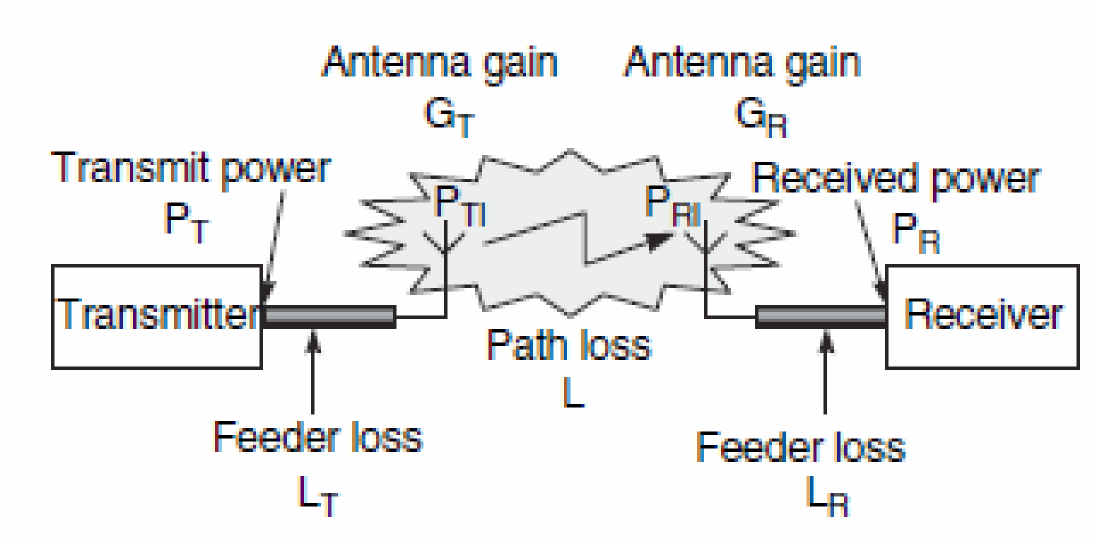
❑Basic propagation models: 1- Path loss

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

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

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

$$L = \frac{P_T G_T G_R}{P_R L_T L_R} = \frac{P_{TI}}{P_{RI}}$$



- **In dB:**

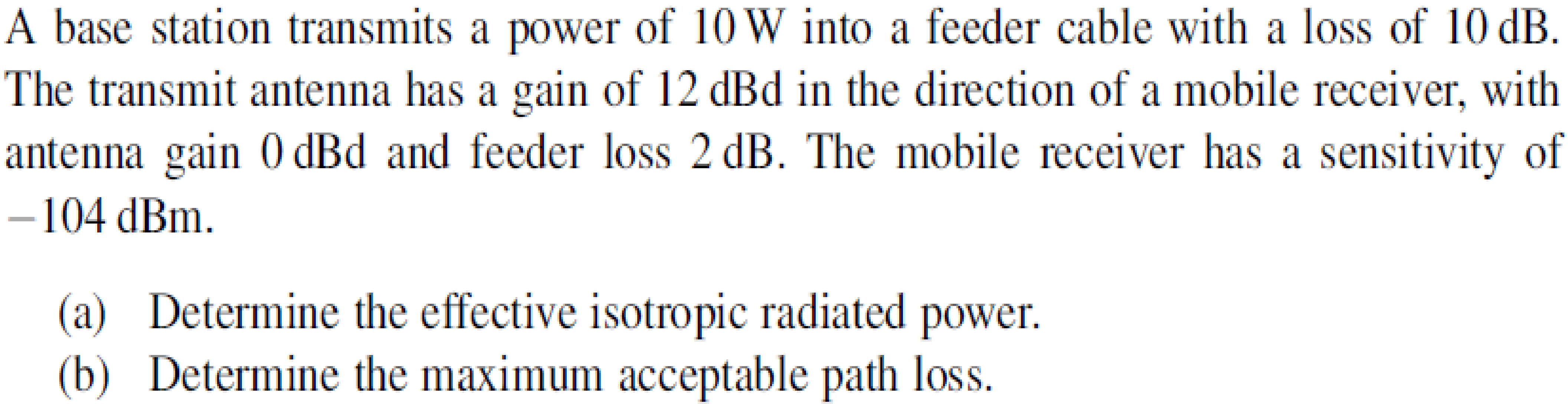
$$L = 10\log\left(\frac{P_{TI}}{P_{RI}}\right) \qquad L = P_T + G_T + G_R - P_R - L_T - L_R$$

