Project: Innovative Open Source Courses for Computer Science

Wireless Signal Processing in GNU Radio Environment
Teaching Material

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30.05.2021

Innovative Open Source Courses for Computer Science

This syllabus was written as one of the outputs of the project "Innovative Open Source Courses for Computer Science", funded by the Erasmus+ grant no. 2019-1-PL01-KA203-065564. The project is coordinated by West Pomeranian University of Technology in Szczecin (Poland) and is implemented in partnership with Mendel University in Brno (Czech Republic) and University of Žilina (Slovak Republic). The project implementation timeline is September 2019 to December 2022.

Project information

Project was implemented under the Erasmus+.
Project name: **"Innovative Open Source courses for Computer Science curriculum"**
Project nr: **2019-1-PL01-KA203-065564**
Key Action: **KA2 – Cooperation for innovation and the exchange of good practices**
Action Type: **KA203 – Strategic Partnerships for higher education**

Consortium
ZACHODNIOPOMORSKI UNIWERSYTET TECHNOLOGICZNY W SZCZECINIE
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Introduction to wireless systems

Project: Innovative Open Source Courses for Computer Science

30.05.2021

Outline

Definitions

Definitions i

Sygnał

A signal can be represented in two domains

- Time domain

$$f(t) = A\sin(\omega t + \theta) \tag{1}$$

- Frequency domain

$$x(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi nft) + \sum_{n=1}^{\infty} b_n \cos(2\pi nft) \tag{2}$$

Definitions ii

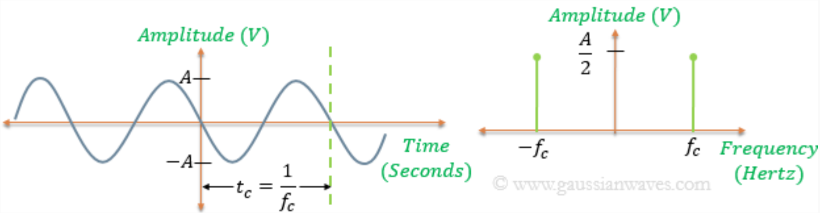

Figure 1: Signal in frequency domain [5].

Definitions iii

- **Source** - generates a message, which can be a human voice, a television image or sound from loudspeakers. The source is converted by an input transducer into an electromagnetic wave called information signal
- **Transmitter** - modifies the signal for efficient transmission. It usually consists of one or more of the following subsystems: sampler, quantizer, encoder and modulator

Definitions iv

- **Channel** - is the medium through which the output signal from the transmitter is transported. It can be a wire, concentric cable, optical fibre, radio link, etc. Based on the type of channel, modern communication systems are divided into two categories: wired communication systems and wireless communication systems
- **Receiver** - re-processes the signal received from the channel by undoing the signal modifications made to the transmitter and the channel. The task of the receiver is to extract the message from the distorted and noisy signal at the output of the channel. The receiver may consist of a demodulator, decoder or filter

Definitions v

Messages can be represented as

- **Analog** - are characterised by data whose values vary in a continuous range. For example, a speech waveform has an amplitude that changes in a continuous range. An image is also an analogue message.
- **Digital** - are made up of a limited number of symbols. For example, a text file is a digital message made up of 80 symbols, consisting of 26 letters, 20 numbers, spaces and punctuation marks. Similarly, telegraphic Morse code is a binary message with only two symbols - characters and space.

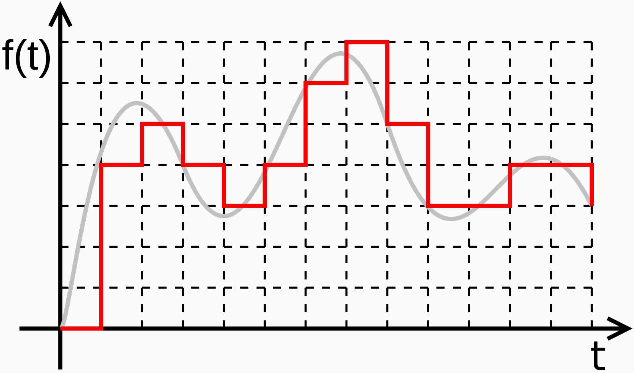

Figure 2: Analog and digital signal [4].

Definitions vii

- **Transmission** – the process of transmitting data between a transmitter and a receiver using a specific method that is understood by both sides. In addition, it follows a specified track - in this case the transmission medium
- **Transmission medium** – an information medium used for the transmission of signals in telecommunications. The parameters of the medium used affect its capabilities and applications. The two main groups are wired and wireless media

Definitions viii

- **Telecommunication** – the discipline concerned with the transmission of information over a distance, defining ways of processing and encoding information. It also includes issues of telecommunications networks, radio wave propagation or telecommunications equipment

Definitions ix

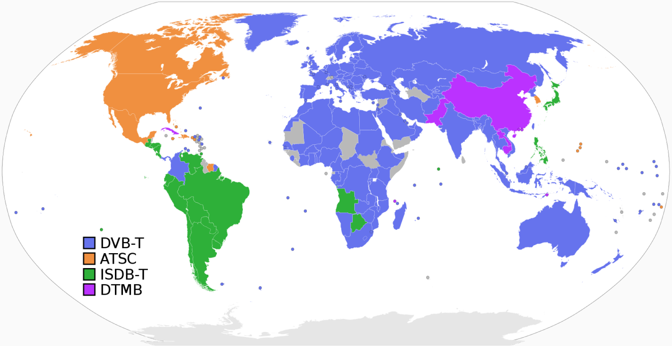

Figure 3: Types of television telecommunications used in the world [6].

Data transmission

Data transmission i

- A communication channel allows the transmission of data between two participants of a set connection
- The division of the medium according to the type of transmission used:
    - Wired - based on solutions using optical cables or copper wires
    - Wireless - uses radio or light waves for transmission

Data transmission ii

- Transmission can be divided by the nature of the data transmitted:
    - Simplex – in single direction
    - Half-duplex – bi-directional non-simultaneous
    - Full-duplex – bi-directional simultaneous

Communication track

Communication track i

- The operation of the transmission system is carried out by:
    - Transmitter - on the sender side, responsible for coding, modulation, signal amplification
    - Physical transmission channel
    - Receiver - at the receiver side, responsible for amplification, demodulation and decoding of the signal in order to reproduce the original message
- It should be remembered that during signal transmission, the message is susceptible to distortions from the external environment (noise, interference)

Communication track ii

Simplified scheme of the communication path, including elements occurring during data transmission

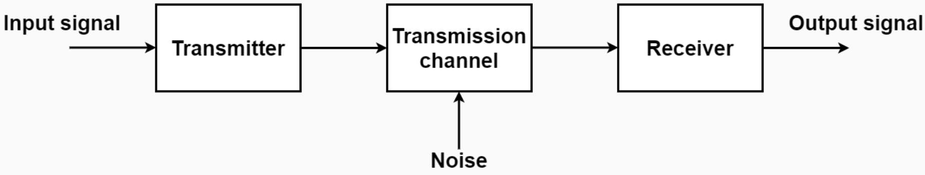

Figure 4: Scheme of the communication path.

Radio waves

Radio waves i

- **Radio waves** – or electromagnetic waves - this phenomenon consists in the propagation of a disturbance of an electric field and an associated magnetic field
- The occurrence of radio waves can be observed in a vacuum or in any other medium

Radio waves ii

Type	Length	Frequency
Radio waves	30 km	10 kHz
Microwaves	30 cm	1 GHz
Infrared	1 mm	300 GHz
Visible light	750 nm	400 THz
Ultraviolet	430 nm	700 THz
Rentgen	10 nm	30 PHz
Gamma	10 pm	30 EHz

Table 1: Frequencies of electromagnetic waves.

Radio waves iii

Band	Frequency	Wavelength
ELF	3 - 30 Hz	100,000 - 10,00 km
SLF	30 - 300 Hz	10,000 - 1,000 km
ULF	0.3 - 3 kHz	1,000 - 100 km
VLF	3 - 30 kHz	100 - 10 km
LF	30 - 300 kHz	10 - 1 km
MF	300 - 3000 kHz	1000 - 100 m

Table 2: Frequency dependency

Radio waves iv

Band	Frequency	Wavelength
HF	3 - 30 MHz	100 - 10 m
VHF	30 - 300 MHz	10 - 1 m
UHF	300 - 3000 MHz	100 - 10 cm
SHF	3 - 30 GHz	10 - 1 cm
EHF	30 - 300 GHz	10 - 1 mm
THF	0,3 - 3 THz	1 - 0.1 mm

Table 3: Frequency dependency

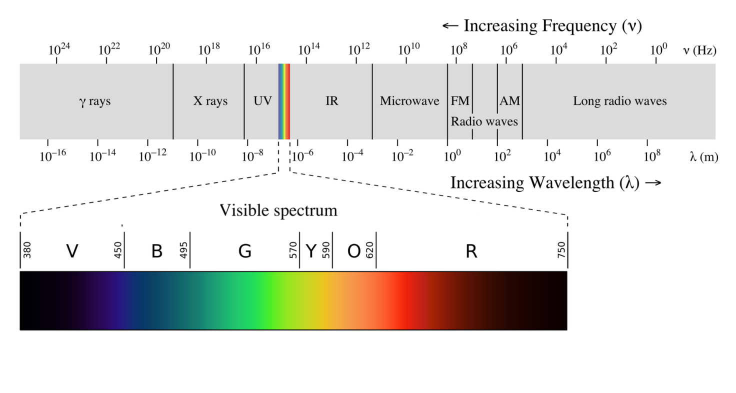

Figure 5: Electromagnetic spectrum of visible light [7].

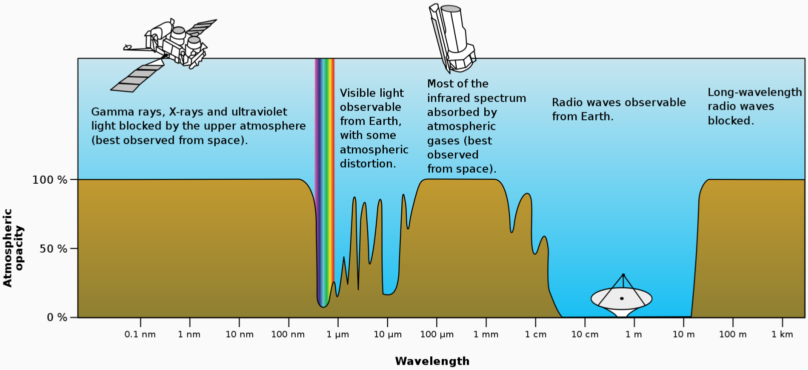

Figure 6: Absorption and scattering diagram of waves [7].

Radio wave properties i

- **Wavelength** – is the minimum distance between two points of the same vibration phase

$$\lambda = c \cdot T \tag{3}$$

- where
  - λ - wavelength [m]
  - c - speed of light (299 792 458 $\frac{m}{s}$)
  - T - oscillation period [s]

Radio wave properties ii

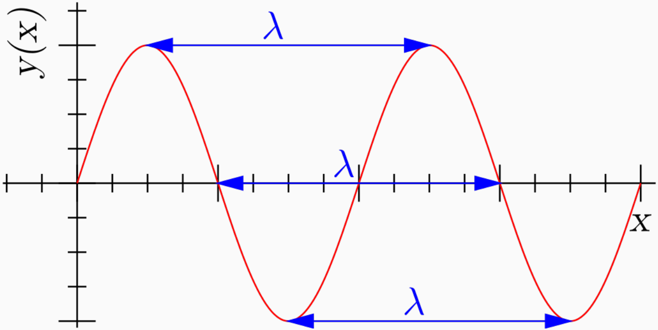

Figure 7: Wavelength [1].

Radio wave properties iii

- **Wave frequency** – specifies the number of complete changes of electric and magnetic field per second, it is expressed in Hertz.

$$f = \frac{1}{T} \tag{4}$$

- where
    - f - frequency [Hz]
    - T - oscillation period [s]

Radio wave properties iv

- **Oscillation period** – time required for the same wave phase to return

$$T = \frac{1}{f} \tag{5}$$

- where
  - T - oscillation period [s]
  - f - frequency [Hz]

Radio wave applications i

- Electromagnetic waves
    - Ultraviolet
    - Infrared
    - Visible light
    - Radio frequencies
- Sound waves
- Satellite signals
- Wireless communication in the frequency range 3 Hz to 3 THz

Radio wave applications ii

Transmission using radio waves:

- Embedded systems
  - Distributed
    - A collection of independent devices combined into one logical whole
    - The main elements are usually computers and automation systems
    - Devices equipped with software that shares system resources
    - Interconnection between devices through computer networks
  - Remote controlled
    - Operation is based on controlling the unit from a physically remote location
    - Controller and executive unit with transmitter and receiver
    - Often used for toys, drones, cameras

Radio wave applications iii

- GSM mobile communications
- WLAN (Wireless Local Area Network)
- Short-range wireless communication
- WWAN (Wireless Wide Area Network) – range from 100 metres to several kilometres

Radio wave applications iv

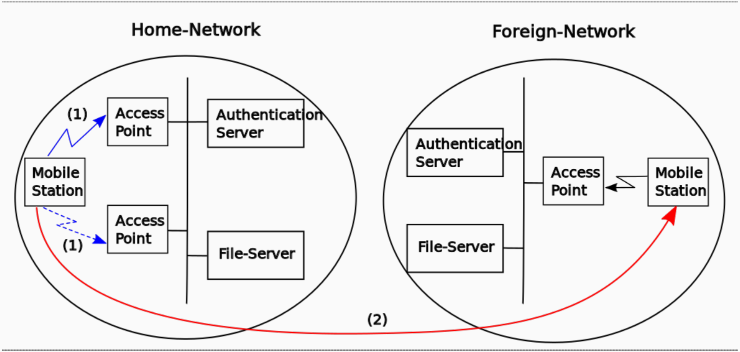

Figure 8: Signal transmission in WLAN [3].

