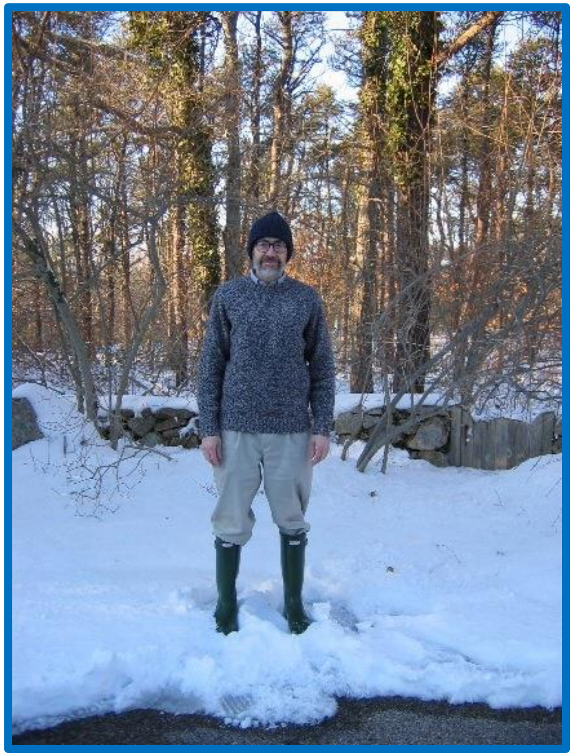
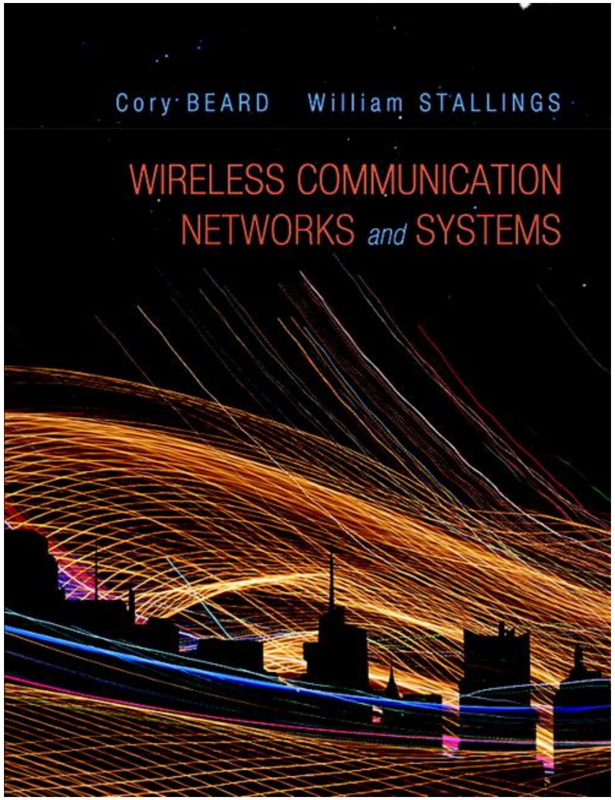


CHAPTER 2 TRANSMISSION FUNDAMENTALS



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Wireless Communication Networks and Systems

1st edition

Cory Beard, William Stallings

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A

DATA COMMUNICATION TERMS

- Data - entities that convey meaning, or information - analog/digital
- Signals - electric or electromagnetic representations of data – analog/digital
- Transmission - communication of data by the propagation and processing of signals

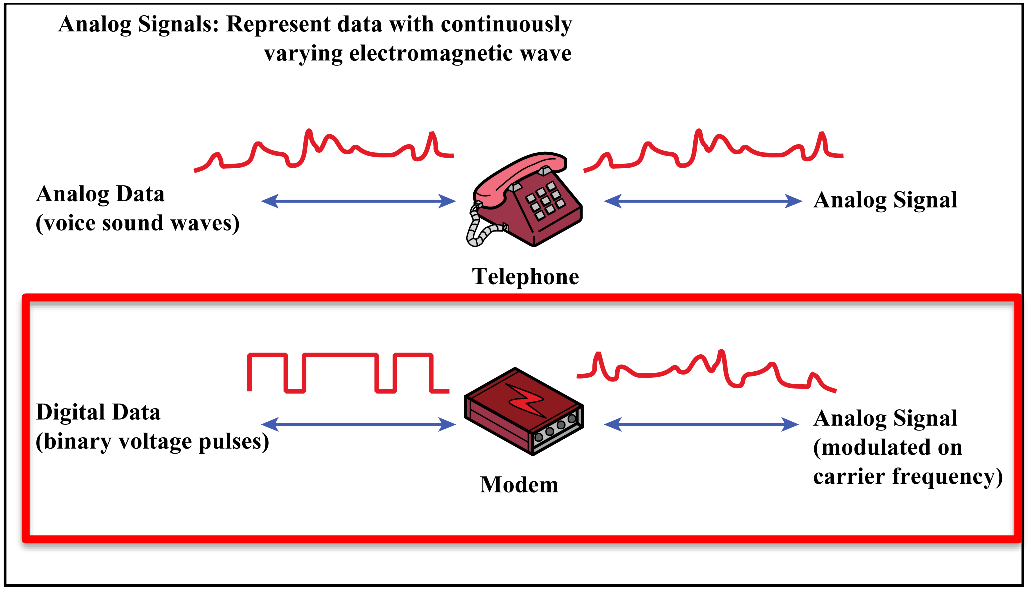
ANALOG SIGNALS

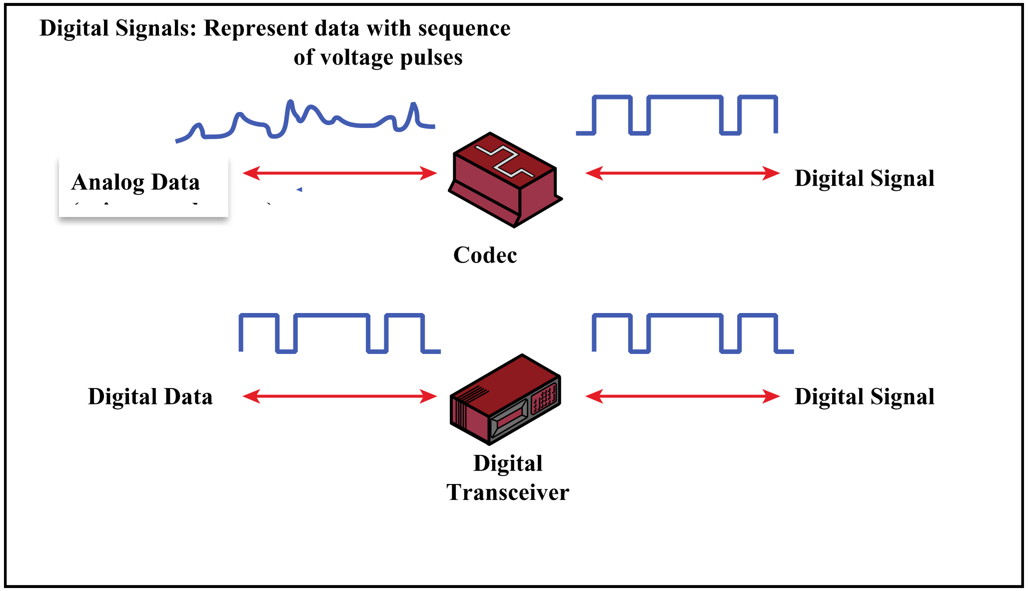
- A continuously varying electromagnetic wave that may be propagated over a variety of media, depending on frequency
- Examples of media:
  – Copper wire media (twisted pair and coaxial cable)
  – Fiber optic cable
  – Atmosphere or space propagation
- Analog signals can propagate analog and digital data

DIGITAL SIGNALS

- A sequence of voltage pulses that may be transmitted over a copper wire medium
- Generally cheaper than analog signaling
- Less susceptible to noise interference
- Suffer more from attenuation
- Digital signals can propagate analog and digital data

ANALOG AND DIGITAL SIGNALING OF ANALOG AND DIGITAL DATA





REASONS FOR CHOOSING DATA AND SIGNAL COMBINATIONS

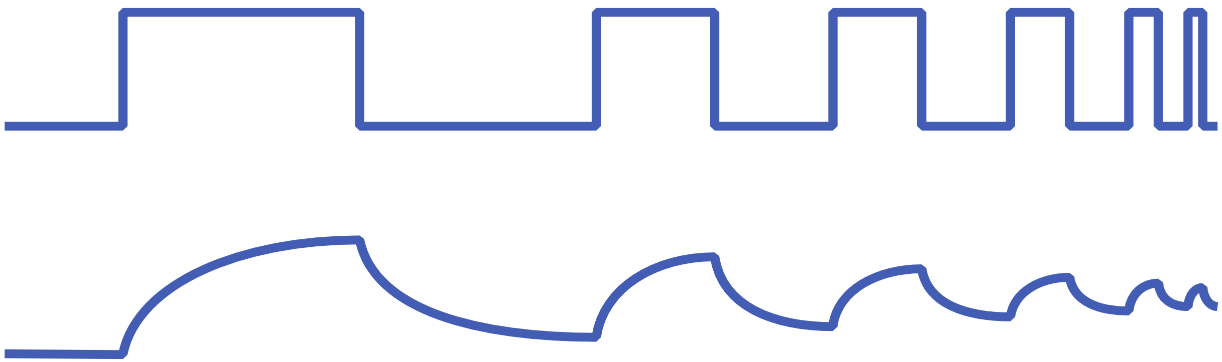
- **Analog data, analog signal**
  - Analog data easily converted to analog signal
- **Digital data, analog signal**
  - Some transmission media (air) will only propagate analog signals
  - Examples include optical, satellite, mobile telephony
- **Analog data, digital signal**
  - Conversion permits use of modern digital transmission and switching equipment
- **Digital data, digital signal**
  - Equipment for encoding is less expensive than digital-to-analog equipment

