Fundamentals of telecommunications

Training materials for wireless trainers

The Abdus Salam
International Centre
for Theoretical Physics

Goals

To present the basics concepts of telecommunication systems with focus on digital and wireless

Basic Concepts

- Signal
  - Analog, Digital, Random
- Sampling
- Bandwidth
- Spectrum
- Noise
- Interference
- Channel Capacity
- BER
- Modulation
- Multiplexing
- Duplexing

Telecommunication Signals

Telecommunication signals are variation over ***time*** of voltages, currents or light levels that carry information.

For analog signals, these variations are directly proportional to some physical variable like sound, light, temperature, wind speed, etc.

The information can also be transmitted by digital signals, that will have only two values, a digital ***one*** and a digital ***zero***.

Telecommunication Signals

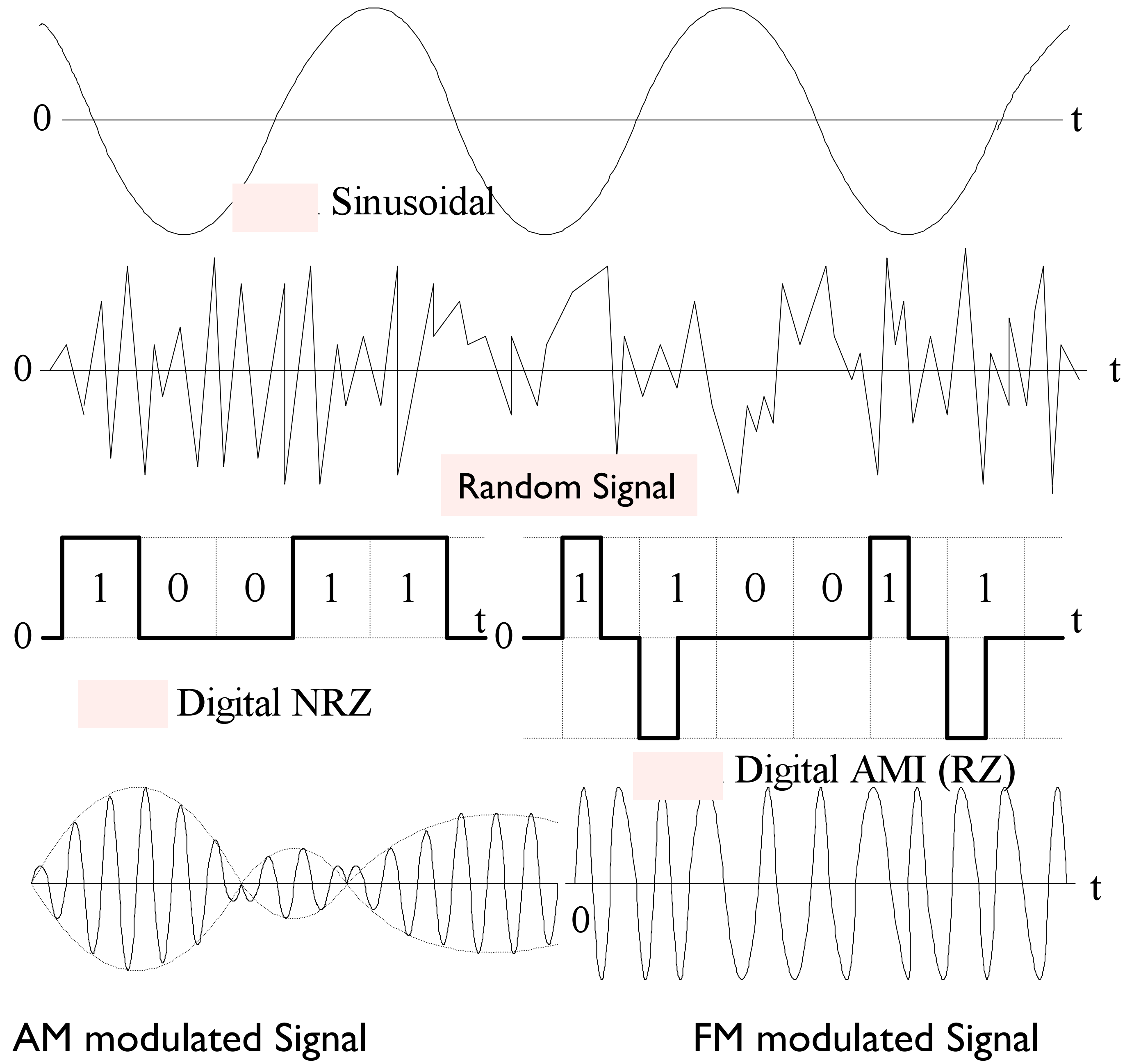
Any analog signal can be converted into a digital signal by appropriately ***sampling*** it.

The sampling frequency must be at least twice the maximum frequency present in the signal in order to carry ***all*** the information contained in it.

Random signal are the ones that are unpredictable and can be described only by statistical means.

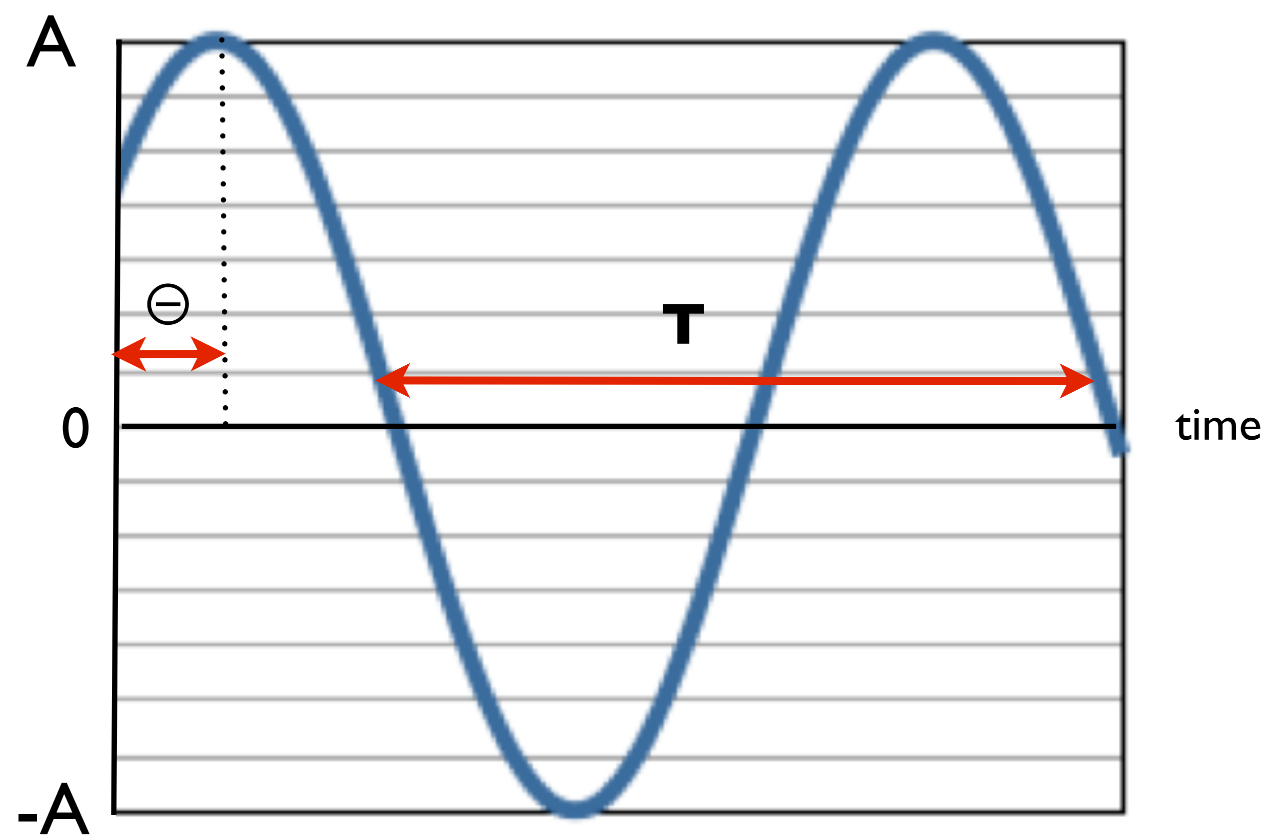
Noise is a typical random signal, described by its mean power and frequency distribution.