Radio wave applications v

Types of frequencies used

- Microwaves > 300 MHz
- Ultra-short 30 -300 MHz
- Short 3 – 30 MHz
- Intermediate 1.5 – 3 MHz
- Medium 100 – 1500 kHz
- Long 15 – 100 kHz
- Ultra-long < 15 kHz

Radio wave applications vi

Band **2.4 GHz** is used by many devices, one of the most popular frequencies

- Bluetooth
- Wi-Fi
- Microwave ovens
- Video cameras
- Monitoring devices
- Smartphones

Advantages and disadvantages of wireless communication

Advantages and disadvantages of wireless communication i

Disadvantages

- Bandwidth constraints
- Susceptibility to interference
- Dependent on weather conditions
- Safety
- The bands used are often shared

Advantages

- Flexibility
- Mobility
- No physical transmission medium cable

Bluetooth

Infrared

- The standard covers data transmission over a distance of < 1 meter
- Three types of transmission
  - AIR – enables multi-user connection, transmission speed depends on the distance of transmitted data
  - IrDA-D – standard for data transmission, available speeds from 115 kbps to 4Mbps
  - IrDA-C – bi-directional, allows transmission of control commands and signals, used in peripheral devices

Bluetooth

- Allows wireless connection of peripheral devices to mobile phones and computers
- Technology designed primarily for short-distance communication
- Low production costs
- Standard described in specification IEEE 802.15.1
- Uses radio waves in the 2.4 GHz ISM frequency band

Bluetooth iii

Sources

1 - https://en.wikipedia.org/wiki/Wavelength

2 - https://en.wikipedia.org/wiki/Oscillation

3 - https://en.wikipedia.org/wiki/Wireless_LAN

4 - https://pl.wikipedia.org/wiki/Sygna%C5%82_cyfrowy

5 - https://www.gaussianwaves.com/2013/12/computation-of-power-of-a-signal-in-matlab-simulation-and-verification/

6 - https://en.wikipedia.org/wiki/Telecommunication

7 - https://en.wikipedia.org/wiki/Electromagnetic_radiation

Thanks for your attention ☺

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Propagation of radio waves. Antenna techniques.

Project: Innovative Open Source Courses for Computer Science

30.05.2021

Outline

Definitions

Radio waves propagation

Phenomena associated with radio wave propagation

Antenna techniques

- Antenna properties

Definitions

Definitions i

Waves

- Radio wave – one of many forms of electromagnetic radiation
- Electromagnetic wave – the electricity carrier

Definitions ii

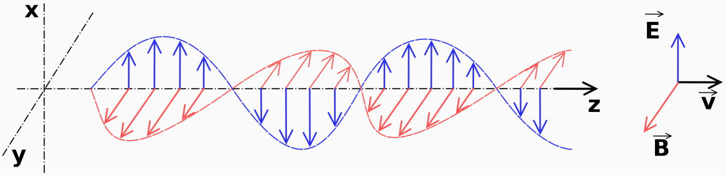

Figure 1: Electromagnetic wave [3].

Definitions iii

- **Polarization** - is a property applying to transverse waves that specifies the geometrical orientation of the oscillations
- Polarization is also called the process of achieving a particular polarization state.
- Types of polarization
    - Linear
    - Circle
    - Elliptic
    - Radial
    - Azimuthal

Definitions iv

- It occurs for such types of waves and such conditions where oscillations can take place in different directions perpendicular to the direction of propagation of the wave.

Radio waves propagation

Radio waves propagation i

Radio waves propagation is the term used to describe the propagation of radio waves, which depends on the characteristics of the wave such as frequency or polarisation, as well as the conditions in the environment in which the wave propagates.

Radio waves propagation ii

Like light waves, radio waves are subject to phenomena

- reflections
- refractions
- difractions
- absorptions
- polarizations
- dispersions

Radio waves propagation iii

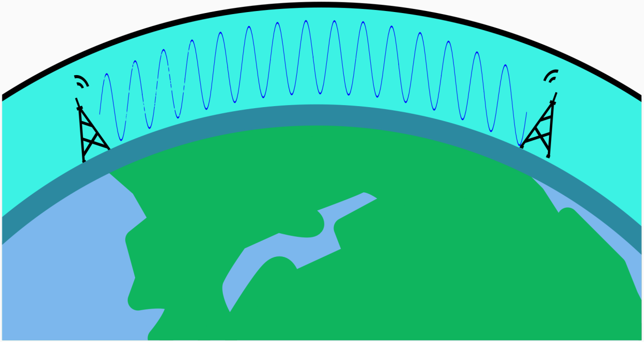

Figure 2: Signal propagation [6].

Radio waves propagation iv

Understanding the effects of changing conditions on radio wave propagation has many practical applications, from frequency selection for international shortwave broadcasters, to the design of reliable mobile phone systems, to radionavigation and the operation of radar systems.

Radio waves propagation v

Several different types of propagation are used in practical radio transmission systems.

- Line-of-sight propagation refers to radio waves that travel in a straight line from the transmitting antenna to the receiving antenna. Used for radio transmission over medium distances such as mobile phones, cordless phones, walkie-talkies, wireless networks, FM radio, TV transmission, radar and satellite communications (e.g. satellite TV)
- Line-of-sight transmission at the Earth's surface is limited to the distance to the visual horizon, which depends on the height of the transmitting and receiving antennas. It is the only propagation method feasible at microwave frequencies and above

Fresnel zone - it is an area where a certain level of energy is maintained

- Defines the area between and around the transmitter and receiver
- This space takes the shape of an ellipsoid
- Primary wave travels in a relative straight line from transmitter to receiver
- If there are obstacles or reflective objects between the transmitter and receiver, the waves may arrive at the receiver with different phase shifts

Radio waves propagation vii

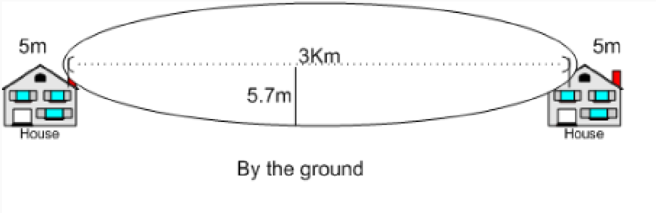

Figure 3: Signal propagation [1].

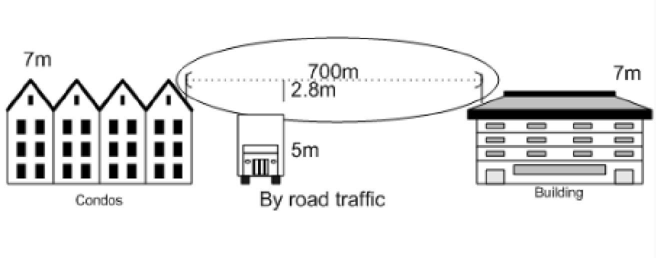

Figure 4: Signal propagation [1].

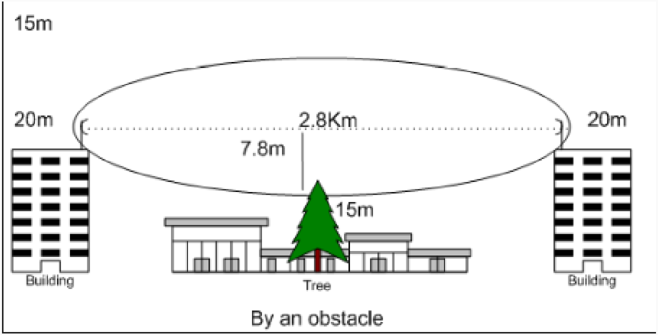

Figure 5: Signal propagation [1].

Radio waves propagation x

- The purpose of all telecommunications systems is to transmit information through a centre of wave propagation. Such centres include:
    - Atmosphere
    - Water
    - Interior of the Earth
    - Copper cable
    - Optical fibre

Radio waves propagation xi

- The transmission, reception, and reproduction of signals depend on the layout of the equipment designed to carry them out. In the case of propagation of radio waves, the conditions of signal propagation depend on many factors that we are not able to regulate

Radio waves propagation xii

- Most of the signals transmitted are propagated through the atmosphere, which is the primary propagation medium for radio waves
- In only a few cases are the waves propagated in free space around the Earth
- From the point of view of radio navigation and radio communication, the relevant layers in the atmosphere are the troposphere and the ionosphere, which are separated by the stratosphere

- **Troposphere** – It extends from the Earth's surface to a height of 10-18 kilometres depending on the latitude. Wave propagation in this space is strongly influenced by meteorological phenomena, which may affect the occurrence of noise in the signal.

Radio waves propagation xiv

- **Ionosphere** – covers areas more than 60 kilometres above the Earth. Radio waves mainly reflect off the ionosphere, and their passage through this layer depends on the wavelength and angle of their incidence on the ionosphere surface. Contact with objects in space is possible through the use of so-called radio windows, allowing the signal to propagate over long distances

Figure 6: Signal propagation [6].

Phenomena associated with radio wave propagation

Phenomena associated with radio wave propagation i

- Reflection of waves from the Earth's surface (refraction)
- Reflection of waves in the troposphere
- Bending of waves above the Earth's surface (diffraction)
- Wave absorption in the atmosphere

Phenomena associated with radio wave propagation ii

- Refraction - occurs at the border of two media with different permeability parameters
  - The refractive index can be expressed as

$$N = \frac{c}{v} \tag{1}$$

  - where
    - N - refractive index
    - c - the speed of light in a vacuum $\left[\frac{m}{s}\right]$
    - v - speed of light in a given medium $\left[\frac{m}{s}\right]$
- Diffraction - occurs when a wave encounters an obstacle; the smaller the dimensions of the obstacle in relation to the wavelength, the greater the value of the diffraction

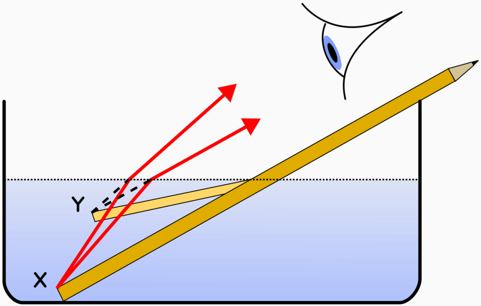

Figure 7: Refraction [7].

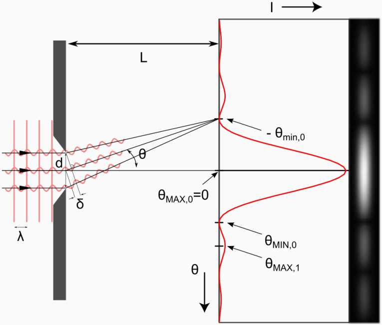

Figure 8: Diffraction [8].

Types of wave propagation according to frequency

Due to the frequencies of waves propagating in space, they can be divided into 4 main types

Type	Frequency	Wavelength
Long waves	30 - 300 KHz	10 km - 1km
Medium waves	300 KHz - 3 MHz	1 km - 100 m
Short waves	3 - 30 MHz	100 m - 10 m
Ultra-short waves	30 MHz - 300 MHz	10 m - 1 m

Table 1: Types of electromagnetic waves

Phenomena associated with radio wave propagation vi

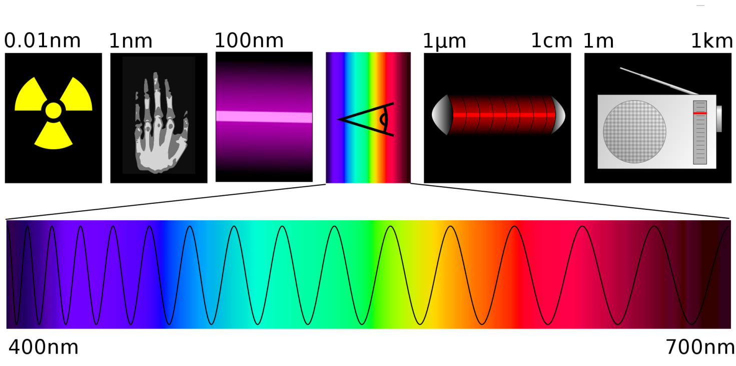

Figure 9: Electromagnetic waves [3].

Antenna techniques

Antenna techniques i

- The first antenna was patented by Japanese scientists in 1940
- The task of antennas is to change electromagnetic signal into electric signal and vice versa

Antenna techniques ii

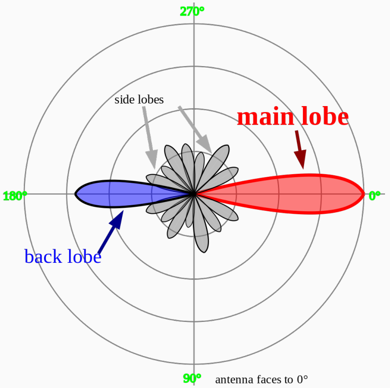

Figure 10: Antenna radiation characteristics [2].