ANALOG TRANSMISSION

- **Attenuation limits length of transmission link**
- Cascaded amplifiers boost signal's energy for longer distances but also **noise** that causes distortion
  - Analog data can sometimes tolerate distortion (e.g. voice)
  - Introduces errors in digital data

Voltage at transmitting end

Voltage at receiving end



DIGITAL TRANSMISSION

- **Attenuation endangers integrity of data**
- Digital Signal
  - Repeaters achieve greater distance
  - Repeaters recover the signal and retransmit
- Analog signal carrying digital data
  - Retransmission device recovers the digital data from analog signal
  - Generates new, clean analog signal

B

DESCRIPTION OF ELECTROMAGNETIC SIGNAL

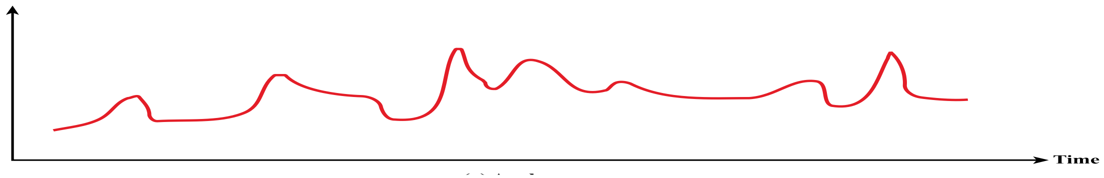
- Function of time – **time domain**

- As a function of frequency – **frequency domain**
  - Signal consists of components of different frequencies (**Fourier**)

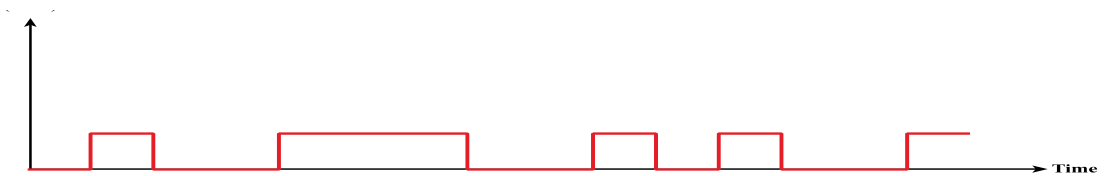
- Frequency domain is more useful!

TIME-DOMAIN CONCEPTS (1)

- **Analog signal** - signal intensity varies in a smooth fashion over time - No breaks or discontinuities in the signal



- **Digital signal** - signal intensity maintains a constant level for some period of time and then changes to another constant level



- **Periodic signal** - analog or digital signal pattern that repeats over time

  $s(t + T) = s(t) \quad -\infty < t < +\infty$, where ***T* is the period of the signal**

- **Aperiodic signal** - analog or digital signal pattern that doesn't repeat over time

ChatGPT 23-11-06

Analog är ett begrepp som används inom olika sammanhang och kan ha olika betydelser beroende på sammanhanget. Här är några av de vanligaste betydelserna:

Analog i elektronik: Inom elektronik refererar "analog" till en typ av signal eller teknik där informationen representeras kontinuerligt, vanligtvis som en spännings- eller strömvariation. Det innebär att signalen kan ha oändligt många värden inom ett visst intervall. Till exempel är en analog klocka en klocka med visare som rör sig kontinuerligt över en urtavla.

Analog i data och kommunikation: Inom datavetenskap och kommunikation avser "analog" data eller signaler som inte är diskreta eller digitala. Det betyder att informationen inte är uppdelad i separata bitar utan istället är kontinuerlig. Ljudvågor är ett exempel på analog data, medan digitala ljudfiler består av diskreta bitar.

Analog i jämförelse med digital: När man jämför med "digital" betyder "analog" att något är baserat på en kontinuerlig representation snarare än en diskret representation i form av 0 och 1. Till exempel, en analog klocka mäter tid kontinuerligt medan en digital klocka visar tiden i diskreta steg.

Så "analog" kan betyda olika saker beroende på sammanhanget, men det innebär vanligtvis något som är kontinuerligt och inte baserat på diskreta värden.

TIME-DOMAIN CONCEPTS (2)

- **Sine wave** $\boxed{s(t) = A \sin(2\pi f t + \phi) = A \sin(\omega\, t + \phi)}$
- $\boxed{2\pi f = \omega \rightarrow f = \omega/2\pi \quad \text{f [Hertz]},\ \omega\ \text{[radian]}}$
- $\boxed{2\pi\ \text{radian} = 360^0 \quad 1\ \text{radian} = 360^0/2\pi = 57{,}3^0}$
- **Peak amplitude** (*A*) - maximum value or strength of the signal over time; typically measured in volts
- **Frequency** (*f*)
  - Rate, in cycles per second, or Hertz (Hz) at which the signal repeats

TIME-DOMAIN CONCEPTS (3)

- **Period** (***T***) - amount of time it takes for one repetition of the signal – **in time**!

  $\boxed{T = 1/f \qquad f = 1/T}$

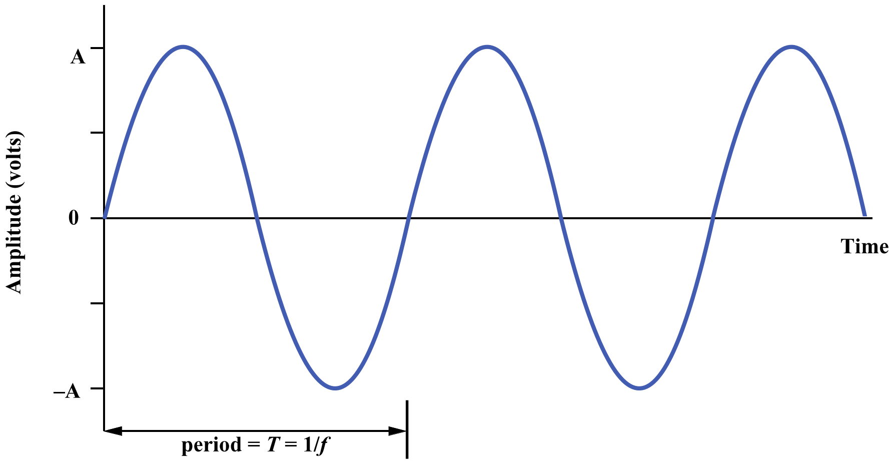
- **Phase** (ϕ) - measure of the relative position in time within a single period of a signal
- **Wavelength** (λ) - distance occupied by a single cycle of the signal – **in space**!

  $\boxed{\lambda = v*T = v/f}$

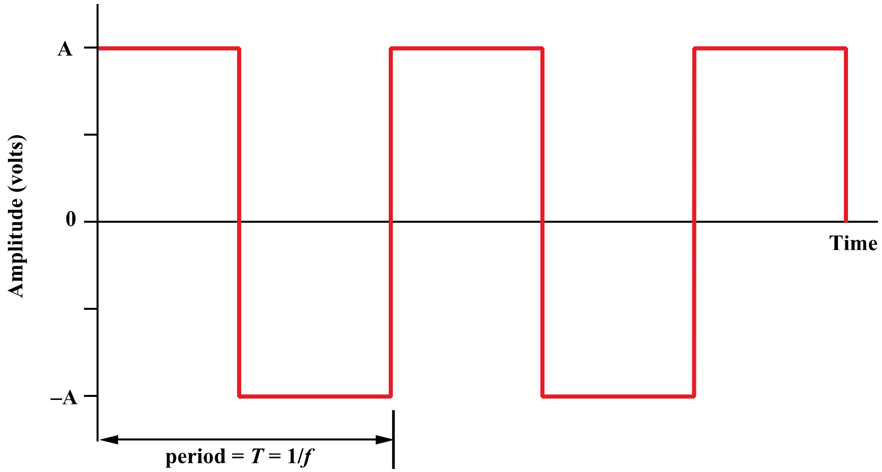
  Microwave oven: v = 300 000 000 m/s, f = 2,45 GHz

