ECE4634
Digital Communications
Fall 2007

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Lecture #4: Introduction to Digital Communications

Analog and Digital Communications

Lecture Overview

- This course deals with the study of digital communications systems
- To date we have reviewed the tools necessary for the study of communication signals and systems
  - Fourier Transforms – allow us to examine the frequency representation of signals
  - Later we will review *random variables* which will allow the study of the *performance*
- Today we begin our study of digital communications systems by examining the basic features of digital systems, particularly baseband systems
- What to read – Skim chapters 5-6 in the text

Communications

- **Definition:** Communications is the transfer of information at one time or location to another time or location

Information Source → **Transmitter** → **Channel** → **Receiver** → **Destination or 'sink'**

Information Source: Can be analog or digital. Almost always baseband signal

Transmitter: Converts information into appropriate waveform
Can include analog-to-digital conversion, modulation and waveform coding. Can be baseband or bandpass

Channel: Transports and corrupts signal

Receiver: Makes best guess as to what the transmitted signal was

Examples

- Broadcast television
- Broadcast radio
- Cellular telephony
- Wireless LAN
- Landline telephony
- Global position system
- Internet
- Cable TV

Transmitting Information

- The basic function of a communication system is to transfer the source information from source to sink
- The transmitter converts the message signal to a format suitable for transmission
- The message sent can be
  - Analog or digital
  - Baseband or bandpass
- In 3614 we emphasized analog message signals
- In this class we will focus on digital messages even if the underlying source is analog
- We will initially focus baseband waveforms and later bandpass waveforms

