“*Basic Concepts in Communication*”

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Arithmetic Operations

Why do we need to know arithmetic operations? To use numbers to tell the story of data.

- Decimal number system: Integers, fractions, rational and irrational numbers
- Arithmetic operations in the decimal number system: +, -, /, *, carry division, integer division, square root, rounding, percentage calculation. In arithmetic operations, units must be equal.
- Arithmetic operations in the binary number system: Bit addition (+), bit shift right or left (multiplication, division)
- Logical operations in the binary number system: and, or, not, nand, nor, xnor, xor
- Comparison: <, <=, >, >=, ==, ≠
- Logarithms
- Complex operations
- Exponential operations
- Functions: Linear, polynomial, exponential, trigonometric, logarithmic
- Vector, Array, Matrix, Eigenvalue, Eigenvectors
- Computational mathematics (Interpretation): Derivative, integral, limit
- Units: gr, m, second, degree, watt, dBm, dB, …
- Removing ambiguities ($1/\infty = 0$, $1/(10^{50}) \approx 1/\infty = 0$)
- Probability and statistical analysis
- Simplification
- Visualization: 2D, 3D
- Signals: Analog and Digital

How signals are represted

Focusing solely on programming wouldn't be a good idea as a software engineer. This is because this field has become a common area of work with artificial intelligence assistants. Therefore, as a software engineer, instead of focusing solely on programming languages, we need to focus on data. This means prioritizing data collection, data storage, data storage management, data preparation, data analytics, writing stories from data, and building intelligent learning models from data.

- Inside the computer, all signal is binary signal as bit:0/1. Data transfer, storage, process all signal as electrical and binary numbering system.
- Outside the computer, all signals are analog, text, image, video, electromagnetic signal, electrical signal (analog signal), voice, vibration, heat, gravitational forces, … So these signals are represented bit: 0/1 inside the computer.
- For example, ADC, DAC: Analog to digital converter or digital to analog converter for electrical signals
- For example, Keyboards letters, numbers or other sybmbols are represented the ASCII. ASIC symbols are represted the 8bits. For example A=41h=(0100 0001)b

Common Powers

Prefix	Symbol	Power of 10	Power of 2	Prefix	Symbol	Power of 10
Kilo	K	1 thousand = 10^3	$2^{10} = 1024$	Milli	m	1 thousandth = 10^{-3}
Mega	M	1 million = 10^6	2^{20}	Micro	μ	1 millionth = 10^{-6}
Giga	G	1 billion = 10^9	2^{30}	Nano	n	1 billionth = 10^{-9}
Tera	T	1 trillion = 10^{12}	2^{40}	Pico	p	1 trillionth = 10^{-12}
Peta	P	1 quadrillion = 10^{15}	2^{50}	Femto	f	1 quadrillionth = 10^{-15}
Exa	E	1 quintillion = 10^{18}	2^{60}	Atto	a	1 quintillionth = 10^{-18}
Zetta	Z	1 sextillion = 10^{21}	2^{70}	Zepto	z	1 sextillionth = 10^{-21}
Yotta	Y	1 septillion = 10^{24}	2^{80}	Yocto	y	1 septillionth = 10^{-24}

Bit: 0/1. Data represents only as bit inside computer.
We use 10 Powers as all units (gr, m, sec, hz, bit or bit/second)
Bit/second: transfer data or the processor's data processing speed.

All Memory Units

1 bit = Binary digit
8 bits = 1 Byte
1024 byte = 1 KB
1024 KB = 1 MB
1024 MB = 1 GB
1024 GB = 1 TB
1024 TB = 1 Peta Byte
1024 PB = 1 Exa Byte
1024 EB = 1 Zetta Byte
1024 ZB = 1 Yotta Byte
1024 YB = 1 Bronto Byte
1024 BB = 1 Geop Byte

- Memory size is always byte as 2 power.
- In the expression 2^n, n = the number of memory address lines. Memory address bus indexing: A0, A1, A2, … , An-1
- 1 byte of a memory cell is 8 bits. 2^n defines the memory size in 8 bits (1 byte), n: 10,20,30, ...

Example: 16Gbyte=? Byte.

- 16Gbyte=2^4 * 2^30 byte=2^34byte
- 16Gbytes how much bits? = 2^3 * 2^34 bit =2^37bit

Examples

Soru-1:

- 2^44 bit how much Terabyte?
- 8 bit equals to 1 byte. 2^44/2^3=2^41byte = 2^1 * 2^40 = 2 Terabyte

What is the capacity of a memory (byte)?

- Answer: 2 Terabyte = 2^41 byte
- In the expression 2^n, n = the number of memory address lines. Here, n=41
- Memory address bus indexing: A0, A1, A2, … , A40

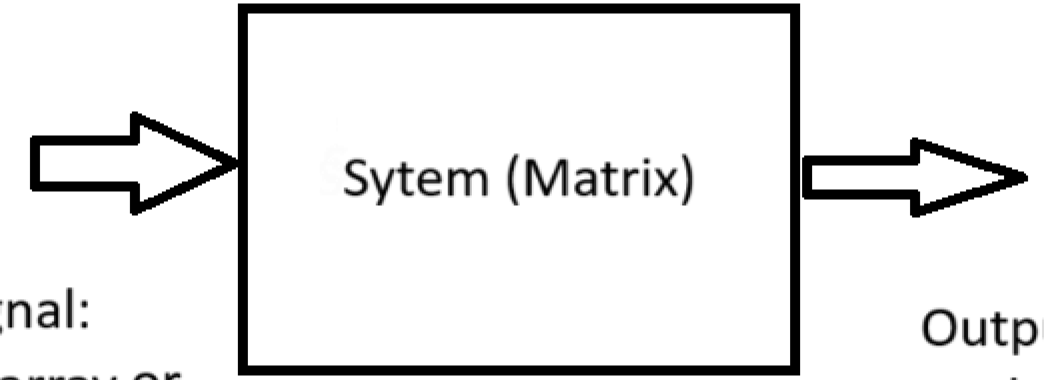
Basic Units

Arithmetic operations must be performed using basic units. The units must be the same in arithmetic operations.

- Seconds
- Grams
- Meters
- Hertz (Hz=1/Second)
- Watts
- Temperature: Degrees
- Angle: Degrees

For example: if Vo=5V, Vi=5mV, and you want to calculateK=Vo/Vi, The units must be the same in arithmetic operations.
K=Vo/Vi;
If K=1 buffer, protection circuit
If K>1 amplifier.
If K<1 attenuation.
Vo = 5V = 5*10^3 mV, Vi=5mV; K=Vo/Vi=5*10^3/5=10^3=1000 (Dimensionless). K>1 so amplifier.

For example, if f=10GHz and d=10km, what is fMhz*dkm=?Here, did you say fMHz*dkm=10*10^3 * 10=10^5 yapar.   F=10Ghz=10*10^3 MHz



Input signal:
analog , array or
vector

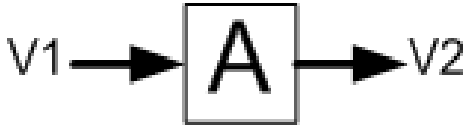
Output signal:
analog, array or
vector

Signa propperties: Direction, Intensity, Sign

$$Ax=b$$

Matris

- A system that acts on a vector (A signal) to produce another vector is called a matrix.



- A=$\begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{pmatrix}$

- A matrix is the sum of vectors. It is denoted by aij. i: represents the row, j: represents the column.
- $B = A\mathrm{X}$
- $\begin{pmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \end{pmatrix}$=$\begin{pmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{pmatrix}\begin{pmatrix} \mathrm{x}_1 \\ \mathrm{x}_2 \\ \vdots \\ \mathrm{x}_n \end{pmatrix}$

Eigenvalue - Eigenvector

When some vectors are multiplied by a matrix A, the direction of the vector remains constant; its direction changes. These special vectors $X^{\rightarrow}$ remain in the same or opposite direction as the vector $B^{\rightarrow}$=A$X^{\rightarrow}$. These vectors are called “eigenvectors.” Eigenvalues are an alternative way to visualize the original structure of a matrix. Matrix A enlarges or shrinks the vector $X^{\rightarrow}$ by the eigenvalue. If the eigenvalue is positive, both vectors ($X^{\rightarrow}$ and $B^{\rightarrow}$) are in the same direction; if the eigenvalue is negative, the vector $B^{\rightarrow}$ is in the opposite direction to the vector $X^{\rightarrow}$.

Bazı vektörler bir A matrisi ile çarpıldıkları zaman vektörün doğrultusu değişmez, yönü değişir. Bu özel $\vec{X}$ vektörleri, $\vec{B} =$A$\vec{X}$ vektörü ile aynı yönde ya da ters yönde kalmaktadır. İşte bu vektörlere “özvektörler” denir. Özdeğerler, bir matrisin orijinal yapısını görmek için kullanılan alternatif bir yoldur. A matrisi $\vec{X}$ vektörünü özdeğer kadar büyütmekte ya da küçültmektedir. Özdeğer pozitif ise her iki ($\vec{X}$ ve $\vec{B}$) vektör aynı yönde, özdeğer negatif ise $\vec{B}$ vektörü $\vec{X}$ vektörüne ters yöndedir.

Data: Signals and Systems

From Data to Wisdom

The goal is to transform data into wisdom.

Data: In computer systems, signals are converted into symbols. This is the raw information carried by signals. This is called data. Data is processed to obtain knowledge. The journey begins from knowledge to wisdom, from wisdom to skill development and experience, and from skill development to awareness.

Information: The answer to the questions of what, who, when, and where.

Understanding: The evaluation of the questions of why and where. It is the attainment of consciousness through understanding, comprehension, and feeling. It is the sharing of knowledge.

Wisdom: Deep, comprehensive, and holistic knowledge that not everyone has access to. It is evaluated understanding. It is the decision-making and interpretation through questioning and inference.

Knowledge: The answer to the question of how. It is the improvement of performance in decision-making, inference, and the search for truth. It is the continuation of learning.

Data Sources

- Voice
- Image
- Video
- Text
- Document
- Analog numbering system
- Binary numbering system
- …

Signal

- A signal is the carrier of information. Information is given meaning through signals. We become conscious by discovering the universe and the information hidden within signals.
- A signal is represented as a mathematical function. It is a concept that carries information about a change and is mathematically represented as a function.
- Signals, which carry information about their source, provide extraordinary properties to the environments they interact with.
- In electronics, a signal is an electric current or electromagnetic field are used to carry data from one place to another.
- Signals propagate over distances as waves. Waves carry signals. Acoustic signals, Seismic signals, Electrical signals, Electromagnetic signals, Heat, Subatomic particles.
- In the near future, information will be carried and processed as signals generated by subatomic particles such as electrons and photons.
- The information carried is stored and given meaning by the signal; information is written on stone, in a book, in a memory, or in the brain. What makes information powerful is that it can be carried and stored in conjunction with signals. Information captured on a clay tablet is preserved for eons, halting time. A signal represents how information behaves according to the laws of physics. Humanity must learn that information is integrated with the physical world.

Signals in Communication Systems

- 2/4-wire: electrical signal (analog)
- Fiber cable: Light signal (on/off, switch)
- Coaxial cable: electrical signal (analog signal)
- Air or space: Electromagnetic waves
- Digital, binary numbering within a computer; bit: 1/0 (Data: Arithmetic, comparison, storage, logical, transfer)

Signal Sources

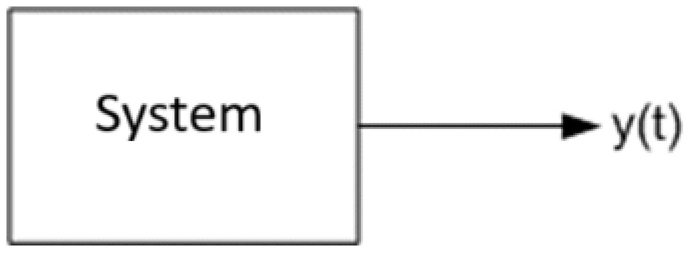
- Electrical Signals
- Electromagnetic Signals (Radiation): electromagnetic waves, light, the sun
- Acustic Signal
- Cosmic rays: Planets, stars
- Mechanical (potential, kinetic, elastic, fluid)
- Chemical (battery, fuel cell, fossil fuels, phase change)
- Thermal Communication, light, sound, vibration, gravitational forces
- Radioactive materials
- Quantum: Photon – Electron
- Lasers: Optical signals
- Electronic energy sources: Pulse generator, oscillator
- Signal Types: Sine wave, ramp, step, chirp, clock, concentration, …
- Noise: Signal to noise ratio
- All Signals are converted to electrical and electromagnetic signals.
- Inside the computer, all signals are digital signals (binary numbering system, bit:0/1)

Signal Detection

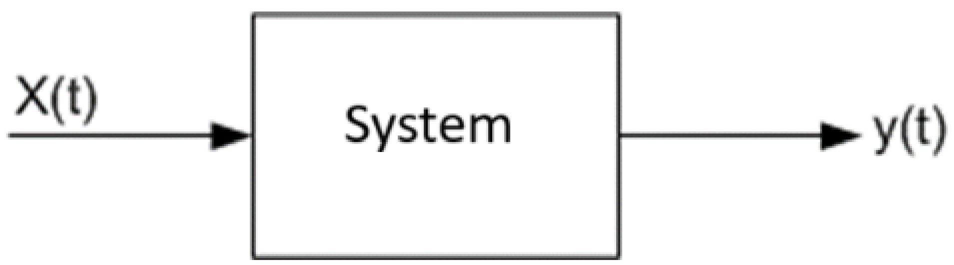
- Perception: The reception, interpretation, selection, and organization of information related to environmental changes as signals. All perceptions involve some degree of uncertainty.
- Sensor: Electronic elements that detect changes in the physical environment are called "sensors," and elements that convert the information they detect into electrical signals are called "transducers."
- Transducers: These elements detect changes in one form of energy and convert them into another form, most commonly environmental changes, into electrical signals.
- Classifying sensors: Type of information, physical principle, absolute and derivative, amount of information (bandwidth), low and high readout (dynamic range), accuracy and sensitivity
- Sensor Types: Location (GSM), imaging, heat, light (optical), sound, magnetic, pressure, force, motion, smoke, gas, vibration, direction, accelerometers/gyroscopes (gravity-independent directional detection), wetness or level, analog laser distance measurement, ultrasonic distance, touch sensors
- Telemetry: The collection of data from meters and automatic transmission to the receiving equipment.
- Actuators: The elements that control or move a mechanism or system and convert mechanical quantities such as electrical, thermal, hydraulic, or pneumatic into motion are called actuators. Actuators are the final control elements and form the interface between the control unit and the movement. They convert low-power signals to the appropriate energy level for process control.
- Indicators: Statistics used to measure current conditions and predict financial or economic trends.

Signals and Systems

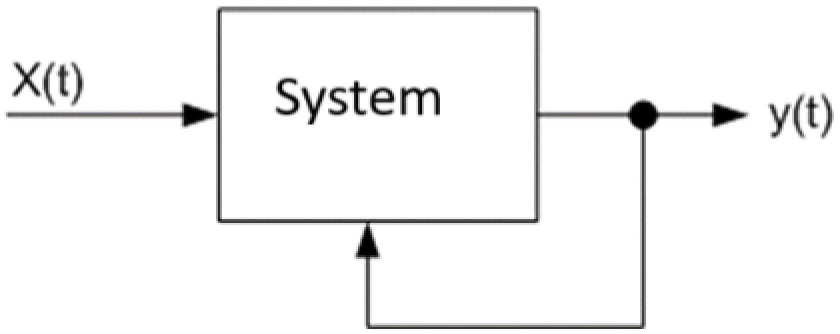
- A signal is the functional definition of a change or transformation that carries a message. Information is given meaning by a signal. Signals gain meaning when they are stored.
- Mathematically, signals are represented as functions of one or more independent variables.
- System: Units that receive, process, and transform input signals into to obtain other signals. Systems are modeled mathematically as well as physically (simulation, optimization, analysis, synthesis, calibration, matematically models, functions, algorithms).
- The inputs and outputs of systems can be mathematical functions (virtual systems - software) or physical real-world signals.



a) Signal Generator



b) Arithmetic operator, Attenuator, Amplifier, Buffer, …

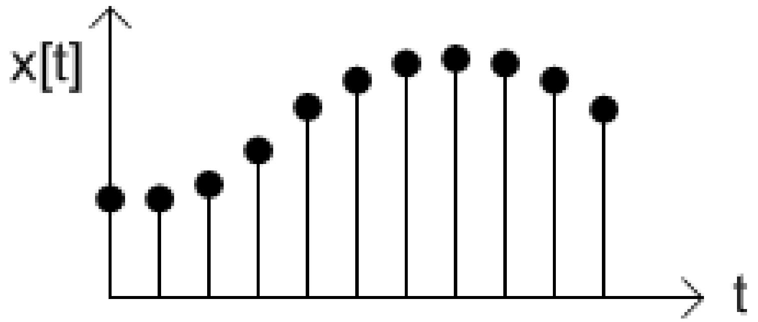


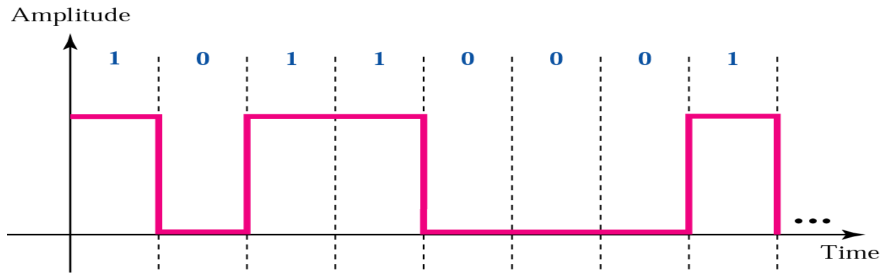
c) Feedback, intelligent system

Classification of Signals in Communication

Signals are basically classified into two different types as follows:

- Continuous time signals: A signal with constant amplitude and time is known as a continuous time signal or analog signal. A signal will have a value at any time. An analog signal is a continuous signal and is often represented by a f(t). Analog signals are created by mixing sinusoidal signals.
- Discrete time signals: The output signal obtained by measuring the input levels as value at same intervals. A discrete-time signal is derived from the input signal by sampling. Samples taken from the discrete-time signal are converted to a digital signal by quantization. Each discrete signal value is represented by a specific group in the binary number system. A digital signal is a discrete time signal, binary signal. An On/Off light switch applies a fixed, predetermined voltage.

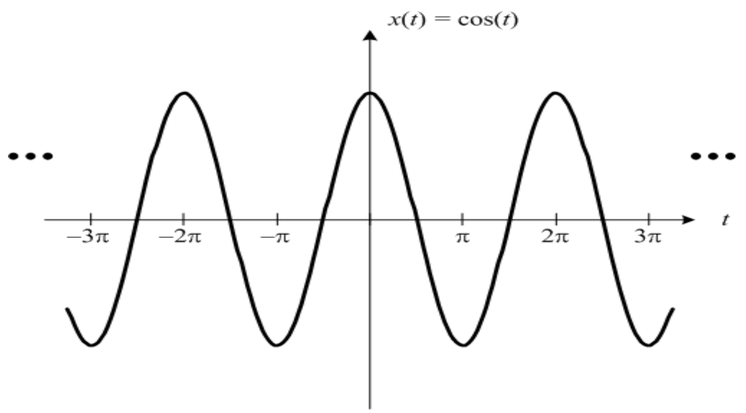




Fundamentals of Analog Signals

- Analog Signal is composed a lot of sinusoidal signals. Components:
  - Time, t [sec]
  - Amplitude, A [Unit, Volt, Amper, Watt]
  - Frequency, f [Hz=1/sec]
  - Phase, θ [degree, rad; rad=pi*degree/180]
  - Wavelength, λ=c/f [m]

Analog signals: These are signals whose amplitude, frequency and phase change over time.



- Sinusoidal signal

A continuous time sinusoidal signal is expressed as follows.