  λ = 300 000 000/2 450 000 000 = 12,2 cm

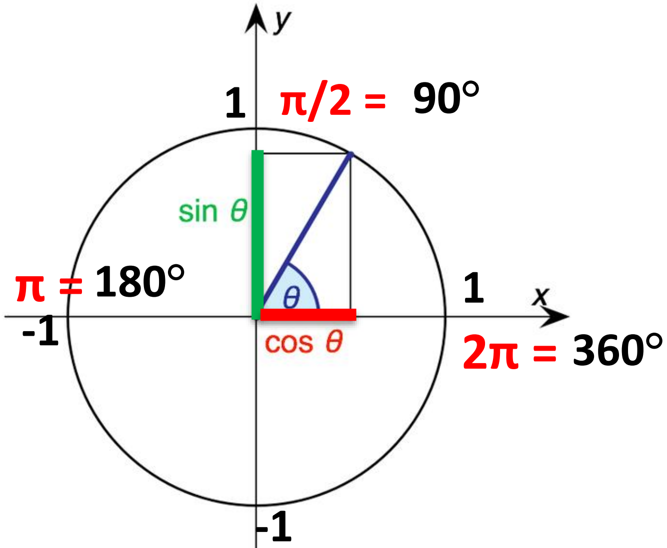
EXAMPLES OF PERIODIC SIGNALS



(a) Sine wave



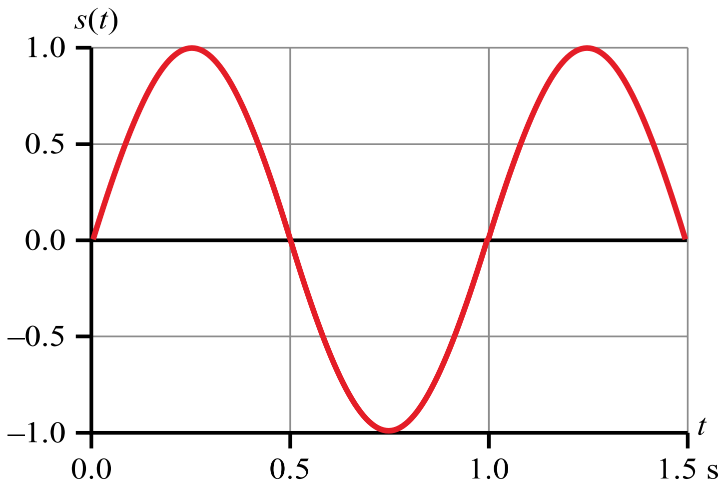
(b) Square wave



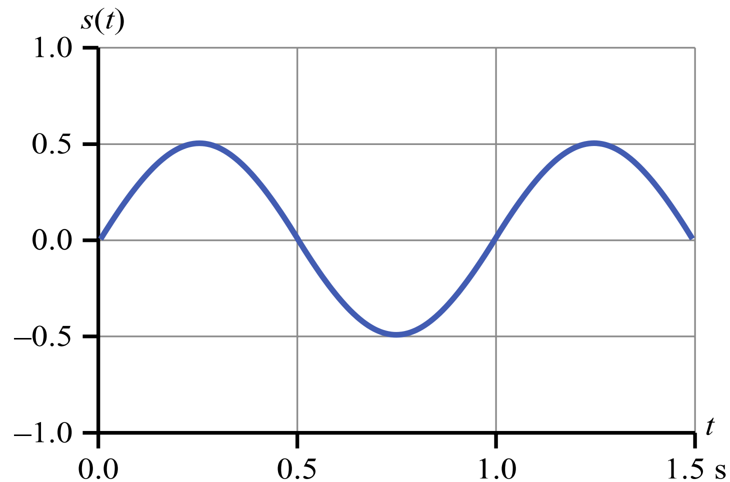
A unit circle is a circle on the Cartesian Plane that has a radius of 1 unit and is centered at the origin (0, 0). The unit circle is a powerful tool that provides us with easier reference when we work with trigonometric functions and angle measurements.

SINE WAVE PARAMETERS

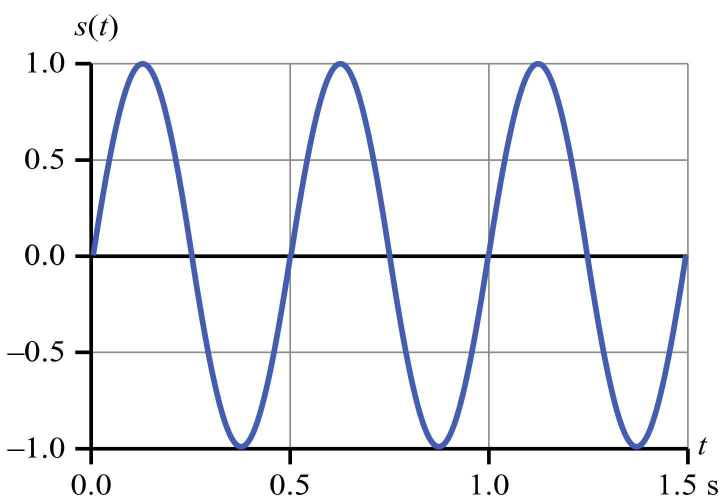
General sine wave $s(t) = A \sin(2\pi ft + \phi)$ **parameters** **A, f, ϕ**



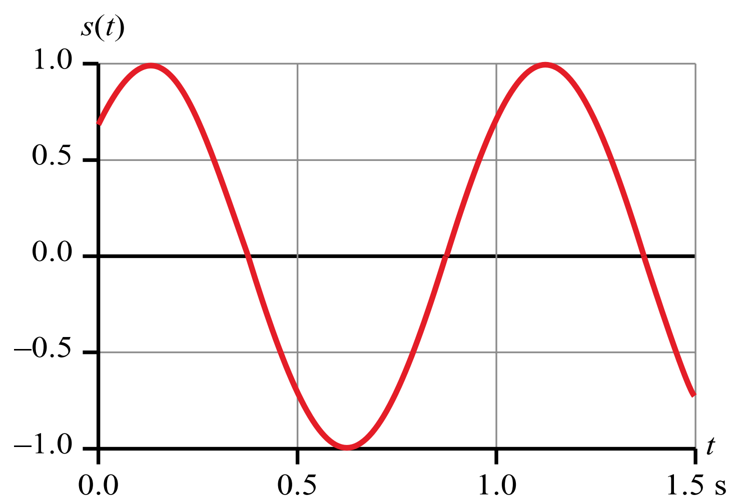
(a) $A = 1, f = 1, \phi = 0$



(b) $A = 0.5, f = 1, \phi = 0$



(c) $A = 1, f = 2, \phi = 0$



(d) $A = 1, f = 1, \phi = \pi/4$

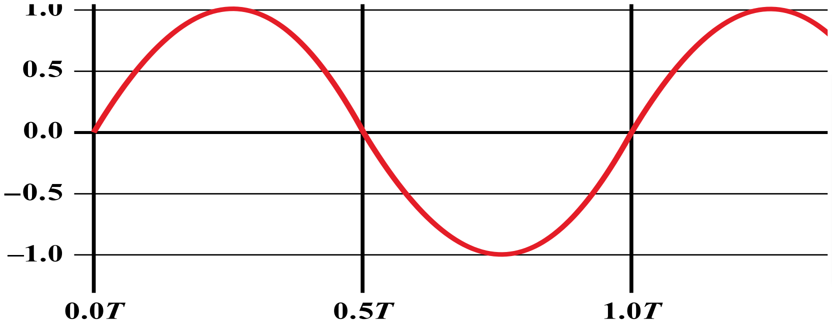
TIME VS. DISTANCE

- When the horizontal axis is ***time*** graphs display the value of a signal at a given point in *space* as a function of *time*
- With the horizontal axis in ***space***, graphs display the value of a signal at a given point in *time* as a function of *distance*

FREQUENCY-DOMAIN CONCEPTS

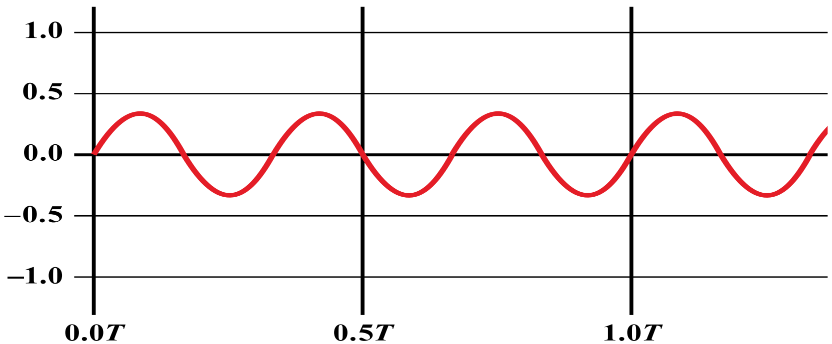
- Any electromagnetic signal can be shown to consist of a collection of periodic analog signals (sine waves) at different amplitudes, frequencies, and phases
- **Fourier analysis (Fourier transform)**
- **Fundamental frequency** - when all frequency components of a signal are integer multiples of one frequency, it's referred to as the fundamental frequency. Other components are called harmonics.
- **Spectrum** - range of frequencies that a signal contains
- **Absolute bandwidth** - width of the spectrum of a signal
- **Effective bandwidth** (or just bandwidth) - narrow band of frequencies that most of the signal's energy is contained in

SQUARE WAVE - ADDITION OF FREQUENCY COMPONENTS



(a) sin (2ϕft)

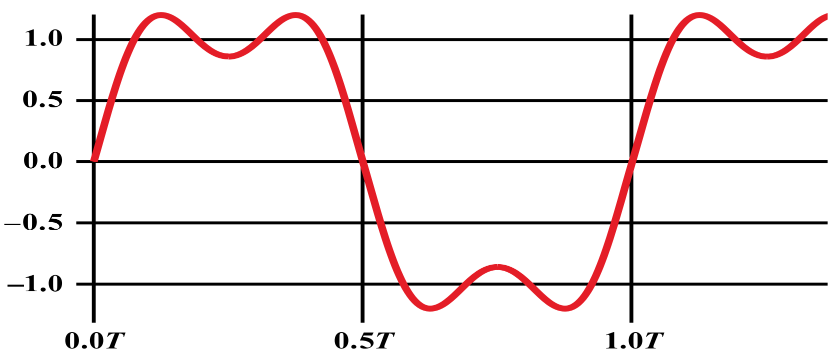
$$\boxed{s(t) = A \times \frac{4}{\pi} \sum_{k \text{ odd}, k=1}^{\infty} \frac{\sin(2\pi k f t)}{k}}$$



(b) (1/3) sin (2ϕ(3f)t)

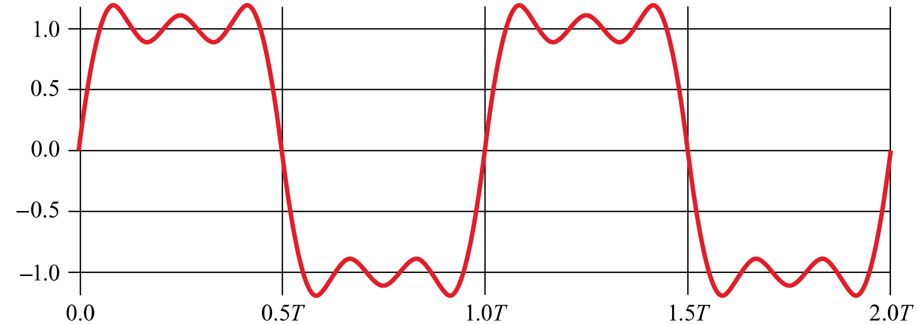
$$\sum_{n=1,3,5\ldots}^{\infty} \frac{4}{n\pi} \sin(2\pi n f_1 t)$$

π not Φ !!!