Antenna techniques iii

- Omni-directional antenna
    - Waves propagate with equal intensity in each direction within a single plane
    - The maximum power drop shall not be less than 3 dB
    - Due to their characteristics they are suitable for mobile applications
- Directional antenna
    - Radiates almost all power in one direction indicated
    - The shape of the characteristic is mostly pin-shaped
    - The beam width at half power angle is several to several degrees

Antenna techniques iv

- Division of antennas
- Due to directionality
  - Omni-directional
  - Directional
- Due to the coupling to the electromagnetic field component
  - Electric
  - Magnetic

Antenna properties i

- Effective area As $[m^2]$ - hypothetical, effective area of radio signal reception
- Directional gain D [dBi] - ratio of radiated power density in a given direction to the average power density
- Energy gain G [dBi] - product of the directional gain and antenna efficiency

$$G = \eta_A \cdot D$$
$$\eta_A \approx 95\% - 98\% \tag{2}$$

- Half power angle $23dB$ - the angle beyond which the signal power falls 3dB below the maximum power

Antenna properties ii

- **Link balance** - comparison of the signal power at the transmitting side of the radio link with the signal power reaching its receiving side, taking into account losses in the communication channel.
- Indicates how to select link components so that the received signal strength is sufficiently higher than the receiver sensitivity

Antenna properties iii

Sources

1 - https://en.wikipedia.org/wiki/Fresnel_zone

2 - https://en.wikipedia.org/wiki/Antenna_(radio)

3 - https://pl.wikipedia.org/wiki/Promieniowanie_elektromagnetyczne

4 - https://en.wikipedia.org/wiki/Wavelength

5 - https://en.wikipedia.org/wiki/Oscillation

6 - https://en.wikipedia.org/wiki/Radio_propagation

7 - https://en.wikipedia.org/wiki/Refraction

8 - https://en.wikipedia.org/wiki/Diffraction

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Analog-digital and digital-analog conversion mechanisms

Project: Innovative Open Source Courses for Computer Science

30.05.2021

Outline

Definitions

Definitions i

Basic parameters of transmission tracks

- **Bandwidth** (Hz) - Bandwidth suitability, difference between upper and lower band frequencies
- **Flow rate** (capacity) - expressed in bits per second, how many bits must be transmitted per second over a specific transmission medium
- **Maximum theoretical capacity** - Shannon law

$$P = B \cdot log_2 \left(1 + \frac{S}{N}\right) \tag{1}$$

- where
    - B - bandwidth
    - S - signal power
    - N - noise power

- **Spectral efficiency** - how many bits can be transmitted at a given frequency
- **Transmission track capacity** - the product of the bit rate and the distance between regenerators
- **Error rate** - the fidelity of the information transmitted by the track
- **Transmission effectiveness** - the ratio of the number of information bits to the total number of bits

Definitions iii

- **Sampling** - sampling of the signal at specified intervals
- **Quantisation** - recording of recorded samples in discrete form
- **Coding** - assignment of bit values to samples after quantisation

Definitions iv

- **Converter** – a device that converts a given quantity to some other quantity according to a specified method. They are characterised by small dimensions, low power consumption and a wide measuring range.
- Based on the type of application, a distinction can be made:
  - Analog-digital converters
  - Digital-analog converters

Analog-digital converter

Analog-digital converter (A/D)

- Its task is to convert an analogue (continuous) signal into a corresponding digital representation (digital signal)
- Used in many electronic devices based on zero-one architecture, making it possible to process recorded signals
- The conversion process consists in simplifying an analogue signal into a discrete signal, which means converting continuous values into their equivalents in a step form

Analog-digital converter ii

During the operation of an A/D converter, 3 main stages can be distinguished:

- Sampling
- Quantisation
- Coding

In addition, during the operation of the converter, a process of **filtering** takes place. It boils down to performing certain operations on a set of input samples adjacent to the current sample, and sometimes also using a number of previous samples of the output signal.

Analog-digital converter iii

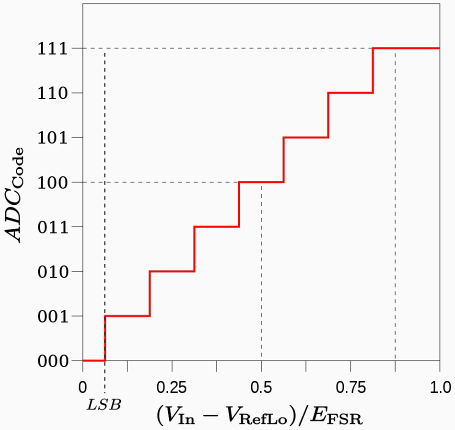

Figure 1: Voltage levels versus quantisation level [9].

Sampling i

Sampling – a process in which values at specific points in time are extracted from a continuous signal, thereby allowing the analogue signal to be represented by a sequence of discrete samples

- The signal should be sampled at a frequency at least 2 times higher than the maximum signal frequency to obtain a reliable representation (Nyquist-Shannon law)
- Sampling should take place at equal intervals

Sampling ii

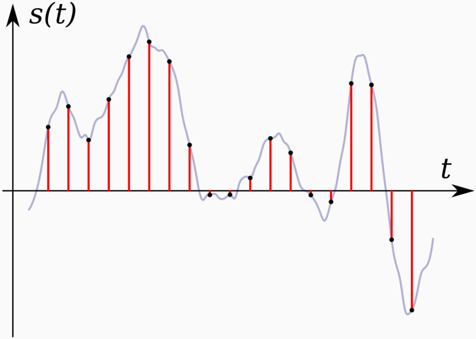

Figure 2: Signal sampling [1].

Sampling iii

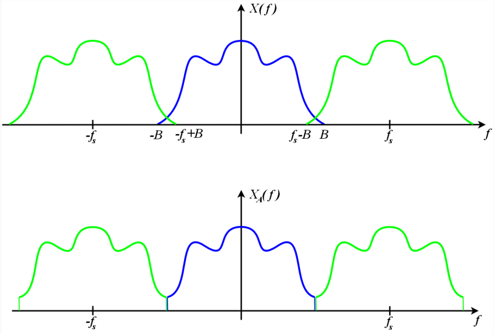

Figure 3: Spectrum of a discrete signal and aliasing [8].

Quantisation i

Quantisation (discretization) – the process by which the recorded samples are assigned an appropriate discrete value

- The assigned discrete value for a given sample depends on a fixed quantisation level
- The more quantisation levels, the better the representation of the input signal

Quantisation ii

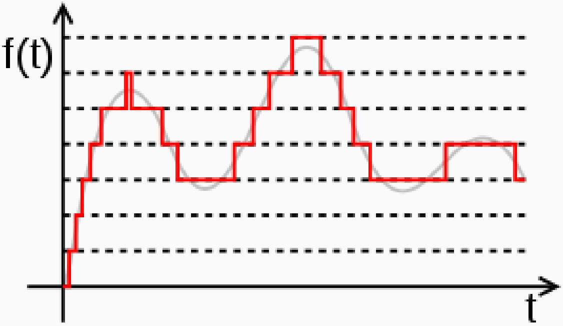

Figure 4: Signal quantisation [2].

Quantisation iii

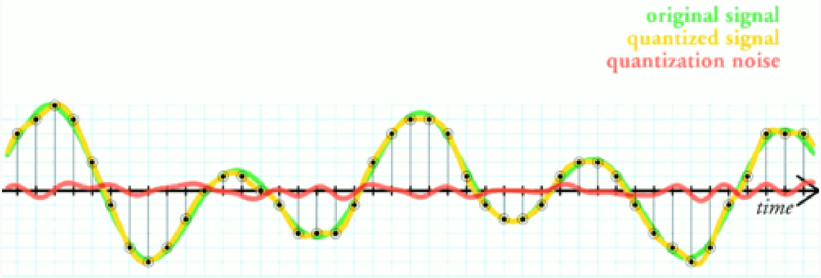

Figure 5: Signal quantisation [6].

Quantisation iv

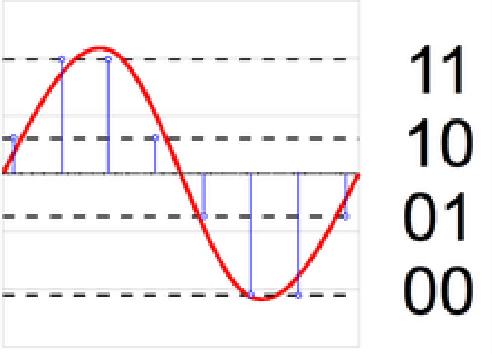

Figure 6: 2-bit quantizer [6].

Quantisation v

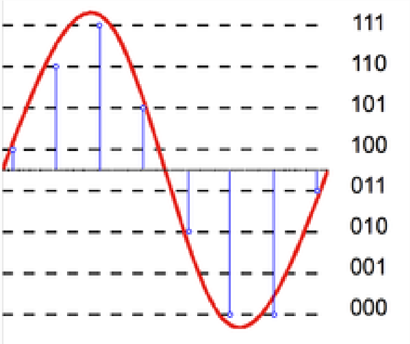

Figure 7: 3-bit quantizer [6].

Coding i

Coding – the process by which bit counterparts representing these samples are assigned to the assigned quantisation levels. The coding method depends on the quantisation level adopted

- 2 bits (00, 01, 10, 11)
- 3 bits (000, 001, 010, 011, 100, 101, 110, 111)
- The larger the bit representation, the lower the quantisation noise

Coding ii

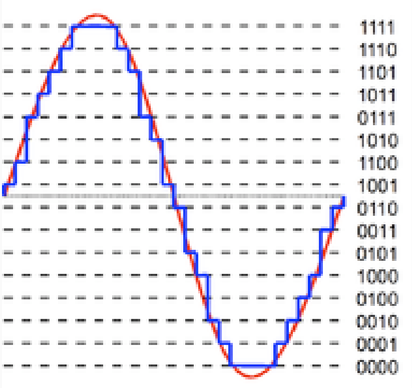

Figure 8: Discrete signal coding [3].

Scheme of operations performed by the analogue-to-digital converter

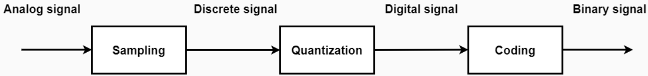

Figure 9: Workflow of the A/D converter

Digital-analog converter

Digital-analog converter i

- Digital-analog converter (D/A) is an electronic device for converting a digital signal (binary signal) to an analogue signal. It has m inputs and one output.

Digital-analog converter ii

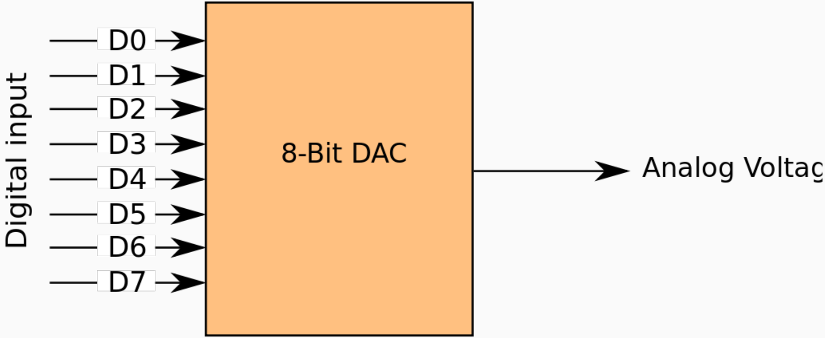

Figure 10: D/A converter [7].

Digital-analog converter iii

Digital-to-analogue converters can be distinguished according to the way the input circuits work

- Parallel - bits of the signal are fed in simultaneously
- Serial - the output signal is produced only after all input bits have been taken in sequence

Digital-analog converter iv

DAC design

- Status register - may be an integrated switch unit
- Electronic switch unit - controlled by digital signals
- Resistor network
- Voltage source

Construction of an example digital-to-analogue converter

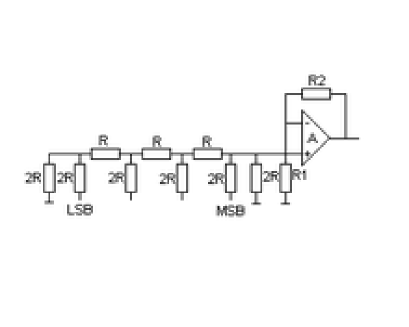

Figure 11: Design of DAC [4].

Digital-analog converter vi

DAC parameters

- Scaling error
- Processing speed
- Determination time
- Switching disturbances
- Scale of dynamics
- Maximum sampling frequency
- Input voltage rate of change

Digital-analog converter vii

Applications

- Audio equipment
- CD players
- Game consoles
- Mobile devices
- Smartphones
- Personal computers

Digital-analog converter viii

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IOSCS

Representation of radio signals in the frequency domain

Project: Innovative Open Source Courses for Computer Science

30.05.2021

Outline

Definitions

Modulation in telecommunications

Demodulation in telecommunications

Analog modulation

Digital modulation

- ASK modulation
- FSK modulation
- PSK modulation

Definitions

- **Carrier wave** - fixed frequency electromagnetic wave, generated by an electromagnetic wave transmitter
- **Modulation** - random or intentional variation of signal parameters to match a signal to specified requirements
- **Demodulation** - is the extraction of the original signal carrying the information from the carrier wave

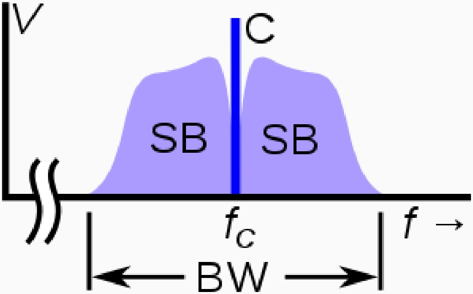

Figure 1: Signal carrier wave. Source [8].

