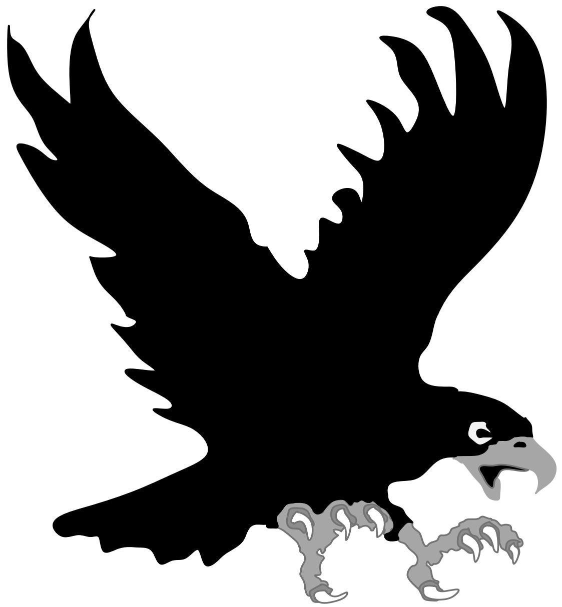


Antenna and Propagation

“Link Analysis”

Dr. Cahit Karakuş, 2018

Exponential Function

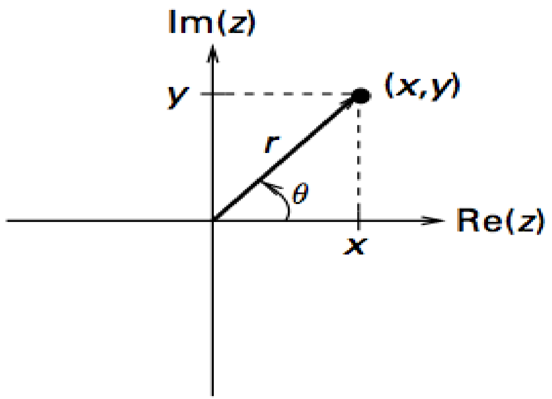
Complex numbers

- Complex numbers provide a compact way of describing amplitude and phase (and the operations that affect them, such as filtering)

Complex number $z = x + \mathrm{j}y$ (x and y real-valued; $\mathrm{j} = \sqrt{-1}$.)

$$e^{\mathrm{j}\theta} = \cos\theta + \mathrm{j}\sin\theta$$

$$r = |z| = \sqrt{x^2 + y^2},$$
$$\theta = \arg(z) = \tan^{-1}\frac{y}{x}$$



Exponential Function

- The function defined by is called an exponential function with base *b* and exponent *x*.
- The domain of *f* is the set of all real numbers.

$$f(x) = b^x \qquad (b > 0,\ b \neq 1)$$

- The exponential function with base 2 is the function with domain $(-\infty, \infty)$.
- The values of $f(x)$ for selected values of *x* follow:

$$f(x) = 2^x \qquad f(3) = 2^3 = 8$$

$$f(0) = 2^0 = 1$$

Laws of Exponents

- Let *a* and *b* be positive numbers and let *x* and *y* be real numbers. Then,

1. $$b^x \cdot b^y = b^{x+y}$$
2. $$\frac{b^x}{b^y} = b^{x-y}$$
3. $$\left(b^x\right)^y = b^{xy}$$
4. $$(ab)^x = a^x b^x$$
5. $$\left(\frac{a}{b}\right)^x = \frac{a^x}{b^x}$$

Examples

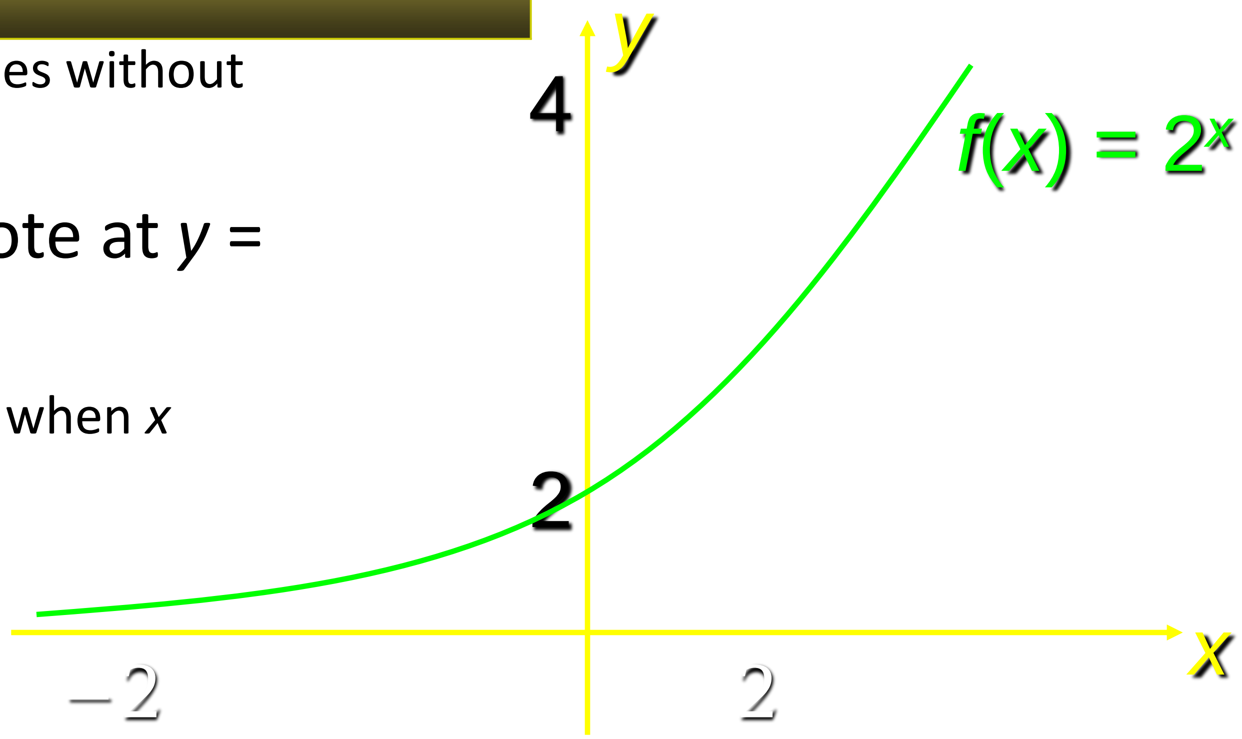
- Sketch the graph of the exponential function $f(x) = 2^x$.

Solution

- Now, consider a few values for x:

x	– 5	– 4	– 3	– 2	– 1	0	1	2	3	4	5
y	1/32	1/16	1/8	1/4	1/2	1	2	4	8	16	32

- Note that 2^x approaches zero as x decreases without bound:
  - There is a horizontal asymptote at $y = 0$.
- Furthermore, 2^x increases without bound when x increases without bound.
- Thus, the range of f is the interval $(0, \infty)$.



Properties of Exponential Functions

- The exponential function $y = b^x$ $(b > 0, b \neq 1)$ has the following properties:
  1. Its domain is $(-\infty, \infty)$.
  2. Its range is $(0, \infty)$.
  3. Its graph passes through the point (0, 1)
  4. It is continuous on $(-\infty, \infty)$.
  5. It is increasing on $(-\infty, \infty)$ if $b > 1$ and decreasing on $(-\infty, \infty)$ if $b < 1$.

The Base *e*

- Exponential functions to the base *e*, where *e* is an irrational number whose value is 2.7182818…, play an important role in both theoretical and applied problems.
- It can be shown that

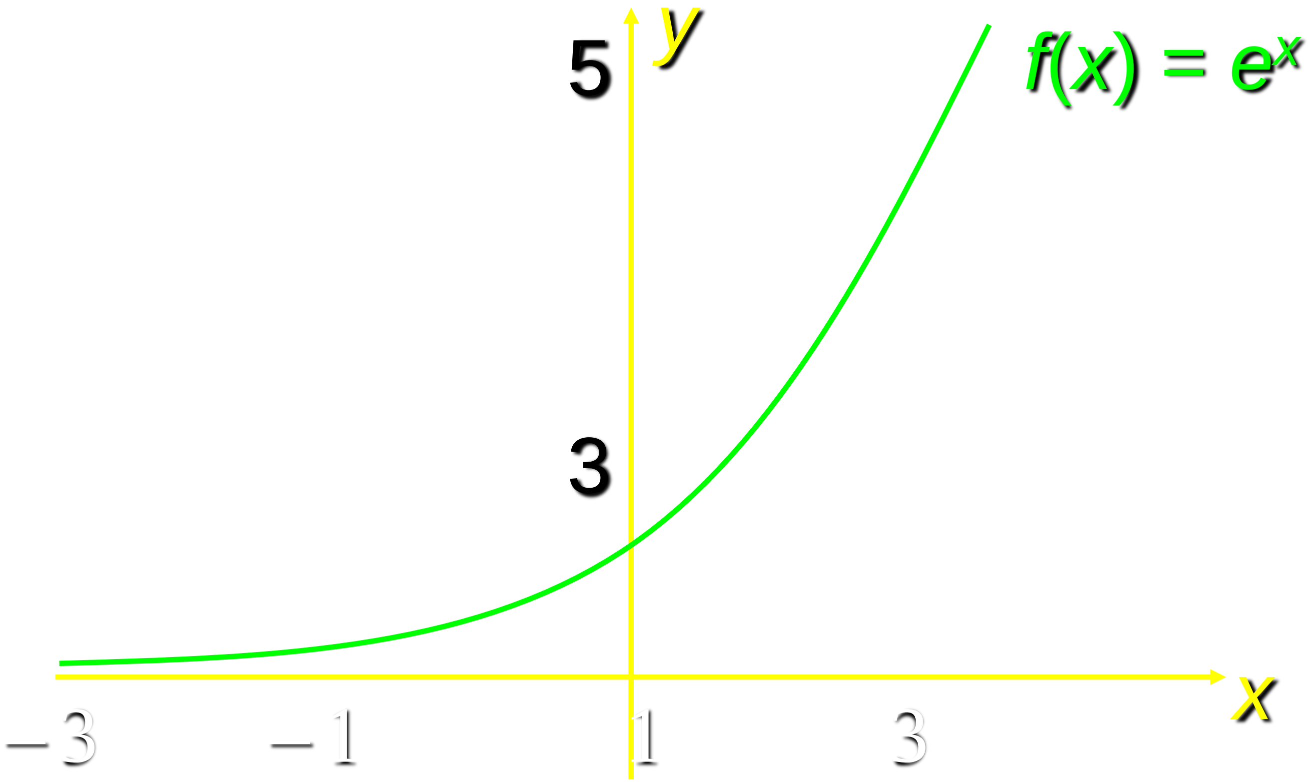
$$e = \lim_{m \to \infty} \left(1 + \frac{1}{m}\right)^m$$

Examples

- Sketch the graph of the exponential function $f(x) = e^x$.

Solution

- Sketching the graph:



Examples

- Sketch the graph of the exponential function $f(x) = e^{-x}$.

Solution

- Since $e^{-x} > 0$ it follows that $0 < 1/e < 1$ and so
  $f(x) = e^{-x} = 1/e^x = (1/e)^x$ is an exponential function with base less than 1.
- Therefore, it has a graph similar to that of $y = (1/2)^x$.
- Consider a few values for x:

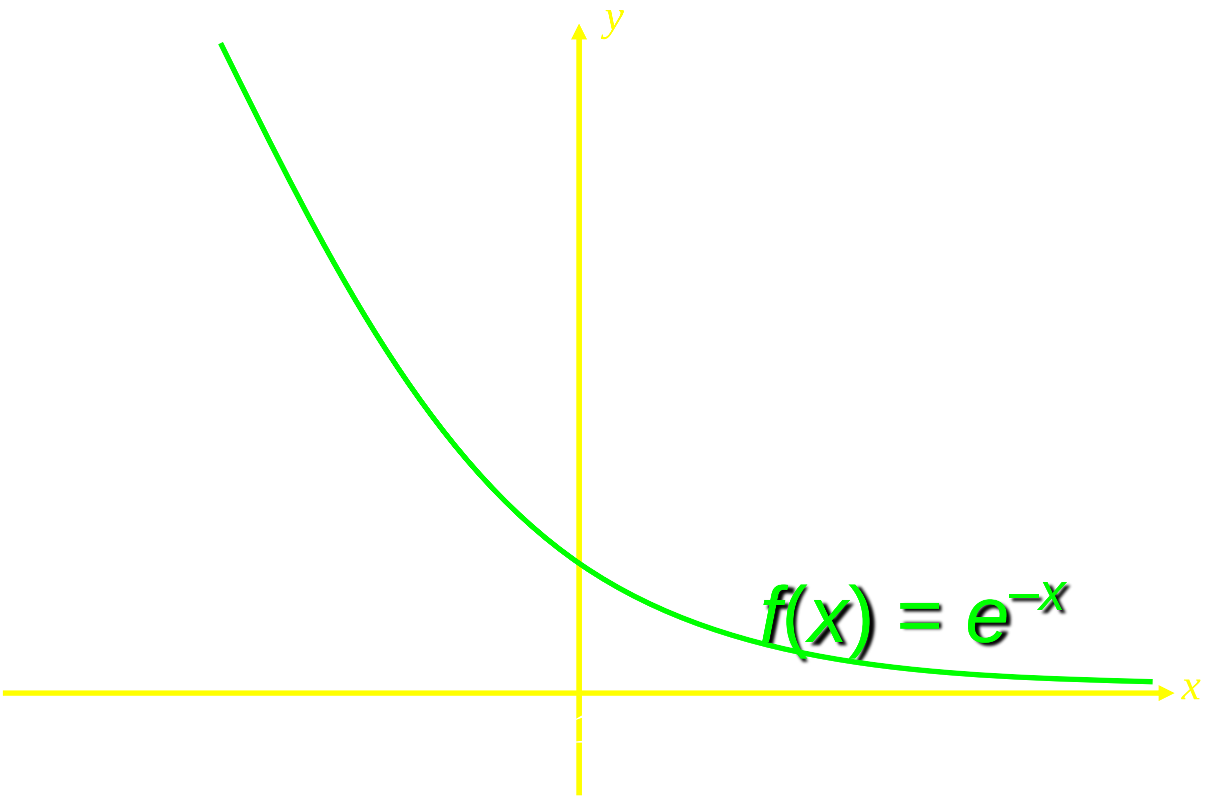
x	– 3	– 2	– 1	0	1	2	3
y	20.09	7.39	2.72	1	0.37	0.14	0.05

Examples

- Sketch the graph of the exponential function $f(x) = e^{-x}$.

<u>Solution</u>

- Sketching the graph:



Logarithms

Logarithms

- Exponential equations of the form

$$y = b^x \qquad (b > 0,\ b \neq 1)$$

- The logarithm of x to the base b, and is denoted $\log_b x$.
- Logarithm of x to the base b

$$y = \log_b x \quad \text{if and only if} \quad x = b^y \qquad (x > 0)$$

$\log x = \log_{10} x$ Common logarithm

$\ln x = \log_e x$ Natural logarithm

$y = \log_b x$ ise $x = b^y$

Laws of Logarithms

- If *m* and *n* are positive numbers, then

$$\log_b mn = \log_b m + \log_b n$$

$$\log_b \frac{m}{n} = \log_b m - \log_b n$$

$$\log_b m^n = n \log_b m$$

$$\log_b 1 = 0$$

$$\log_b b = 1$$

log 2 ≈ 0.3, log 3 ≈ 0.5, log 5 ≈ 0.7, log 7 ≈ 0.8

Properties of Logarithmic Functions

- The logarithmic function $y = \log_b x (b > 0, b \neq 1)$ has the following properties:
  1. Its domain is $(0, \infty)$.
  2. Its range is $(-\infty, \infty)$.
  3. Its graph passes through the point (1, 0).
  4. It is continuous on $(0, \infty)$.
  5. It is increasing on $(0, \infty)$ if $b > 1$ and decreasing on $(0, \infty)$ if $b < 1$.

Exponential Logarithmic Functions

- Solve the equation $2e^{x+2} = 5$.

<u>Solution</u>

- Divide both sides of the equation by 2 to obtain: $e^{x+2} = \frac{5}{2} = 2.5$

- Take the natural logarithm of each side of the equation and solve:

$$\begin{aligned} \ln e^{x+2} &= \ln 2.5 \\ (x+2)\ln e &= \ln 2.5 \\ x+2 &= \ln 2.5 \\ x &= -2 + \ln 2.5 \\ x &\approx -1.08 \end{aligned}$$

- Properties relating e^x and $\ln x$: $e^{\ln x} = x \quad (x > 0)$

  $\ln e^x = x \quad$ (for any real number x)

Common Errors with Logarithms

Each of the following represent common errors when calculating with logarithms:

$$\log_b(m + n) \neq \log_b(m) + \log_b(n)$$

$$\log_b(m - n) \neq \log_b(m) - \log_b(n)$$

$$\log_b\left(\frac{m}{n}\right) \neq \frac{\log_b(m)}{\log_b(n)}$$

$$\log_b(m \cdot n) \neq (\log_b(m))(\log_b(n))$$

$$\log_b(m \cdot n^p) \neq p \log_b(m \cdot n)$$

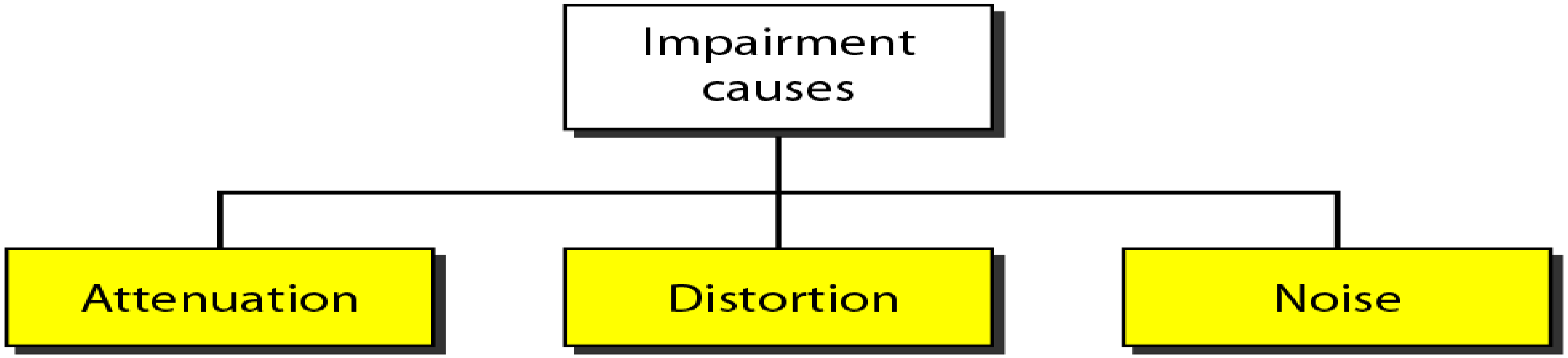
Transmisyon Ortamlarının Olumsuz Etkileri

Transmission Impairments

- Signal received may differ from signal transmitted
- Analog - degradation of signal quality
- Digital - bit errors
- Caused by
  - Attenuation and attenuation distortion
  - Delay distortion
  - Noise

TRANSMISSION IMPAIRMENT

Sinyaller, mükemmel olmayan iletim ortamından geçer. İletim ortamının kusurları, sinyal bozulmasına neden olur. Bu, ortamın başlangıcındaki sinyalin, ortamın sonundaki sinyalin aynısı olmadığı anlamına gelir. Gönderilen, alınan şey değildir. Bozulmanın üç nedeni zayıflama, bozulma ve gürültüdür.



Zayıflama

– Kablosuz iletimin tüm ortamlarında sinyaller zayıflar ve bozulur. Sinyal zayıflaması, verici ve alıcı arasındaki mesafenin karesiyle orantılıdır.

Gürültü

– Gürültü, iletişim sistemlerine ve ortamlarına iletişim aracıyla giren ve iletilen mesaja müdahale eden rastgele, istenmeyen elektriksel enerjidir.

Zayıflama

- Means loss of energy -> weaker signal
- When a signal travels through a medium it loses energy overcoming the resistance of the medium
- Amplifiers are used to compensate for this loss of energy by amplifying the signal.
- Signal strength falls off with distance
- Depends on medium
- Received signal strength:
  - must be enough to be detected
  - must be sufficiently higher than noise to be received without error
- Attenuation is an increasing function of frequency

- To show the loss or gain of energy the unit “decibel” is used.

$$dB = 10\log_{10}P_2/P_1$$

P_1 - input signal

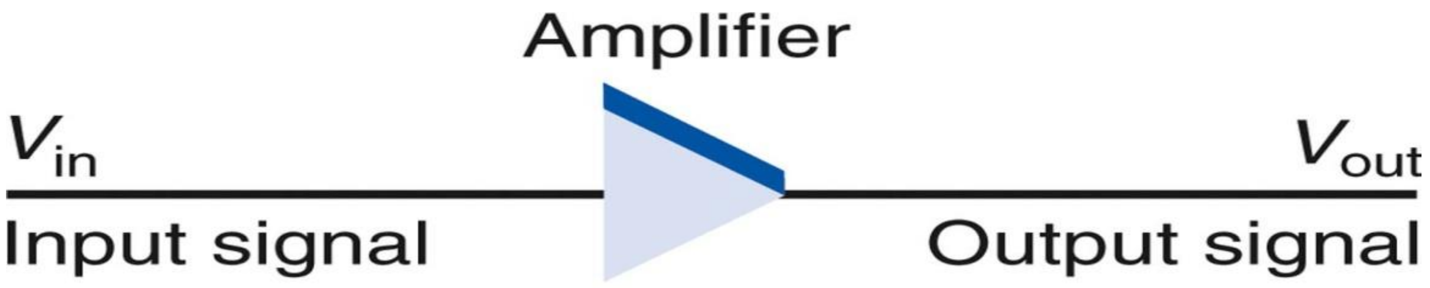
P_2 - output signal

Gain, Attenuation, and Decibels

Gain

- **Gain** means amplification. It is the ratio of a circuit's output to its input.

$$A_V = \frac{\text{output}}{\text{input}} = \frac{V_{out}}{V_{in}}$$



$$A = \text{gain} = \frac{V_{out}}{V_{in}}$$

An amplifier has gain.