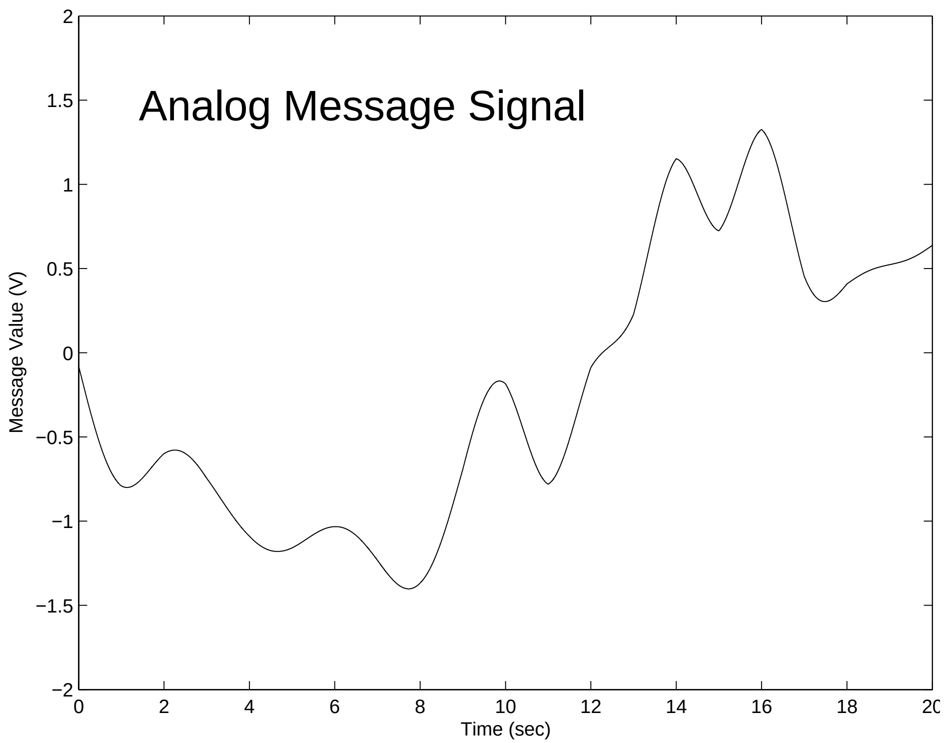
Analog vs. Digital

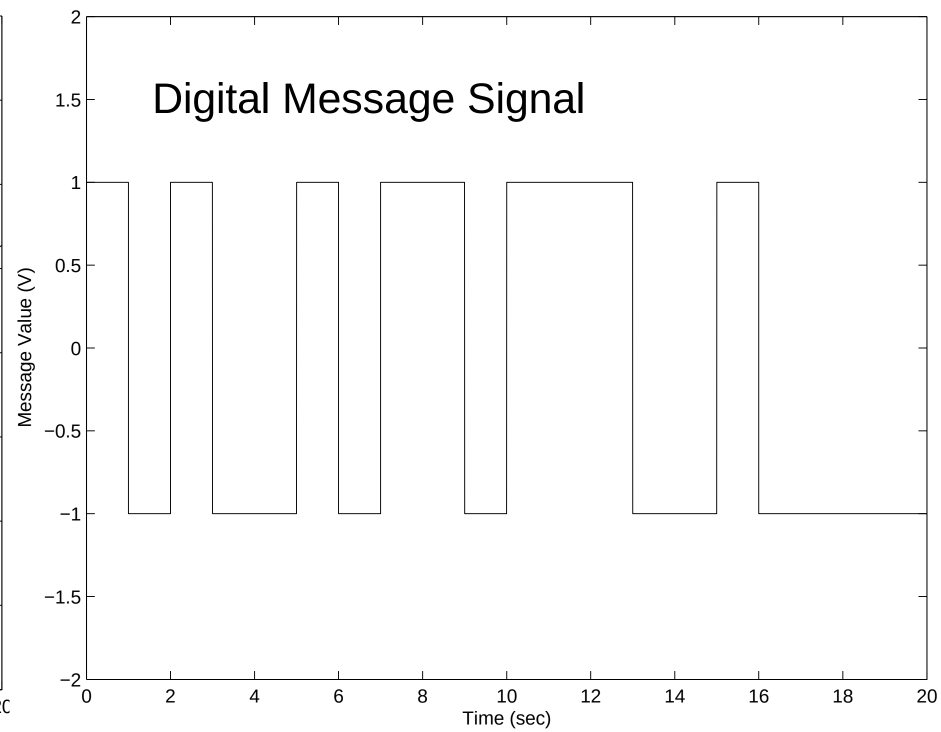
- Analog Communications
  - The message signal can take on an infinite number of possible values
  - Directly uses an analog information source (or some one-to-one mapping of it) as the message to be sent
- Digital Communications
  - The message signal must be one of a small number of discrete messages
  - Must convert analog signals into a sequence of discrete messages
  - If the number of possible messages is 2, the system is *binary* and the messages are termed binary digits or *bits*.

Example

- Analog system that transmits a voltage value between -2V and +2V.

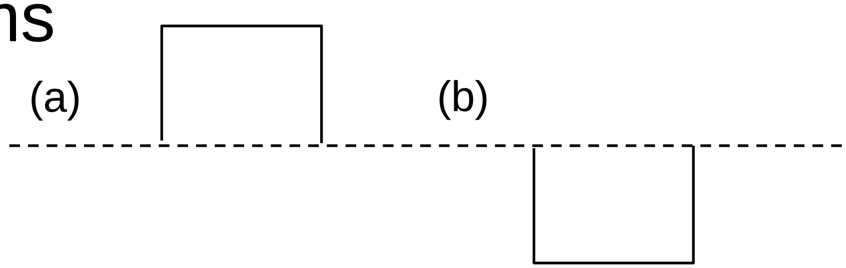
- An example digital system transmits either +1V or -1V



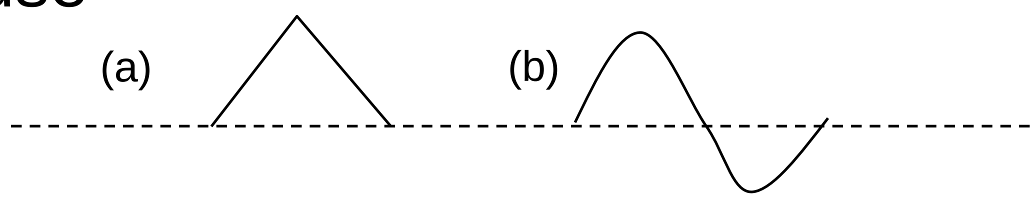


Digital Examples

- The previous example of a digital system used the two waveforms



- We could use any two (or more) waveforms that we wished to use
  - Ex:



  - The keys to choosing waveforms are (a) are they easy to distinguish from each other and (b) what are their spectra like?

Baseband vs Bandpass

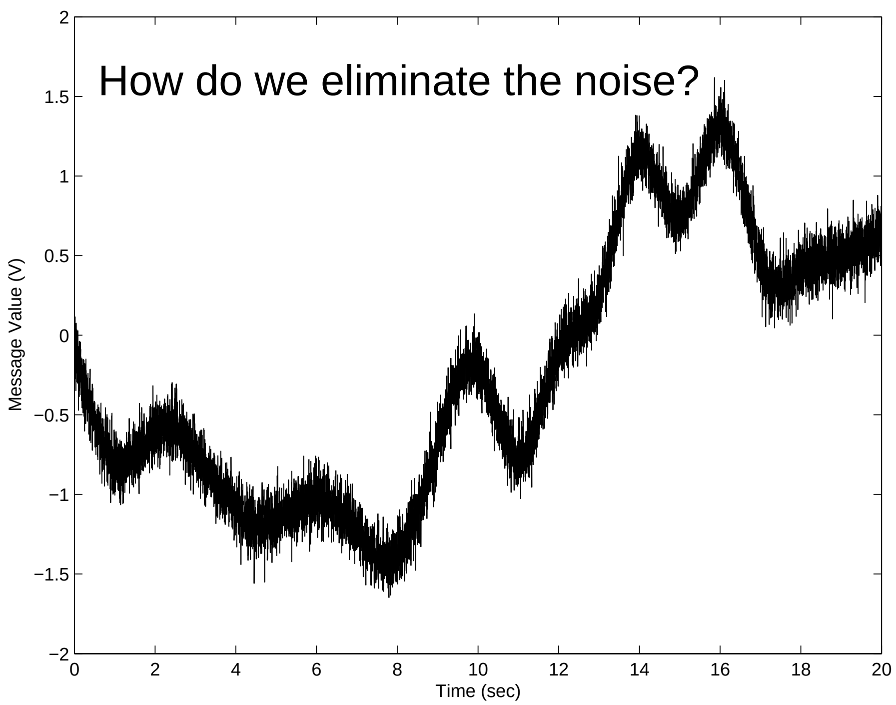
- The transmitter's job is to convert the information source into a waveform suitable for transmission.
- The resulting transmit signal can either be "baseband" or "bandpass"
  - Baseband - frequency content is primarily around DC
    - sent signal is typically a series of modulated pulses
  - Bandpass – frequency content is primarily around some center frequency $f_c >> 0$
    - sent signal is typically a modulated sinusoid