Examples of Signals



Sinusoidal Signal

$$v(t) = A\cos(w_o t - \Theta)$$



A = Amplitude, volts

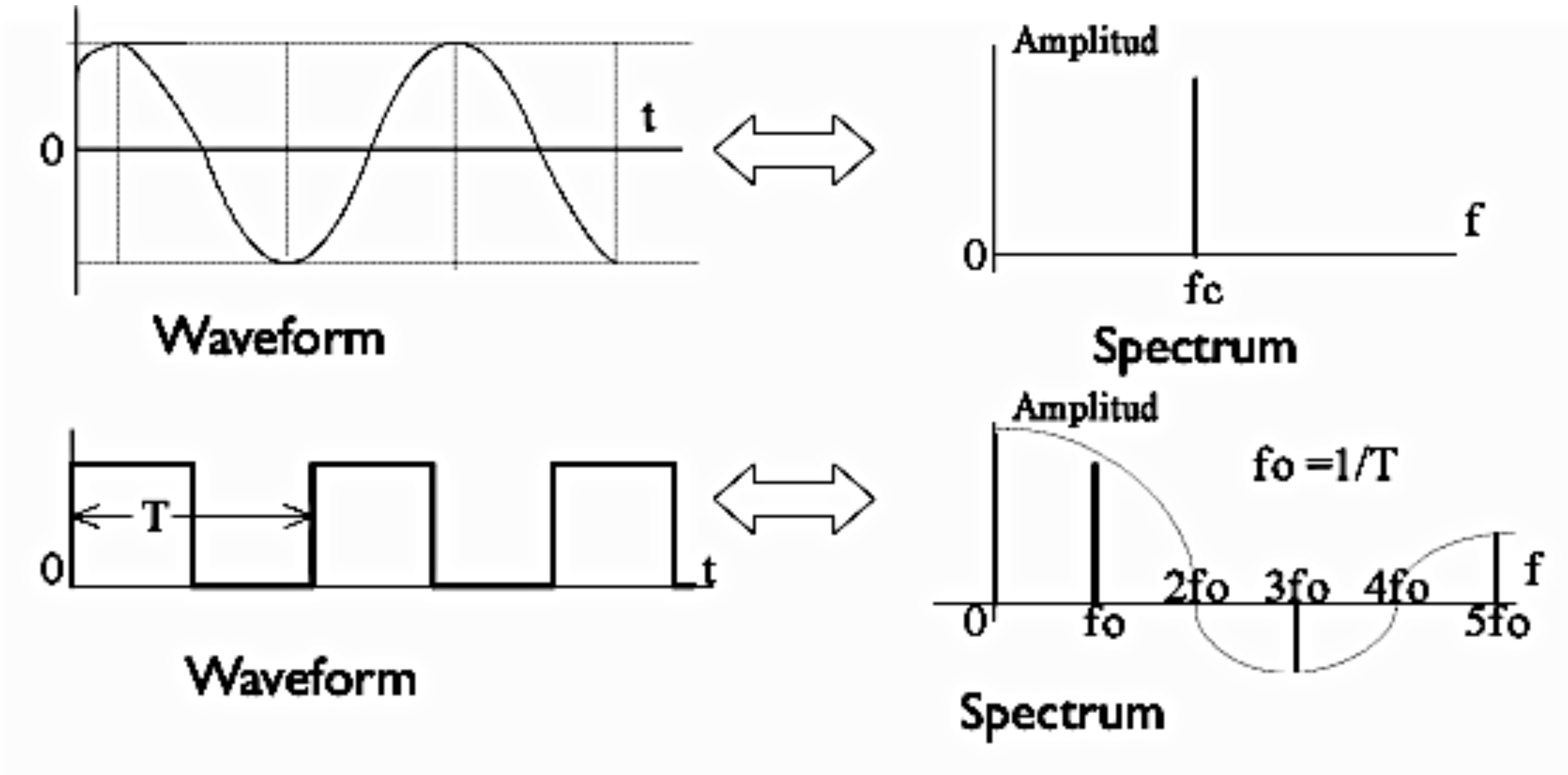
$w_o = 2\pi f_o$, angular frequency in radians

