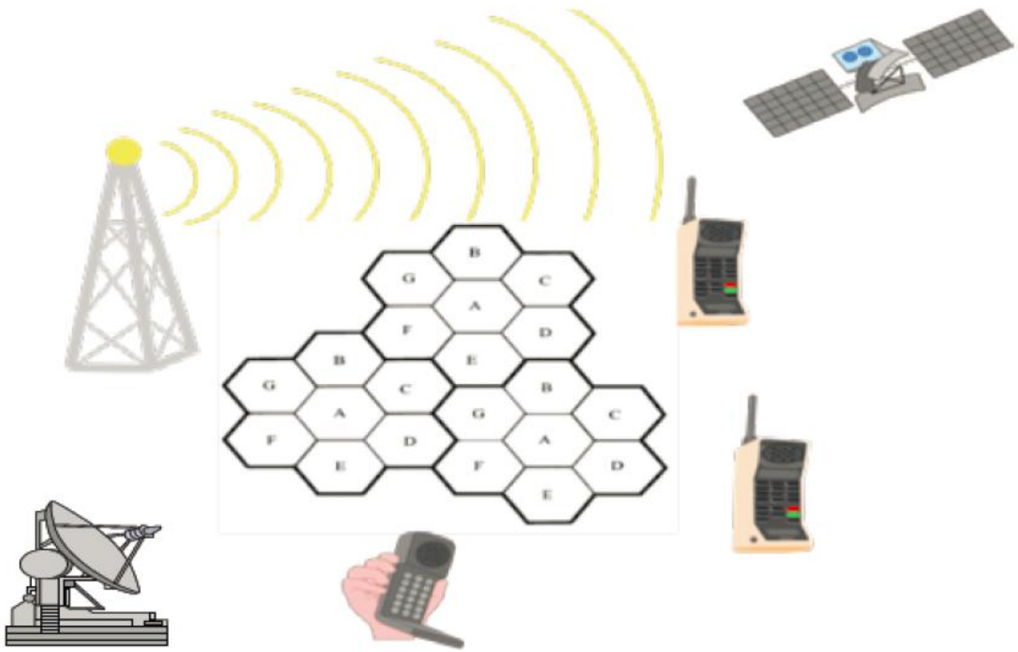
Principles of Communications



Prof. An Liu
College of ISEE, Zhejiang University

Who am I?

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ACADEMIC QUALIFICATIONS:

Peking University	2005. 09-2011. 01	Ph.D.
Peking University	2000. 09-2004. 06	B.S. – ranked 4st

CURRENT POSITION:

Professor, College of ISEE, Zhejiang University; Senior Member of IEEE

PREVIOUS RESEARCH EXPERIENCE:

2014. 01-2018. 02	HKUST	Research/Visiting Assistant Professor
2011. 03-2014. 01	HKUST	Postdoctoral Research Associate
2008. 10-2010. 10	University of Colorado, Boulder	Visiting Scholar

AREAS OF EXPERTISE:

- Emerging technologies for future wireless systems (Massive MIMO, mmWave communications, Heterogeneous ultra-dense networks)
- Stochastic optimization and its applications in signal processing and machine learning
- Compressive sensing for wireless communications
- Interference-aware edge caching

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PROFESSIONAL SERVICE:

Editor, IEEE Trans. Wireless Commun., IEEE Trans. Signal Processing and IEEE Wireless Commun. Lett.

IEEE Technical Program Committee and/or **Session Chairs** for the following conferences:

- IEEE International Conference on Communications (ICC)
- IEEE Global Telecommunications Conference (Globecom)
- IEEE Vehicular Technology Conference (VTC)
- IEEE Wireless Communications & Networking Conference (WCNC)
- IEEE Asia-Pacific Conference on Communications (APCC)

AWARDS:

- Natural Science Award of Higher Education of China (Second Class), Ministry of Education, China, 2018
- Thousand Youth Talent Award Recipient, 2017

SUMMARY OF CAREER TOTALS:

IEEE Journal Publications (60+); IEEE Conference Publications (50+); US Patents (1); China Patents (4); Books(1)

Necessary Background

It is assumed that students taking this course are familiar with the following topics:

- **Signal and Linear System Analysis**
  - ✓Signal Models
  - ✓Fourier Transform
  - ✓Signals and Linear Systems
  - ✓Sampling Theory
- **Noise and Stochastic Processes**
  - ✓Random Processes
  - ✓Correlation Functions and Power Spectra
  - ✓White Noise

Outline

- Overview of Communication Systems，2学时
- Deterministic Signal Analysis，3学时
- Random Signal Analysis，3学时
- Anolog Communications – Part I. Amplitude Modulation (AM)，5学时
- Anolog Communications – Part II. Frequency Modulation (FM)，5学时
- Analog-to-Digital (A-D) and Digital-to-Analog (D-A) Conversion，3学时
- Digital Modulation，5学时
- Digital Demodulation，5学时
- Signal Space Concepts and Geometric Representation of Signals，4学时
- Applications of Signal Space: M-ary Modulator and Optimal Detection，5学时
- MFSK Error Analysis，3学时
- MQAM Error Analysis，3学时
- Summary，2学时

Textbook and References

- **Textbook**
  - R. E. Ziemer and W. H. Tranter, *Principles of Communications: Systems*, *Modulation and Noise* (7th edition), John Wiley & Sons, 2014.
- **Reference books**
  - [R1] J. G. Proakis and M. Salehi, Communication Systems Engineering (2nd edition), Prentice Hall, 2002.
  - [R2]《通信原理教程》, 樊昌信
  - [R3] B. Sklar, Digital Communications: Fundamentals and Applications (2nd edition), Prentice Hall, 2001.
  - [R4] M. P. Fitz, Fundamentals of Communications Systems, McGraw Hill, 2007.

Course Notes

- Course notes are available from the web in pdf format:
- They will be posted at least 1 lecture in advance.
- Please print them out and have them ready for the lecture to make additional notes on.
- I will also make some hand written comments on the white board and you should also note these in your copies of the notes.

Assessment Weighting

The **final grade** will be determined as a weighted combination of the results as following:

Homework (5 at 3%)	15%
Midterm	20%
Group Project	15%
Final Exam	50%

*Participation includes class attendence and Q&A in class.

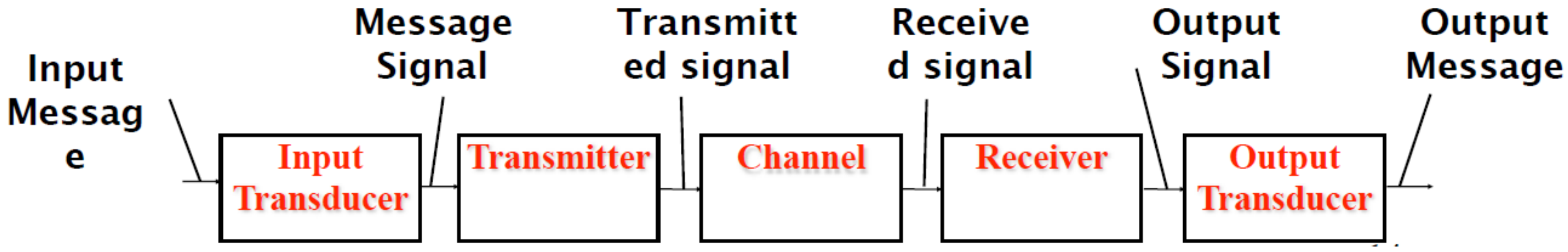
OVERVIEW

- **Nowadays communications is essential to all sectors of society**
- **From stock market to battlefield, fast and reliable information transmission is EXTREMELY IMPORTANT**
- **In this era of information technology, it is believed that the prosperity and continued development of modern nations will depend primarily on communications**
- **Digital communications is the basic and key workhorse behind the information age.**

Nature of Telecommunications

- From engineers' point of view, **Communications** involves the **transmission of information or messages** from one point to another.

- A block diagram of a typical communication system is shown below



Function of Each Block

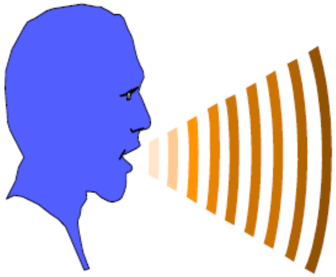
- The **transducer converts the original message into an appropriate electrical form - microphone, video camera, telegraph**;
- The **transmitter couples the electric message to the channel**
- The **channel medium carrying the message between the two points- twisted pair, coax, wireless or optical**.
- The **receiver extracts the original electric signal among many signals in the channel**.
- The **Output transducer recovers the message from the electric signal**.

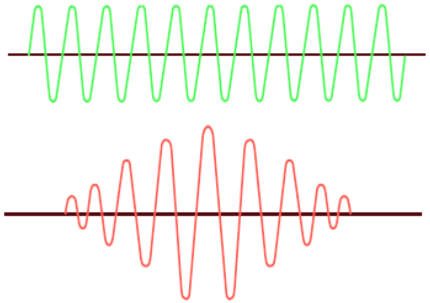
- No matter whether the communication system is for mobile telephones, pagers, TV or computers **these** 5 **components will always be present**.
- Some fundamental **operations** and **techniques** are always involved in each block.
- **Yet each specific communication system is unique** in its implementation and design.
- It's performance differs under different circumstances.

- **Understanding and analysis of these basic operations** is of fundamental importance in order to be able to analyze and design simple and/or state-of-the-art as well as complex communications systems
- The **goal** of this course is to **introduce the basic and fundamental knowledge** so that one can determine the advantages and weaknesses of different systems and to eventually design improved systems for a customer.
- **Emphasis** will be placed **on** the **theoretical basis** of modern communications.

Transmission Systems

- Analog Communications
  - Continuous modulation
  - Fidelity is usually defined in terms of SNR.
- Digital Communications
  - Signals made up of discrete symbols selected from a finite set (e.g., binary data).
  - Fidelity or Accuracy is specified in terms of bit error rate (Probability of making a bit error).