- Note1: If P_R is the Rx sensitivity then the calculate path loss L is maximum acceptable.
- Note2: Use antenna gain unit in dBi

Propagation models

❑Basic propagation models: 1- Path loss

- **Example**



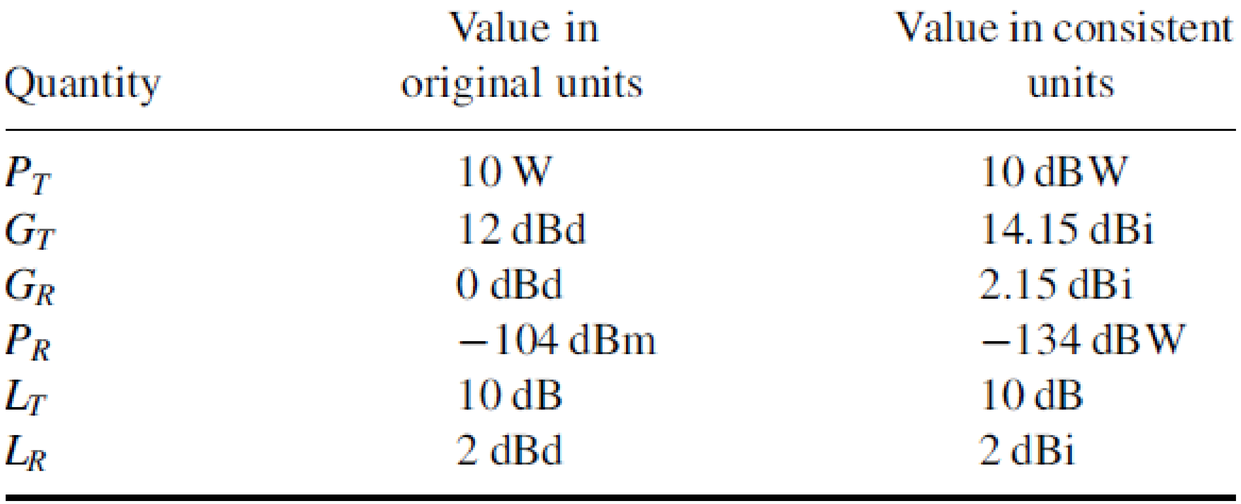
A base station transmits a power of 10 W into a feeder cable with a loss of 10 dB. The transmit antenna has a gain of 12 dBd in the direction of a mobile receiver, with antenna gain 0 dBd and feeder loss 2 dB. The mobile receiver has a sensitivity of −104 dBm.

(a) Determine the effective isotropic radiated power.
(b) Determine the maximum acceptable path loss.

