Introduction to wireless communication.

Communication as transfer of information.

ELGB26 Electronic Communication
(Elektronisk kommunikation)

Spring 2018
Arild Moldsvor

Introduction Telecom

Telecommunication = communication over **long distances**

Examples: tele-phone
tele-vision (TV)
tele-lens (photo)
tele-graphy ("graphy" = write, *ex. stenography, seismography*)
tele-printer

Today: Communication using electronic devices

Earlier:
- Smoke signals — Electromagnetic wave, "digital modulation"
- Fires on mountain tops — Electromagnetic wave
- Drums — Acoustic wave

- Tele-graphy — "digital modulation" (The "Morse alphabet")

Transmission of information:
The information is coupled to a parameter of the carrier (modulated in)
One parameter (ex. the amplitude) is changed according to the information.

Historic perspective, Communication

- **Telegraphy**
  - 1831 Electromagnetic induction, *Faraday*
  - 1837 The Morse Telegraph, *Samuel Morse*
  - 1843 Telegraph line Washington – Baltimore started (cable in ground)
    Inter symbol interference (growing pulse widths) causes problems
  - 1928 Thermal noise and its inherent short-comings discovered, *Harry Nyquist*
- **Telephone**
  - 1876 Patent on electromagnetic telephone, *Alexander Graham-Bell*
  - 1877 First telephone station (21 prescribers)
  - 1880 First telephone station in Sweden (Stockholm) *Lars Magnus Ericsson*
- **Transmission without cable**
  - 1864 Electromagnetic waves, *James Clark Maxwell*
  - 1887/88 First antenna experiment, *Henrich Hertz*

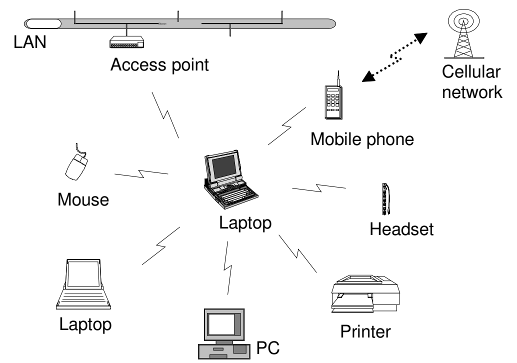
Historic perspective, cont.

- **Radio**
  - 1896 Patent on wireless telegraphy, *Marconi* (Italy – England)
  - 1901 Wireless telegraphy over the Atlantic (Cornwell – New Foundland)
    (Spark transmitter coupled to an antenna)
  - 1907 The electron tube discovered, *deForest*
  - 1909 Nobel price to *Marconi*
  - 1922 The superheterodyne principle, *Armstrong*
  - 1925 "Radiotjänst" in Sweden
  - 1948 The transistor
  - 1955 The beginning of the Swedish FM-net
  - 1962 First satellite launched
- **TV**
  - 1925 First electronic TV camera tube
  - 1936 First ordinary TV broadcast, BBC, London
  - 1956 Ordinary TV broadcast in Sweden
  - 1970 Color TV, Sweden
  - 1980 Text TV, Sweden

- **Radar**
  1935 Pulse radar
- **Navigation**
- **Satellite**

Now focus on new services instead of technology.

Bluetooth



- Personal computers
- Computer accessories
  - PC-card, PCMCIA-card,
  - Modem adapters, Port adapters,
  - etc. etc.
- Mobile phone, Cordless phone
- Headset
- Scanners
- Digital video camera
- Etc. etc.

- "Bluetooth" – common standard (de facto) for mobile wireless LAN with automated connection between e.g. computers and all peripheral devices, digital cameras, scanners, mobile phones in different environments etc.
- The devices automatically recognize all other devices and prepare for connections as soon as they are put on. The frequency is about 2.45 GHz.