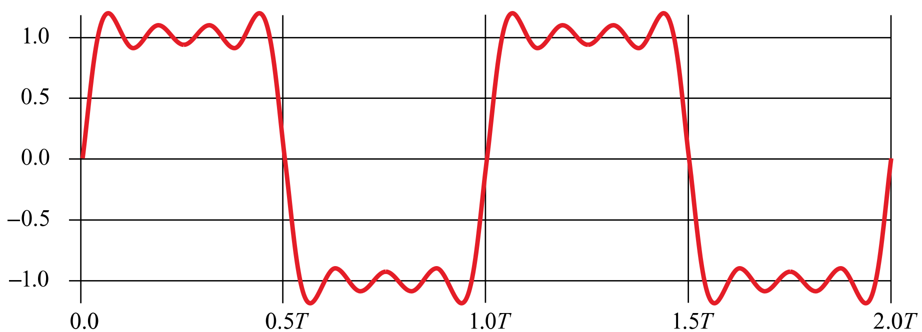


(c) (4/ϕ) [sin (2ϕft) + (1/3) sin (2ϕ(3

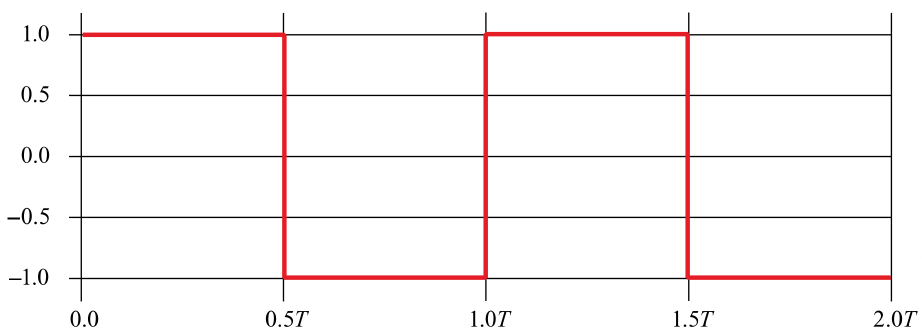
FREQUENCY COMPONENTS OF SQUARE WAVE



(a) $(4/\phi)$ [$\sin(2\phi ft) + (1/3)\sin(2\phi(3f)t) + (1/5)\sin(2\phi(5f)t)$]



(b) $(4/\phi)$ [$\sin(2\phi ft) + (1/3)\sin(2\phi(3f)t) + (1/5)\sin(2\phi(5f)t) + (1/7)\sin(2\phi(7f)t)$]



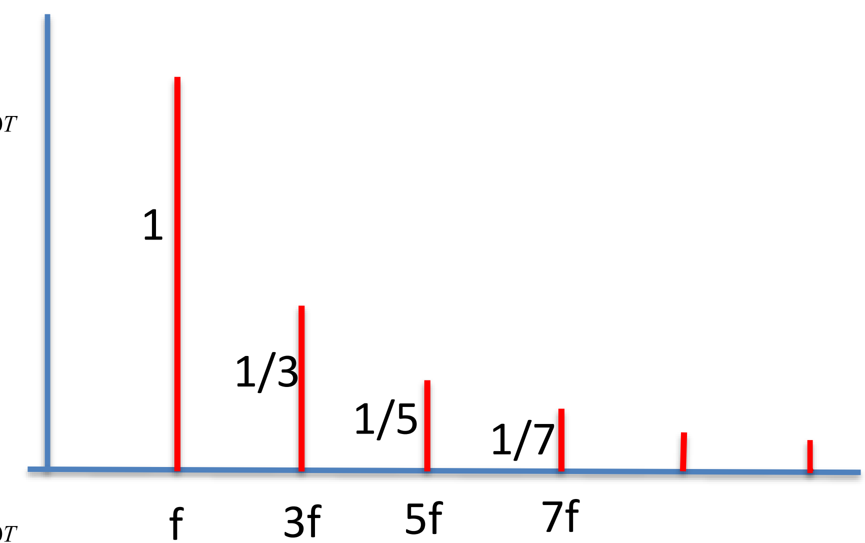
(c) $(4/\phi)\ \Sigma(1/k)\sin(2\phi(kf)t)$, for k odd

$$s(t) = A \times \frac{4}{\pi} \sum_{k\ \mathrm{odd},\ k=1}^{\infty} \frac{\sin(2\pi kft)}{k}$$

k = 1,3,5,7, ...

→ frekvensen: f, 3f, 5f, 7f, ...

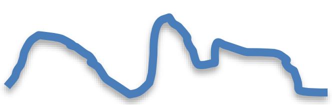
amplituden: 4A/π *(1, 1/3, 1/5, 1/7, ...)

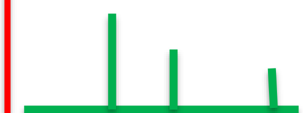


FFT / IFFT

Signal

Spektrum





Fourier transform

Inverse Fourier transform

Fast Fourier transform (FFT)

Inverse Fast Fourier transform (IFFT)

LUCAS (Lund University Content Addressable System)

1.5 Product description

The ODIN-W2 series module supports Wi-Fi, Bluetooth BR/EDR, and Bluetooth Low Energy (dual-mode / Bluetooth Smart Ready). The Wi-Fi support conforms to IEEE 802.11a/b/g/n, and has support for dual-band 2.4 GHz and 5 GHz operations and 2×2 MIMO (2.4 GHz).

Wi-Fi	Classic Bluetooth	Bluetooth Low Energy
IEEE 802.11a/b/g/n IEEE 802.11d/e/i/h/w*** ODIN-W260: 2X2 MIMO (2.4 GHz only)	Classic Bluetooth v2.1+EDR Maximum number of Peripherals: 7 Bluetooth profiles: SPP, DUN, GATT and PAN	Bluetooth LE 4.2 dual-mode
Band support Station mode: 2.4 GHz, channel 1-13* 5 GHz, channel 36-165* Access Point mode: 2.4 GHz, channel 1-11 5 GHz, channel 36-48	Band support 2.4 GHz, 79 channels	Band support 2.4 GHz, 40 channels
Maximum conducted output power 15 dBm	Maximum conducted output power 11 dBm	Maximum conducted output power 7 dBm
Maximum radiated output power 18 dBm EIRP**	Maximum radiated output power 14 dBm EIRP**	Maximum radiated output power 10 dBm EIRP**
Conducted sensitivity 2.4 GHz: -95 dBm 5 GHz: -90 dBm	Conducted sensitivity -90 dBm	Conducted sensitivity -95 dBm
Data rates: IEEE 802.11b:	Data rates: 1 / 2 / 3 Mbit/s	Data rates: 1 Mbit/s

LOGARITMER

Läs gärna: http://en.wikipedia.org/wiki/Logarithm

Definition

Om $x = a^y$ så $y = \log_a(x)$

Exempel

a (basen) = 10

$x = 10^y$ $y = \log_{10}(x)$

$1 = 10^0$ $0 = \log_{10}(1)$

$10 = 10^1$ $1 = \log_{10}(10)$

$10000 = 10^4$ $4 = \log_{10}(10000)$

$0{,}1 = 10^{-1}$ $-1 = \log_{10}(0{,}1)$

$0{,}001 = 10^{-3}$ $-3 = \log_{10}(0{,}001)$

a (basen) = 2

$x = 2^y$ $y = \log_2(x)$

$x = 2^y$ $y = \log_2(x)$

$2 = 2^1$ $1 = \log_2(2)$

$4 = 2^2$ $2 = \log_2(4)$

$16 = 2^4$ $4 = \log_2(16)$

$1024 = 2^{10}$ $10 = \log_2(1024)$

Några regler

$\log(x*y) = \log(x) + \log(y)$

$\log(x/y) = \log(x) – \log(y)$

$\log(x^p) = p*\log(x)$

$\log_a(x) = \log_c(x)/\log_c(a)$

$\log_2(x) = \log_{10}(x)/\log_{10}(2) = \log_{10}(x)/0{,}3$

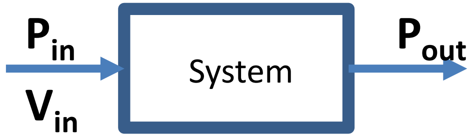
$= 3{,}3*\log_{10}(x)$

$\log_{10}(x) = 0{,}3*\log_2(x)$

DECIBEL

Läs gärna: http://en.wikipedia.org/wiki/Decibel

De numeriska värdena i samband med signalöverföring kan variera inom stora områden. Ofta använder man därför logaritmiska skalor och decibel. Detta ger dessutom räknemässiga fördelar till följd av logaritmlagarna.