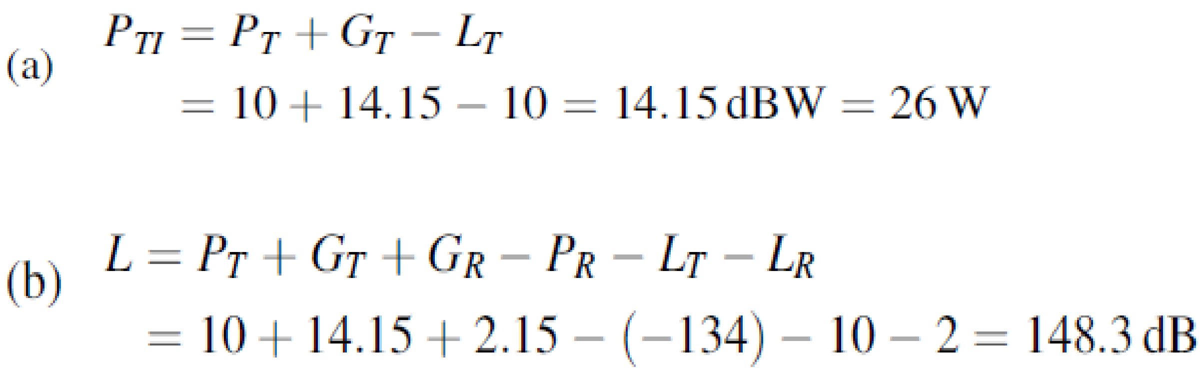
Propagation models

❑Basic propagation models: 1- Path loss

- **Solution:**



Quantity	Value in original units	Value in consistent units
P_T	10 W	10 dBW
G_T	12 dBd	14.15 dBi
G_R	0 dBd	2.15 dBi
P_R	−104 dBm	−134 dBW
L_T	10 dB	10 dB
L_R	2 dBd	2 dBi