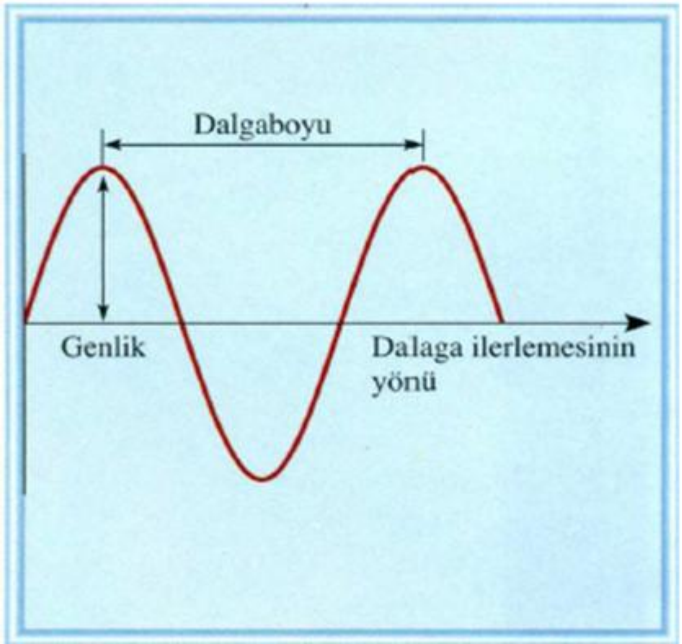
$X(t)=A*Cos(wt + \Psi)$

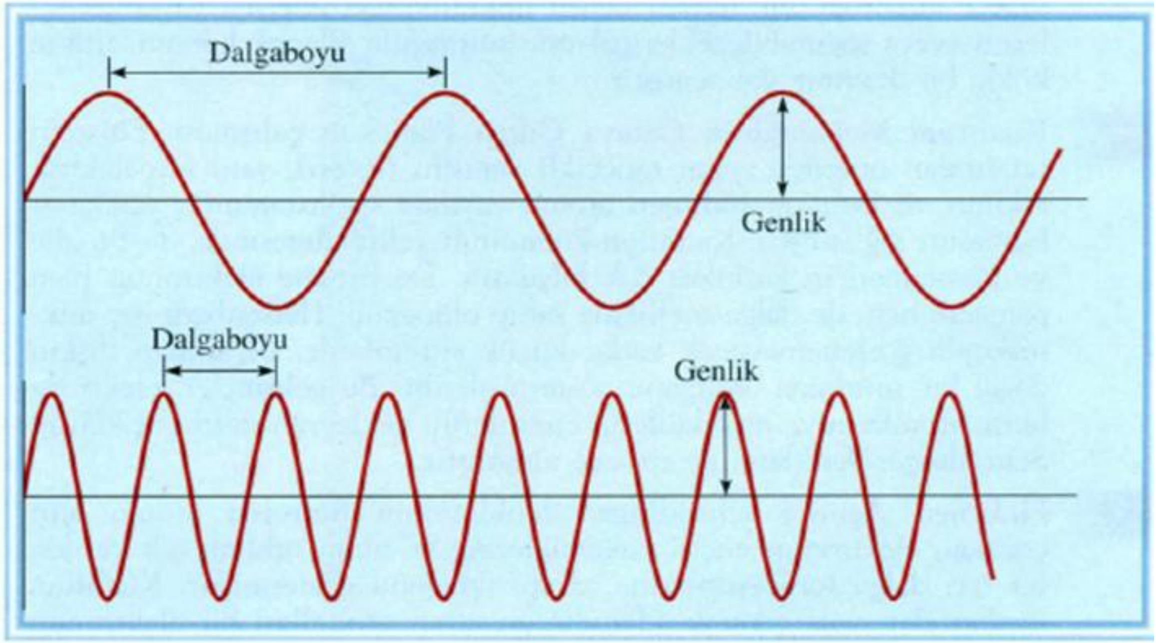
  - Time, t [sec]
  - Amplitude, A [Unit, Volt, Amper, Watt]
  - Frequency, f [Hz=1/sec]
  - Phase, Ψ [degree, rad; rad=pi*degree/180]
  - Wavelength, λ=c/f (meter)
  - Period, T=2π /w (second)
  - Frequency, f=1/T , Herts (Hz)=1/sec
  - w=2πf

Akustik Sinyaller
(Ses Dalgaları)

Dalga Kavramı

- Dalgalar, ses dalgaları, elektromanyetik dalgalar, ...
- Kuantum kavramın anlayabilmek için dalgalar hakkındaki kavramların çok iyi bilinmesi gerekir.
- Dalga, titreşmeyle enerjisini aktaran bir olgu olarak düşünülebilir.
- Bir dalganın hızı dalganın türüne ve yol aldığı ortama bağlıdır.
- Ardışık dalgalarda eş noktalar arasındaki mesafeye dalga boyu denir. Genellikle, λ ile tanımlanır.
- Bir dalganın fekansı ise belirli bir noktadan bir saniyede geçen dalga sayısıdır. Genellikle f ya da υ ile gösterilir.
- Bir dalgaya ilişkin genlik (ya da yükseklik), dalganın orta çizgisinden tepesine ya da çukuruna olan dik mesafe olarak tanımlanır.





Akustik Dalgalar

- Akustik dalgaları aldıkları çeşitli enerjiler sayesinde titreşim hareketi yaparlar ve sahip oldukları enerjiyi bulundukları ortamdaki taneciklere aktararak taneciklerin kinetik enerji kazanmasını sağlarlar. Kinetik enerji kazanan tanecikler, etrafındaki diğer taneciklere çarparak diğer tanecikleri de titreştirirler. Yayıldıkları ortamdaki taneciklerin titreşim enerjilerini birbirlerine aktarması sonucu akustik dalgaları oluşur ve akustik dalgalar kinetik enerjinin taşınmasını sağlar.
- Akustik dalga: Hava, gaz, sıvı ya da katı materyaller gibi ortam içerisinde yayılan bir dizi basınç darbesi veya elastik yer değiştirmelerinden oluşan uzunlamasına dalgadır.
- Akustik dalga elastik bir dalgadır. Elastik madde çekildikten veya bastırıldıktan sonra orijinal şekline veya boyutuna dönebilir.
- **Piezoelektrik malzemelerin** özelliği, kristal yapılarına bağlı olarak bir kuvvet uygulandığında elektrik akımı üretmeleri; elektrik alan etkisi altında kaldıklarında da biçim değiştirmeleridir. Tersi de doğrudur.
- Bir cismin sabit bir nokta etrafında yaptığı ileri – geri gidip gelme hareketine **titreşim** hareketi denir.

Ses Dalgaları

- Ses dalgası: İnsan kulağının duyulabilir aralığına düşen frekans dalgalar ile sınırlıdır. Yaklaşık 20Hz ila 20kHz arasındadır. 20kHz'den büyük frekans dalgaları ultrasonik dalgalardır.
- Sesin havada ortalama yayılma hızı=342 m/s. Yayılma hızı hava sıcaklığı ve diğer koşullara bağlı olarak değişim gösterir.
- Sesin yayılma hızı ortam özellikleriyle ilgilidir. Ortamın özgül ağırlığı ve esneklik katsayısı önemlidir.
- Sıcaklık yükseldikçe ses hızı artar. Sesin yayılma hızı; katı ortamlarda, gaz ortamdan daha fazladır.
- Ses dalgası: Nesnelerin titreşiminden meydana gelen ve hava, su, katı gibi uygun bir ortam içerisinde bir yerden başka bir yere, sıkışma (compressions) ve genleşmeler (rarefactions) şeklinde ilerleyen bir dalgadır. Ses, bir basınç dalgasıdır.
- Ses dalgaları boşlukta yayılmaz. Görsel köpürür. Ses dalgalarının oluşabilmesi için bir ses kaynağı, sesin içerisinden geçeceği bir ortam ve bir alıcı gerekir.
- Ses dalgaları su dalgalarına benzer fakat su dalgaları gibi görünen dairesel dalgalar şeklinde değil, görünmeyen küresel dalgalar şeklinde yayılır. (Tribündeki seyircilerin dalga hareketine benzer).

Ses Dalgalarının Genel Özellikleri

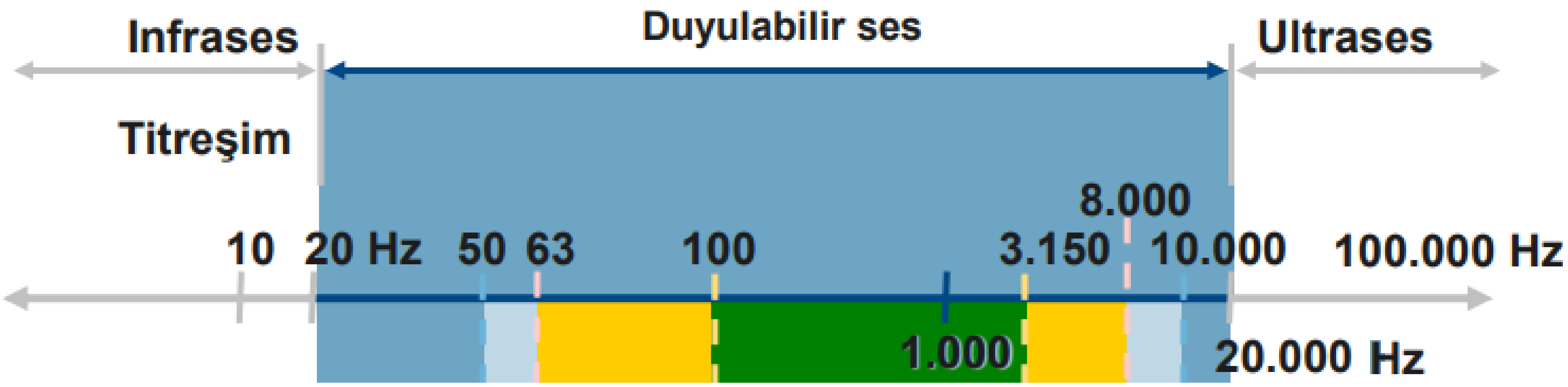
Ses sinyallerinin bileşenleri: Frekans, genlik, faz, dalga boyu ve periyod gibi özellikleri vardır.

- Sesin Şiddeti ve Desibel Ölçeği
- Ses Basınç Seviyesi
- Sesin Kalitesi: Tanıma, Anlama, Hissetme ve Gecikme
- Ses dalgaları kırılma, yansıma ve girişim özelliklerini gösterirler.
- Yansıtıcı yüzeylerde aynı zamanda yutulma da olur.
- **Sesin** maddeler tarafından emilmesine (tutulmasına) sesin soğurulması denir.

Ses titreşimlerinin(frekans) malzemelerde yayılma hızı

Medium	velocity m/sec
air (20 C)	343
air (0 C)	331
water (25 C)	1493
sea water	1533
diamond	12000
iron	5130
copper	3560
glass	5640

Ses akustiğinde frekans aralığı



- Ses ötesi (Infrasound); 20 hertz ve altındaki ses dalgalardır.
- İşitilebilir ses; 20Hz-20 000 hertz arasında olan ses dalgalardır.
- Ultra ses (Ultrasound); 20KHz (20.000 hertz) den 15MHz'e kadar olan ses dalgalarıdır. Bu dalgalar anne karnında bebek görüntüleme ve böbrek taşı kırmada kullanılır.
- Hiperses(Hypersound): frekansları 15MHz'den yukarı olan ses dalgalarıdır.
- 10^9-10^{13} Hz frekans dalgalarına hipersonik dalgalar denir.

Sesin Sınır Frekans Aralığı

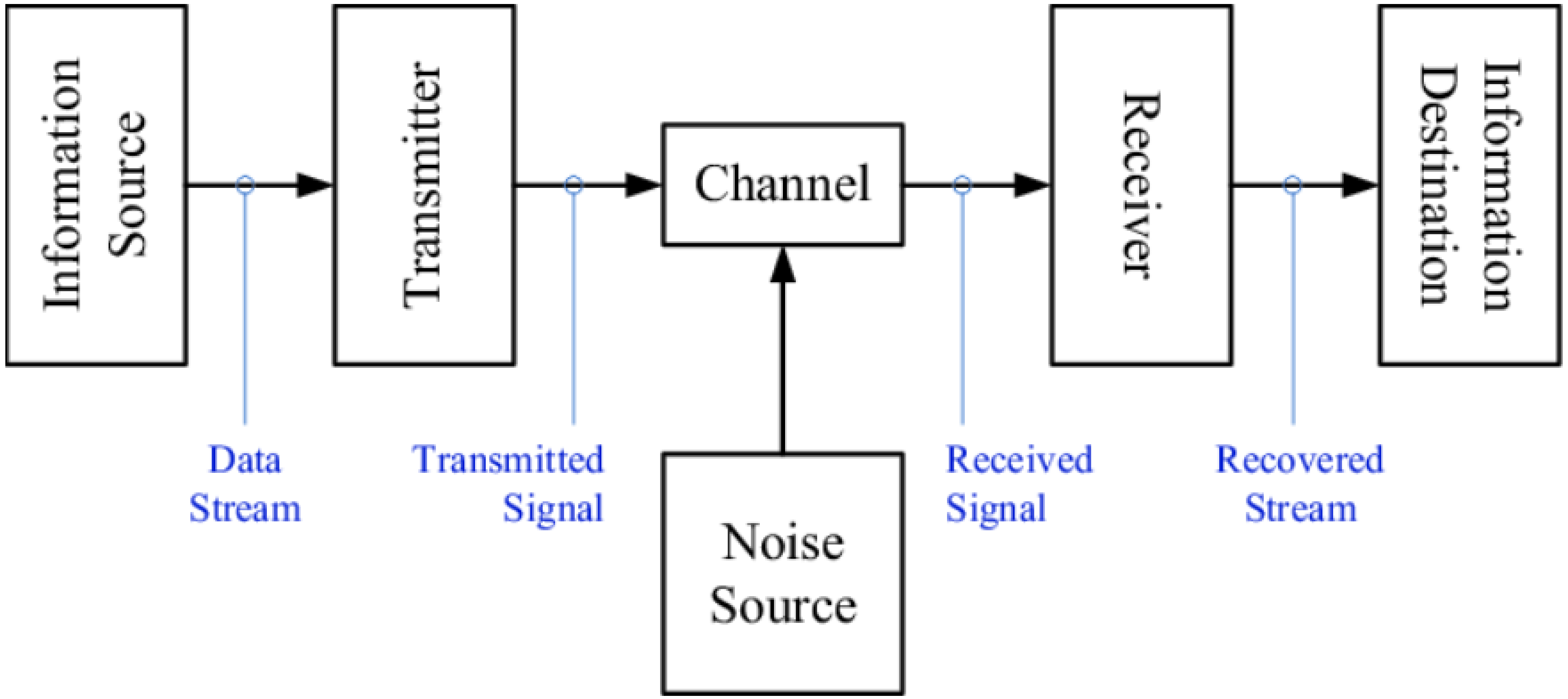
- Sesin işitme frekans aralığı, 20Hz-16kHz dir. Konuşma 100Hz-7kHz aralığındadır.
- Ses dalgaları mikrofon yardımıyla elektriksel analog sinyale dönüştürülür. Peryodik sinüsoidal sinyallerden oluşur. İletim için kolayca elektromanyetik sinyale dönüştürülür
- Sesin sınır frekans aralığı kaliteyi belirleyen minumum sınır değerlerini sağlar: (300Hz- 3400Hz)
- Kaliteyi belirleyen minumum sınır değerleri: Tanıma, Anlama, Hissetme, Gecikme.
- Haberleşme tteknolojilerinde sesin sınır frekans aralığı: 4KHz dir.
- Ses, bir noktadan diğer bir noktaya iletilmek için elektrik sinyaline dönüşür.
- Analog sinyalin karekteristikleri: Genlik, frekans (f), Dalga boyu (λ), Faz

İşitme

- İnsan kulağı, nominal olarak 20 Hz (0.02 kHz) ila 20.000 Hz (20 kHz) arasındaki sesleri duyabilir. Üst sınır yaşla azalma eğilimindedir; yetişkinlerin çoğu 16 kHz'in üzerinde duyamıyor.
- İdeal laboratuar koşullarında müzik tonu olarak tanımlanan en düşük frekans 12 Hz'dir.
- 4 ila 16 Hz arasındaki tonlar vücudun dokunma duyusuyla algılanabilir.
- 111 Hz ile 121Hz arası ses dalgalarının duygusallık oluşturduğu gözlenmiştir.
- Kulakta duymak kadar kemik ve dokularda da titreşen sesler duyulur. Tanımlayamadığınız başka bir yerden bir ses geldiğini hissederseniz transa bile geçebilirsiniz.
- Koku parçacık yayılımıdır.

Transmission Media (Channel)

Block Diagram of a Basic Communication System



Signal Transmission Media

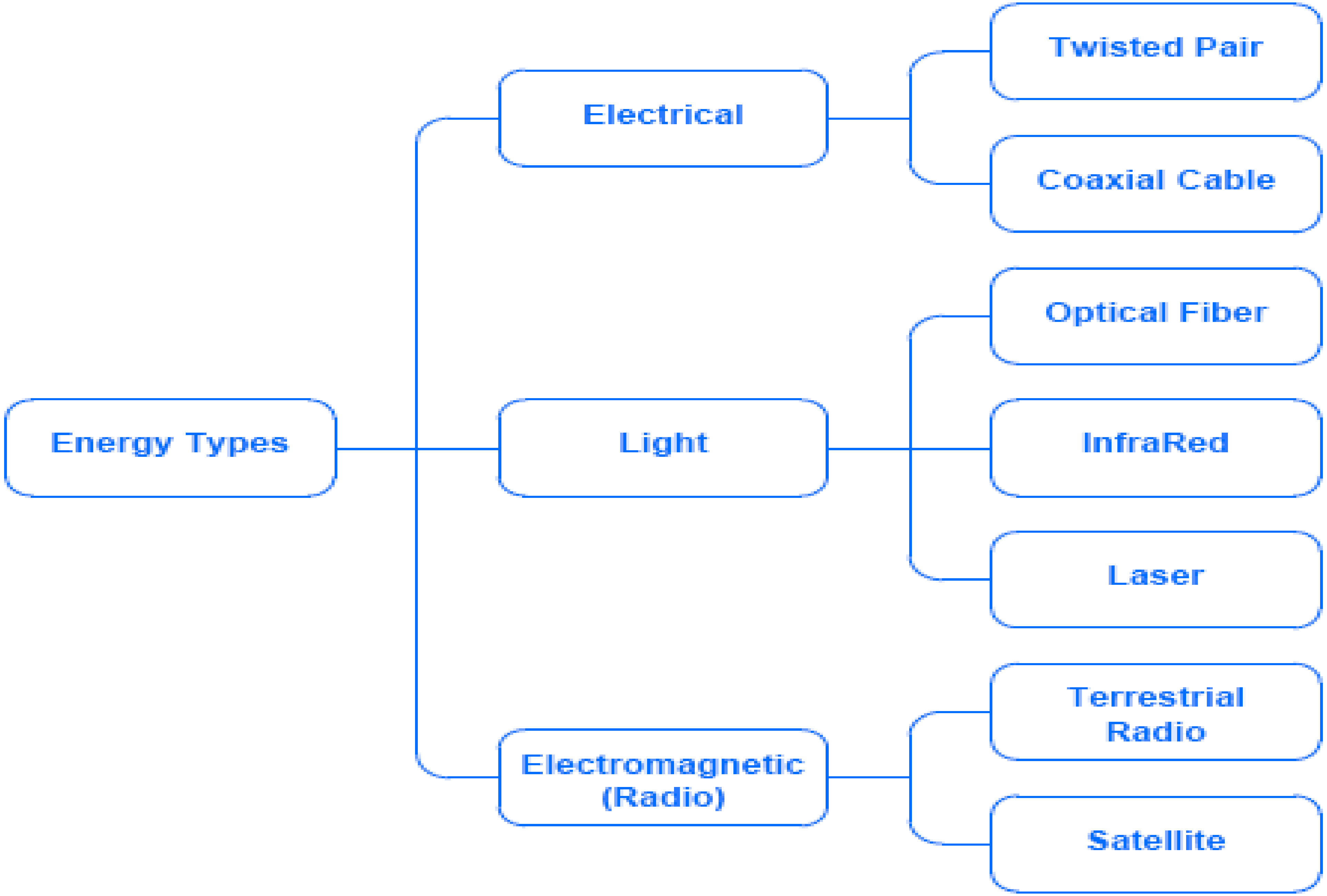
- Communication Mediums
  - Conductor Twisted Wire (2/4 Wire): electrical signal
  - Fiber Optic Cables: light on or off
  - Coaxial Cables: electrical signal
  - Space, Air : Electromagnetic signal
  - Special Environments (For example, water is a medium for sonar): Acustic signal
  - Laser: light on/off
  - Infrared: Electromagnetic signal

- Question: Rank transmission media from best to worst based on the number of noise sources that disrupt the signal: fiber, conductive cable, air. Question: Because signals rapidly attenuate and degrade as they travel through communication media, digital signals cannot be transmitted through communication media. They are transmitted as analog signals. A modem is used to convert or simulate a digital signal into an analog signal. A modem is a system that allows signals to be transmitted without being affected by the environment.

Communication Media (Channel)

- Medium: It involves encoding data as an electrical and electromagnetic signal and sending these signal over a transmission medium. Transmission medium are divided into two groups:
  - Guided medium: communication follows a specific path (like a cable)
    - Twisted pair (2/4 wire), optical fiber, coaxial cable
    - Telephone line, two wires/four wires; UTP cable: four twisted pair wires
  - Unguided medium: communication does not follow a specific path (like electromagnetic wave transmission)
    - Air, water, vacuum (Infrared, Thermal communication, Optical light)
- The most fundamental feature of fiber cable among communication media is broadband, high-data transmission.
- Connections are categorized by the type of energy used for transmission:
  - Electrical energy (electrical signal) is used in wires.
  - Radio frequency (electromagnetic signal) is used for wireless transmission.
  - Light is used for optical fibers and lasers.

Taxonomy by Forms of Energy



Physical Transmission Media

Type of Cable and LAN	Transfer Rates
Twisted Pair	
• 10Base-T (Ethernet)	10 Mbps
• 100Base-T (Fast Ethernet)	100 Mbps
• 1000Base-T (Gigabit Ethernet)	1000 Mbps
• Token ring	4 - 16 Mbps
Coaxial Cable	
• 10Base2 (ThinWire Ethernet)	10 Mbps
• 10Base5 (ThickWire Ethernet)	10 Mbps
Fiber-Optic Cable	
• 10Base-F (Ethernet)	10 Mbps
• 100Base-FX (Fast Ethernet)	100 Mbps
• FDDI (Fiber Distributed-Data Interface) token ring	100 Mbps

Wireless channel capacity:

Channel	Transfer Rates
Broadcast radio	Up to 2 Mbps
Microwave radio	45 Mbps
Communications satellite	50 Mbps
Cellular radio	9,600 bps to 14.4 Kbps
Infrared	1 to 4 Mbps

100 Mbps is how many bits per sec?

Which is bigger:
10,000 Mbps, 0.01Tbps or 10Gbps?

