Electromagnetics:

Microwave Engineering

Wireless Communications

Lecture Outline

- Wireless Systems
- The Friis Formula
- Link Budget and Link Margin
- Examples

Wireless Systems

Wireless communication is the transfer of information between two points without direct connection. Most rely on RF or microwave frequencies.
Types of wireless systems by user placement:

<u>Point-to-Point:</u> Single transmitter-single receiver (radios, data communications, backhaul communications).

<u>Point-to-Multipoint:</u> Single transmitter-multiple receivers (radio, television).

<u>Multipoint-to-Multipoint:</u> Multiple transmitters-multiple receivers (internet, cellphones).

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Wireless Systems

Types of wireless systems by directionality:

<u>Simplex:</u> Communication in only one direction (radio, television, paging systems).

<u>Half-Duplex:</u> Communication in two directions, but not at the same time (push-to-talk, walkie-talkies).

<u>Full-Duplex:</u> Simultaneous, two-way transmission and reception (cellphone, radio systems).

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Wireless Systems

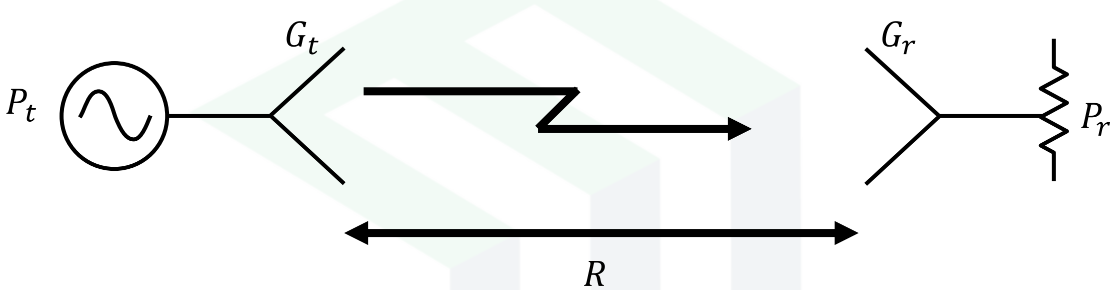
Satellite communications can also be used for voice, video, and data communications. Satellites can be placed in a geosynchronous earth orbit 36,000 km above Earth.

These satellites are useful for point-to-point radio links, television and data communications around the world.

It was also used for transcontinental telephone communications before the advent of undersea optical cables.

Drawbacks of satellite communications include delay and reduced signal strength.

The Friis Formula

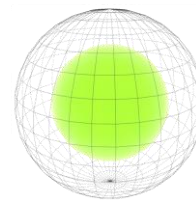


P_t — Transmit Power
G_t — Transmit Antenna Gain
G_r —Receive Antenna Gain
P_r —Received Power (delivered to matched load)
R —Distance Between Antennas

The Friis Formula

The power density radiated by an isotropic antenna $(D = 1 = 0\ \text{dB})$ at a distance R is

$$S_{avg} = \frac{P_t}{4\pi R^2} \quad W/m^2$$



If the transmit antenna has losses, we can include the radiation efficiency

$$S_{avg} = \frac{G_t P_t}{4\pi R^2} \quad W/m^2$$

If the power density is incident at the receive antenna, using the concept of effective area we obtain

$$P_r = A_e S_{avg} = \frac{G_t P_t A_e}{4\pi R^2}$$

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The Friis Formula

Since $A_e = \frac{D\lambda^2}{4\pi}$, we obtain the final result for the received power:

$$\boxed{P_r = \frac{G_t G_r \lambda^2}{(4\pi R)^2} P_t}$$

Friis Radio Link Formula

The received power is proportional to the transmitted power product $P_t G_t$. In the main beam of the antenna, this can be interpreted as the power radiated by an isotropic antenna with input power $P_t G_t$, defined as *effective isotropic radiated power* (EIRP).

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Link Budget

The various terms in the Friis formula are often tabulated separately in a link budget, where each of the factors are considered individually. Other factors such as line losses or impedance mismatch can also be added to the budget.