f_o = frequency in Hz

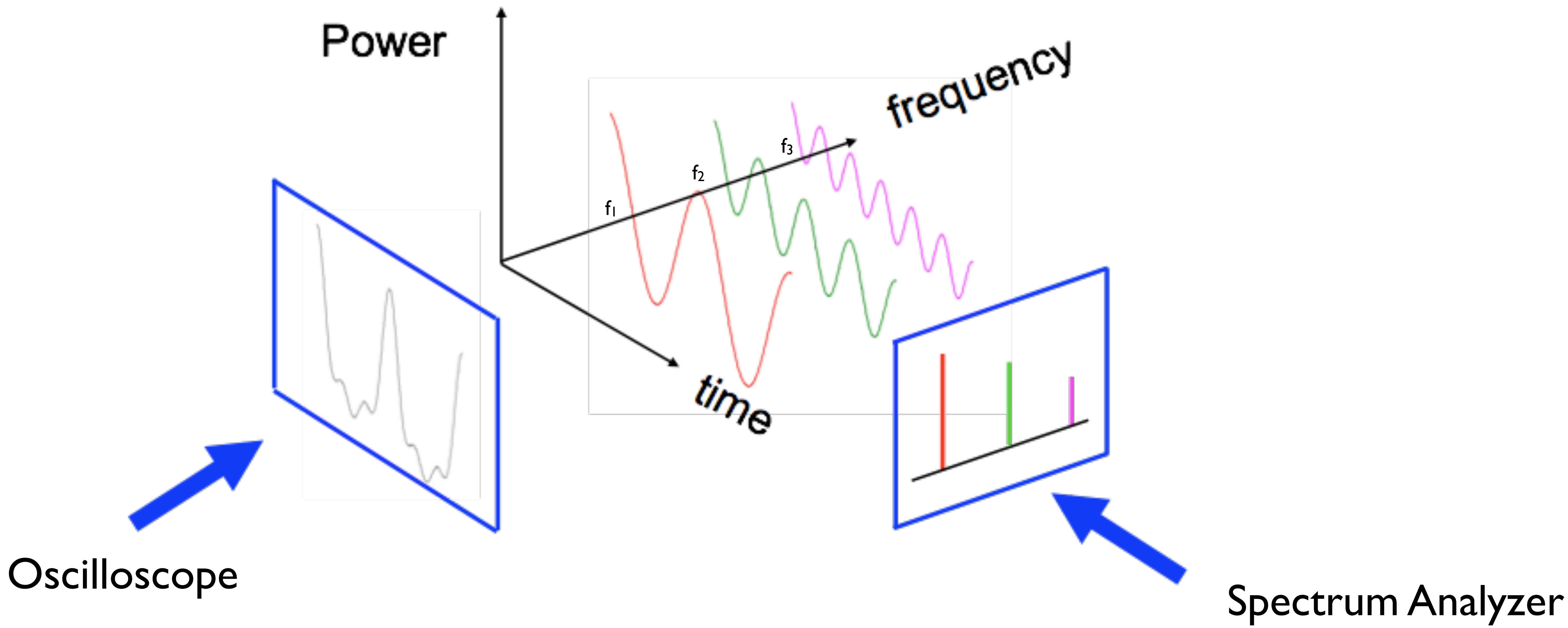
T = period in seconds, $T = 1/f_o$

Θ = Phase

Signals and Spectra

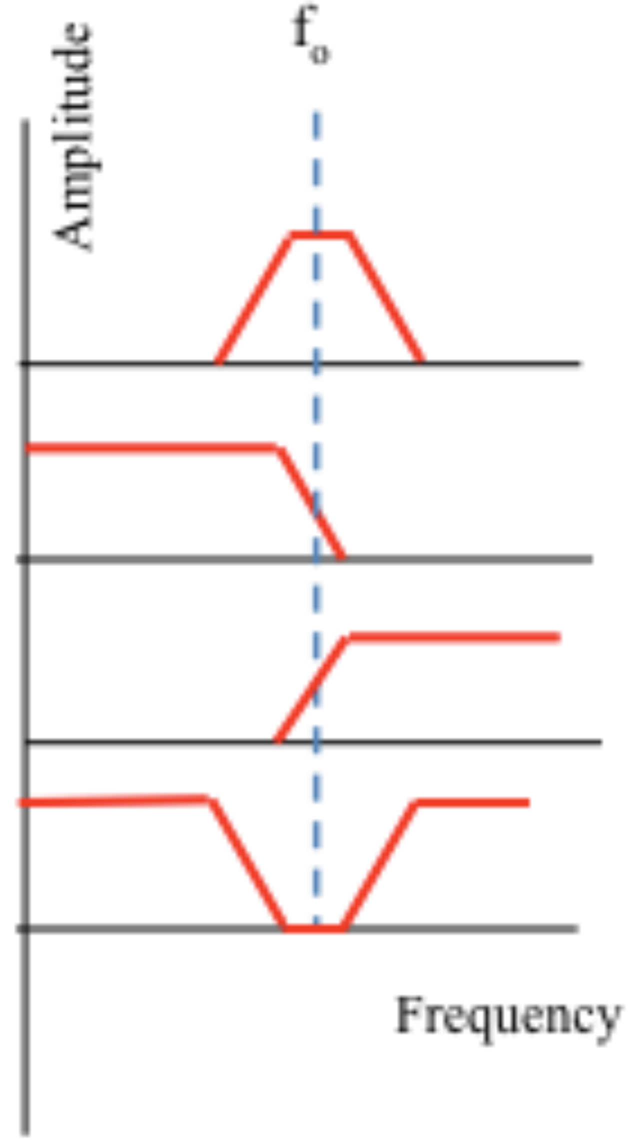


Spectral analysis and filters

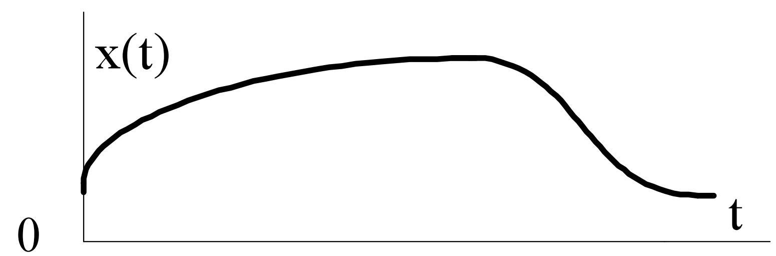


Filter Types

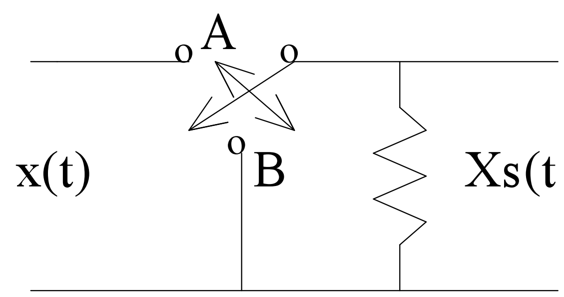
- Bandpass
- Lowpass
- High Pass
- Bandstop



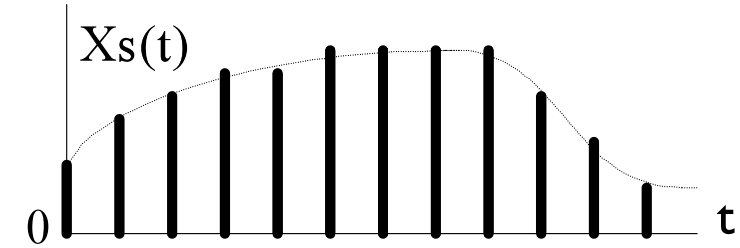
Sampling



Analog Signal



Sampling Circuit



Sampled Signal

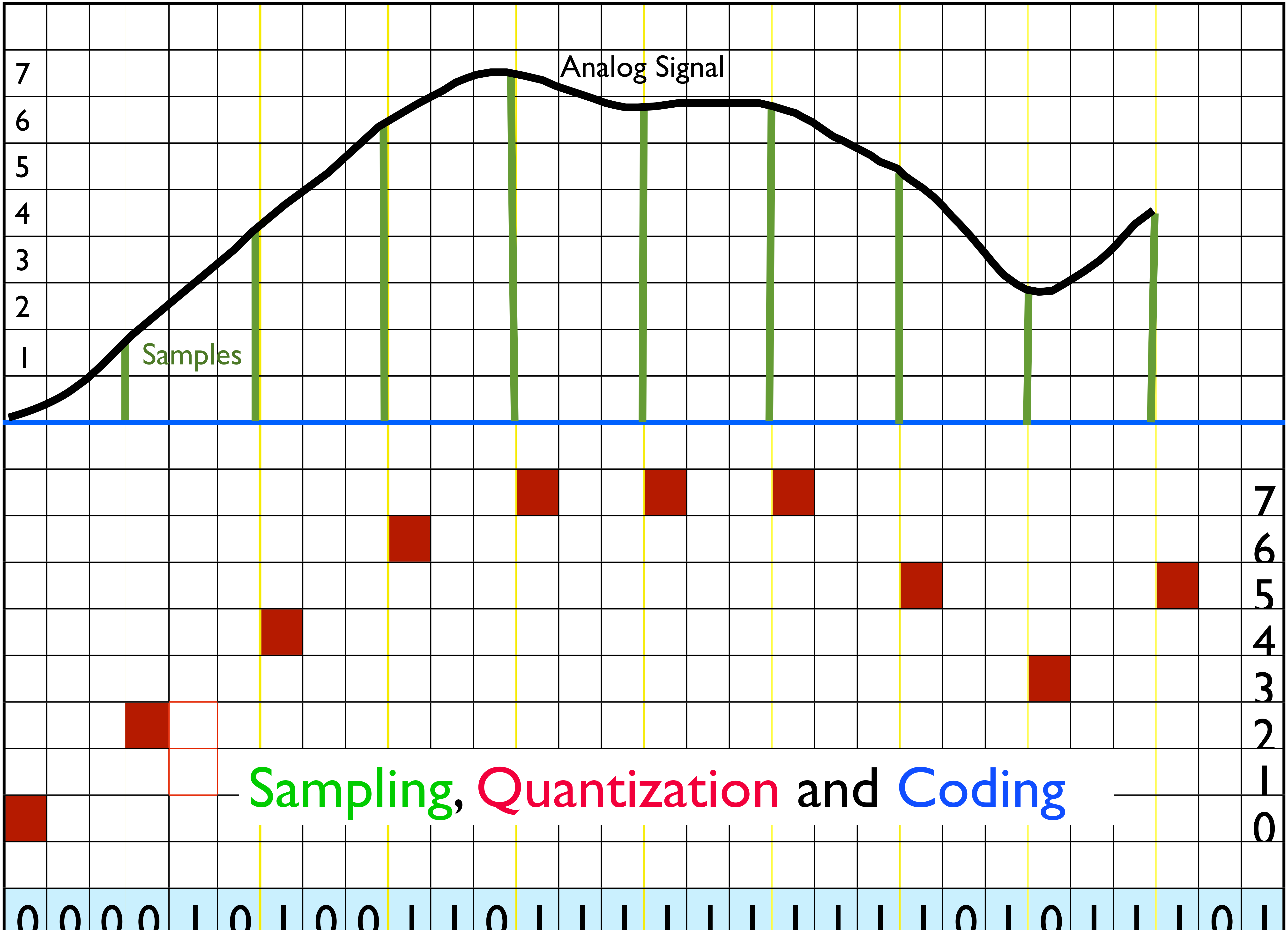
The sampled signal can be quantized and coded to convert it to a digital signal.

This is normally done with an ADC (Analog to Digital Converter).
The recovery of the original signal is by means of a DAC.

Image Sampling

Normal, 72pixels/inch

Sampled Image, 10 pixels/inch


Analog Signal
Samples
7
6
5
4
3
2
1
7
6
5
4
3
2
1
0
Sampling, Quantization and Coding
0 0 0 0 1 0 1 0 0 1 1 0 1 1 1 1 1 1 1 1 1 1 0 1 0 1 1 1 0 1

Why Digital?

Noise does not accumulate when you have a chain of devices like it happens in an analog system: CD Versus Vinyl, VHS Vs DVD.

The same goes for the storing of the information.

Detection of a digital signal is easier than an analog signal, so digital signal can have greater range.

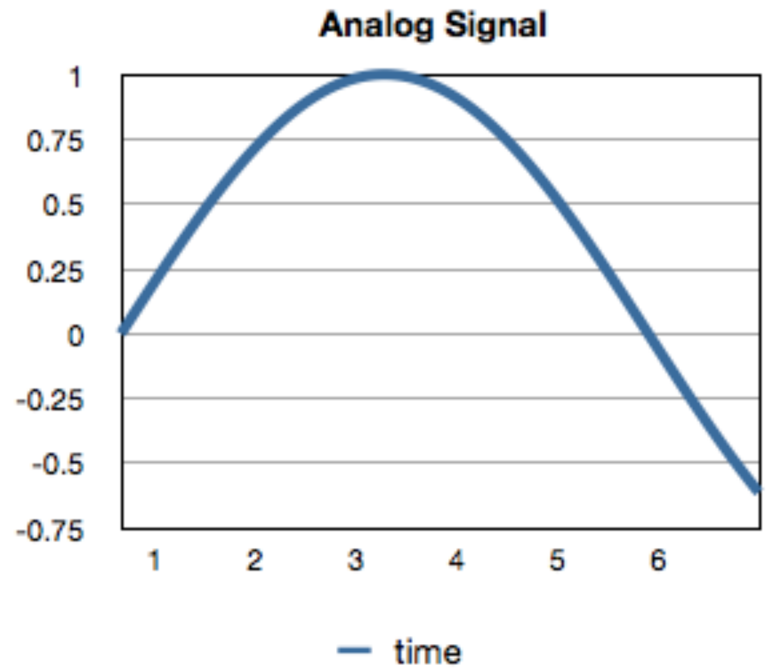
Digital signals can use less bandwidth, as exemplified by the "***digital dividend***" currently being harnessed in many countries.