- UTP (Unshielded Twisted Pair),
- STP (Shielded Twisted Pair),
- FTP (Foiled Twisted Pair),
- S-FTP (Shielded - Foiled Twisted Pair),
- These type cables have 4 twisted pair cables

If you plain or project the critical infrastructure, you must use S-FTP or fiber cable

Advantages of fiber optical cables and systems

- Enormous **capacity**: every fiber core has 1.3 μm ... 1.55 μm allocates bandwidth of 37 THz!!
- Low transmission **loss**
  - Optical fiber loss can be as low as 0.2 dB/km. Compare to loss of coaxial cables: 10 … 300 dB/km !
- Cables and equipment have **small size and weight**
  - A large number of fibers fit easily into an optical cable
  - Applications in special environments as in aircrafts, satellites, ships, industrial areias, intercities or countries
- **Immunity** to interference
  - Nuclear power plants, hospitals, EMP (Electromagnetic pulse) resistive systems (installations for defense)
- Electrical **isolation**
  - electrical hazardous environments
  - negligible crosstalk
- Signal **security**
  - banking, computer networks, military systems
- Silica fibers have **abundant raw material**

Corning's standard submarine cables can have up to 144 fibers in a single cable housing

Figure 7.12 *Propagation modes*

1. Single-mode fiber
   Carries light pulses along single path.
2. Multimode fiber
   Many pulses of light travel at different angles

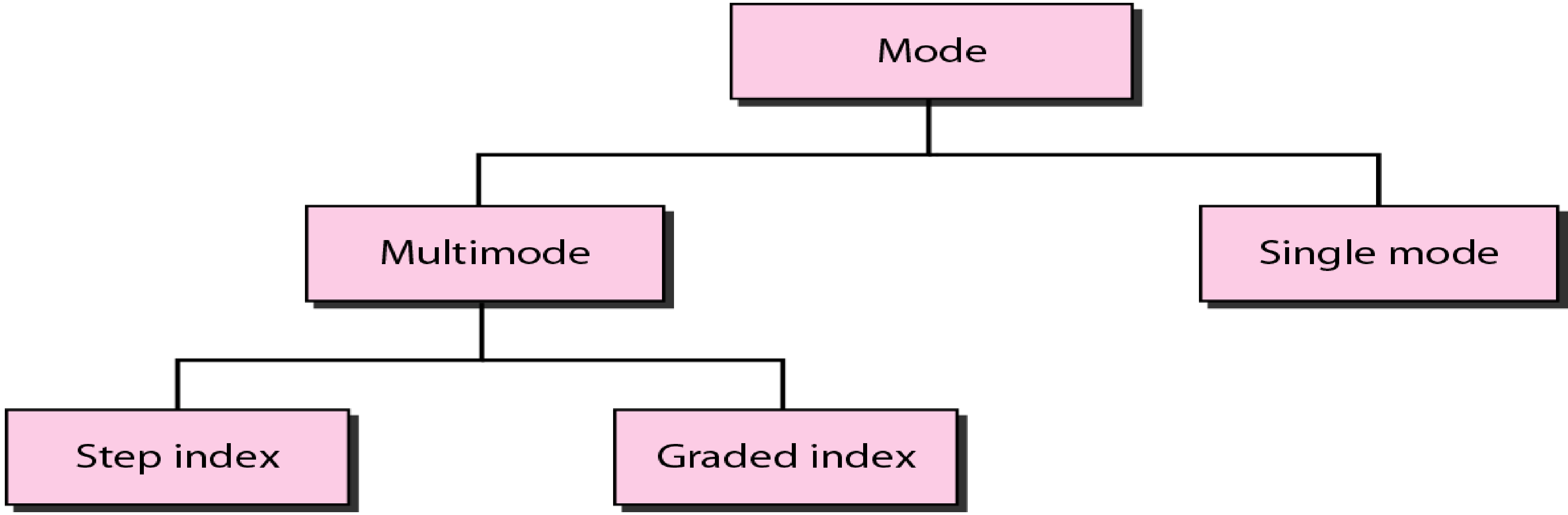
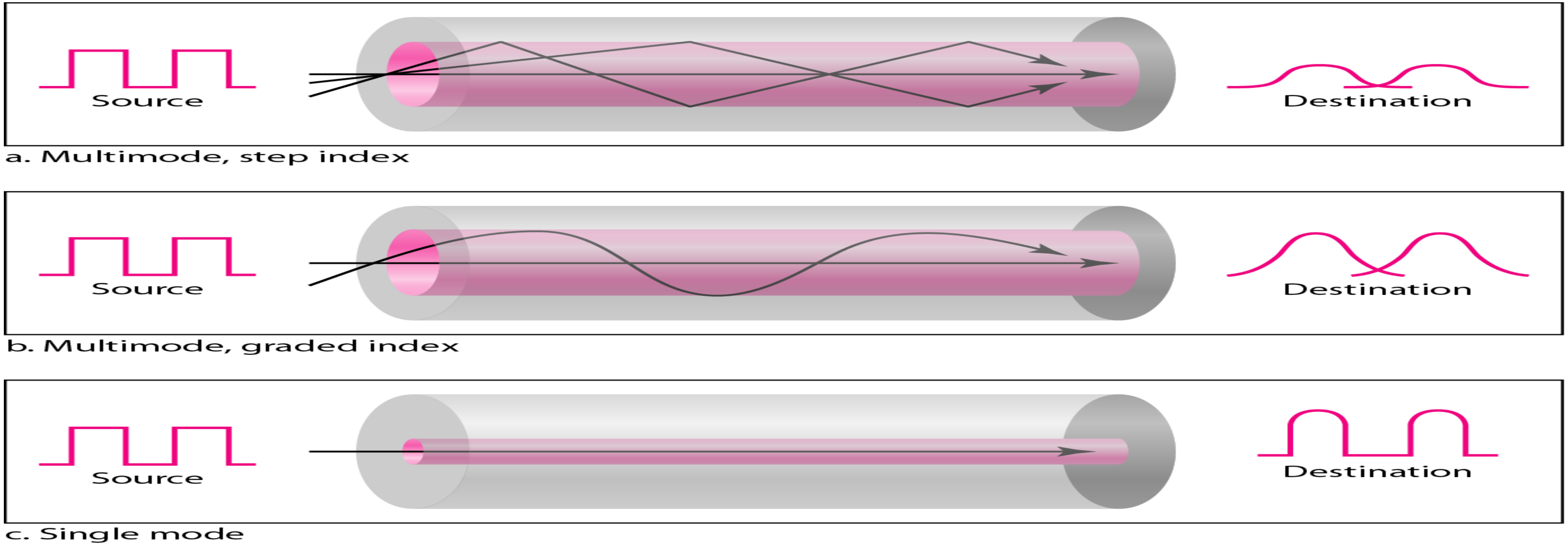
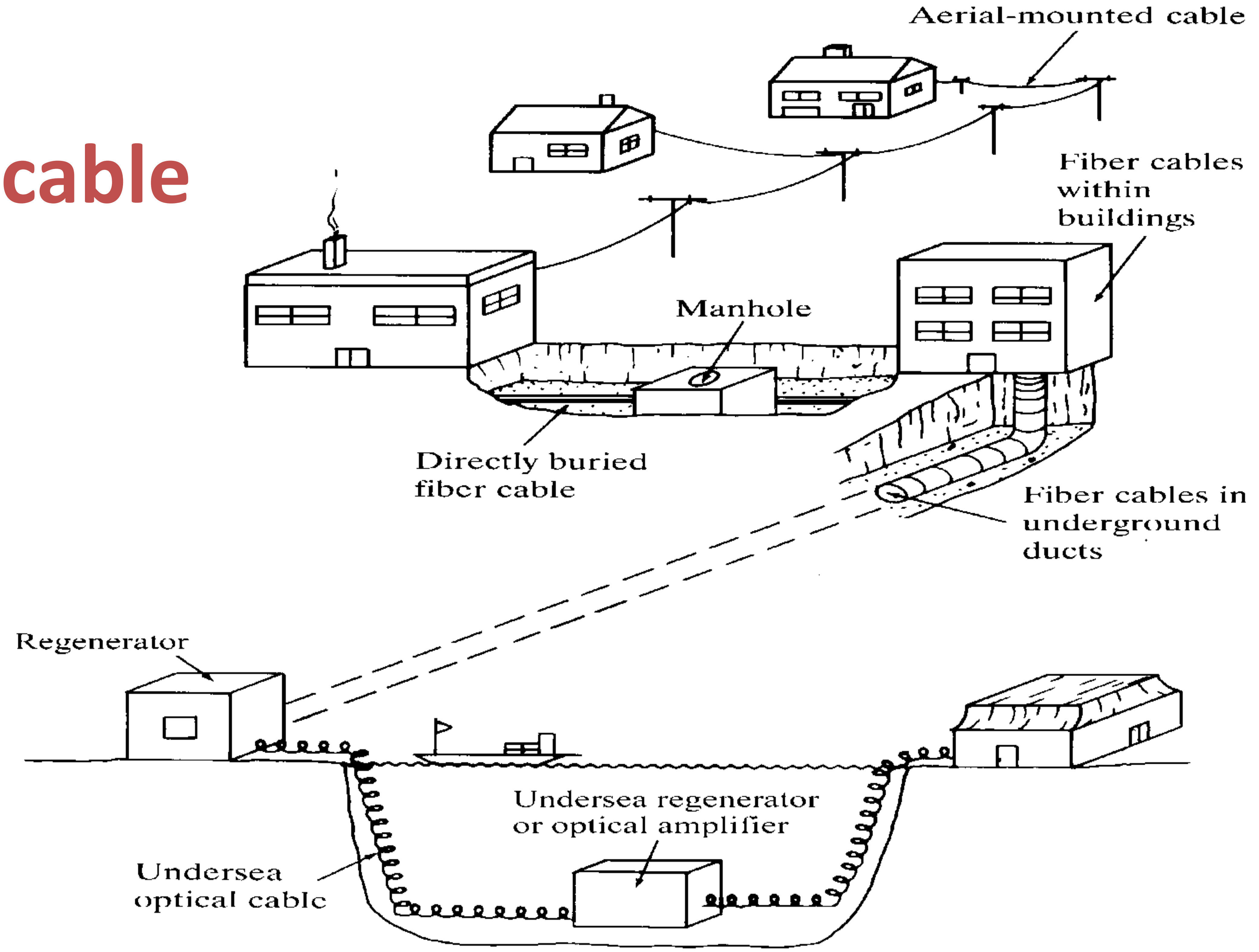


Figure 7.13 *Modes*



Optical fiber cable installations



Wireless Transmission Media

- Broadcast Radio
  - Distributes signals over long distances through the air
  - Uses antennas
  - Typically for fixed locations
  - Can be short-range
- Cellular Radio
  - A form of radio broadcasting used for mobile communication
  - High-frequency radio waves for transmitting voice or data
  - Frequency reuse
- Microwaves
  - Radio waves provide high-speed transmission.
  - Point-to-point (cannot be blocked).
  - Also used for satellite communication.
- Infrared (IR)
  - Wireless transmission media that sends signals using infrared light- waves

Frequency Spectrum

- It is the classification of signal frequencies based on their wavelengths in electromagnetic waves, frequencies change from low Hz to high giga or tera Hz.
- Communication systems are grouped according to their frequency spectrum.
- **Electromagnetic (EM) waves** are oscillations of **electric** and **magnetic** fields that travel through space at the **speed of light** ($\approx 3\times10^8$ m/s in vacuum).
- They can travel through vacuum.
- Each EM wave has:
  - a **frequency (f)** — how many oscillations per second (in hertz, Hz),
  - a **wavelength (λ)** — distance between two wave peaks (in meters), and they're related by: $\lambda = c/f$,
- EM Wavelength, $\lambda = c/f$, c: speed of light = 3*10^8 m/sec, f: frequency (Hz = 1/sec)
- In guided media, wavelength, $\lambda = v/f$, v: speed of propagation of the signal in the medium (m/sec)

The Electromagnetic Spectrum

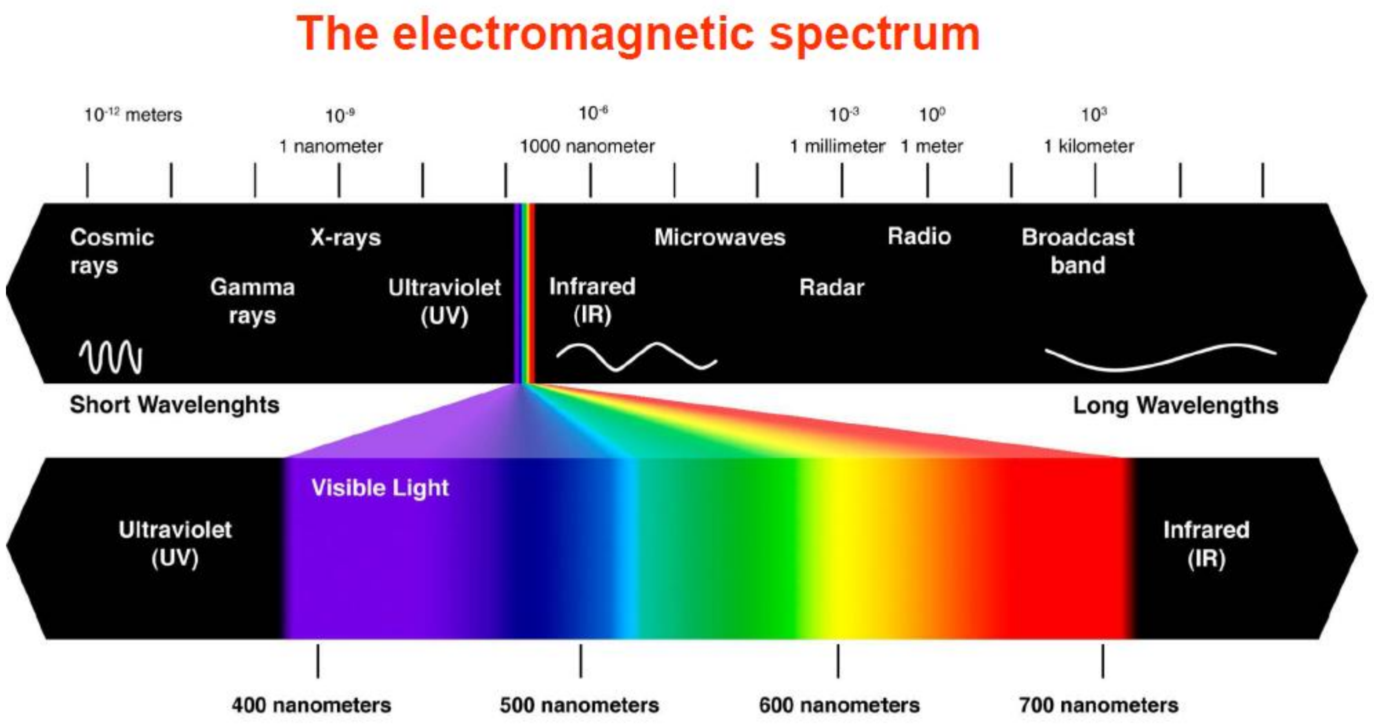
Type of Radiation	Frequency Range (approx.)	Wavelength Range	Typical Uses / Examples
Radio Waves	< 300 MHz (10^6–10^9 Hz)	> 1 m	AM/FM radio, TV, Wi-Fi, radar
Microwaves	300 MHz – 300 GHz	1 m – 1 mm	Microwave ovens, satellites, 5G
Infrared (IR)	300 GHz – 430 THz	1 mm – 700 nm	Remote controls, heat sensors
Visible Light	430–770 THz	700–400 nm	Human vision (ROYGBIV colors)
Ultraviolet (UV)	770 THz – 30 PHz	400–10 nm	Sterilization, black lights
X-Rays	30 PHz – 30 EHz	10–0.01 nm	Medical imaging, security scanners
Gamma Rays	> 30 EHz (10^{20} Hz)	< 0.01 nm	Nuclear reactions, cosmic sources

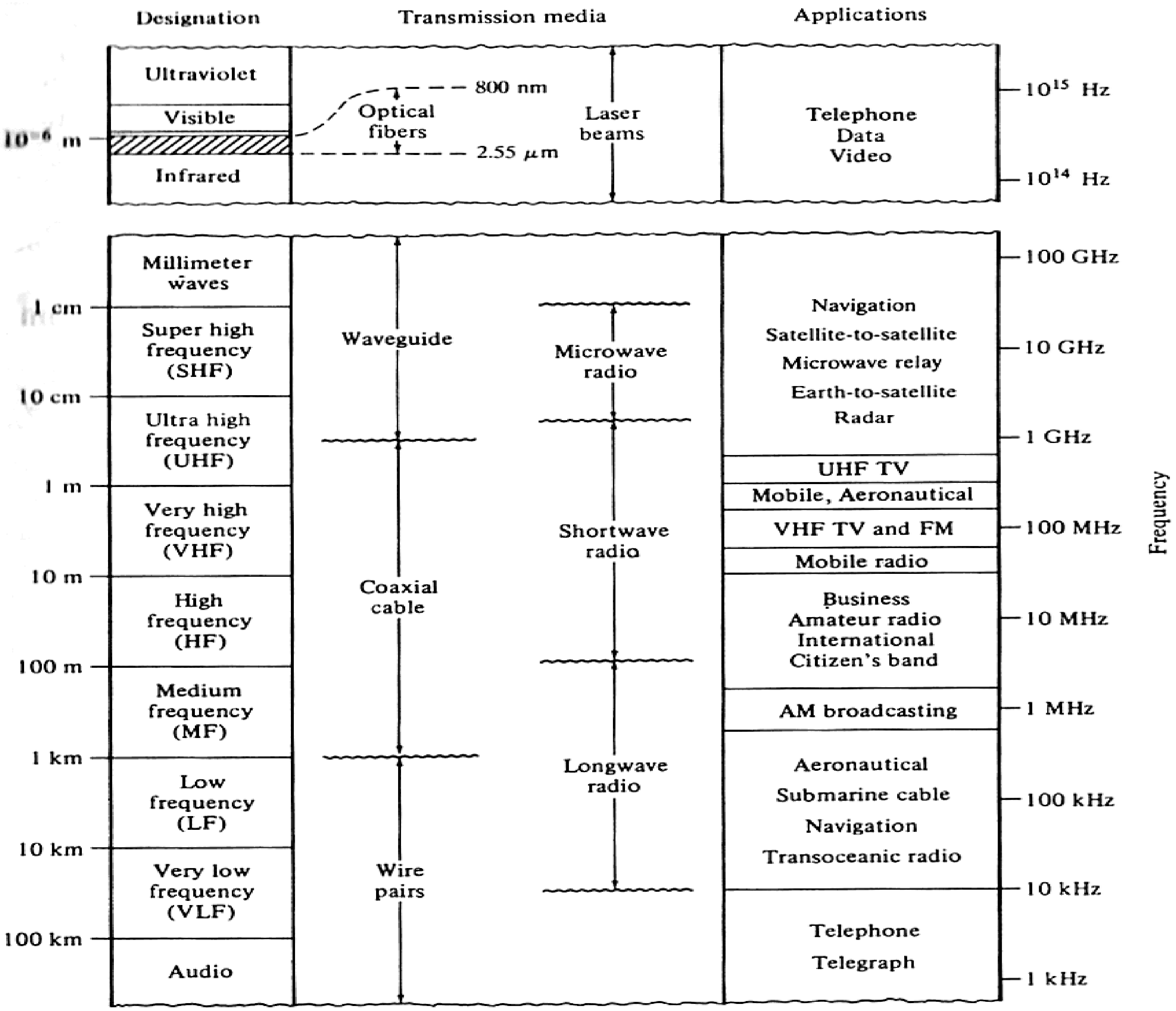
How the Spectrum Is Organized

- The electromagnetic spectrum is the entire range of EM wave frequencies — from the longest radio waves to the shortest gamma rays.
- The EM spectrum isn't divided by physics itself — it's continuous — but we group frequencies based on **how they interact with matter**:
  - **Low frequencies (radio–microwave):** cause **electron oscillations** → used for communication.
  - **Mid frequencies (infrared–visible):** cause **molecular vibrations** → felt as heat or seen as light.
  - **High frequencies (UV–gamma):** cause **ionization** → can damage DNA or produce X-rays.

Frequency Ranges (Spectrume) in Telecommunications

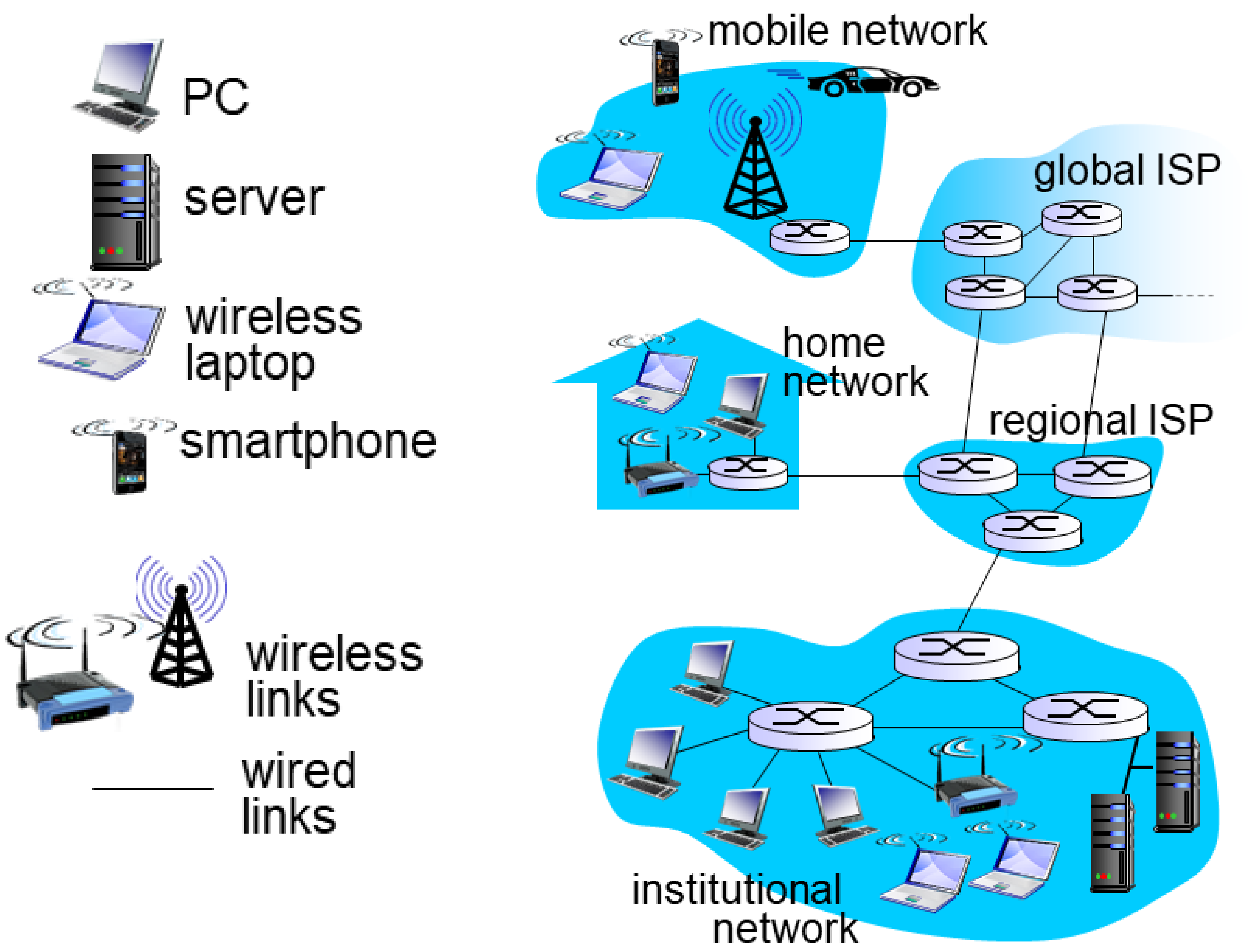
- Increase of telecommunications capacity and rates requires higher carrier frequencies





Block Diagram of a Basic Network System

- millions of connected computing devices:
  - *hosts* = *end systems*
  - running *network apps*
- *communication links*
  - fiber, copper, radio, satellite
  - transmission rate: *bandwidth*
- *Packet switches:* forward packets (chunks of data)
  - *routers* and *switches*

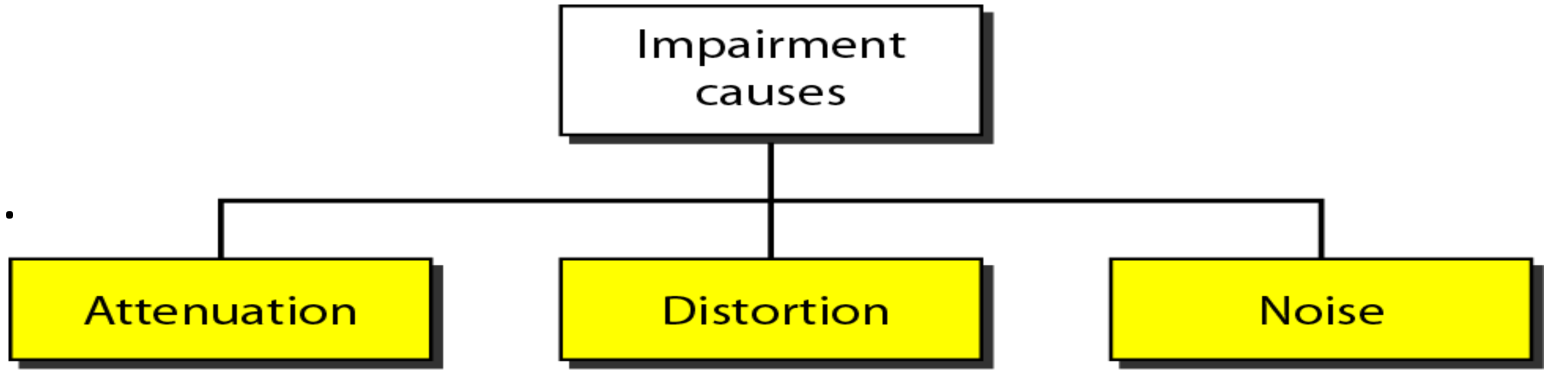


Main equipments at network systems are ethernet switches and routers or gateways

Impairment Causes

The signals transmitted in communication environments are different from the signal originating from the transmitter.