Gain, Attenuation and Decibels

- Most amplifiers are also power amplifiers, so the same procedure can be used to calculate power gain A_P where P_{in} is the power input and P_{out} is the power output.

$$\text{Power gain } (A_p) = P_{out} / P_{in}$$

- **Example:** The power output of an amplifier is 6 watts (W). The power gain is 80. What is the input power?

$$A_p = P_{out} / P_{in} \quad \text{therefore} \quad P_{in} = P_{out} / A_p$$

$$P_{in} = 6 / 80 = 0.075 \text{ W} = 75 \text{ mW}$$

Gain, Attenuation and Decibels

Decibels: Decibel Calculations

- Voltage Gain or Attenuation

$$dB = 20 \log V_{out} / V_{in}$$

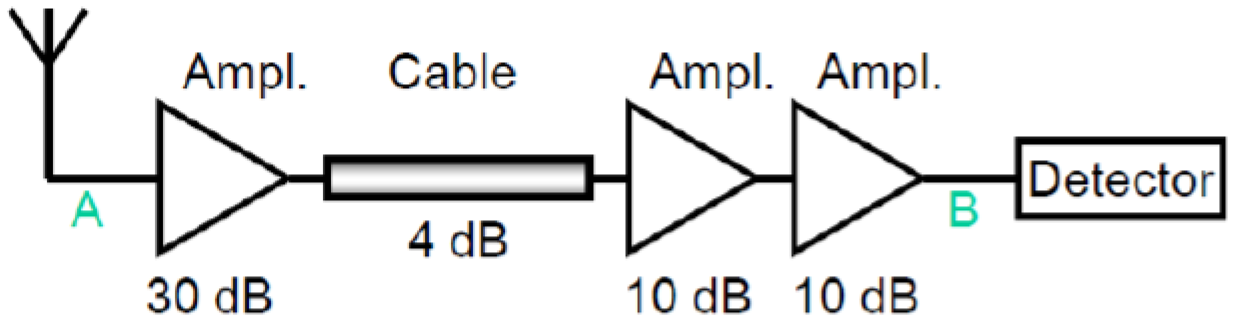
- Current Gain or Attenuation

$$dB = 20 \log I_{out} / I_{in}$$

- Power Gain or Attenuation

$$dB = 10 \log P_{out} / P_{in}$$

Amplification and Attenuation



The total amplification of the (simplified) receiver chain (between A and B) is

$$G_{A,B}\,|_{dB} = 30 - 4 + 10 + 10 = 46$$

Tx Power

Tx is short for "Transmit"

All radios have a certain level or Tx power that the radio generates at the RF interface. This power is calculated as the amount of energy given across a defined bandwidth and is usually measured in one of two units:

1. dBm – a relative power level referencing 1 milliwatt
2. W – a linear power level referencing Watts

dBm = 10 x log[Power in Watts / 0.001W]

$$W = 0.001 \times 10^{[\text{Power in dBm} / 10 \text{ dBm}]}$$

The NCL and LMS radios have Tx power of +18dBm, which translates into .064 W or 64 mW.

dBm=dBw+30
dBm=dBm-30

Gain, Attenuation and Decibels

Decibels: Decibel Calculations

- **Example**:

  An amplifier has an input of 3 mV and an output of 5 V. What is the gain in decibels?

  dB = 20 log 5/0.003

  = 20 log 1666.67

  = 20 (3.22)

  = 64.4

Gain, Attenuation and Decibels

Decibels: Decibel Calculations

- **Example:**

  A filter has a power input of 50 mW and an output of 2 mW. What is the gain or attenuation?

  $$dB = 10 \log (2/50)$$
  $$= 10 \log (0.04)$$
  $$= 10 (-1.398)$$
  $$= -13.98$$

  – If the decibel figure is positive, that denotes a gain.

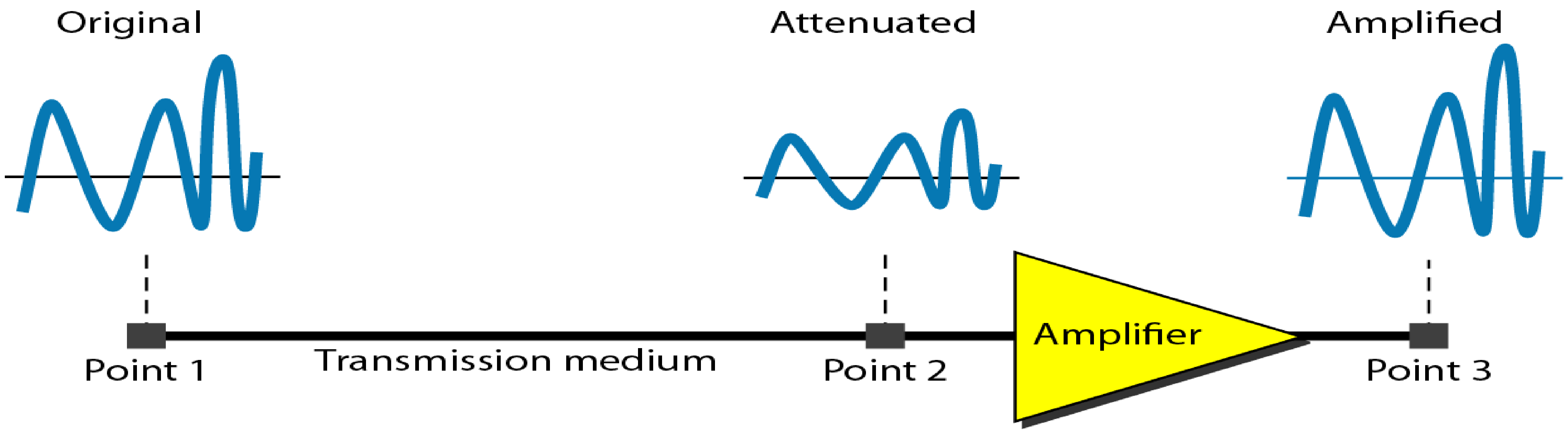
$$P(dBw) \doteq 10\ \log_{10}\left(\frac{P}{1\,W}\right)$$

For example, $P = 100$ Watts can alternatively be expressed as $P(dBw) = +20\,dBw$. Likewise, $P = 1\,mW$ can be expressed as $P(dBw) = -30\,dBw$.

$$P(dBm) \doteq 10\ \log_{10}\left(\frac{P}{1\,mW}\right)$$

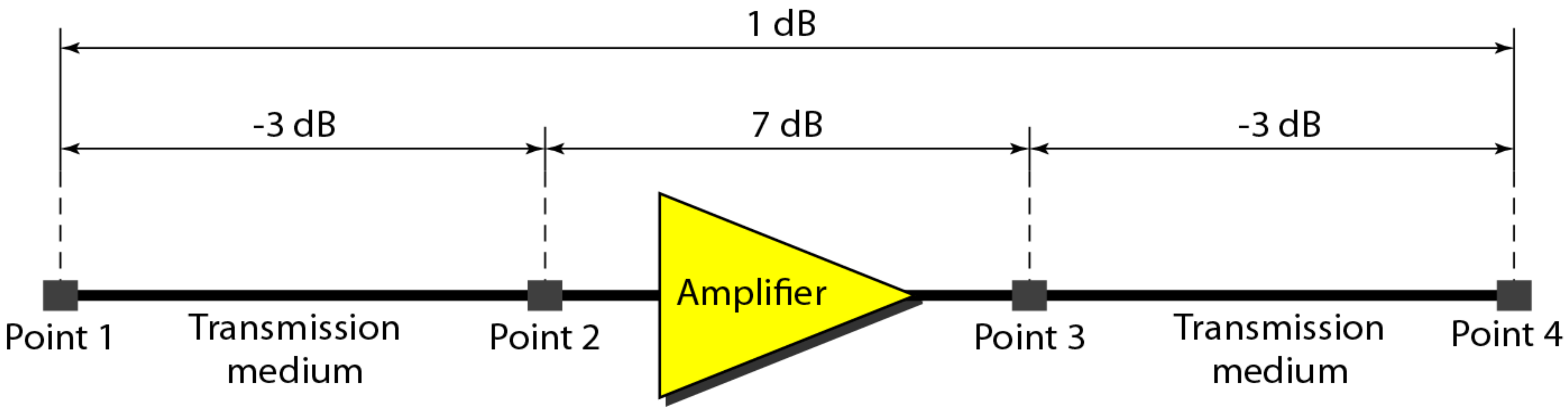
For example, $P = 100$ Watts can alternatively be expressed as $P(dBm) = +50\,dBm$. Likewise, $P = 1\,mW$ can be expressed as $P(dBm) = 0\,dBm$.

Attenuation



Example

One reason that engineers use the decibel to measure the changes in the strength of a signal is that decibel numbers can be added (or subtracted) when we are measuring several points (cascading) instead of just two. In this case, the decibel value can be calculated as $dB = -3 + 7 - 3 = +1$



Example

Sometimes the decibel is used to measure signal power in milliwatts. In this case, it is referred to as dB_m and is calculated as $dB_m = 10 \log10 P_m$, where P_m is the power in milliwatts. Calculate the power of a signal with $dB_m = -30$.

Solution

We can calculate the power in the signal as

$$dB_m = 10 \log_{10} P_m = -30$$

$$\log_{10} P_m = -3 \qquad P_m = 10^{-3} \text{ mW}$$

Example

The loss in a cable is usually defined in decibels per kilometer (dB/km). If the signal at the beginning of a cable with −0.3 dB/km has a power of 2 mW, what is the power of the signal at 5 km?

Solution

The loss in the cable in decibels is 5 × (−0.3) = −1.5 dB. We can calculate the power as

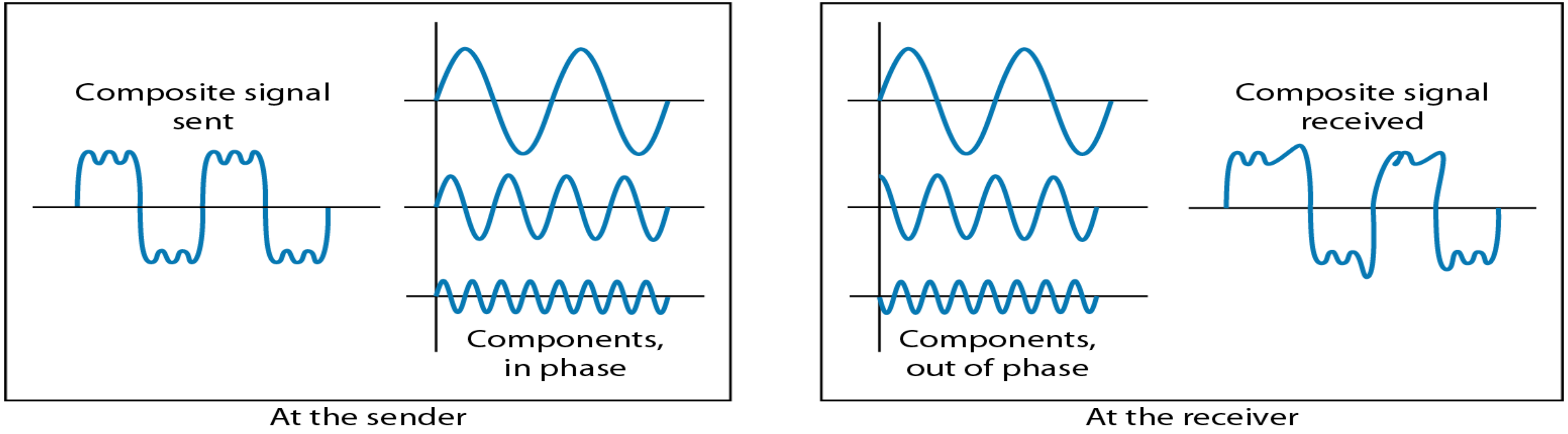
$$\text{dB} = 10 \log_{10} \frac{P_2}{P_1} = -1.5$$

$$\frac{P_2}{P_1} = 10^{-0.15} = 0.71$$

$$P_2 = 0.71 P_1 = 0.7 \times 2 = 1.4 \text{ mW}$$

Distortion

- Means that the signal changes its form or shape
- Distortion occurs in composite signals
- Each frequency component has its own propagation speed traveling through a medium.
- The different components therefore arrive with different delays at the receiver.
- That means that the signals have different phases at the receiver than they did at the source.

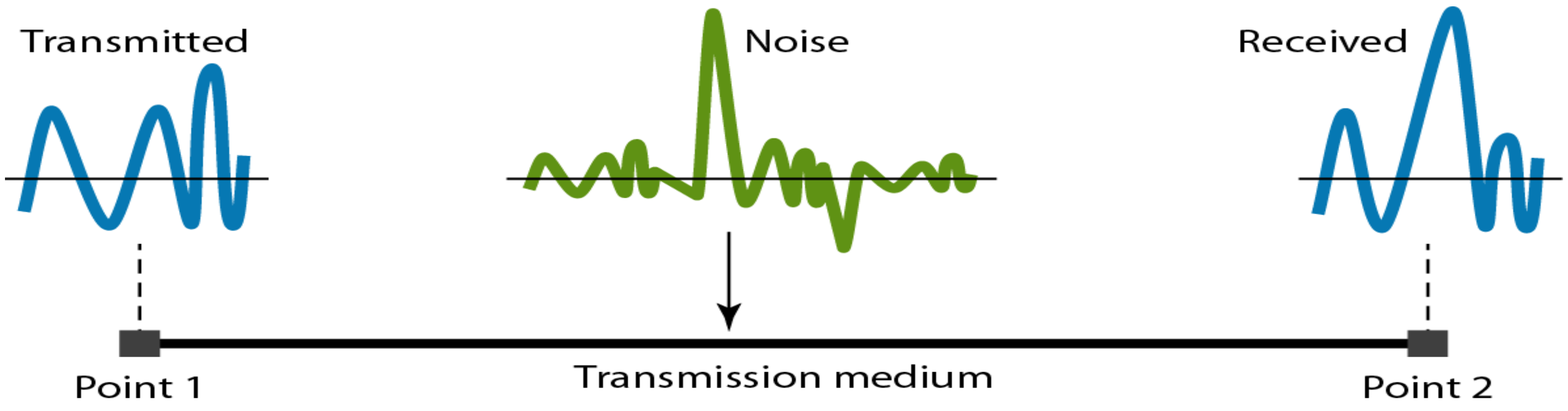


Noise

- Additional signals inserted between transmitter and receiver
- Thermal
  - Due to thermal agitation of electrons
  - Uniformly distributed
  - White noise
- Intermodulation
  - Signals that are the sum and difference of original frequencies sharing a medium
- Crosstalk
  - A signal from one line is picked up by another
- Impulse
  - Irregular pulses or spikes
  - e.g. External electromagnetic interference
  - Short duration
  - High amplitude

Noise

- There are different types of noise
  - Thermal - random noise of electrons in the wire creates an extra signal
  - Induced - from motors and appliances, devices act are transmitter antenna and medium as receiving antenna.
  - Crosstalk - same as above but between two wires.
  - Impulse - Spikes that result from power lines, lighning, etc.



Signal to Noise Ratio (SNR)

- To measure the quality of a system the SNR is often used. It indicates the strength of the signal wrt the noise power in the system.
- It is the ratio between two powers.
- It is usually given in dB and referred to as $SNR_{dB.}$

Example

The power of a signal is 10 mW and the power of the noise is 1 μW; what are the values of SNR and SNR_{dB} ?

Solution: The values of SNR and SNRdB can be calculated as follows:

$$SNR = \frac{10{,}000\ \mu W}{1\ mW} = 10{,}000$$

$$SNR_{dB} = 10 \log_{10} 10{,}000 = 10 \log_{10} 10^4 = 40$$

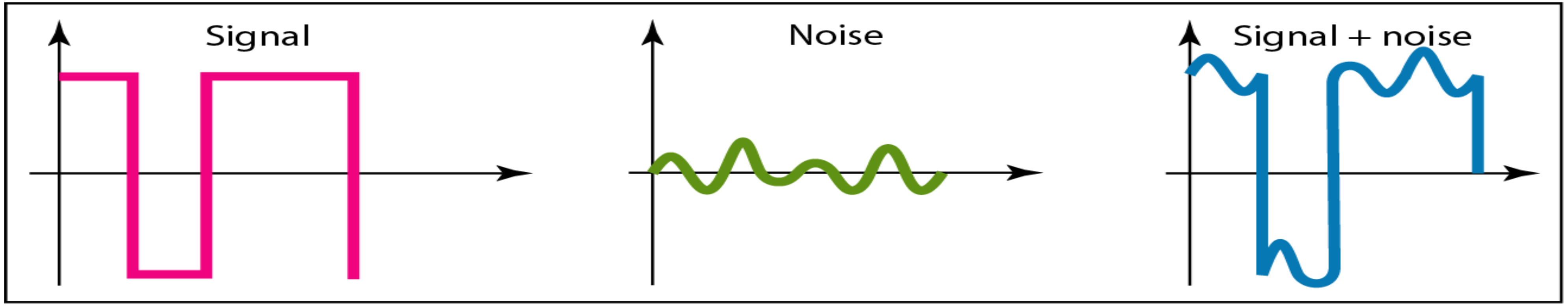
The values of SNR and SNRdB for a noiseless channel are

$$SNR = \frac{\text{signal power}}{0} = \infty$$

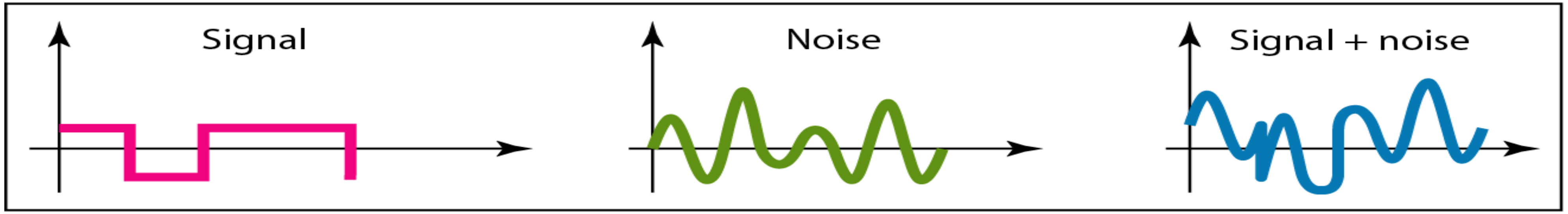
$$SNR_{dB} = 10 \log_{10} \infty = \infty$$

We can never achieve this ratio in real life; it is an ideal.

Two cases of SNR: a high SNR and a low SNR



a. Large SNR



b. Small SNR

Propagation & Transmission delay

- Propagation speed - speed at which a bit travels though the medium from source to destination.
- Transmission speed - the speed at which all the bits in a message arrive at the destination. (difference in arrival time of first and last bit)
- Propagation Delay = Distance/Propagation speed
- Transmission Delay = Message size/bandwidth bps
- Latency = Propagation delay + Transmission delay + Queueing time + Processing time

Example

What is the propagation time if the distance between the two points is 12,000 km? Assume the propagation speed to be 2.4 × 10^8 m/s in cable.

Solution

We can calculate the propagation time as

$$\text{Propagation time} = \frac{12{,}000 \times 1000}{2.4 \times 10^{8}} = 50 \text{ ms}$$

The example shows that a bit can go over the Atlantic Ocean in only 50 ms if there is a direct cable between the source and the destination.

Example

What are the propagation time and the transmission time for a 2.5-kbyte message (an e-mail) if the bandwidth of the network is 1 Gbps? Assume that the distance between the sender and the receiver is 12,000 km and that light travels at 2.4 × 108 m/s.

Solution

We can calculate the propagation and transmission time as shown on the next slide:

$$\text{Propagation time} = \frac{12{,}000 \times 1000}{2.4 \times 10^8} = 50 \text{ ms}$$

$$\text{Transmission time} = \frac{2500 \times 8}{10^9} = 0.020 \text{ ms}$$

Note that in this case, because the message is short and the bandwidth is high, the dominant factor is the propagation time, not the transmission time. The transmission time can be ignored.