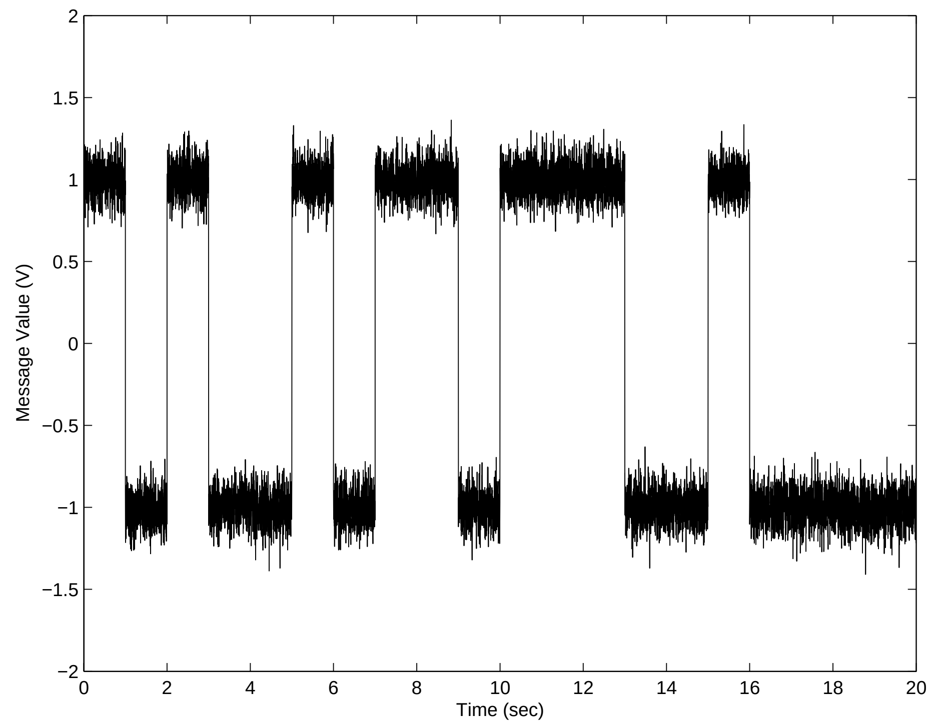
Why digital communications?

- Any noise introduces distortion to an analog signal. Since a digital receiver need only distinguish between a finite number of waveforms it is possible to recover digital information without corruption a large percentage time.
- Many signal processing techniques are available to improve system performance: source coding, channel (error-correction) coding, equalization, encryption
- Digital ICs are inexpensive to manufacture. A single chip can be mass produced at low cost, no mater how complex
- Digital communications allows integration of voice, video, and data on a single system
- Digital communications systems provide a more flexible tradeoff between bandwidth efficiency and energy efficiency than analog communications

Example Revisited

- When noise is added to the signal, all of the values are still valid
- When noise is added to the signal, the resulting values are not valid, thus we can correct them.