The path loss is one of the terms added to the link budget, accounting for free-space reduction in signal strength

$$L_o(\text{dB}) = 20\log\left(\frac{4\pi R}{\lambda}\right)$$

Link Budget

Term Description	Friis Formula Term
Transmit Power	P_t
Transmit Antenna Loss	$(-)L_t$
Transmit Antenna Gain	G_t
Path loss (free-space)	$(-)L_0$
Atmospheric Attenuation	$(-)L_A$
Receive Antenna Gain	G_r
Receive Antenna Loss	$(-)L_r$
Receive Power	P_r

$$P_r = P_t - L_t + G_t - L_0 - L_A + G_r - L_r$$

Power Conversions:

Decibel Milliwatt	$dBm \rightarrow 10\log(P(\text{mW}))$
Decibel Watt	$dBW \rightarrow 10\log(P(\text{W}))$
From dBm to dBW	subtract 30
From dBW to dBm	add 30

Other terms:

Decibel over isotropic dBi

The gain of an antena relative to a hypothetical isotropic antenna

Decibel over dipole dBd

The gain of an antena relative to a dipole ($0\ dBd = 2.15\ dBi$)

Link Margin

In communication systems it is usually desired to have the received power level greater than a certain threshold to have a minimum acceptable service. This allowance is called link margin and is expressed as the difference between the design value of received power and the minimum threshold value:

$$Link\ Margin\ (dB) = LM = P_r - P_{r(min)} > 0$$

A good link margin provides robustness to account for variables such as weather, buildings, movement of users, and other factors that can degrade the performance of the service.

Example 1 – Link Analysis of Direct Broadcast TV System

The Direct Broadcast System (DBS) in North America operates at $12.2 - 12.7$ GHz, with a transmit carrier power of 120 W, a transmit antena gain of 34 dB, and a worst-case slant angle $(30°)$ distance from the geostationary satellite to Earth of $39{,}000$ km. The 18 −inch receiving antenna has a gain of $33.5\ dB$. Find the link budget for the received carrier power at the antenna terminals.

Solution:

The middle frequency is 12.45 GHz, so $\lambda = 0.0241$ m.

$$L_0 = 20\log\left(\frac{4\pi R}{\lambda}\right) = 20\log\left(\frac{4\pi(39\times10^6\ \text{m})}{0.0241}\right) = 206.2\ dB$$
$$P_t = 120\ \text{W} = 10\log(120\ \text{W}) = 20.8\ dBW$$
$$G_t = 34.0\ dB$$
$$G_r = 33.5\ dB$$

Example 1 – Link Analysis of Direct Broadcast TV System

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<u>Solution:</u>

L_0	$-206.2\ dB$
P_t	$20.8\ dBW$
G_t	$34.0\ dB$
G_r	$33.5\ dB$
P_r	$-117.9\ dBW = 1.63 \times 10^{-12}\ W$

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Example 2 – Communications System Design

A communications engineer is tasked to design a communications link at 2.456 GHz. The receive antenna gain is 10 dB, and the transmit antenna gain is 18 dB. Both antenas are oriented such that they point at each other with maximum directivity. Assuming no other factors or losses, calculate the maximum distance between the antenas, if the minimum power needed by the receiver to overcome the noise is $2\ \mu W$, and the transmit power is $10\ W$.

<u>Solution:</u>

At 2.456 GHz, the wavelength λ is 0.1225 m

$$P_r = G_t G_r \left(\frac{\lambda}{4\pi R}\right)^2 P_t$$

$$R = \frac{\lambda}{4\pi \left(\frac{P_r}{P_t G_t G_r}\right)^{1/2}}$$

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Solution:

$$\lambda = 0.1225\ \mathrm{m}$$
$$P_t = 10\ W$$
$$P_r = 2 \times 10^{-6}\ W$$
$$G_r = 10\ dB \rightarrow 10^{10/10} = 10$$
$$G_t = 18\ dB \rightarrow 10^{18/10} = 63.1$$

$$R = \frac{0.1225\ \mathrm{m}}{4\pi \left(\frac{2 \times 10^{-6}\ W}{(10\ W)(63.1)(10)} \right)^{1/2}} = \boxed{547.55\ \mathrm{m}}$$

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Example 3 – GPS Communications

A GPS system is working at a frequency of 1.57 GHz, connected to a satellite located 20 km above the Earth's surface. The transmitter is a dish-type antena with a gain of 30 dB. The satellite uses a similar dish-type antena with the same gain. Calculate the minimum acceptable transmit power in dBm for this system if the minimum aceptable power is $-120\ dBm$ to overcome noise.

Solution:

At a frequency of 1.57 GHz, $\lambda = 0.191\ \mathrm{m}$

$$R = 20 \times 10^3\ m$$
$$G_r = G_t \rightarrow 10^{30/10} = 1000$$
$$P_r = -120\ dBm \rightarrow 10^{-\frac{120}{10}} = 1 \times 10^{-12}\ mW$$

$$P_t = \frac{P_r}{G_t G_r} \left(\frac{4\pi R}{\lambda} \right)^2 = \frac{1 \times 10^{-12}}{(1000)^2} \left(\frac{4\pi (20 \times 10^3)}{0.191} \right)^2 = \boxed{1.7315 \times 10^{-6}\ mW = -57.62\ dBm}$$

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