Electromagnetic spectrum

		Frequency (wavelength)	
• ELF	Extremely Low Freq.	3 Hz (100 Mm)	- 3 kHz (100km)
• VLF	Very Low Frequency	3 kHz (100km)	- 30 kHz (10 km)
• LF	Low Frequency	30 kHz (10 km)	- 300 kHz (1 km)
• MF	Medium Frequency	300 kHz (1 km)	- 3 MHz (100 m)
• HF	High Frequency	3 MHz (100 m)	- 30 MHz (10 m)
• VHF	Very High Frequency	30 MHz (10 m)	- 300 MHz (1 m)
• UHF	Ultra High Frequency	300 MHz (1 m)	- 3 GHz (10 cm)
• *SHF*	*Super High Frequency*	*3 GHz (10 cm)*	*- 30 GHz (1 cm)*
• *EHF*	*Extremely High Freq.*	*30 GHz (1 cm)*	*- 300 GHz (1 mm)*

Electromagnetic spectrum, cont.

"**Microwave** region" **1 GHz** (30 cm) – **300 GHz** (1 mm) :

- L-band 1 – 2 GHz , → S-band 2 – 4 GHz
- C-band 4 – 8 GHz , → X-band 8 – 12 GHz
- K_u-band 12 – 18 GHz
- K-band 18 – 27 GHz , → K_a-band 27 – 40 GHz
- **Millimeter wave** band
  40 – 300 GHz alt. **30 GHz** (**10 mm**) – **300 GHz** (**1 mm**)

- Infra-read 300 GHz – 390 THz (1 mm – 770 nm)
- Visible light 390 THz – 770 THz (770 nm – 390 nm)
- Ultra-violet $770 \cdot 10^{12}$ - $3 \cdot 10^{16}$ Hz (390 nm – 10 nm)

- X-rays $\approx 2 \cdot 10^{15}$ - $2 \cdot 10^{20}$ Hz
- Gamma rays $\approx 10^{18}$ - 10^{22} Hz
- Cosmic rays $\approx 10^{22}$ Hz -

Examples of Signals and Systems

Signals:

- Speech — telephony, radio, TV
- Video — TV, video, multimedia
- Ultra-sound — within medicine, mechanics and seismic
- ECG (EKG) — within medicine (Electro-Cardio-Gram)
- Radar — military/civil applications
- Sonar (acoustic signals) — military/civil applications
- Seismology — e.g. earthquakes, nuclear weapons
- Nuclear research
- Data

Systems:

- Public Switched Telephone System (PSTS)
- Mobile Phone system
- Broadcast systems

The **source signals** are normally analog (continuous in time and amplitude), but the systems are now mostly digital.

- Data networks (LAN, WAN, wireless)
- Internet
- GPS (Global Positioning System)

etc.

The source signals are digital.

Signal Processing (highlights)

Signal processing properties:
- Remove (filter out) interference, and reduce noise effects
- Extract characteristic parameters
- Modify the signal to present in a desired format
- Compensate for channel distortion or fading

  etc.

More application examples:
- Frequency selective filters
- Communication, e.g. mobile phone (GSM) and wireless systems
- Speech synthesis (e.g. Linear Predictive Coding)
- Adaptive array antennas
  (scanning beam, digital beam-forming networks, signal proc antennas, MIMO)
- Image processing (2-dimensional)
  weather satellite / surveillance / space applications etc
  photo/video (digitalized), ultra-sound, X-ray
- Image processing (3D or multi-dimensional)
  seismology (earthquake, oil prospecting, nuclear weapons etc.)
- Multimedia (. . . computer games)

etc.

Signal Processing (history).

DSP - Digital Signal Processing
- Abbreviation also used for the hard-ware (the processors)

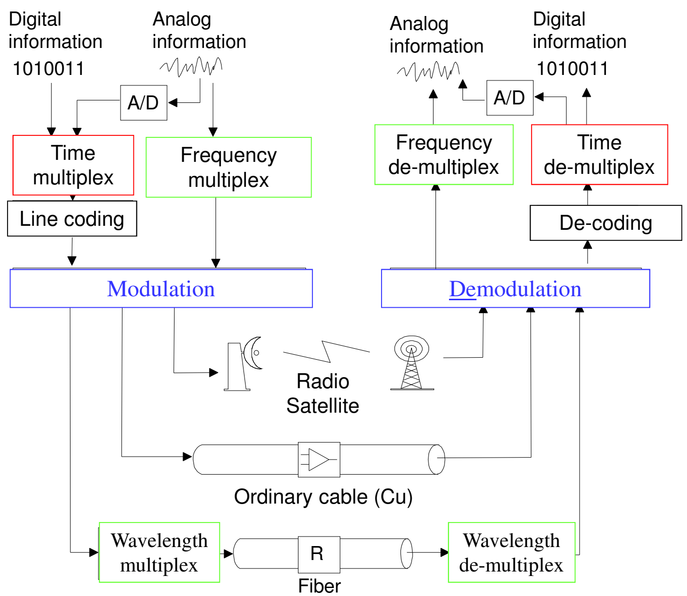
Early attitude/thinking:
- Only for simulation and approximation of analog signal processing systems.
  (Could NOT be done in real time!)