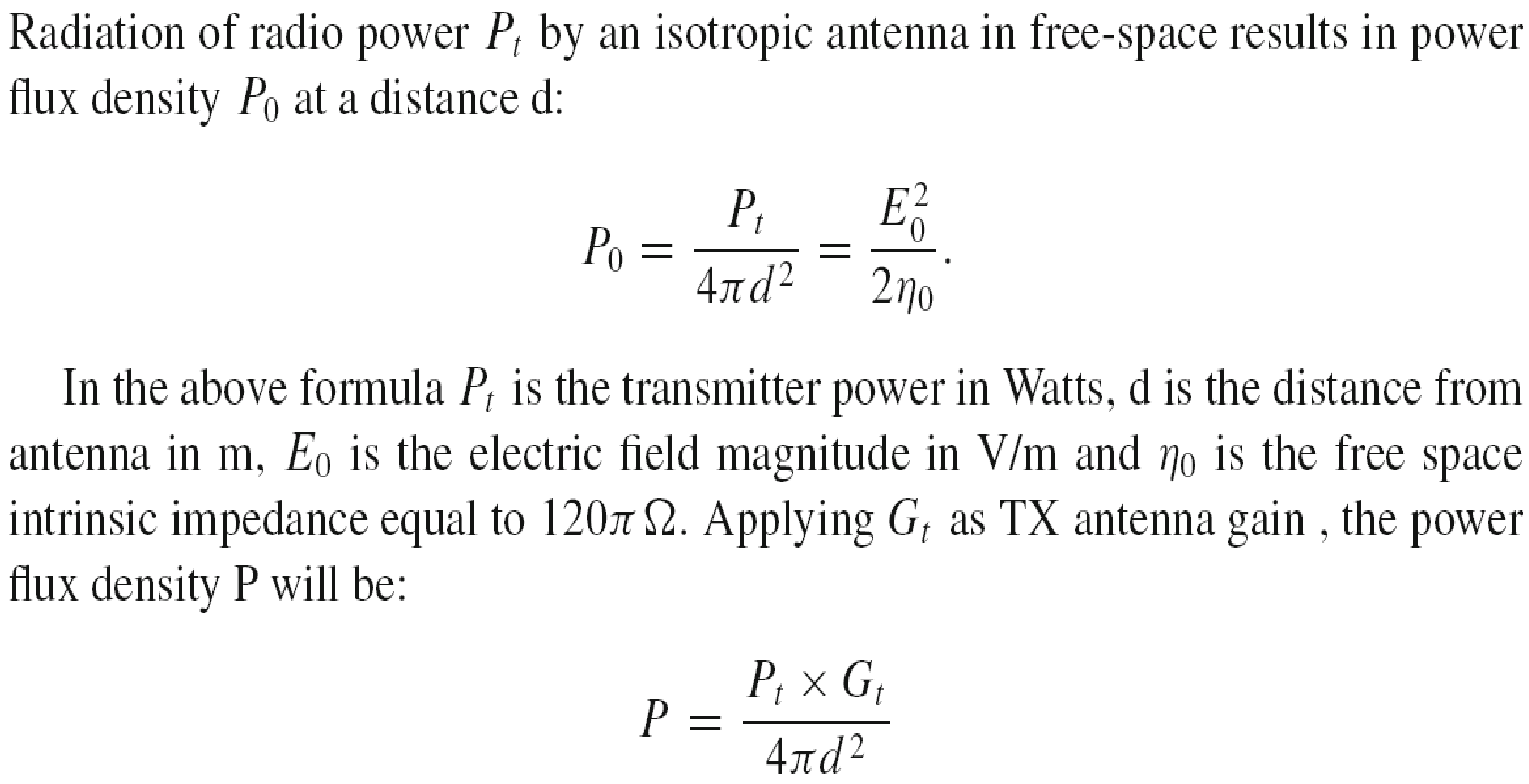


(a)
$$\begin{aligned} P_{TI} &= P_T + G_T - L_T \\ &= 10 + 14.15 - 10 = 14.15\,\text{dBW} = 26\,\text{W} \end{aligned}$$

(b)
$$\begin{aligned} L &= P_T + G_T + G_R - P_R - L_T - L_R \\ &= 10 + 14.15 + 2.15 - (-134) - 10 - 2 = 148.3\,\text{dB} \end{aligned}$$

Propagation models

❑Basic propagation models: 2- Free Space Loss & Friis Formula



Radiation of radio power P_t by an isotropic antenna in free-space results in power flux density P_0 at a distance d:

$$P_0 = \frac{P_t}{4\pi d^2} = \frac{E_0^2}{2\eta_0}.$$

In the above formula P_t is the transmitter power in Watts, d is the distance from antenna in m, E_0 is the electric field magnitude in V/m and η_0 is the free space intrinsic impedance equal to $120\pi\,\Omega$. Applying G_t as TX antenna gain , the power flux density P will be:

$$P = \frac{P_t \times G_t}{4\pi d^2}$$

Propagation models

❑Basic propagation models: 2- Free Space Loss & Friis Formula

Using a receiving antenna with an effective aperture area A_e, the received signal power would be:

$$P_r = P \times A_e.$$

A_e according to the EM waves theory is:

$$A_e = \frac{G_r \times \lambda^2}{4\pi}.$$

By manipulating the last three relations, the following formula is derived:

$$P_r = \frac{P_t \times G_t}{4\pi d^2} \times \frac{G_r \times \lambda^2}{4\pi} = \frac{P_t \times G_t \times G_r \times \lambda^2}{(4\pi d)^2}.$$

Friis transmission formula

Propagation models

❑Basic propagation models: 2- Free Space Loss & Friis Formula

$$\Rightarrow \quad L_f = \frac{(4\pi d)^2}{\lambda^2}$$

- In dB

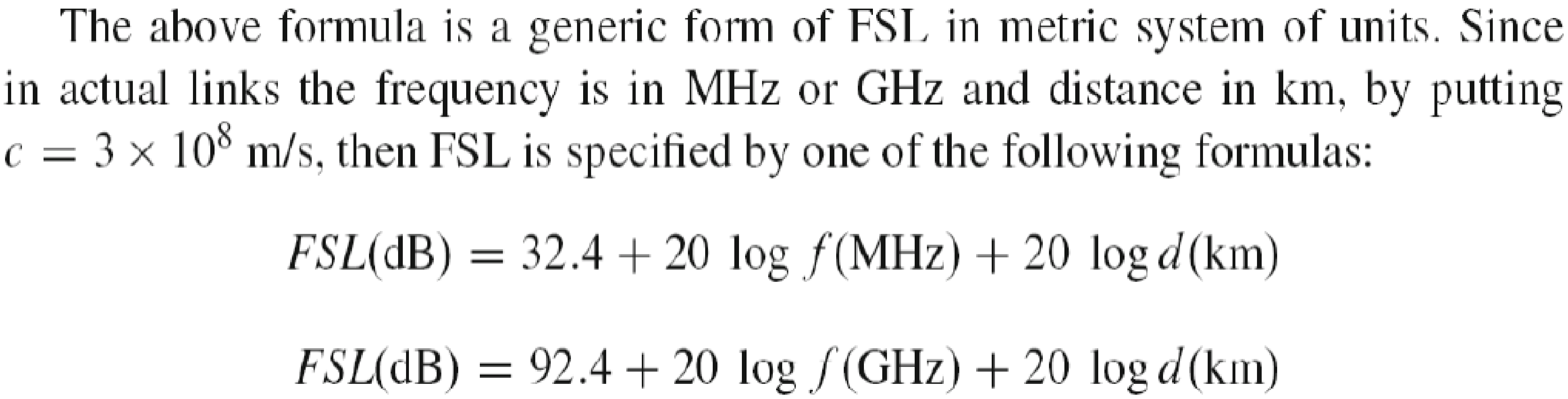
$$FSL = 20 \ \log \frac{4\pi d}{\lambda}$$