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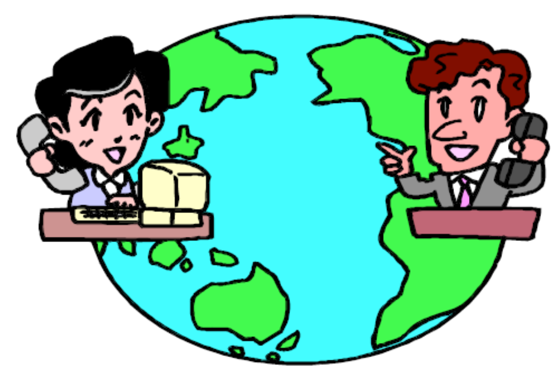
Transmission Protocols

- Simplex
  - Communication flow can only occur in one direction (e.g., typical courses at ZJU)
- Half Duplex
  - Communication flow can occur in both directions, but not at the same time
- Full Duplex
  - Communication link can support simultaneous two way communications.

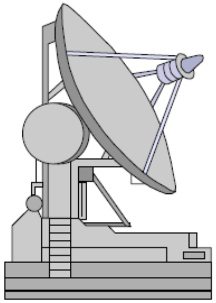
Simplex
Broadcast radio or TV)

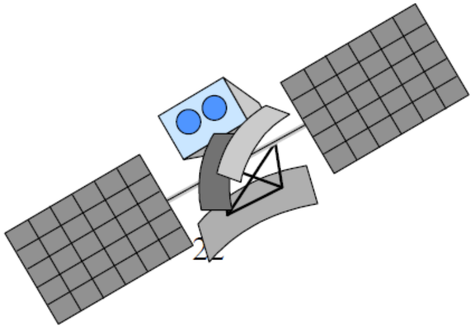
Half Duplex
Walkie-Talkies, CB radio



Digital Data Transmission

- One of the most significant changes that has occurred in Electronic, Information and Computer engineering in the last 5 years is the **digital revolution**
- Nearly all forms of **information transmission** are or will be performed by digital techniques-Mobiles, CD’s, TV and radio, satellites, etc





Why digital communications?

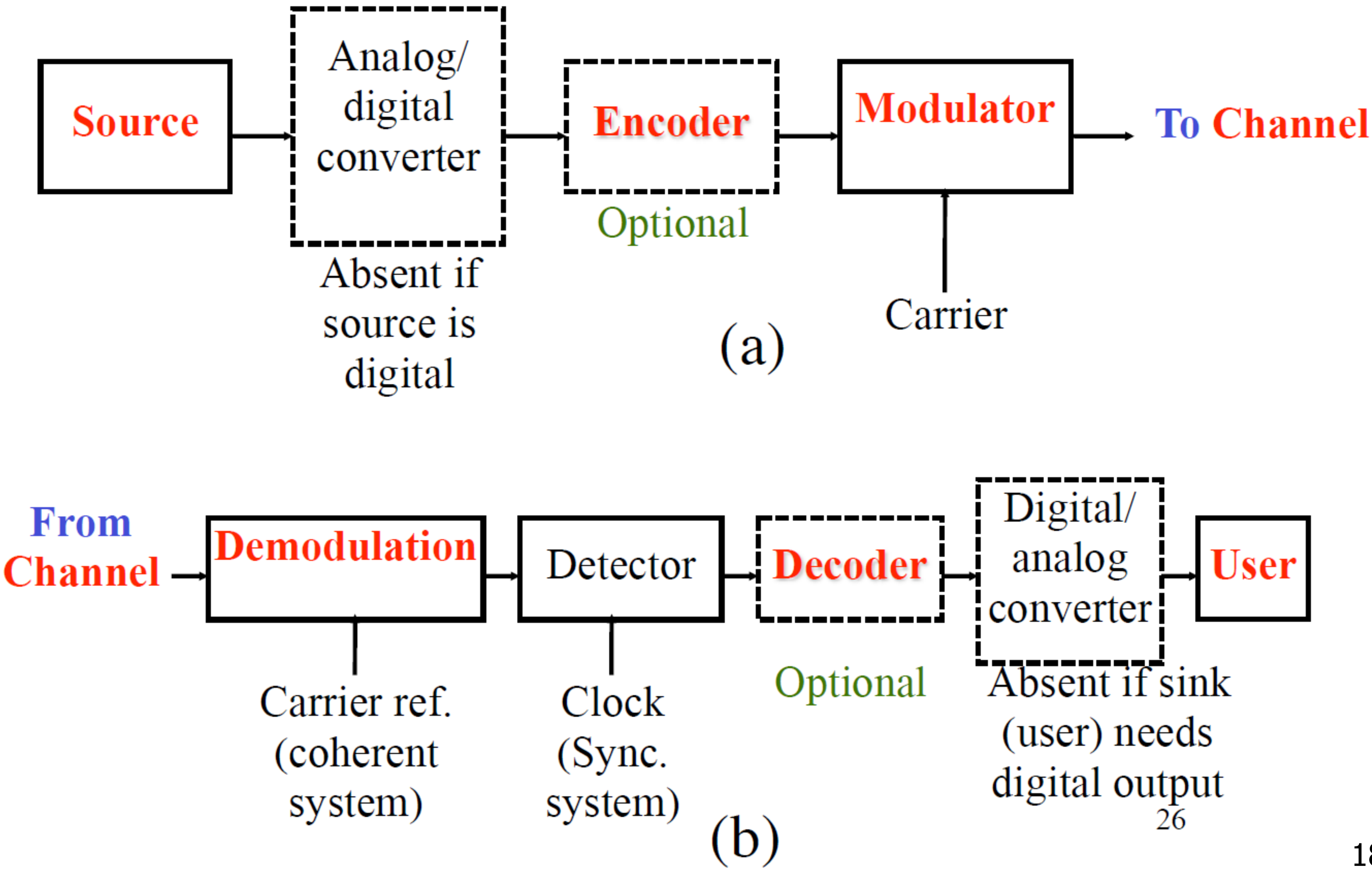
- Noise introduces distortion to analog signals.

- Because a digital receiver need only to distinguish between two waveforms, it is possible to exactly recover digital information.

- Many signal processing techniques are available to improve system performance: Source coding, channel (error-correction) coding, equalization, encryption, Digital ICs are inexpensive to manufacture.

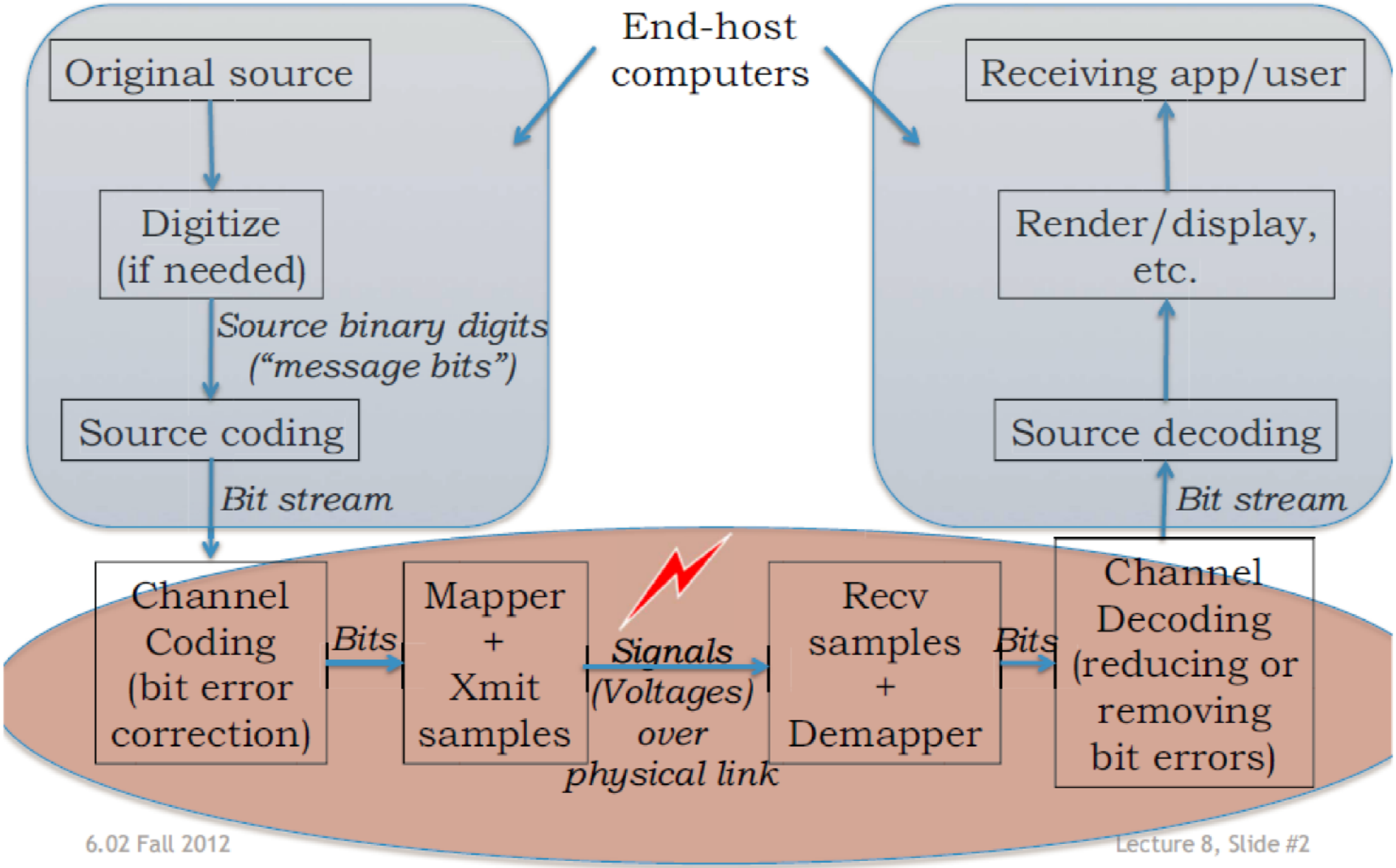
Block diagram of a digital communication system