Bra att veta:
3 dB betyder 2 ggr
-3 dB betyder 0,5 ggr
10 dB betyder 10 ggr

Förstärkning (gain) in decibel: $G_{dB} = 10 \log_{10} (P_{out}/P_{in})$

Dämpning (loss) in decibel $L_{dB} = 10 \log_{10} (P_{in}/P_{out}) = - 10 \log_{10} (P_{out}/P_{in}) = - G_{dB}$

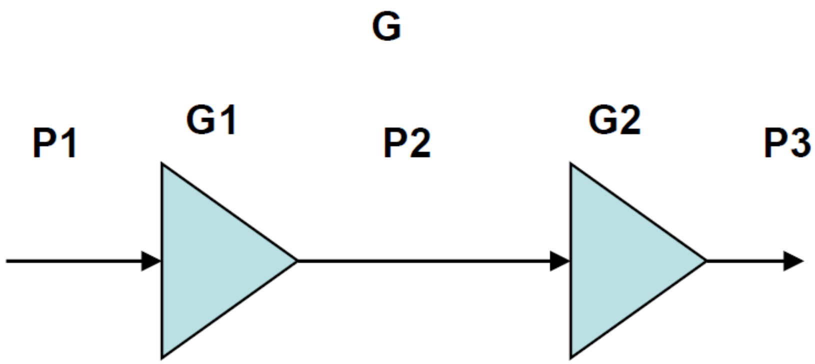
$P_{dBW} = 10 \log_{10} (P_W/1\text{ W})$

$P_{dBm} = 10 \log_{10} (P_{mW}/1\text{ mW})$

$G_{dB} = 20 \log_{10} (V_{out}/V_{in})$ V_{out}

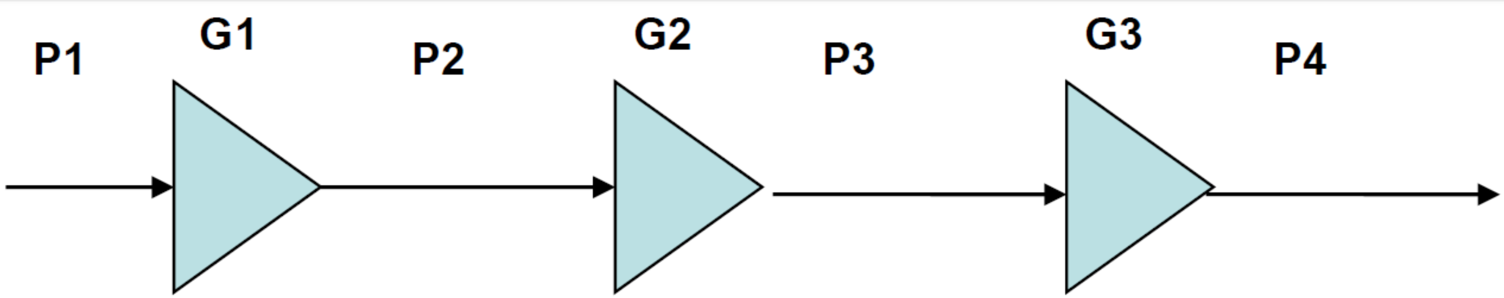
$L_{dB} = 20 \log_{10} (V_{in}/V_{out})$

$dBV = 10 \log_{10}(S_V/1V)$



G1 = 10log(P2/P1), G2 = 10log(P3/P2), G = 10log(P3/P1)

G = G1 + G2 = 10 log P2/P1 + 10 log P3/P2 = 10 (log P2/P1 + log P3/P2) =
= 10 (log P2 –log P1 + log P3 – log P2) = 10 (log P3 – log P1) = **10 log P3/P1**



G1 = -12dB, G2 = 35 dB, G3 = -10 dB, P1 = 4mW, P4 = ?

G = -12 + 35 - 10 = 13 dB = 10 log (P4/4mW)
13 = 10log(P4/P1)
1.3 = log P4 – log 4 = logP4 – 0.6
1.9 = log P4, P4 = $10^{1.9}$ = 80 mW

If an amplifier has a 30 dB voltage gain, what voltage ratio does the gain represent?

$G_V = 30\ dBV = 20*\log_{10}(V2/V1)$

$1{,}5 = \log_{10}(V2/V1)$

$V2/V1 = 10^{1{,}5} = 31{,}6$

An amplifier has an output of 20 W. What is its output in dBW?

$Power(dBW) = 10*\log_{10}(Power/1W) = 10*\log_{10}(20) = 10*1{,}3 = 13\ dBW$

1970 Low-loss optical fibres demonstrated

The design principles of an **optical fiber cable for communication using laser light** were published in 1966 by Standard Telecom Labs in UK.

In 1970, Robert Maurer led a team at US Company Corning Glass which produced the first optical fiber with acceptable **attenuation** (less than **1 dB/km**).

The first field trial of an optical fiber telephone system was carried out by Western Electric and Bell Labs in 1975. The cable carried 144 optical fibers with a capacity of 100 000 telephone circuits.

RG58-ANTENNKABEL	
450 MHz	0,33 dB/m
900 MHz	0,49 dB/m
1 800 MHz	0,73 dB/m
2 400 MHz	1,06 dB/m

Fiber - dämpning (attenuation)

1 km (1970): $1\ dB = 10 \log(P_{in}/P_{ut})$

$0{,}1 = \log(P_{in}/P_{ut}) >> P_{in}/P_{ut} = 10^{0{,}1} = 1{,}26 >>$ $\mathbf{P_{in} = 1{,}26{*}P_{ut}}$

10 km: $10{*}1\ dB = 10\ dB = 10 \log(P_{in}/P_{ut})$

$1 = \log(P_{in}/P_{ut}) >> P_{in}/P_{ut} = 10^{1} = 10 >>$ $\mathbf{P_{in} = 10{*}P_{ut}}$

$\mathbf{1{,}26^{10} = 10}$

1 km (2023): $0{,}3\ dB = 10 \log(P_{in}/P_{ut})$

$0{,}03 = \log(P_{in}/P_{ut}) >> P_{in}/P_{ut} = 10^{0{,}03} = 1{,}07 >>$ $\mathbf{P_{in} = 1{,}07{*}P_{ut}}$

10 km: $10{*}0{,}3\ dB = 3\ dB = 10 \log(P_{in}/P_{ut})$

$0{,}3 = \log(P_{in}/P_{ut}) >> P_{in}/P_{ut} = 10^{0{,}3} = 1{,}99 >>$ $\mathbf{P_{in} = 2{*}P_{ut}}$

$\mathbf{1{,}07^{10} = 2}$

10*1 dB = 10 dB

$1{,}26{*}1{,}26{*}1{,}26{*}\ldots{*}1{,}26 = 1{,}26^{10} = 9{,}99$

Koaxial kabel – dämpning

1 m: **0,49 dB** = 10 log(P_{in}/P_{ut})

0,049 = log(P_{in}/P_{ut}) >> $P_{in}/P_{ut} = 10^{0,049}$ = 1,011 >> **P_{in} = 1,07*P_{ut}**

10 m: **10*0,49 dB = 4,9 dB** = 10 log(P_{in}/P_{ut})

0,49 = log(P_{in}/P_{ut}) >> $P_{in}/P_{ut} = 10^{0,49}$ = 3,09 >> **P_{in} = 3,09*P_{ut}**

1 km: **1000*0,49 dB = 490 dB** = 10 log(P_{in}/P_{ut})

49 = log(P_{in}/P_{ut}) >> $P_{in}/P_{ut} = 10^{49}$ >> **$P_{in} = 10^{49}$*P_{ut}**

D

CHANNEL CAPACITY

- **Channel Capacity, C** – the maximum rate at which data can be transmitted over a given communication path, or channel, under given conditions

- Impairments, such as noise, limit data rate

IMPORTANT QUESTION:

- For digital data, to what extent do impairments limit data rate?

