MCT 4334

Embedded System Design

Week 11 Communication with other Devices

Reference: Data Communications and Networking, Behrouz Forouzan, 4th edition, McGraw-Hill Science

Outline

- Introduction
- Type of communication systems
- Transmitting data in digital form
- Transmitting data in analog form

Introduction

- Many embedded systems are embedded in the environment.
- There is a need for embedded systems to communicate with one another (e.g. to share information)

Examples

Glass break detector

Baseband

Home security system

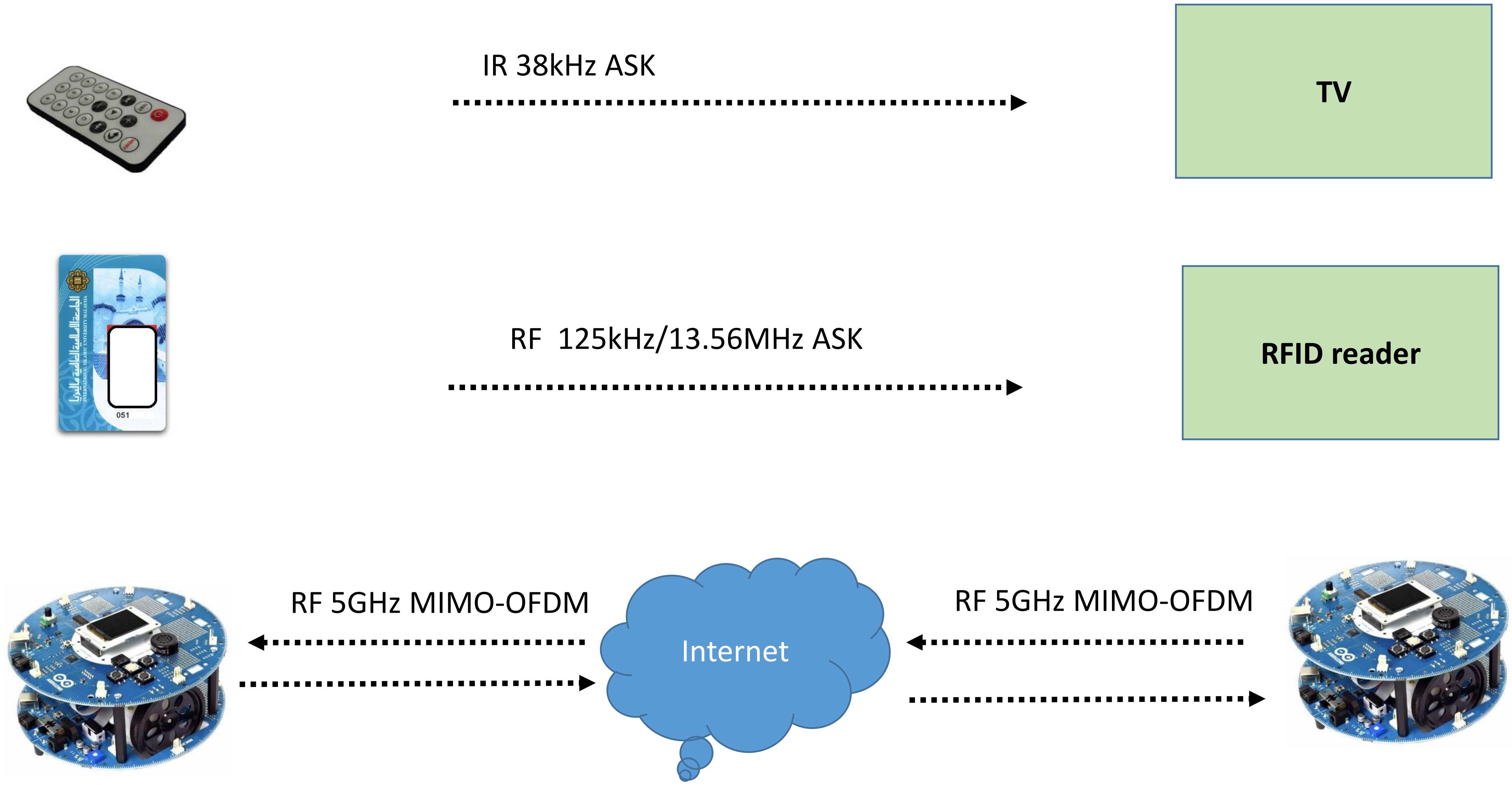
Baseband 4D-PAM5 (Ethernet)

Network video recorder

RF 315/433 MHz ASK

Auto-gate system

Examples



IR 38kHz ASK
TV
RF 125kHz/13.56MHz ASK
RFID reader
051
RF 5GHz MIMO-OFDM
Internet
RF 5GHz MIMO-OFDM

Data flow

Communication systems can be divided into 3 categories based on direction of data flow.