(a) Transmitter. (b) Receiver



A Toy Example: Communications between Two Computers Over an Acoustic Channel

Single Link Communication Model



From Baseband to Modulated Signal, and Back

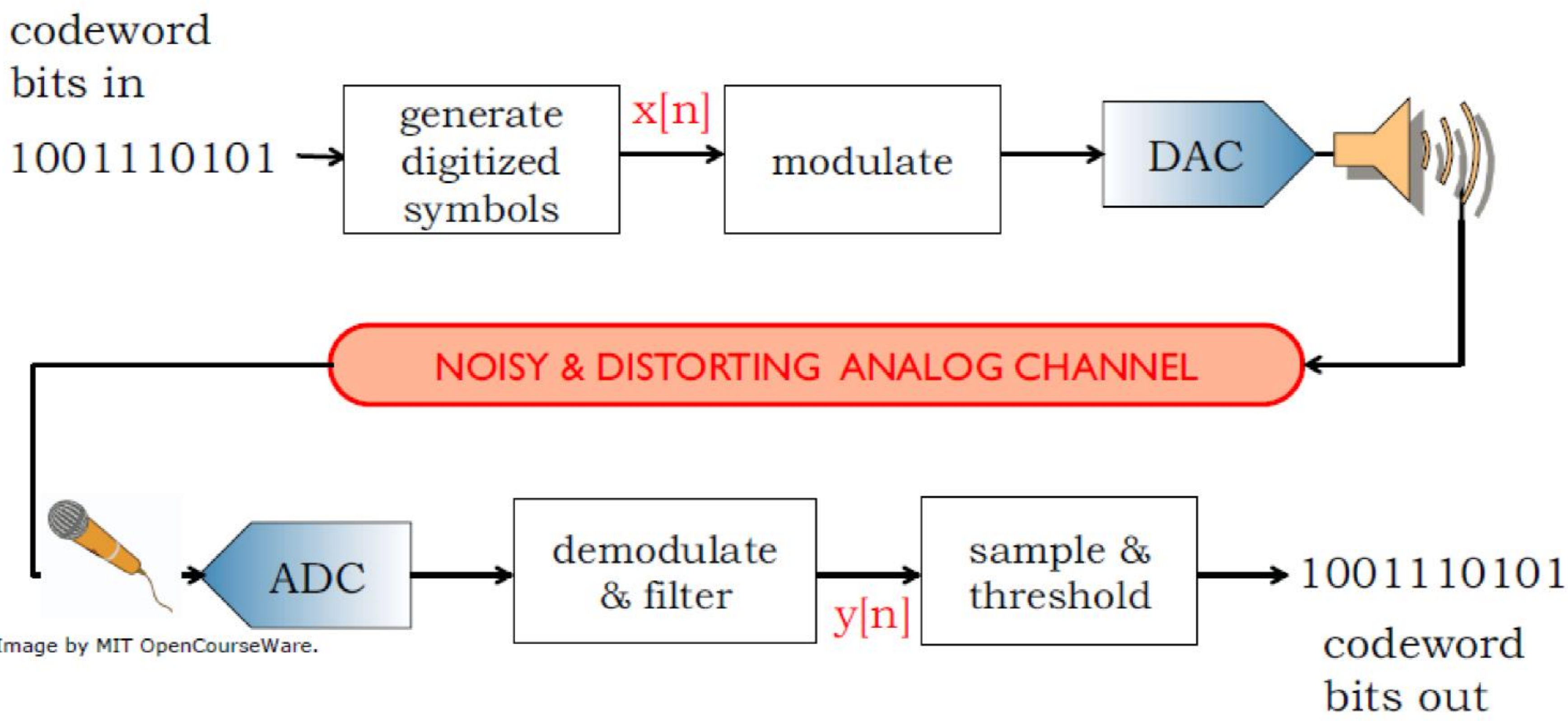


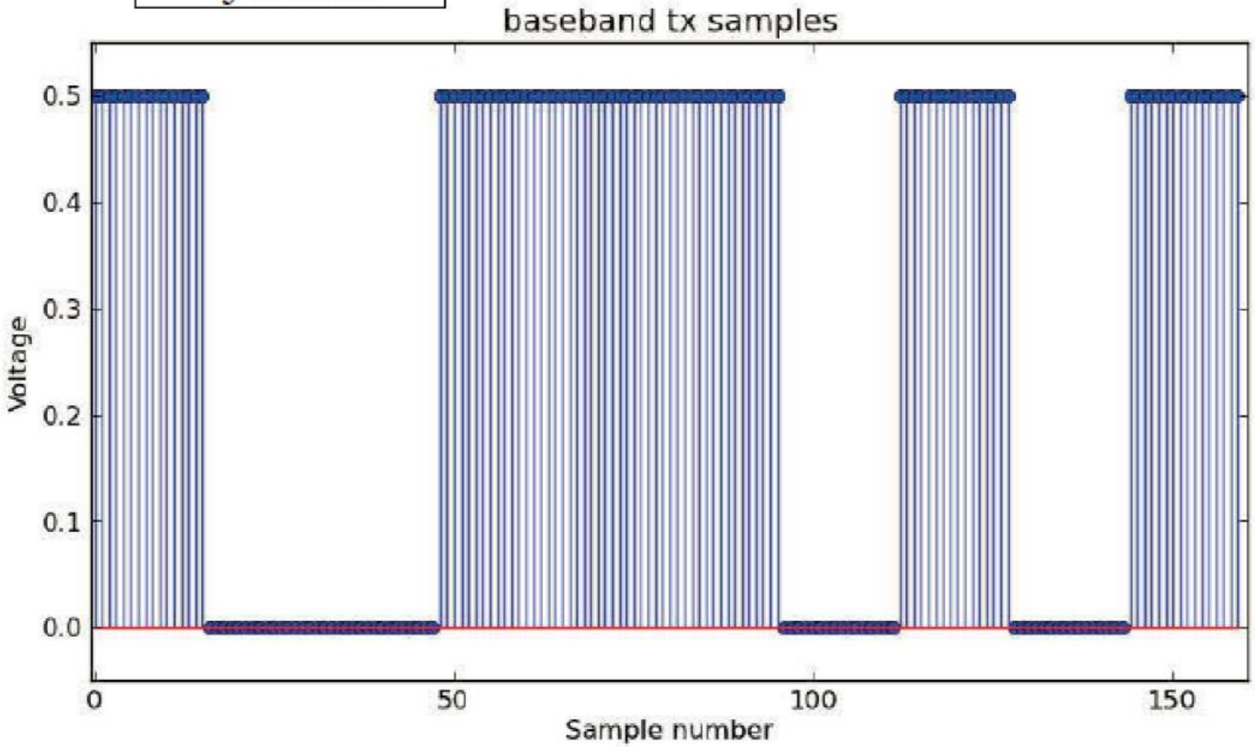
Image by MIT OpenCourseWare.

Mapping Bits to Samples at Transmitter

codeword bits in

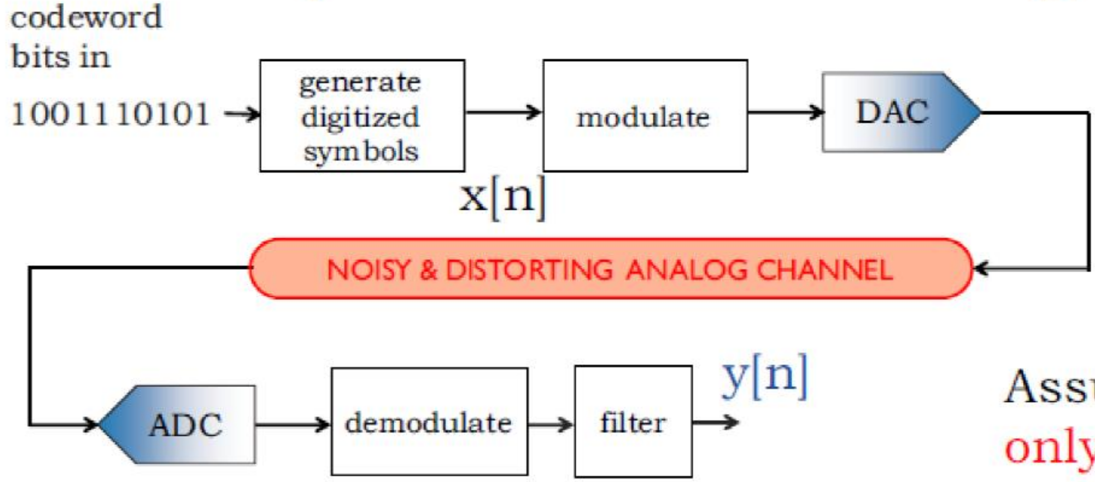
1001110101 → generate digitized symbols → x[n]