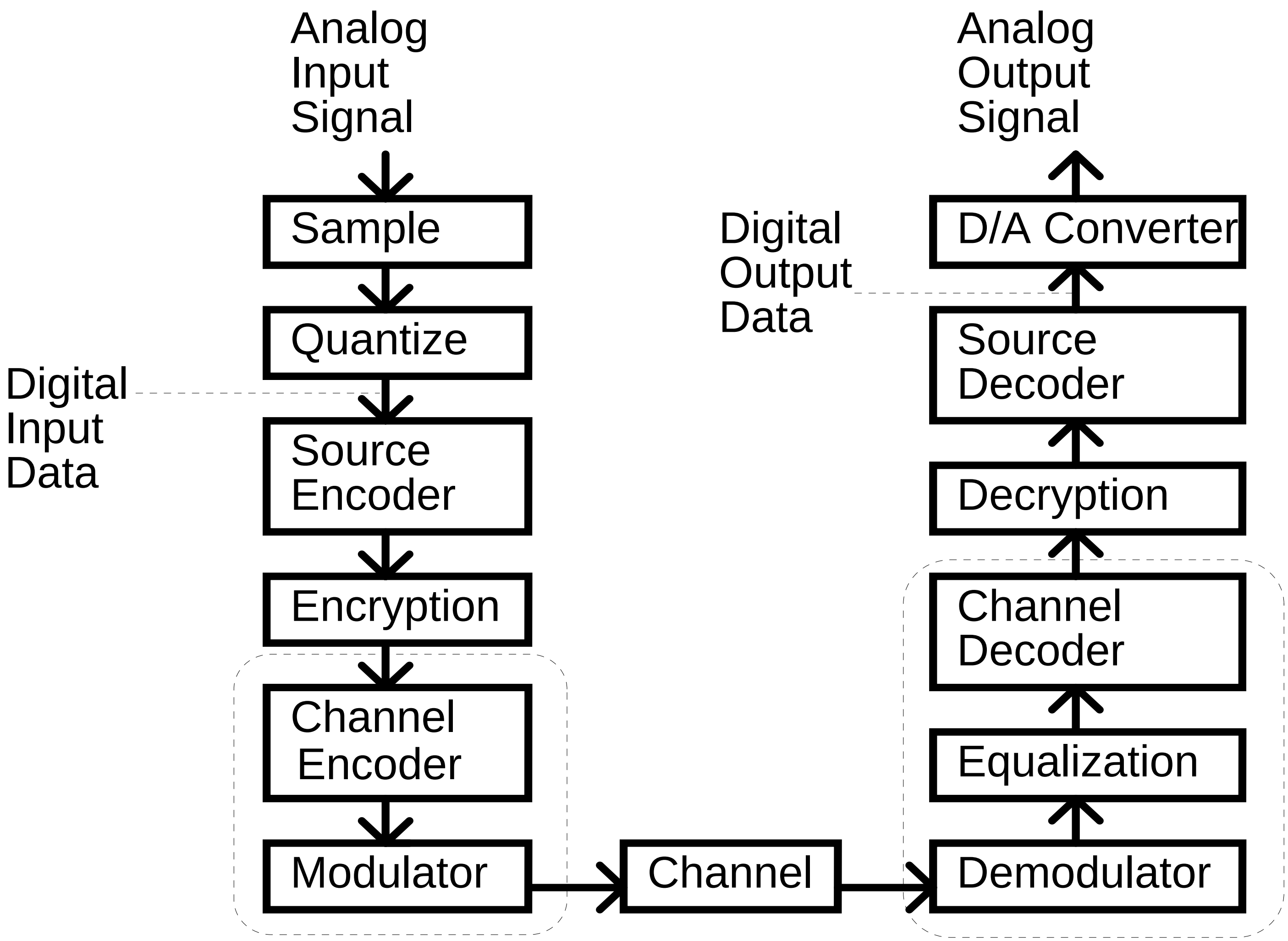


Limitation of Digital

- Analog system can naturally represent all of the message signal values
- Digital systems cannot represent all possible input values, thus, if the message is analog then all of the information can not be transmitted
- The process of converting an analog input signal to a digital signal is termed *analog-to-digital conversion* and is a lossy process

In class drill

Block Diagram of Digital Communications System



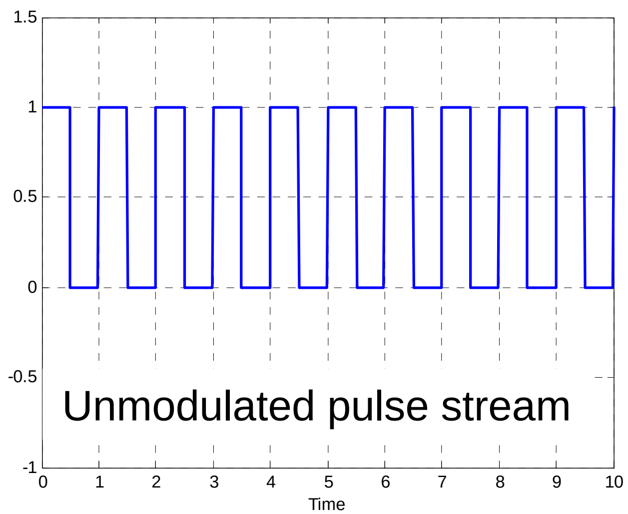
Overview of Upcoming Lectures/Chapters

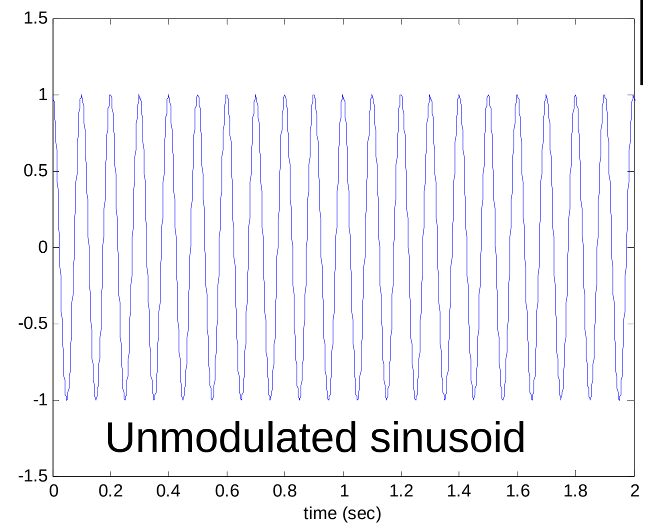
- Sampling (Lecture 5 – Section 5.1)
  - Needed for analog information source
- Analog Pulse Modulation (Lecture 6 – Sections 5.2-5.3)
- Digital Pulse Modulation (Lectures 7-9 – Sections 5.4-5.9)
  - Includes quantization for analog information source
- Choosing the proper pulse or 'pulse shaping' – Lectures 10-12 (Sections 6.1-6.8)
  - Includes intersymbol interference and equalization
- Sinusoidal modulation (Lectures 13-21 – Chapter 7)