Considering $\lambda = c/f$ we have:

$$FSL = 20 \ \log \frac{4\pi f.d}{c}.$$

Propagation models

❑Basic propagation models: 2- Free Space Loss & Friis Formula



The above formula is a generic form of FSL in metric system of units. Since in actual links the frequency is in MHz or GHz and distance in km, by putting $c = 3 \times 10^8$ m/s, then FSL is specified by one of the following formulas:

$$FSL(\mathrm{dB}) = 32.4 + 20\ \log f(\mathrm{MHz}) + 20\ \log d(\mathrm{km})$$

$$FSL(\mathrm{dB}) = 92.4 + 20\ \log f(\mathrm{GHz}) + 20\ \log d(\mathrm{km})$$

Propagation models

❑Basic propagation models: 2- Free Space Loss

Example . In a radio link of 40 km length and working at 7.5 GHz, 60% of free-space loss is compensated by using high-gain TX and RX antennas.

1. How much is the received signal level (RSL) at the output of RX antenna with one watt TX output power and considering 15 dB additional losses.
2. Find fade margin of the link if RX threshold is to be $P_{\mathrm{th}} = -78\ \mathrm{dB}_m$

***Solution*:**

1.

$$FSL = 92.4 + 20\ \log f.d\ = 141\ \mathrm{dB}$$

$$P_t = 1\ \mathrm{W} \quad \Rightarrow \quad P_t\,(\mathrm{dB}_m) = 30\ \mathrm{dB}_m$$

$$P_r = RSL = P_t\,(\mathrm{dB}_m) - 0.4\,FSL - L_a$$

$$= 30 - 56.8 - 15 = -41.4\ \mathrm{dB}_m$$

Actual received power is much less than that. Because in practice other loss sources exist and affect.

2.

$$FM = P_r\,(\mathrm{dB}_m) - P_{\mathrm{th}}\,(\mathrm{db}_m) = -41.4 + 78 = 36.6\ \mathrm{dB} \qquad \blacksquare$$

Propagation models

❑Basic propagation models: 2- Free Space Loss & Friis Formula

- The fields of an antenna can broadly be classified in two regions, the far field and the near field.
- *The Friis equation is used only beyond the far field distance, df , which is dependent upon the largest dimension of the antenna as*