16 samples per bit

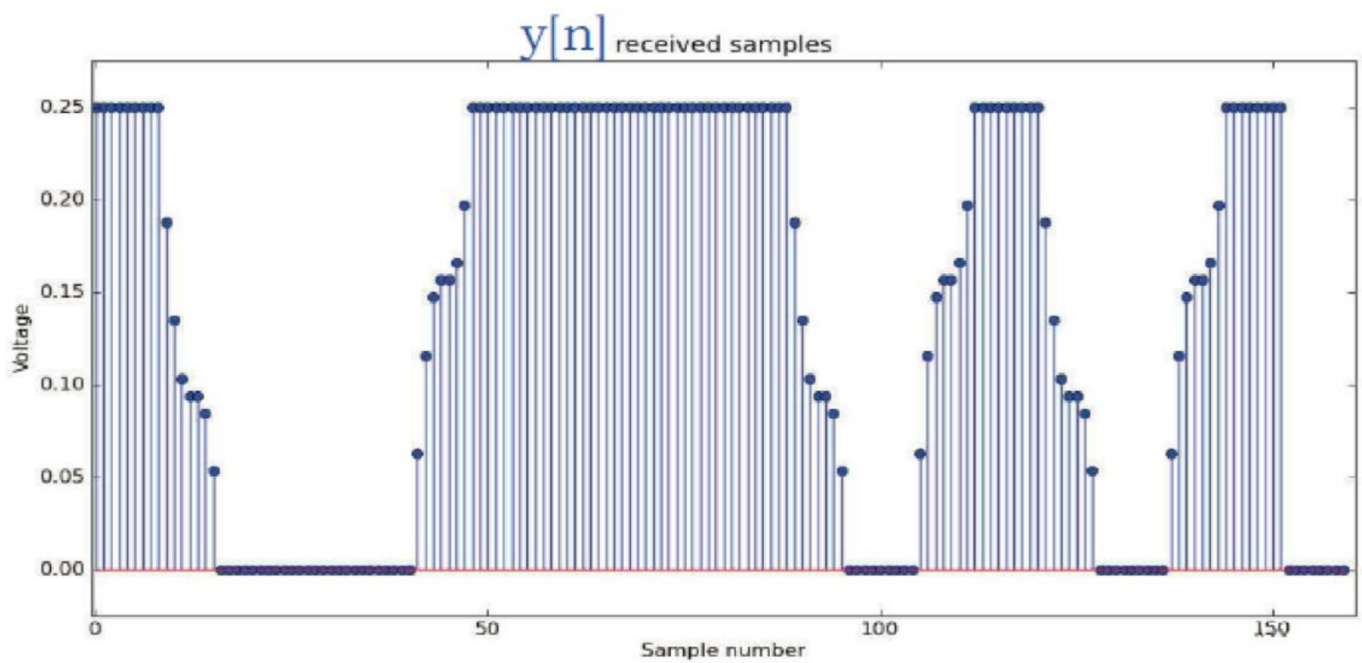


1 0 0 1 1 1 0 1 0 1

Samples after Processing at Receiver



Assuming no noise,
only end-to-end distortion



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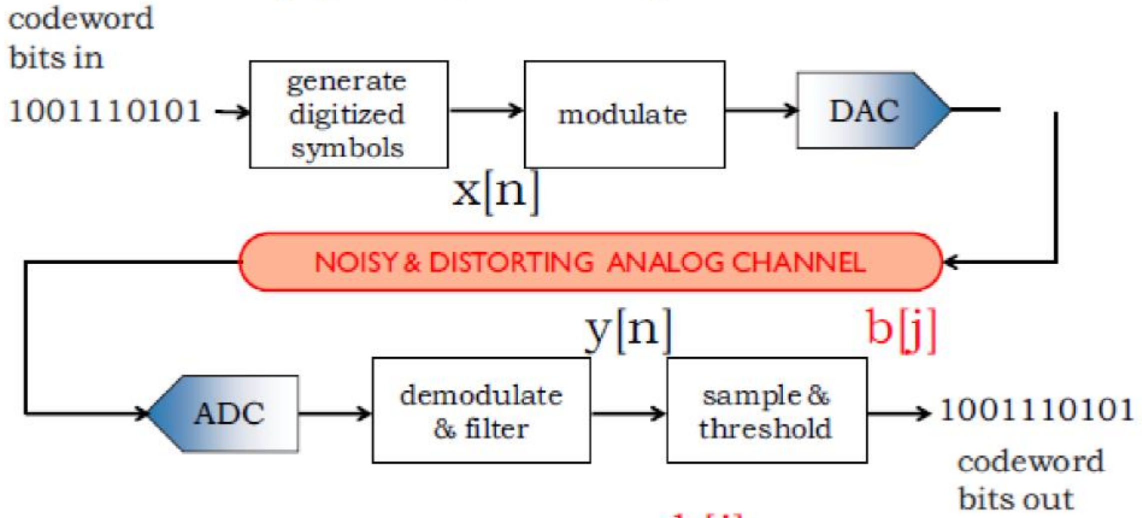
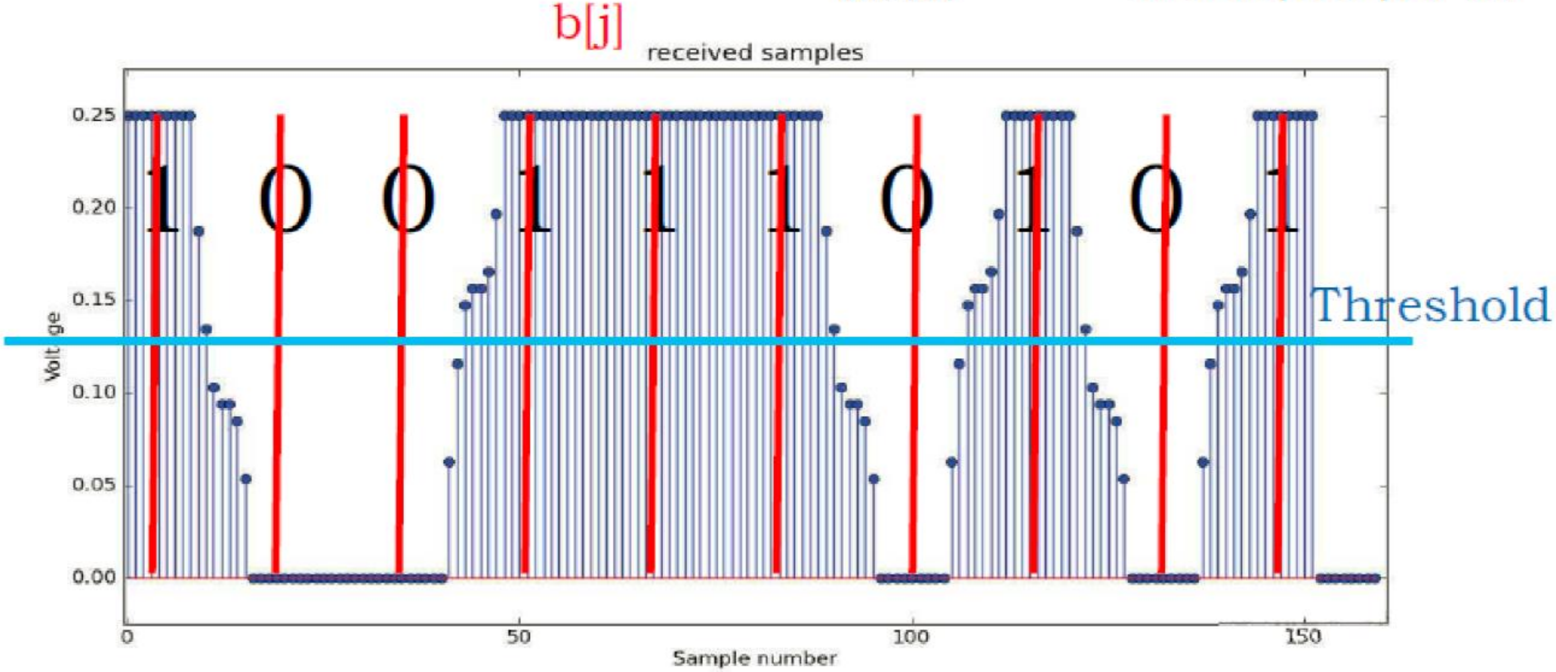
Mapping Samples to Bits at Receiver



n = sample index
j = bit index

16 samples per bit



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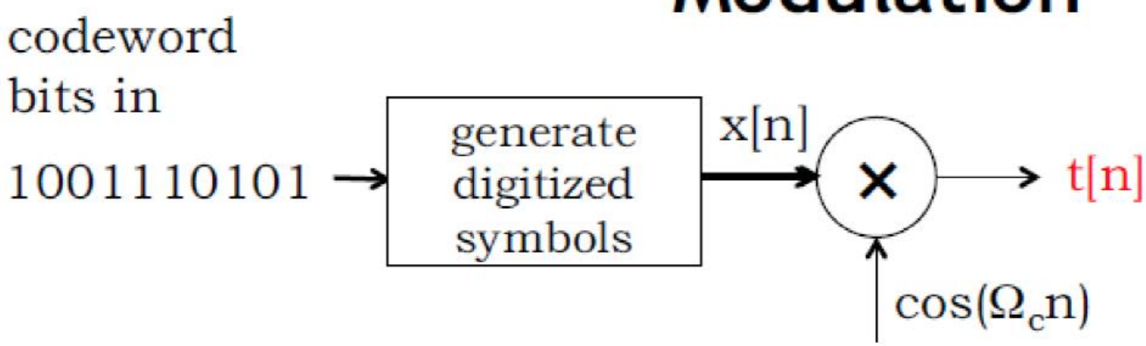
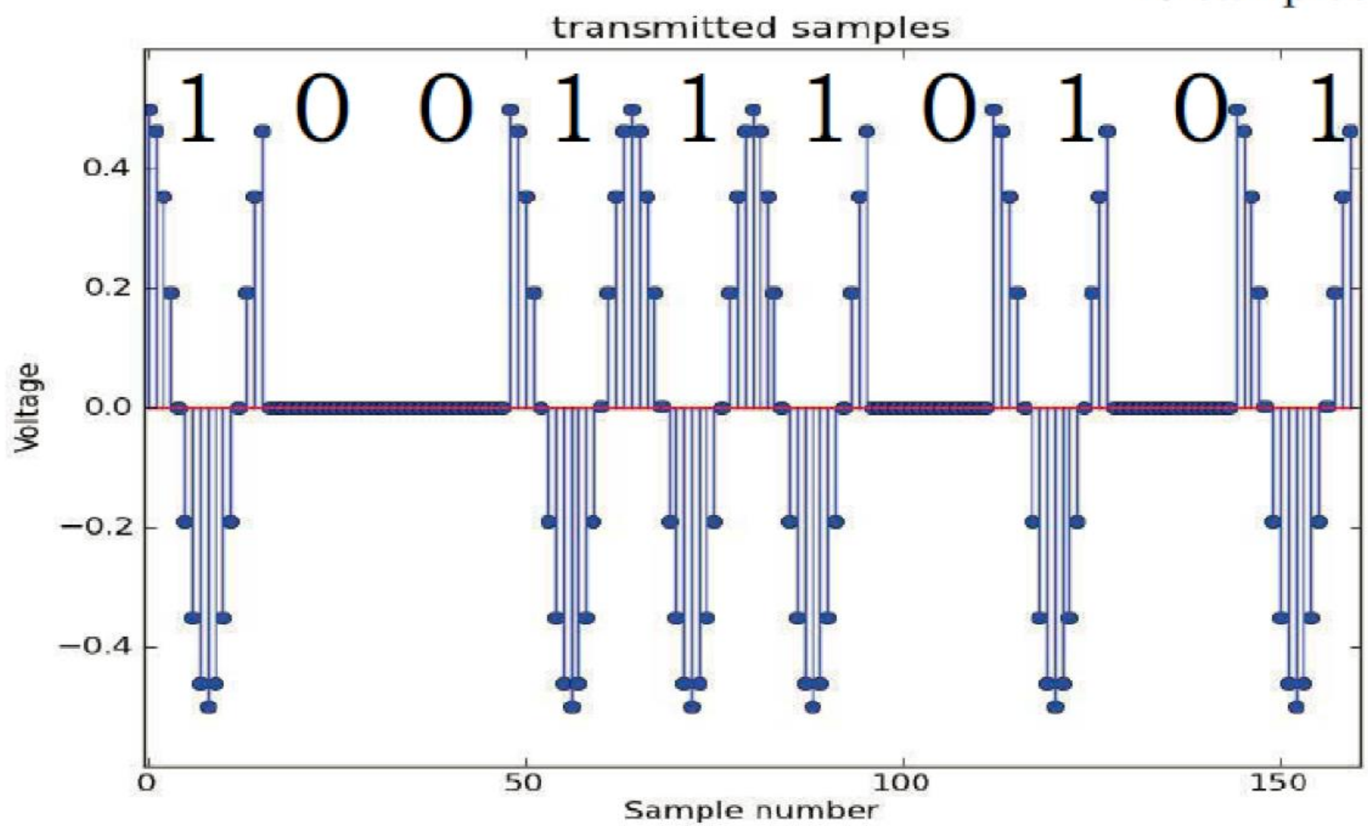
Modulation