Developments:
- In **1965** the FFT (Fast Fourier Transform) came
- Now DFT (Discrete Fourier Transform) became an alternative in real time processing as an accurate time discrete concept (not only approximate simulation)
- rapid electronics developed
- digital routines can do things impossible (or very difficult) to achieve with analog components (e.g. averaging, median filtering etc.)
- easy integration in monolithic technology (IC circuits)

⇒ DSP soon got an independent position as a self-supporting concept

Today:
- DSP is now a very important concept!
- Hardware: Microprocessors (very widespread), DSP's, Computers
- Software/Computer programs (e.g. MATLAB) ⇒ Accurate simulations!

Information transfer

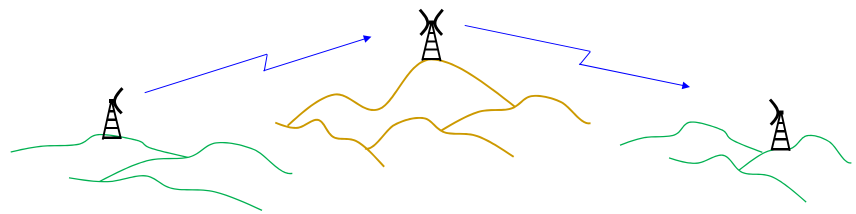


Radio Links / Microwave Radio Relay

See: http://en.wikipedia.org/wiki/Microwave_transmission

Point-to-point (line-of-sight) communication without any cables, utilizing towers with parabolic antennas on elevated points (hills/mountains).

Used:
- in areas with difficult topography (hilly terrain, mountains etc)
- in "developing" countries (without well developed infra-structure) for rapid establishment of basic communication systems
- for short term communication needs (natural disasters, war, etc)
- etc



Fiber Optic System

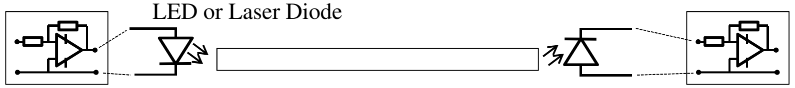
http://en.wikipedia.org/wiki/Light-emitting_diode
(http://en.wikipedia.org/wiki/Laser_diode)
http://www.arcelect.com/fibercable.htm

Very good descriptions

Transmitter

Receiver

LED or Laser Diode

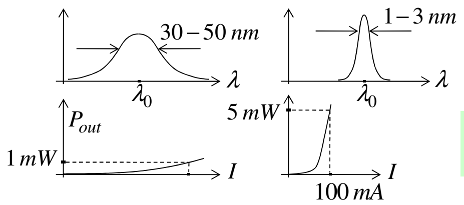


Electronic circuits | Electrical to optical conversion | Fiber optic cable | Optical to electrical conversion | Electronic circuits