As signals travel from transmitter to receiver,



- They travel through imperfect environments.
- They weaken.
- They are trapped in noise.
- They are delayed. Time = Distance / Speed.
- They interact with disruptive signals.
- Interference: Interference, mixing, blocking.
- Harmonics: Under the influence of nonlinear loads on semiconductor elements, current and voltage waveforms are formed by the sum of a periodic sinusoidal wave and other sinusoidal waves of varying frequency and amplitude. Signals other than the fundamental wave are called harmonic signals.
- Distortion, in its most general definition, is the distortion or change of a signal from its original state.

Noise

- Noise: Unwanted signals that disrupt signals. Noise is random, unwanted electrical energy that enters communication systems and environments via the communication medium and interferes with the message being transmitted.

- Noise (also called random electromagnetic radiation or electrical signal) permeates the environment. Even communication systems produce small amounts of electrical noise as a side effect of normal operation. Noise can interfere with the signals used for communication.

- When electromagnetic radiation hits metal, it produces a small signal. Because metal absorbs radiation, it also acts as a shield, preventing noise from reaching the cables. Therefore, placing enough metal between a noise source and a communication medium can prevent noise from interfering.

- There are different types of noise:
  - Induced: Motors and other devices act as transmitter and receiver antennas.
  - Crosstalk: Unwanted signal transfer between communication channels. Unwanted signal propagation between two cables. A signal from one line is received by the other.
  - Impulse: Sudden spikes caused by power lines, lighting, etc. Irregular pulses or spikes. For example, external electromagnetic interference. It is short-lived and high amplitude.

Noise Sources -1

Noise sources that disrupt signals can be examined in four main groups: natural, artificial, electronic element and channel-sourced.

1. Natural Noise Sources:
   - Atmospheric noise (storms, lightning, thunder, climatic conditions): This is a significant disruptive factor, especially in shortwave communications.
   - Cosmic noise: Electromagnetic waves originating from the Sun, stars, and the Milky Way.
   - Thermal (Johnson-Nyquist) noise: It creates an extraneous signal from the random motion of electrons in conductors. It is generated by the thermal radiation of electrons. It is also called white noise. It is present at all temperatures.

2. Human-Sourced (Artificial) Noise:
   - Industrial noise: Motors, generators, electrical appliances, fluorescent lamps, transformers, and power lines.
   - Radio frequency interference (RFI): Radio and TV transmitters, cell phone base stations, Wi-Fi devices.
   - Switched hhigh power supplies and digital circuits: Produce high-frequency interference.

Noise Sources-2

3. Semiconductor and Electronic Component Noise:
   - Shot (tunneling) noise: Caused by irregular carrier transitions in semiconductors such as diodes and transistors.
   - Flicker (1/f) noise: Noise seen at low frequencies (especially <100 Hz) and significant in transistors and resistors.
   - Burst (popcorn) noise: Sudden signal jumps due to manufacturing defects in semiconductors.

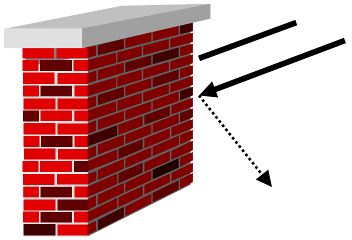
4. Channel-borne Noise:
   - Multipath propagation: Interference occurs when a signal reaches the receiver via different paths.
   - Attenuation, refraction, scattering, diffraction and reflection: The reflection of the signal from walls and objects, especially in wireless communication.
   - Intermodulation noise: Farklı frekanslardaki sinyallerin birbirine karışarak yeni parazit sinyaller oluşturması. Bir ortamı paylaşan orijinal frekansların toplamı ve farkı olan istenmeyen sinyallerdir.

Negative Factors Affecting Wireless Communication Environments

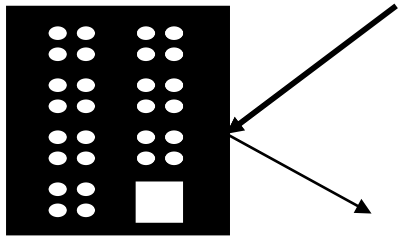
- Antenna mounted surface vibration
- Free-Space Loss (Zayıflama): Signals disperse with distance
- Atmospheric Absorption: Water vapor and oxygen contribute to signal loss. Steam, Cold Air, Fog; Weakens, Disperses, Strengthens.
- Multipath: Obstacles reflect signal creating multiple copies
- Refraction: Change in signal speed due to atmospheric conditions
- Thermal Noise: White noise, arises from thermal activity of devices
- Scattering, Reflection
- Diffraction: Wave bends as it passes an obstacle.

EM Signal propagation

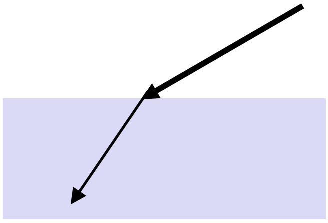
- Propagation in free space always like light (straight line)
- Line of sight (LOS): Direct View: The antennas can see each other directly without any obstruction.
- Receiving power proportional to $1/d^2$ in vacuum – much more in real environments
  (d = distance between sender and receiver)
- Receiving power additionally influenced by
  - fading (frequency dependent, weakening of communication due to weather conditions)
  - shadowing
  - reflection at large obstacles
  - refraction depending on the density of a medium
  - scattering at small obstacles
  - diffraction at edges



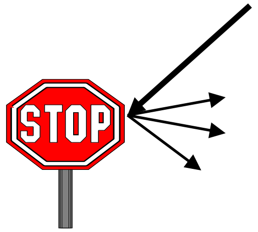
shadowing



reflection



refraction



scattering

diffraction

Logarithms

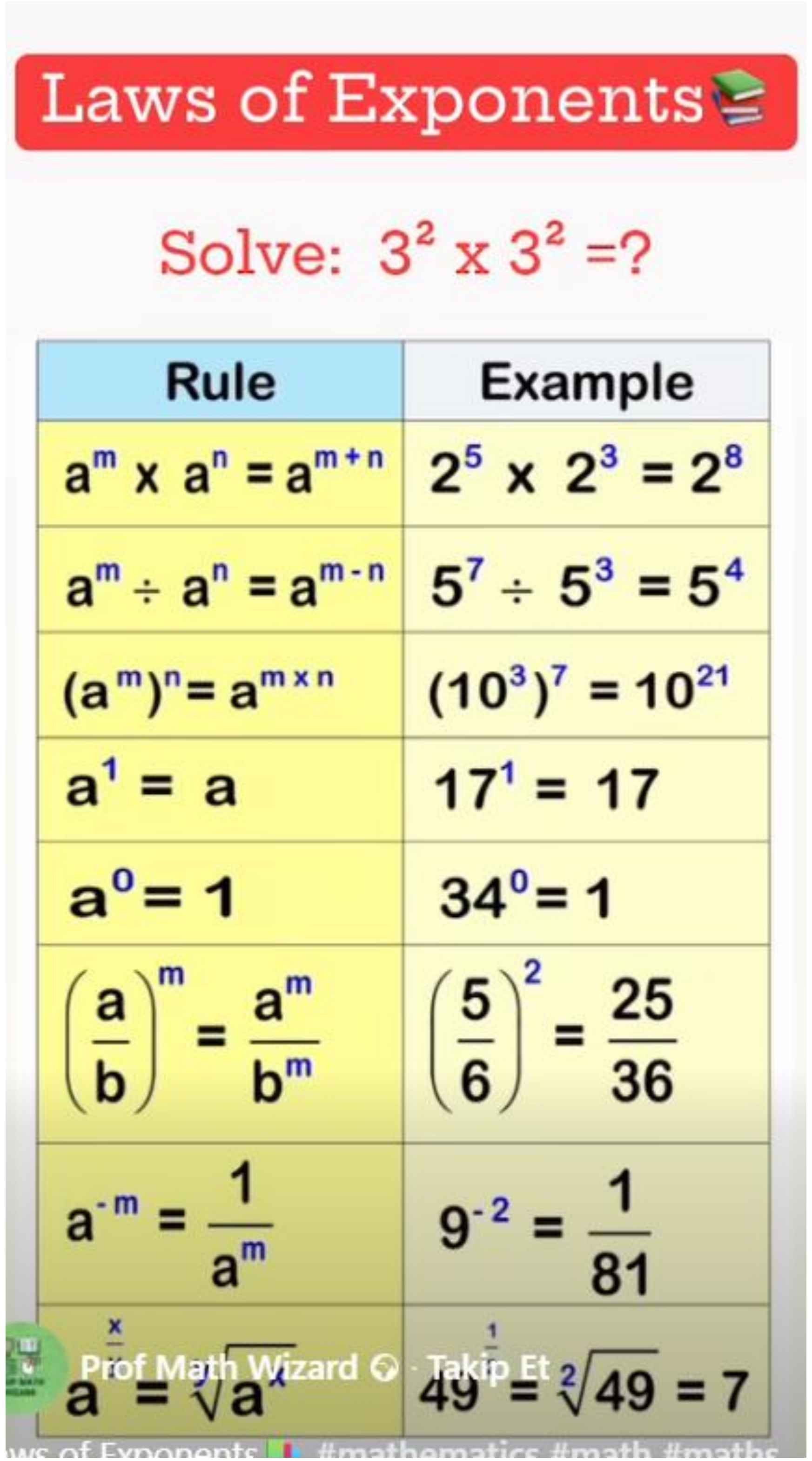
Logarithm Rules

Rules	Mathamatical Form
Product Rule	$\log_b(xy) = \log_b x + \log_b y$
Quotient Rule	$\log_b\left(\frac{x}{y}\right) = \log_b x - \log_b y$
Power Rule	$\log_b(x^n) = n \log_b x$
Change of Base Rule	$\log_b x = \frac{\log_c x}{\log_c b}$ or, $\log_b x \cdot \log_c b = \log_c x$
Zero Rule	$\log_b(1) = 0$
Identity Rule	$\log_b(b) = 1$
Equality Rule	$\log_b x = \log_b y \Rightarrow x = y$
Inverse Rule	$b^{\log_b x} = x\log_b(b^x) = x$
Reciprocal Rule	$\log_b\left(\frac{1}{x}\right) = -\log_b(x)$

Logarithm of Multipliers

- Log(a*b*c*d)=log(a)+Log(b)+Log(c)+Log(d)
- log(a*b)=loga + logb; $\log a^n = n * \log a$
- 10 base logarithm, Log1=0, Log 2 ≈ 0.3, Log 3 ≈ 0.5, Log 5 ≈ 0.7, Log 7 ≈ 0.8, Log10=1
- Example: Log(420) =Log(10x7x2x3) =Log(10) + Log(7) + Log(3) + Log(2) = 1 + 0.8 + 0.5 + 0.3 = 2.6
- Example: Log(75)=Log(3*25)= Log(3) + Log(25) = Log(3) + 2log(5) =0.5+1.4=1.9

Exponential Operations



Laws of Exponents 📚

Solve: $3^2 \times 3^2 = ?$

Rule	Example
$a^m \times a^n = a^{m+n}$	$2^5 \times 2^3 = 2^8$
$a^m \div a^n = a^{m-n}$	$5^7 \div 5^3 = 5^4$
$(a^m)^n = a^{m \times n}$	$(10^3)^7 = 10^{21}$
$a^1 = a$	$17^1 = 17$
$a^0 = 1$	$34^0 = 1$
$\left(\frac{a}{b}\right)^m = \frac{a^m}{b^m}$	$\left(\frac{5}{6}\right)^2 = \frac{25}{36}$
$a^{-m} = \frac{1}{a^m}$	$9^{-2} = \frac{1}{81}$
$a^{\frac{x}{y}} = \sqrt[y]{a^x}$	$49^{\frac{1}{2}} = \sqrt[2]{49} = 7$

If the base is the same, the exponents are added.

$$(x^7)^2 = x^{14}$$

$$\left(x^{7^2}\right) = ???$$

=x^49

Gain, Attenuation, and Decibels

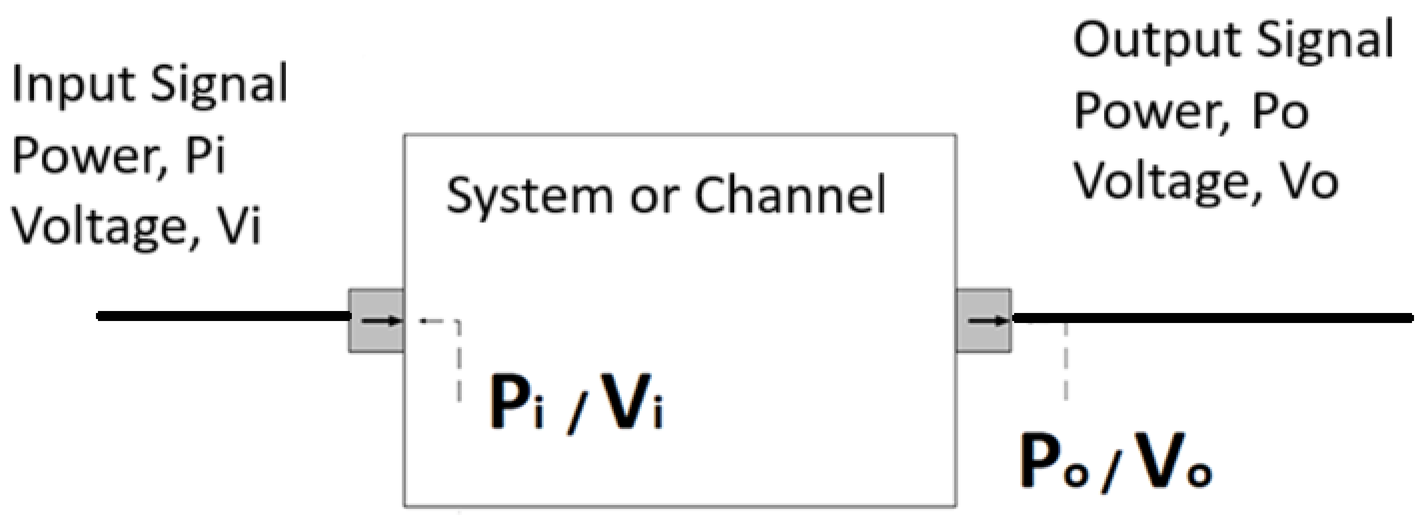
Gain and attenuation are very important feature in communication systems because as a signal is transferred from one point to another, it weakens, becomes distorted, and is delayed. How can gain and attenuatin calculated?

Gain, Attenuation

- To calculate gain, K where P_{in} (Watt) is the power input and P_{out} (Watt) is the power output.

$$\text{Gain } (K) = P_{out} / P_{in}$$

If Pout is greater than Pin, K>1, Signal is amplifing, There is gain.
If Pout is less than Pin, K<1, signal is weakening. There is attenuation.
If Pout equals Pin, K=1, There is a buffering, filtering, or impedance matching.



Example: Gain, Attenuation

Example: The Output power of an amplifier is 6 Watts (W). The power gain, K is 80. What is the input power (miliwatt)?

$K = P_{out} / P_{in}$ therefore $P_{in} = P_{out} / K$

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

Example: The Output power of an amplifier is 6 Watt (W). The input power ise 6 Miliwatt, Calculate K, Has the system gain or attenuatin?

Nots: Units must be same. If given vaules are different,

Convert maximum value to minumum value.

$K = P_{out}$ / Pin

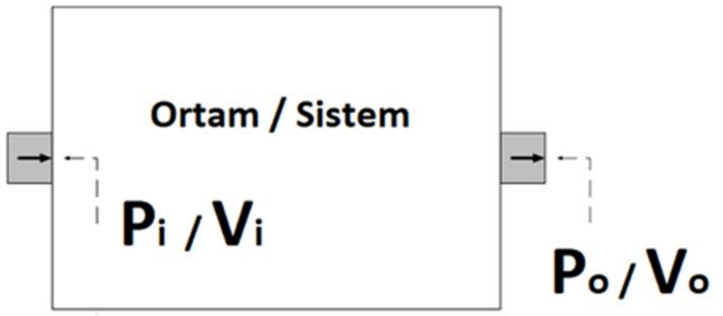
Pout=6 Watt=6*10^3 mili watt= 6000miliwatt

Pin=6 Miliwatt

K=6000/6=1000, grater 1, so the system has gain.

Gain and Attenuation can be shown in dB (desibel – logaritmik)

dB- decibel is a logarithmic expression, dimensionless number since it is defined as the ratio of two power levels.



KdB= $10Log(\frac{P_o}{P_i})$ dB

- The two power levels are proportionally related to each other.
- If Pout is greater than Pin, K>0, Signal is amplifing, There is gain.
- If Pout is less than Pin, K<0, signal is weakening. There is attenuation.
- If Pout equals Pin, K=0, There is a buffering, filtering, or impedance matching.

The Power on a resistor R in an electrical circuit is calculated by the following expression.

$$P = \frac{V^2}{R}$$

If voltages are measured at the same resistance values, the dB value is written in terms of voltages as follows.

$$K = 20Log(\frac{V_o}{V_i})$$

Example

Example: The Output power of an amplifier is 6 Watt (W). The input power ise 6 Miliwatt, Calculate KdB, Has the system gain or attenuatin?

KdB=10log(Po/Pi); Po:output power(Watt), Pi: input power(Watt).

Log(10)=1

Nots: Units must be same. If given vaules are different, Convert maximum value to minumum value.

$KdB = 10*\mathrm{Log}(P_{out} / \mathrm{Pin})$

Pout=6 Watt=6*10^3 mili watt= 6000miliwatt

Pin=6 Miliwatt

KdB=10*Log(6000/6)=10*Log(1000)=10*Log(10^3)=3*10*Log(10)=30, grater 0, so the system has gain.

Example: A system's power output is 1 watt. Its input power is 10 watts. Calculate the gain of system as a logarithmic value. Has the system gain or loss?

Units are same. (Log1=0, log(a/b)=log a-log b)

K=10log(1/10) = 10*Log(1) – 10Log(10) =10*0 – 10*1 = -10

There is attenuation because, KdB<0.

Example: Gain / Attenuation (Decibels)

Decibel Calculations

If Vout and Vin are given as Volt. We can calculate KdB=20log(Vout/Vin)

If Pout and Pin are given as Watt: We can calculate KdB=10Log(Pout/Pin)

- **Example**:

  An amplifier has an input of 3miliV and an output of 6V. What is the gain in decibels?

  KdB = 20 logVout/Vin

  Vout=6V

  Vin=3miliV

  In arithmetic operations, units must be equal (V and mili volt iare diferent units).

  Vout=6*10^3 miliV,

  Vin=3miliV

  KdB=20Log(6*10^3 / 3)= 20*Log(2*10^3) = 20* (Log2) + 20*log10^3 = 20*0.3 + 20*3*Log10

  KdB=6 + 60 =66dB

base 10 logarithm, Log1=0, Log 2 ≈ 0.3, Log 3 ≈ 0.5, Log 5 ≈ 0.7, Log 7 ≈ 0.8, Log10=1

Log (a*b) =Loga + Log b;   Log (a/b)= Log a – Log b

Örnek: 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?

  Not: Log1=0, Log 2 ≈ 0.3, Log 3 ≈ 0.5, Log 5 ≈ 0.7, Log 7 ≈ 0.8, Log10=1

  Not: Log a/b=Log a – Log b; Log (a*b)=Log a + Log b

  KdB = 10 log (2/50)

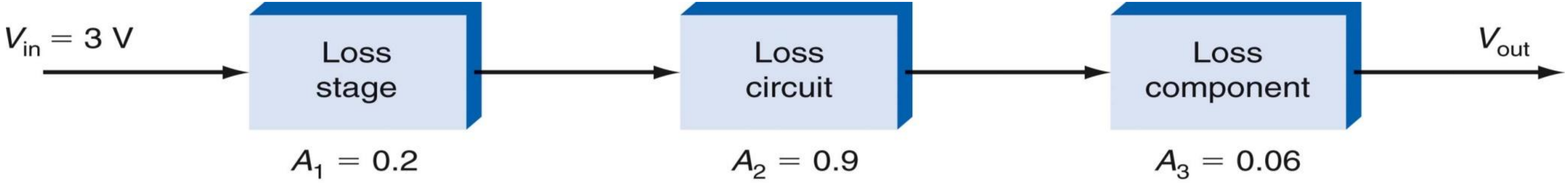
  = 10 log (2)-10Log(50)=10Log(2)-10Log(5)-10Log(10)

  = 10*0.3 -10*0.7 – 10

  =3-7-10=14dB

  - If the decibel figure is positive, that denotes a gain.
  - If the decibel figure is positive, that denotes an attenuation.