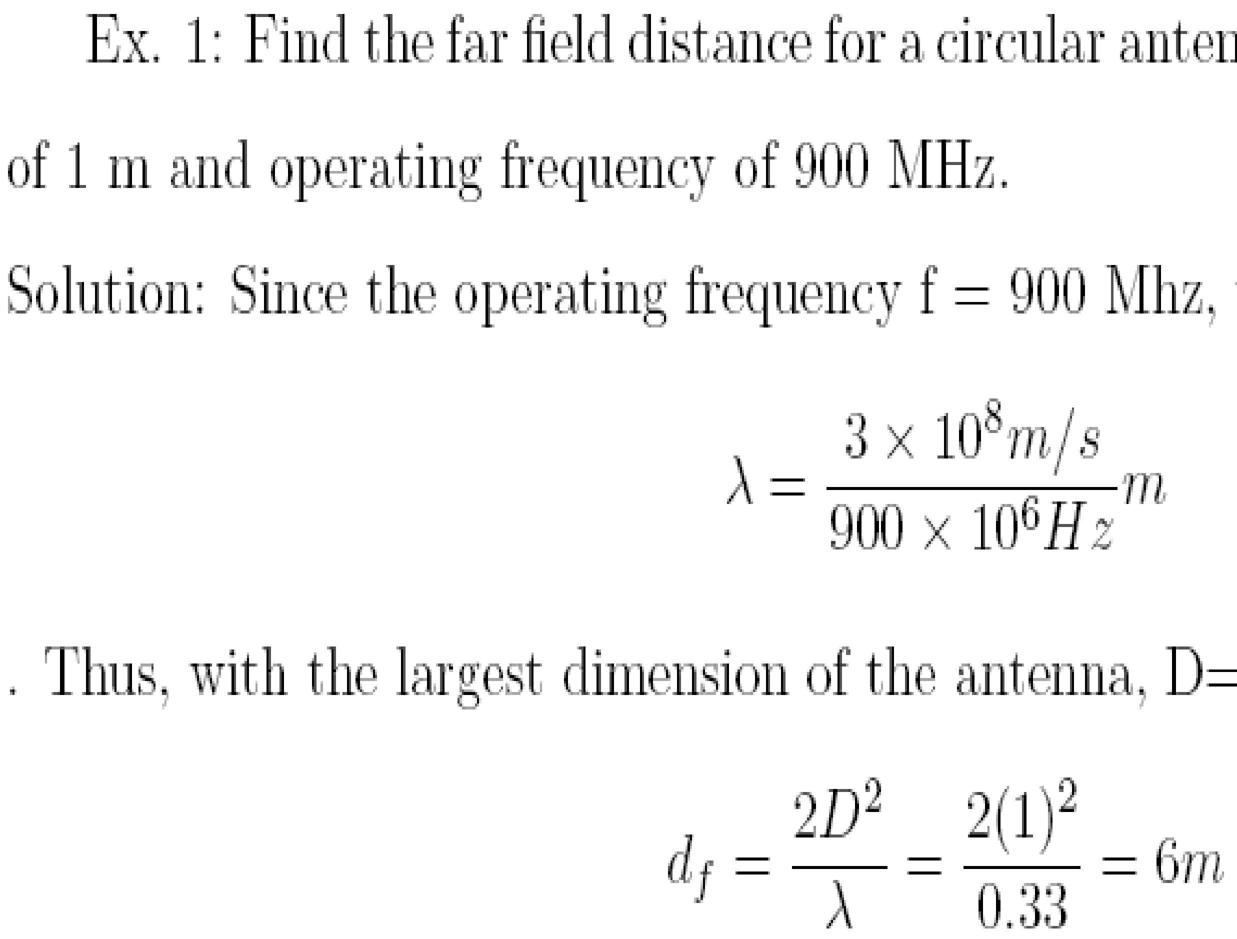
$$d_f = 2D^2/\lambda.$$

- *Also we can see that the Friis equation is not defined for d=0. For this reason, we use a close in distance, do, as a reference point. The power received, Pr(d), is then given by:*

$$P_r(d) = P_r(d_o)(d_o/d)^2 \longrightarrow \underset{\text{dBm}}{P_r(d)} = \underset{\text{dBm}}{P_r(d_0)} + 20\log\left(\frac{d_0}{d}\right)$$

Propagation models

❑Basic propagation models: 2- Free Space Loss & Friis Formula



Ex. 1: Find the far field distance for a circular antenna with maximum dimension of 1 m and operating frequency of 900 MHz.