Modulation

- In communication systems, information is conveyed by *modulating* (i.e., changing some parameter of) a carrier
- The carrier is typically either
  - Pulse train
  - Sinusoid
- Modulation can either be
  - Analog – an infinite number of possible messages
  - Digital – a finite number of possible messages

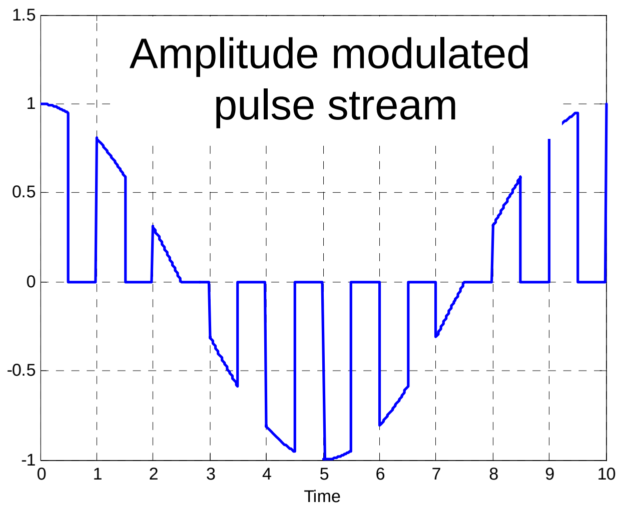
Modulation

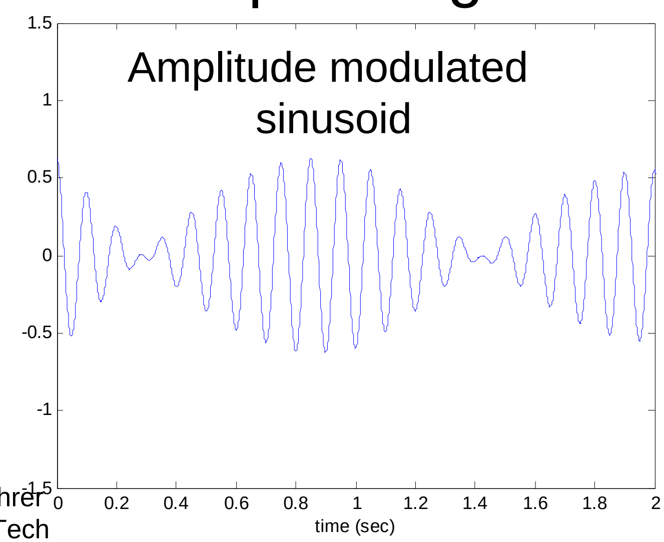




Baseband signal

Bandpass signal





Baseband Communications

Analog and Digital Communications

- Over the next few weeks we will study baseband communications techniques that modulate a pulse train using the message signal
  - Pulse Amplitude Modulation (PAM)
  - Pulse Width Modulation (PWM)
  - Pulse Position Modulation (PPM)
  - Pulse Code Modulation (PCM)