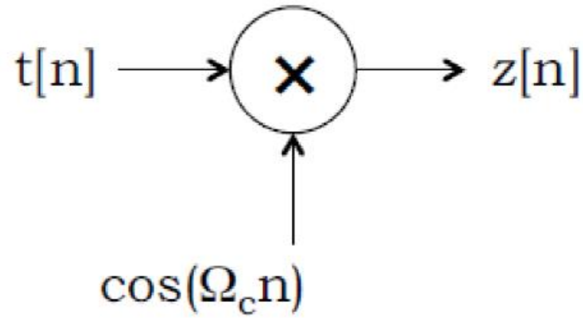
$\Omega_c = 2\pi/16$

16 samples per cycle



Demodulation

Assuming no distortion or noise on channel, so what was transmitted is received



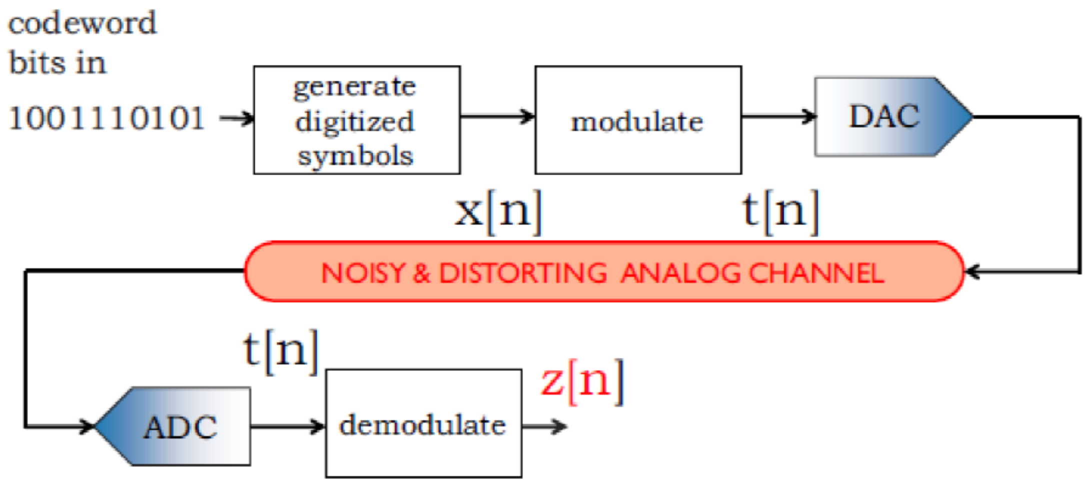
$$z[n] = t[n]\cos(\Omega_c n)$$

$$z[n] = x[n]\cos(\Omega_c n)\cos(\Omega_c n)$$

$$z[n] = 0.5x[n](1+\cos(2\Omega_c n))$$

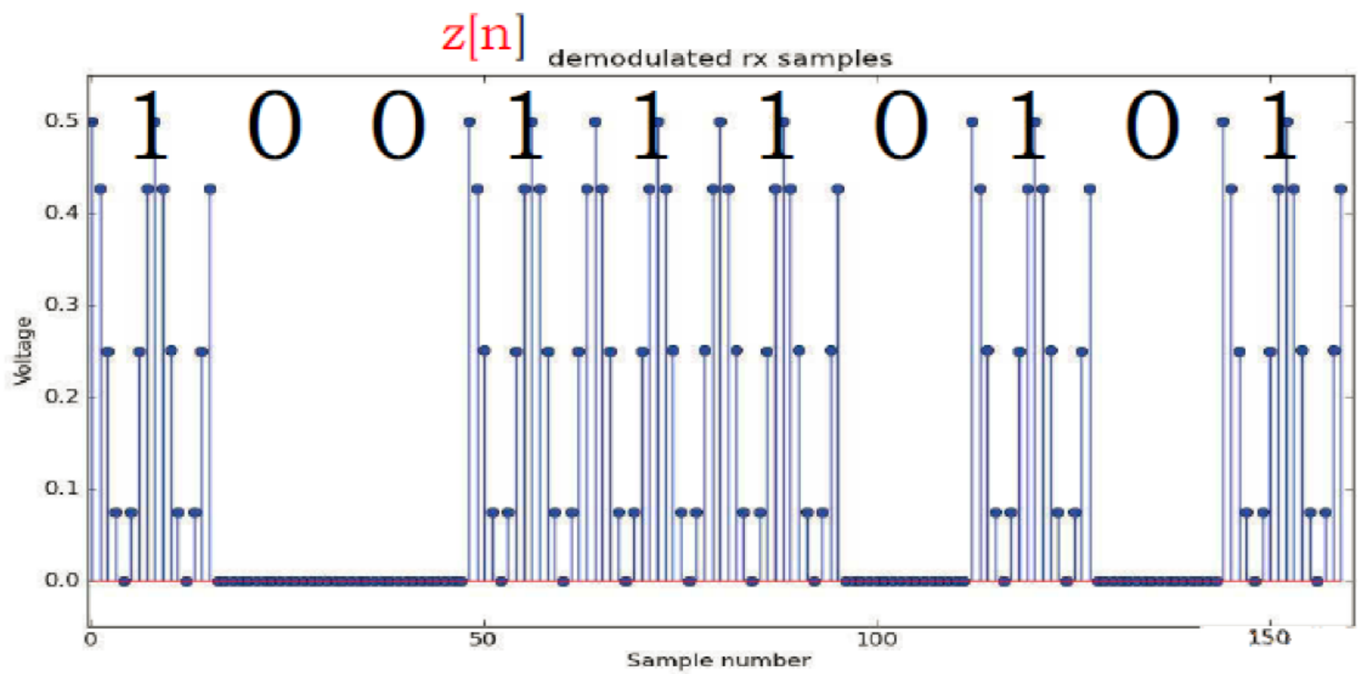
$$z[n] = 0.5x[n] + 0.5x[n]\cos(2\Omega_c n)$$

Demodulation

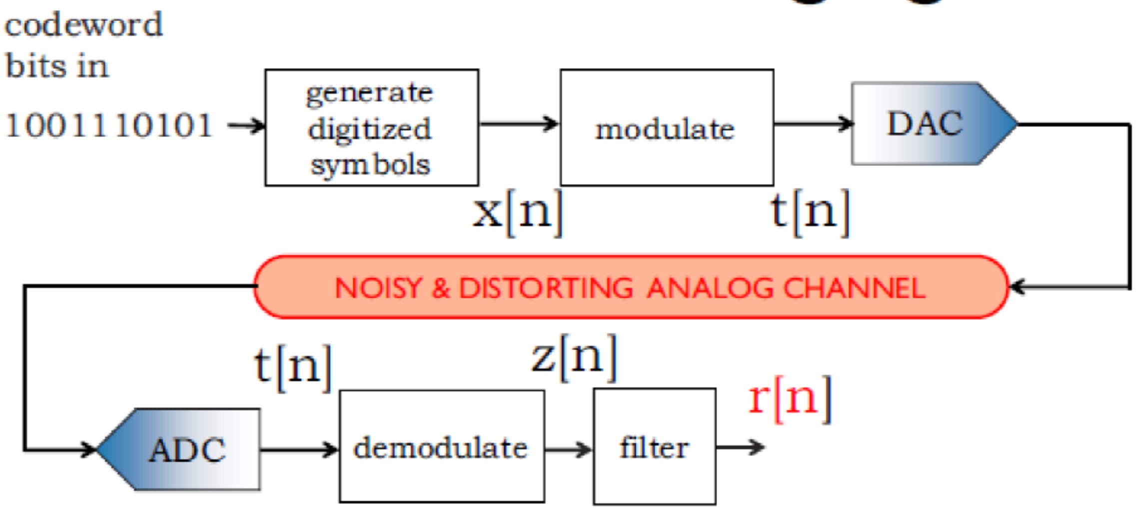


$\Omega_c = 2\pi / 16$

16 samples per cycle



Averaging filter



$\Omega_c = 2\pi/16$

16 samples per cycle

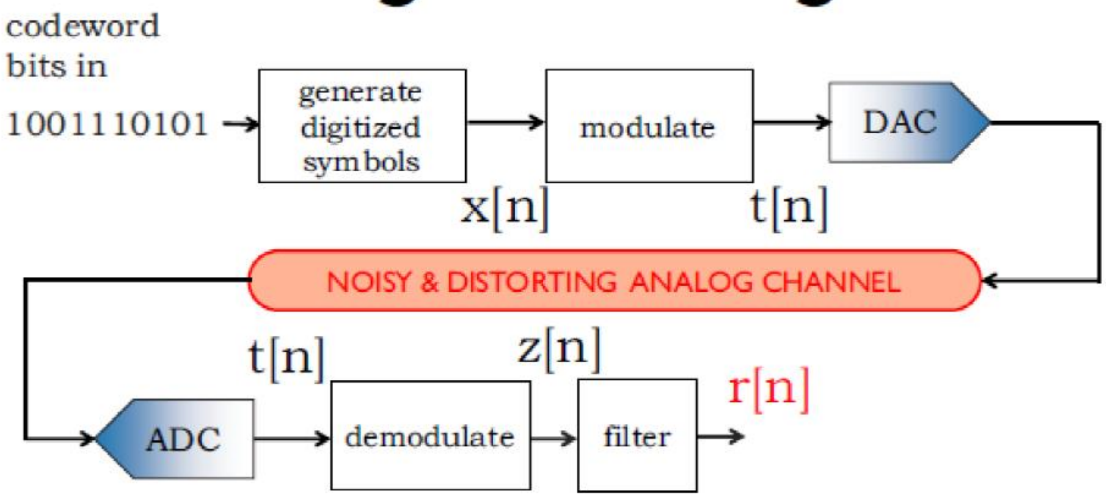
r[n] = z[n]+…+z[n-L], L+1 length of the averaging filter