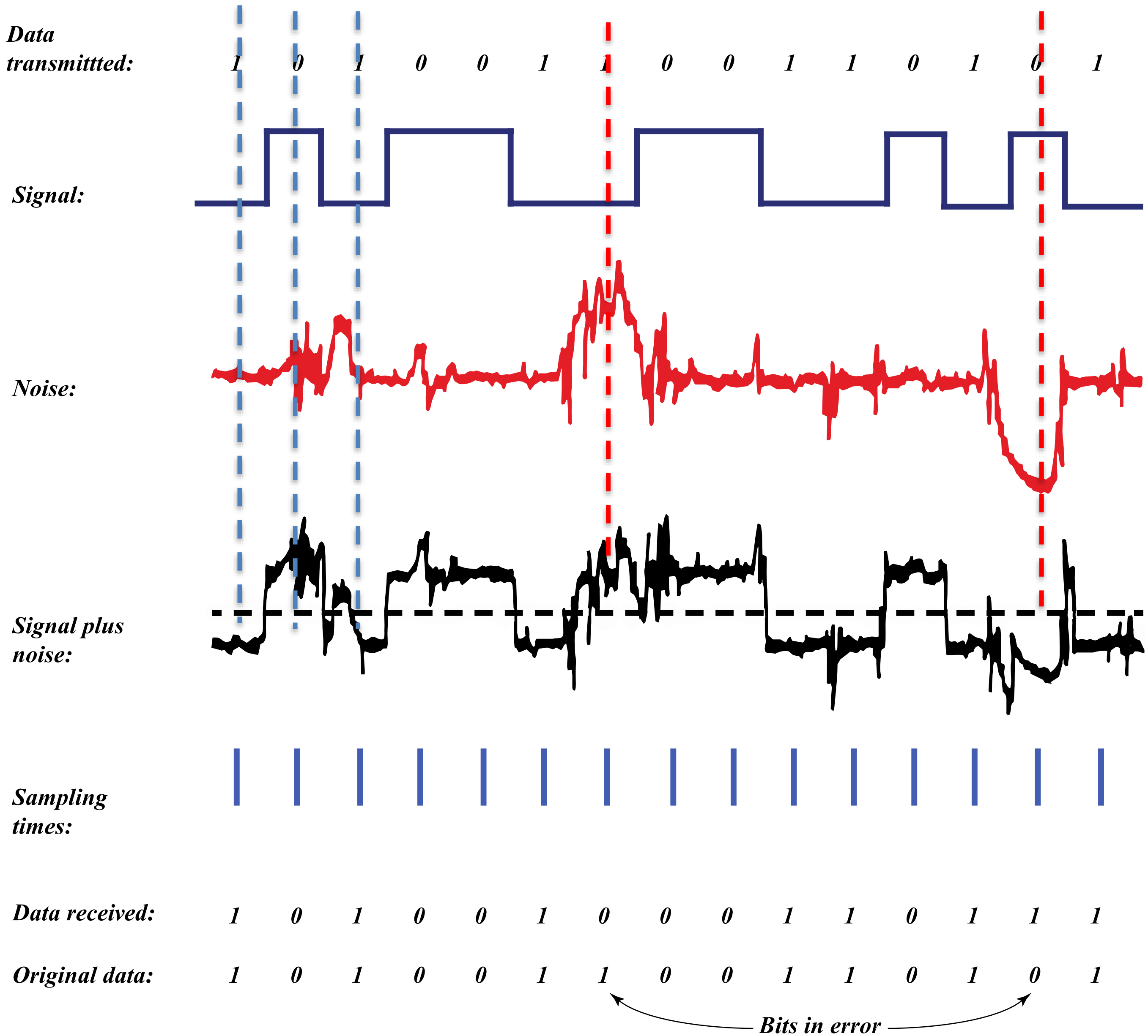
CONCEPTS RELATED TO CHANNEL CAPACITY

- **Data rate** - rate at which data can be communicated (bps)
- **Error rate (BER)** - rate at which errors occur
  - Error = transmit 1 and receive 0; transmit 0 and receive 1
- **Bandwidth** - the bandwidth of the transmitted signal as constrained by the transmitter and the nature of the transmission medium (Hz)
- **Noise** - average level of noise over the communications path

RELATIONSHIP BETWEEN DATA RATE AND BANDWIDTH

- Any digital waveform will have infinite bandwidth
- The greater the bandwidth, the higher the information-carrying capacity
- The transmission system will limit the bandwidth that can be transmitted
- For any given medium, the greater the bandwidth transmitted, the greater the cost
- Limiting the bandwidth creates distortions

EFFECT OF NOISE ON DIGITAL SIGNAL



NYQUIST BANDWIDTH

- **No noise!**
- Bandwidth *B[Hz]*, Data rate *C [bps]*

- For binary signals (two voltage levels)

  $\boxed{\boldsymbol{C = 2B}}$ *(voice channel, 3100 Hz → 6200 bps)*

- With multilevel signaling

  $\boxed{\boldsymbol{C = 2B \log_2 M}}$ M = number of discrete signal levels

  M=8 *(voice channel, 3100 Hz → 18600 bps)*

Harry Nyquist, född som *Harry Theodor Nyqvist* den 7 februari 1889, död 4 april 1976, var en svensk-amerikansk elektroingenjör och fysiker, vars arbeten om signalöverföring bidrog till utvecklingen av informationsteorin.

1927 slog Nyquist fast att **en telegrafledning kan överföra pulser med en frekvens på som mest dubbla ledningens bandbredd**. Nyquist publicerade detta i rapporten *Certain topics in Telegraph Transmission Theory* (1928).

Samma teori gäller vid digital signalbehandling där **en analog signal måste samplas vid dubbla frekvensen av den mest högfrekventa signalkomponenten för att kunna återskapas utan förvrängning**, så kallad vikningsdistorsion. Detta samband är idag känt som **Nyquist-Shannons samplingsteorem**.

SIGNAL-TO-NOISE RATIO

- Ratio of the power in a signal to the power contained in the noise that's present at a particular point in the transmission
- Typically measured at a receiver
- Signal-to-noise ratio (SNR, or S/N)

$$SNR = \frac{\text{signal power}}{\text{noise power}}$$

$$(SNR)_{\text{dB}} = 10 \log_{10} \frac{\text{signal power}}{\text{noise power}}$$

- A high SNR means a high-quality signal
- SNR sets upper bound on achievable data rate

SHANNON CAPACITY FORMULA

NOT dB!!!

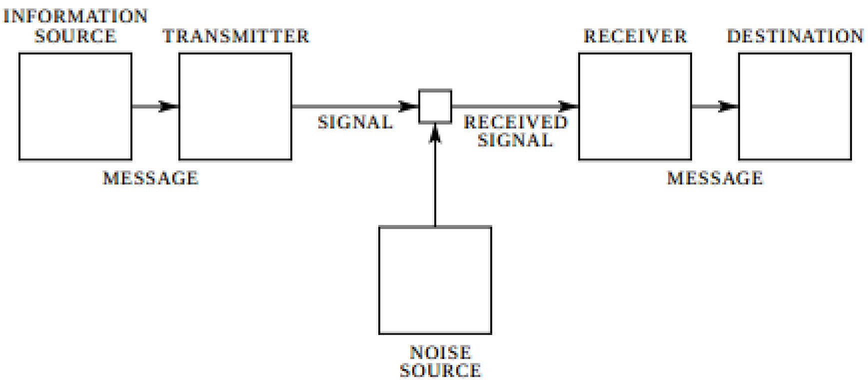
$$\boxed{C = B\log_2\left(1+\mathrm{SNR}\right)}$$

- Bandwidth *B[Hz]*, Data rate *C [bps]*
- Represents theoretical maximum that can be achieved
- In practice, only lower rates attained
  - Formula assumes white noise **(thermal noise)**
  - Other types of noise, e.g. **impulse noise,** is not accounted for

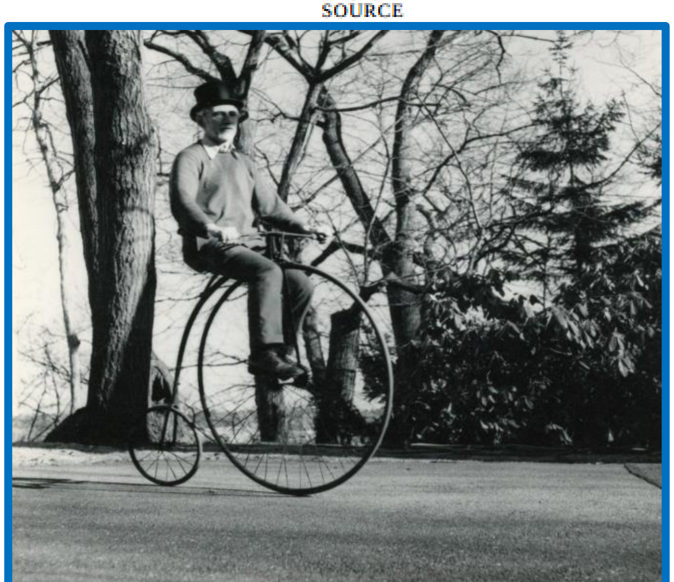
CLAUDE SHANNON

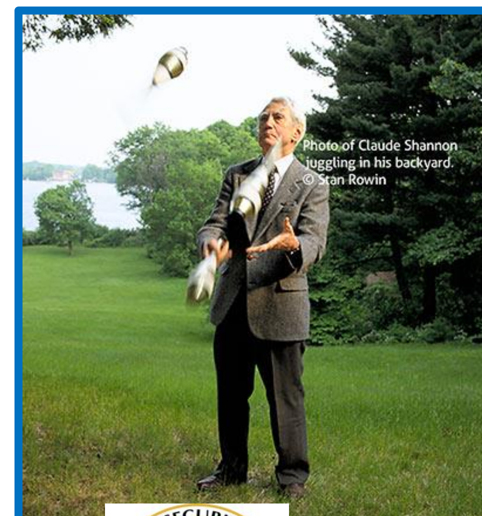
1916-2001

$$\boxed{C = B\log_2\left(1+\mathrm{SNR}\right)}$$



A Mathematical Theory of Communication (1948) - Shannons viktigaste och mest kända verk. I detta utvecklades en teori kring begreppen information, entropi och redundans. Ordet 'bit' användes här för första gången





What is the maximum data rate, **C**, for a typical telephone line with **SNR** of 30 dB and audio bandwidth **B** of 3,1 kHz?

30 dB = 10 log(SNR) → 3 = log(SNR) → SNR = 10^3 = 1000

C = B $\log_2$(1+SNR) = 3100 $\log_2$(1001) =

3100 $\log_{10}$(1001) *3,3 = 3100*3*3,3 = 31 000 bps = **31 kbps**

What is **C** for a satellite TV channel with a **signal-to noise ratio** of 20 dB and a video **bandwidth** of 10 MHz?

20 dB = 10 log(SNR) → 2 = log(SNR) → SNR = 10^2= 100

C = B $\log_2$(1+SNR) = 10^7 $\log_2$(101) = 10^7 $\log_{10}$(101) *3,3 = 10^7*2*3,3 = **66 Mbps**

If an optical fiber has a **bandwidth** of 2 Gigahertz and a modem uses **M** = 512 signal levels, what is the maximum data rate according to Nyquist?