Solution: Since the operating frequency f = 900 Mhz, the wavelength

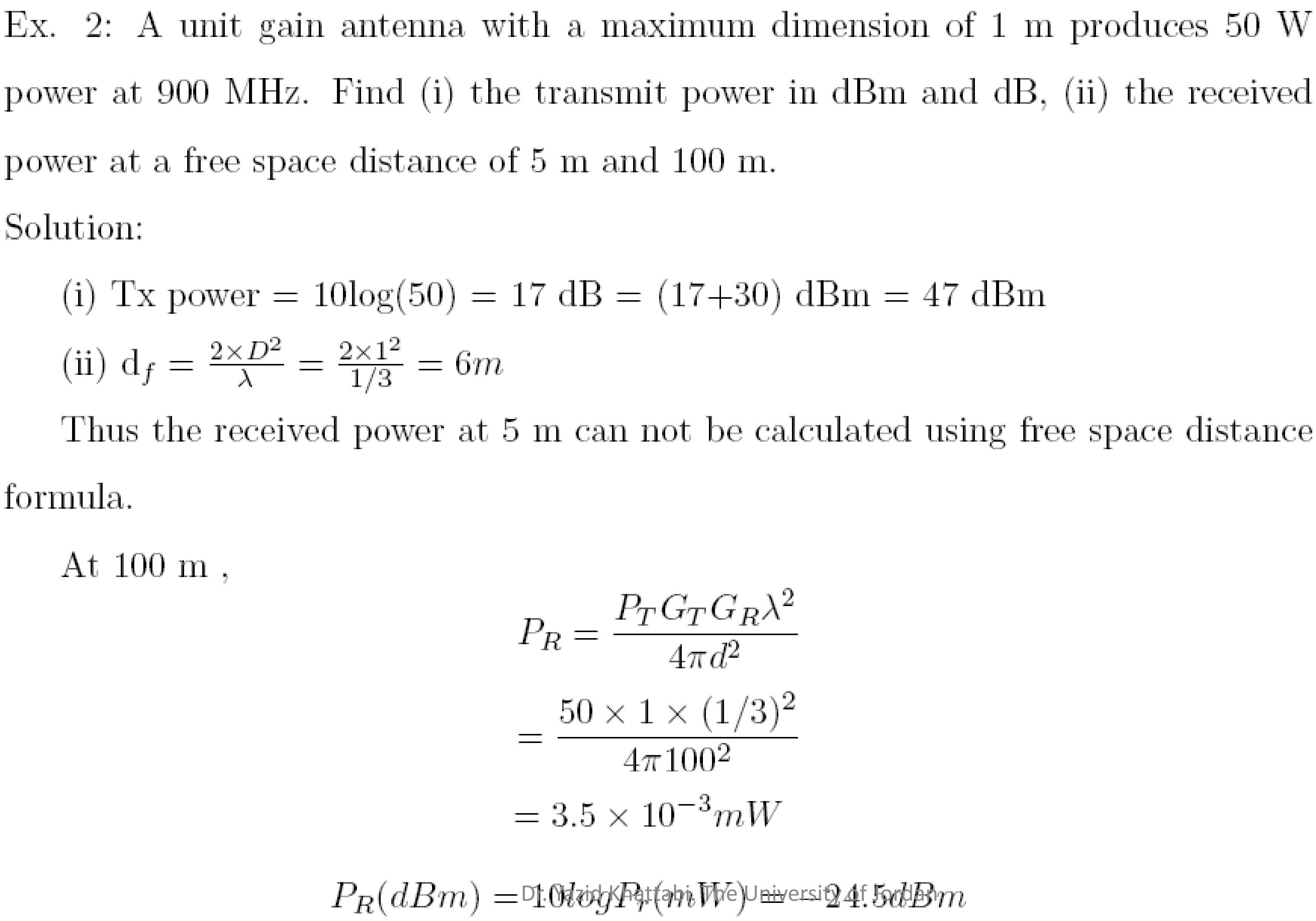
$$\lambda = \frac{3 \times 10^8 m/s}{900 \times 10^6 Hz} m$$

. Thus, with the largest dimension of the antenna, D=1m, the far field distance is

$$d_f = \frac{2D^2}{\lambda} = \frac{2(1)^2}{0.33} = 6m$$

Propagation models

❑Basic propagation models: 2- Free Space Loss & Friis Formula



Ex. 2: A unit gain antenna with a maximum dimension of 1 m produces 50 W power at 900 MHz. Find (i) the transmit power in dBm and dB, (ii) the received power at a free space distance of 5 m and 100 m.

Solution:

(i) Tx power = 10log(50) = 17 dB = (17+30) dBm = 47 dBm

(ii) $d_f = \frac{2\times D^2}{\lambda} = \frac{2\times 1^2}{1/3} = 6m$

Thus the received power at 5 m can not be calculated using free space distance formula.