For L+1=8, $2\Omega_c$ component is at $2\pi/8$, which is 8 samples per cycle

So, the $2\Omega_c$ component gets averaged out

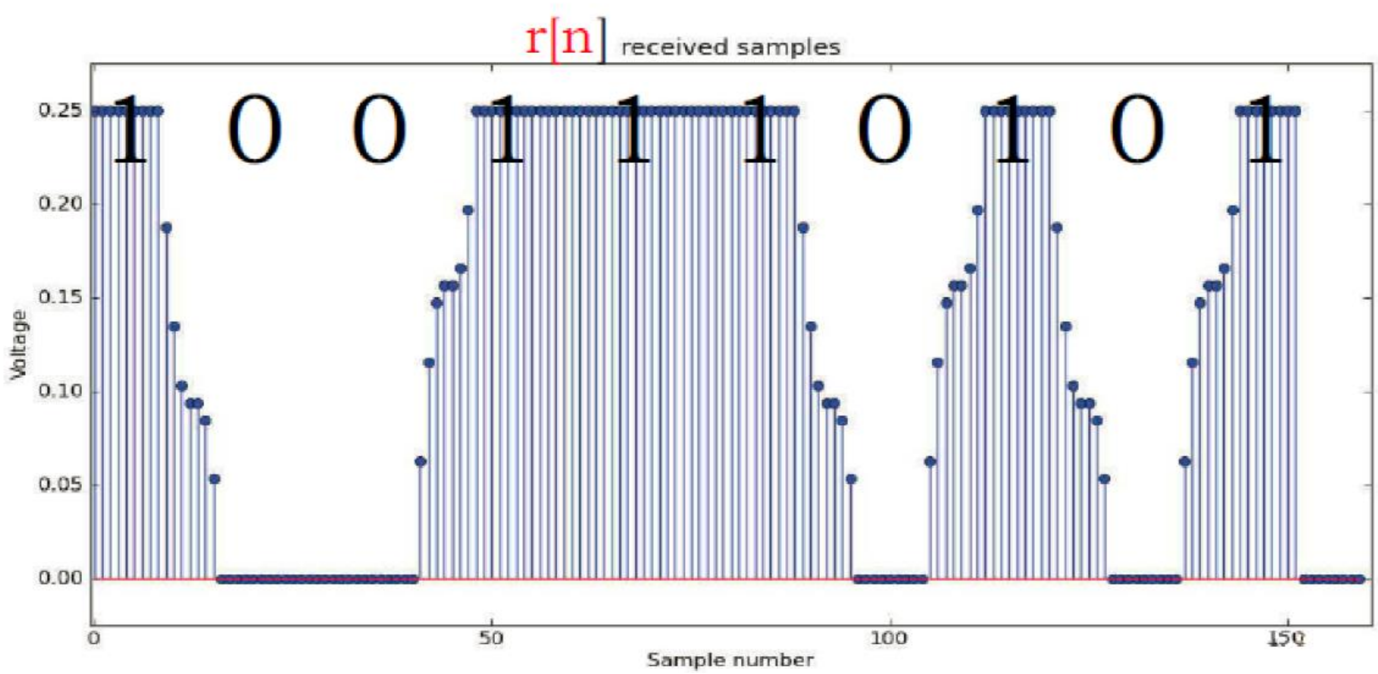
*At transitions, there is a bit of degradation, but we make decisions on the middle samples

Filtering: Removing the $2\Omega_c$ component



$\Omega_c = 2\pi/16$

16 samples per cycle



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Overview of Different Blocks in General Digital Communication Systems

Analog Input Signal

- **Continuous time and amplitude signal from voice, video or image**

- **Goal is to minimize distortion of analog signals**

Sampling

- **Sampling makes signal discrete in time**

- **Sampling Theorem: Bandlimited signals can be sampled without introducing distortion**

- **What is the Sampling Theorem?**

Quantization

- **Quantizer makes signal discrete in amplitude**
- **Quantizer introduces some distortion**
- **Good quantizers are able to use few bits and introduce small distortion**

Modulator

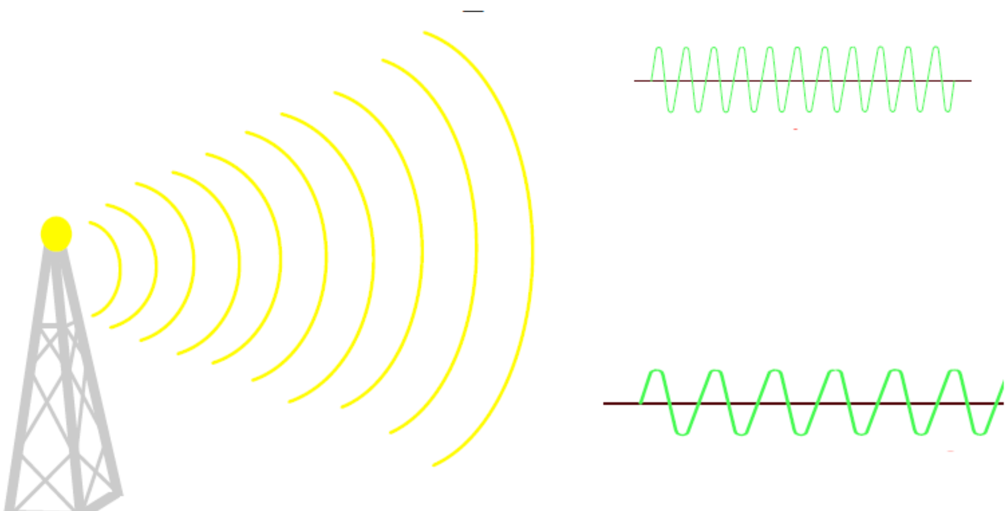
- Converts digital data to a continuous waveform suitable for transmission over communications channels - usually a sinusoidal wave
- Information is transmitted by varying one or more parameters of the transmitted signal or waveform:
  - Phase – Phase Shift Keying (PSK)
  - Frequency – Frequency Shift Keying (FSK)
  - Amplitude – Amplitude Shift Keying (ASK) or On/Off Keying (OOK)
- Extremely important for digital communications

Channel

- Carries signals - could be a telephone wire, free space and often presents distorted signal to demodulator
- • Effects include
  - Attenuation
  - Noise (e.g., additive Gaussian noise or AWGN).
  - Filtering
    - Channel can have a bandwidth that is small compared to the signal bandwidth (e.g. in a telephone channel).
    - Transmitted pulses will be changed in shape and smeared out in time causing Inter-symbol interference or ISI.
  - Fading (Wireless Communications)
    - Signal amplitude can change in a random fashion
    - Fading is very important

Radio Waves often form part of the Channel

- There are three basic concepts about radio channels that are important to understand
- Concept 1: The radio waves can have different frequencies

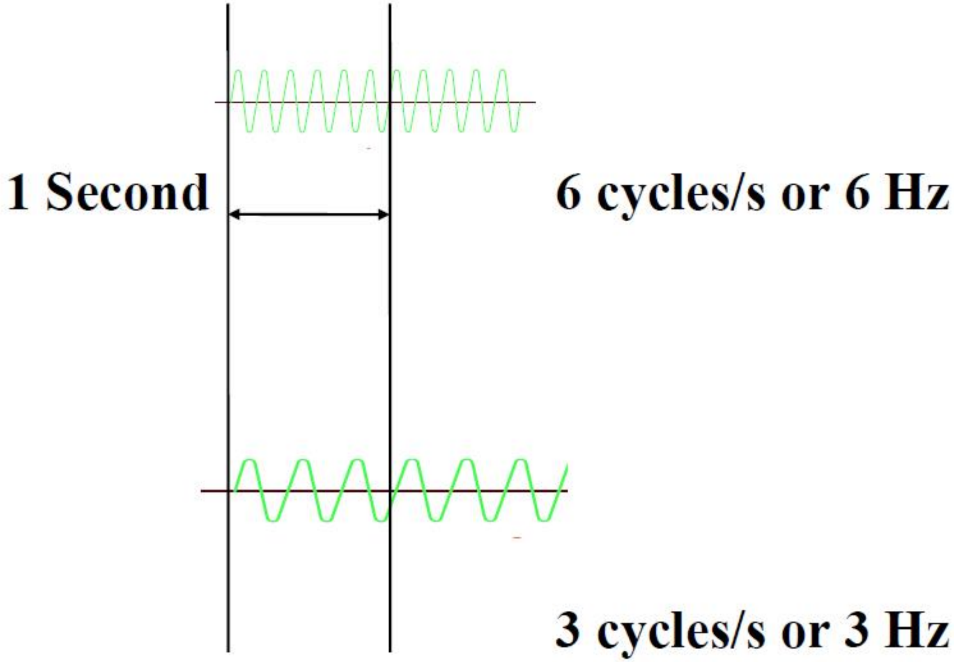


High frequency- the waves vary quickly

Low frequency- the waves vary slowly

Concept 1: Frequency

- **The frequency of the waves is specified in cycles per second- or Hertz (after the inventor of the first antenna)**