$C = 2B \log_2(M) = 2 * 2*10^9 \log_2(512) = 2 * 2*10^9*9 =$ **36 Gbps**

Using the fiber in the previous question, if the average **signal power** is 405 units and the average **noise power** is 27 units, what is the maximum channel capacity according to Shannon?

$C = B*\log_2(1+S/N) = 2*10^9*\log_2(1+405/27) = 2*10^9*\log_2(16) = 2*10^9*4 =$ **8 Gbps**

Given a channel with an intended **capacity** of 20 Mbps and **bandwidth** of 3 MHz. What **signal-to noise radio** is requird to allow this capacity?

$C = B*\log_2(1+SNR)$ $20*10^6 = 3*10^6*\log_2(1+SNR)$

$6{,}67 = \log_2(1+SNR)$ $1+SNR = 2^{6{,}67} = 102$

$SNR =$ **101** $SNR_{dB} = 10`*\log_{10}(101) = 10*2 =$ **20 dB**

At a **SNR** of 0 dB (Signal power = Noise power) what is the Channel capacity in bits/s?
(B, bandwidth)

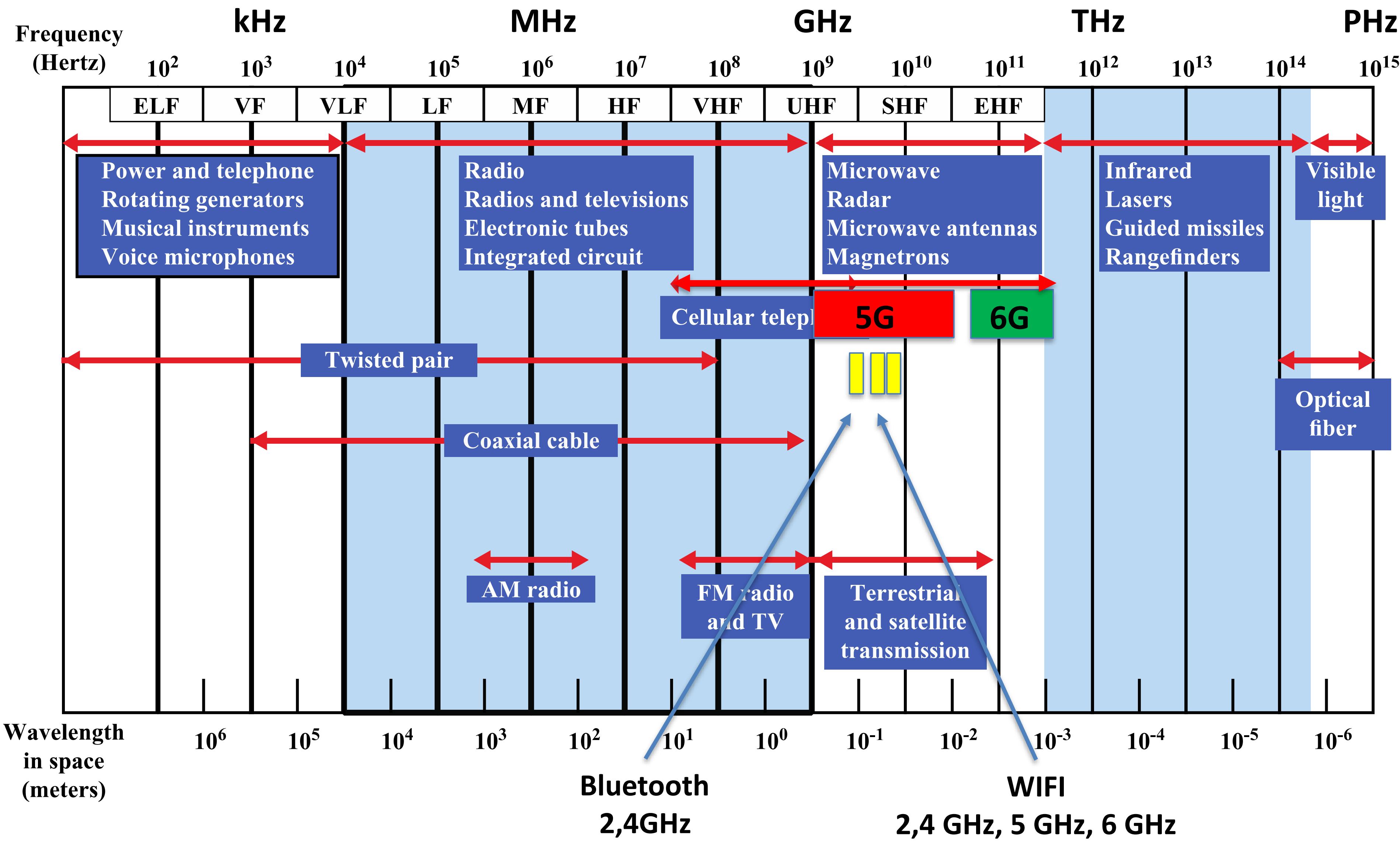
If the **SNR** is 20 dB, and the bandwidth **B** available is 4 kHz, then what is the channel capacity?
(26.6 kbps)

If the requirement is to transmit at 50 kbps, and a bandwidth **B** of 10 kHz is used, then what is the minimum S/N required?
(S/N = 31, corresponding to an SNR of 14.9 dB)

CLASSIFICATIONS OF TRANSMISSION MEDIA

- Transmission Medium
  - Physical path between transmitter and receiver
- Guided Media
  - Waves are guided along a solid medium
  - E.g., copper twisted pair, copper coaxial cable, optical fiber
- Unguided Media
  - Provides means of transmission but does not guide electromagnetic signals
  - Usually referred to as wireless transmission
  - Transmission and reception are achieved by means of an antenna
  - Configurations for wireless transmission:
    - Directional
    - Omnidirectional
  - Atmosphere, outer space

ELECTROMAGNETIC SPECTRUM OF TELECOMMUNICATIONS



Spektrumband för 5G och deras egenskaper

Lågband (600-900 MHz)
+ Större täckningsyta
+ Bra inomhuspenetration
- Låg kapacitet (bandbredd)

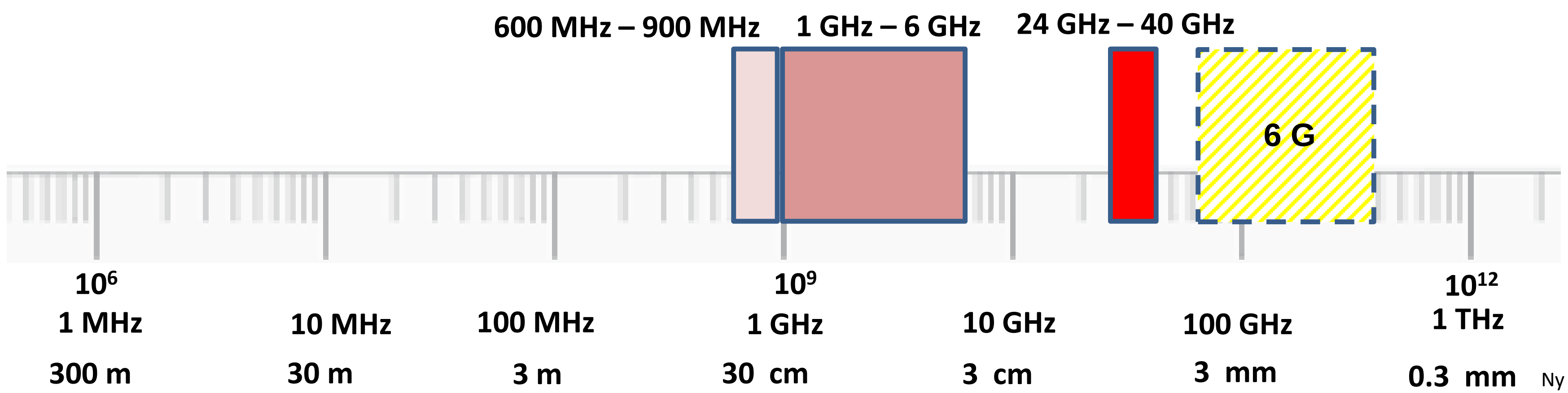
Massiv maskintypskommunikation, Täckning av stora områden. IoT

Mellanband (1-6 GHz)
+ Högre kapacitet
+ Lägre fördröjning
- Mindre täckningsyta

Mobilt bredband. Fast trådlöst tillgång (fixed wireless acces), Streaming applications.

Millimeterband (24-40 GHz)
+ Extremt låg fördröjning
+ Extrem hög kapacitet
- Liten täckningsyta
- Känslig för brus

Kritisk maskintypskommunikation. Fordon till X kommunikation. Kirurgi på distans.