Gain, Attenuation with no Decibels



$$A_T = A_1 \times A_2 \times A_3 = 0.2 \times 0.9 \times 0.06 = 0.0108$$

$$V_{out} = A_T V_{in} = 0.0324 = 32.4 \text{ mV}$$

Total attenuation is the product of individual attenuations of each cascaded circuit. Here the term A is used instead of K.

Örnek: Gain, Attenuation with no Decibels

- An amplifier is **cascaded** when two or more stages are connected together.
- The overall gain is the product of the individual circuit gains.

- **Example:**

Three cascaded amplifiers have power gains of K1=5, K2=2, and K3=20. The input power is 40 mW. What is the output power as Watt?

Not: units are different. So first, The result is found in the smaller unit and then converted to the larger unit.

$$K_{\mathrm{p}} = K_1 \times K_2 \times K_3 = 5 \times 2 \times 20 = 200$$

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

$$P_{\mathrm{out}} = 200 * 40 = 8000\text{miliwatt} = 8000 \times 10^{-3} = 8\mathrm{W}$$

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

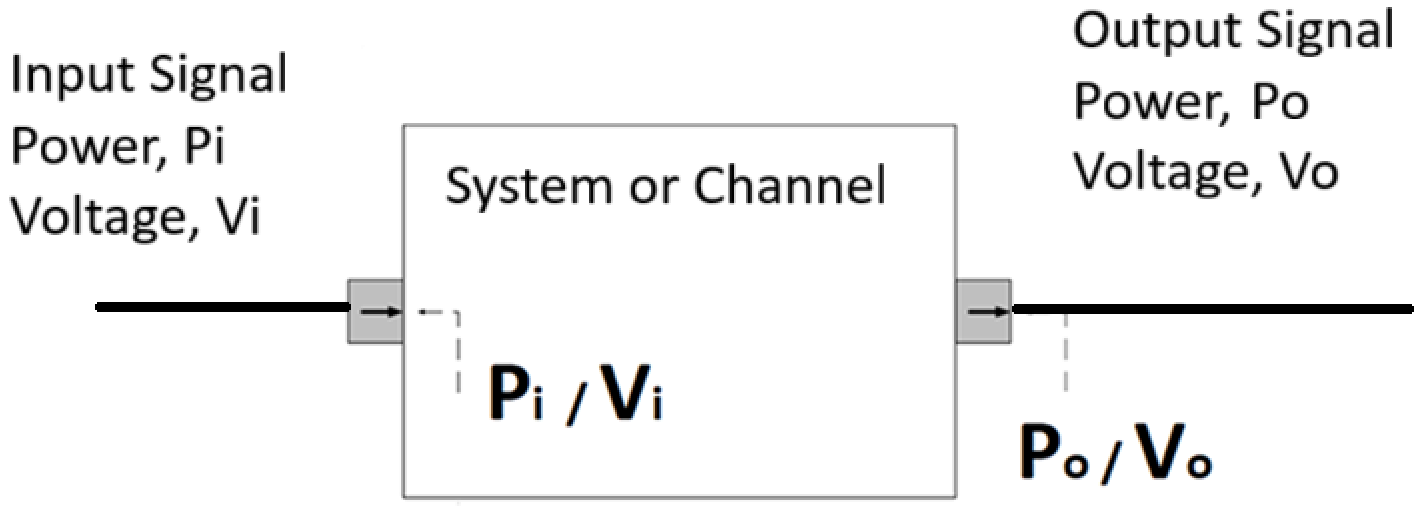
For example, $P = 100$ Watts can alternatively be expressed as $P(dBw) = +20\,dBw$. Likewise, $P = 1\,mW$ can be expressed as $P(dBw) = -30\,dBw$.

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

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

Watt - dBW, Miliwatt-dBm

Watt - dBW, Miliwatt-dBm



- Pi: Watt or DbWatt; miliwatt or dBm
- Po: Watt or DbWatt; miliwatt or dBm
- A Watt= A*10^3miliWatt
- A miliWatt=A*10^-3 Watt

- PdBW= 10Log(PW)
- PdBm= 10Log (PmiliW)

- K=Po(Watt)/Pi(Watt)= Po(miliW) / Pi (miliW)= Ratio (Birimsiz)
- KdB=10Log(Po/Pi)=20Log(Vo/Vi)

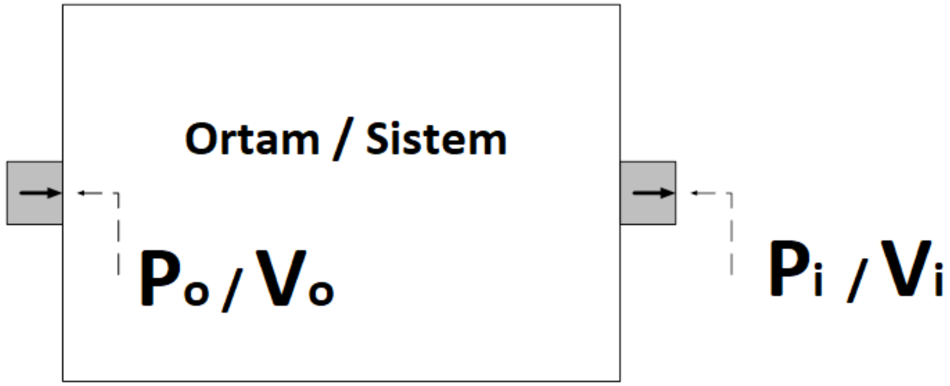
dBm, dBw

- dBW is the logarithmic value of the ratio of the measured power P [Watt] to the reference power of 1W.
- dBm is the logarithmic value of the ratio of the measured power P [Watt] to the reference power of 1mW = Watt.

dBm=dBW+30

dBW=dBm-30

- P_{dBW}=10log(P_W)
- P_{dBm}=10log(Pm_W)
- If P=1W=10^3 miliW. PdBm=10Log(10^3)=30dBm
- If P=1mW=10^{-3} Watt. PdBW=10Log(10^{-3})=-30dBW=0 dBm



Example

- Log(a*b)=Log(a) + Log(b), Log(2)=0.3, Log(10)=1
- P=40Watt than PdBW=?, PdBm=?
- Pmiliwatt=40Watt=40*10^3 miliWatt=4*10^4mW
- PdBW=10*Log(Pwatt)=10Log(40)=10*Log4+10*Log10=10*Log2^2+10=20*Log2+10 =20*0.3+10 = 16dBW
- PdBm=10*Log(Pmiliwatt)=10Log(4*10^4)=10*Log4+40=46dBm
- PdBm=PdBW+30=16+30=46dBm

Tx Power

Tx is short for "Transmit"

Tx power, the output of a wireless system 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. dBw – a linear power level referencing Watt

$$dBm = 10 \text{ x } \log[PmW]$$

$$dBw = 10 \text{ x } \log[Pw]$$

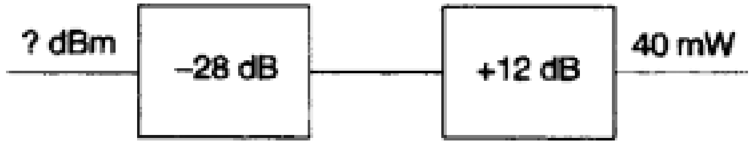
In a system, there is one dBm (mW) or dBw (W); there are many dBs, which are made up of + and –.

dBm=dBw+30
dBw=dBm-30

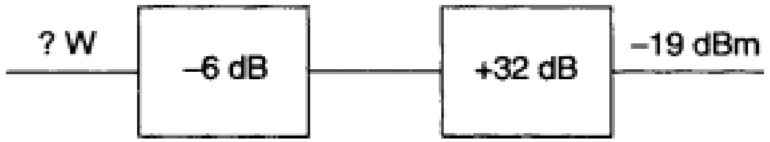
Exercise 1*a*.

Exercise 1*b*.

Exercise 1*c*.



Exercise 1*d*.



(*Answers*: 1*a*: +13 dBm = 20 mW; 1*b*: +29 dBW, 1*c*: +32 dBm, and 1*d*: +7 dBm = 0.005 W).

- There is no multiplication or division in logarithmic operations. There is addition and subtraction.
- Log(a*b*c*d)=Loga + Logb + Logc + Logd, Log(a/b(=Log a – log b

- dB is a ratio. It represents loss or gain. It is added or subtracted. Watts, milliwatts (dBW, dBm), represent power. It represents the signal source.

- When dBW and dB are added, the result is dBW. When dBm and dB are added, the result is dBm. When dB and dB are added, the result is dB.
- dBm and dBW cannot be added. Why? In arithmetic operations, the units must be the same.

Example

- If Po=4 Watt, K=-10 dB then Pi=?
- K_{dB}=10log(Po/Pi),
- K_{dB}=-10=10Log(Po/Pi); -1=Log(Po/Pi)
- K=Po/Pi=10^{-1}=1/10=0.1
- Pi=Po/K=4/0.1=40W
- As you can see, when a 40W signal enters the input, the output is 4W. There is attenuation or loss.

Example

- If Po=40dBm, Pi=20dBw than K=?

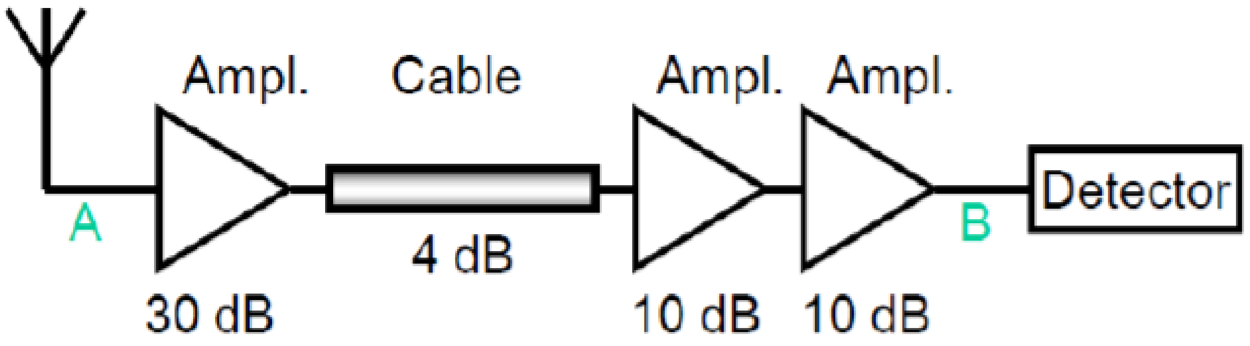
KdB=10Log(Po)-10Log(Pi)

KdB=Po_dBm – Pi_dBm, ya da

KdB=Po_dBW – Pi_dBW olur.

- Input power is given in dBm, while output power is in dBW. Both must be the same level.
- PdBW=PdBm - 30
- PdBm=PdBW+30
- These can be converted to each other.
- Pi=20dBw+30=50dBm
- K=50-40=-10dB

Amplification and Attenuation



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

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

Signal to Noise Ratio (SNR)

Signal to Noise Ratio (SNR)

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

Example

A signal has a power of 10 mW and a noise has a power of 1 μW; what are the SNR and SNRdB values? Solution: The SNR and SNRdB values can be calculated as follows:

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

$$\mathrm{SNR}_{\mathrm{dB}} = 10 \log_{10} 10{,}000 = 10 \log_{10} 10^4 = 40$$

The values of SNR and SNRdB for a noiseless channel are

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

$$\mathrm{SNR}_{\mathrm{dB}} = 10 \log_{10} \infty = \infty$$

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

Example

If the signal level is 100 milliwatts and the noise level is 0.01 milliwatts, calculate the signal-to-noise ratio in dB. If the ratio is less than 30dB, the system is not operating. Then, interpret the value given in the example. KdB = 10 Log (Signal/Noise)

KdB = 10 Log (100/0.01) = 10 Log (10000) = 40dB

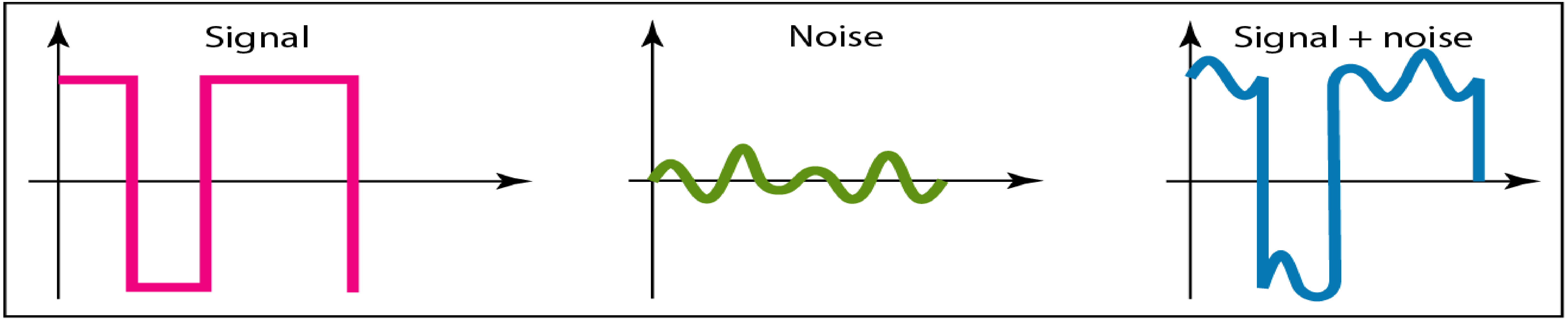
Since KdB >= 30, the system is operating.

If the signal level is 10 milliwatts and the noise level is 0.1 milliwatts, calculate the signal-to-noise ratio in dB. If the ratio is less than 30dB, the system is not operating. Then, interpret the value given in the example. KdB=10Log(Signal/Noise)

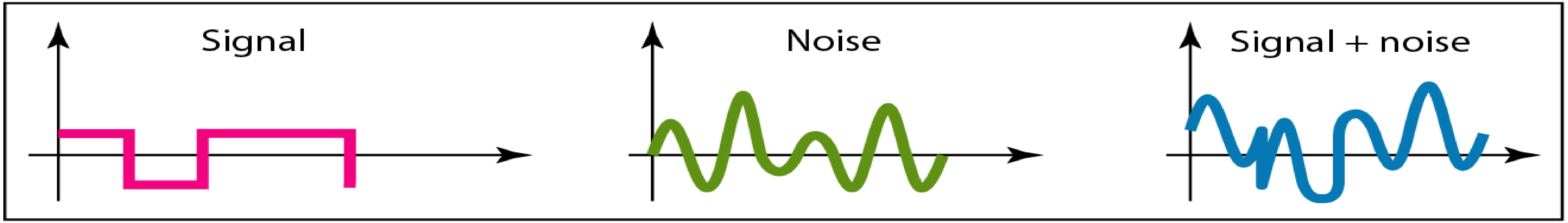
KdB=10Log(10/0.1)=10Log(100)=20dB

Since KdB<30, the system will not work.

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



a. Large SNR



b. Small SNR

Attenuation

Attenuation

- Attenuation means energy level loss. A weaker signal!
- When a signal passes through a medium, it loses energy as it overcomes the medium's resistance.
- Amplifiers are used to compensate for energy loss by amplifying the signal.
- Signal strength decreases with distance.
- Attenuation depends on the medium.
- For the received signal strength to be sufficient, the level of the error-free signal must be sufficiently high above the noise.
- Attenuation is an increasing function of frequency and path.
- The unit "decibel" is used to represent energy loss or gain. $K_{dB} = 10\log_{10} P_2/P_1$, P_1: input signal, P_2: output signal
- One reason engineers use decibels to measure changes in signal strength is that they can be added or subtracted instead of multiplied or divided. This is because decibels are logarithmic. If the summed value is expressed as $K=a*b*c*d$, the decibel value can be calculated as follows: $K_{dB}=10Log(a*b*c*d)=10Log(a)+10Log(b)+10Log(c)+10Log(d)$
- In decibels, gains are positive, and attenuations are negative.
- If the signal entering a system is attenuated by B (dB) as it passes through a cable, and then amplified by C (dB) through an amplifier, what will be the system output D (dBm)? D(dBm)=A(dBm)-B(dB)+C(dB)

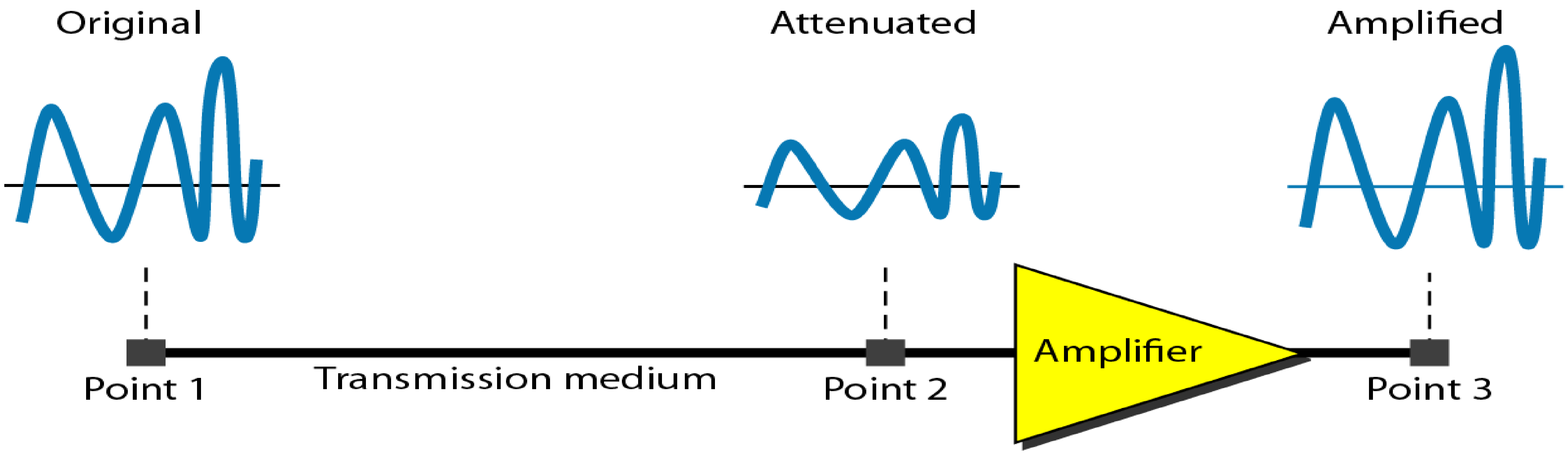
Sistemlerin hassasiyet alış seviyesi

- Sinyal zayıflarsa, alıcı sistemin hassasiyetinde düşük ise bur durumda sistem çalışmaz.
- Örnek: Sistemin çalışma hassasiyet alış güç seviyesi -76 dBm. Açıklayınız. Bu seviyeden daha düşük sinyal alınırsa sistem çalışmaz.
- Sisteme gelen sinyal seviyesi – 67dBm ise sistem çalışır.
- Sisteme gelen sinyal seviyesi -96dBm ise sistem çalışır mı? Çalışmaz. Ne kadar güç seviyesinde kuvvetlendirmek gerekir? -76 –(-96) + eşik değer (5dB)=-76+96+5=25dB kuvvetlendirici lazım.

- İstenmeyen sinyalin gönderilmemesi için filtre kullanılır.

Attenuation

Amplifiers are used to compensate for this energy loss by amplifying the signal. On the transmitter side: Power Amplifier, On the receiver side: LNA (Low Noise Amplifier), LNB



Example

The decibel is sometimes used to measure signal strength in milliwatts. In this case, it is called PdBm and is calculated as PdBm = 10 log10 PmiliW, where PmW is the power in milliwatts. Calculate the strength of a signal where PdBm = -30 dBm.

Solution

We can calculate the power in the signal as

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

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

Example

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

Solution

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

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

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

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

Example

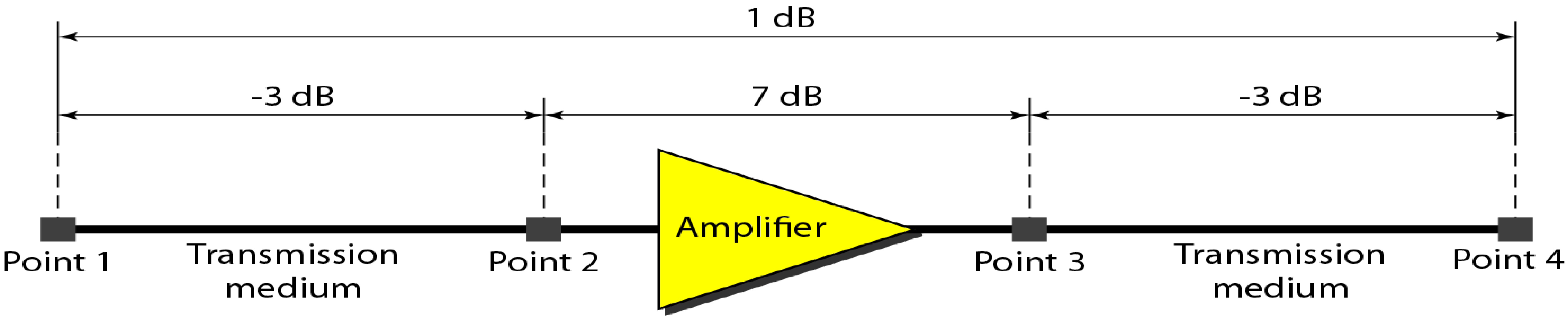
A signal passes through an amplifier and its power increases by a factor of 10. This means that P2 = 10P1. In this case, the amplification (power gain) can be calculated as follows.

$$\boxed{10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{10P_1}{P_1}}$$

$$\boxed{= 10 \log_{10} 10 = 10(1) = 10 \text{ dB}}$$

Example

One reason engineers use decibels to measure changes in signal strength is that when measuring multiple points (steps) instead of just two, the decibel numbers can be added (or subtracted). In the figure, a signal moves from point 1 to point 4. In this case, the decibel value can be calculated as follows.



$$\boxed{dB = -3 + 7 - 3 = +1}$$

Delay

Delay - Speed of Signal Propagation

- Propagation velocity - the speed at which data travels from a source to a destination across a medium.
- Transmission velocity - the speed at which all bits in a message reach the destination. (The difference in the arrival time of the first and last bits)
- Propagation Delay = Distance / Propagation speed
- Transmission Delay = Message size / Bandwidth bps
- Delay = Propagation delay + Transmission delay + Queueing time + Processing time
- Propagation velocity varies with frequency

Example: How many seconds does it take for light reflected from the Moon to reach our eyes?