LED | Laser Diode

Spectral width

Transfer characteristic

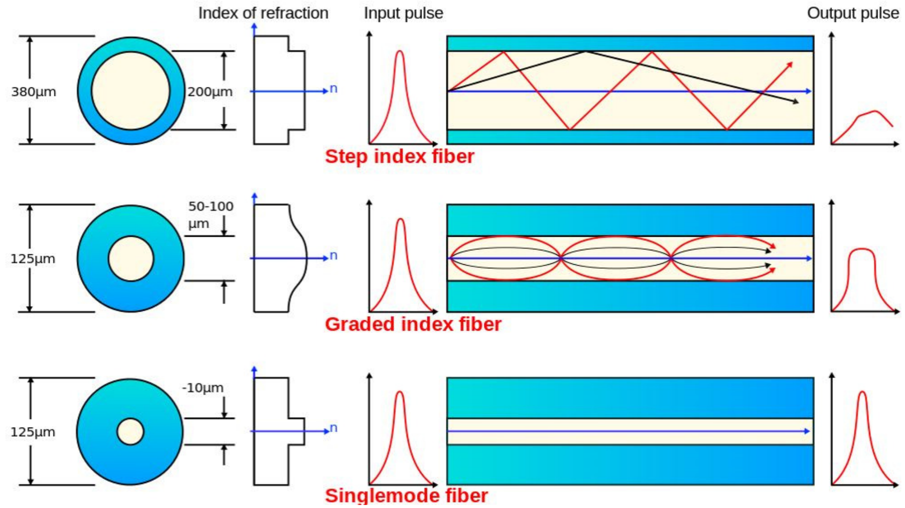


Better spectral purity

Larger output power (for less current)

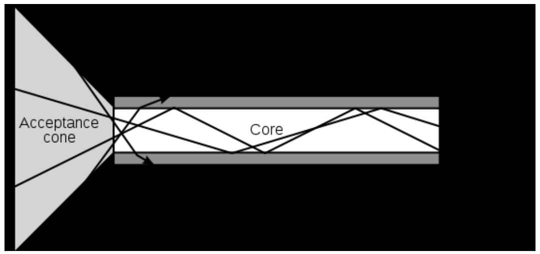
Optical fiber system

https://en.wikipedia.org/wiki/Optical_fiber



Optical fiber and laser

https://en.wikipedia.org/wiki/Optical_fiber



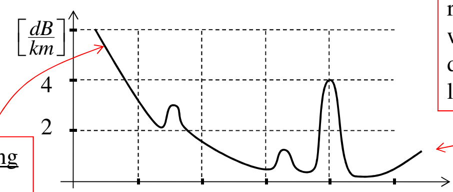
See films at:
https://en.wikipedia.org/wiki/File:Fiber-engineerguy.ogv (5:31)
https://www.youtube.com/watch?v=LVRUwlt0_BM (3:20)

Attenuation in fiber optic cable

http://www.ciscopress.com/articles/article.asp?p=170740&seqNum=6
http://en.wikipedia.org/wiki/Optical_fiber

Typical attenuation in a fiber optic cable (made of Silica) as a function of free space wavelength.

Infrared absorption
(due to molecular resonances and heat) will increase and dominate for lower frequencies.

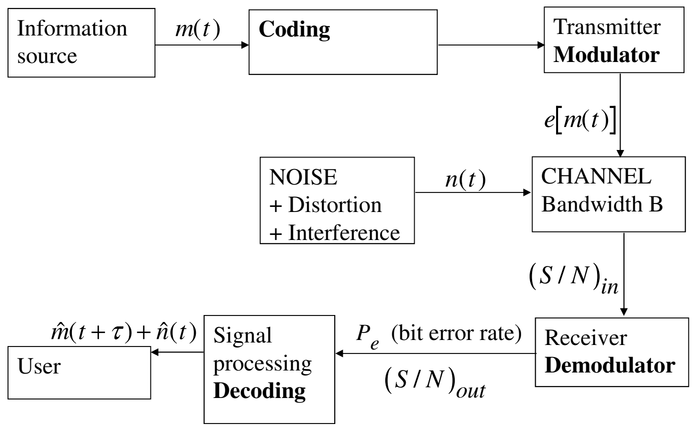


Rayleigh scattering
(due to irregular and rough internal surfaces) dominates for higher frequencies.

800	1000	1200	1400	1600	1800	Wavelenght $\lambda\,[nm]$
3.75	3.00	2.50	2.143	1.875	1.667	Frequency $f \cdot 10^{14}\,[Hz]$

The absorption tops are due to water impurities in the glass (OH^-)

Information transfer (alternative)



The CHANNEL:
- Metallic cables: twisted pair, coaxial cable
- Fiber-optic cable: [laser/LED light in very thin oxide (glass) cable]
- Radio link: 50-60 km for some hundreds of MHz and 15-20 km for 10-20 GHz
- Satellite: Both for fixed and mobile systems