Definitions iii

- **Signal spectrum** – the set of frequency components of a signal known as harmonics. The spectrum of a signal is presented in the frequency domain
- Frequency representation of the signal

$$x(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi n f t) + \sum_{n=1}^{\infty} b_n \cos(2\pi n f t) \qquad (1)$$

Definitions iv

Discrete Fourier Transform

$$A_k = \sum_{n=0}^{N-1} a_n w_N^{-kn}, 0 \leqslant k \leqslant N-1, \qquad w_N = e^{i\frac{2\pi}{N}} \tag{2}$$

- i - complex value
- k - harmonic number
- n - signal sample number
- a_n - signal sample value
- N - number of samples

The graphical representation of the signal in the spectral domain may be represented by the following diagram

- The values on the X axis are the signal frequency values
- The values on the Y axis represent the signal amplitude at a given frequency

Definitions vi

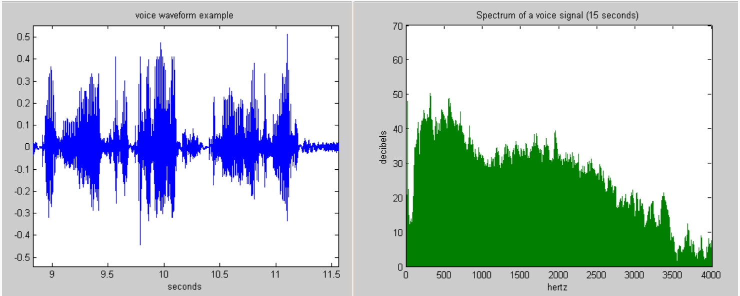

Figure 2: Frequency domain signal representation [9].

Definitions vii

- **Modulator** – an electronic circuit which implements the modulation process, operating according to a chosen modulation method which is responsible for modifying the transported information
- It has two inputs:
    - Information signal
    - Carrier signal

Definitions viii

- **Demodulator** – Usually in the form of an electronic circuit, a computer program or a programmable radio, its function is to recover the information content from a modulated carrier wave, it has implemented demodulating solutions in matching with its complementary modulator

Definitions ix

- **Spectrogram** - is a visual representation of the frequency spectrum of a signal that changes over time. When applied to an audio signal, spectrograms are sometimes called sonographs. When the data is represented in a 3D graph, they may be called waterfalls.
- They are also widely used in the fields of music, linguistics, sonar, radar, speech processing, or seismology. Sound spectrograms can be used for phonetic identification of spoken words and for the analysis of various animal calls.

Definitions x

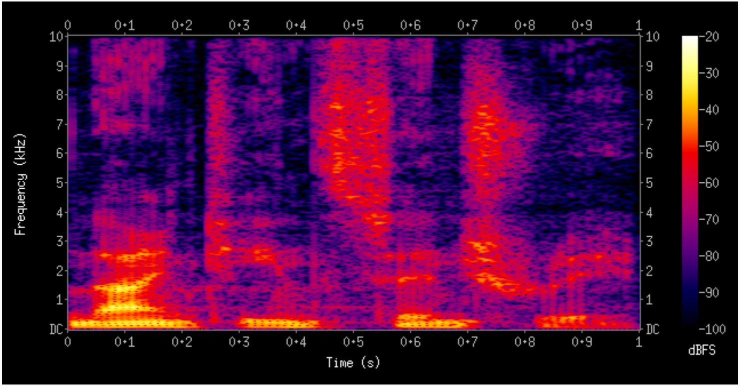

Figure 3: Spectrogram [5].

Modulation in telecommunications

Modulation in telecommunications i

- Modulation is a necessary element during signal transmission due to the transmission media used
- Physical constraints mean that information may be distorted by external interference
- The transported signal must be delivered in such a form that the information contained in it can be extracted correctly

Modulation in telecommunications ii

Transmission in telecommunications

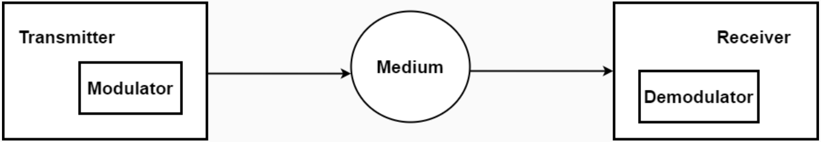

Figure 4: Transmission with modulation

Modulation in telecommunications iii

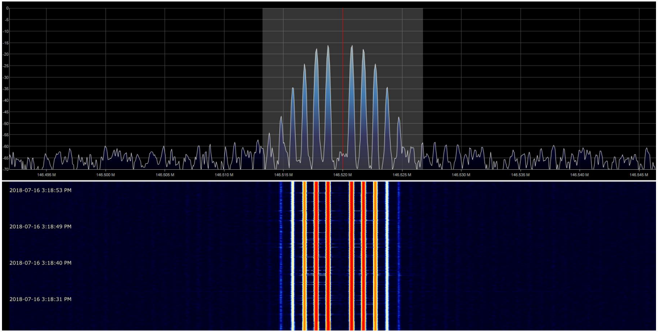

Figure 5: Modulation example [1].

Demodulation in telecommunications

Demodulation in telecommunications i

- Demodulation is the opposite process to modulation. The demodulator reconstructs the modulating signal from the modulated waveform.
- During this process, carrier wave information is extracted from the original signal
- Due to different modulation methods, there are many types of demodulators

Demodulation in telecommunications ii

The output signal from the demodulator may take the form

- Sound
- Image
- Binary data

Analog modulation

Analog modulation i

Analog modulation refers to the process of transferring an analogue baseband (low frequency) signal such as an audio or television signal to a higher frequency signal such as a radio frequency band.

Analog modulation ii

The modulation process is used to adjust the values of signal parameters in such a way that the information sent can be transported through a given medium having specific requirements as to the form of the signal transported

Analog modulation iii

There are also 3 basic analog modulations

- AM amplitude modulation - influence the change of amplitude of the modulated signal
- FM frequency modulation - change the frequency of the modulated signal
- PM phase modulation - influences the phase (offset) of the modulated signal

Digital modulation

Digital modulation i

- Digital modulation – is the process of changing a carrier signal in an analogue form to a signal in a binary form that can be easily transmitted over a transmission medium
- The digital modulation process is otherwise known as a keying operation

Digital modulation ii

There are 3 basic operations of digital modulation

- ASK – (Amplitude Shift Keying) – modification of the signal amplitude
- FSK – (Frequency Shift Keying) – modification of the signal frequency
- PSK – (Phase Shift Keying) – modification of the signal phase

Amplitude keying

- It consists in changing the amplitude of the carrier signal depending on the digital modulating signal
- The distinctive feature is that, due to the digital signal, the full amplitude of the modulated signal is present during the high state. On the other hand, in the low state this amplitude is reduced

ASK modulation ii

$$z_A(t) = \begin{cases} A_1 \cdot \sin(2\pi \cdot f_n \cdot t) & \text{dla } b[n] = 0 \\ A_2 \cdot \sin(2\pi \cdot f_n \cdot t) & \text{dla } b[n] = 1 \end{cases} \tag{3}$$

- n = 0, . . ., B - 1
- B - number of bits in signal

ASK modulation iii

Graphical representation of a signal modulated by ASK modulation

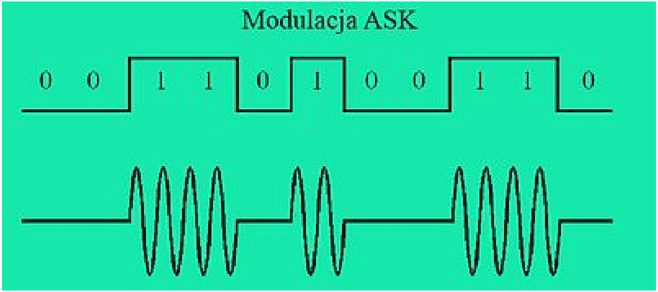

Figure 6: Signal waveform before and after ASK modulation [2].

FSK modulation i

Frequency keying

- It consists in assigning an appropriate carrier signal frequency to each of the two modulating signal states
- It has a constant instantaneous amplitude independent of the modulating signal
- It is resistant to pulse interference, attenuation and delay distortion, which makes it more attractive to use than ASK modulation

FSK modulation ii

$$z_F(t) = \begin{cases} \sin(2\pi \cdot f_{n1} \cdot t) & \text{dla } b[n] = 0 \\ \sin(2\pi \cdot f_{n2} \cdot t) & \text{dla } b[n] = 1 \end{cases} \quad (4)$$

- n = 0, . . ., B - 1
- B - number of bits in signal

FSK modulation iii

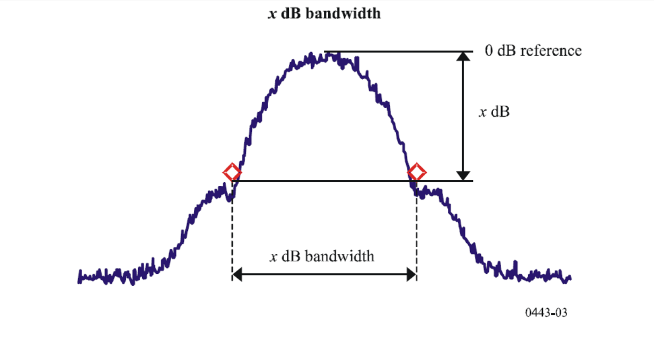

Figure 7: Signal frequency waveform [3].

FSK modulation iv

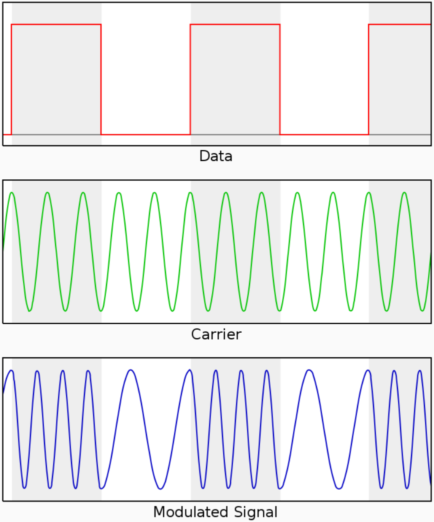

Figure 8: Frequency keying waveform [4].

PSK modulation i

Phase keying

- It consists in shifting the carrier wave of the signal depending on the state of the primary information
- Constant amplitude and frequency of the modulated signal are maintained
- Rarely used in digital systems
- The hardware implementation of FSK modulation is simpler

PSK modulation ii

$$z_P(t) = \begin{cases} \sin(2\pi \cdot f_n \cdot t) & \text{dla } b[n] = 0 \\ \sin(2\pi \cdot f_n \cdot t + \pi) & \text{dla } b[n] = 1 \end{cases} \quad (5)$$

- n = 0, . . ., B - 1
- B - number of bits in signal

Constellation diagram

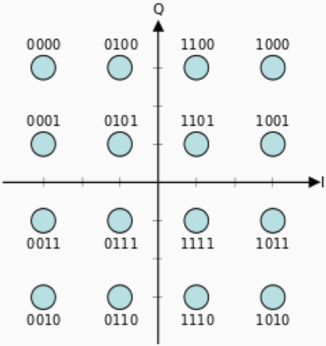

Figure 9: Constellation diagram [10].

Graphical representation of signal modulated by PSK modulation

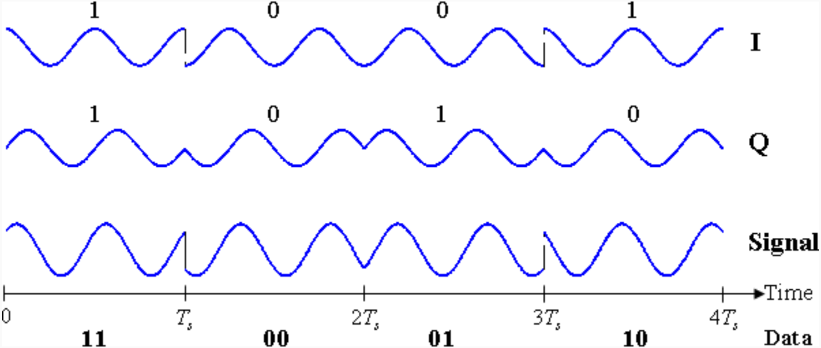

Figure 10: QPSK keying waveform [6].