Kablosuz İletim Ortamları

UNGUIDED MEDIA: WIRELESS

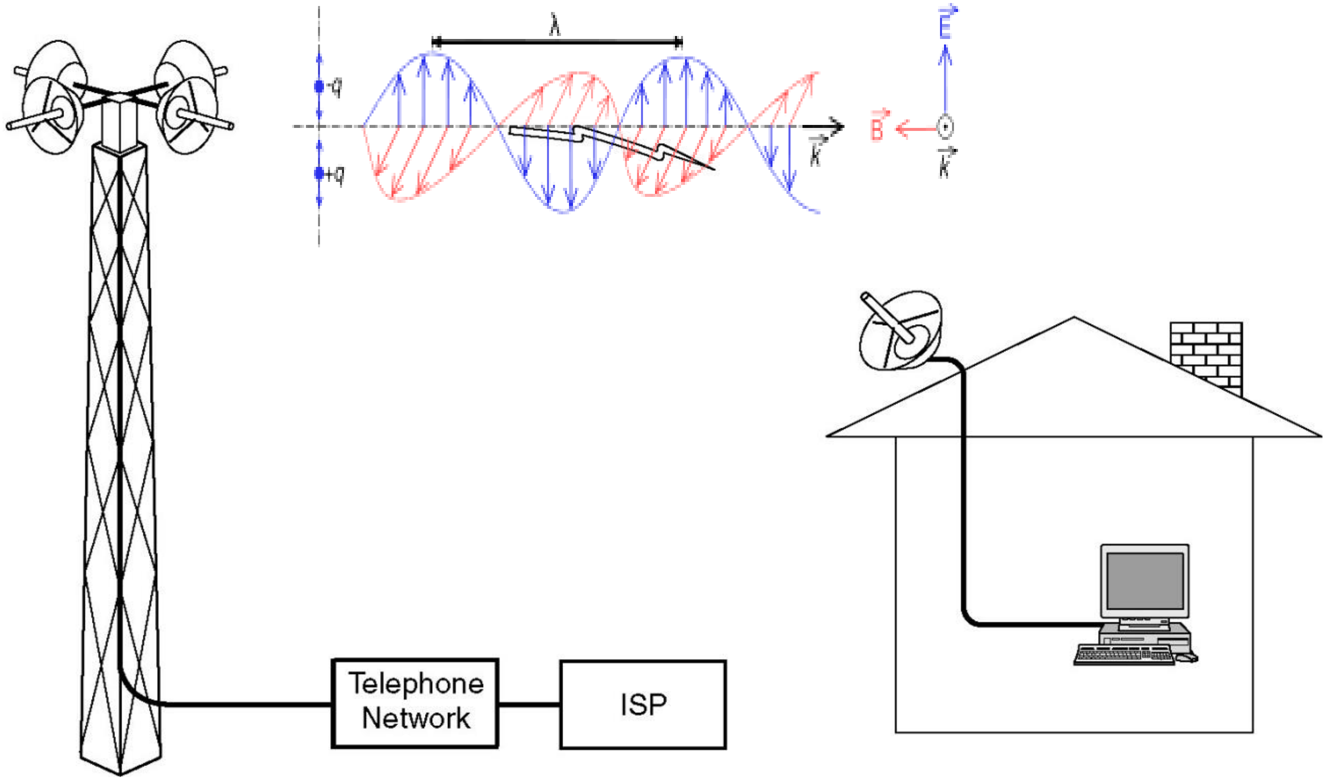
Unguided media transport electromagnetic waves without using a physical conductor. This type of communication is often referred to as wireless communication.

İletilebilecek, Bilgi (Veri) elektromanyetik sinyallere dönüştürülmelidir.

Radio Waves

Microwaves

Infrared



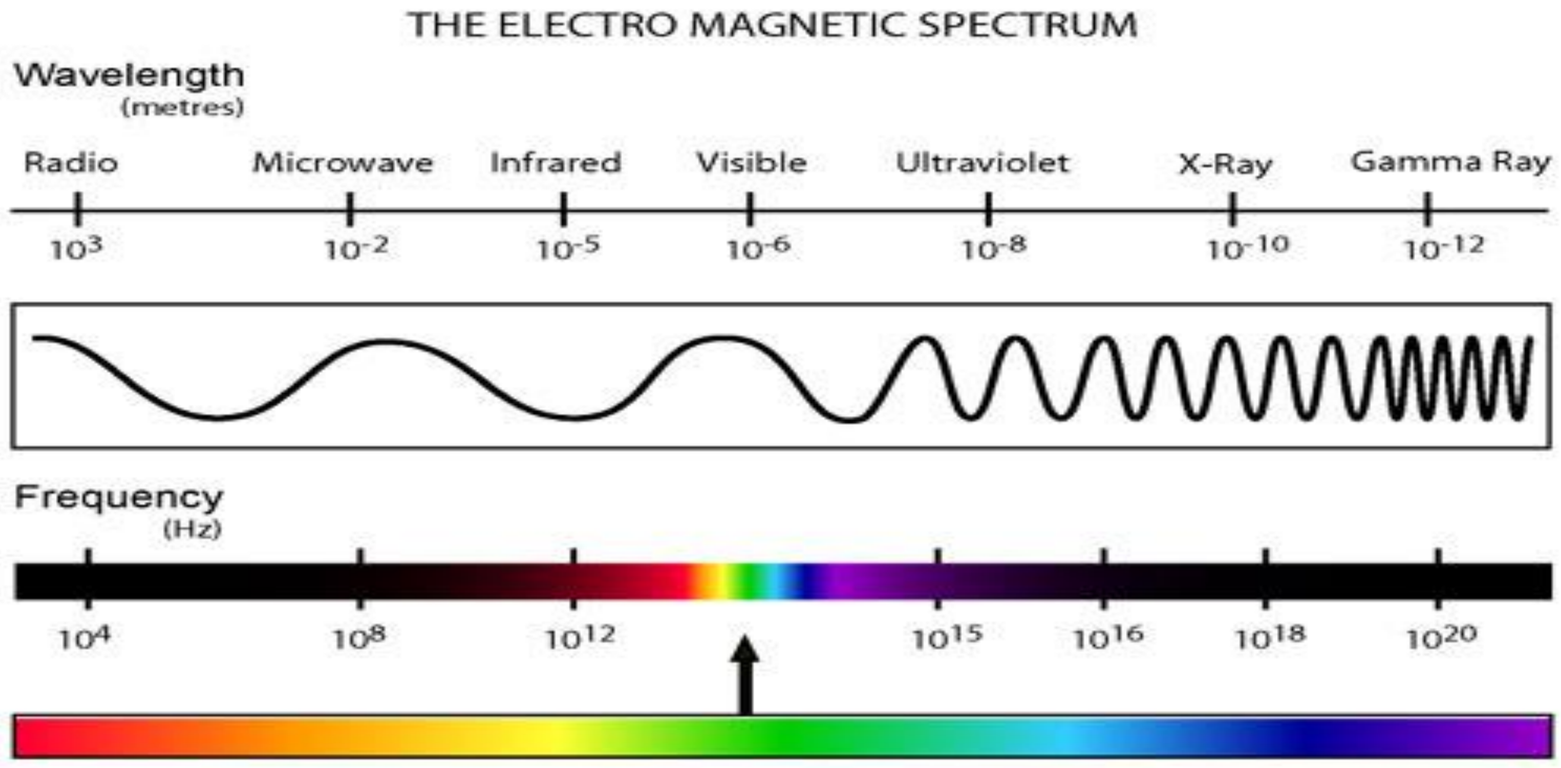
Kablosuz İletim

- Kablolama yapılamayacak durumlarda ve mesafelerde Kablosuz iletim kullanılabilmektedir.
- Veri kablosuz iletişim sistemleri aracılığıyla da serbest uzaydan elektromanyetik dalgalar halinde iletilebilir.
- Elektromanyetik dalgalar, elektronların hareketleriyle oluşur ve serbest uzayda yayılırlar.
- Bir elektrik devresine eklenen uygun büyüklükteki bir anten, elektromanyetik dalgaları yayabilir ve uzaktaki bir alıcı (başka bir anten) tarafından alınmasını sağlayabilir.
- Tüm kablosuz iletişimler bu ilkeye göre çalışmaktadırlar.

Electromagnetic Spectrum

- İyonize radyasyon, Gamma ve X ışınları olarak sıralanır. İyonize radyasyon insan hücrelerinin değişimine neden oldukları, kanser oluşturdukları ve kromozomları değiştirdikleri için tehlikelidir.

- İyonize olmayan dalgalar ise Ses dalgaları, Radyo dalgaları, Mikrodalga, Kızıl ötesi ışık, Görünen ışık, ve Morötesi ışık olarak sıralanır. İyonize olmayan dalgalar girdikleri dokulara enerjilerini aktararak ısısını artırır ya da hücre zarlarının çalışma biçimini değiştirir.



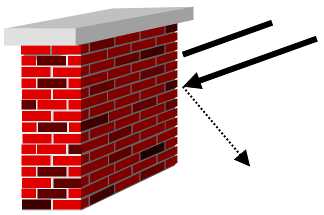
Wireless Transmission Media

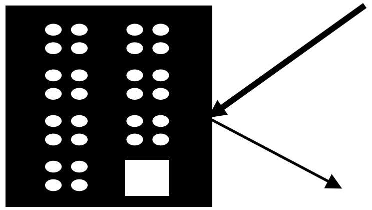
- Microwaves
  - Radio waves providing high speed transmission
  - They are point-to-point (can't be obstructed)
  - Used for satellite communication
- Infrared (IR)
  - Wireless transmission media that sends signals using infrared light- waves
- Broadcast Radio
  - Distribute signals through the air over long distance
  - Uses an antenna
  - Typically for stationary locations
  - Can be short range
- Cellular Radio
  - A form of broadcast radio used for mobile communication
  - High frequency radio waves to transmit voice or data
  - Utilizes frequency-reuse

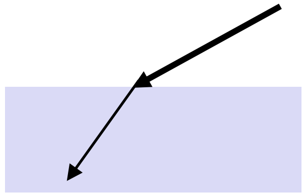
Signal propagation

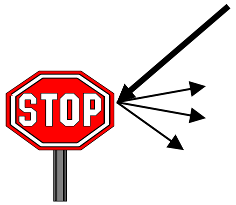
- Propagation in free space always like light (straight line)
- Receiving power proportional to $1/d^2$ in vacuum – much more in real environments
  (d = distance between sender and receiver)
- Receiving power additionally influenced by
- fading (frequency dependent)
- shadowing
- reflection at large obstacles
- refraction depending on the density of a medium
- scattering at small obstacles
- diffraction at edges

- EM wave propagation is affected by the following mechanisms:
  - reflection at large obstacles
  - scattering at small obstacles
  - diffraction at edges


shadowing


reflection


refraction

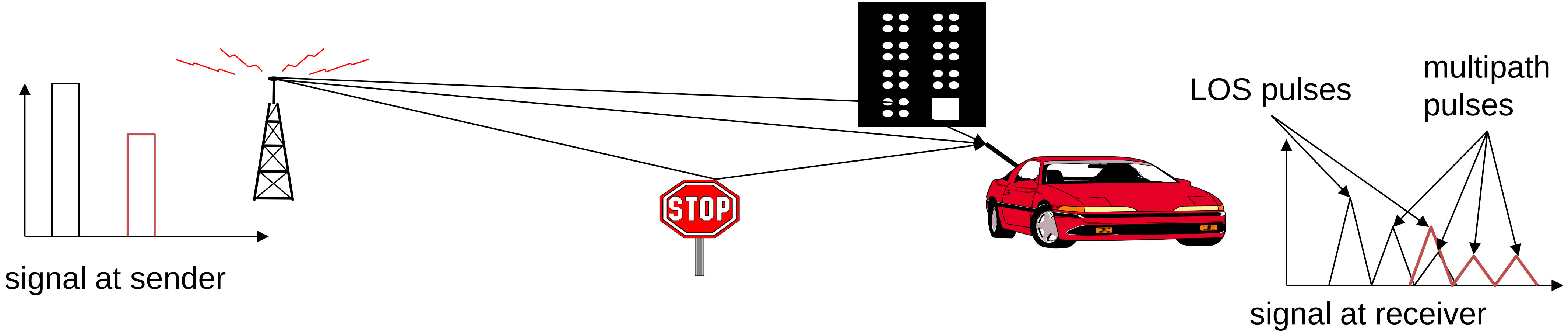


scattering


diffraction

Multipath propagation

- Signal can take many different paths between sender and receiver due to reflection, scattering, diffraction



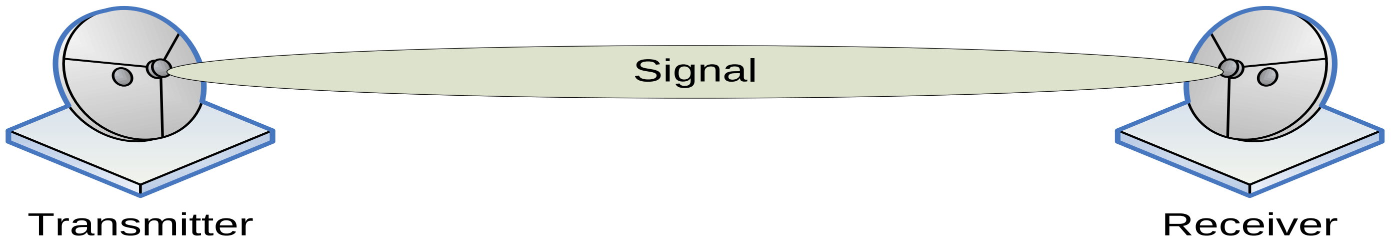
- Time dispersion: signal is dispersed over time
  - interference with "neighbor" symbols, Inter Symbol Interference (ISI)
- The signal reaches a receiver directly and phase shifted
  - distorted signal depending on the phases of the different parts

Spectrum, Frequency and Bandwidth

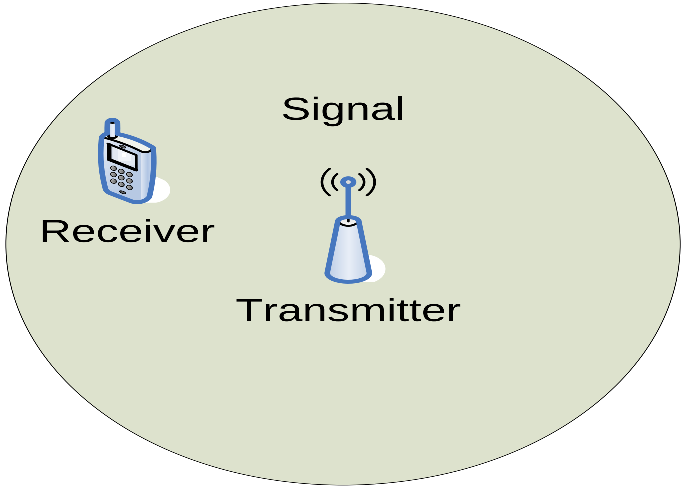
- A signal is sent at some frequency f with bandwidth b
  - The set of all frequencies available is called the spectrum
- Why is the frequency (and bandwidth) important?
  - Data rate
    - A higher bandwidth (and frequency) generally leads to higher data rate
  - Transmission range
    - Higher frequency leads to shorter range
    - Different frequency signals are affected by obstacles in different ways
      - E.g. some frequencies are affected by rain, some frequencies will pass through walls, others wont, …
  - Interference
    - If other people/technologies use the same frequency, they may interfere, causing lower data rates
      - E.g. some cordless home phones may interfere with wireless LAN
  - Cost
    - The spectrum is limited and managed by national/international organisations
    - Some frequencies are free to use by anybody (within some rules)
      - E.g. most wireless LANs operate at the free Industrial Scientific Medical (ISM) frequency
    - Other frequencies you need a license to use
      - The license may be expensive, e.g. companies in Germany spent 2 trillion Baht (2,000,000,000,000) on licenses to use spectrum for 3G mobile networks

Wireless Transmission Topology

- Point-to-point
  - Transmit antenna points at receive antenna: directional
  - Signal power is concentrated between transmitter and receiver



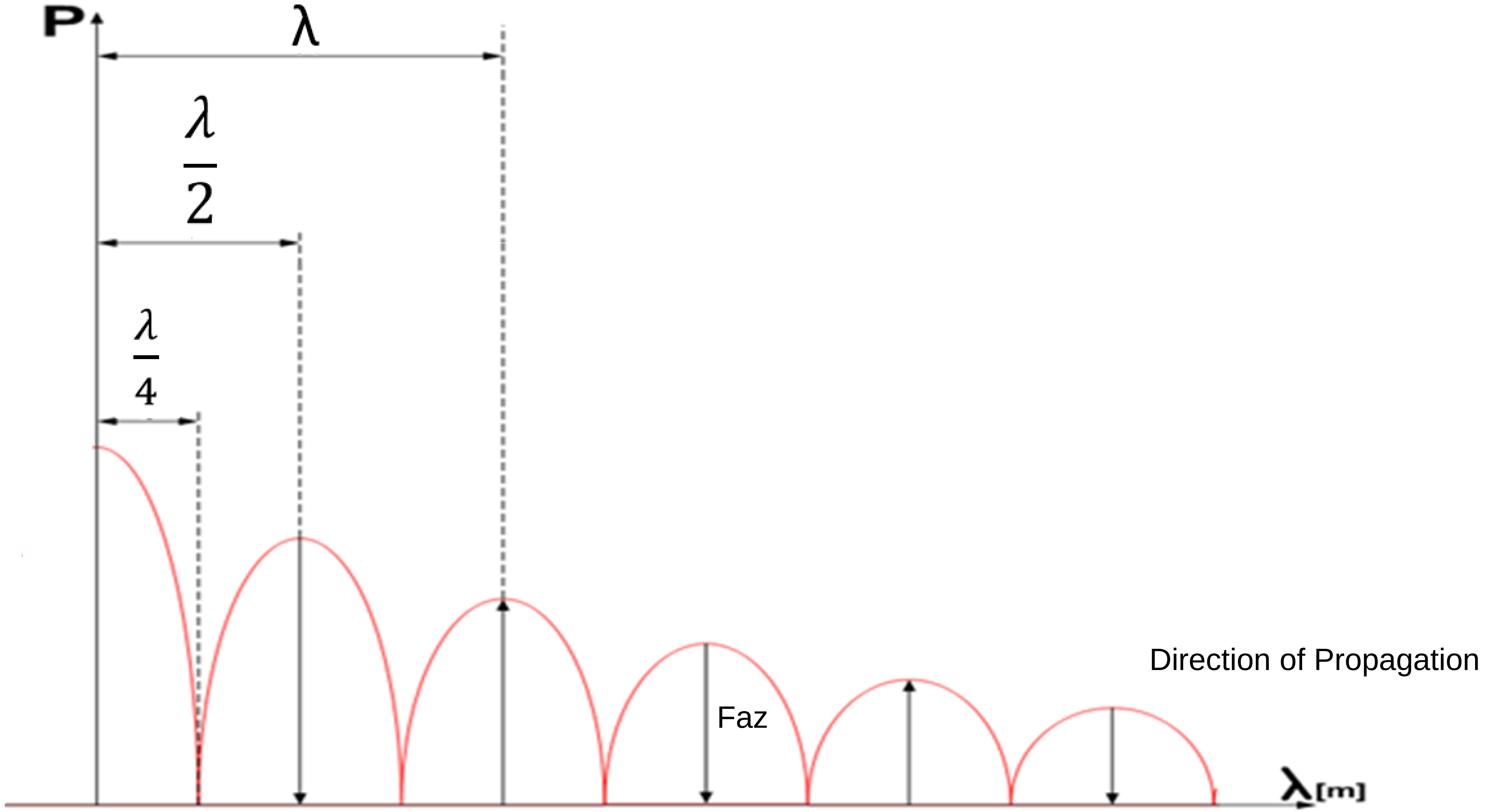
- Broadcast Radio (point-to-multipoint)
  - Transmitter sends signal in every direction: omni-directional
  - Anyone "within range" can receive the signal



Kablosuz İletim Ortamları

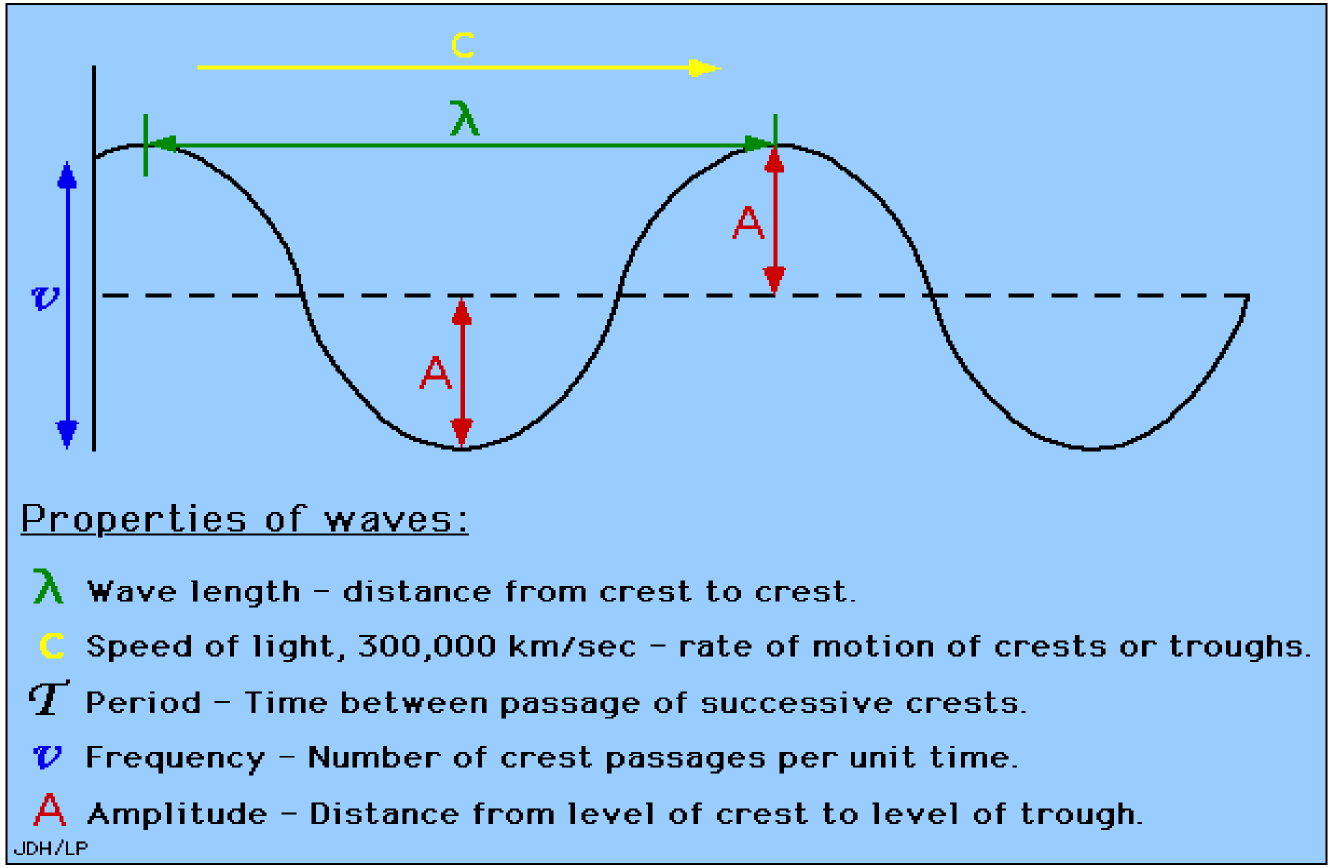
- Kablosuz iletişim için 2 biçim bulunmaktadır:
  - Tek yönlü (directional):
    - Anten, odaklanmış tek bir elektromanyetik ışın yayar.
    - Bu nedenle gönderici ve alıcı antenler, dikkatli bir şekilde hizalanmak zorundadırlar.
  - Çok Yönlü (omni-directional)
    - Bu durumda ise elektromanyetik enerji tüm yönlere dağılır ve bir çok anten tarafından algılanabilir.
- **Mikrodalga ve RF Teknolojileri**
  - Mikrodalga Antenler
  - Bluetooth
  - Hücresel şebekeler
- **Kızıl Ötesi Teknolojisi**
  - Infrared teknolojisi
  - Lazer teknolojisi

Radiation Power



Elektromanyetik Işıma

- Elektrik ve manyetik alanların dalgalar şeklinde yayıldığı bir ortamdan veya vakumdan yayılan enerji şeklidir.
- **Dalga,** bir ortamda enerji taşıyan bir uyarıcıdır.
- **Dalga boyu (λ),** birbirini izleyen iki tepeciğin en alt ya da en üst noktaları arasındaki uzaklıktır.
- **Frekans (ν),** belirli bir noktadan birim zamanda geçen max veya min sayısıdır. Birimi 1/zaman yani 1/s olup saniyedeki çevrim sayısıdır.
- **Dalganın hızı,** dalganın frekansı ile dalga boyunun çarpımıdır.