Information transfer – OSI model

Information transfer:
- Semantics (languages)
- Information theory
- Signals

Modulation

Hardware:
- System
- Circuits
- Components
- Physics

The information signal is "matched" to the channel to minimize the effect of noise and interference.
(*Multiplex - Several simultaneous info-signals*)

Compare with the different levels in the **OSI model**
(**O**pen **S**ystem **I**nterconnection – general model for data communication)

Tillämpning		Application layer
Presentation		Presentation
Sessionsskiktet		Session layer
Transportskiktet		Transport layer
Nätskiktet	Nätskiktet	Network layer
Datalänkskiktet	Datalänkskiktet	Data link layer
Fysiska skiktet	Fysisk	Physical layer

Modulation, Compared with packet transport

A packet (information) is to be sent from one person (transmitter) to another (receiver) using a car [train/ship/airplane] to carry the packet on the road [railway/water/air].

The packet is "fastened" to the transport carrier (i.e. the car) which is travelling along the transfer channel (i.e. the road).

To be sent:	Transport carrier:	Channel:
Packet	car/train/ship/airplane	road/railway/water/air
Information	carrier frequency	cable/air

Modulation (two definitions):
- The information signal is "matched" to the channel to minimize the effect of noise and interference.
- A parameter (characteristic) of the carrier is changed according to the information signal.

Basic modulation methods

Modulation (two definitions):
- The information signal is "matched" to the channel to minimize the effect of noise and interference.
- A parameter (characteristic) of the carrier is changed according to the information signal.

Analog modulation:
- Amplitude modulation: AM, DSBSC, SSB, VSB
- Frequency (angle) modulation: FM, PM

Digital modulation:
- Base-band modulation: PCM, DPCM, DM
- Digital carrier modulation: ASK, FSK, PSK, QAM

Convolution - Multiplication

Convolution in time domain $\Rightarrow$ Multiplication in frequency domain

$$\mathfrak{F}\{x_1(t) * x_2(t)\} = X_1(\omega) \cdot X_2(\omega)$$

Convolution in frequency domain $\Rightarrow$ Multiplication in time domain

$$X_3(\omega) = X_1(\omega) * X_2(\omega)$$

$$\Updownarrow$$

$$x_3(t) = \mathfrak{F}^{-1}\{X_3(\omega)\} = \frac{1}{2\pi}\int_{-\infty}^{\infty}\left[\int_{-\infty}^{\infty} X_1(\nu)\cdot X_2(\omega-\nu)\,d\nu\right] e^{j\omega t}\,d\omega$$

Substitute: $\lambda = \omega - \nu \quad \Rightarrow \quad \omega = \lambda + \nu \quad , \quad d\omega = d\lambda$

$$x_3(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} X_1(\nu)\cdot X_2(\lambda)\cdot e^{j(\lambda+\nu)t}\,d\nu\ d\lambda$$

$$= \frac{1}{2\pi}\int_{-\infty}^{\infty} X_1(\nu)\cdot e^{j\nu t}\,d\nu \cdot \int_{-\infty}^{\infty} X_2(\lambda)\cdot e^{j\lambda t}\,d\lambda$$

$$x_3(t) = x_1(t)\cdot x_2(t)\,2\pi \qquad \Leftrightarrow \qquad \mathfrak{F}\{x_1(t)\cdot x_2(t)\} = \frac{1}{2\pi} X_1(\omega) * X_2(\omega)$$

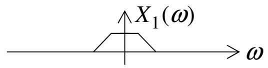
Modulation seen as convolution

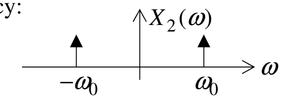
Modulation:

Let $x_1(t)$ be a band limited (information) signal and $y(t)$ the multiplication with a carrier frequency:

$$y(t) = x_1(t)\cdot x_2(t) = x_1(t)\cdot\cos(\omega_0 t)$$

What will the spectrum of y(t) be?