- Distance, L = 384.403 km
- Speed, C = 3*10^8 m/second
- Distance = Speed * Time
- Time, t = Distance / Speed = 384403000/3*10^8 = 1.28 seconds

Delay

- Time=Distance/Speed (m/sec, km/sec)
- Electromagnetic signals travel at the speed of light along the path, c=3*10^8 m/sec.
- Therefore, the signal travel time to and from the communication satellite is t=L/c; L: Distance in meters, c: Speed of light, meters/second. Distance=45,000km.
- t=2*45,000,000/(3*10^8)=90/300=3/10=0.3 seconds=300 milliseconds.
- Satellite communication time orbiting Jupiter's Europe satellite is
- t=2*750,000,000,000/(3*10^8)=1500,000,000,000/(3*10^8)=15,000/3=5000 seconds=84 minutes=1.4 hours.

Speed of Sound Propagation

- Natural Communication: Sound, Smoke, Vibration, Smell, Temperature
- Swallows can detect the smell of carrion from 200 km away.
- Elephants can detect rain from 20 km away.
- Sound: The hearing frequency range is 300Hz to 16kHz; signals between 300Hz and 3400Hz are used in telephone communication.
- Sound propagation speed in air: 342m/s (varies with temperature). The speed of sound transmission in steel is 5000m/s

Transmission Speed in Satellite Communication

- What seconds does it take for data sent to a satellite 42000 km away to travel back and forth from the Earth's surface?
- Distance = 2*42000 km = 84000 km
- The speed of data propagation is the speed of light. This is because the speed of electromagnetic waves in a vacuum or air = 3*10^8 m/sec.
- Distance = Speed * Time
- Distance = 84000000 m
- Time = Distance / Speed = 84*10^6/3*10^8 = (84/3)*10^-2 seconds = 28*10^-2 seconds = 2.8*10^-3 seconds = 2.8 milliseconds

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:

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

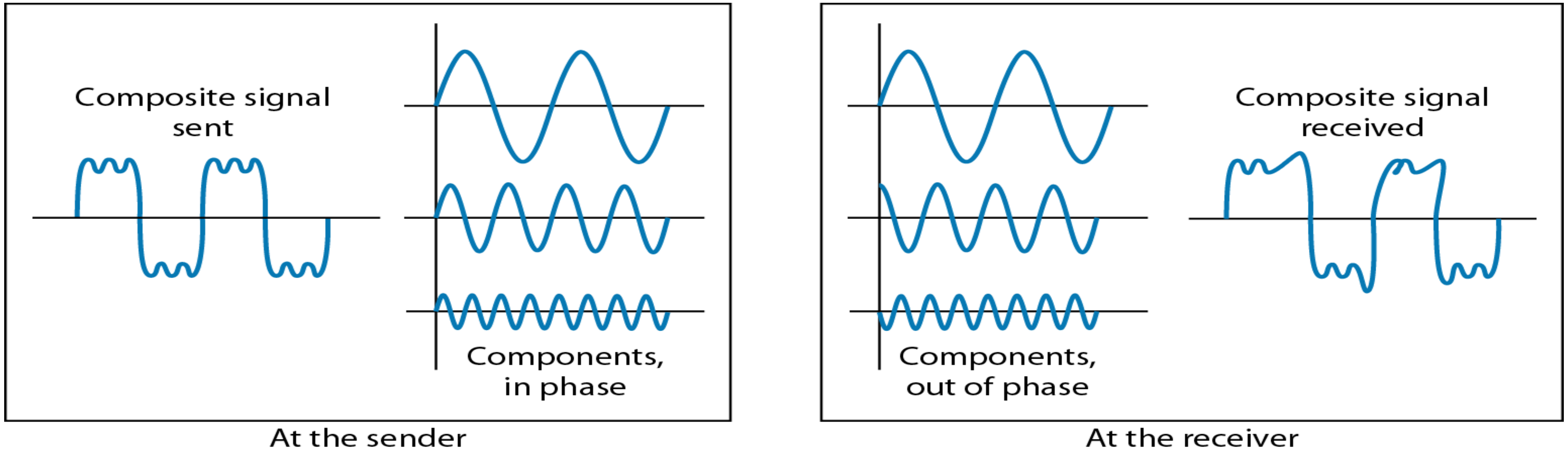
$$\text{Transmission time} = \frac{2500 \times 8}{10^9} = 0.020 \text{ ms}$$

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.

Distortion

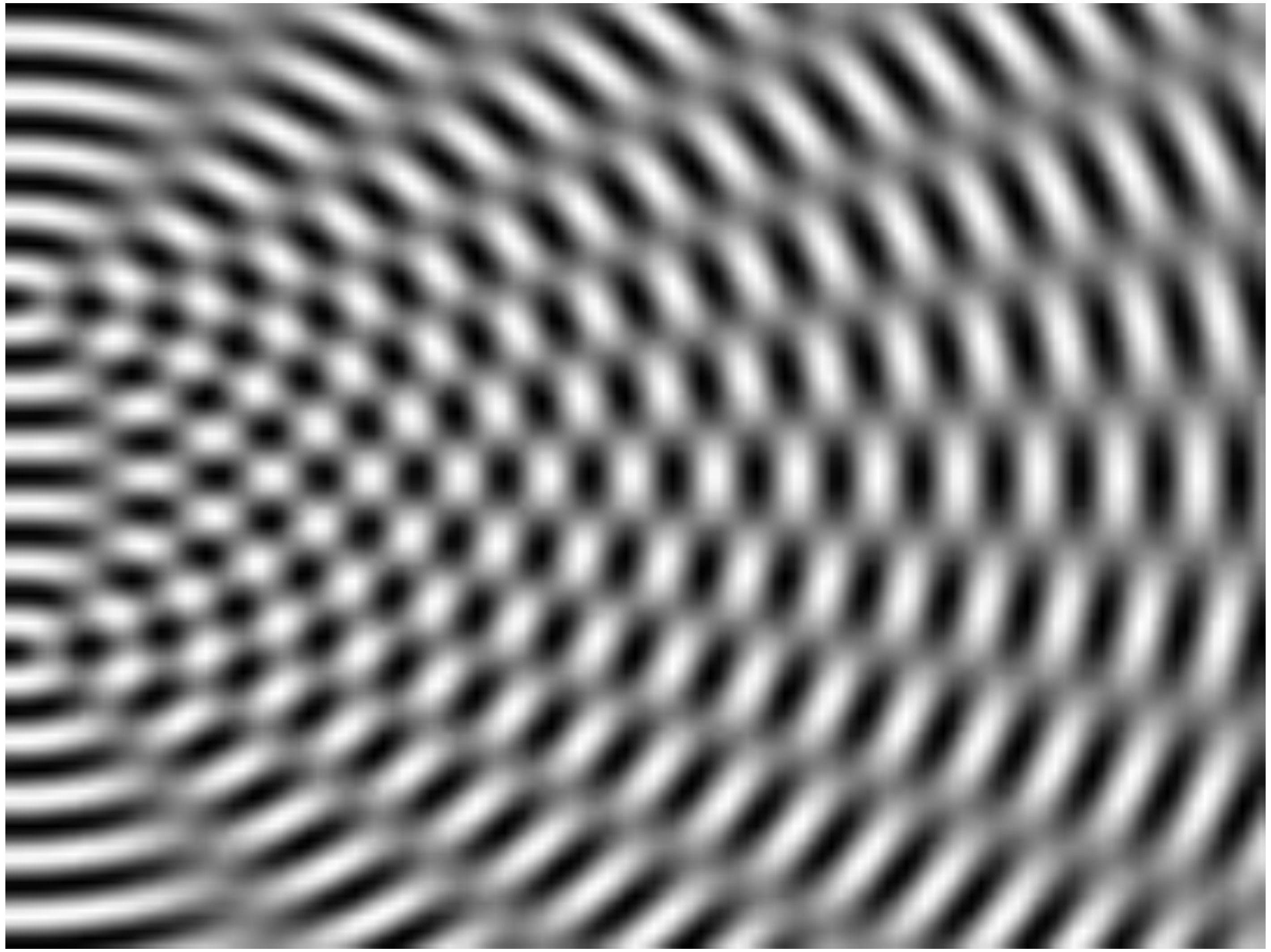
Distortion

- It refers to the presence of another signal that changes the shape or form of the signal. Distortion occurs in composite signals. Each frequency component has its own propagation speed within a medium. Therefore, different components reach the receiver with different delays. This means that signals have different phases at the receiver than at the source.



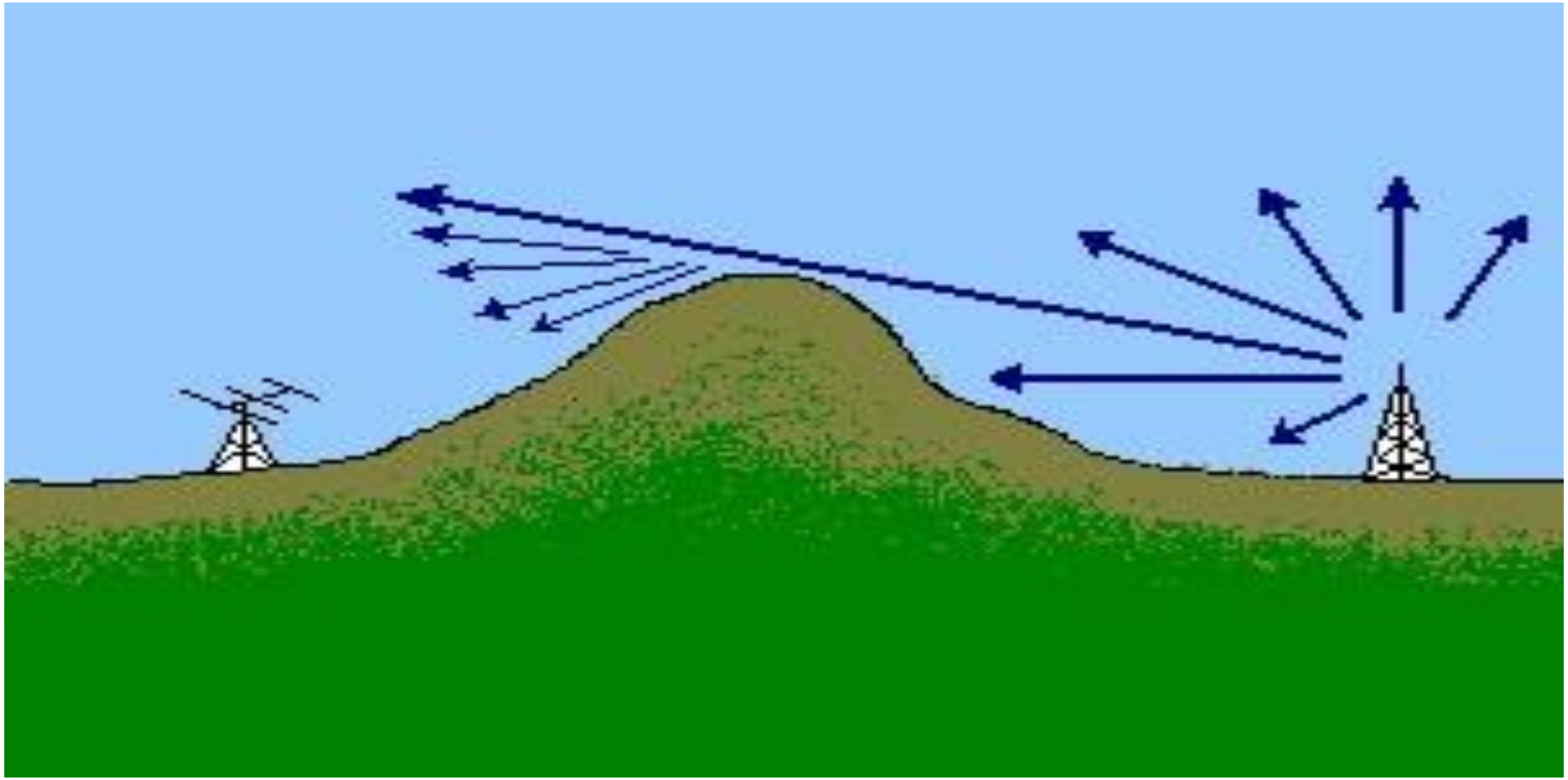
Interference and Diffraction

Two Waves Interfering



Diffraction

Wave bends as it passes an obstacle.



Binary Numbering System

Bit, Bit/San

Bit: In computer systems, the binary number system only has the values 0 and 1. All operations are performed using these two values. Each bit of information, either 0 or 1, is called a bit. Bit→Information consisting of 0/1

- Bits are the units used to describe an amount of data in a network
  - 1 kilobit (Kbit) = 1 x 10^3 bits = 1,000 bits
  - 1 megabit (Mbit) = 1 x 10^6 bits = 1,000,000 bits
  - 1 gigabit (Gbit) = 1 x 10^9 bits = 1,000,000,000 bits

Bit/Second: Information transmitted from one point to another. Or, the amount of bits, or information, processed per second. BPS (Bit Per Second): The number of bits transmitted per second is called bps.

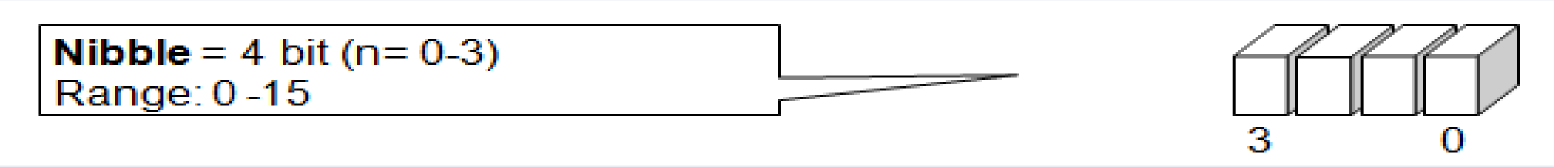
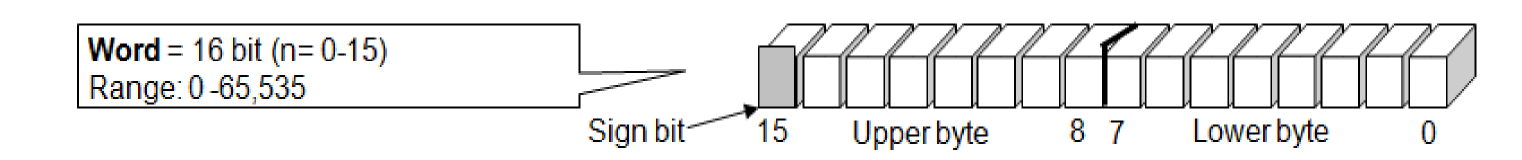
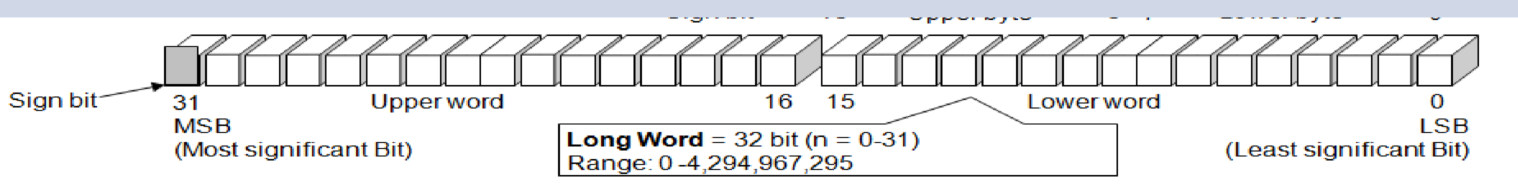
- Seconds are the units used to measure time
  - 1 millisecond (msec) = 1 x 10^{-3} seconds = 0.001 seconds
  - 1 microsecond (msec) = 1 x 10^{-6} seconds = 0.000001 seconds
  - 1 nanosecond (nsec) = 1 x 10^{-9} seconds = 0.000000001 seconds
- Bits per second are the units used to measure channel capacity/bandwidth and throughput
  - bit per second (bps)
  - kilobits per second (Kbps)
  - megabits per second (Mbps)

Byte

Byte: A measure of memory size. In computer science, it is a unit of memory measurement that generally contains the values 1 or 0 across an 8-bit sequence and is independent of the type of information stored.

Kilobyte	Kb	2^{10} Byte
Mega Byte	Mb	2^{20} Byte
Giga Byte	Gb	2^{30} Byte
Tera Byte	Tb	2^{40} Byte
Peta Byte	Pb	2^{50} Byte
Exa Byte	Eb	2^{60} Byte
Zetta Byte	Zb	2^{70} Byte
Yotta Byte	Yb	2^{80} Byte

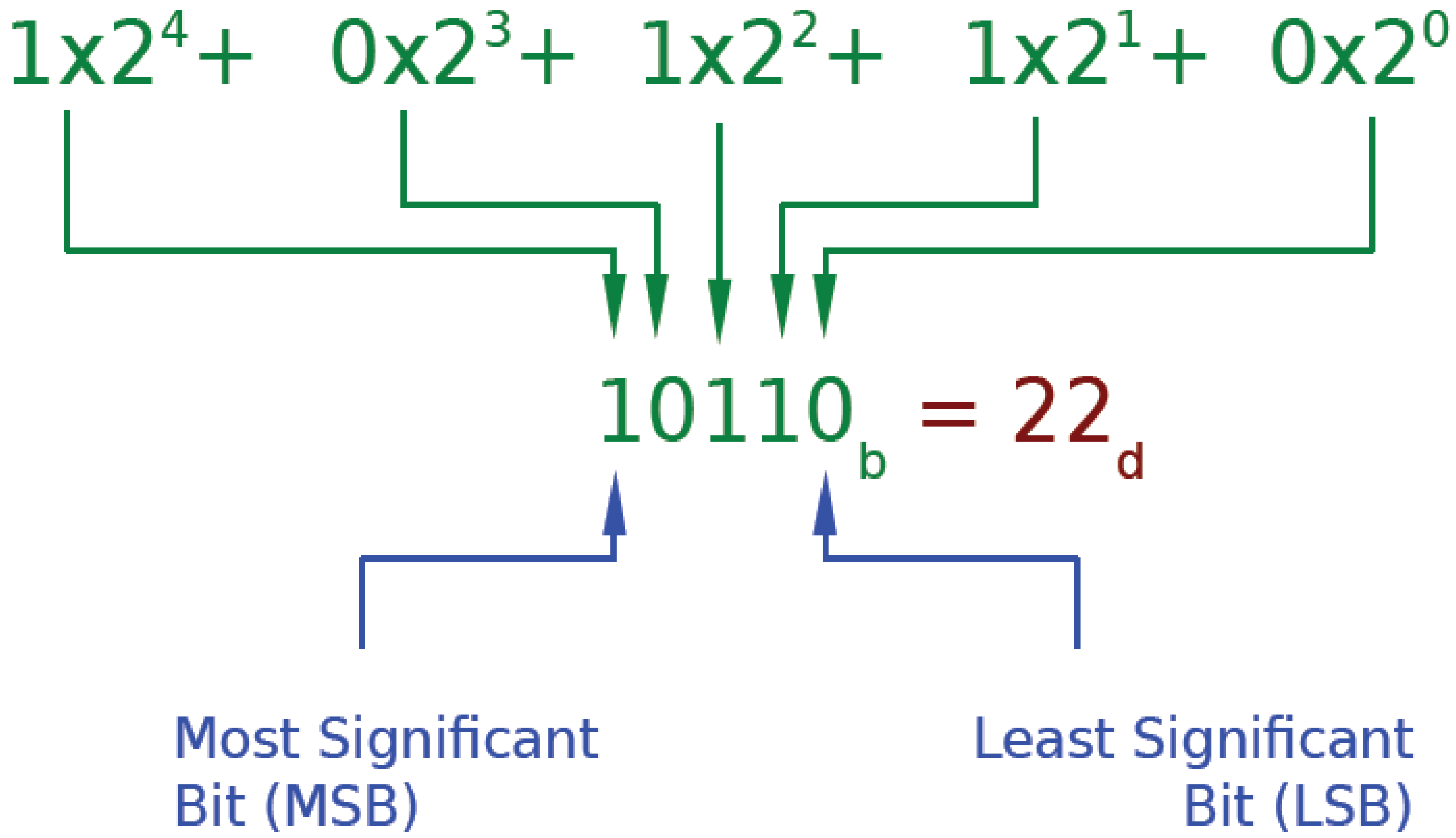
DATA SIZE

Nibble	**4 bit**	
Byte	**8 bit**	
Word	**16 bit**	
Long word	**32 bit**	

Binary

- Binary is exactly the same, only instead of ten digits/states (0 to 9) we have just two, so the base becomes 2:

In computer systems, indexing is in the form of 0,1,2,3,.. Indexing starts from the right.