Wavelength (λ)

- You may recall from physics that wavelength (λ) and frequency (f) of an electromagnetic wave in free space are related by the speed of light (c)

$$c = f\lambda \quad \text{or} \quad \lambda = \frac{c}{f}$$

- Therefore, if a radio station is broadcasting at a frequency of 100 MHz, the wavelength of its signal is given

$$\lambda = \frac{c}{f} = \frac{3.0 \times 10^8 \text{ m/s}}{100 \times 10^6 \text{ cycle/s}} = 3 \text{ m}$$

The dimensions of an antenna are usually expressed in terms of wavelength.
Dalga boyu antenin boyutlarının belirlenmesinde temel parametredir.

Low frequencies imply long wavelengths, hence low frequency antennas are very large. High frequencies imply short wavelengths, hence high frequency antennas are usually small.

Elektromagnetik dalga yayınım denklemi

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

Burada

P_r: alış güç seviyesi, (Watt)

P_d: alış güç yoğunluğu, (W/m^2)

P_t: verici çıkış gücü, (Watt)

G_t: verici anten kazancı, (numerik),

L_t: verici tarafta hat kaybı, (numerik),

G_r: alıcı anten kazancı (numerik),

L_r: alıcı tarafta hat kaybı (numerik),

R: Alıcı verici antenler arasındaki uzaklık (metre),

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

Burada

λ: dalga uzunluğu, (metre),

c=ışık hızı=3×10^8 m/s

f=frekans, (Hz=1/s) dir.

Link Analizi

Denklem logaritmik olarak düzenlenirse, Pr, dBm cinsinden aşağıdaki biçimde yazılır.

$P_r = P_t + G_t + G_r - L_t – L_r – FSL$ (2)

FSL: terim serbest uzay yol kaybı olarak adlandırılır.

FSL= $32.45 + 20\log(R_{km} \times f_{MHz})$

Verici antenden R m uzaktaki güç yoğunluğu

$$P_d = \frac{P_t G_t L_t}{4\pi R^2} \quad W/m^2 \qquad (3)$$

Serbest uzaydaki uzak alanda elektrpmagnetik dalganın taşıdığı güç yoğunluğu elektrik alan şiddetinden de hesaplanır.

$$P_d = \frac{E^2}{\eta_0} = \frac{E^2}{120\pi} \quad W/m^2 \qquad (4)$$

Link Analysis
Radiated Power
Rx Sensitivity
Path Loss

Power (dBW and dBm)

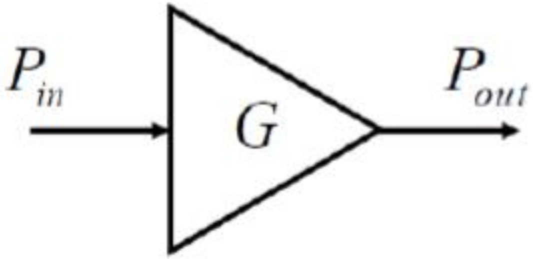
We usually measure power in Watt (W) and milliWatt [mW]

The corresponding dB notations are dB and dBm

	Non-dB	dB
Watt:	$P\|_W$	$P\|_{dB} = 10\log\left(\frac{P\|_W}{1\|_W}\right) = 10\log(P\|_W)$
milliWatt:	$P\|_{mW}$	$P\|_{dBm} = 10\log\left(\frac{P\|_{mW}}{1\|_{mW}}\right) = 10\log(P\|_{mW})$
RELATION:	$P\|_{dBm} = 10\log\left(\frac{P\|_W}{0.001\|_W}\right) = 10\log(P\|_W) + 30\|_{dB} = P\|_{dB} + 30\|_{dB}$	

Amplification and Attenuation

(Power) Amplification:



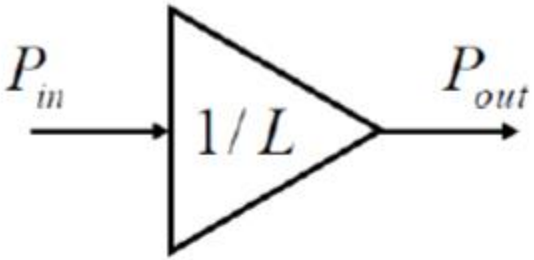
$$P_{out} = GP_{in} \Rightarrow G = \frac{P_{out}}{P_{in}}$$

The amplification is already dimension-less and can be converted directly to dB:

$$G|_{dB} = 10\log_{10} G$$

Note: It doesn't matter if the power is in mW or W. Same result!

(Power) Attenuation:

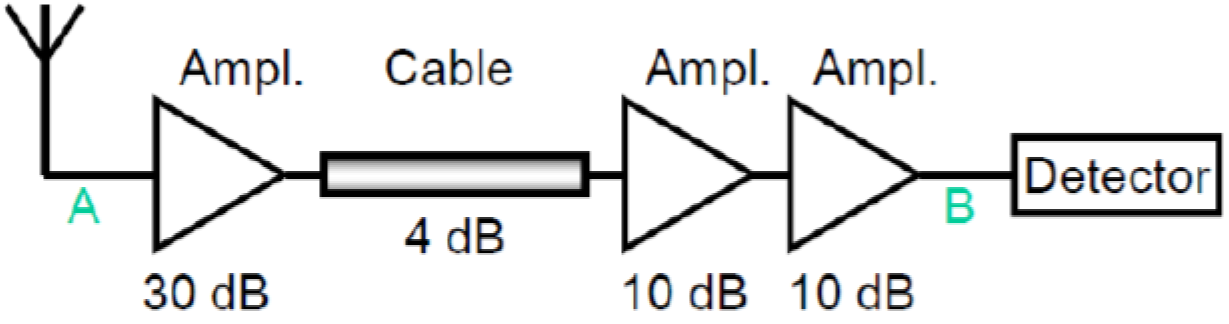


$$P_{out} = \frac{P_{in}}{L} \Rightarrow L = \frac{P_{in}}{P_{out}}$$

The attenuation is already dimension-less and can be converted directly to dB:

$$L|_{dB} = 10\log_{10} L$$

Amplification and Attenuation



The total amplification of the (simplified) receiver chain (between A and B) is

$$G_{A,B}\,|_{dB} = 30 - 4 + 10 + 10 = 46$$

Energy Losses

In all wireless communication systems there are several factors that contribute to the loss of signal strength. Cabling, connectors, lightning arrestors can all impact the performance of your system if not installed properly.

In a 'low power' system (such as the NCL and LMS products) every dB you can save is important!! Remember the "3 dB Rule".

For every 3 dB gain/loss you will either double your power (gain) or lose half your power (loss).

-3 dB = 1/2 power

-6 dB = 1/4 power

+3 dB = 2x power

+6 dB = 4x power

Sources of loss in a wireless system: free space, cables, connectors, jumpers, obstructions

Radiated Power

In a wireless system, antennas are used to convert electrical waves into electromagnetic waves. The amount of energy the antenna can 'boost' the sent and received signal by is referred to as the antennas **Gain.**

Antenna gain is measured in:

1. dBi: relative to an isotropic radiator
2. dBd: relative to a dipole radiator

0 dBd = 2.15 dBi

There are certain guidelines set by the FCC that must be met in terms of the amount of energy radiated out of an antenna. This 'energy' is measured in one of two ways:

1. ***Effective Isotropic Radiated Power (EIRP)***

   measured in dBm = power at antenna input [dBm] + relative antenna gain [dBi]

2. ***Effective Radiated Power (ERP)***

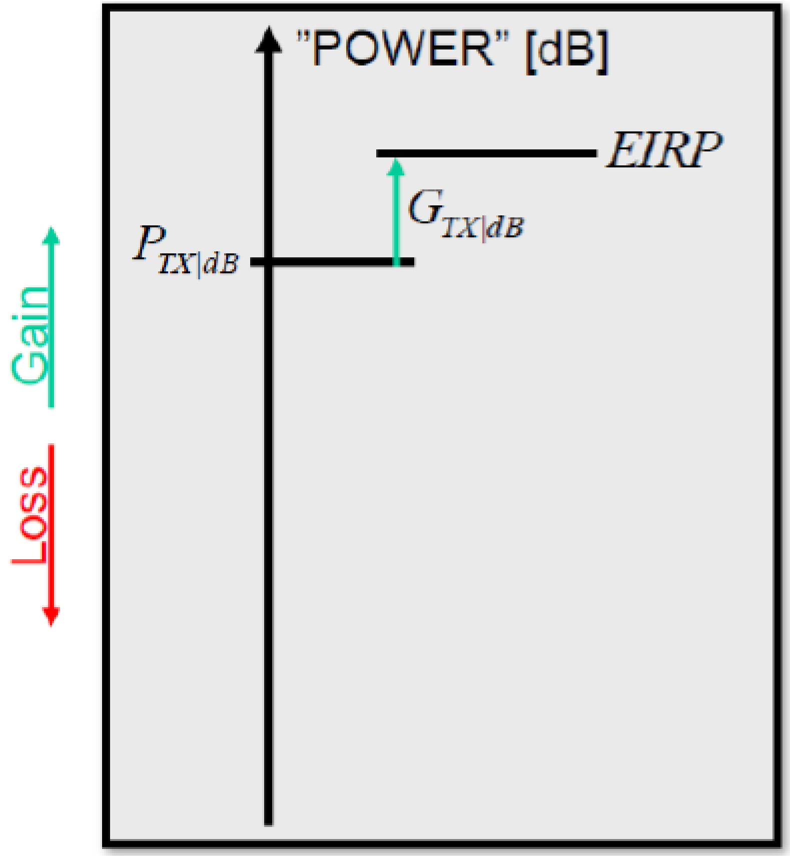
   measured in dBm = power at antenna input [dBm] + relative antenna gain [dBd]

EIRP and the Link Budget

EIRP = Transmit power (fed to the antenna) + antenna gain

$$\mathrm{EIRP}_{dB} = P_{t|dBm} + G_{t|dB}$$

- EIRP answers the questions:
  - How much transmit power would we need to feed an isotropic antenna to obtain the same maximum on the radiated power?
  - How strong is our radiation in the maximal direction of the antenna?



$$EIRP\,|_{dB} = P_{TX|dB} + G_{TX|dB}$$

Antenna Parameters

- Relation between the effective area (A_e) and the physical area (A_p) of an antenna
  - **efficiency parameter of an antenna** η


$$A_e = \eta A_p$$

Dish antenna η = 0.55, horn antenna η = 0.75.


  - **Directive gain**

$$G = \frac{\text{maximum power intensity}}{\text{average power intensity of } 4\pi \text{ steradians}}$$

in a direction

Power radiated by an isotropic radiator

(If there is no loss or impedance mismatch, the antenna gain is equal to the directive Gain, which is the assumption here.)

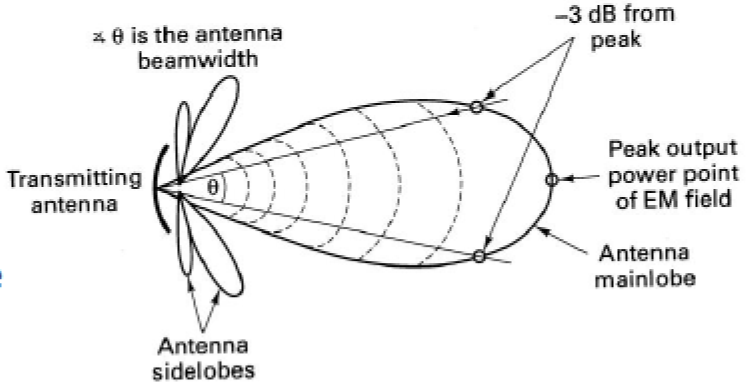
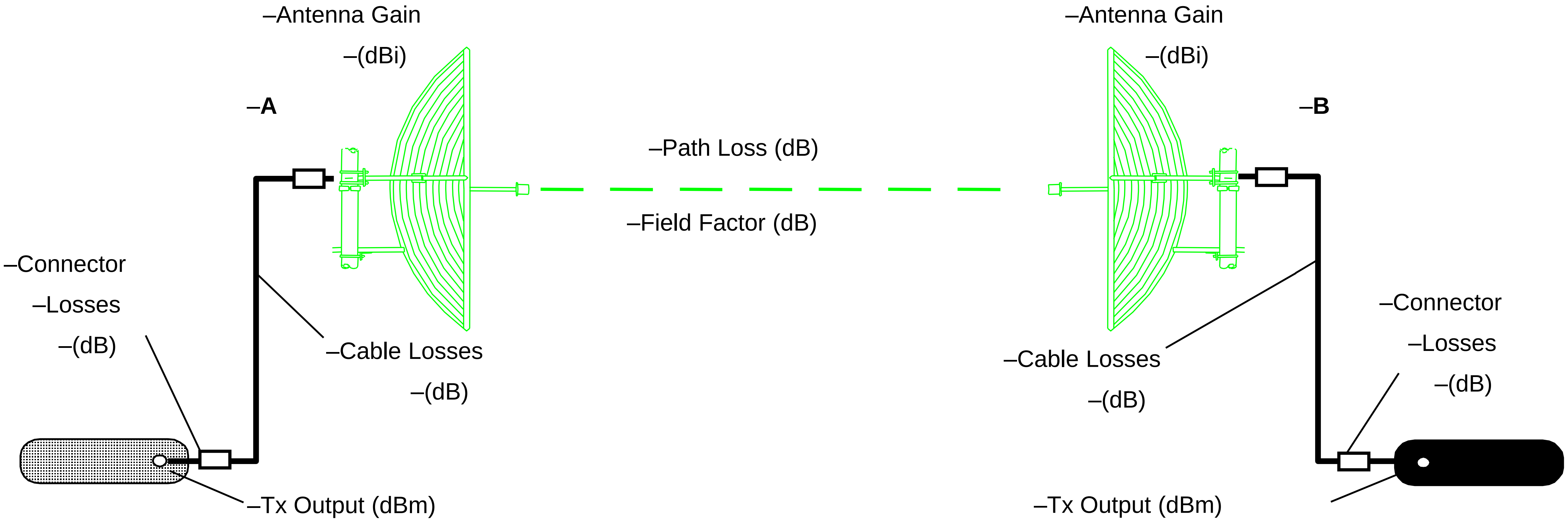


Figure 5.4 Antenna gain is the result of concentrating the isotropic RF flux.



–**Received Signal Level** – (dBm) = Tx Output (dBm) - Path
–Loss(dB) - Field Factor (dB) + Total Antenna Gains (dB) - Total
–Cable Losses (dB) - Total Connector Losses (dB)

FREE SPACE LOSS

Losses experienced in Line of Sight links

The losses experienced by the signal fall into these categories.

- Free Space Loss
- Rain
- Antenna Misalignment
- Gaseous Absorption

Free Space Loss

This is the largest signal energy attenuation as a function of the distance traveled. For line of sight links, this loss is a function of the square of the distance. Radar signals which also fall partly in the line of sight category typically suffer a free space loss which is a function of the cube of the distance traveled.

Computing Free Space Loss

For a signal going from ground to the satellite, the free space loss is largest of all other types of losses. It can be simplified and written as

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

Simplifying, we can write this in dB form as

$$FSL(dB) = 32.45 + 20Logf(MHz) + 20Logr(km)$$

Putting together the radio link budget, with gains and losses...

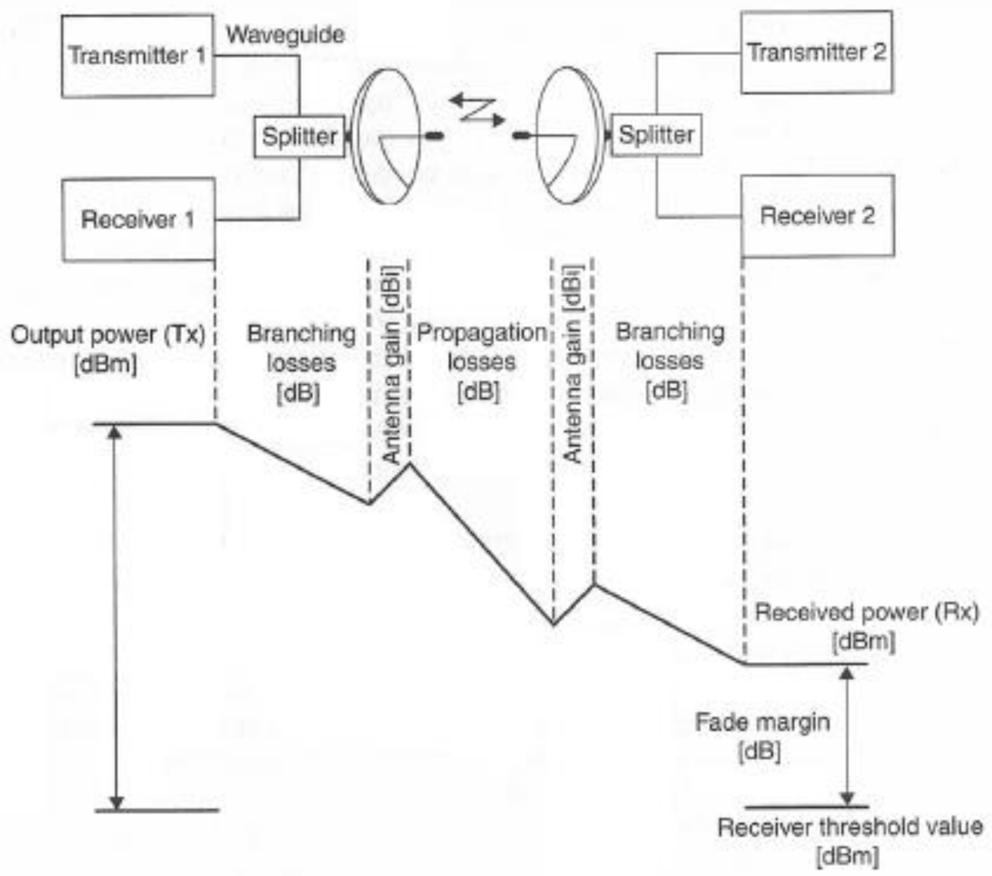


Figure 2.11 Radio path link budget

Source: Lehpamer, H., *Microwave Transmission Networks: Planning, Design, and Deployment (Second Edition)*, McGraw-Hill, 2010.