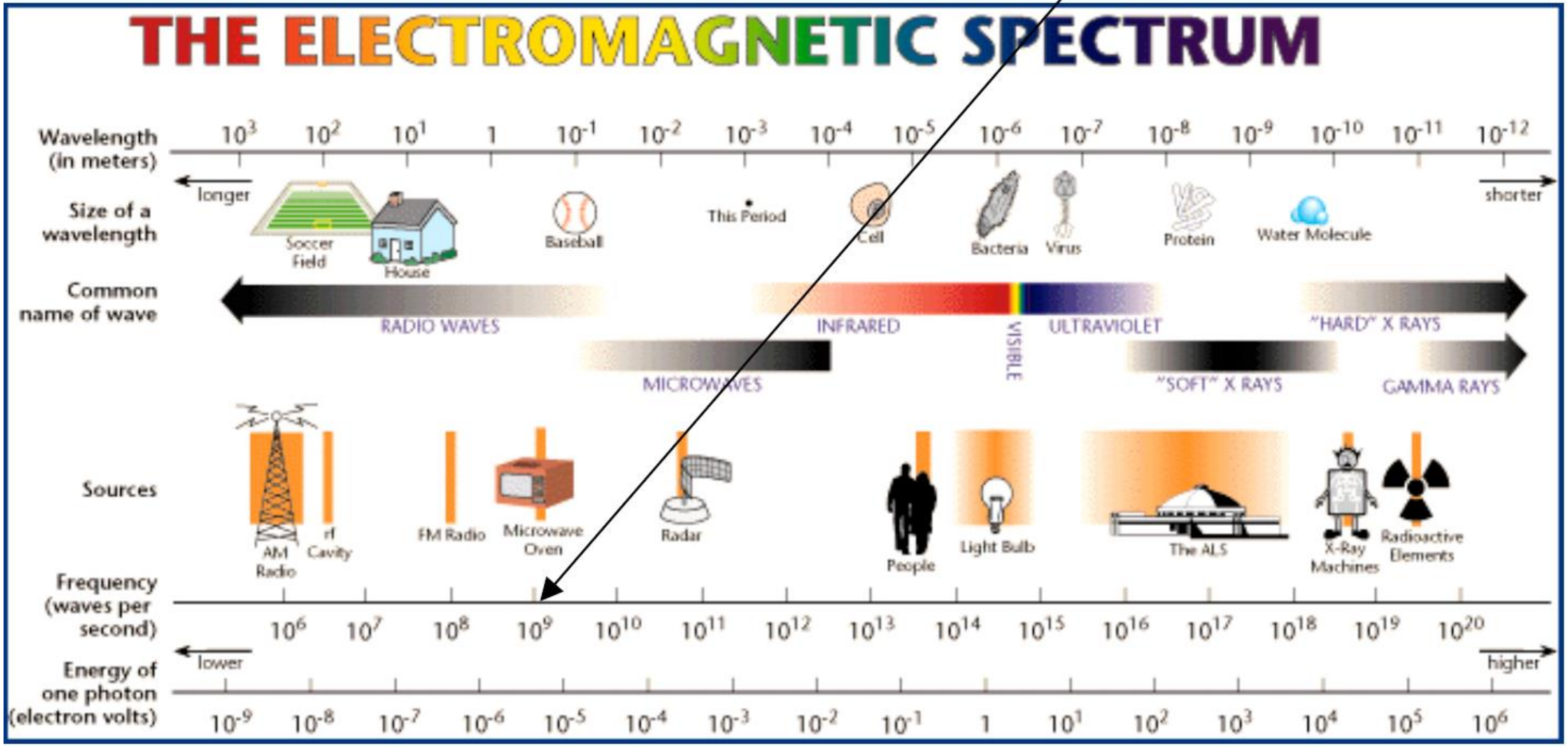
Radio Spectrum

- **The set of all frequencies from 0Hz to infinity is known as the radio spectrum and is used for many different applications**

Frequency	Usage
30-300Hz ELF	
300-3kHz VF	
3k-30kHz VLF	
30k-300kHz LF	
300k-3MHz MF	Broadcast AM
3M-30MHz HF	
30M-300MHz VHF	Paging/TV/Broadcast FM
300M-3GHz UHF	Mobile
3G-30GHz SHF	Satellite
30G-300GHz EHF	
Infrared	Remote control
6000 GHz Light	Camera Medicine

Radio Spectrum

Mobile Phone, Wireless LANs, etc



Concept 2: Sharing and Regulation

- Concept 2: Radio waves travel or propagate through a common channel that everybody shares
- That is for a particular frequency only one person, user or company can use it- otherwise there will be interference and chaos!

Regulation of Radio Spectrum

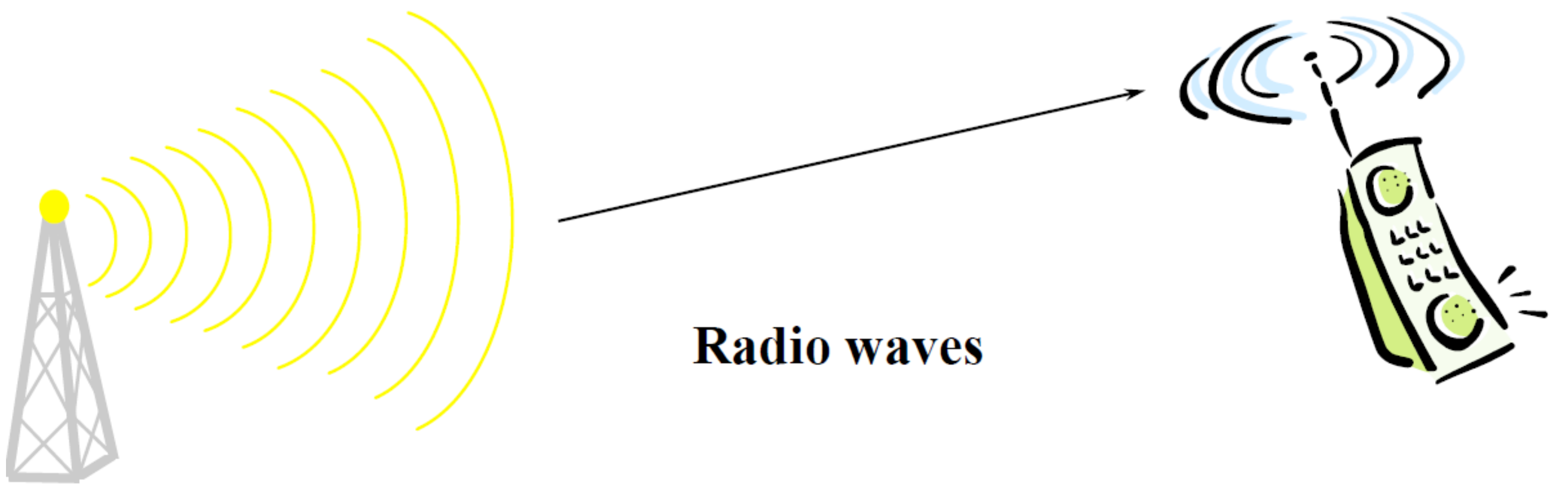
- The government effectively owns the radio spectrum and regulates it
- In some cases the government sells the spectrum to a user or company
- The government of different countries must coordinate the regulation of the spectrum

Regulation of Radio Spectrum

- In most countries this process has been performed by auction- the government will sell the spectrum to the highest bidder
- This is thought more efficient since it allows the spectrum to be allocated by the free market
- Most auctions now take place over the internet and may take several weeks!
- In the UK the 3G spectrum was auctioned for over HK$200 Billion! Absolutely incredible!

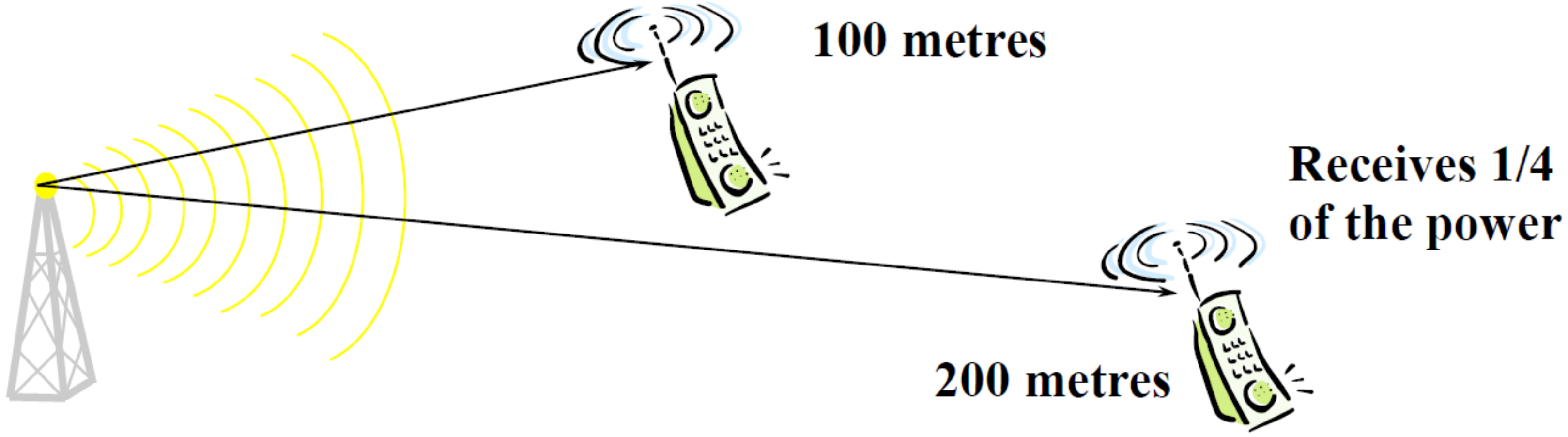
Concept 3: Propagation

- As the radio waves travel from the transmitter to the receiver their strength decreases or attenuates
- Therefore the further the receiver is away from the transmitter the more power that needs to be transmitted



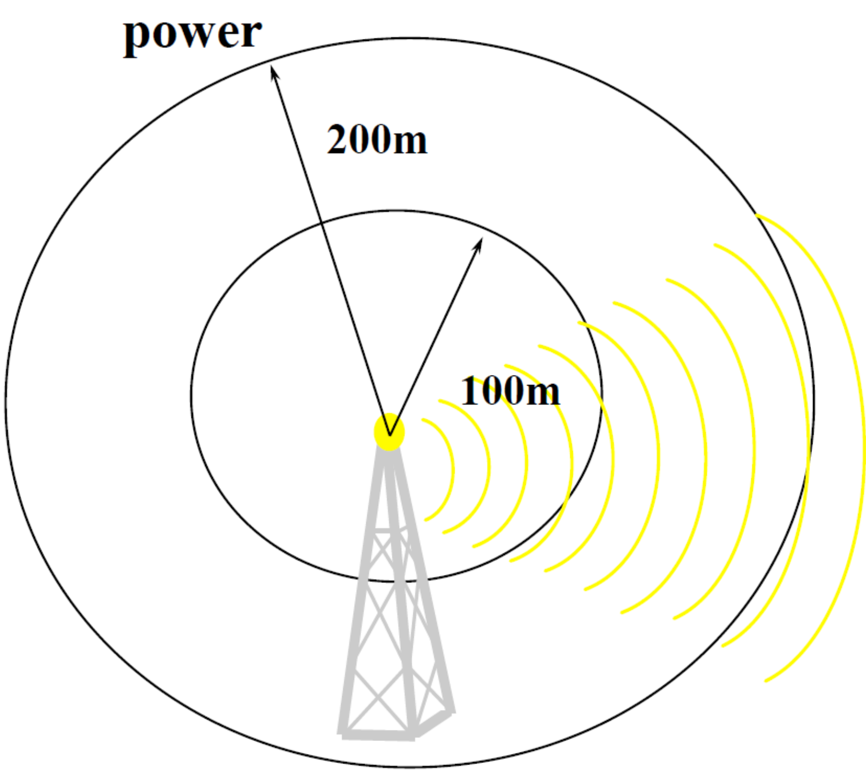
Propagation

- Calculating the attenuation is very difficult
- However it roughly obeys an inverse square distance law- that is every doubling of distance means the receiver receives 1/4 less power