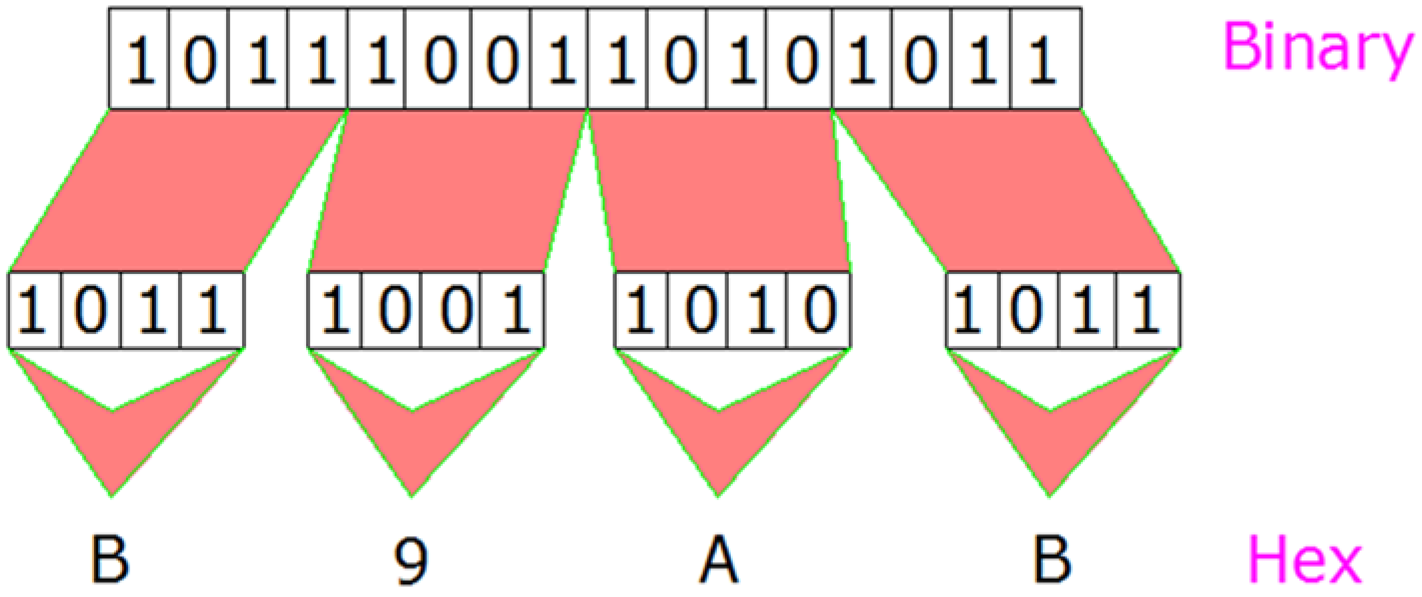


Hexa Numbering System

Hexadecimal	Binary	Decimal
0	0000	0
1	0001	1
2	0010	2
3	0011	3
4	0100	4
5	0101	5
6	0110	6
7	0111	7
8	1000	8
9	1001	9
A	1010	10
B	1011	11
C	1100	12
D	1101	13
E	1110	14
F	1111	15

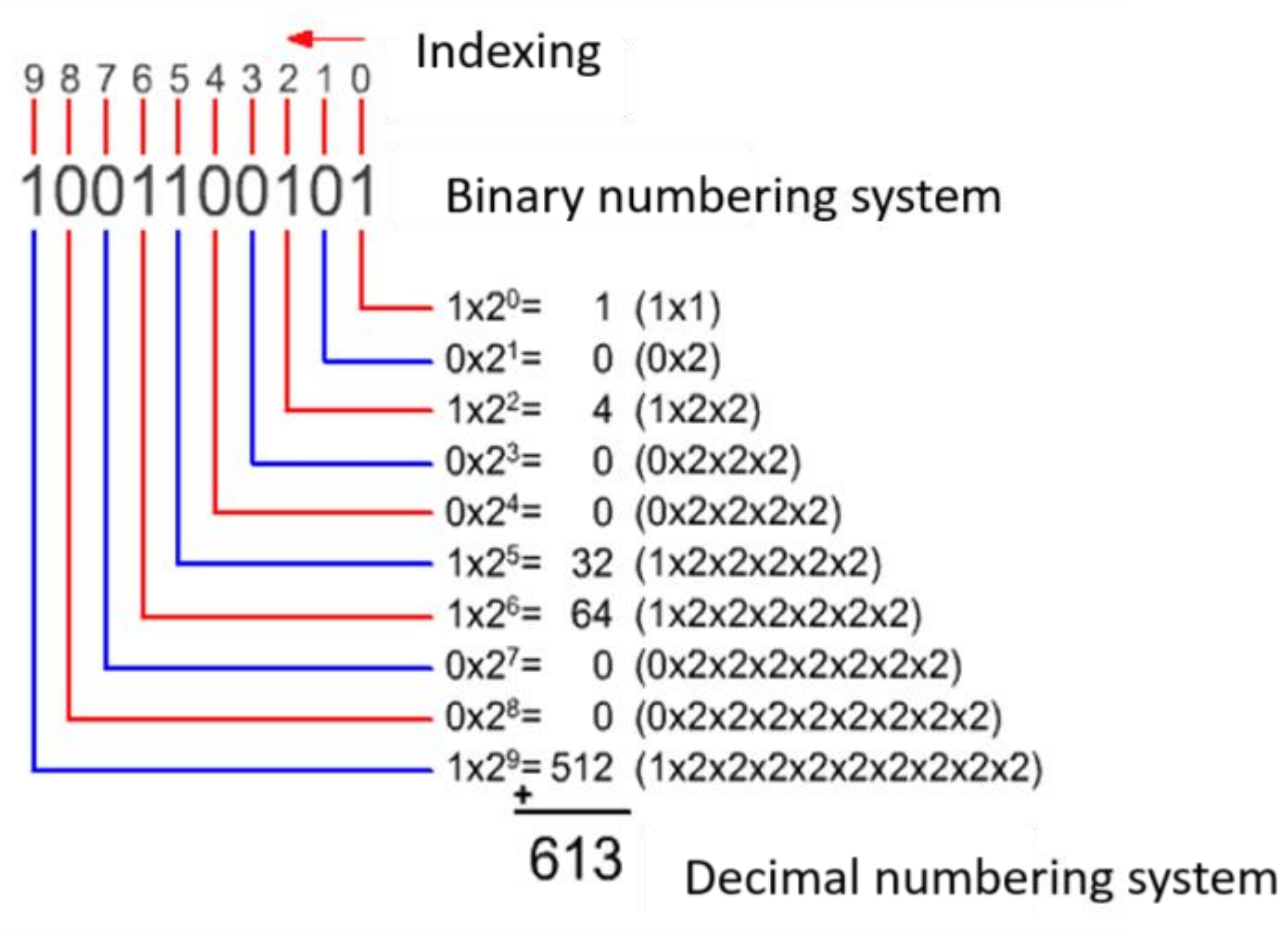
- Short-hand for all these 1s and 0s
- HEX notation
- Each group of 4 bits represents a number in the range 0 – 15
- Hex is used as a notation for any sequence of bits (e.g. ASCII characters require just two hex digits)

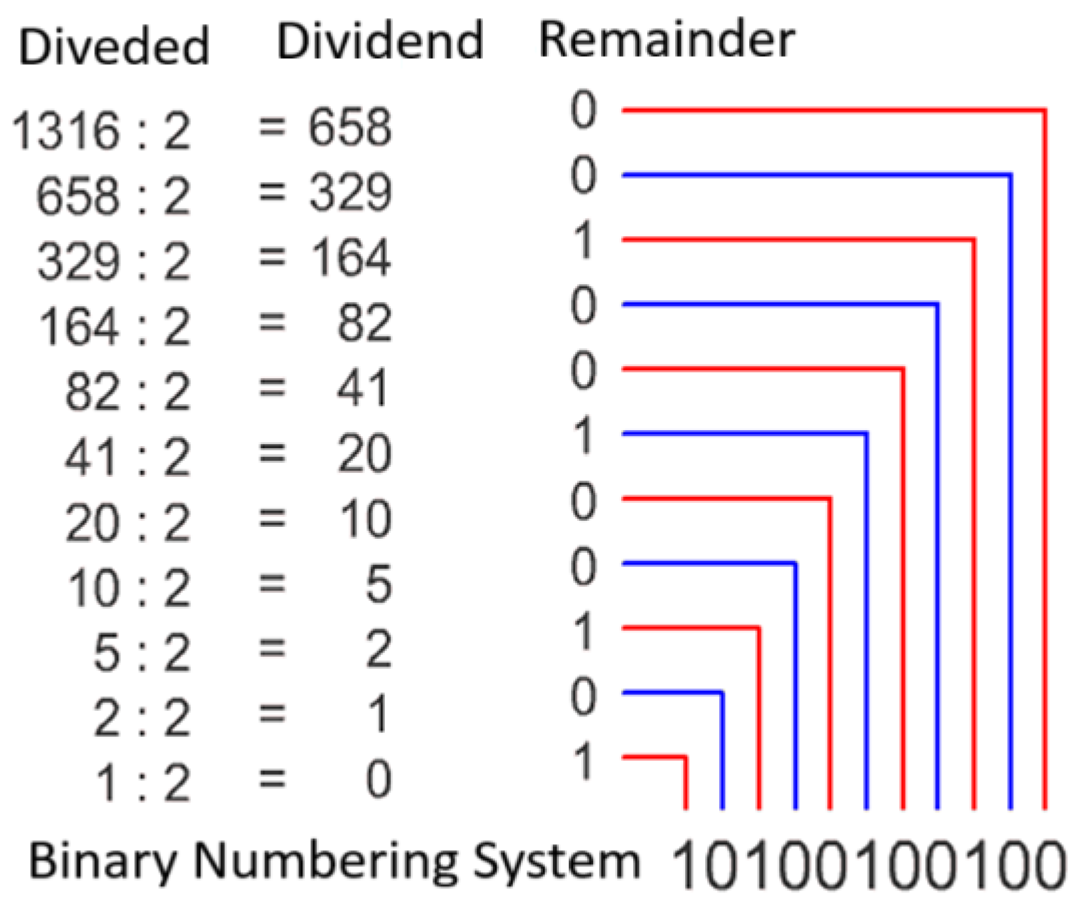
Conversion of Binary Number to Hexa Decimal



The binary number system is grouped into 4 bits, starting from the right. The hexadecimal equivalent of each 4 bit is written.

Converting from binary to decimal number system





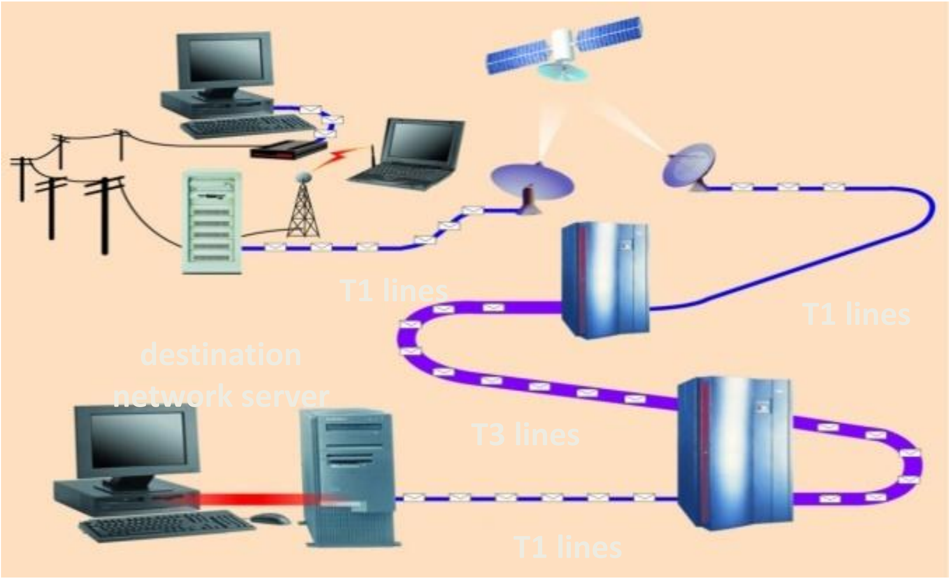
Addition (binary)

$$
\begin{array}{r} 0 \\ +\,0 \\ \hline 0 \end{array}
\qquad
\begin{array}{r} 1 \\ +\,0 \\ \hline 1 \end{array}
\qquad
\begin{array}{r} 0 \\ +\,1 \\ \hline 1 \end{array}
\qquad
\begin{array}{r} {}^{1}1 \\ +\,1 \\ \hline 10 \end{array}
\qquad
\begin{array}{r} 1 \\ 1 \\ +\,1 \\ \hline 11 \end{array}
$$

Channel Capacity

Communication Channels

- A **channel** is a path between two communication devices (Transmitter and Reciever)
- **Channel capacity**: How much data can be transfered through the channel (bit/sec)
- **Channel bandwidth, B=fmax – fmin,** fmax: the maximum frequency of a signal, film: the minimum frequency of a signal
- Consists of one or more **transmission media**
  - Materials carrying the signal
  - Two types:
    - Physical: wire cable
    - Wireless: Air, Space



Location of a communication channel

- Information Source
- Transmitter
- Channel (Noise) : There is a analog signal
- Receiver
- Information
- In an Analog signal, There are alot of amplitutes, frequencies, phases. All of them change by time.
- It consists of a mixture of many sinusoidal signals (different frequencies) in an analog signal..

Channel Capacity: Data Rate & Bandwidth

- Data rate
  - In bits per second
  - Rate at which data can be communicated
- Bandwidth
  - In cycles per second of Hertz
  - Constrained by transmitter and medium

Bandwidth of an Analog Signal

- **Bandwidth (B) of analog signal** is the difference between the highest and lowest frequencies of the constituent parts of the signal (i.e., the highest and the lowest frequencies obtained by Fourier analysis).
- The difference between the maximum and minimum frequencies of an analog signal is called bandwidth.

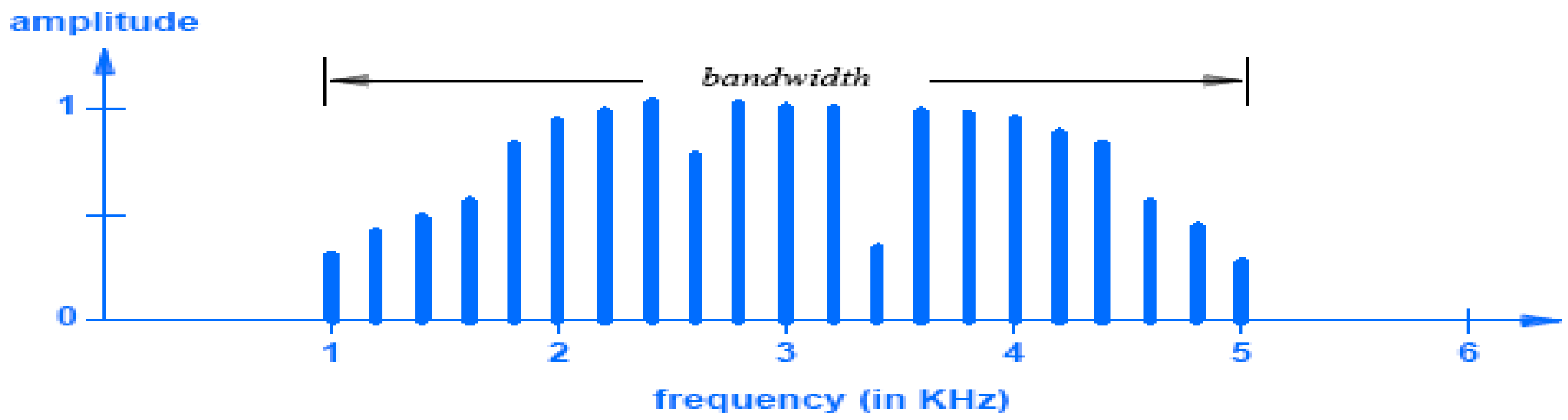


Figure shows a Frequency Domain plot with frequencies measured in Kilohertz (KHz) Such frequencies are in the range audible to a human ear.

- In the figure, the bandwidth is the difference between the highest and lowest frequency (5 KHz - 1 KHz = 4 KHz)
- Example: In analog telephone systems, the usable frequency range is 300 Hz to 3400 Hz range, B= 3400-300=3100Hz

Soru: The period of a signal is 100 ms. What is its frequency in kilohertz?

Solution

First we change 100 ms to seconds, and then we calculate the frequency from the period (1 Hz = 10^{-3} kHz).

$$100 \text{ ms} = 100 \times 10^{-3} \text{ s} = 10^{-1} \text{ s}$$

$$f = \frac{1}{T} = \frac{1}{10^{-1}} \text{ Hz} = 10 \text{ Hz} = 10 \times 10^{-3} \text{ kHz} = 10^{-2} \text{ kHz}$$

Note: Units are converted to base units.

100ms=(?) seconds

100ms=100*10^-3 seconds=10^-1 seconds

Parameters determining channel capacity

- Data rate is the speed at how much data is transmitted in one second.
- Frequency is the number of pulses or periods per second (Hertz).
- Bandwidth
- Noise level, Signal level; S/N, SNR
- Attenuation
- Interference, distortion
- Data rate is a unit of measurement indicating the amount of data transferred in one second.
- 1 Kbit/s (Kbps) = 10^3 bit/s
- 1 Mbit/s = 10^6 bit/s

Methods of Using the Communication Channel Efficiently

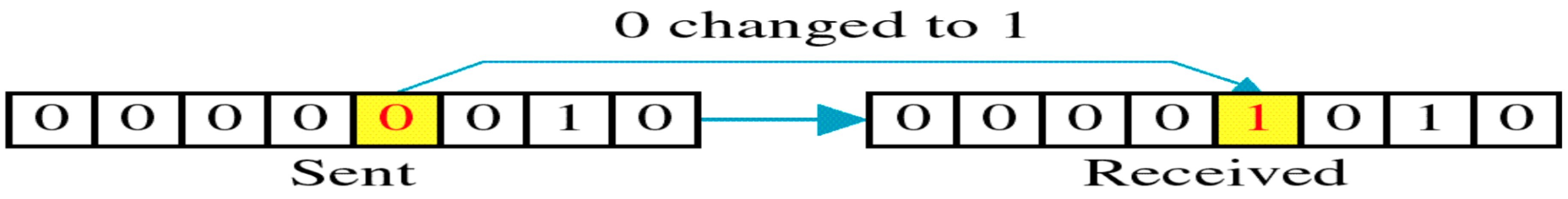
- As bandwidth increases, the data rate also increases, but the signal-to-noise ratio, called S/N, decreases. The signal is lost in the noise.
- As bandwidth decreases, the data rate also decreases, but the signal-to-noise ratio, called S/N, increases. The signal is transmitted without being contaminated by noise.
- Question: How can high data rates be transferred without increasing bandwidth?

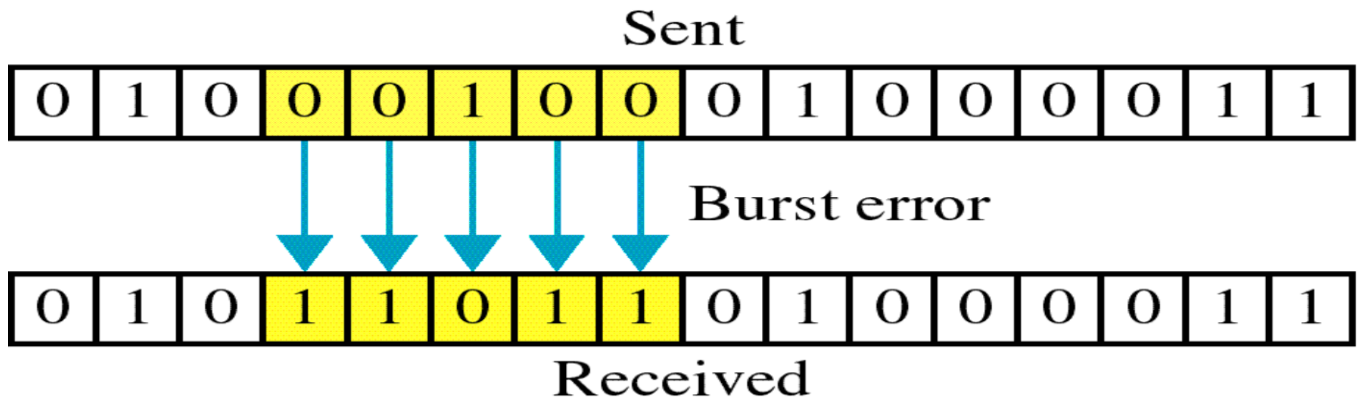
How can we transfer high data rates without being contaminated by noise?

- Bit compression,
- Reduction, dimension reduction,
- Coding,
- Modulation,
- Densification.

BER

- BER: Bit Error Rate: In digital data transmission, this refers to the rate at which bits are corrupted or incorrectly detected within the transmitted data. BER = Number of Erroneous Bits Sent / Total Number of Bits Sent.
- Communication media: fiber, copper wire, air (medium) - space
- Example: If BER = 10^-6, how many bits are erroneous when 1 million bits are sent?
- BER = 10^-6 = 1/10^6 = Number of Erroneous Bits Sent / Total Number of Bits Sent. One bit in 1 million bits (10^6bit) is error.
- Example: If 16 bit errors occur when 512,000,000 bits are sent, what is the bit error rate?
- BER = Number of Erroneous Bits Sent / Total Number of Bits Sent
- BER=16/512 000 000=3,125 x 10-8
- Bit Errors; Single bit, Multiple bit, Burst
- Ber is important for performance of communicaiton systems.





Baud Rate

Baud rate is the number of samples taken from an analog signal per second. It is also the number of symbols sent per second, because each sample is a symbol.

Example: When converting an analog signal to a digital signal, samples are taken at regular intervals. If the baud rate is 1000, it means that 1000 samples are taken per second. If each sample is represented by 8 bits, calculate the bit rate.

- Baud rate = 1000 bauds per second (baud/s)
- Bit rate = Baud rate (Number of samples taken in one second) x Number of bits representing a sample taken from the analog signal = 1000 x 8 = 8000 bps
- The bit rate of a signal is 4000. If each signal unit carries 4bits, what is the baud rate?
- Baud rate = 8000/8 =1000 bauds/sec

Example

- If the total number of symbols = 975 and B = 64 kHz, what is the noise-free channel capacity in Kbit/sec? N = 2^m, m = 10. Because, 2^m > = Total number of symbols
- C=2*64000*10=128*10^4bit/sec=1280Kb/s=1280Kbps

DATA RATE or Channel capacity LIMITS

A crucial factor in data communication is the speed at which we send data, in bits per second, over a channel. Data rate depends on three factors:

1. Bandwidth
2. The level of the signals (SNR) we use
3. Channel quality (noise level)

- Noiseless Channel: Nyquist Bit Rate
- Noisy Channel: Shannon Capacity

Increasing the levels of a signal increases the probability of an error occurring, in other words, reduces the reliability of the system.
There is not the noiseless channel.
Noisy Channel is possible in the all communication systems.

Nyquist Theorem: Channel capacity in a noiseless environment

- The Nyquist theorem calculates the channel capacity for a noiseless channel:
  - $C = 2\ B \log_2 2^m = 2\ B\ m$
  - m: the number of bits by which a symbol or a sample is represented (total number of symbols or the number of sampling intervals, $n=2^m$)
  - n: The number of amplitude intervals in the sampling process. Quantization is the number of amplitude levels.
  - C: Channel capacity, the number of bits transferred per second through a channel. Its unit is bits/second.
  - B: Bandwidth, its unit is Hz.