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Properties of wireless channels

Project: Innovative Open Source Courses for Computer Science

30.05.2021

Outline

Definitions

Definitions i

- **Transmission** - the process of transmitting any message, or data in general, between a sender and a receiver, coded in a mutually intelligible way along a specified path
- **Wireless transmission** - real-time transmission using wireless communication methods between parties located at considerable distances from each other

Definitions ii

- **Wired medium** – a transmission medium in which a physical element connecting the receiver to the sender is used to transmit a signal
- **Wireless medium** – a transmission medium that transfers information between a transmitter and a receiver without using a physical medium

Definitions iii

- **Electromagnetic wave** - predicted by J.C Maxwell in 1834 and discovered by Heinrich Hertz in 1887
  - It is a plane, transverse wave, propagating perpendicular to the vibrations of the electric and magnetic fields
  - propagates at a speed of 3 $\cdot 10^8 \frac{m}{s}$
- **Electromagnetic waves** - areas of use
  - in the infrared range
  - in the radio spectrum

Radio waves

Radio waves i

- Radio wave sources can be either natural or artificial, e.g. emitted by mobile phone transmitting stations
- The main purpose is to carry information
- In telecommunications, used for data transmission
- There are several types of radio waves
- Ultra-short, short, medium and long waves are used for data transmission

Standards in wireless networks

Standards in wireless networks i

- IEEE 802.11 - IEEE 802 subgroup of standards
- Describes the physical layer and MAC physical sublayer of wireless local area networks
- Includes 4 independent protocols focusing on coding
- 802.11 are the basis for the certification of Wi-Fi networks

Standards in wireless networks ii

Standard	Frequency	Maximum bandwidth
802.11a	5 GHz	54 Mb/s
802.11b	2.4 GHz	11 Mb/s
802.11g	2.4 GHz	54 Mb/s
802.11n	2.4 GHz, 5 GHz	150 Mb/s, 600 Mb/ s
802.11ac	5 GHz	up to several Gb/s

Table 1: Table with data describing wireless standards

Signal interference

Signal interference i

During the transmission of information between sender and receiver, the signal is exposed to external factors that may cause transmission errors

- Intersymbol interference
- Attenuation
- AWG channels - with Gaussian distribution noise
- Delays
- Noise
- Bit misrepresentation
- Loss of information

Signal interference ii

- In addition, correction and detection codes shall be used in order to find and prevent the distortion of the message to be sent

Signal interference iii

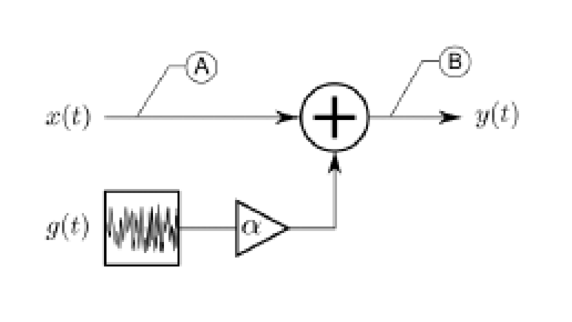

Figure 1: Interference model with additive noise [1].

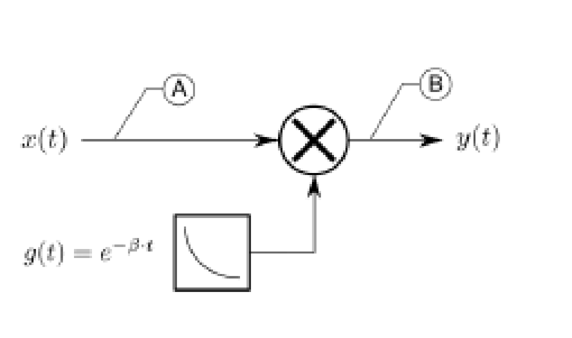

Figure 2: Signal attenuation model [1].

Signal interference v

- Bit error rate
- Referred to as BER = $\frac{E}{N}$
- gdzie
    - E - number of bits incorrectly received
    - N - number of bits transmitted

Wireless network

Wireless network i

- PAN – Personal Area Network – at distances of up to 10 metres
    - For example, the use of Bluetooth technology
- WLAN - Wireless Local Area Network - up to 100 metres in the open air
    - For example, the IEEE 802.11a/b/g/n standard
- WWAN - Wireless Wide Area Network - up to 5 kilometres
    - GSM, GPRS, EDGE mobile phone network systems

Wireless network ii

- LTE - Long Term Evolution - a data transmission standard that is the successor to 3G systems. Higher transmission speeds, reduced delays, increased efficiency and lower transmission costs
- 5G - fifth generation mobile technology, the successor to 4G. Significantly higher requirements are placed on the speed of transmission, or the reduction of errors

Wi-Fi i

It consists of wireless communication in two used frequency ranges

- 2.4 GHz
- 5 GHz

The exact frequency used in a specific wireless network depends on the transmission channel used

- 11 channels are used in the USA
- In Poland 13 channels
- In Japan 14
- By contrast, in France only 4

Wi-Fi network security i

Wireless networks are exposed to network threats. Therefore, security tools are used to increase the effectiveness of the defence against attacks carried out. The most important security mechanisms in wireless networks are:

- SSID (Service Set ID) - provides a very limited form of access control due to the need to provide this ID when establishing a connection

Wi-Fi network security ii

- WEP (Wired Equivalent Privacy) encryption - available in every Wi-Fi system, encryption is based on a shared encryption key
- 802.1.x standard - centralizes user identification, authentication and dynamic key management
- WPA (Wi-Fi Protected Access) encryption - uses the TKIP protocol to automatically change the encryption key after a period of time

Bluetooth i

- Bluetooth technology is a global initiative providing wireless radio access. It was initiated by equipment manufacturers such as: IBM, Intel, Nokia, Toshiba, Ericsson.
- A solution was proposed in 1994 in Sweden.

Bluetooth ii

- Based on short-range radio connections between mobile phones, portable computers, peripherals and audiovisual devices
- Communication between different mobile devices at up to 1 Mbps is possible

Wireless transmission applications i

- In places where it is not possible to lay cables, a wireless network often proves indispensable.
- There are also situations where the currently existing wired network cannot be extended with additional connections. Then the only solution may be to use wireless transmission

Wireless transmission applications ii

- Informatisation of historic buildings
  - Due to the lack of possibility to interfere with the structure and design of the building, it is not possible to lay a wired transmission medium
- Business
  - Especially in places that are used temporarily for the organization of various events, conferences, outdoor events

Wireless transmission applications iii

- Industry
  - Convenient as no additional wiring of production facilities is required
  - However, this requires greater reliability and stability of the transmission system

Advantages of a wireless network i

Wireless networks are readily used because of:

- Low cost
- Quick installation
- Easy to expand
- No interference with the infrastructure
- Connectivity from anywhere

Disadvantages of a wireless network i

However, the use of wireless networks also has its drawbacks:

- Slower data transfer than in wired medium
- Less secure
  - Need to provide additional security, which reduces transmission speed
- Need to reserve sufficient bandwidth
- More susceptible to interference
- The transmission rate depends on the distance between the communicating devices

Disadvantages of a wireless network ii

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Principles of the modulation process

Project: Innovative Open Source Courses for Computer Science

30.05.2021

Outline

Definitions

Communication track

Digital modulations

- QPSK modulation
- QAM modulation

Definitions

Definitions i

- **Modulation speed** - determine the maximum number of changes of moments or characteristic states in 1 second
  - expressed in baud
  - 1 baud = 1 $\frac{b}{s}$ - only in telegraphic signals
  - mostly 1 bod $\neq 1\text{b}_{\bar{s}}$
- **Transmission speed** - number of bits transmitted per second at a given error rate
- Baud rate a Bit rate
  - Baud rate specifies the modulation speed
  - Bit rate specifies the transmission speed

Definitions ii

- **Modulation** - the process of changing the parameters of a signal (amplitude, frequency, phase) in order to match its properties to the medium used transmisyjnego
- **Modulation in telecommunications** – the process of changing the parameters of a carrier wave to enable the transmission of information
- **Demodulation** – reverse process to modulation, reconstruction of modulating signal from modulated waveform

Definitions iii

- **Constellation diagram** - graphic representation of modulation
    - Constellation points define the distance from a coordinate point
- **Basic parameters in the signal**
    - Amplitude
    - Frequency
    - Phase

Definitions iv

Modulation types

- Analog
  - AM – amplitude modulation
  - FM – frequency modulation
  - PM – phase modulation
- Digital
  - ASK – amplitude shift keying
  - FSK – frequency shift keying
  - PSK – phase shift keying

Communication track

Communication track i

Modulated signal communication track

In order to enable the use of modulation methods during the transmission of information between the sender and the receiver, there must be devices on both sides that are responsible for modifying the signal and for reading it. In the transmission medium, the signal is transported in a modulated form.

On the sender's side, there is a **modulator** that matches the signal parameters to the transmission channel.

On the receiver side there is a **demodulator** which reproduces the primary signal.

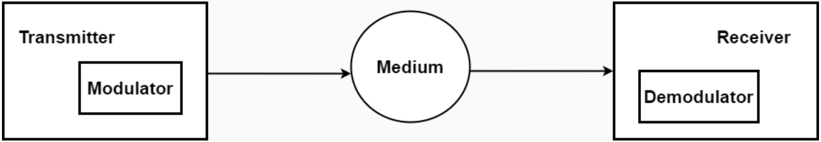

Figure 1: Signal waveform in the transimission channel.

Digital modulations

QPSK modulation i

- **QPSK modulation** (Quadrature Phase Shift Keying) – is the modified phase modulation method
- It consists of encoding the transmitted signal with 2 bits and representing it on 4 orthogonal phase shifts

QPSK modulation ii

The most common approach used in QPSK modulation involves defining the following values for phase shifts:

- Bits: 00 – 45 °
- Bits: 01 – 135 °
- Bits: 10 – 225 °
- Bits: 11 – 315 °

QPSK modulation iii

- The main advantage of this modulation is that the phase of the signal can be represented by values that are 90 ^{rc} apart
- In addition, the 2-bit representation allows for a more accurate representation of the signal

QPSK diagram for 2-bit quantisation level

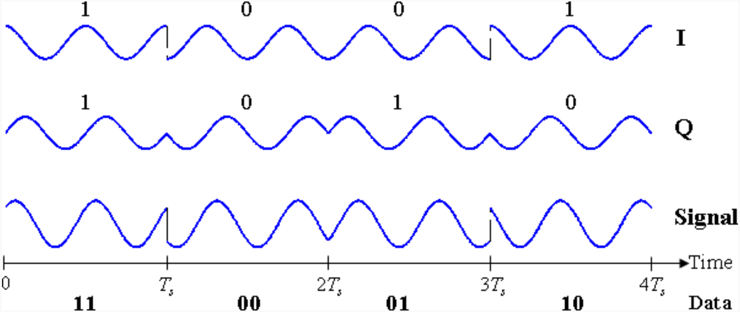

Figure 2: Diagram of QPSK [3].

Construction of the QPSK modulator

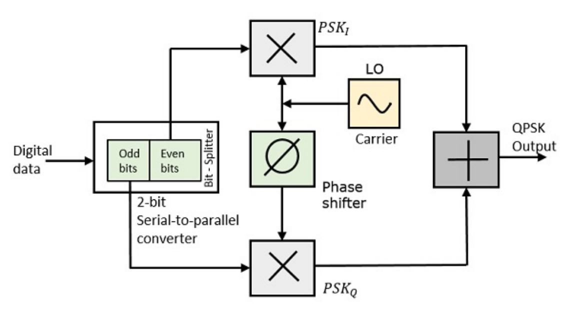

Figure 3: QPSK modulator [2].

QAM modulation i

- **QAM modulation** (Quadrature Amplitude Modulation) – quadrature amplitude-phase modulation used in digital modulation process Combines ASK and PSK keying
- Data represented by a binary string of specified length, which are equivalent to a description of both amplitude and phase
- Constellation diagram used for the graphical representation of the modulation process and the representation of states

QAM modulation ii

- Constellation diagram for 16-QAM modulation
- 16 states stored on 4 bits
- Each state is called a constellation point
- Neighbouring states generated from the Grey code
    - Neighbouring states are bitwise different in only one position

QAM modulation iii

Graphical representation of the constellation diagram for QAM-16

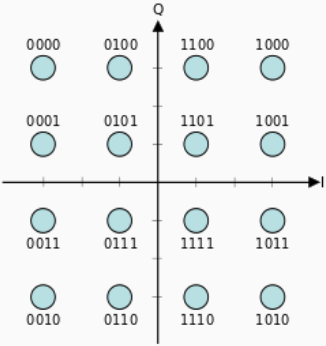

Figure 4: Constellation diagram [1].

Comparison of constellation diagrams for FSK, QPSK, 16 QAM and 64 QAM modulations

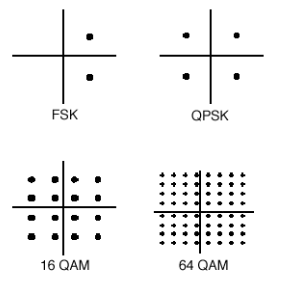

Figure 5: Constellation diagram [5].

QAM modulation v

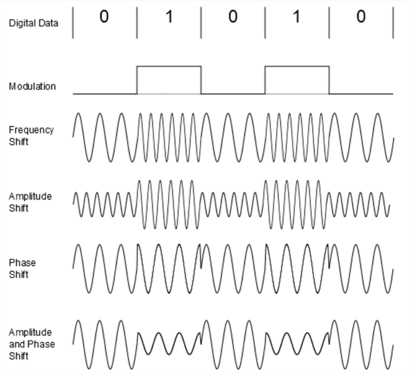

Figure 6: Ranges of different digital modulations [4].