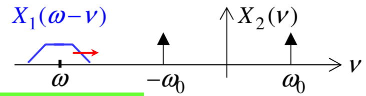


Multiplication in time domain $\Rightarrow$ Convolution in frequency domain

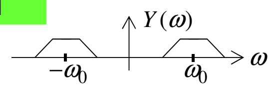
$$Y(\omega) = \mathfrak{F}\{y(t)\} = \mathfrak{F}\{x_1(t)\cdot x_2(t)\}$$

$$= \frac{1}{2\pi} X_1(\omega) * X_2(\omega)$$

$$\propto \int_{-\infty}^{\infty} X_1(\omega-\nu)\cdot X_2(\nu)\,d\nu$$



ω is a parameter in the integral



Important mathematical background

Mathematical background/prerequisites:

- Complex mathematics (including the "Euler formula")
- The Complex method in AC circuit analysis (" jω-method ")
- Phasors and phasor diagrams in the complex plane

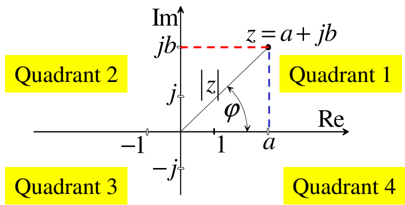
- Trigonometry (of course)
- Differential equations
- Fourier series / Fourier transform
- Laplace transform, z-transform

- Basic analog and digital signal processing
  - Time domain – Frequency domain
  - Multiplication-Convolution concept
  - Frequency spectrum (single sided / double sided)
  - Transfer functions and Bode diagrams

- Feedback control (basic knowledge)
  [important for: PLL (Phase Locked Loop), AGC (Automatic Gain Control), and AFC (Automatic Frequency Control, or stabilization), etc.]

- Transmission line theory and the Smith Chart (basic knowledge)

Complex numbers



Check the **quadrant** so that the **angle** is correct (check the sign of the real and imaginary parts).

$$z = a + jb = |z|\,e^{j\varphi} \quad , \quad a = |z|\cos\varphi \quad , \quad b = |z|\sin\varphi$$

$$|z| = \sqrt{a^2 + b^2} \quad , \quad \varphi = arg(z) = \arctan\left(\frac{b}{a}\right) \quad \{\pm\pi\}$$

The Euler formula: $\begin{cases} e^{j\varphi} = \cos\varphi + j\sin\varphi \\ e^{-j\varphi} = \cos\varphi - j\sin\varphi \end{cases}$

$$e^{j\frac{\pi}{2}} = j \qquad\qquad j^2 = e^{j\pi} = e^{-j\pi} = -1$$

Complex numbers, cont.

Complex conjugate (*)

$$\left.\begin{array}{l} z = a + jb = |z|\,e^{j\varphi} \\ z^* = a - jb = |z|\,e^{-j\varphi} \end{array}\right\} \Rightarrow \quad z \cdot z^* = |z|^2 = a^2 + b^2$$

Addition $\quad (a+jb)+(c+jd) = a+c \ + j(b+d)$

Subtraction $\quad (a+jb)-(c+jd) = a-c \ + j(b-d)$

Multiplication $\quad z_1 \cdot z_2 = |z_1|e^{j\varphi_1} \cdot |z_2|e^{j\varphi_2} = |z_1||z_2|e^{j(\varphi_1-\varphi_2)}$

Division $\quad \dfrac{z_1}{z_2} = \dfrac{|z_1|e^{j\varphi_1}}{|z_2|e^{j\varphi_2}} = \dfrac{|z_1|}{|z_2|}e^{j(\varphi_1-\varphi_2)}$

Square root $\quad \sqrt{z} = \left(|z|e^{j\varphi}\right)^{\frac{1}{2}} = \sqrt{|z|}e^{j\frac{\varphi}{2}}$ eller $\sqrt{|z|}e^{j\left(\frac{\varphi}{2}+\pi\right)}$

Phasors

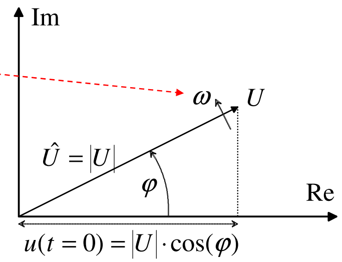
Physically the signals are always real. However, it is easier to calculate using complex quantities (phasors). Phasor diagrams is often very illustrative.