Ny Teknik

GENERAL FREQUENCY RANGES

- Radio/TV frequency range
  - 30 MHz to 1 GHz
  - Suitable for omnidirectional applications

- Microwave frequency range
  - 1 GHz to 40 GHz
  - Directional beams possible
  - Suitable for point-to-point transmission
  - Used for satellite communications, 5G
  - 100 GHz+ 6G

- Infrared frequency range
  - Roughly, 1 THz to 100 THz
  - Useful in local point-to-point/multipoint applications within confined areas

BROADCAST RADIO

- Broadcast radio
  - 30 MHZ to 1GHz
  - Covers FM radio television
- Broadcast radio antennas
  - Omnidirectional
  - Antennas not required to be dish-shaped
  - Antennas need not be rigidly mounted to a precise alignment

TERRESTRIAL MICROWAVE

- A typical microwave antenna:
  - Parabolic "dish“
  - Fixed rigidly and focuses a narrow beam
  - Achieves **line-of-sight** transmission to receiving antenna
  - Located at substantial heights above ground level
- Applications
  - Long haul telecommunications service
  - Short point-to-point links between buildings

Band (GHz)	Bandwidth (MHz)	Data Rate (Mbps)
2	7	12
6	30	90
11	40	135
18	220	274

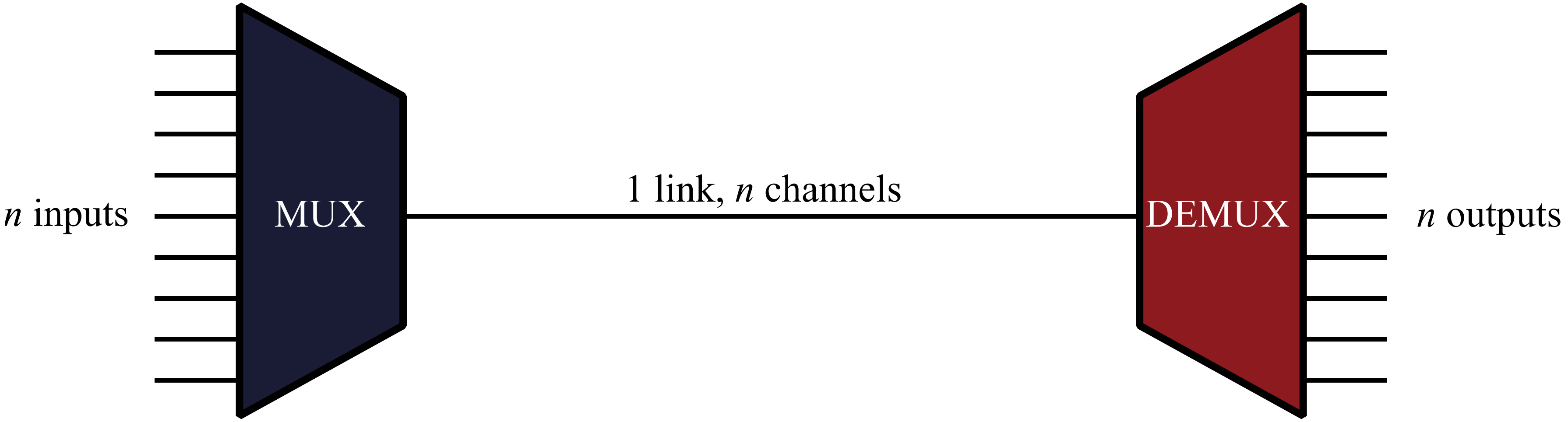
SATELLITE MICROWAVE

- Communication satellite
  - Microwave relay station
  - Used to link two or more ground-based microwave transmitter/receivers
  - Receives transmissions on one frequency band (uplink), amplifies or repeats the signal, and transmits it on another frequency (downlink)

- Applications
  - Television distribution
  - Long-distance telephone transmission
  - Private business networks
  - 5G

MULTIPLEXING

- Capacity of transmission medium usually exceeds capacity required for transmission of a single signal
- Multiplexing - carrying multiple signals on a single medium
  - More efficient use of transmission medium



REASONS FOR WIDESPREAD USE OF MULTIPLEXING

- Cost per kbps of transmission facility declines with an increase in the data rate
- Cost of transmission and receiving equipment declines with increased data rate
- Most individual data communicating devices require relatively modest data rate support

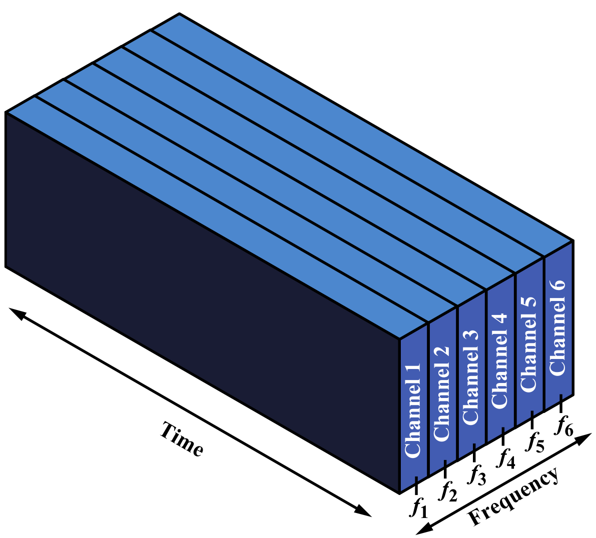
BASIC MULTIPLEXING TECHNIQUES

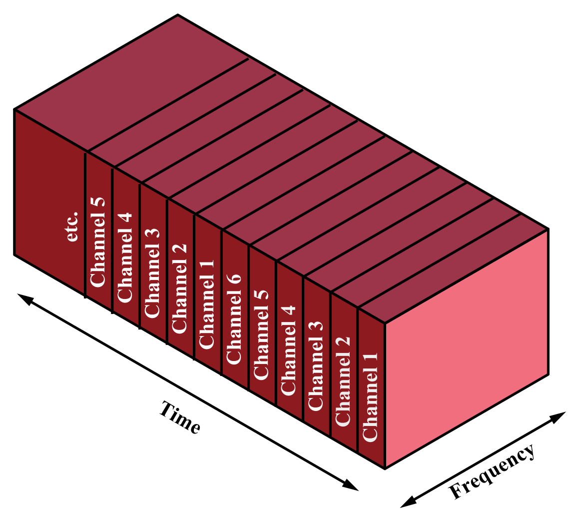
Frequency-division multiplexing (FDM)

- Takes advantage of the fact that the useful bandwidth of the medium exceeds the required bandwidth of a given signal

Time-division multiplexing (TDM)

- Takes advantage of the fact that the achievable bit rate of the medium exceeds the required data rate of a digital signal





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Key Terms

- analog data
- analog signal
- analog transmission
- aperiodic
- bandwidth
- broadcast radio
- channel capacity
- decibel (dB)
- digital data
- digital signal
- digital transmission
- frequency
- frequency division multiplexing (FDM)
- frequency domain
- fundamental frequency
- guided media
- infrared
- microwave
- multiplexing
- noise
- peak amplitude
- period
- periodic
- phase
- radio
- satellite microwave
- spectrum
- synchronous TDM
- terrestrial microwave
- time division multiplexing (TDM)
- time domain
- transmission media
- unguided media
- wavelength
- wireless

REVIEW QUESTIONS

- 2.1 Differentiate between an analog and a digital electromagnetic signal.
- 2.2 What are three important characteristics of a periodic signal?
- 2.3 How many radians are there in a complete circle of 360 degrees?
- 2.4 What is the relationship between the wavelength and frequency of a sine wave?
- 2.5 What is the relationship between a signal's spectrum and its bandwidth?
- 2.6 What is attenuation?
- 2.7 Define channel capacity.
- 2.8 What key factors affect channel capacity?
- 2.9 Differentiate between guided media and unguided media.
- 2.10 What are some major advantages and disadvantages of microwave transmissior
- 2.11 What is direct broadcast satellite (DBS)?
- 2.12 Why must a satellite have distinct uplink and downlink frequencies?
- 2.13 Indicate some significant differences between broadcast radio and microwave.
- 2.14 Why is multiplexing so cost-effective?
- 2.15 How is interference avoided by using frequency division multiplexing?
- 2.16 Explain how synchronous time division multiplexing (TDM) works.

ANSWERS TO QUESTIONS

2.1 A continuous or analog signal is one in which the signal intensity varies in a smooth fashion over time while a discrete or digital signal is one in which the signal intensity maintains one of a finite number of constant levels for some period of time and then changes to another constant level.

2.2 Amplitude, frequency, and phase are three important characteristics of a periodic signal.

2.3 2π radians.

2.4 The relationship is $\lambda f = v$, where λ is the wavelength, f is the frequency, and v is the speed at which the signal is traveling.

2.5 The spectrum of a signal consists of the frequencies it contains; the bandwidth of a signal is the width of the spectrum.

2.6 Attenuation is the gradual weakening of a signal over distance.

2.7 The rate at which data can be transmitted over a given communication path, or channel, under given conditions, is referred to as the channel capacity.

2.8 Bandwidth, noise, and error rate affect channel capacity.

2.9 With guided media, the electromagnetic waves are guided along an enclosed physical path, whereas unguided media provide a means for transmitting electromagnetic waves through space, air, or water, but do not guide them.

2.10 Point-to-point microwave transmission has a high data rate and less attenuation than twisted pair or coaxial cable. It is affected by rainfall, however, especially above 10 GHz. It is also requires line of sight and is subject to interference from other microwave transmission, which can be intense in some places.

2.11 Direct broadcast transmission is a technique in which satellite video signals are transmitted directly to the home for continuous operation.

2.12 A satellite must use different uplink and downlink frequencies for continuous operation in order to avoid interference.

2.13 Broadcast is omnidirectional, does not require dish shaped antennas, and the antennas do not have to be rigidly mounted in precise alignment.

2.14 Multiplexing is cost-effective because the higher the data rate, the more cost-effective the transmission facility.

2.15 Interference is avoided under frequency division multiplexing by the use of guard bands, which are unused portions of the frequency spectrum between subchannels.

2.16 A synchronous time division multiplexer interleaves bits from each signal and takes turns transmitting bits from each of the signals in a round-robin fashion.