Pulse modulated by analog or digital signal

Requires conversion to digital signal prior to modulation

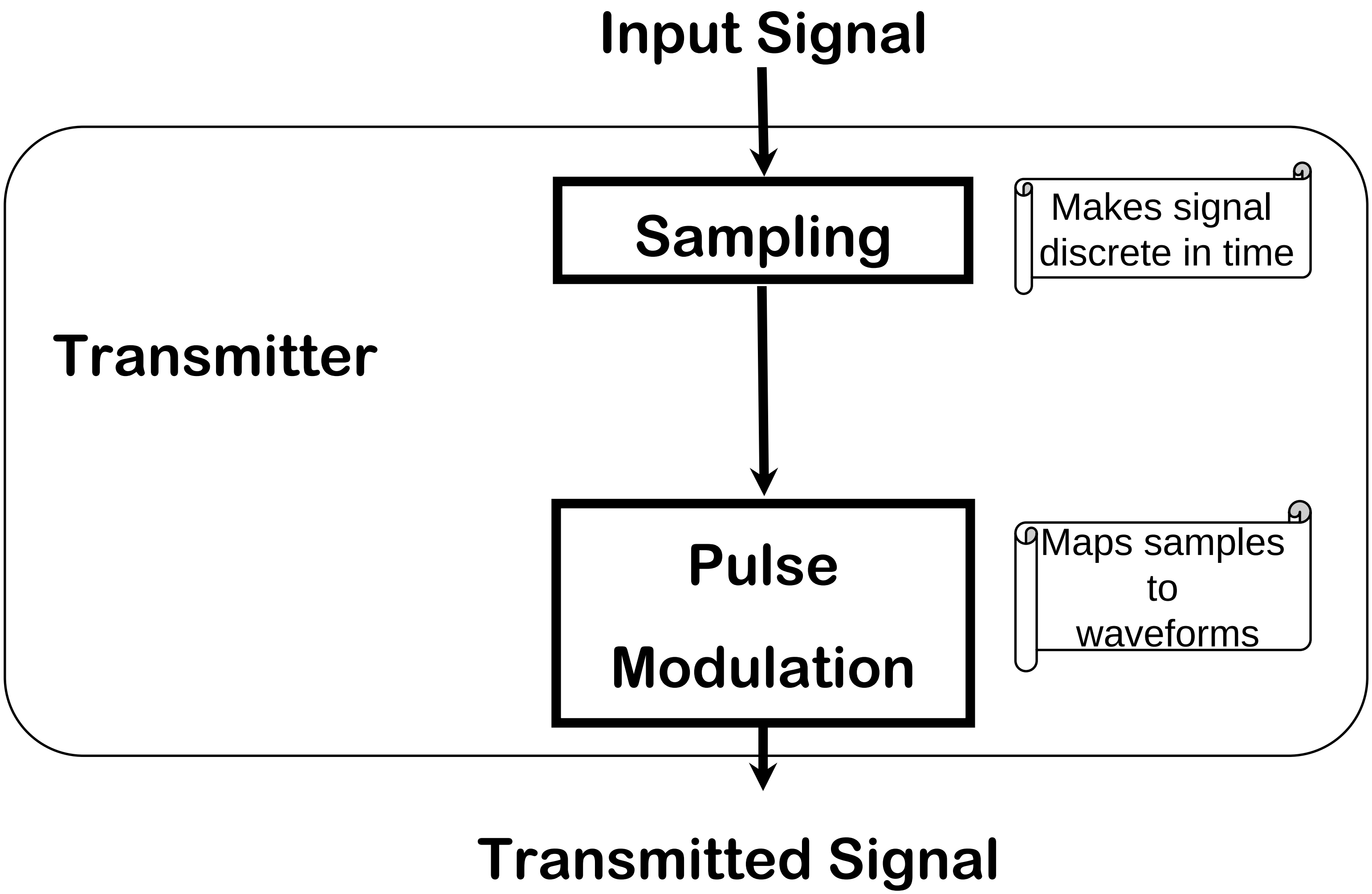
Analog Information

- Regardless of the type of system (analog or digital; bandpass or baseband) the original information source can be either analog or digital
- Traditional communication systems focused on the transfer of analog information
  - Examples: voice or video
- If the system uses continuous pulse modulation, the analog information signal must be sampled (made discrete in time)
- If the system is digital, the analog information signal must be sampled and quantized (made discrete in time and amplitude)