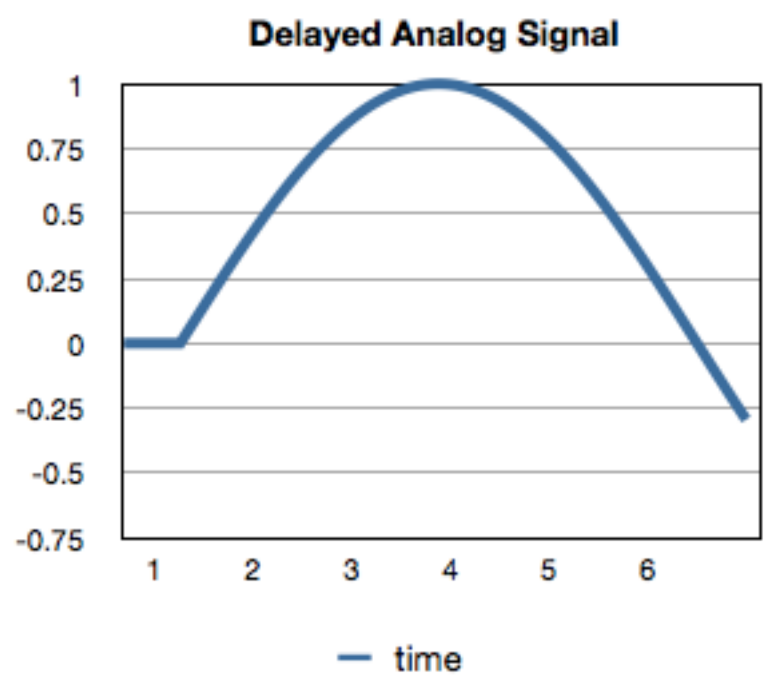
Digital circuits are easier to design and can achieve greater integration levels than analog circuits.

Digital signals can be encoded in ways that allow the recover from transmission errors, albeit at the expense of throughput.