Calculation of Received Signal (RSL) with Fading

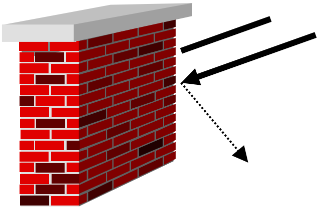
$$RSL = P_o - L_{tx} + G_{atx} - FSL - MFM - RA - L_{rc} + G_{rc} - L_m$$

P_o = Transmitter power output (dBm)
L_{tx} = All losses between transmitter and its antenna (dB)
G_{atx} = Gain of transmitting antenna (dBi)
FSL = Free space loss (dB)
MFM = Multipath fade margin (dB)
RA = Rain attenuation (dB)
L_{rc} = All losses between receiver and its antenna (dB)
G_{rc} = Gain of receiving antenna (dBi)
L_m = Miscellaneous losses (obstacle, misalignment, aging) (dB)

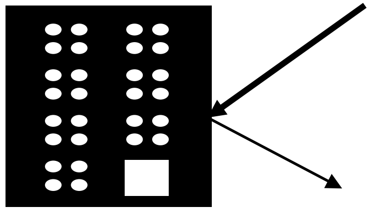
Signal Propagation

Signal propagation

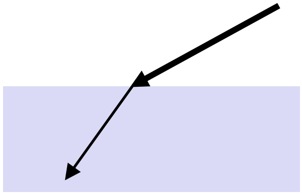
- Propagation in free space always like light (straight line)
- Receiving power proportional to $1/d^2$
  (d = distance between sender and receiver)
- Receiving power additionally influenced by
- fading (frequency dependent)
- shadowing
- reflection at large obstacles
- refraction depending on the density of a medium
- scattering at small obstacles
- diffraction at edges



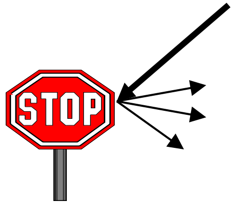
shadowing



reflection



refraction

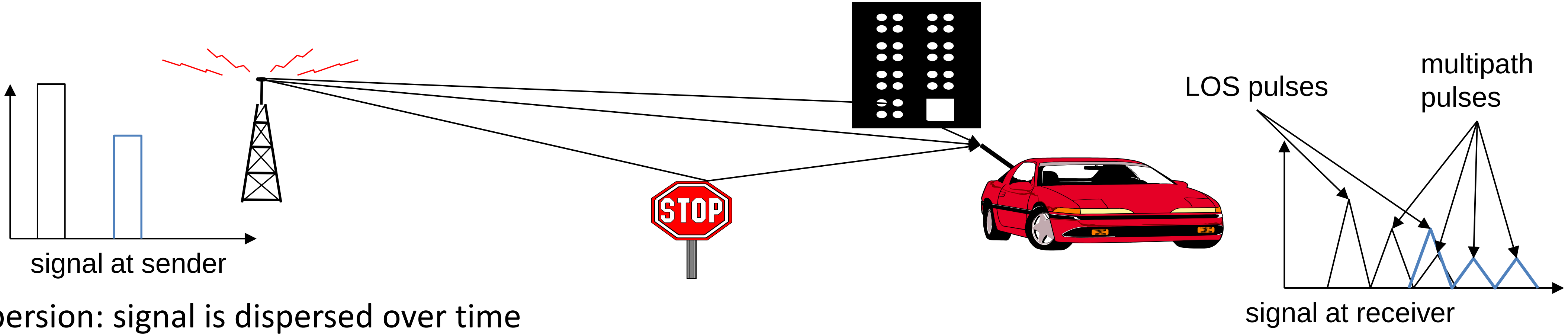


scattering

Diffraction:
kırınım

Multipath propagation

- Signal can take many different paths between sender and receiver due to reflection, scattering, diffraction



- Time dispersion: signal is dispersed over time
- ➔ interference with “neighbor” symbols, Inter Symbol Interference (ISI)
- The signal reaches a receiver directly and phase shifted
- ➔ distorted signal depending on the phases of the different parts

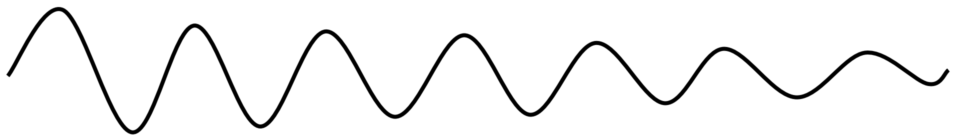
- Reflection - occurs when signal encounters a surface that is large relative to the wavelength of the signal
- Diffraction - occurs at the edge of an impenetrable body that is large compared to wavelength of radio wave
- Scattering – occurs when incoming signal hits an object whose size in the order of the wavelength of the signal or less

The Effects of Multipath Propagation

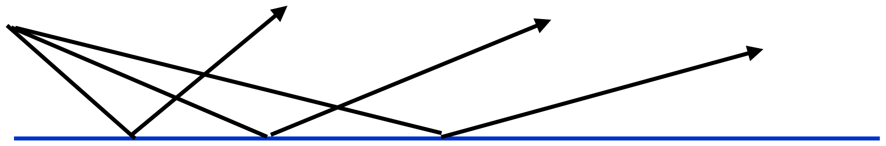
- Multiple copies of a signal may arrive at different phases
  - If phases add destructively, the signal level relative to noise declines, making detection more difficult
- Intersymbol interference (ISI)
  - One or more delayed copies of a pulse may arrive at the same time as the primary pulse for a subsequent bit

Radar beams can be attenuated, reflected and bent by the environment

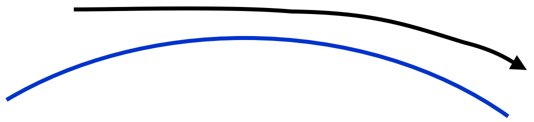
- Atmospheric attenuation



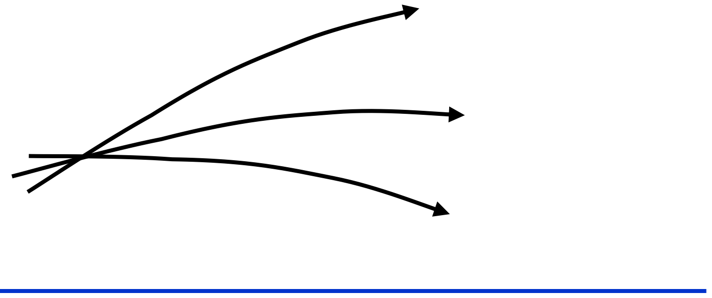
- Reflection off of earth's surface



- Over-the-horizon diffraction



- Atmospheric refraction



Reflection

- Specular reflection: smooth surface
  - Angle of incidence = angle of reflection
- Diffuse reflection: rough surface
  - Reflection in all directions because angle of incidence varies over the surface due to its roughness
- *Reflections* can occur as the microwave signal traverses a body of water or fog bank; cause multipath conditions

Refraction

- Occurs when waves move from one medium to another with a different propagation velocity
- Index of refraction *n* is used in refraction calculations
- Bending of signals by atmosphere decreases with increasing frequency

- Bending of signals by atmosphere increases with increasing ionization

$$n = \sqrt{\varepsilon_r}$$

Refraction

- Refractivity and Modified Refractivity
- Effective Earth Radius Factor
- Refractive Gradients (Standard, Subrefraction, Superrefraction, Trapping)
- Atmospheric Ducts (Surface ducts, Evaporation ducts, Elevated ducts)

Diffraction

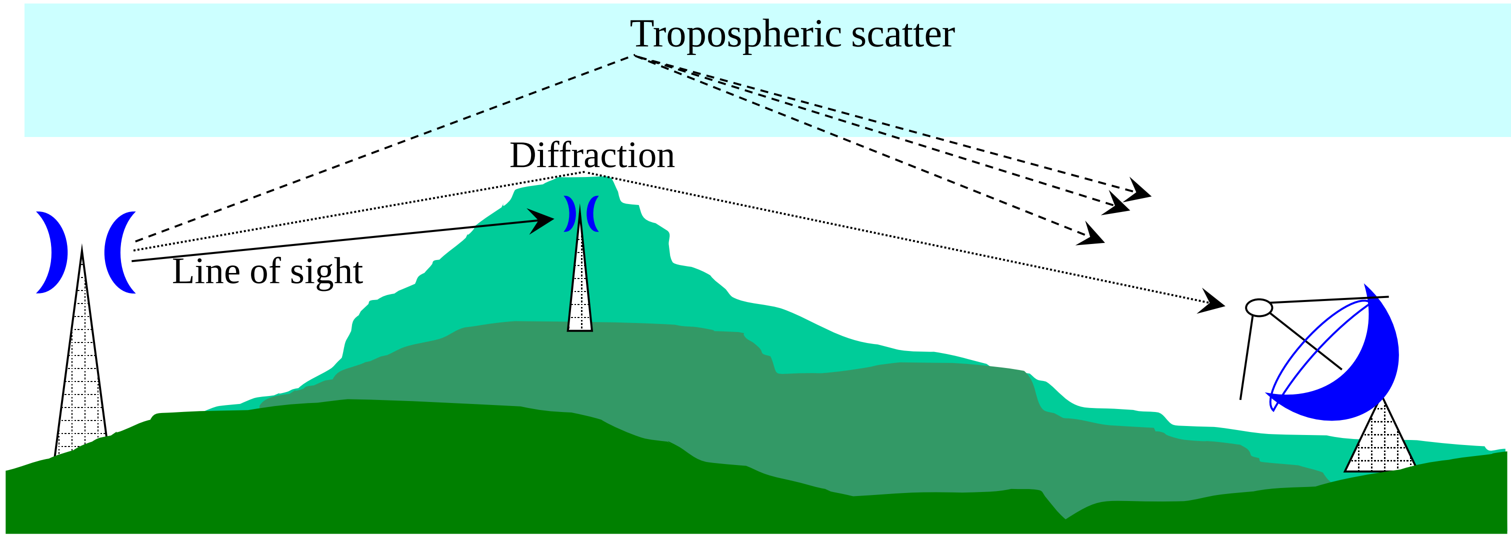
- Occurs when radiation passes an object with dimensions small compared with wavelength
- The object appears to act as a source of radiation
- Allows radio stations to be received on the shadow side of obstacles
- *Diffraction* is the result of variations in the terrain the signal crosses

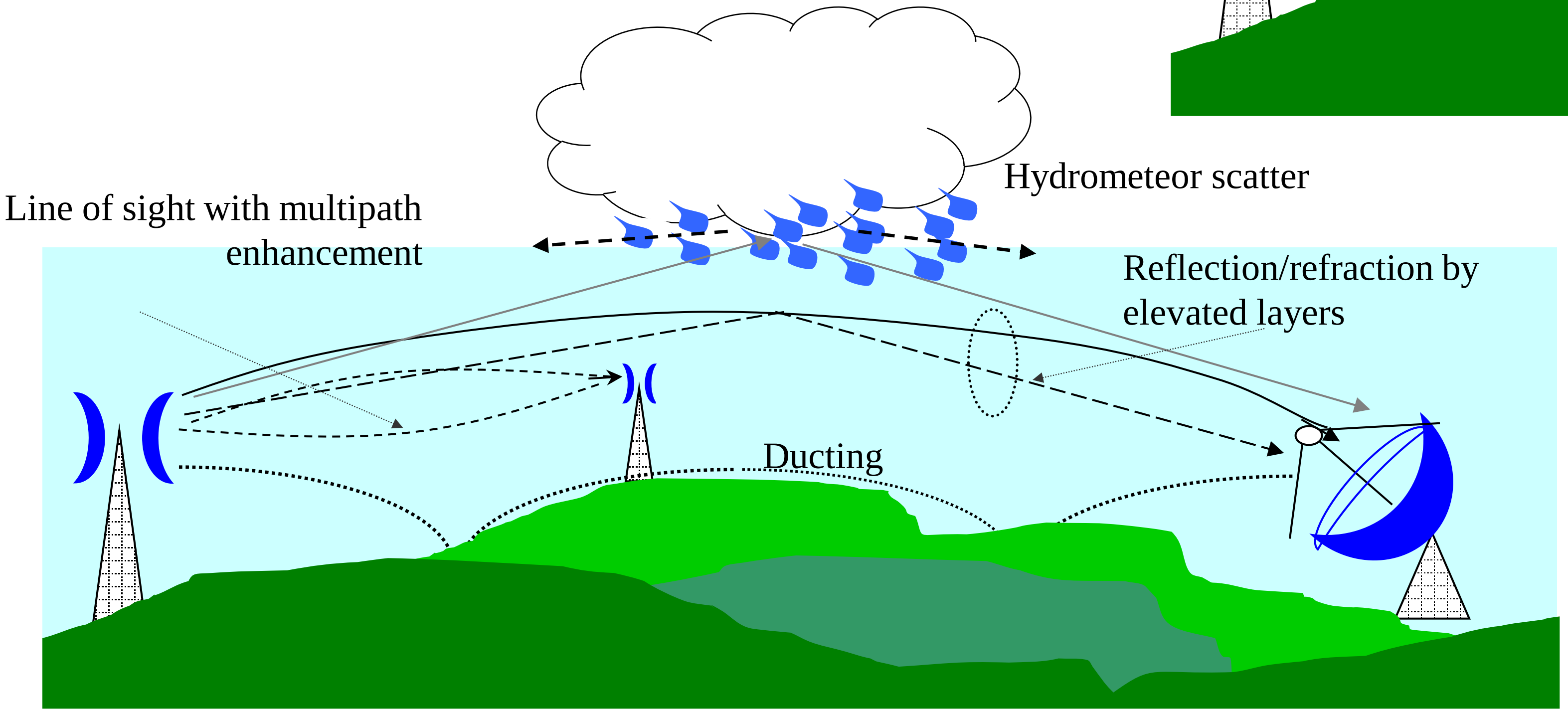
Polarization

- Polarization of a wave is the direction of the electric field vector
- Linearly polarized waves have the vector in the same direction at all times
  - Horizontal and vertical polarization are common
- Circular and elliptical polarization are also possible

Interference mechanisms

Long-term effects ⇨





⇦ Short-term effects

Interference

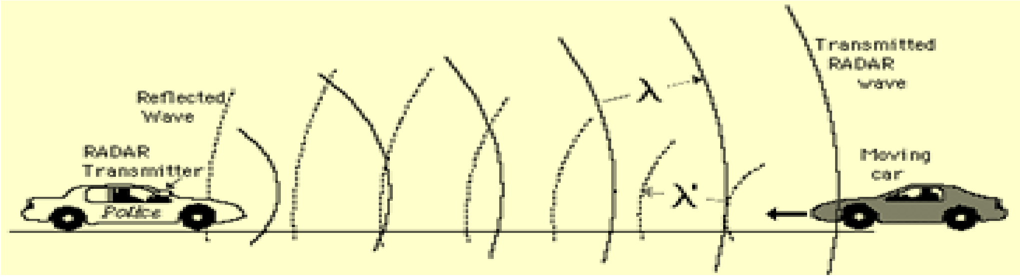
- Adjacent Channel Interference
  - digital not greatly affected
- Overreach
  - caused by signal feeding past a repeater to the receiving antenna at the next station in the route. Eliminated by zigzag path alignment or alternate frequency use between adjacent stations

Interference Countermeasures

1. Short Paths
2. Narrow Beam Antennas (high gain)
3. Frequency Selection
4. Antenna Polarization
5. Antenna Azimuth
6. Equipment/Antenna Location

Doppler Shift

Applications: Police Radar



Here there is a double effect:
First, my car is moving toward the radar transmitter as an “observer”; second, my car acts as a source which is moving toward the police car receiver.

$$\rightarrow \quad f'' \approx f'(1+\tfrac{v}{c}) \approx f(1+\tfrac{v}{c})^2 \approx f(1+\tfrac{2v}{c})$$

Ex. $v = 100 \text{ miles/hour} = 44.7 \text{ m/s}$

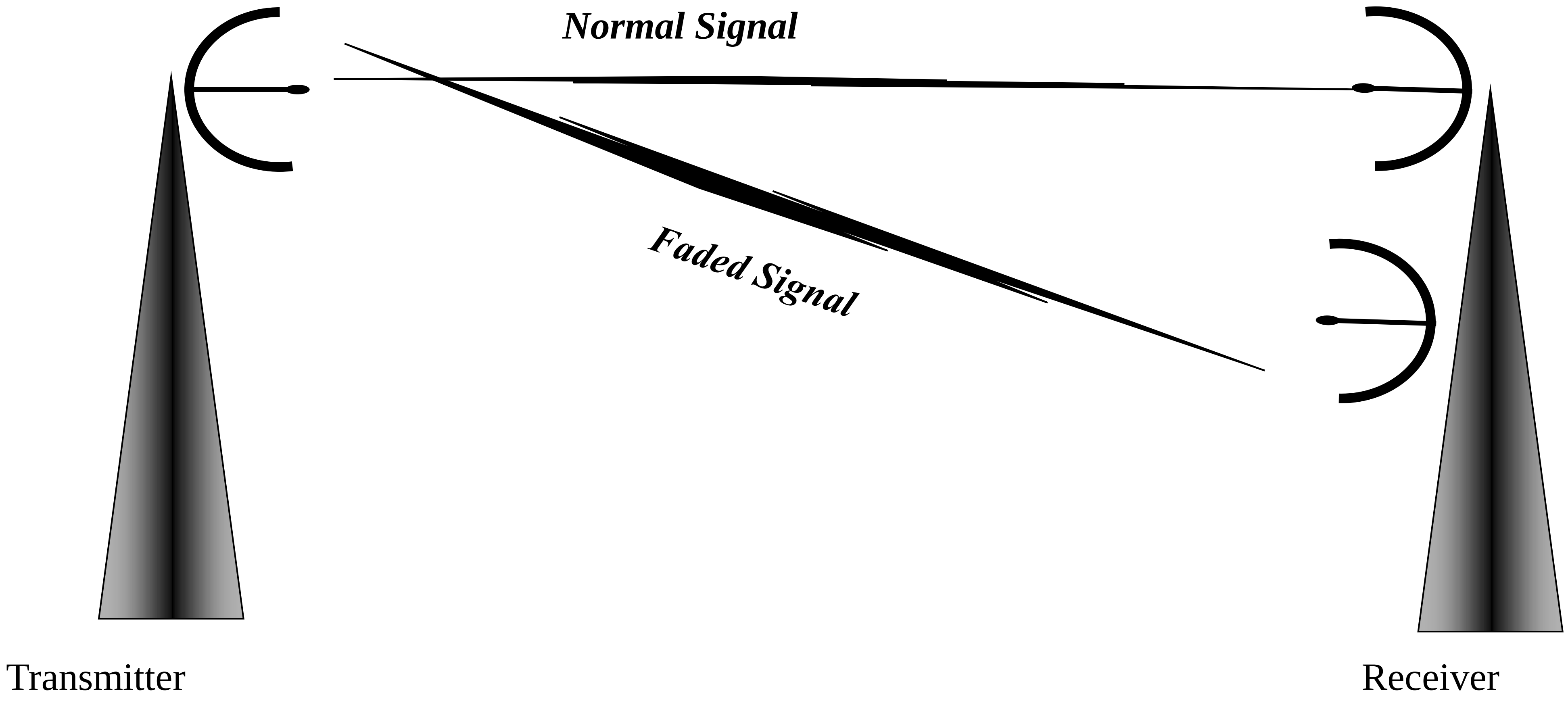
$f = 10.6 \text{ GHz}$ $\quad f'' = 10.60000316 \text{ GHz}$ $\quad \Delta f = 3160 \text{ Hz}$

Diversity

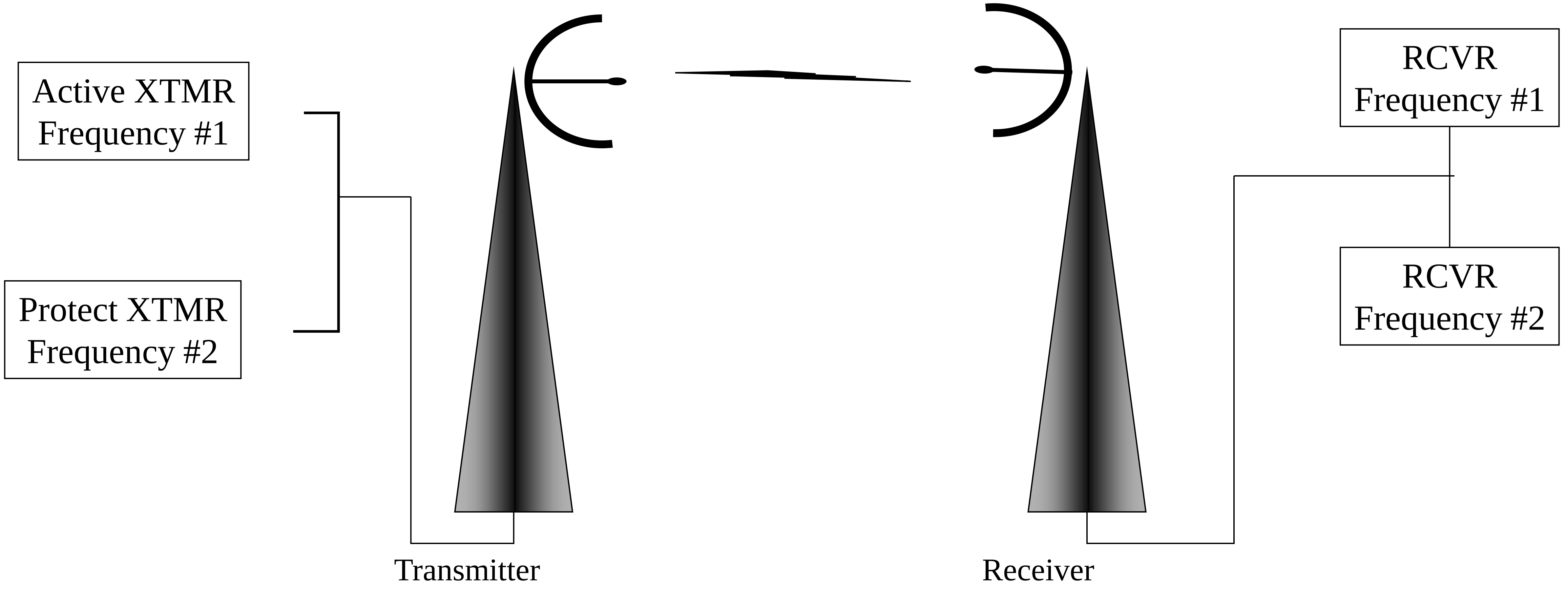
Improving the Microwave System

- Hardware Redundancy
  - Hot standby protection
  - Multichannel and multiline protection
- Diversity Improvement
  - Space Diversity
  - Angle Diversity
  - Frequency Diversity
  - Crossband Diversity
  - Route Diversity
  - Hybrid Diversity
  - Media Diversity