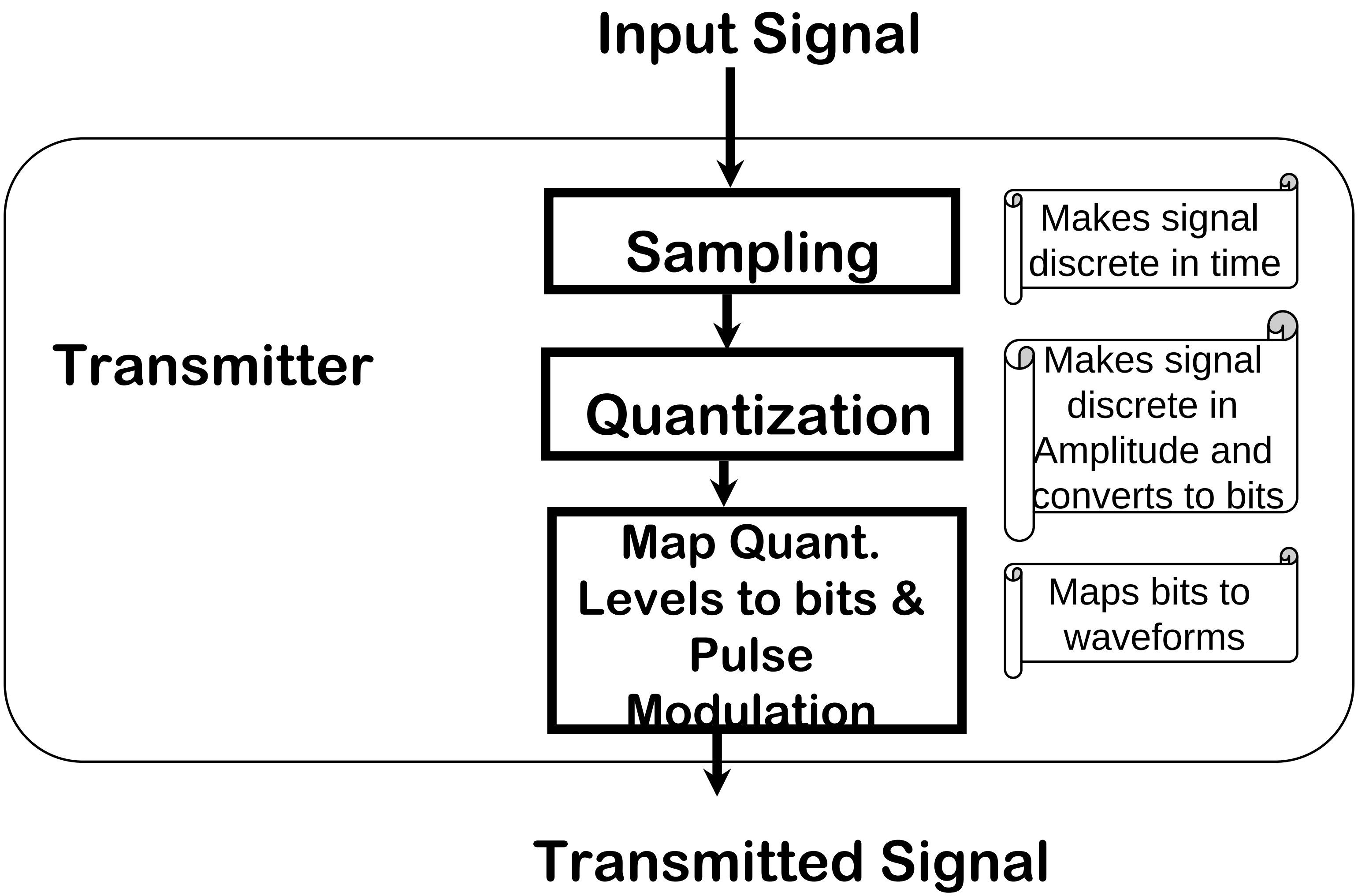
Digital Information

- With the rise of the internet, very often the ‘source’ of information is simply a computer which inherently uses digital information
- Such digital information fits naturally with a digital communication system
- No analog-to-digital conversion is necessary
- There may be conversion from binary to *M*-ary information within the digital communication system

Basic Structure of PAM / PPM / PWM



Basic Structure of PCM

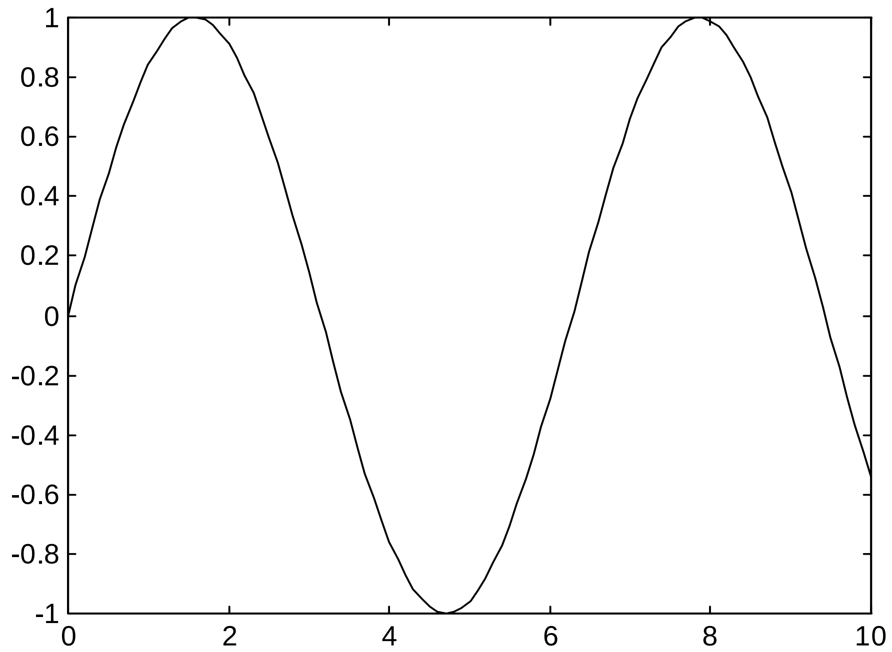


PAM / PWM / PPM vs PCM

- PAM/PWM/PPM are systems where the information signal is typically discrete in time but not necessarily in amplitude (thus not truly digital)
  - Infinite number of waveforms can be sent
  - Useful for time multiplexing multiple signals
  - Noise readily degrades information
  - Not particularly common
  - PAM is the first step in PCM, thus is useful for study of PCM
- PCM are systems where the information must be discrete in time and amplitude
  - Finite number of waveforms can be sent (i.e., digital)
  - Requires both sampling and quantization
  - Can be made more robust to noise
- Both require sampling, thus we study sampling first