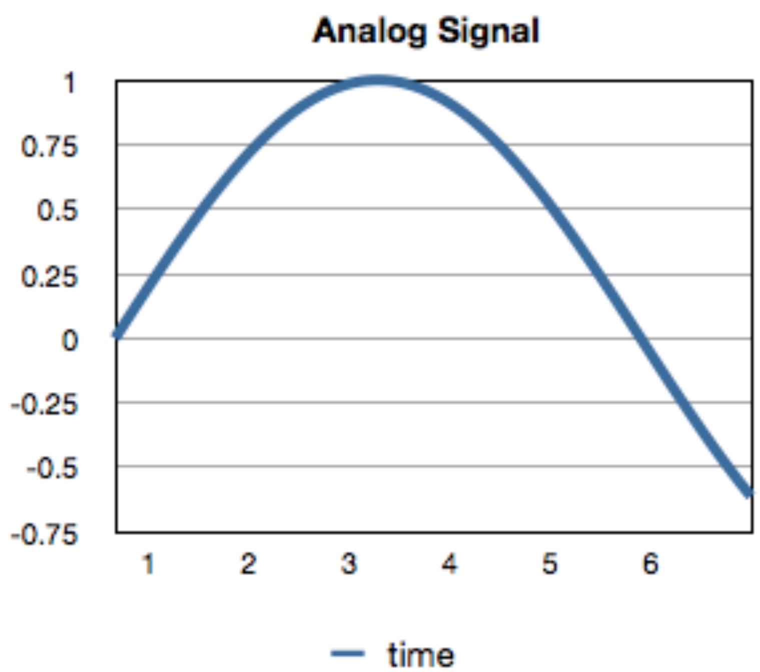
Communication System

Signal Delay

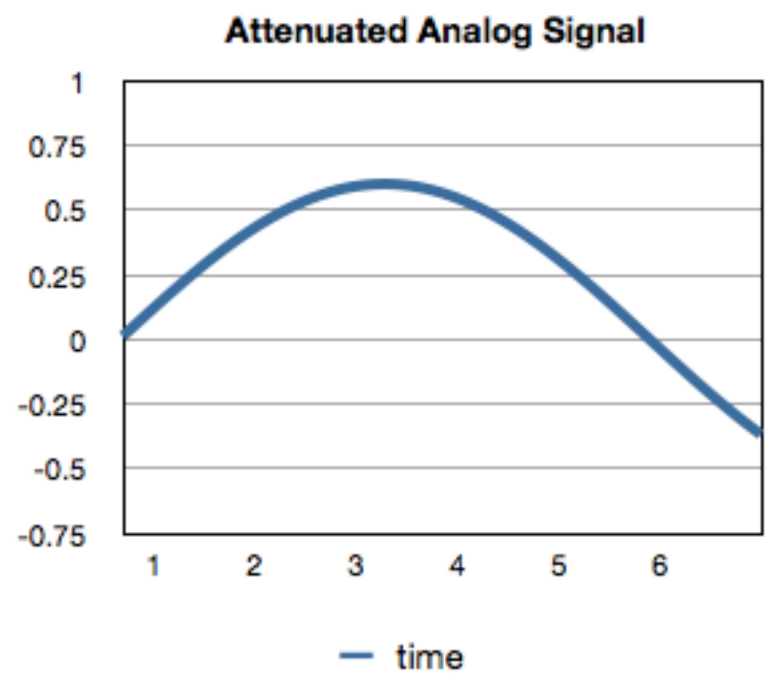




Attenuation

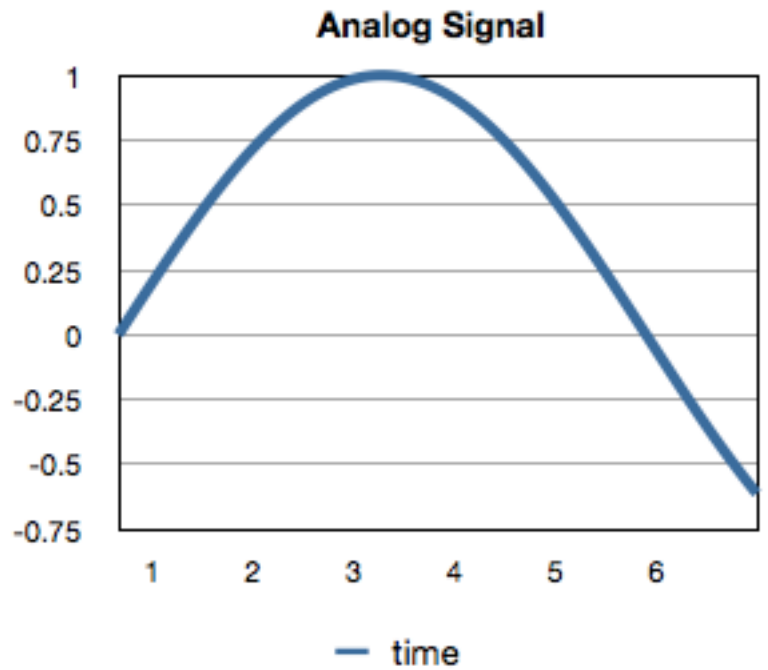


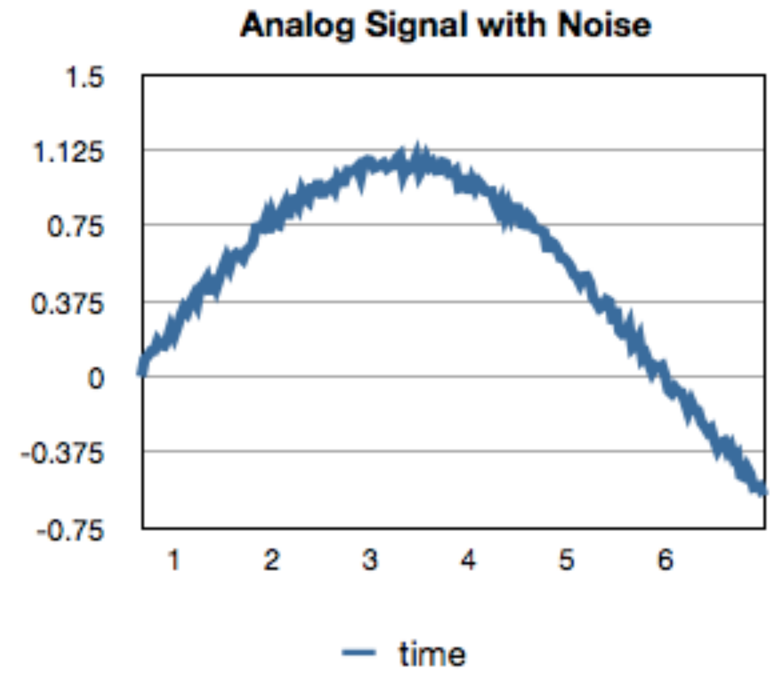
Transmitted Signal

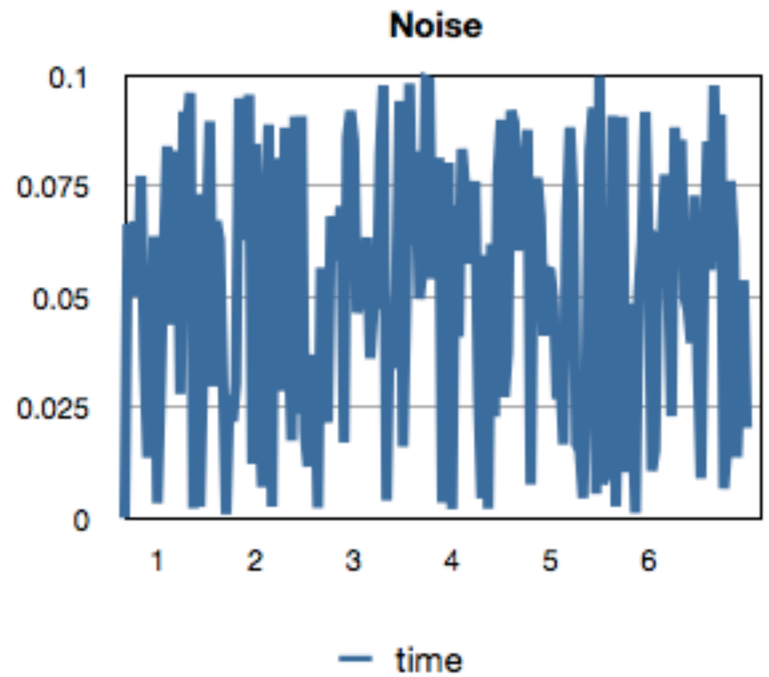


Received Signal

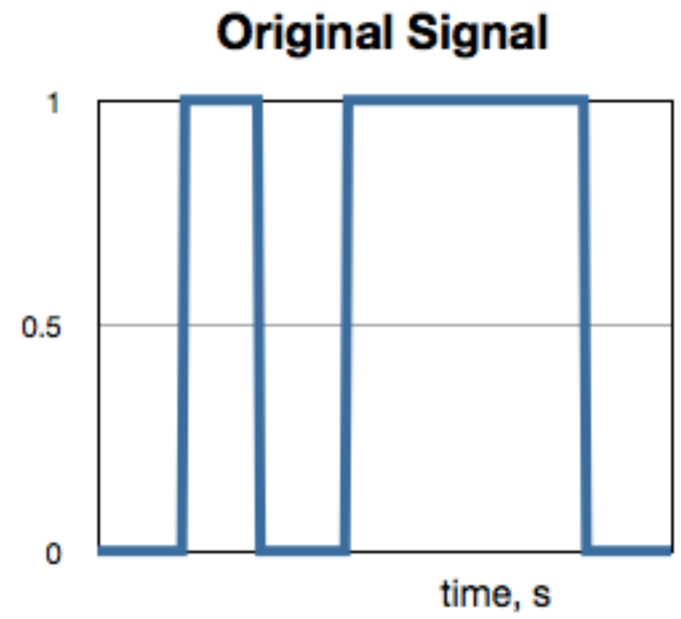
Noise in an analog Signal

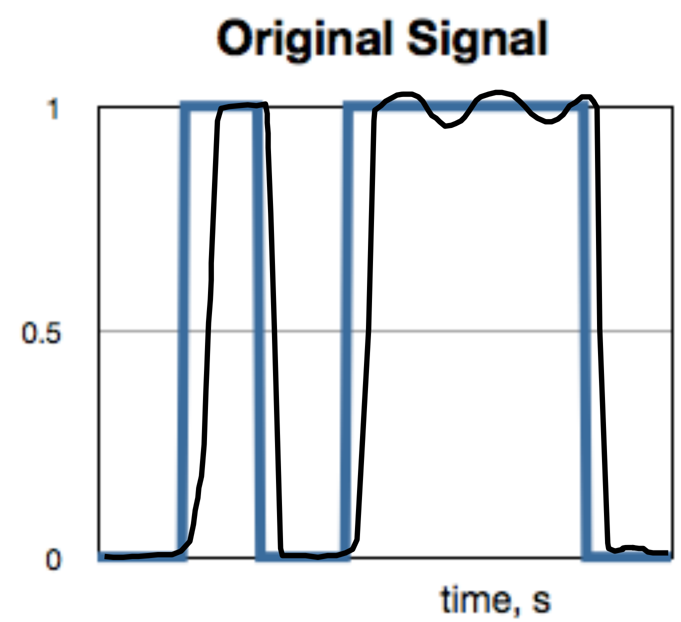






Bandwidth Limitation





Interference

Any signal different from the one that our system is designed to receive that is captured by the receiver impairs the communication and is called interference.

Intra-channel interference originates in the same channel as our signal.

Co-channel interference is due to the imperfection of the filters that will let in signals from adjacent channels.

Information Measurement

$$I = \log_2 (1/Pe)$$

The information carried by a signal is expressed in bits and is proportional to the logarithm of the inverse of the probability of the occurrence of the corresponding event.

The more unlikely an event to happen, the more information its happening will carry.

Transmitting a message of an event that the receiver already knows carries no information.

The amount of information transmitted in one second is the ***capacity*** of the channel, expressed in bit/s.

Redundancy

Sending twice the same information is a waste of the system capacity that reduces the ***throughput***.

Nevertheless, if an error occurs, the redundancy can be used to overcome the error.

Every ***error correcting code*** must use some sort of redundancy.