Space Diversity

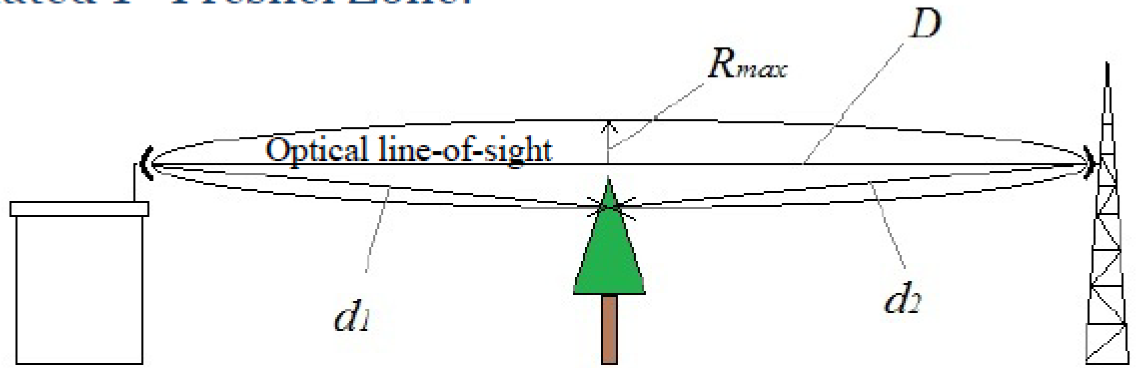


Frequency Diversity



Fresnel Zones

For "Fresnel clearance" of a microwave link, we consider the calculated 1st Fresnel Zone:



Radius of F.Z. at any point along the path (in meters):

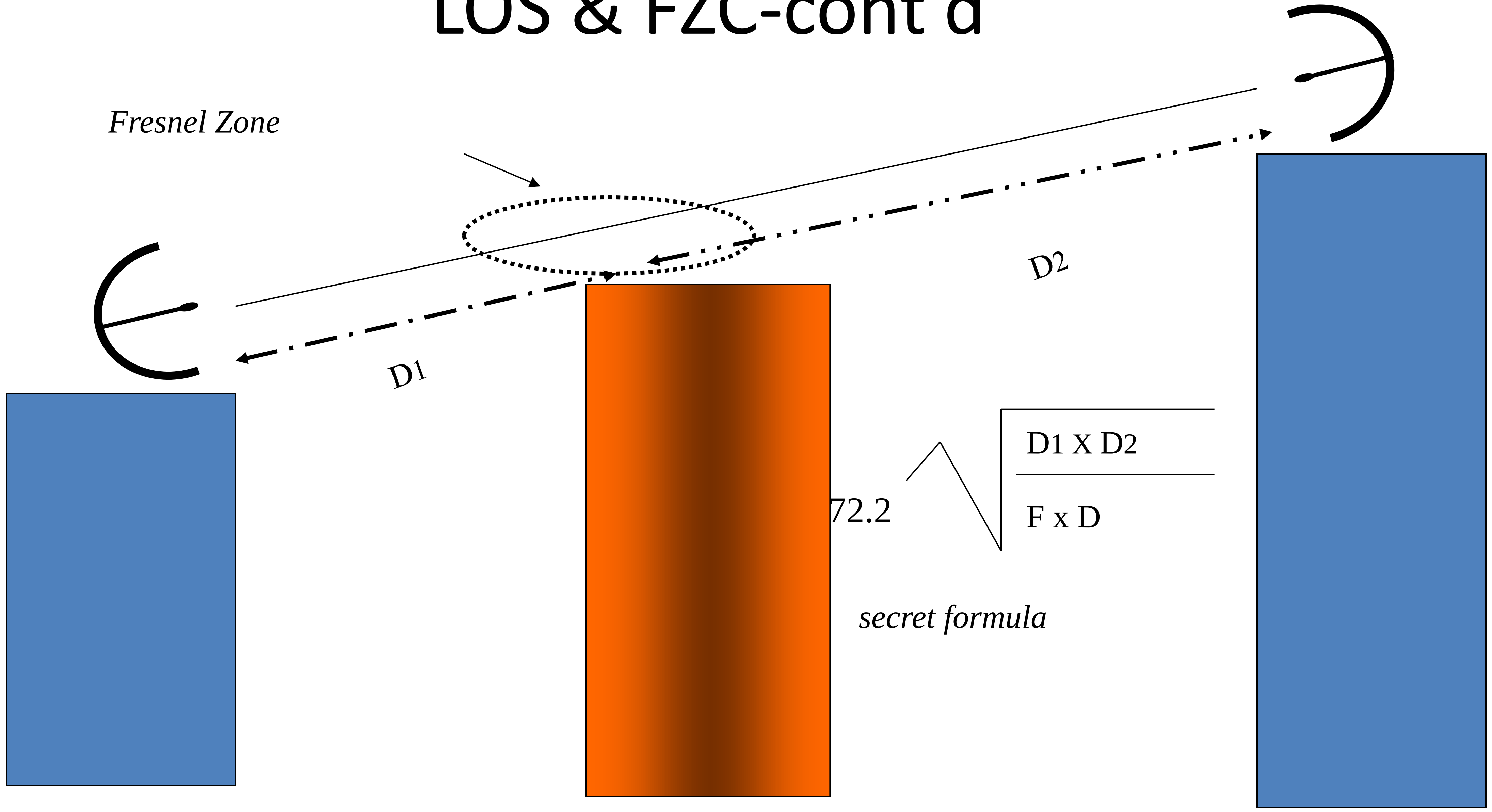
$$R = 17.3\ \text{SQRT}[d_1 d_2 / f_{\text{GHz}} (d_1 + d_2)]$$

F.Z. Radius at the path midpoint (where it's at maximum):

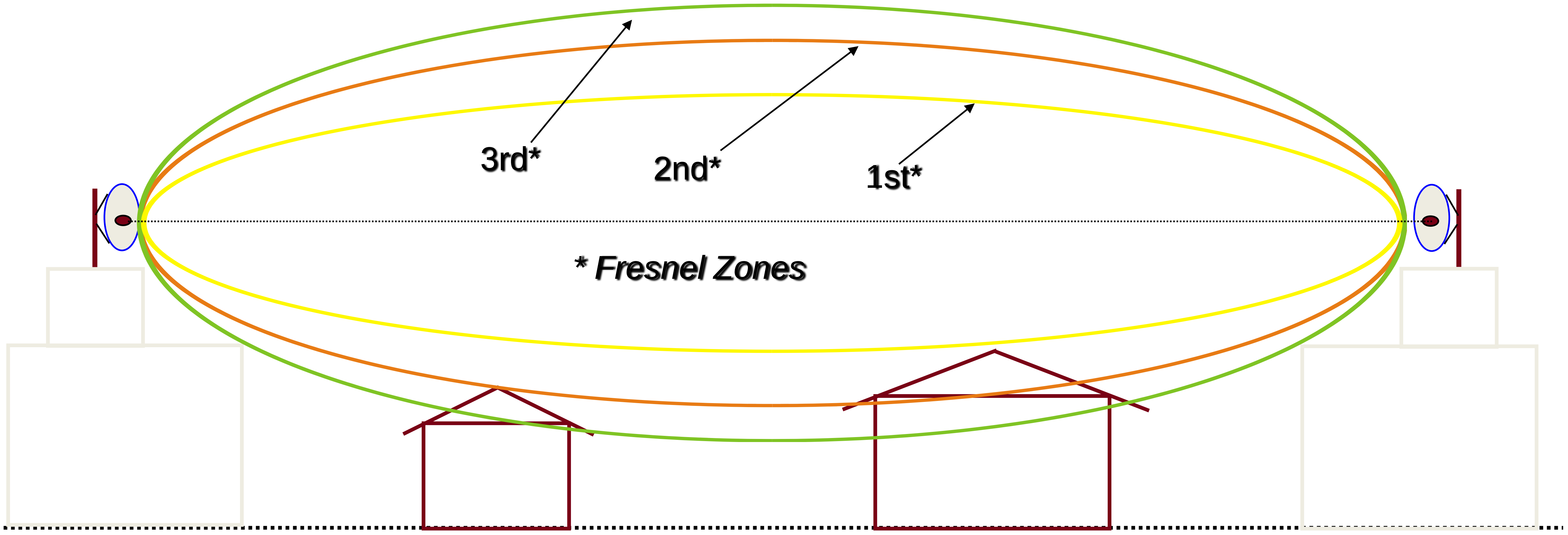
$$R_{max} = 8.66\ \text{SQRT}(D_{km} / f_{\text{GHz}})$$

Rule of thumb for clearance is 60% of the F.Z. Radius. To simplify, we can use R_{max} over entire path (e.g., for map overlays).

LOS & FZC-cont’d



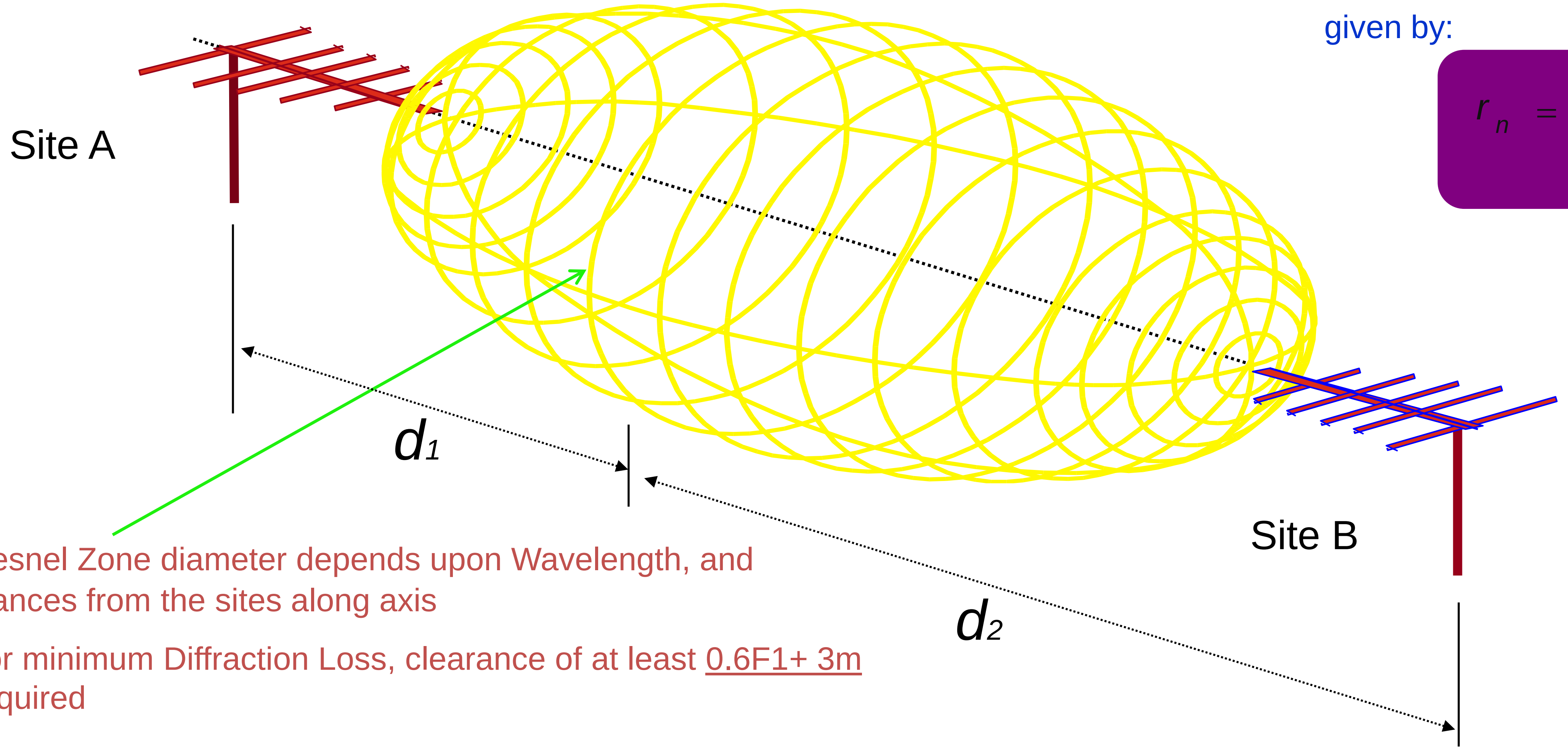
Fresnel Zones



The First Fresnel Zone

Radius of n^{th} Fresnel Zone given by:

$$r_n = \sqrt{\frac{n \lambda d_1 d_2}{d_1 + d_2}}$$



- Fresnel Zone diameter depends upon Wavelength, and Distances from the sites along axis
- For minimum Diffraction Loss, clearance of at least <u>0.6F1+ 3m</u> is required

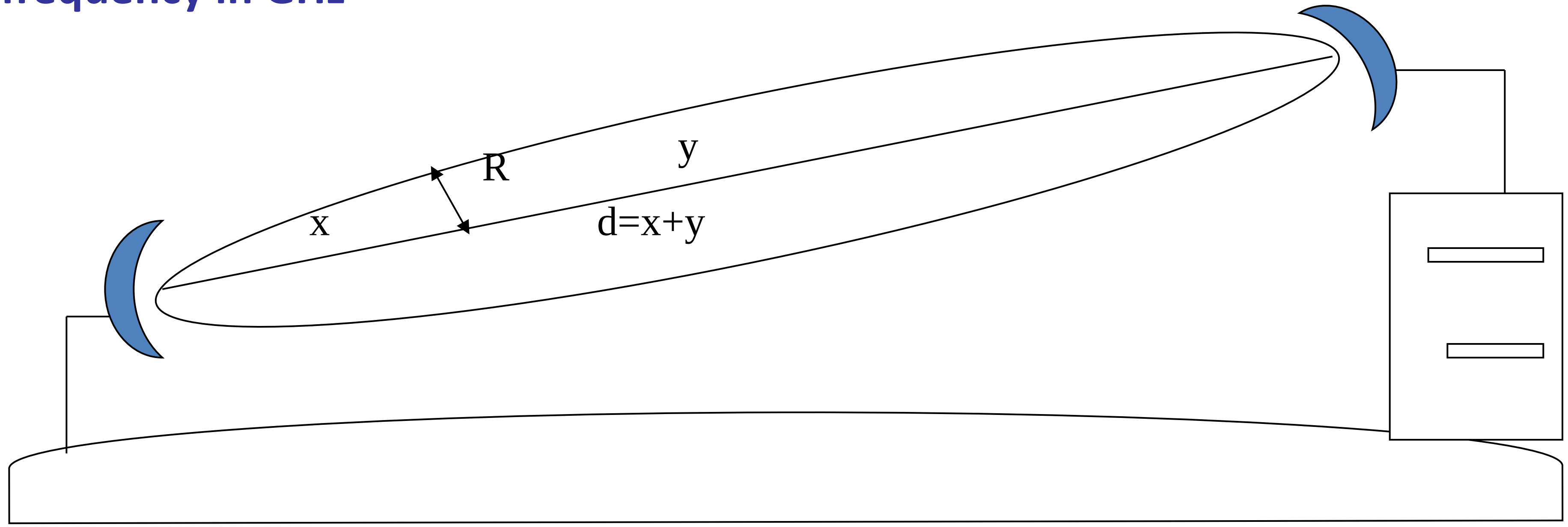
- Radius of the first Fresnel zone

$$R=17.32(x(d-x)/fd)^{1/2}$$

where d = distance between antennas (in Km)

R= first Fresnel zone radius in meters

f= frequency in GHz



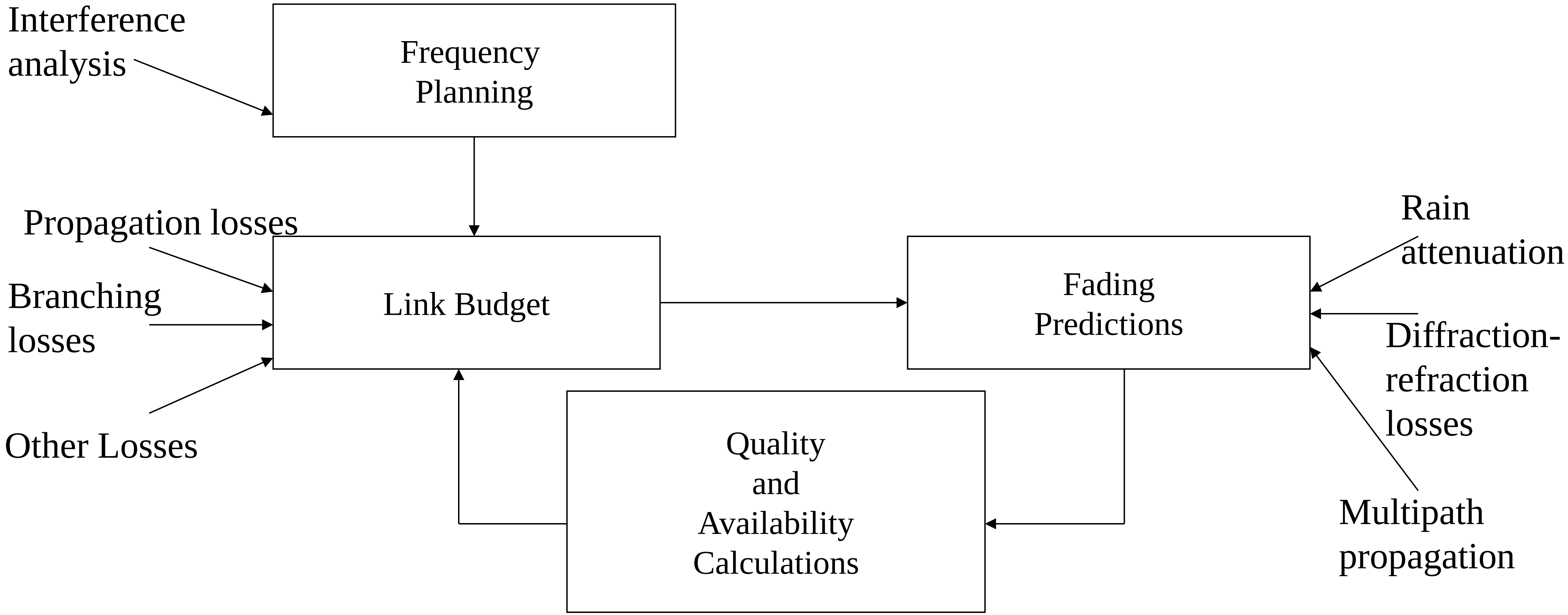
Microwave Link Design

Microwave Link Design is a methodical, systematic and sometimes lengthy process that includes

- Loss/attenuation Calculations
- Fading and fade margins calculations
- Frequency planning and interference calculations
- Quality and availability calculations

Microwave Link Design Process

The whole process is iterative and may go through many redesign phases before the required quality and availability are achieved



Loss / Attenuation Calculations

The loss/attenuation calculations are composed of three main contributions

- Propagation losses

  (Due to Earth's atmosphere and terrain)

- Branching losses

  (comes from the hardware used to deliver the transmitter/receiver output to/from the antenna)

- Miscellaneous (other) losses

  (unpredictable and sporadic in character like fog, moving objects crossing the path, poor equipment installation and less than perfect antenna alignment etc)

  This contribution is not calculated but is considered in the planning process as an additional loss

Fading and Fade margins

- Microwave path lengths must be reduced in areas where rain outages are severe
- The available rainfall data is usually in the form of a statistical description of the amount of rain that falls at a given measurement point over a period of time.The total annual rainfall in an area has little relation to the rain attenuation for the area
- Hence a margin is included to compensate for the effects of rain at a given level of availability. Increased fade margin (margins as high as 45 to 60dB) is of some help in rainfall attenuation fading.

- Reducing the Effects of Rain
  - Multipath fading is at its minimum during periods of heavy rainfall with well aligned dishes, so entire path fade margin is available to combat the rain attenuation (wet-radome loss effects are minimum with shrouded antennas)
  - When permitted, crossband diversity is very effective
  - Route diversity with paths separated by more than about 8 Km can be used successfully

Fading and Fade margins

- Radios with Automatic Transmitter Power Control have been used in some highly vulnerable links
- Vertical polarization is far less susceptible to rainfall attenuation (40 to 60%) than are horizontal polarisation frequencies.