QAM modulation vi

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Digital modulations

Project: Innovative Open Source Courses for Computer Science

30.05.2021

Outline

Definitions

Definitions i

- **Modulation** – process of changing signal parametersproces zmiany parametrów sygnału
- **Digital modulation** - the process of changing an analogue carrier signal by a binary modulating signal which can be transmitted easily over a transmission medium
- Types of digital modulation:
    - **ASK** – Amplitude Shift Keying
    - **FSK** – Frequency Shift Keying
    - **PSK** – Phase Shift Keying
    - Others: np. QAM, PCM, CAP, TCM

Definitions ii

- **Modulated signal** – signal converted during the process of modulation
- **Modulating signal** – signal in binary form specifying the modulation rules

Graphical representation of modulated, modulating and modulated signals

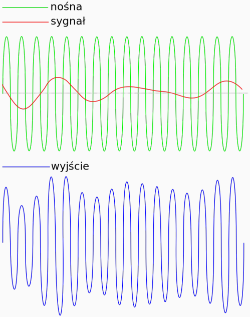

Figure 1: Example of amplitude modulation [2].

Digital modulations

ASK modulation i

- **ASK modulation** (Amplitude Shift Keying) – consists in changing the amplitude of the carrier wave in a modulated signal
- The ASK signal can be written using the following formula

$$\varphi_{ASK} = \frac{1}{2}A_0[1 + x(t)]\cos\omega_0 t \tag{1}$$

- lub

$$\varphi_{ASK}(t) = \begin{cases} 0 & \text{dla } x(t) = -1 \\ A_0\cos\omega_0 t & \text{dla } x(t) = 1 \end{cases} \tag{2}$$

- where
  - $x(t)$ - zero-one keying waveform
  - ω_0 - carrier wave pulsation

FSK modulation i

- **FSK modulation** (Frequency Shift Keying) – consists in changing the frequency of the carrier wave in the modulated signal at a constant amplitude
- The following formula may be used to determine the modulation code

$$\varphi_{FSK} = \begin{cases} A_0 \cos \omega_1 t & \text{dla } x_n = 1 \\ A_0 \cos \omega_2 t & \text{dla } x_n = 0 \end{cases} \qquad (3)$$

- where
  - $\omega_1 \omega_2$ - characteristic frequencies
  - A_0 - amplitude of the carrier signal

PSK modulation i

PSK modulation (Phase Shift Keying) – a type of digital modulation consisting in changing the phase of the carrier wave of a modulated signal

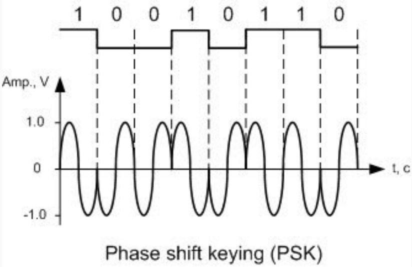

Figure 2: PSK modulation waveform [3].

MSK modulation i

- **MSK modulation** (Minimum Shift Keying) – FSK modulation variant
- It is characterised by good energy properties and the absence of phase jumps in the modulated signal
- Due to the absence of phase jumps it is possible to significantly reduce the frequency band occupied by the signal

MSK modulation ii

The general formula for the modulated signal can be expressed by

$$S(t) = A\cos\left[\omega_0 t + \phi(t)\right] \tag{4}$$

MSK modulation iii

- The initial phase is always equal to the end phase of the previous period
- MSK modulation uses two carrier frequencies for bit 0 and 1
- When designating the key frequency as f:
    - $f_0 = \frac{3}{4}$ f
    - $f_1 = \frac{5}{4}$ f

MSK modulation iv

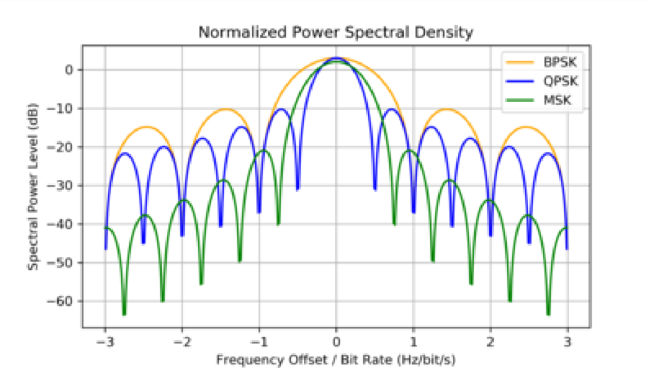

Figure 3: MSK diagram [1].

GMSK modulation i

- **GMSK modulation** (Gaussian Minimum Shift Keying) – minimum-phase with Gaussian filter
- This is a modification of the frequency keying and MSK
- Rectangular pulse is replaced by sinusoidal pulse due to smaller sidebands and narrower bandwidth compared to rectangular pulse
- The main application of this modulation is in the GSM mobile phone system

GMSK modulation ii

- The bandwidth of the system is defined by the relation between the working width B of the Gaussian filter and the oscillation period T
- The smaller the BT value, the narrower the signal spectrum. However, there may be a greater number of errors registered in the transmitted signal
- GSM system uses BT = 0.3

GMSK modulation iii

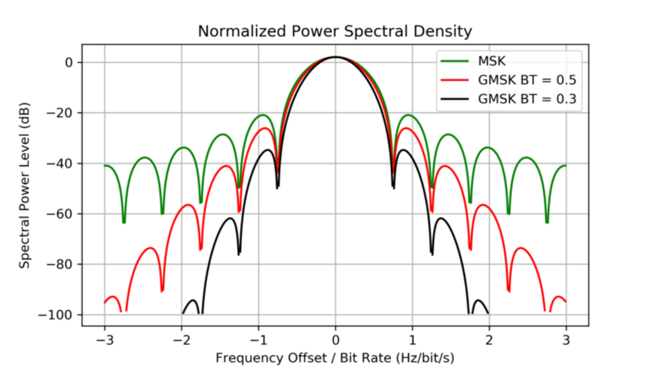

Figure 4: GMSK diagram comparison [1].

GMSK modulation iv

Sources

1 - https://en.wikipedia.org/wiki/Minimum-shift_keying

2 - https://pl.wikipedia.org/wiki/Modulacja

3 - https://www.tmatlantic.com/encyclopedia/index.php?ELEMENT_ID=10478

Thanks for your attention ☺

Co-funded by the Erasmus+ Programme of the European Union

Spread spectrum systems

Project: Innovative Open Source Courses for Computer Science

30.05.2021

Outline

Definitions

Spectral dispersion of the signal

History of signal spectrum spreading techniques

Spread Spectrum Systems

- DSSS systems
- FHSS systems
- THSS systems

Definitions

Definitions i

- **Signal spectrum** – the representation of a signal in the frequency domain obtained by a Fourier transform
- **Signal Spectrum Spreading** - a method of widening the bandwidth of a signal by using a spreading process

Definitions ii

- The application of spectrum spreading is mainly to allow multiple users to work while using the same band
- It is mainly used in Wi-Fi standard, Bluetooth networks and ZigBee networks (sensor networks and building automation)

Definitions iii

Spectrum dispersion methods:

- CM (Chirp Modulation) – frequency sweep
- FH (Frequency Hopping) – dispersion by frequency hopping
- TM (Time Hopping) - distraction by jumping in time
- DS (Direct Sequence) – dispersion by direct keying

Definitions iv

Advantages of using spectrum spreading:

- Increased bandwidth efficiency
- Possibility of protecting data against information interception
- Higher interference immunity

Spectral dispersion of the signal

Spectral dispersion of the signal i

Based on Shanonn-Hartley's theorem on the capacity of a telecommunications channel

- C – capacity (bit/s)

$$C = B \cdot \log 2(1 + S/N) \tag{1}$$

- B – bandwidth (Hz)
- S/N – signal power to noise and interference ratio

and relations describing the required channel widths to achieve the assumed throughput

$$B = C/\log 2(1 + S/N) \tag{2}$$

results that the lower the ratio of signal power to the power of noise and interference in the channel, the wider the bandwidth it must occupy.

Spectral dispersion of the signal iii

Therefore, signal spectrum spreading is used to transform a narrowband information signal into one with a spectrum several times wider

Spectral dispersion of the signal iv

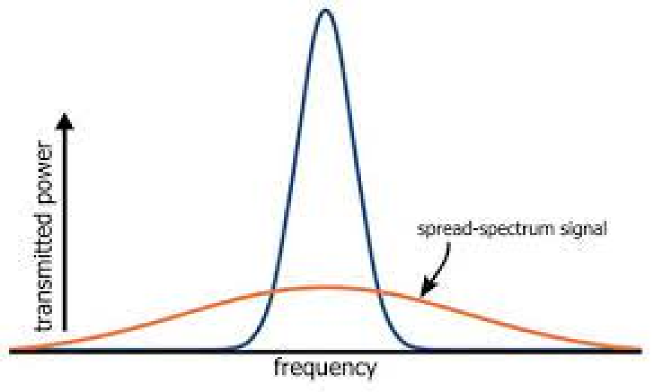

Figure 1: Spread spectrum signal [1].

Spectral dispersion of the signal v

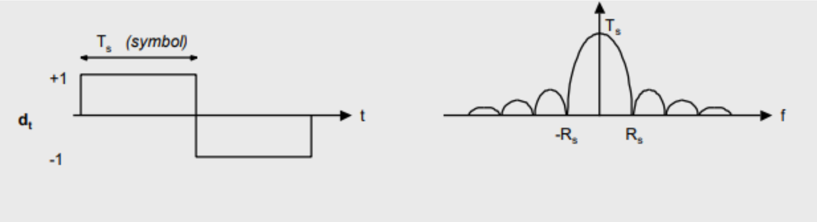

Figure 2: Spectrum signal [2].

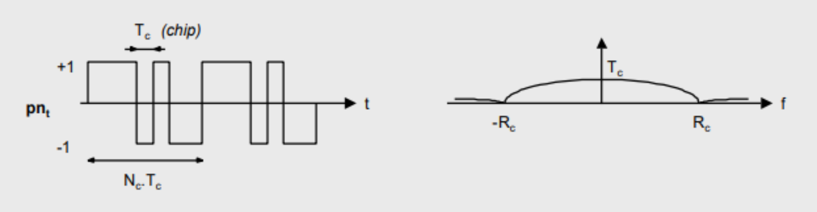

Figure 3: Spread spectrum signal [2].

Spectral dispersion of the signal vii

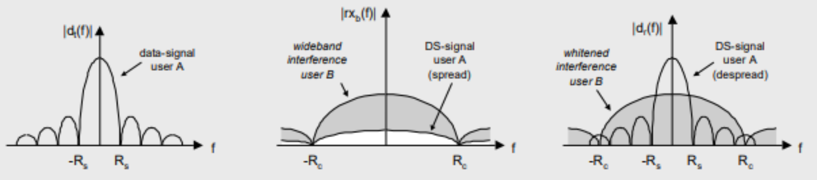

Figure 4: Spread spectrum signal with noise [2].

Spectral dispersion of the signal viii

Spectrum spreading in telecommunications

- Spread spectrum uses a sequential noise-like signal structure to spread a narrowband information signal over a relatively broad radio frequency band
- The receiver correlates the received signals in order to recover the original form of the information signal

Spectral dispersion of the signal ix

- The original use included
  - Actions to counter attempts by enemies to disrupt communications
  - Actions to conceal the fact of communications between the parties

History of signal spectrum spreading techniques

History of signal spectrum spreading techniques i

- These techniques have been known since the 1940s
- The first attempts to experiment with the reception of selected frequencies while minimising interference were made by Guglielmo Marconi in 1899
- They were initially used only in military communication systems

History of signal spectrum spreading techniques ii

- During World War II, actress Hedy Lamarr and composer George Antheil developed a radio guidance system for use in Allied torpedoes that proved immune to interference
- Currently, these systems are mainly used in Wi-Fi and Bluetooth networks, where their task is to minimise the occurrence of interference in order to increase transmission reliability

Spread Spectrum Systems

DSSS systems i

- DSSS – Direct Sequence Spread Spectrum – is based on the direct modulation of the carrier code sequence with the use of scattering strings
- It is a spread spectrum modulation technique mainly used to reduce overall signal interference
- The use of direct frequency makes the transmitted signal wider in bandwidth than the bandwidth of the information
- When modulation is dispersed or removed at the receiver, the initial bandwidth is restored, but unintentional and intentional interference is significantly reduced

DSSS systems ii

- The use of the DSSS in series consists in comparing the output of the correlator block with a set threshold value. If this value is lower, the pseudorandom sequence generator is adjusted accordingly. Otherwise, the tuning phase is completed. The disadvantage of this solution is the long adjustment time.
- In a parallel configuration, more correlators are used. This allows multiple comparisons to be performed simultaneously, making the tuning process significantly faster. However, this has the disadvantage of high cost and increased receiver complexity.

DSSS systems iii

Dispersal codes used:

- Gold's code
- Barker's code
- Pseudorandom code

The codes generated are expected to be orthogonal and have good correlation and statistical properties.

DSSS systems iv

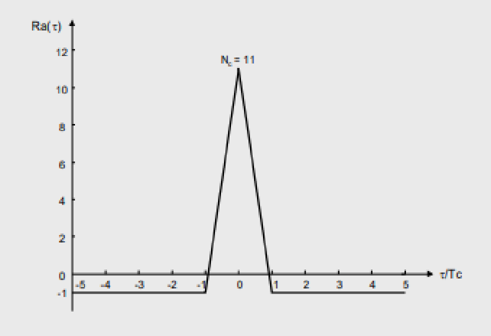

Figure 5: Barker sequence [2].