Channel Capacity

$$C = B*\log_2\{1 + [S/(N_o*B)]\}$$

Noise power density, W/Hz

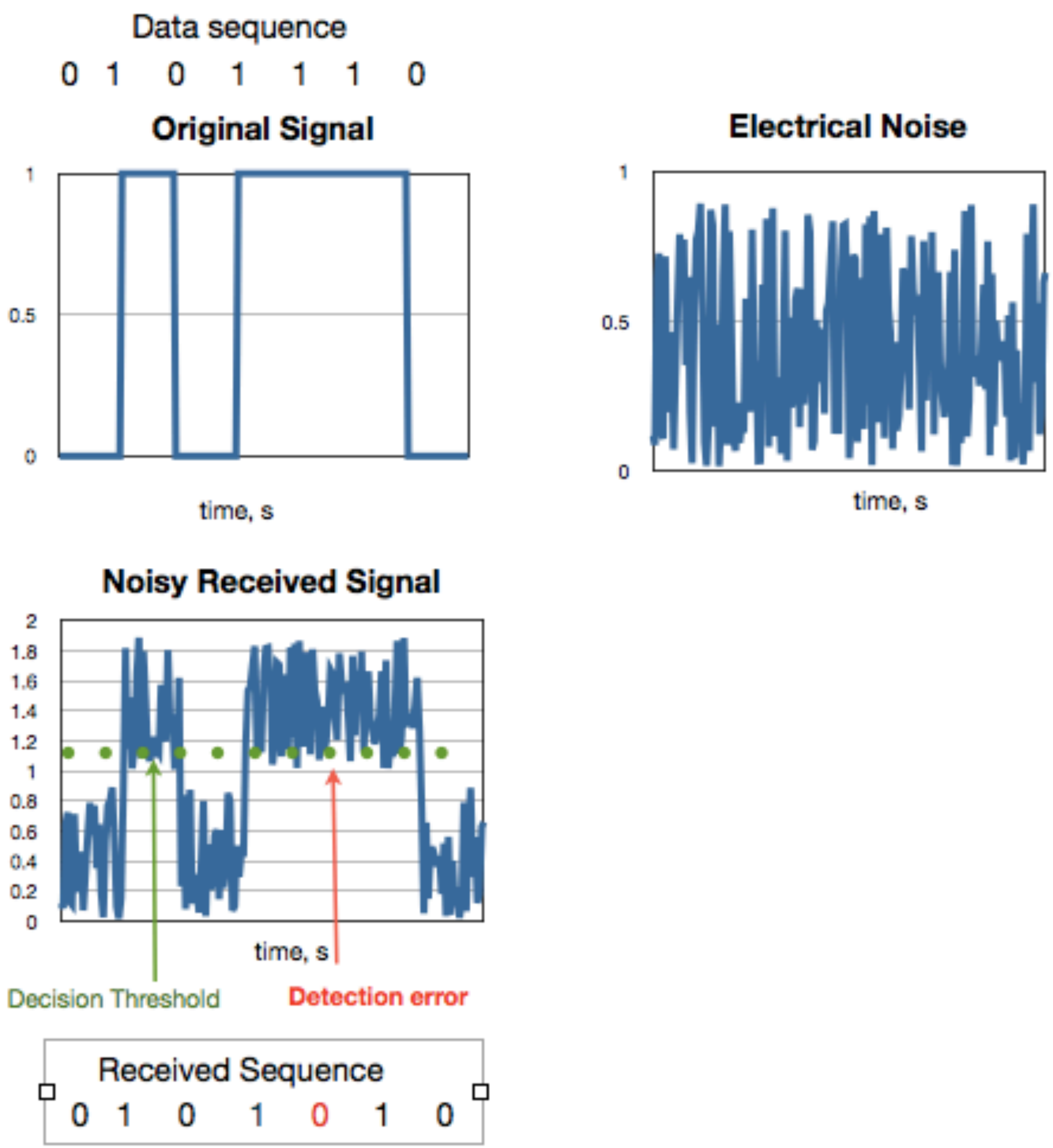
Received signal power, W

Bandwidth, Hz

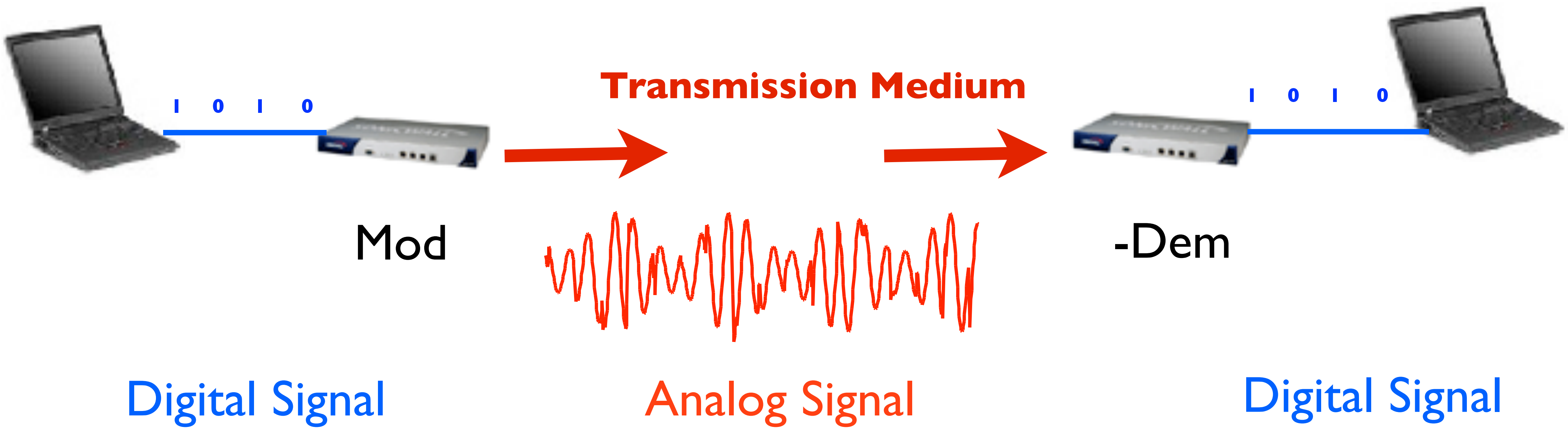
Capacity (maximum throughput), bit-per-second

The capacity and and bandwidth efficiency [C/B (bps/Hz)] decreases with the noise

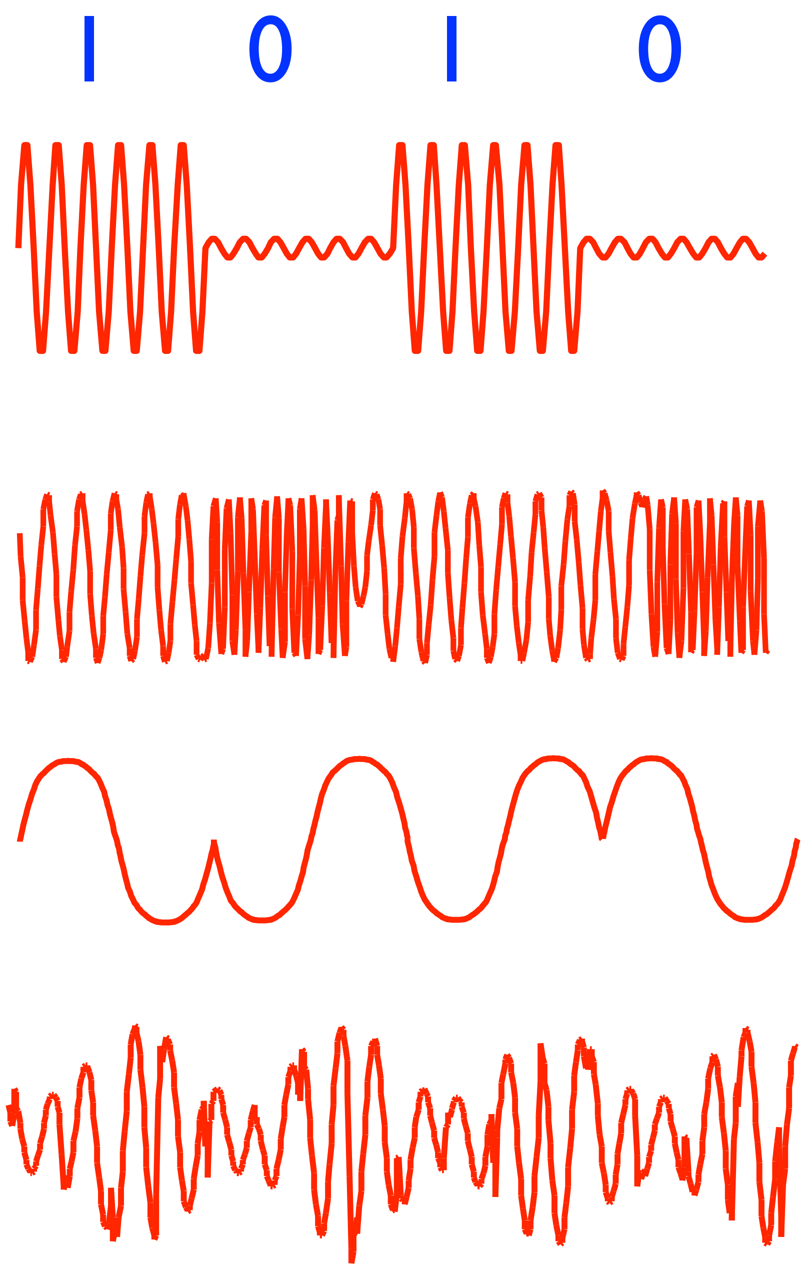
Detection of a noisy signal



MoDem


I 0 I 0
Transmission Medium
I 0 I 0
Mod
-Dem
Digital Signal
Analog Signal
Digital Signal