- Example: B=10MHz, m=8bit than C=? (Mbps)
- B=10MHz =10 *10^6Hz

  C=2*B*m=2*10*10^6*8=160*10^6bps=160Mbps

Questions

Question 1. The Nyquist theorem calculates the channel capacity for a noiseless channel: The formula for calculating the capacity of a channel is given by C = 2Bm bits/second. Here, B is the bandwidth (Hz = 1/second), the amplitude of the analog signal is calculated using the 2^m interval equation, and m is the number of symbols. Therefore, if the bandwidth is 1 MHz and the symbol count is 8 bits, calculate the channel capacity in bits/second. Note: Pay attention to the consistency of unit lengths in arithmetic operations.

- **C=2*B*m = 2* 10^6*8=16*10^6bit/sec**

Question 2. The Nyquist theorem calculates the channel capacity for a noiseless channel: The formula for calculating the capacity of a channel is given by C = 2Bm bits/second. Here, B is the bandwidth (Hz = 1/second), the amplitude of the analog signal is calculated using the 2^m interval equation, and m is the number of symbols. Therefore, if the bandwidth is 8 MHz and the symbol count is 8 bits, calculate the channel capacity in bits/second. Note: Pay attention to the compatibility of unit lengths in arithmetic operations.

- **C=2*B*m = 2* 8*10^6*8=128*10^6bit/sec**

Example: Nyquist Theorem

Question: Calculate the bandwidth if the number of sampling interval levels n is 1024 for data transfer with a noise-free channel capacity of 1Mbps.

- C=1Mbps= …. bps?

  C=1Mbps=10^6 bps
- If the number of sampling interval levels is n=1024 and n=2^m, find m.

  m=10
- If C and m are known, calculate the B band width in kHz from the formula C=2Bm.

  10^6 =2B10 ise B=50x 10^3 Hz= 50KHz dir.

Question: B=4000Hz, m=8 ise C=2*4000*8=64000bps

Question: The Nyquist theorem calculates the channel capacity for a noiseless channel. m: is the number of bits representing a symbol, n = 2^m, n: is the number of sampling intervals. If m = 4, how many sampling intervals does this channel have? n = 2^4 = 16

Question: We need to send 265 kbps over a noise-free channel with a 20 kHz bandwidth. What signal level do we need?

We can use the Nyquist formula as shown: 265000=2*20000*m
m=6.625, m=7 is taken. (Shifted to the power of 2)
Symbol bit count = 7
Number of signal levels or total number of symbols = 2^7 = 128
The amplitude of the analog signal will be divided into 128 parts. In this case, the channel capacity is C=2*B*m=2*20000*7=280000bps

Note: If we have 128 levels, the bit rate is 280 kbps. If we have 64 levels, the bit rate is 240 kbps.

Shannon Capacity Formula (Gürültülü)

- Consider data rate,noise and error rate
- Faster data rate shortens each bit so burst of noise affects more bits
  - At given noise level, high data rate means higher error rate
- Signal to noise ration (in decibels)
- SNR_{db}=10 $\log_{10}$ (signal/noise)
- **Capacity, $C=B \log_2(1+SNR)$**
- This is error free capacity

Shannon's Theorem

- The signal-to-noise ratio in a noisy channel is calculated using Shannon's Capacity Theorem. The SNR value is converted to the power of 2, which simplifies the calculation of logarithms to the base 2. $Log_2 2^n=n$.

$$C = B \log_2(1 + SNR)$$

C=n*B olur.

For example, if SNR=20000 Unit and B=10MHz, calculate the channel capacity in a noisy environment. You must find 2^n from SNR without dB.
B=10MHz=10*10^6Hz

- 20000<= 2^n, n=15. C=n*B =15*10*10^6=150*10^6=150Mbps.
- Note: SNR is usually given in decibels, base 10.
- If 10Log10 SNR=SNRdB, then SNR=10SNRdB/10.
- If 10SNRdB/10=2n, then SNRdB *Log1010 /10=n*log102. Log102=0.3. SNRdB/3=n.
- SNRdB/3=n is found. The capacity is found in bps from C=n*B.
- The Shannon capacity gives us an upper limit; the Nyquist formula tells us how many signal levels we need.
- The SNR level cannot be lower than the threshold value. In communication systems, threshold values must be greater than 6dB.

Example: Shannon Theorem

- The signal-to-noise ratio in a noisy channel is calculated using Shannon's Capacity Theorem. SNR is usually given in decibels, base 10. SNRdB/3=n, where C=n*B, the capacity is found in bps.
- If the channel capacity is 64000bps and the signal-to-noise ratio is 48dB, find the bandwidth.
- n=48/3=16, 64000=16*B, B=64000/16=4000Hz

Question:

We can calculate the theoretical maximum bit rate for a typical telephone line. A telephone line typically has a bandwidth of 3000 Hz. The signal-to-noise ratio is typically 3162. The capacity for this channel is calculated as follows.

$$C = B \log_2 (1 + \text{SNR}) = 3000 \log_2 (1 + 3162) = 3000 \log_2 3163$$
$$= 3000 \times 11.62 = 34{,}860 \text{ bps}$$

$1+\text{SNR}=1 + 3162=3163 \cong 2^{12}$ is taken. C=n*B=12*3000=36.000 Kbps is found.

- This means that the maximum bit rate for a phone line is 36,000 kbps. If we want to send data faster than this, we can either increase the line's bandwidth or improve the signal-to-noise ratio.

Shannon’s Theorem

Example: Data transfer at 1 Mbps in a noisy channel is transmitted over a 50 kHz bandwidth channel. Calculate the signal-to-noise ratio.Explanation: The signal-to-noise ratio in a noisy channel is calculated using the Shannon Capacity Theorem.

$C = B \log_2(1 + SNR)$

1+SNR=2^n olur ise C=B*n is taken.

$X = Y\mathrm{Log}_2\ (Z)$ ise $Z = 2^{X/Y}$.

$10^6 = 50 \times 10^3 \log_2(1 + SNR)$
$(1 + SNR) = 2^{20}$
$\mathrm{Log}_{10}(1+SNR) = \mathrm{Log}_{10} 2^{20} = 20 \times 0.3 = 6$dB is found

Question:

Consider an extremely noisy channel where the signal-to-noise ratio is nearly zero. In other words, the noise is so strong that the signal is weak. The capacity C for this channel is calculated as follows.

$$\boxed{C = B \log_2 (1 + \text{SNR}) = B \log_2 (1 + 0) = B \log_2 1 = B \times 0 = 0}$$

This means that regardless of bandwidth, the capacity of this channel is zero. This means that no data can be sent over this channel.

Question:

The signal-to-noise ratio is usually given in decibels with a logarithm of base 10. Assume SNRdB = 36 dB and a channel bandwidth of 2 MHz. The theoretical channel capacity can be calculated as follows.

SNRdB/3 ≅n

SNRdB/3 =36/3=12

C=12*2=24Mbps

$$SNR_{dB} = 10 \log_{10} SNR \rightarrow SNR = 10^{SNR_{dB}/10} \rightarrow SNR = 10^{3.6} = 3981$$

$$C = B \log_2 (1+ SNR) = 2 \times 10^6 \times \log_2 3982 = 24 \text{ Mbps}$$

Example

For practical purposes, when the SNR is very high, we can assume that SNR + 1 is almost the same as SNR. In these cases, the theoretical channel capacity can be simplified to

$$\boxed{C = B \times \frac{\mathrm{SNR}_{\mathrm{dB}}}{3}}$$

For example, we can calculate the theoretical capacity of the previous example as

$$\boxed{C = 2\ \mathrm{MHz} \times \frac{36}{3} = 24\ \mathrm{Mbps}}$$

Example

We have a channel with a 1-MHz bandwidth. The SNR for this channel is 63. What are the appropriate bit rate and signal level?

Solution

First, we use the Shannon formula to find the upper limit.

$$\boxed{C = B \log_2 (1 + \text{SNR}) = 10^6 \log_2 (1 + 63) = 10^6 \log_2 64 = 6 \text{ Mbps}}$$

The Shannon formula gives us 6 Mbps, the upper limit. For better performance we choose something lower, 4 Mbps, for example. Then we use the Nyquist formula to find the number of signal levels.

$$\boxed{4 \text{ Mbps} = 2 \times 1 \text{ MHz} \times \log_2 L \quad \rightarrow \quad L = 4}$$

Example

A network with bandwidth of 10 Mbps can pass only an average of 12,000 frames per minute with each frame carrying an average of 10,000 bits. What is the throughput of this network?

Solution

We can calculate the throughput as

$$\boxed{\text{Throughput} = \frac{12{,}000 \times 10{,}000}{60} = 2 \text{ Mbps}}$$

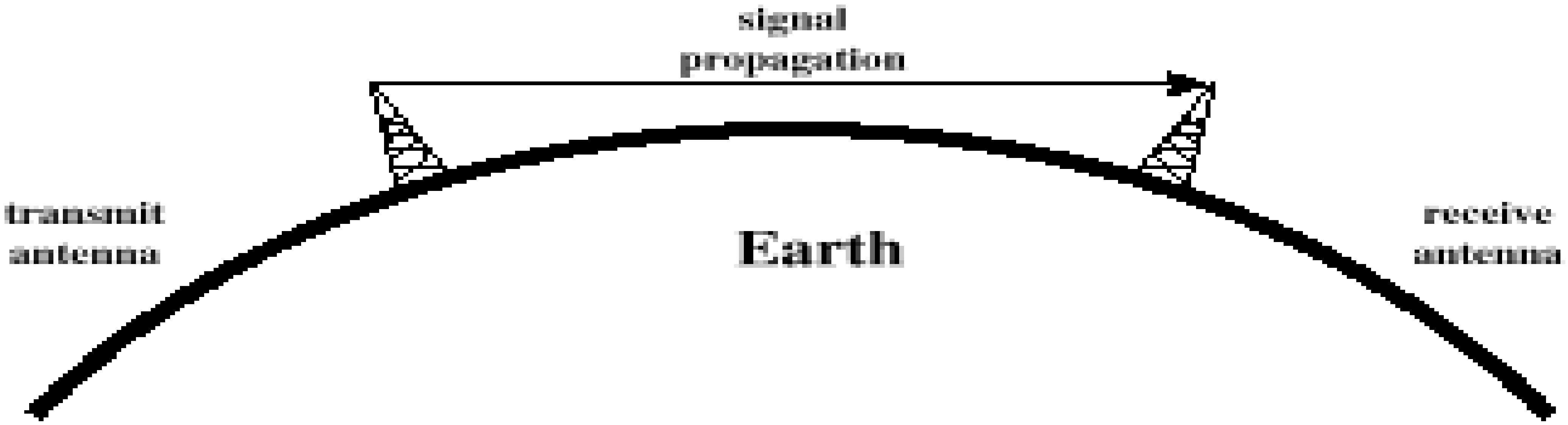
The throughput is almost one-fifth of the bandwidth in this case.

Electromagnetic Radiation

Dalga Kavramı

- Waves, sound waves, electromagnetic waves,...
- A wave can be thought of as a phenomenon that transfers energy by vibration.
- The speed of a wave depends on the type of wave and the medium through which it travels.
- The distance between congruent points in successive waves is called wavelength. It is usually defined by λ.
- The frequency of a wave is the number of waves passing a given point in one second. It is usually denoted by f or υ.
- The amplitude (or height) of a wave is defined as the perpendicular distance from the wave's midline to its crest or trough.
- Frequency, on the other hand, is given in Hz. The two relationships between frequency and period are expressed by $f=1/T$, $f=Wave/Time$. T is the period, denoted in seconds.$C=\lambda \times f$
- $\lambda=C/f$

Line-of-Sight Propagation



Line-of-Sight Propagation

- Transmitting and receiving antennas must be within line of sight
  - Satellite communication – signal above 30 MHz not reflected by ionosphere
  - Ground communication – antennas within *effective* line of sight due to refraction
- Refraction – bending of microwaves by the atmosphere
  - Velocity of an electromagnetic wave is a function of the density of the medium
  - When wave changes medium, speed changes
  - Wave bends at the boundary between mediums
- Mobile phone systems, satellite systems, cordless phones, etc.

Line-of-Sight Equations

- Optical line of sight

$$d = 3.57\sqrt{h}$$

- Effective, or radio, line of sight

$$d = 3.57\sqrt{\mathrm{K}h}$$

  - *d* = distance between antenna and horizon (km)
  - *h* = antenna height (m) (altitude relative to a receiver at the sea level)
  - K = adjustment factor to account for refraction caused by atmospherics layers; rule of thumb K = 4/3

Line-of-Sight Equations

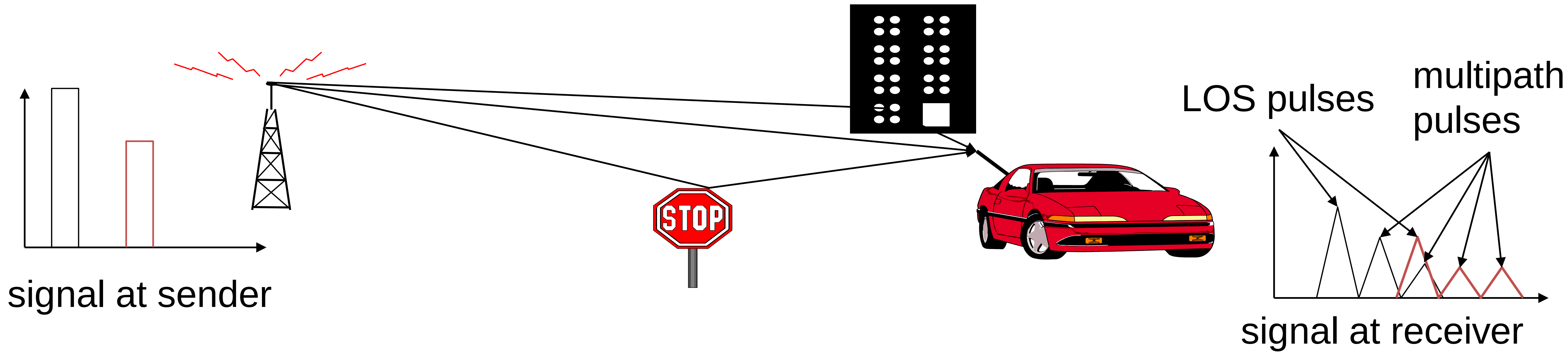
- Maximum distance between two antennas for LOS propagation:

$$3.57\left(\sqrt{\mathrm{K}h_1}+\sqrt{\mathrm{K}h_2}\right)$$

  - h_1 = height of antenna one
  - h_2 = height of antenna two

Multi-path 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

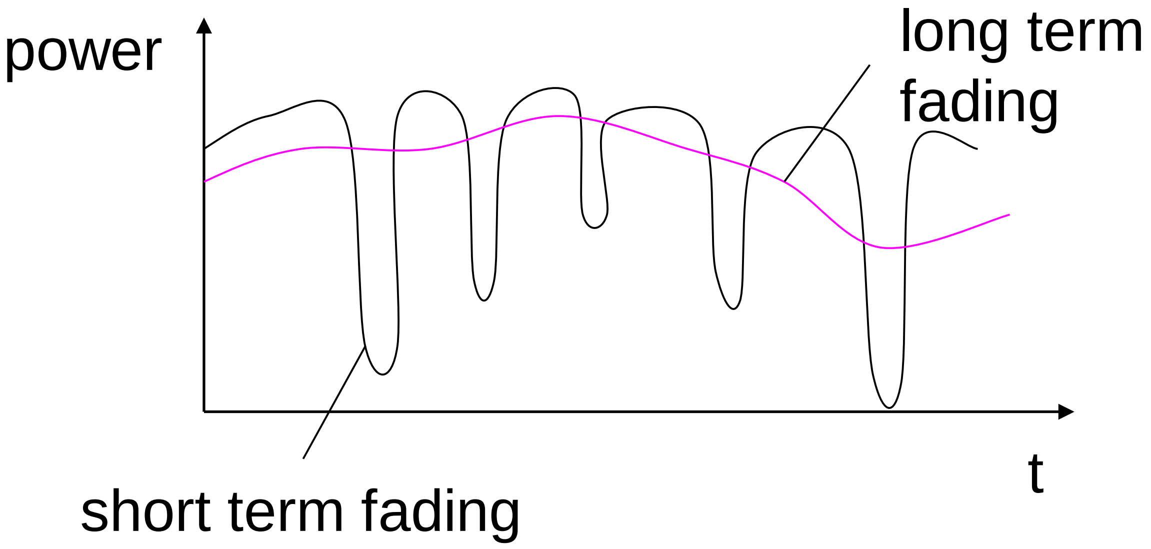
Atmospheric Absorption

- Water vapor and oxygen contribute the most.
- Water vapor: Peak attenuation around 22 GHz, low below 15 GHz.
- Oxygen: Absorption peaks around 60 GHz, below 30 GHz.
- Rain and fog can scatter (thus attenuate) the propagation of radio waves.

Effects of Mobility

- Channel characteristics change over time and location
  - signal paths change
  - different delay variations of different signal parts
  - different phases of signal parts
  - ➔ quick changes in the power received (short term fading)

- Additional changes in
  - distance to sender
  - obstacles further away
  - ➔ slow changes in the average power received (long term fading)



Fading Channels

- Fading: The change in received signal strength over time.Mobility complicates the modeling problem.Multipath propagation is a significant cause.The most challenging technical problem for mobile, satellite and radiolink communications.

Attenuation of Electromagnetic Emissions

Problems in LOS Wireless Transmission

- Attenuation and distortion
- Free-space propagation loss
- Atmospheric absorption
- Multipath (diffraction, reflection, refraction, etc.)
- Noise
- Thermal noise

Attenuation in Wireless Environment

- Signal strength decreases with distance over the wireless transmission medium.
- Attenuation factors for unguided media:
  - The received signal must have sufficient strength for the receiver circuitry to interpret it.
  - The signal must remain at a sufficiently high level above the noise to be received without error.
  - Attenuation is greater at higher frequencies, causing distortion (attenuation distortion).

Free Space Path Loss

- Free space path loss, ideal isotropic antenna

$$\frac{P_t}{P_r} = \frac{(4\pi d)^2}{\lambda^2} = \frac{(4\pi f d)^2}{c^2}$$

  - P_t = signal power at transmitting antenna
  - P_r = signal power at receiving antenna
  - λ = carrier wavelength
  - d = propagation distance between antennas
  - c = speed of light ($\approx 3 \times 10$ 8 m/s)

  where d and λ are in the same units (e.g., meters)

Signals weaken and deteriorate in all transmission environments. In wireless environments, signal attenuation is proportional to the square of the distance between the transmitter and receiver.
Log10(2)=0.3, Log(3)=0.477, Log(7)=0.845
FSL=32.45+20log(dkm*fMHz)
Signal reception level in decibels, Pr=Pt+Gt+Gr-FSL-PLcable

Link Analysis

- Pr and Pt are taken in dBm.
- Gt and Gr are taken in dBi.
- Lt, LR, and FSL are takenin dB.
- When dB and dBi values are combined in dBm, the result is found in dBm.
- FSL is called free space path loss.
- Pd: Electromagnetic power density at a distance of R meters from the transmitting antenna
- The power density carried by an electromagnetic wave in the far field in free space can also be calculated in terms of the electric field.

$$P_r = P_t + G_t + G_r - L_t - L_r - FSL$$

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

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

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

Example:

A wireless communication transmitter system radiates at a frequency of f=2GHz. If the output power, Pt=4 watts, transmitter antenna gain, Gt=20dBi, receiver antenna gain, Gr=3dBi, and total cable and connector loss, Ltot=10 dB, what will be the Pr reception level at a distance of 10 km in dBm? Note: Log(2)=0.3, Log(10)=1

Pr=Pt+Gt+Gr-FSL-Ltop

FSL=32.45+20Log(dkm*fMHz)

FSL=32.45+20Log(10*2000)=32.45+20Log(2*10^4)=32.45+20log(2)+80Log(10)=32.45+20*0.3+80=112.45dB

If Pt=4 watt=4000mW, Pt=10Log(4000) dBm = 10Log(2^2)+10Log(10^3) = 20Log(2)+30Log(10) = 20*0.3+30 = 36dBm

Pr=36+20+3-112.45-10=-53.45dBm

If the receiving sensitivity level of a receiving device 10km away is Pr(sensitivity)=-80dBm, will this device work?

Since Pr>Pr(sensitivity), the system works.

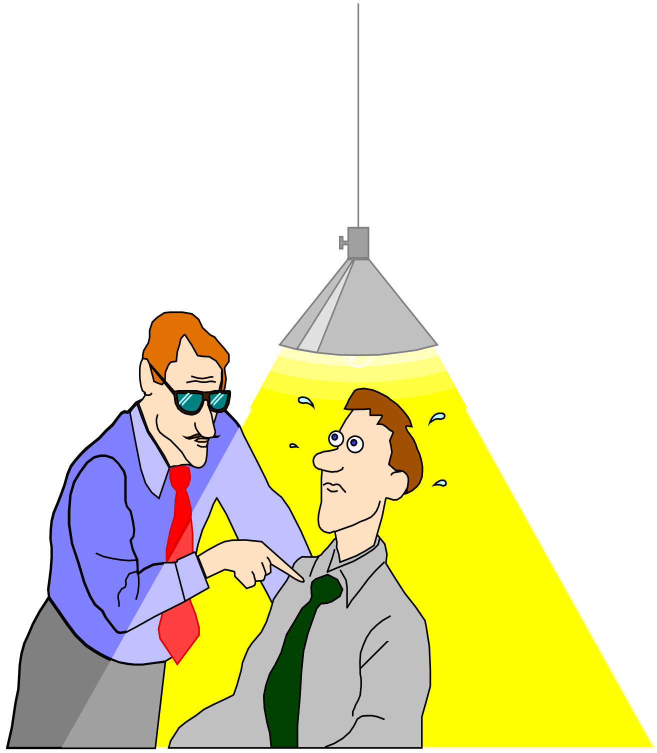
How many watts is Pr=-50dBm?

If Pr(dBm)=10Log(Prmw),

If -50=10Log(Prmw), then Prw=10^-5mw=10^-8w

My essence is to light a spark in your brain.

Questions?



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Sincerely,

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thank you