At 100 m ,

$$P_R = \frac{P_T G_T G_R \lambda^2}{4\pi d^2}$$

$$= \frac{50 \times 1 \times (1/3)^2}{4\pi 100^2}$$

$$= 3.5 \times 10^{-3} mW$$

$$P_R(dBm) = 10 log P_r(mW) = -24.5 dBm$$

Propagation models

❑Basic propagation models: 3- Long distance path model

- Empirical models (field measurements + fitting curves) valid for the environment in which measurements were taken.
- So, long distance path model is used to predict average large-scale coverage for mobile communication systems with arbitrary T-R separation .
- **The received power at *d* :**

$$P_r(d) = P_r(d_o)(d_o/d)^n$$

- **The path loss at *d* :**

$$L(\text{dB}) = L(d_0) + 10n\log\left(\frac{d}{d_0}\right)$$

❖*n* is the path loss exponent: *indicates the rate at which the path loss increases with distance,*

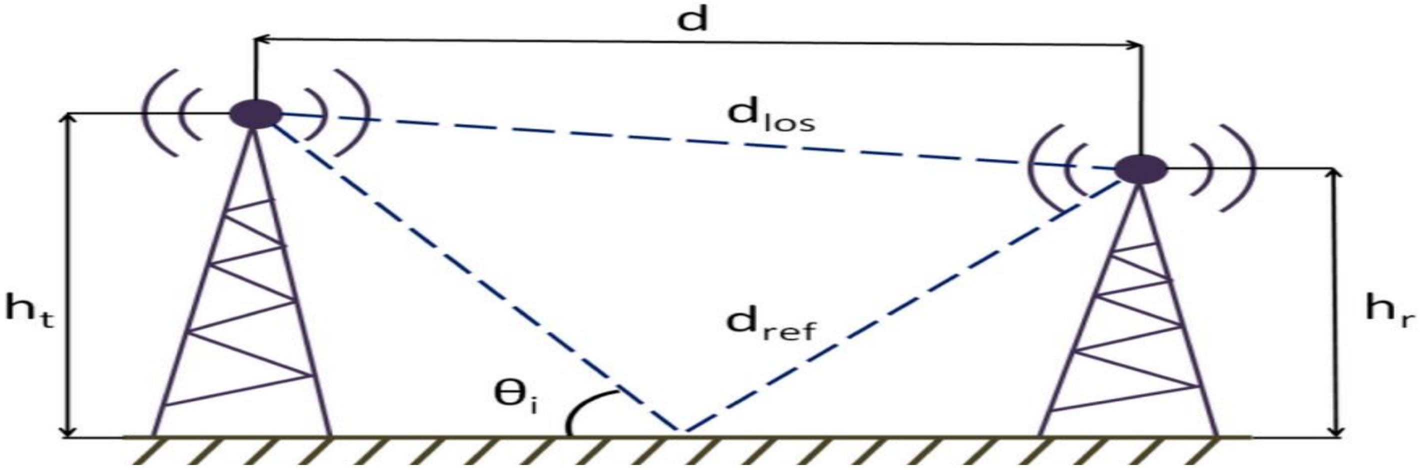
❖d0 is the close-in reference distance: *is determined from measurements close to the transmitter.*

- In large coverage cellular systems, 1 km reference distances are commonly used, whereas in microcellular systems, much smaller distances (such as 100 m or 1 m) are used.

Environment	Path Loss Exponent, n
Free space	2
Urban area cellular radio	2.7 to 3.5
Shadowed urban cellular radio	3 to 5
In building line-of-sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

Propagation models

❑Basic propagation models: 4- <u>two-ray reflection model</u>



- Received power: $$P_r = \frac{P_t G_t G_r h_t^2 h_r^2}{L d^4}.$$
- Two-ray loss: $$PL(\text{dB}) = 40\log d - (20\log h_t + 20\log h_r)$$

- *L*: is the system hardware losses (L ≥ 1) are usually due to: transmission line attenuation, filter losses, and antenna losses in the communication system. A value of L = 1 indicates no loss in the system hardware

Thank you