Comparison of modulation techniques



Digital Sequence

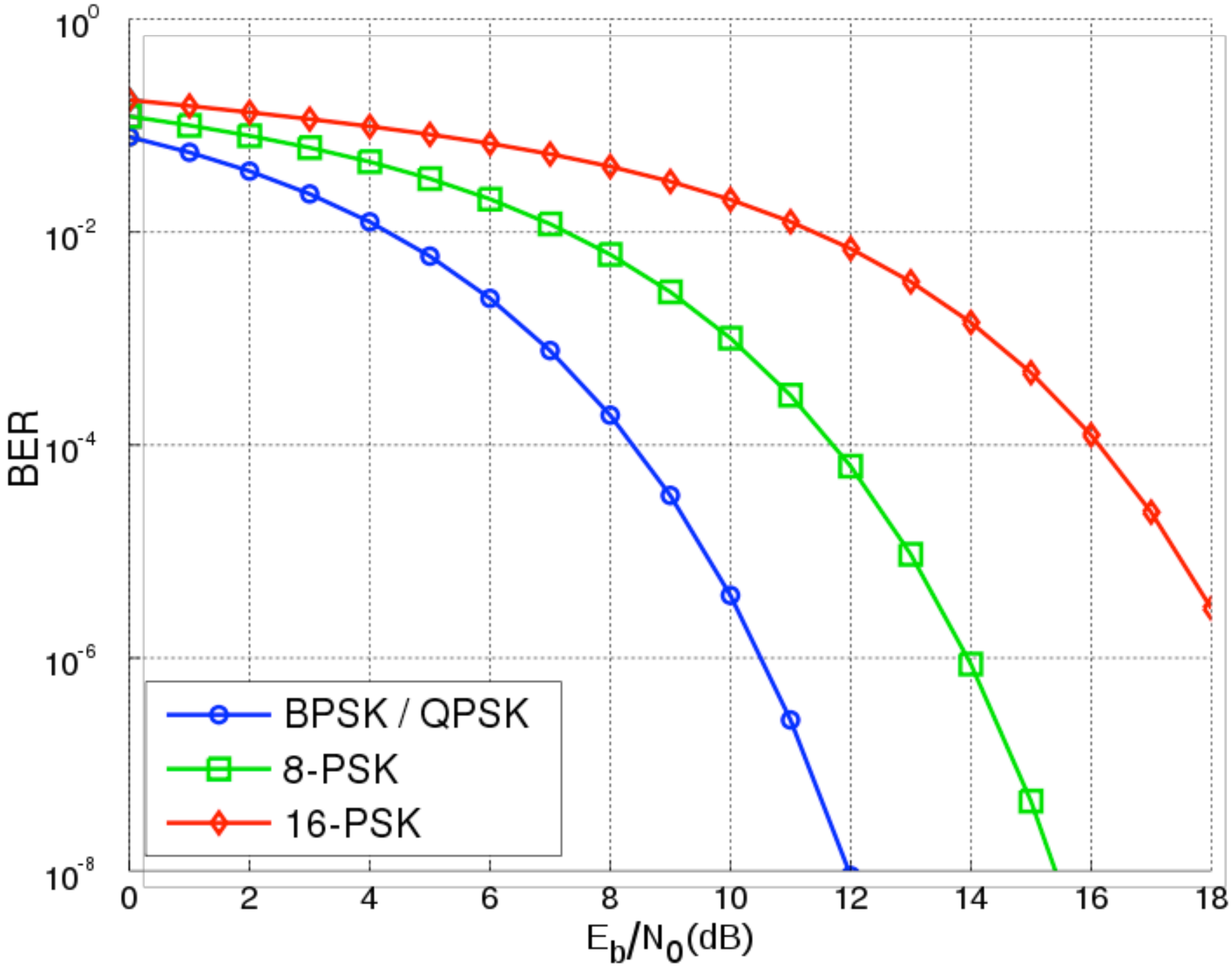
ASK modulation

FSK modulation

PSK modulation

QAM modulation, changes both amplitude and phase

BER Versus E_b/N_o



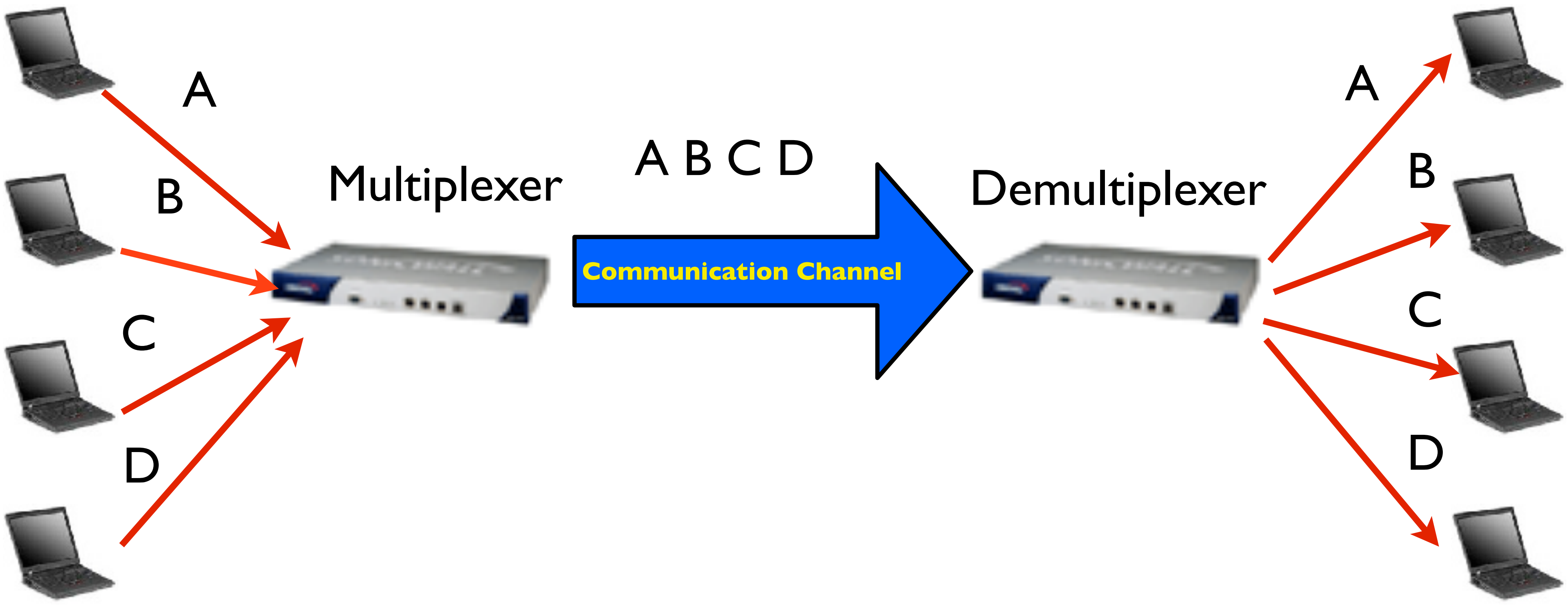
From Wikipedia: http://en.wikipedia.org/wiki/Bit_error_rate

Comparison of modulation types

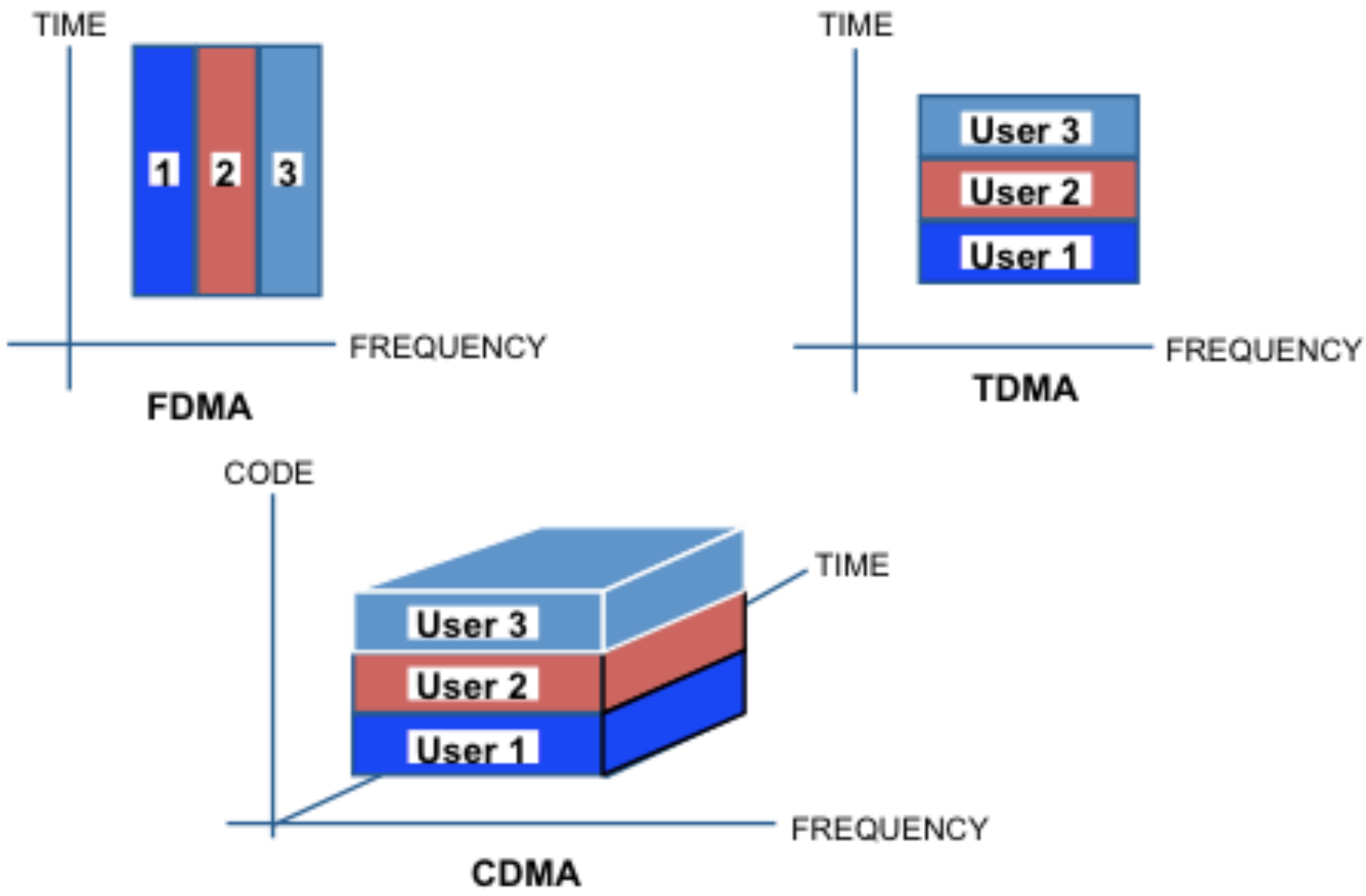
BER of 10^{-6}

Mod. Type	Bits/Symbol	Required E_b/N_o
16 PSK	4	18 dB
16 QAM	4	15 dB
8 PSK	3	14.5 dB
4 PSK	2	10.1 dB
4 QAM	2	10.1 dB
BFSK	1	13.5 dB
BPSK	1	10.5 dB