Propagation

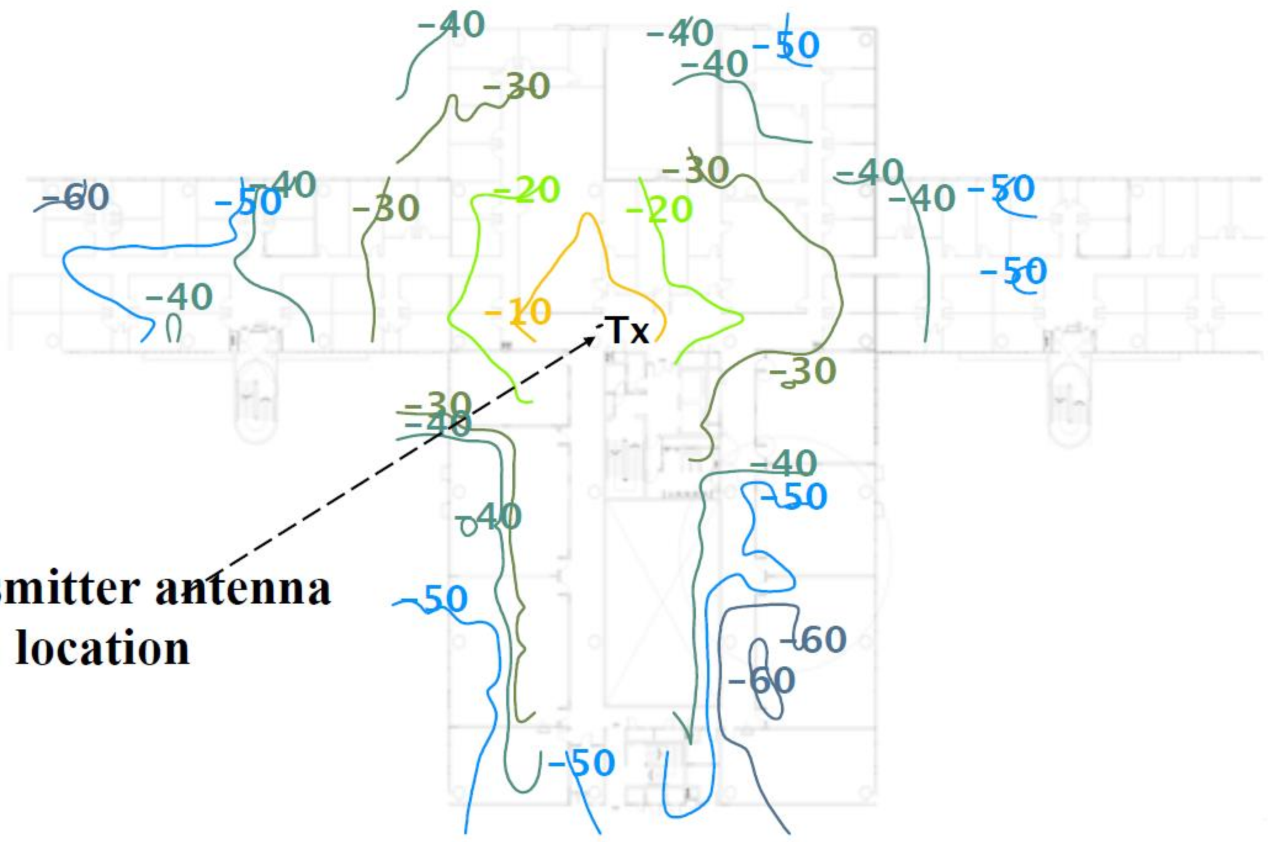
- **The reason for this is simple conservation of power**



- Total power input must equal total power output
- Surface area of sphere is $4\pi r^2$
- Therefore as radius or distance increases total power on surface must decrease as inverse square distance

Propagation

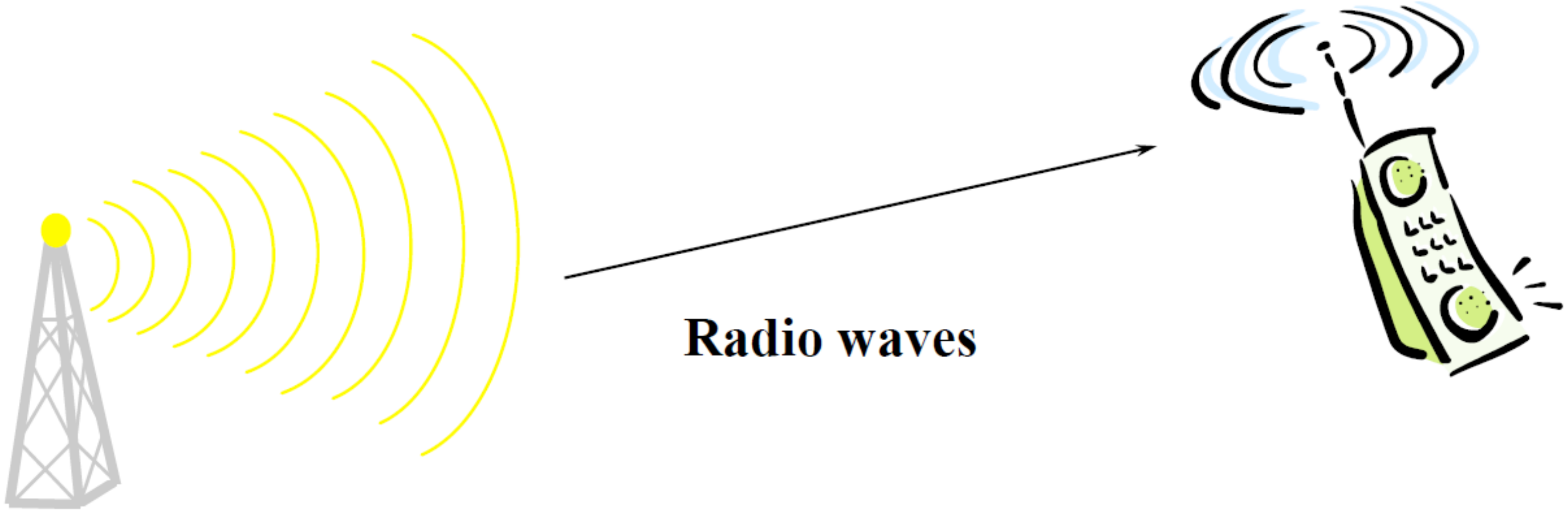
- **In more complicated situations it is not so straight forward however it roughly follows the general inverse distance square law**



Transmitter antenna location

Summary of basic Radio Channel Concepts

- There are three important concepts to do with radio waves
  - Frequency
  - Sharing and regulation
  - Propagation



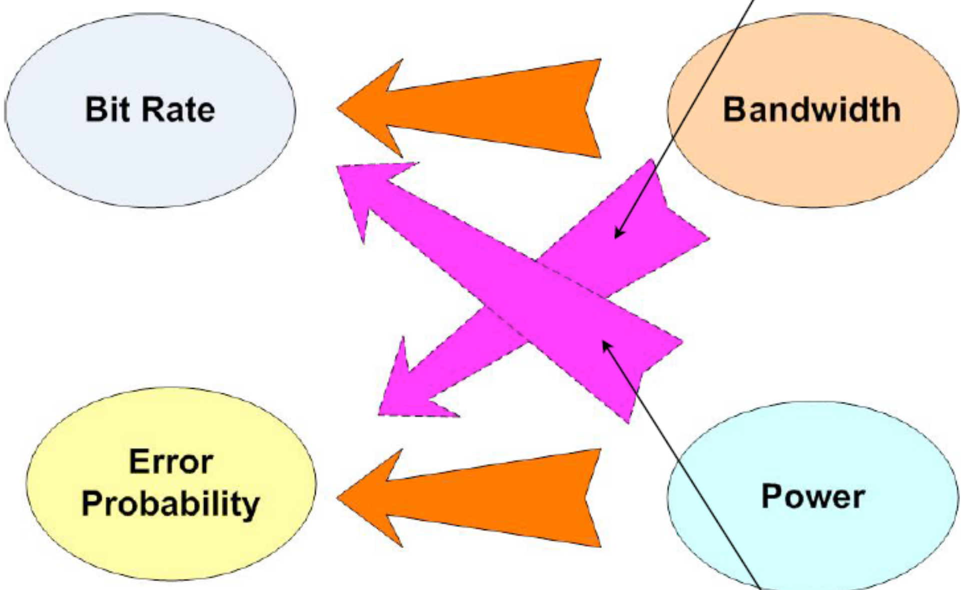
What are the Features of a Good Digital Communication System?

- Digital Communications:
  - Input (Output) to the transmitter (from the receiver) is bit stream.
- Performance Goals
  - Large data rate (measured in bits/sec)
  - Reliable (measured in BER or PER)
- • Resource Goals
  - Small signal power (measured in Watts or dBW)
  - Small bandwidth (measured in Hertz)

In practice, there must be <u>tradeoffs</u> made in achieving these goals

Tradeoffs in Digital Communication Systems

Achieving better "performance" by sacrificing bandwidth (***Power Efficient Modulation***)



Achieving better "performance" by sacrificing power (***Bandwidth Efficient Modulation***) 47