Refraction – Diffraction Fading

- Also known as k-type fading
- For low k values, the Earth's surface becomes curved and terrain irregularities, man-made structures and other objects may intercept the Fresnel Zone.
- For high k values, the Earth's surface gets close to a plane surface and better LOS(lower antenna height) is obtained
- The probability of refraction-diffraction fading is therefore indirectly connected to obstruction attenuation for a given value of Earth –radius factor
- Since the Earth-radius factor is not constant, the probability of refraction-diffraction fading is calculated based on cumulative distributions of the Earth-radius factor

Interference fade margin

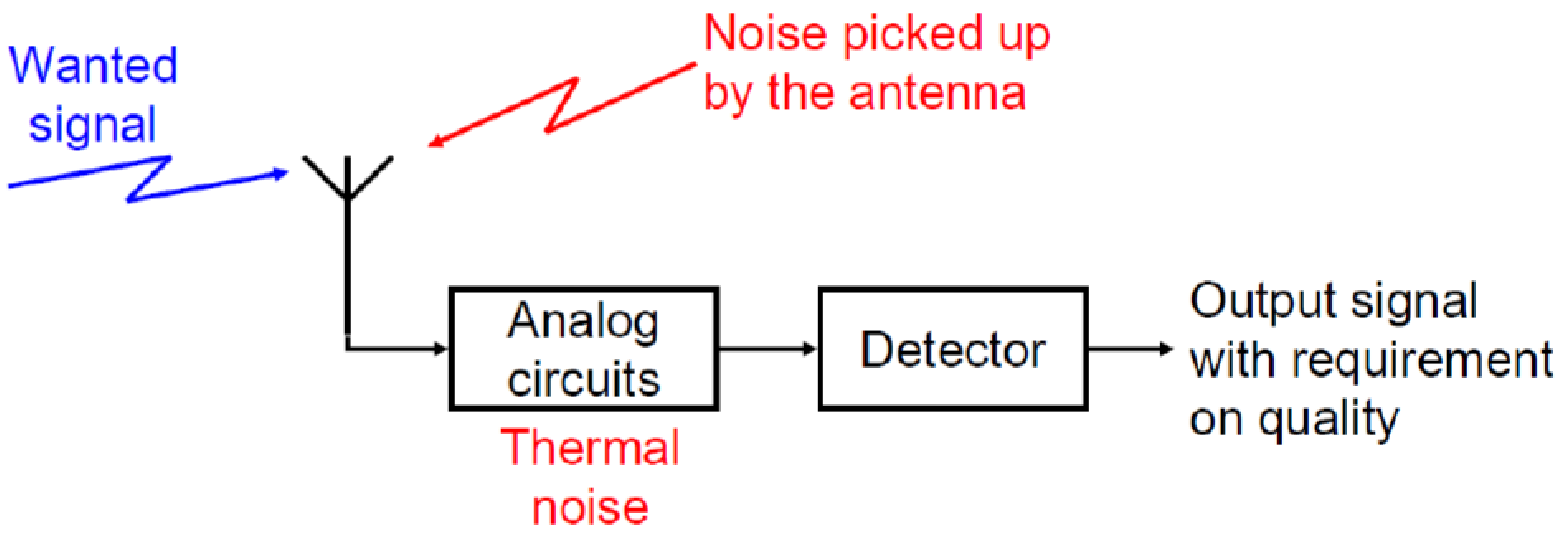
To accurately predict the performance of a digital radio path, the effect of interference must be considered.Interference in microwave systems is caused by the presence of an undesired signal in a receiver.When this undesired signal exceeds certain limiting values, the quality of the desired received signal is affected. To maintain reliable service, the ratio of the desired received signal to the (undesired) interfering signal should always be larger than the threshold value.

- **In normal unfaded conditions the digital signal can tolerate high levels of interference but in deep fades it is critical to control interference.**
- **Adjacent-channel interference fade margin (AIFM) (in decibels) accounts for receiver threshold degradation due to interference from adjacent channel transmitters**
- **Interference fade margin (IFM) is the depth of fade to the point at which RF interference degrades the BER to 1x 10^{-3} . The actual IFM value used in a path calculation depends on the method of frequency coordination being used.**

NOISE

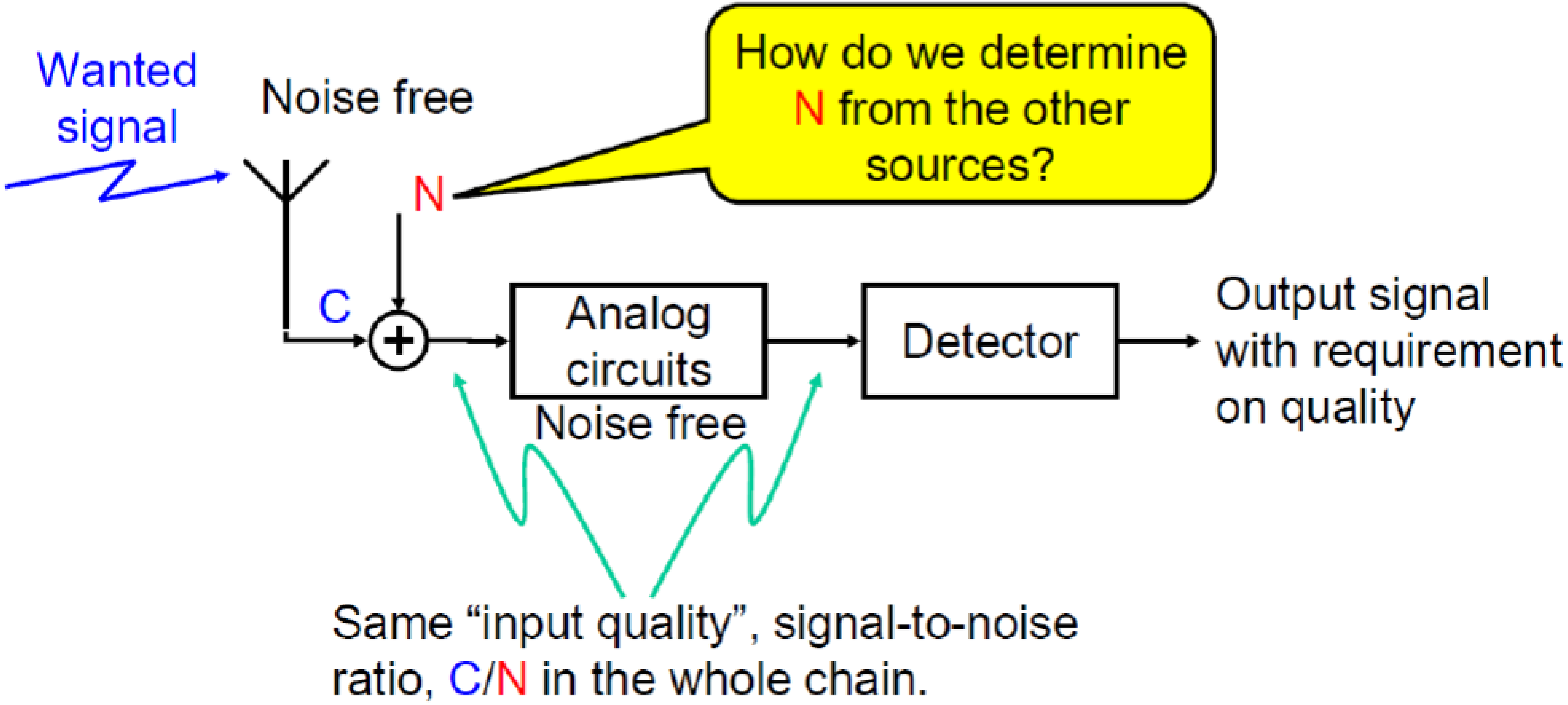
Noise Sources

The noise situation in a receiver depends on several noise sources



Noise Sources

To simplify the situation, we replace all noise sources with a single equivalent noise source.



Categories of Noise

- Thermal Noise
- Intermodulation noise
- Crosstalk
- Impulse Noise

Termal (Johnson) Gürültü

- Cihaz parçalarında elektronların rasgele hareketi (termal çalkalanma) sonucu meydana gelir.
- Devrede herhangi bir akım olmadığı durumda dahi termal gürültü vardır. Sadece mutlak sıfırda (0 K veya –273 °C) mevcut değildir.

Termal gürültüyü azaltmanın yolları

- 1)Dar frekans aralığı
- 2)Devre elemanlarının azaltılması
- 3)Elektronik bileşenlerin sıcaklığını düşürmek

Termal gürültü frekans aralığına bağlıyken frekansın kendisinden bağımsızıdır.

Thermal Noise

- Amount of thermal noise to be found in a bandwidth of 1Hz in any device or conductor is:

$$N_0 = \mathrm{k}T\left(\mathrm{W/Hz}\right)$$

  - N_0 = noise power density in watts per 1 Hz of bandwidth
  - k = Boltzmann's constant = 1.3803 x 10^{-23} J/K
  - T = temperature, in kelvins (absolute temperature)

Thermal Noise

- Noise is assumed to be independent of frequency
- Thermal noise present in a bandwidth of *B* Hertz (in watts):

$$N = \mathrm{k}TB$$

or, in decibel-watts

$$N = 10 \log \mathrm{k} + 10 \log T + 10 \log B$$
$$= -228.6\,\mathrm{dBW} + 10 \log T + 10 \log B$$

LINK POWER & NOISE -LOS

EIRP = Power of transmitter x Gain of the antenna

$= P_{amp} \times G_{antenna}$ or in dB,

$EIRP = P_{amp} + G_{antenna}$

Putting together the link power and noise

Now let's write the link equation in terms of C/N

$$C = EIRP + G - Losses$$

In above, first write out the carrier power, which is just the sum of the EIRP of the transmitter, the gain of the receiver and any associated implementation losses. So thats all the power that is available to the signal.

Remember we said that

$$N = k\,T\,B_N,$$

Now divide the above expression for C, with expression for N and write it out in dB form

$$C/N = EIRP + G/T - Losses - k - B_n$$

LINK POWER & NOISE -LOS

$P_{received} = EIRP + G_R - FSL$

$$\frac{G}{T} = G_R - T \quad dB\ K^{-1}$$

G_R = Gain of the Receiving Antenna

T = Thermal Noise temperature of the receiver

An antenna has a noise temperature of 70°K. What is the noise power density? (b) What is the noise power if we assume that the bandwidth is 24 MHz.

(a) $N_0 = k\,T_N = 1.38 \times 10_{-23} \times 70 = 9.66 \times 10^{-22}$ Joules

(b) $P_N = N_0\,B_N = 9.66 \times 10^{-22} \times 24 \times 10^{6} = 2.3 \times 10^{-14}$ Watts

Noise Figure

- Noise figure, F, relates the SNR at the input of a network to the SNR at the output of the network:

$$F = \frac{(\mathrm{SNR})_{in}}{\mathrm{SNR})_{out}}$$

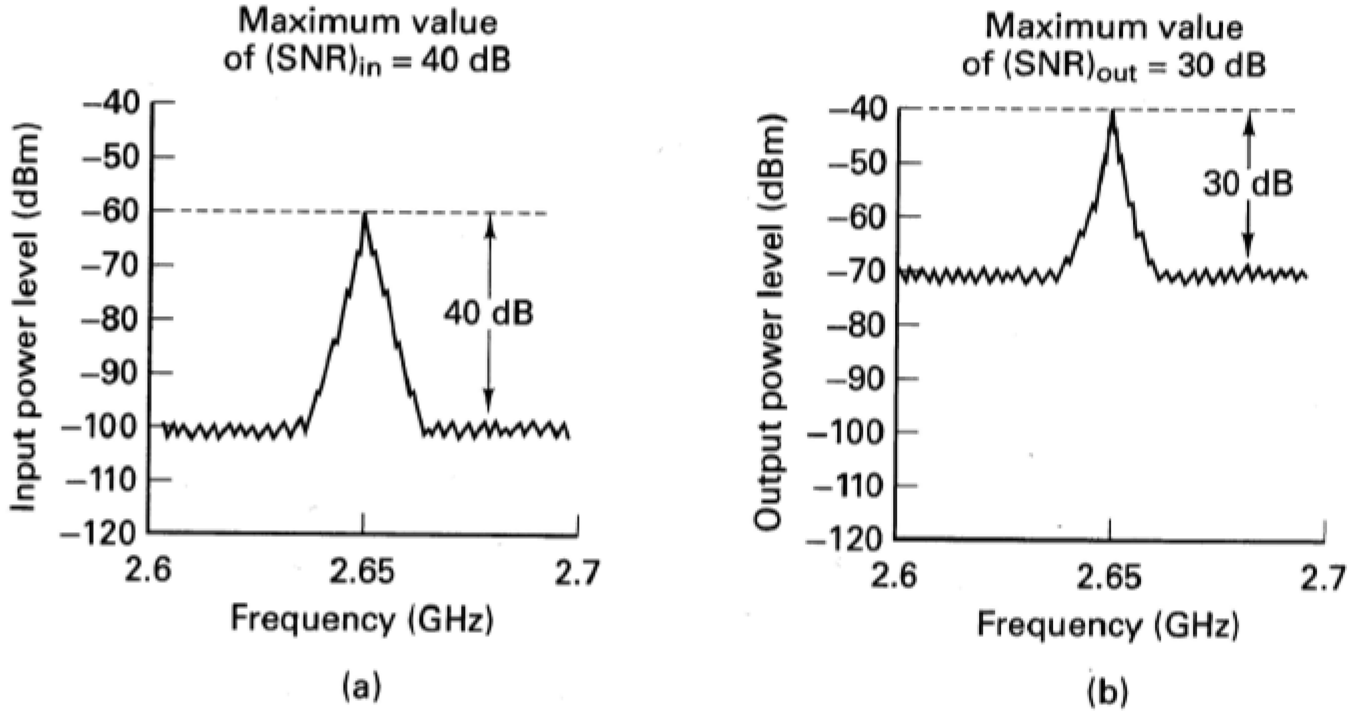


Figure 5.14 Amplifier signal and noise levels as a function of frequency. (a) Amplifier input. (b) Amplifier output.

Noise Figure

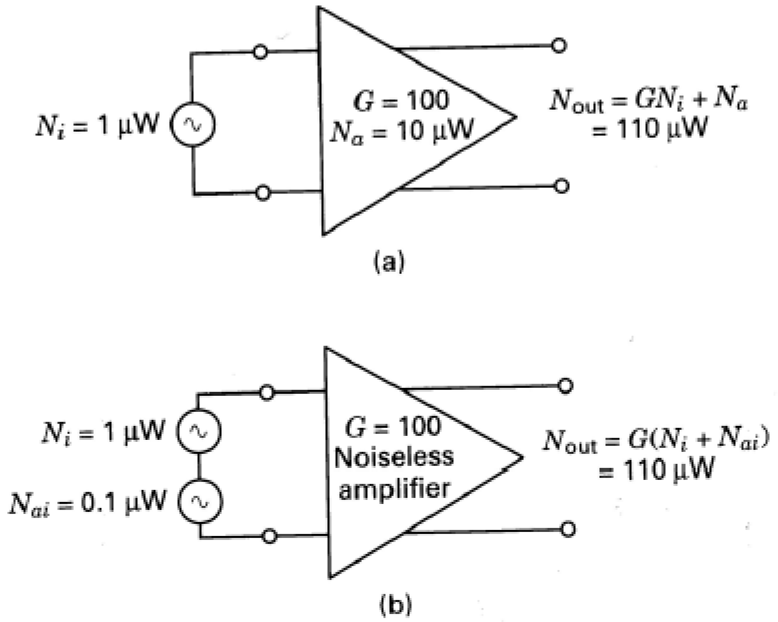


Figure 5.15 Example of noise treatment in amplifiers.

* An amplifier amplifies the input signal but also amplifies the input noise and also introduces additional noise.

$$F = \frac{(\mathrm{SNR})_{in}}{(\mathrm{SNR})_{out}} = \frac{S_i/N_i}{GS_i/G(N_i+N_{ai})} = 1 + \frac{N_{ai}}{N_i}$$

(Typical value of F: 1 – 10 dB)

S_i: signal power at the amplifier input port

N_i: noise power at the amplifier input port

N_a: noise power introduced at the amplifier

N_{ai}: amplifier noise referred to the input port

G: amplifier gain.

- A reference for N_i is when $T_0 = 290\ ^{o}K$ (reference temperature), i.e.

$N_o = \kappa T_o = 1.38 \times 10^{-23} \times 290 = 4.00 \times 10^{-21}$ W/Hz

$N_o = -204$ dBW/Hz @ $T_0 = 290\ ^{o}K$

Noise Temperature

$$F = 1 + \frac{N_{ai}}{N_i} \rightarrow N_{ai} = (F-1)N_i$$ (What percentage of N_i is N_{ai}? $[0,\infty)$)

- T_0 = 290 °K: **reference temperature**, T_R: **effective noise temperature** of the receiver (network).

$$\kappa T_R W = (F-1)\kappa T_0 W \Longrightarrow T_R = (F-1)290^\circ K$$

(N_i @ T_R) (N_i @ T_0)

- For the output of an amplifier, we can write the output noise power as

$$\begin{aligned} N_{out} &= GN_i + GN_{ai} \\ &= G\kappa T_g W + G\kappa T_R W \\ &= G\kappa(T_g + (F-1)(290^\circ K))W \end{aligned}$$

T_g: temperature of the source.

Line loss

- An amplifier amplifies the input signal, but also amplifies the input noise and also introduces additional noise.
- A **Lossy Line** attenuates the input signal but does not introduce additional noise.

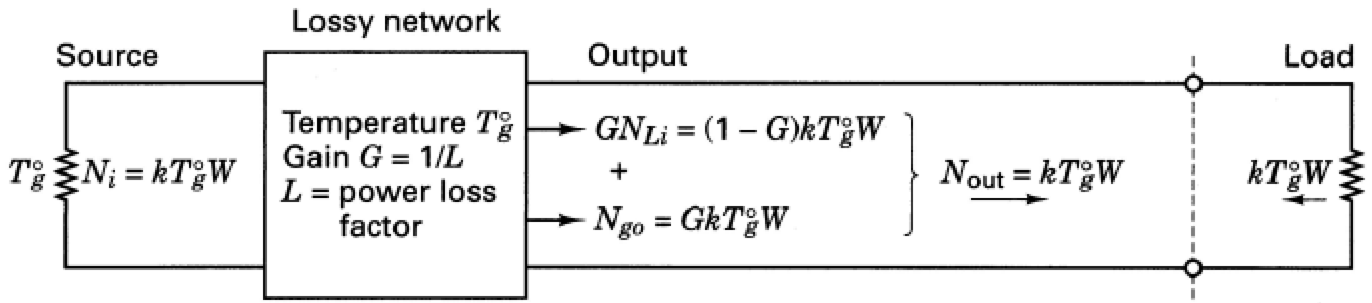


Figure 5.16 Lossy line: impedance matched and temperature matched at both ends.

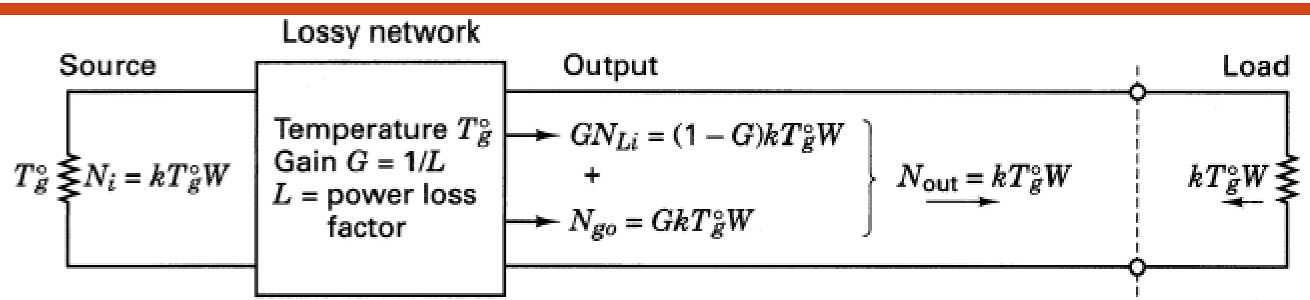
- **Power Loss**:

$$L = \frac{\text{input power}}{\text{output power}}$$

- **Gain**:

$$G = \frac{1}{L}$$

Line Noise



- Let all components be at temperature T_g.
- There is thermal equilibrium -> no current flows due to noise.
- Assume that the impedances of the input and output of the network is matched with the source and the load.
- The total output noise power N_{out} flowing from the network to the load:

$$\begin{aligned} N_{out} &= \kappa T_g W \\ &= N_{go} + GN_{Li} \end{aligned}$$

- N_{go}: noise at the output due to the source
- GN_{Li}: noise at the output due to the lossy network (N_{Li}: network noise relative to its input)
- Due to thermal equilibrium, noise power of the load is also equal to $\kappa T_g W$.

Line Noise

- N_{Li}: network noise relative to its input:

$$\begin{aligned} N_{out} &= \kappa T_g W \\ &= G\kappa T_g W + G N_{Li} \end{aligned} \implies N_{Li} = \kappa(\tfrac{1-G}{G} T_g) W = \kappa T_L W$$

- **Effective noise temperature of the line**, T_L, is

$$\begin{aligned} T_L &= \tfrac{1-G}{G} T_g \\ &= (L-1) T_g \end{aligned}$$

- If the ambient temperature is $T_g = T_0 = 290\ ^oK$ (above derivation assumes line temp. is at T_g)

$$T_L = (L-1) 290^\circ K$$

- **Noise figure for a lossy line** is

$$F = 1 + \frac{T_L}{290^\circ K} = L$$

$$\left\{ \begin{aligned} T_R &= (F-1) 290^\circ K \\ T_L &= (L-1) 290^\circ K \end{aligned} \right.$$

- Then the output noise power is (see pg. 36)

$$\begin{aligned} N_{out} &= G\kappa T_g W + G\kappa(F-1) T_0 W \\ &= \tfrac{1}{L}\kappa T_g W + \tfrac{1}{L}\kappa(L-1) T_0 W \end{aligned} \qquad (G = \tfrac{1}{L})$$

Line Loss

- Example:
  - T_0 = 290ºK
  - T_g = 1450ºK
  - S_i = 100 pW
  - W = 1 GHz
  - L=2
  - Calculate $(SNR)_{in}$, $(SNR)_{out}$ and T_{L}.