The complex phasor: $U = |U|e^{j\varphi} \cdot e^{j\omega t}$
Anticipating harmonic time variation with an angular frequency ω the real time function $u(t)$ is given by:

$$\begin{aligned} u(t) &= \mathrm{Re}\left\{U \cdot (e^{j\omega t})\right\} \\ &= \mathrm{Re}\left\{|U|e^{j\varphi} \cdot e^{j\omega t}\right\} \\ &= |U| \cdot \mathrm{Re}\left\{e^{j(\omega t+\varphi)}\right\} \\ &= |U| \cdot \cos(\omega t + \varphi) \end{aligned}$$

This can be illustrated in the complex plane by taking the real part of a complex phasor rotating with the angular frequency ω.
[Or, take the projection of the rotating phasor onto the real axis.]

If several phasors have the same frequency, they can be added geometrically, as vectors in the complex plane.



Negative frequencies

Using the Euler formula, a (unity) complex harmonic signal can be written as:

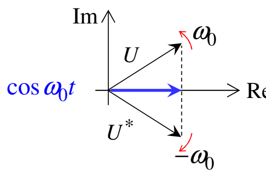
$$U = e^{\pm j\omega_0 t} = \cos\omega_0 t \pm j\sin\omega_0 t$$

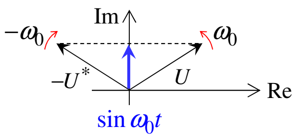
A real time-harmonic signal can then be written as a sum of two complex signals:

$$\cos\omega_0 t = \frac{1}{2}\left(e^{j\omega_0 t} + e^{-j\omega_0 t}\right) = \frac{1}{2}(U + U^*)$$

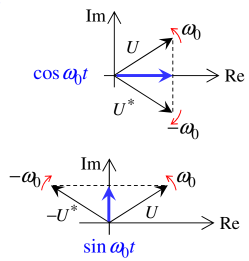
$$\sin\omega_0 t = \frac{1}{2j}\left(e^{j\omega_0 t} - e^{-j\omega_0 t}\right) = \frac{1}{2j}(U - U^*)$$

We now define **negative frequencies** as an important mathematical concept. In the complex plane this corresponds to a phasor rotating in the negative direction, e.g. U^*.





Double sided frequency spectrum

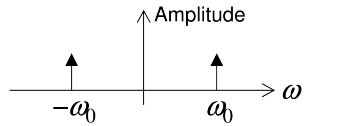


$$\cos\omega_0 t = \frac{1}{2}\left(e^{j\omega_0 t} + e^{-j\omega_0 t}\right) = \frac{1}{2}(U + U^*)$$

$$\sin\omega_0 t = \frac{1}{2j}\left(e^{j\omega_0 t} - e^{-j\omega_0 t}\right) = \frac{1}{2j}(U - U^*)$$

The concept of negative frequencies give rise to the double sided frequency spectrum:

The cosine and sine signal have the same amplitude spectrum (90 degrees phase shift only).



Double sided amplitude (magnitude) frequency spectrum

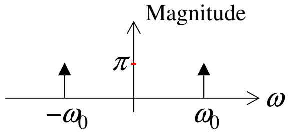
Single sided and Double sided spectrum

Formally the frequency spectrum is given by the **Fourier transform**.
A complex harmonic signal has a single sided spectrum:
[The factor 2π is due to using ω instead of f in the Fourier transform.]

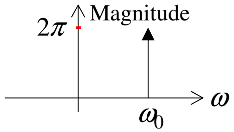
$$\mathfrak{F}\left\{e^{j\omega_0 t}\right\} = \int_{-\infty}^{\infty} e^{j\omega_0 t} \cdot e^{-j\omega t}\, dt = \int_{-\infty}^{\infty} e^{-j(\omega-\omega_0)t}\, dt = 2\pi\left[\delta(\omega-\omega_0)\right]$$

A real harmonic signal (sine or cosine) has a double sided spectrum,
(note the factor ½ in the amplitude/magnitude):

$$\mathfrak{F}\{\cos\omega_0 t\} = \int_{-\infty}^{\infty} \frac{1}{2}\left(e^{j\omega_0 t} + e^{-j\omega_0 t}\right)\cdot e^{-j\omega t}\, dt = \frac{1}{2} 2\pi\left[\delta(\omega-\omega_0) + \delta(\omega+\omega_0)\right]$$



Double sided



Single sided