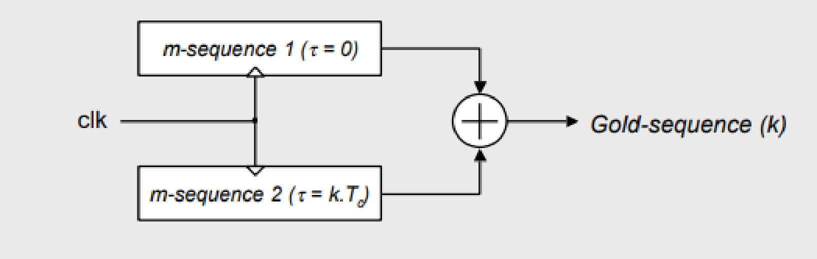

Figure 6: Schematic of Gold's code generator [2].

FHSS systems i

- FHSS – Frequency-Hopping Spread Spectrum – metoda Spectrum spreading in broadband systems, consisting of ”hopping” around the frequencies of a signal at preset intervals in the available spectrum
- There are two basic varieties:
    - Slow FHSS – the bit duration is shorter than the dwell time at the frequency in question
    - Fast FHSS – change of frequency several times during the bit

FHSS systems ii

- 'Hopping' means a rapid change of carrier frequency among many different frequencies occupying a large spectral bandwidth.
- Used to avoid interference, prevent eavesdropping and enable code division multiple access (CDMA) communications.

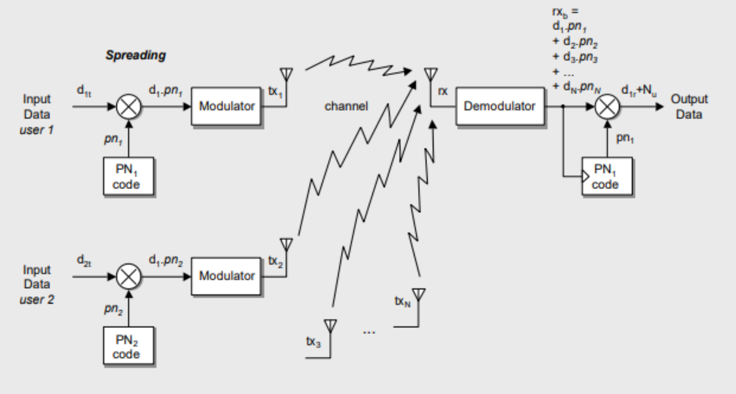

Figure 7: CDMA operation scheme [2].

FHSS systems iv

- Many smaller sub-bands are available in the frequency band. Signals in short intervals ”jump” on the carrier frequencies between the centre frequencies of these sub-bands in a fixed order.
- Emerging interference at a certain frequency will only affect the signal at short intervals.

FHSS systems v

- Main application advantages compared to fixed frequency transmission:
    - Highly resistant to narrowband interference
    - Difficult to intercept if the jump pattern is not known
    - Can share frequency bandwidth with many types of transmission

FHSS systems vi

Applications

- Military
  - Jamming of broadcast signals
  - Military radios are responsible for generating the frequency hopping pattern under the control of a secret transmission security key, and the sender and receiver share it in advance
- Civil
  - For radio-controlled receivers
  - In selected controlled car models, drones
  - In police radar

THSS systems i

- THSS – Time-Hopping Spread Spectrum – a technique used in spreading the spectrum of a signal to achieve a low probability of interference
- In order to achieve a low chance of signal interference, the transmission time is randomly changed by varying the period and cycle of the carrier pulse using a pseudorandom sequence
- This will ensure that the transmitted signal has a discontinuous start and stop time

Sources

1 - https://www.allaboutcircuits.com/textbook/radio-frequency-analysis-design/selected-topics/understanding-spread-spectrum-rf-communication/

2 - http://www.sss-mag.com/pdf/Ss_jme_denayer_intro_print.pdf

Thanks for your attention ☺

Co-funded by the
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Software defined radio

Project: Innovative Open Source Courses for Computer Science

30.05.2021

Outline

Definitions

Definitions i

History

- The term ”software radio” was invented in 1984 to refer to a digital broadband receiver
- Provides programmable interference suppression and demodulation for wideband signals using thousands of adaptive filters
- In 1991, Joe Mitola independently reinvented the term software radio for a plan to build a GSM base station that would combine a digital receiver with digitally controlled communications jammers

Definitions ii

- **Software-Defined Radio - (SDR)** – otherwise known as a digital radio receiver, it is a radio communication system where the operation of the basic electronic components is realised by a computer program.
- The idea of a programmable radio had existed for quite some time, but the lack of effective hardware implementations caused a standstill in practical ways of using this system

Definitions iii

- The basic implementation of programmable radio includes:
    - Computer equipped with a sound card or other A/D converter
    - Electronic circuit to receive a modulated high frequency signal
- The signal from the receiver is transferred to a lower band which is within the processing range of the sound card or the A/D converter

Definitions iv

- Signal processing is mainly carried out by a general purpose processor
- The receiver is able to handle different types of radio transmissions by changing the signal processing program

Principle of operation of the SDR

Principle of operation of the SDR i

- RF (Radio-Frequency) communication is performed by software or firmware to perform signal processing tasks that are normally processed by hardware.
- This equipment includes mixers, filters, amplifiers, modulators, demodulators, etc.
- Therefore, SDR uses only an ADC and DAC to convert analogue to digital and digital to analogue signals together with antennas, without the need for multiple hardware components.

Principle of operation of the SDR ii

- This, in turn, makes SDR very flexible and makes it easier to solve problems when they arise, as most of the processing is done in software rather than hardware.
- The software can be run both on a personal computer and on an embedded system.

Principle of operation of the SDR iii

Figure 1: Example of SDR [2].

Software

Software i

- Software is a key element in a programmable radio.
- One of the most popular packages offering the possibility of programming SDR chips is the GNU Radio package.
- GNU Radio is open source software that allows both the design and commissioning of SDR systems and observing their operation.

Software ii

- In addition to this solution, other software can be used, such as
  - SDR
  - HDSDR
  - SDR-RADIO.com V2/V3
  - SDR++
  - GQRX

Software iii

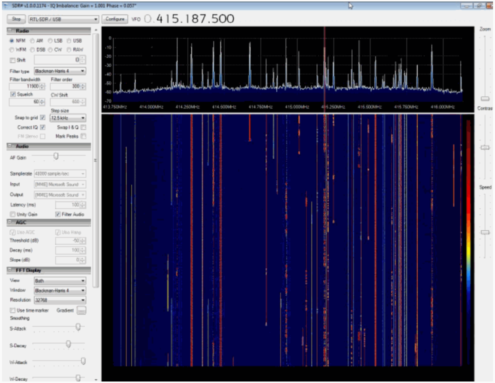


Figure 2: SDR [1].

Software iv

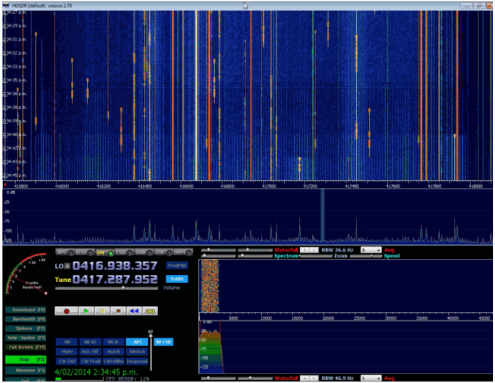


Figure 3: HDSDR [1].

Software v

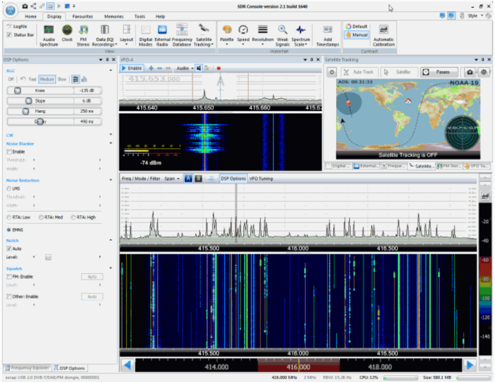


Figure 4: SDR-RADIO.com V2/V3 [1].

Software vi

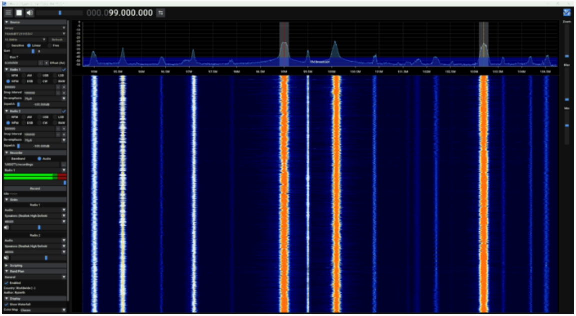


Figure 5: SDR++ [1].

Software vii

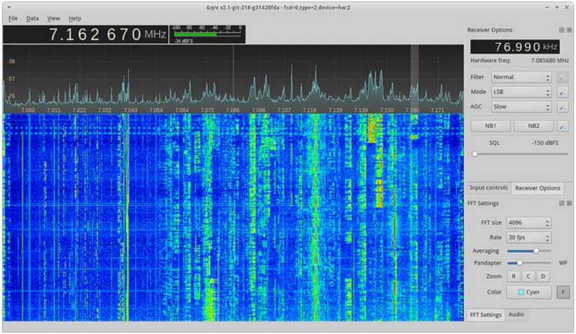


Figure 6: GQRX [1].

GNU Radio

GNU Radio i

- GNU Radio has a graphical interface that allows the design and modelling of operations required during signal processing.
- It is also possible to generate code in Python
- It is an alternative to programs such as Matlab and LabView

GNU Radio ii

- The software is ”open source” so you can use it without any licence restrictions and also add new components
- Use of systems based on GNU Radio:
  - RFID readers
  - Secondary Surveillance Radar (SSR) receivers for air traffic control
  - Construction of radio transmission receivers and transmitters

GNU Radio iii

Figure 7:

GNU Radio iv

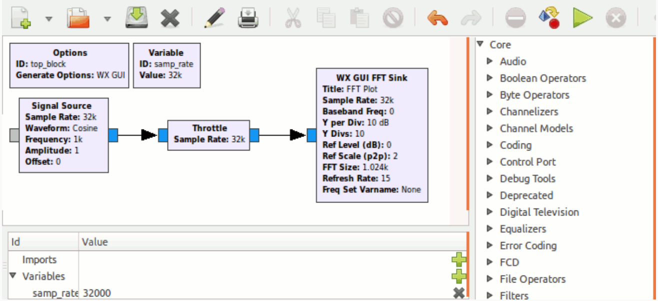
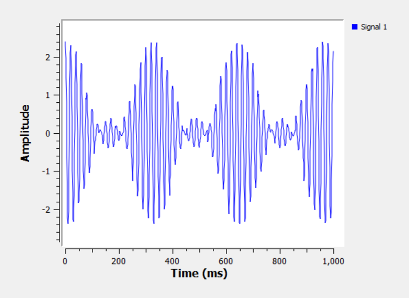


Figure 8: Appearance of components

GNU Radio v



Advantages of a programmable radio

Advantages of a programmable radio i

- Ability to achieve very high performance levels
- Possibility to change performance through software upgrade (but hardware dependent attributes will not be upgradeable)
- Possibility to reconfigure radios through software update
- Possibility to use the same hardware platform for several different radios

Disadvantages of the programmable radioo

Disadvantages of the programmable radio i

- ADCs limit the highest frequencies that can be used by the digital section
- Both hardware and software skills are required for SDR development

Applications

Applications i

- SDR systems play an important role where speed of operation and the flexibility to adapt the solutions used to the latest techniques count
- They are also desirable in technical areas where an easy change of signal transmission is required
- There are two main categories of SDRs:
    - Systems designed as SDR receivers
    - Systems designed as SDR transmitters

Applications ii

Areas of application:

- Mobile devices
- Military communications
- Reception of radio broadcasts
- Radio astronomy
- Tracking of vessels through AIS transmissions
- Tracking of aircraft with S Mode transmission

Applications iii

Sources

1 - https://www.rtl-sdr.com/big-list-rtl-sdr-supported-software/

2 - https://en.wikipedia.org/wiki/Software-defined_radio

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Co-funded by the Erasmus+ Programme of the European Union

Introduction to wireless systems

Project: Innovative Open Source Courses for Computer Science

30.05.2021

Outline

Definitions

Definitions i

Sygnał

A signal can be represented in two domains

- Time domain

$$f(t) = A\sin(\omega t + \theta) \tag{1}$$

- Frequency domain

$$x(t) = \frac{1}{2}c + \sum_{n=1}^{\infty} a_n \sin(2\pi nft) + \sum_{n=1}^{\infty} b_n \cos(2\pi nft) \tag{2}$$

Definitions ii

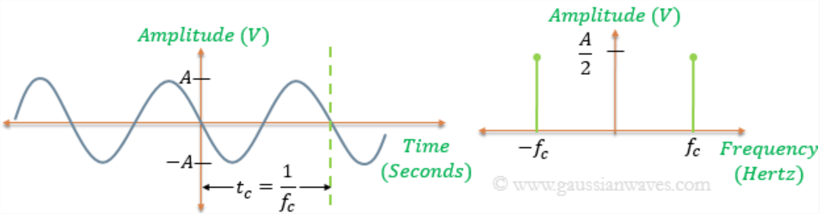

Figure 1: Signal in frequency domain [5].