- $(SNR)_{in} = \frac{S_i}{N_i} \Longrightarrow N_i = \kappa T_g W$

$$\begin{aligned} N_i &= \kappa T_g W \\ &= 1.38 \times 10^{-23} W/K - Hz \times 1450^\circ K \times 10^9 Hz \\ &= 20pW \end{aligned}$$

$$(SNR)_{in} = \frac{100pW}{20pW} = 5\ (7dB)$$

- $(SNR)_{out} = \frac{S_o}{N_o} \Longrightarrow \quad S_o = \frac{S_i}{L} = \frac{100pW}{2} = 50pW$

$$T_L = (L-1)T_0 = 1 \times 290^\circ K = 290^\circ K$$

$$\begin{aligned} N_{out} &= \frac{\kappa T_g W}{L} + \frac{\kappa T_L W}{L} \\ &= \frac{2\times 10^{-11}}{2} W + \frac{4\times 10^{-12}}{2} W \\ &= 12pW \end{aligned}$$

$$\Longrightarrow (SNR)_{out} = \frac{50pW}{12pW} = 4.17\ (6.2dB)$$

Composite Noise Figure

- Connect two networks in series:

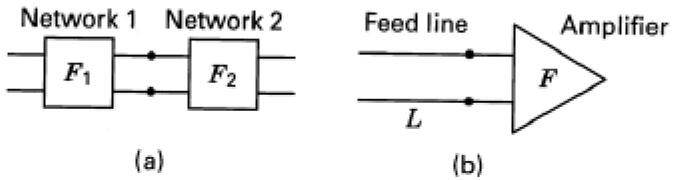


Figure 5.17 Networks connected in series.

- **Noise figure of the composite network** is:

$$F_{comp} = F_1 + \frac{F_2 - 1}{G_1} \qquad \left(F_{comp} = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \cdots + \frac{F_n - 1}{G_1 G_2 \cdots G_{n-1}}\right)$$

- **Design goal**: keep F_1 as low as possible & keep G_1 as high as possible (conflicting goals!).

  First stage should be a low-noise-(pre)amplifier (LNA)!

- **Effective noise temperature of the composite network:**

$$T_{comp} = T_1 + \frac{T_2}{G_1} + \frac{T_3}{G_1 G_2} + \cdots + \frac{T_n}{G_1 G_2 \cdots G_{n-1}}$$

- If there is a feed line prior to the amplifier:

$F_1 = L$

composite temperature

$$F_{comp} = L + L(F - 1) = LF \implies T_{comp} = (LF - 1) 290^\circ K$$

System Effective Temperature

- Apart from the transmission line and pre-amplifier, external noise sources are also present.
  - natural noise sources: lightning, atmospheric noise, cosmic noise, thermal radiation from the ground, etc.
  - man-made noise sources: automobile ignition, electrical machinery, other radio signals, etc.
- They are represented by **antenna temperature** T_A ($\kappa T_A W$).

- System temperature is

$$T_s = T_A + T_{comp}$$

$$\begin{aligned} T_s &= T_A + T_L + LT_R \\ &= T_A + (LF - 1)290^\circ K \end{aligned}$$

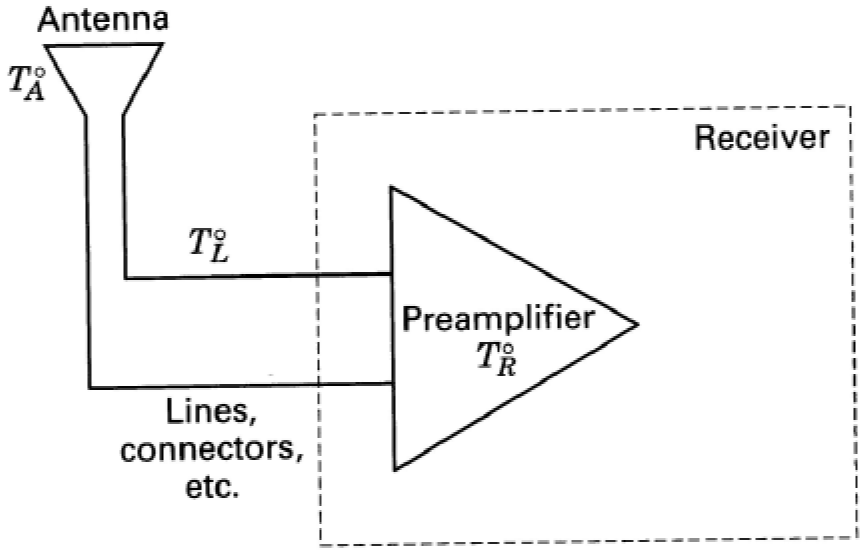
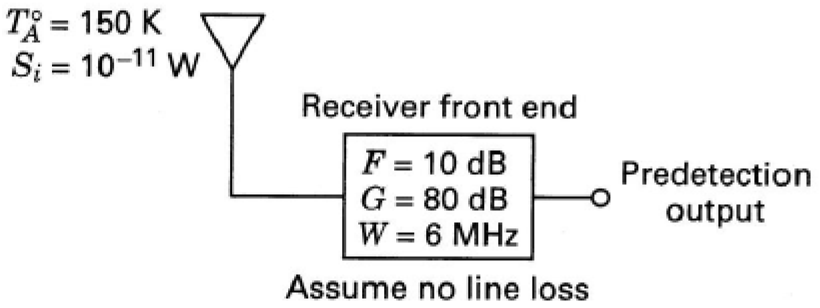


Figure 5.18 Major noise contributors of a receiving system.

System Performance (w/o LNA)

- Example: Receiver without a LNA preamplifier (no line loss)



(a)

$$S_{in} = 10^{-11}\text{W}$$

$$\begin{aligned} N_{in} &= \kappa T_A W \\ &= 1.38 \times 10^{-23} \text{ W/K-Hz} \times 150°\text{K} \times 6 \times 10^6 \text{ Hz} \\ &= 1.24 \times 10^{-14} \text{ W} \end{aligned}$$

$$\Longrightarrow (SNR)_{in} = \frac{S_{in}}{N_{in}} = 806.5 \ (29.1 \text{ dB})$$

$$S_{out} = G \times S_{in} = 10^8 \times 10^{-11}\text{W} = 10^{-3}\text{W}$$

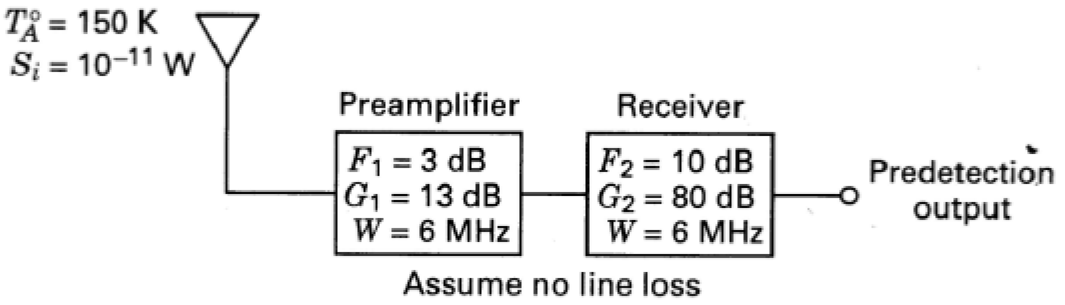
$$\begin{aligned} N_{out} &= G\kappa T_A W + G\kappa T_R W \\ &= G\kappa(T_A + (F-1)T_0)W \\ &= 10^8 \times 1.38 \times 10^{-23} \text{ W/K-Hz } (150°\text{K} + (10-1) \times 290°\text{K}) \times 6 \times 10^6 \text{ Hz} \\ &= 1.2 \ \mu\text{W} + 21.6 \ \mu\text{W} = 22.8 \ \mu\text{W} \end{aligned}$$

From source From front-end

$$\Longrightarrow (SNR)_{out} = \frac{S_{out}}{N_{out}} = \frac{1 \text{ mW}}{22.8 \ \mu\text{W}} = 43.9 \ (16.4 \text{ dB})$$

System Performance (w LNA)

- Example: Receiver with a LNA preamplifier (no line loss)



(b)

$$(SNR)_{in} = \frac{S_{in}}{N_{in}} = 806.5 \ (29.1 \text{ dB})$$

$$T_{R1} = (F_1 - 1)T_0 = (2-1)290 = 290°\text{K}$$

$$T_{R2} = (F_2 - 1)T_0 = (10-1)290 = 2610°\text{K}$$

$$\Longrightarrow T_{comp} = T_{R1} + \frac{T_{R2}}{G_1} = 290°\text{K} + \frac{2610°\text{K}}{20} = 420.5°\text{K}$$

$$S_{out} = G_1 \times G_2 \times S_{in} = 20 \times 10^8 \times 10^{-11}\text{W} = 20\text{mW}$$

$$\begin{aligned} N_{out} &= G\kappa T_A W + G\kappa T_{comp} W \\ &= 24.8 \ \mu\text{W} + 69.6 \ \mu\text{W} = 94.4 \ \mu\text{W} \end{aligned}$$

From source — From front-end

$$\left(F_{comp} = F_1 + \frac{F_2 - 1}{G_1} = 2 + \frac{9}{20} = 2.5 \ (4 \text{ dB})\right)$$

Lower noise figure than F_2 only.

$$\Longrightarrow (SNR)_{out} = \frac{S_{out}}{N_{out}} = \frac{20 \text{ mW}}{94.4 \ \mu\text{W}} = 212.0 \ (23.3 \text{ dB})$$

Sky Noise Temperature

- When the antenna points towards the sky:
  - Up to 1 GHz, galactic noise is dominant.
  - After 10 GHz atmospheric noise is dominant.
  - There is an available window in between with low natural noise.

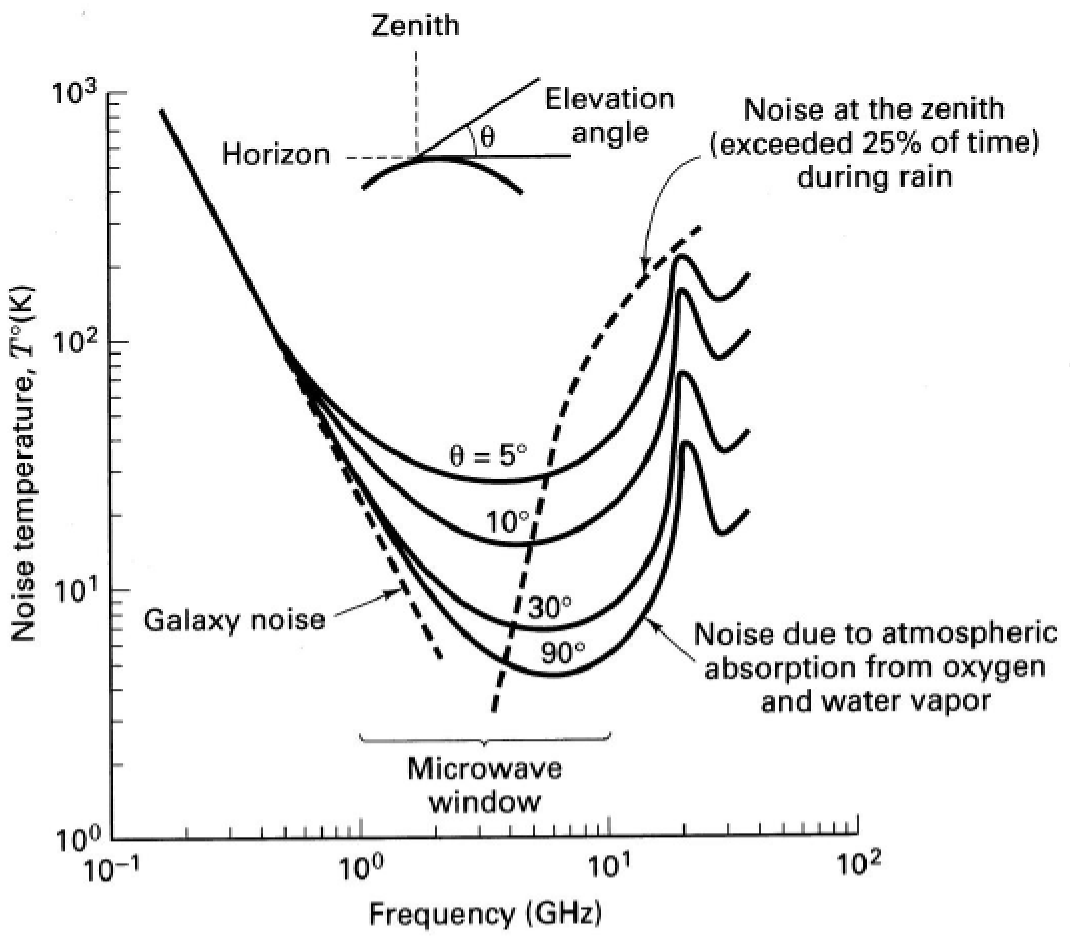


Figure 5.20 Sky noise temperature.

Sample Link Analysis

Brackets: (<.>) loss

No brackets: gain

Box: subtotals

Double box: link margin.

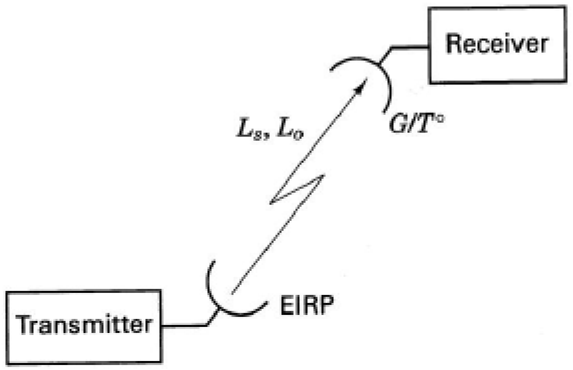


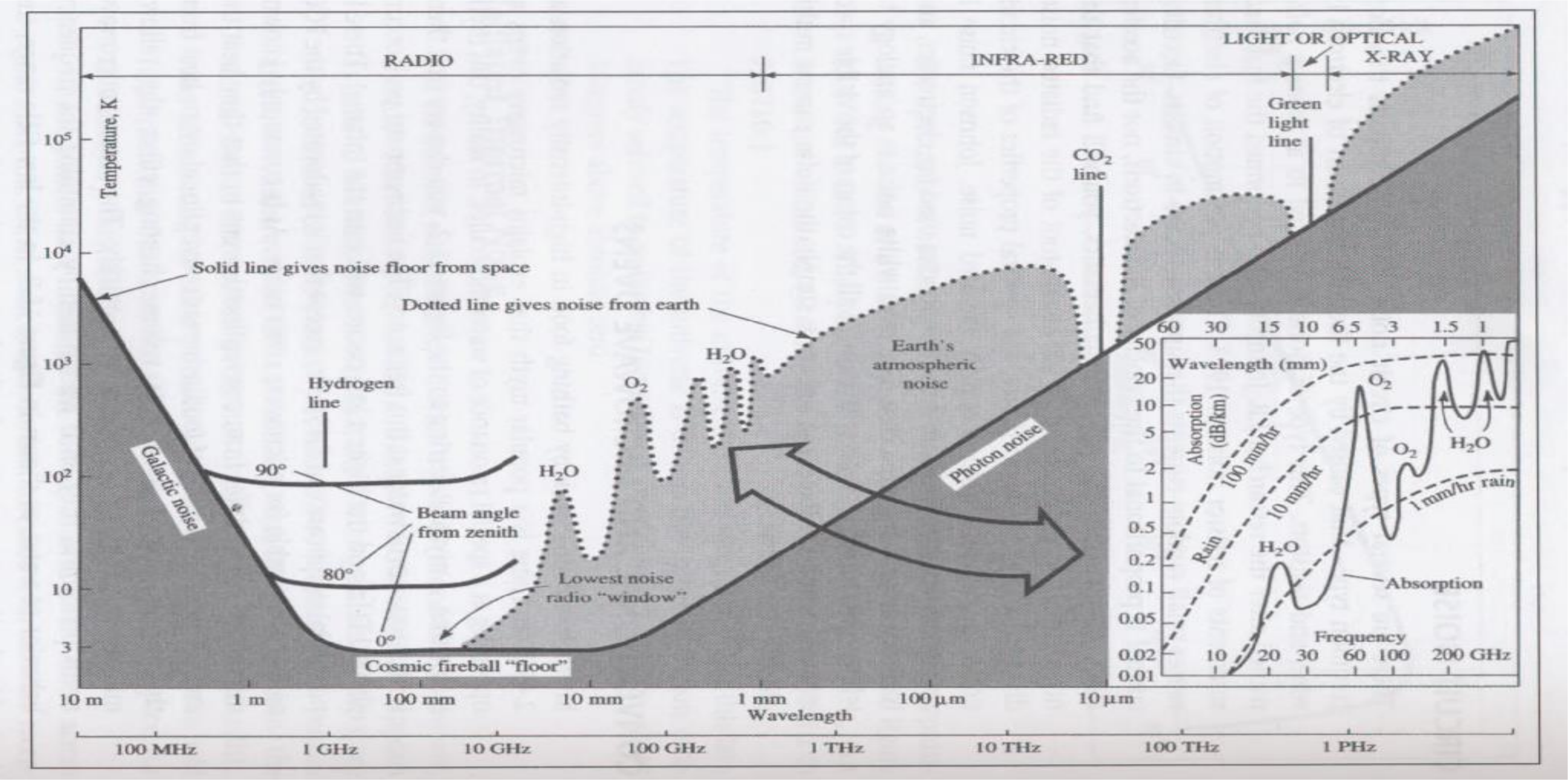
Figure 5.23 Key parameters of a link analysis.

TABLE 5.2 Earth Terminal to Satellite Link Budget Example: Frequency = 8 GHz, Range = 21,915 Nautical Miles.

1. Transmitter power (dBW)	(100.00W)	20.0*	P_t
2. Transmitter circuit loss (dB)		⟨2.0⟩	L_o
3. Tramsmitter antenna gain (peak dBi)		51.6	G_t
Dish diameter (ft)	20.00		
Half-power beamwidth (degrees)	0.45		
4. Terminal EIRP (dBW)		[69.6]	EIRP
5. Path loss (dB)	(10° elev.)	⟨202.7⟩	L_s
6. Fade allowance (dB)		⟨4.0⟩	L_o
7. Other losses (dB)		⟨6.0⟩	L_o
8. Received isotropic power (dBW)		[–143.1]	
9. Receiver antenna gain (peak dBi)		35.1	G_r
Dish diameter (ft)	3.00		
Half-power beamwidth (degrees)	2.99		
10. Edge-of-coverage loss (dB)		⟨2.0⟩	L_o
11. Received signal power (dBW)		[–110.0]	P_r
Receiver noise figure at antenna port (dB)			11.5
Receiver temperature (dB-K)			35.8 (3806 K)
Receiver antenna temperature (dB-K)			24.8 (300 K)
12. System temperature (dB-K)			36.1 (4106 K)
13. System $G/T°$ (dB/K)	–1.0		$G/T°$
14. Boltzmann's constant (dBW/K-Hz)			–228.60
15. Noise spectral density (dBW/Hz)		⟨–192.5⟩	$N_0 = kT°$
16. Received P_r/N_0 (dB-Hz)		[82.5]	$(P_r/N_0)_r$
17. Data rate (dB-bit/s)	(2 Mbits/s)	⟨63.0⟩	R
18. Received E_b/N_0 (dB)		[19.5]	$(E_b/N_0)_r$
19. Implementation loss (dB)		⟨1.5⟩	L_o
20. Required E_b/N_0 (dB)		⟨10.0⟩	$(E_b/N_0)_{reqd}$
21. Margin (dB)		[[8.0]]	M

Noise Figure, Noise Factor and Sensitivity

“Sky” Noise



RADIO
INFRA-RED
LIGHT OR OPTICAL
X-RAY
Temperature, K
Green light line
CO2 line
Solid line gives noise floor from space
Dotted line gives noise from earth
Earth's atmospheric noise
Hydrogen line
Galactic noise
Beam angle from zenith
90°
80°
0°
Lowest noise radio "window"
Cosmic fireball "floor"
Photon noise
H2O
O2
Wavelength (mm)
Absorption (dB/km)
100 mm/hr
10 mm/hr
1 mm/hr rain
Rain
Absorption
Frequency
10 20 30 60 100 200 GHz
10 m
1 m
100 mm
10 mm
1 mm
100 μm
10 μm
Wavelength
100 MHz
1 GHz
10 GHz
100 GHz
1 THz
10 THz
100 THz
1 PHz

Noise factor (cont.)

$$F = \frac{(N_i G(f) + N_a) S_i}{N_i S_o} = \frac{S_i}{N_i} \frac{N_o}{S_o} = 1 + \frac{N_a}{G(f) N_i}$$

- It is a measure of the degradation of SNR due to the noise added -
- Implies that SNR gets worse as we process the signal
- Spot noise factor
- The answer is the bandwidth

$$F = 1 + \frac{N_a}{kT}$$

$$F = \frac{SNR_i}{SNR_o} \geq 1$$

Noise factor (cont.)

- Quantitative measure of receiver performance wrt noise for a given bandwidth
- Noise figure
  - Typically 8-10 db for modern receivers

$$NF = 10\log(F)$$

- Multistage (cascaded) system

$$F = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \ldots + \frac{F_n - 1}{G_1 G_2 \cdots G_{n-1}}$$

Sensitivity

- Minimum detectable input signal level for a given output SNR (also called *noise floor*)
- Not necessarily related to required output SNR

Kaynaklar

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- Lecture notes from internet.

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Sincerely,

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