- **Simplex**

  Unidirectional

  Examples: servo motors, sensors

- **Half-duplex**

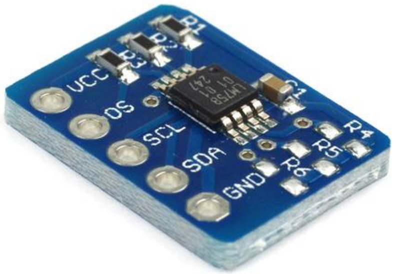
  Each device can transmit and receive. But not at the same time.

  Example: walkie-talkies

- **Full-duplex**

  Bidirectional

  Example: touch screen, hard disk, flash drive



I2C temperature sensor

2.8” TFT Touch Screen (SPI)

Example

Suppose Microcontroller A has to send **a single bit** of information to Microcontroller B.
Assume that they share the same GND.

PB0 of Microcontroller A is configured as output.
PB0 of Microcontroller B is configured as input.

Question
If the PB0 of Microcontroller B is LOW, is Microcontroller A trying to send a LOW bit or not sending anything?

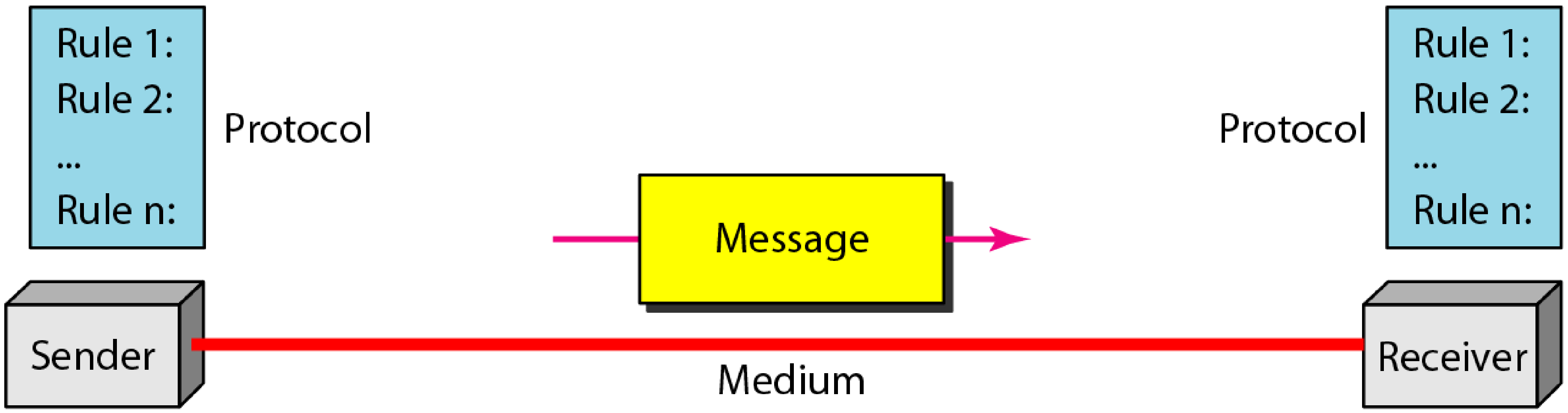
PB4 configured as output

PB4 configured as input

Protocols

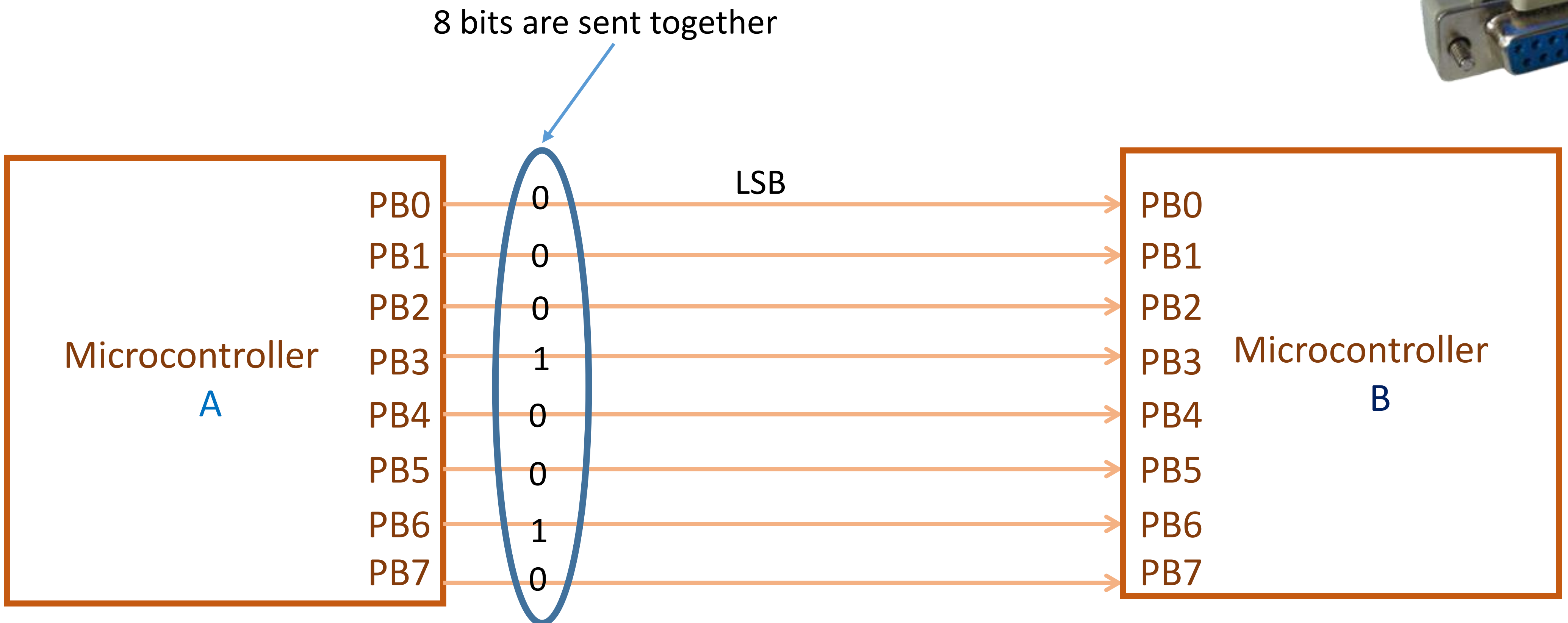
- The communicating devices need to agree on rules to send and receive data.
- This set of rules is called a protocol.
- Without a protocol, two devices may just be connected but not be communicating.