Digital Representation of Analog Signals

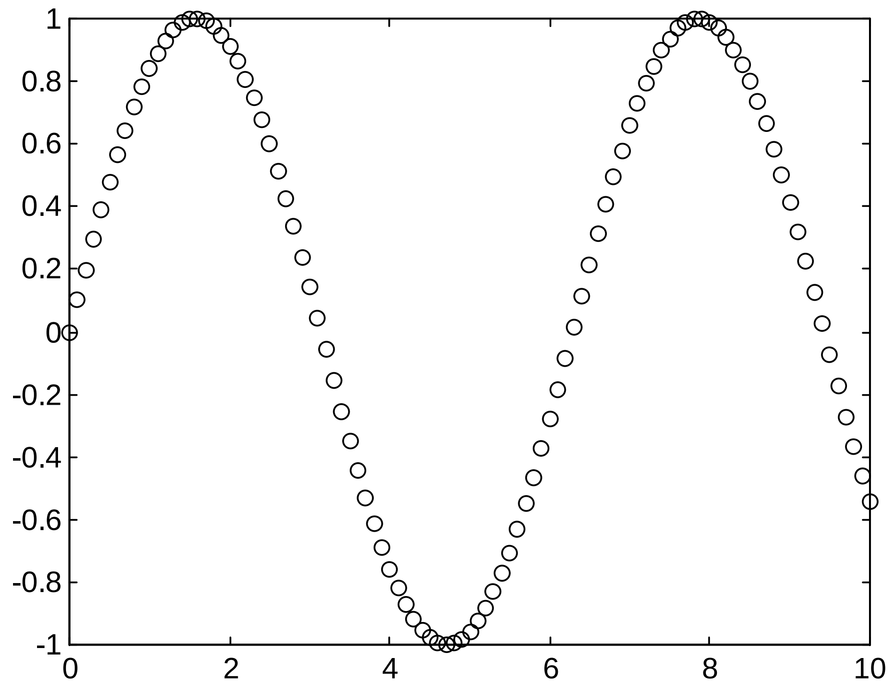
- Analog signals (e.g. voice,video) are continuous in time and amplitude:



Digital Representation of Analog Signals

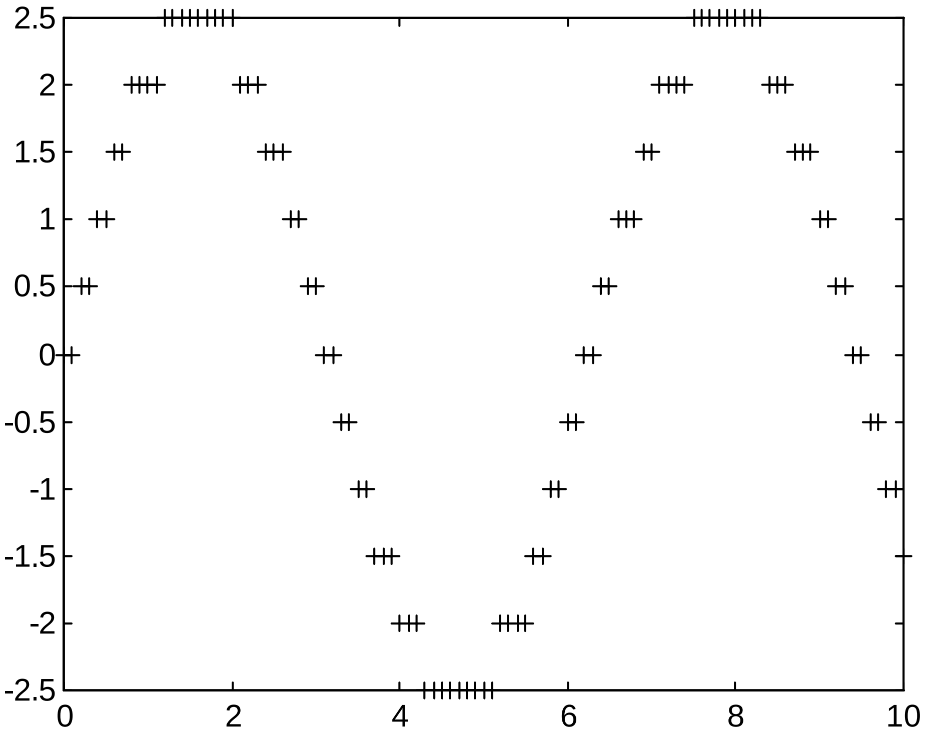
Analog and Digital Communications

- Sampling analog signals makes them discrete in *time*:



Digital Representation of Analog Signals

- <u>Quantization</u> of sampled analog signals makes the samples discrete in amplitude:



•The number of discrete amplitude levels is directly related to the number of bits we are willing to use to represent each sample. Thus, we trade-off bit rate and fidelity

Digital Representation of Analog Signals

- If done properly, sampling introduces no distortion into the signal
- Quantization does introduce distortion
  - There is a tradeoff between distortion and bandwidth requirements
  - More bits per sample $\rightarrow$less distortion
  - Fewer bits per sample $\rightarrow$ lower bandwidth requirements
- We will consider sampling in the next lecture.
- We will discuss quantization next week.

Summary

- In this lecture we have briefly overviewed some of the basic concepts in digital communications including
  - Analog vs Digital communications
  - Baseband vs. Bandpass signals
  - Pulse Amplitude Modulation, Pulse Position Modulation, Pulse Code Modulation
- Next lecture we begin to study digital communications in detail by studying sampling