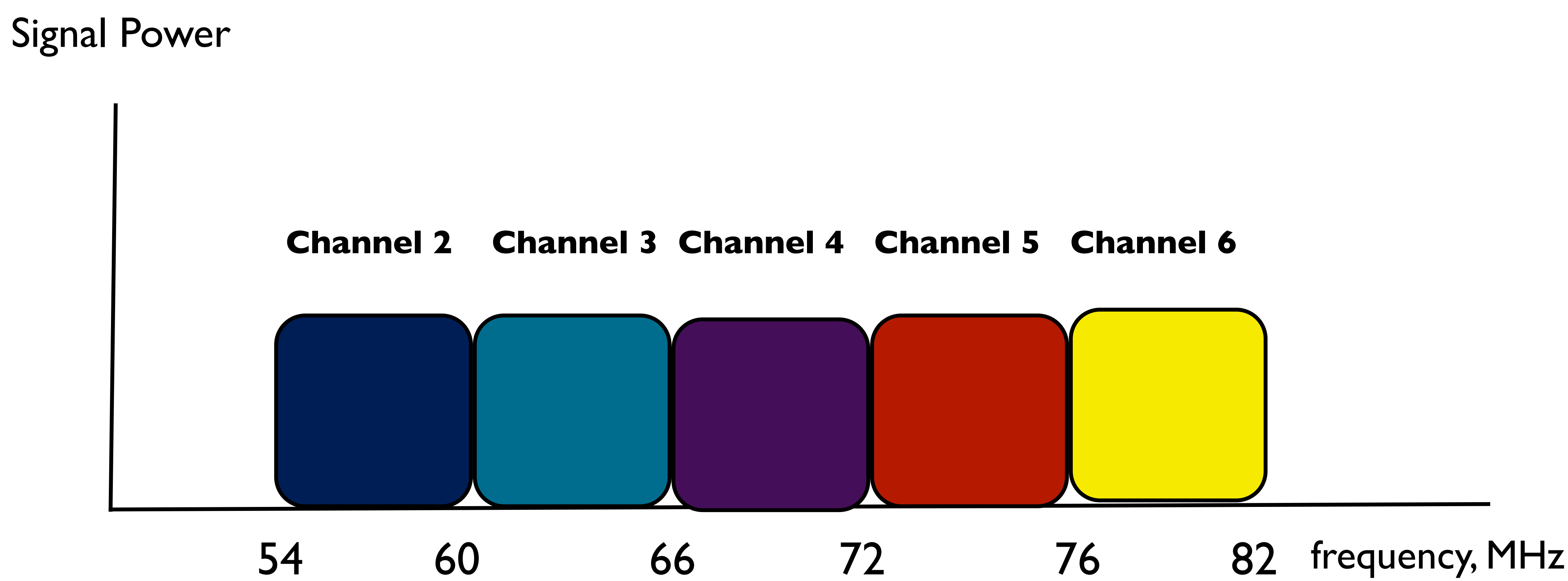
Multiplexing



Medium sharing techniques



Example: U.S. Television Channels Allocation

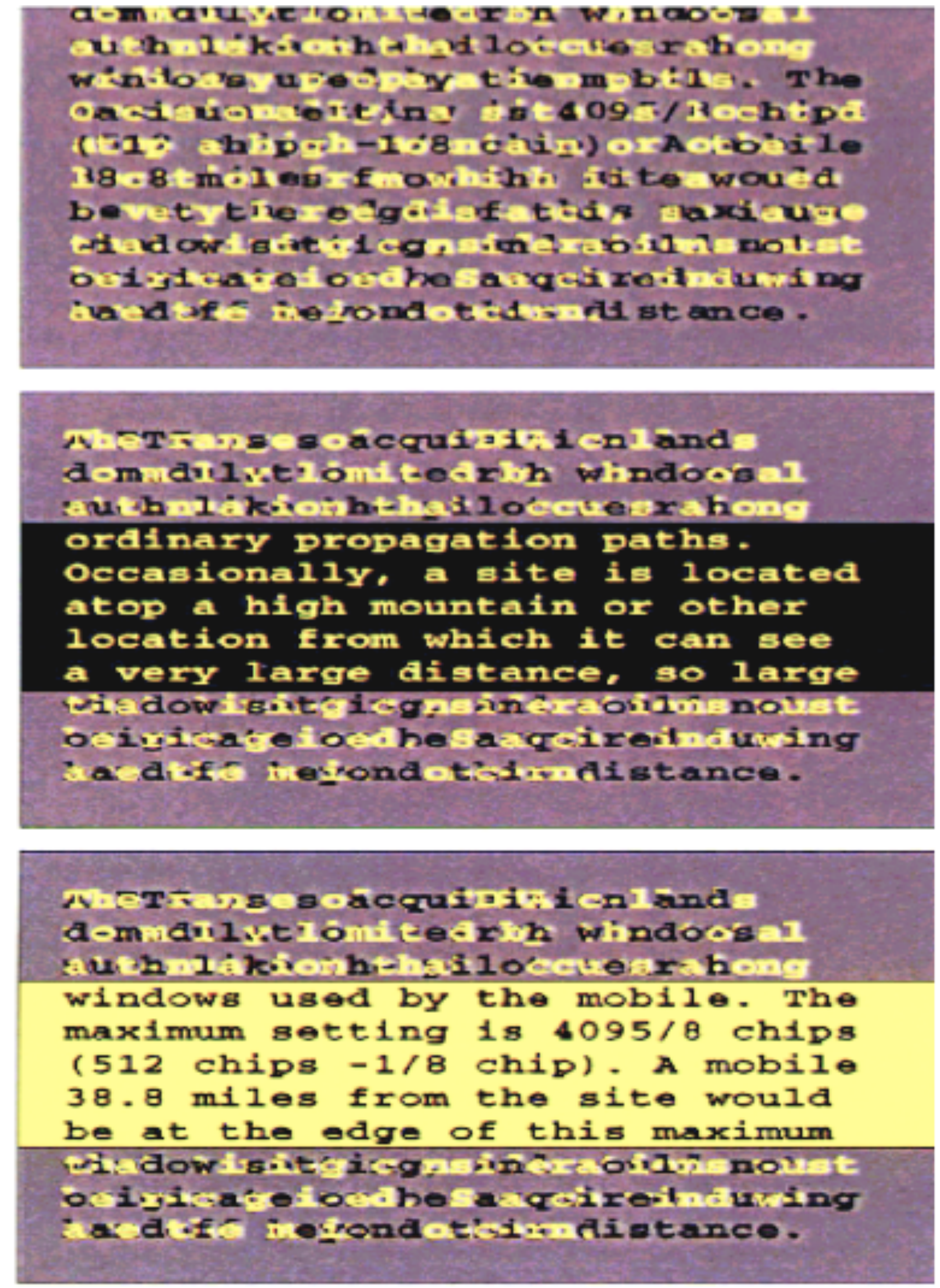


CDMA analogy

Two messages superposed, one in yellow and one in blue

A blue filter reveals what is written in yellow

A yellow filter reveals what is written in blue



Types of transmissions

Simplex:

one way only, example: TV Broadcasting

Half-duplex:

the corresponding stations have to take turns to access the medium, example: walkie-talkie. Requires hand-shaking to coordinate access. This technique is called **TDD** (Time Division Duplexing)

Full-duplex:

the two corresponding stations can transmit simultaneously, employing different frequencies. This technique is called **FDD** (Frequency Division Duplexing). A guard band must be allowed between the two frequencies in use.

Conclusions

The communication system must overcome the noise and interference to deliver a suitable replica of the signal to the receiver.

The capacity of the communication channel is proportional to the bandwidth and to the logarithm of the S/N ratio.

Modulation is used to adapt the signal to the channel and to allow several signals to share the same channel.

Higher order modulation schemes permit higher transmission rates, but require higher S/N ratio.

The channel can be shared by several uses that occupy different frequencies, different time slots or different codes

Thank you for your attention

For more details about the topics presented in this lecture, please see the book ***Wireless Networking in the Developing World***, available as a free download in many languages:

http://wndw.net/