Definitions iii

- **Source** - generates a message, which can be a human voice, a television image or sound from loudspeakers. The source is converted by an input transducer into an electromagnetic wave called information signal
- **Transmitter** - modifies the signal for efficient transmission. It usually consists of one or more of the following subsystems: sampler, quantizer, encoder and modulator

Definitions iv

- **Channel** - is the medium through which the output signal from the transmitter is transported. It can be a wire, concentric cable, optical fibre, radio link, etc. Based on the type of channel, modern communication systems are divided into two categories: wired communication systems and wireless communication systems
- **Receiver** - re-processes the signal received from the channel by undoing the signal modifications made to the transmitter and the channel. The task of the receiver is to extract the message from the distorted and noisy signal at the output of the channel. The receiver may consist of a demodulator, decoder or filter

Definitions v

Messages can be represented as

- **Analog** - are characterised by data whose values vary in a continuous range. For example, a speech waveform has an amplitude that changes in a continuous range. An image is also an analogue message.
- **Digital** - are made up of a limited number of symbols. For example, a text file is a digital message made up of 80 symbols, consisting of 26 letters, 20 numbers, spaces and punctuation marks. Similarly, telegraphic Morse code is a binary message with only two symbols - characters and space.

Definitions vi

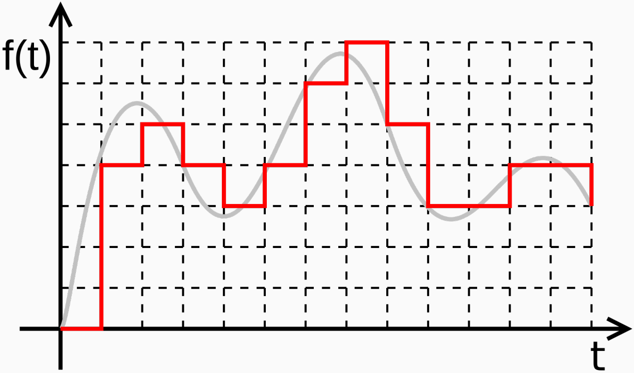

Figure 2: Analog and digital signal [4].

Definitions vii

- **Transmission** – the process of transmitting data between a transmitter and a receiver using a specific method that is understood by both sides. In addition, it follows a specified track - in this case the transmission medium
- **Transmission medium** – an information medium used for the transmission of signals in telecommunications. The parameters of the medium used affect its capabilities and applications. The two main groups are wired and wireless media

Definitions viii

- **Telecommunication** – the discipline concerned with the transmission of information over a distance, defining ways of processing and encoding information. It also includes issues of telecommunications networks, radio wave propagation or telecommunications equipment

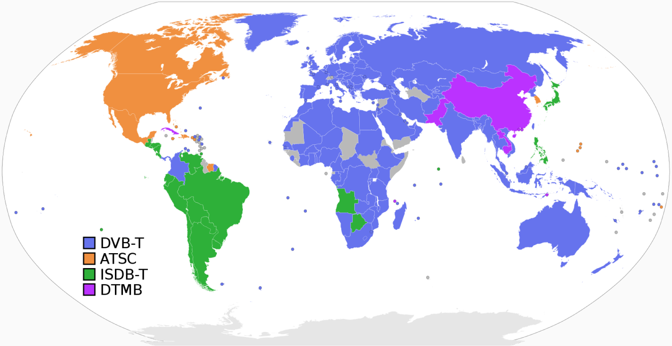

Figure 3: Types of television telecommunications used in the world [6].

Data transmission

Data transmission i

- A communication channel allows the transmission of data between two participants of a set connection
- The division of the medium according to the type of transmission used:
  - Wired - based on solutions using optical cables or copper wires
  - Wireless - uses radio or light waves for transmission

Data transmission ii

- Transmission can be divided by the nature of the data transmitted:
    - Simplex – in single direction
    - Half-duplex – bi-directional non-simultaneous
    - Full-duplex – bi-directional simultaneous

Communication track

Communication track i

- The operation of the transmission system is carried out by:
  - Transmitter - on the sender side, responsible for coding, modulation, signal amplification
  - Physical transmission channel
  - Receiver - at the receiver side, responsible for amplification, demodulation and decoding of the signal in order to reproduce the original message
- It should be remembered that during signal transmission, the message is susceptible to distortions from the external environment (noise, interference)

Communication track ii

Simplified scheme of the communication path, including elements occurring during data transmission

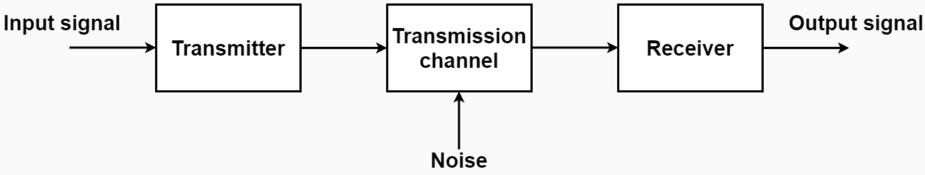

Figure 4: Scheme of the communication path.

Radio waves

Radio waves i

- **Radio waves** – or electromagnetic waves - this phenomenon consists in the propagation of a disturbance of an electric field and an associated magnetic field
- The occurrence of radio waves can be observed in a vacuum or in any other medium

Radio waves ii

Type	Length	Frequency
Radio waves	30 km	10 kHz
Microwaves	30 cm	1 GHz
Infrared	1 mm	300 GHz
Visible light	750 nm	400 THz
Ultraviolet	430 nm	700 THz
Rentgen	10 nm	30 PHz
Gamma	10 pm	30 EHz

Table 1: Frequencies of electromagnetic waves.

Radio waves iii

Band	Frequency	Wavelength
ELF	3 - 30 Hz	100,000 - 10,00 km
SLF	30 - 300 Hz	10,000 - 1,000 km
ULF	0.3 - 3 kHz	1,000 - 100 km
VLF	3 - 30 kHz	100 - 10 km
LF	30 - 300 kHz	10 - 1 km
MF	300 - 3000 kHz	1000 - 100 m

Table 2: Frequency dependency

Radio waves iv

Band	Frequency	Wavelength
HF	3 - 30 MHz	100 - 10 m
VHF	30 - 300 MHz	10 - 1 m
UHF	300 - 3000 MHz	100 - 10 cm
SHF	3 - 30 GHz	10 - 1 cm
EHF	30 - 300 GHz	10 - 1 mm
THF	0,3 - 3 THz	1 - 0.1 mm

Table 3: Frequency dependency

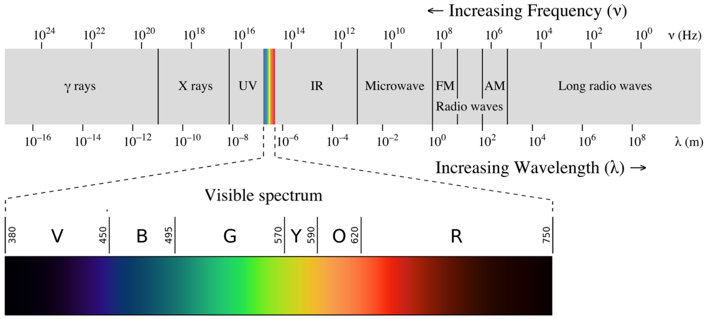

Figure 5: Electromagnetic spectrum of visible light [7].

Radio waves vi

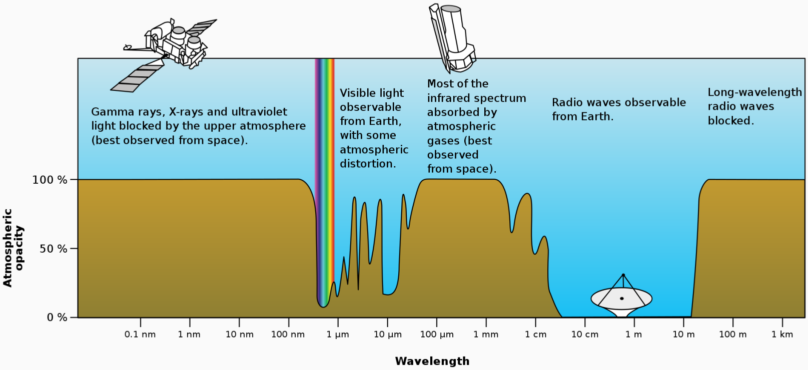

Figure 6: Absorption and scattering diagram of waves [7].

Radio wave properties i

- **Wavelength** – is the minimum distance between two points of the same vibration phase

$$\lambda = c \cdot T \tag{3}$$

- where
    - λ - wavelength [m]
    - c - speed of light (299 792 458 $\frac{m}{s}$)
    - T - oscillation period [s]

Radio wave properties ii

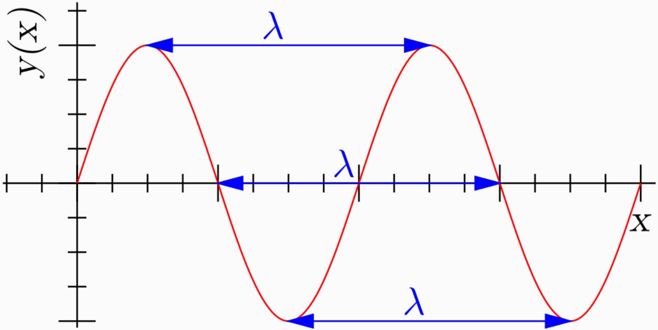

Figure 7: Wavelength [1].

Radio wave properties iii

- **Wave frequency** – specifies the number of complete changes of electric and magnetic field per second, it is expressed in Hertz.

$$f = \frac{1}{T} \tag{4}$$

- where
  - f - frequency [Hz]
  - T - oscillation period [s]

Radio wave properties iv

- **Oscillation period** – time required for the same wave phase to return

$$T = \frac{1}{f} \tag{5}$$

- where
    - T - oscillation period [s]
    - f - frequency [Hz]

Radio wave applications i

- Electromagnetic waves
    - Ultraviolet
    - Infrared
    - Visible light
    - Radio frequencies
- Sound waves
- Satellite signals
- Wireless communication in the frequency range 3 Hz to 3 THz

Radio wave applications ii

Transmission using radio waves:

- Embedded systems
  - Distributed
    - A collection of independent devices combined into one logical whole
    - The main elements are usually computers and automation systems
    - Devices equipped with software that shares system resources
    - Interconnection between devices through computer networks
  - Remote controlled
    - Operation is based on controlling the unit from a physically remote location
    - Controller and executive unit with transmitter and receiver
    - Often used for toys, drones, cameras

Radio wave applications iii

- GSM mobile communications
- WLAN (Wireless Local Area Network)
- Short-range wireless communication
- WWAN (Wireless Wide Area Network) – range from 100 metres to several kilometres

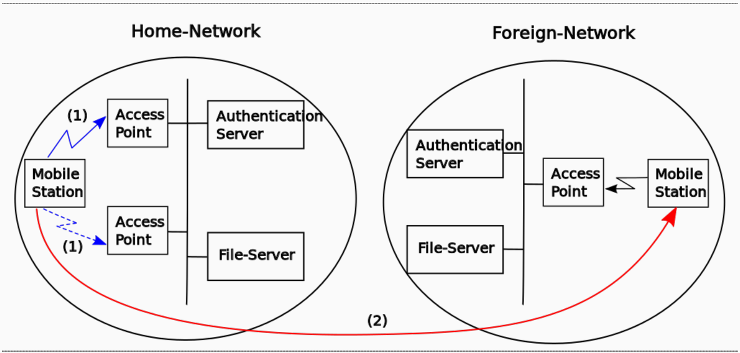

Figure 8: Signal transmission in WLAN [3].

Radio wave applications v

Types of frequencies used

- Microwaves > 300 MHz
- Ultra-short 30 -300 MHz
- Short 3 – 30 MHz
- Intermediate 1.5 – 3 MHz
- Medium 100 – 1500 kHz
- Long 15 – 100 kHz
- Ultra-long < 15 kHz

Radio wave applications vi

Band **2.4 GHz** is used by many devices, one of the most popular frequencies

- Bluetooth
- Wi-Fi
- Microwave ovens
- Video cameras
- Monitoring devices
- Smartphones

Advantages and disadvantages of wireless communication

Advantages and disadvantages of wireless communication i

Disadvantages

- Bandwidth constraints
- Susceptibility to interference
- Dependent on weather conditions
- Safety
- The bands used are often shared

Advantages

- Flexibility
- Mobility
- No physical transmission medium cable

Bluetooth

Bluetooth i

Infrared

- The standard covers data transmission over a distance of < 1 meter
- Three types of transmission
  - AIR – enables multi-user connection, transmission speed depends on the distance of transmitted data
  - IrDA-D – standard for data transmission, available speeds from 115 kbps to 4Mbps
  - IrDA-C – bi-directional, allows transmission of control commands and signals, used in peripheral devices

Bluetooth

- Allows wireless connection of peripheral devices to mobile phones and computers
- Technology designed primarily for short-distance communication
- Low production costs
- Standard described in specification IEEE 802.15.1
- Uses radio waves in the 2.4 GHz ISM frequency band

Bluetooth iii

Sources

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Thanks for your attention ☺