Examples: HTTP, FTP, SMTP, POP, TCP, UDP, IMAP, SOAP



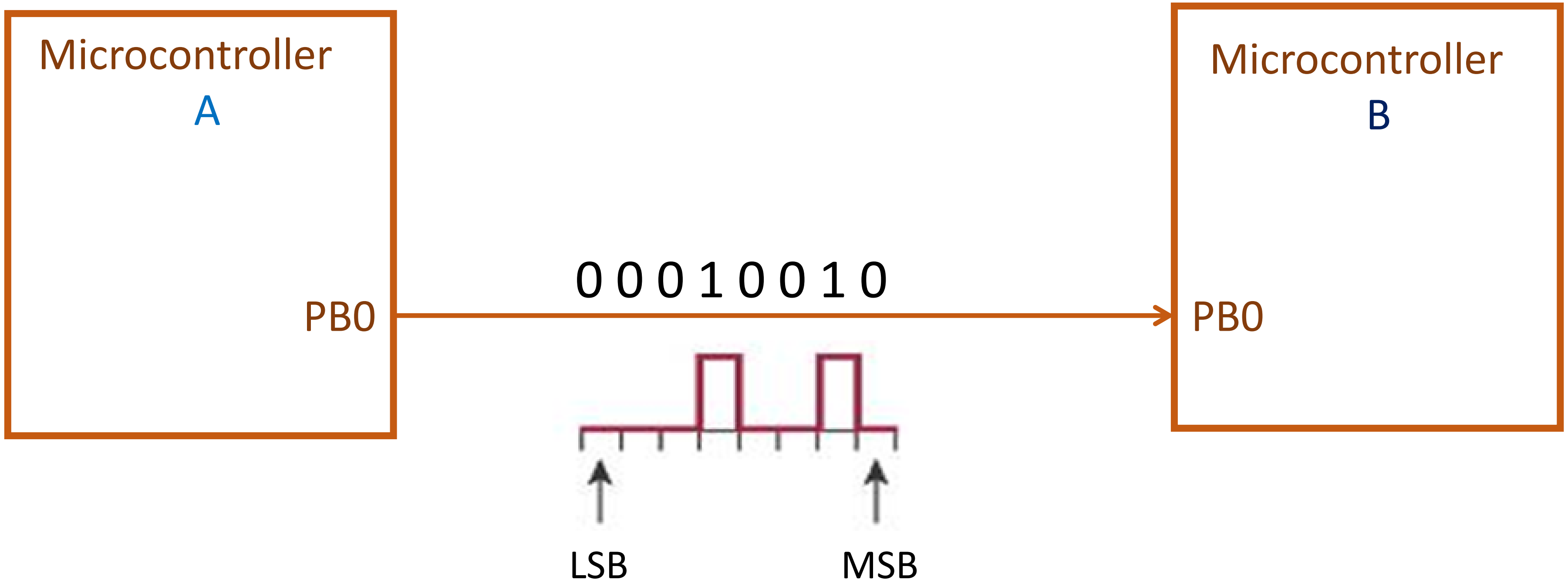
Parallel Transmission

- Suppose Microcontroller A has to send a byte of information to Microcontroller B.
- Using parallel transmission, the entire byte can be sent at once.
- *Drawback:* the entire port B of both microcontrollers get used up.



Serial Transmission

- Using serial transmission, the byte of information gets sent bit by bit.
- Only one data line is required.
- Serial transmission is slower than parallel transmission. Implementation is also more difficult.
- How does the receiver keep track of the bits? 00010010 can be wrongly interpreted as 01010.

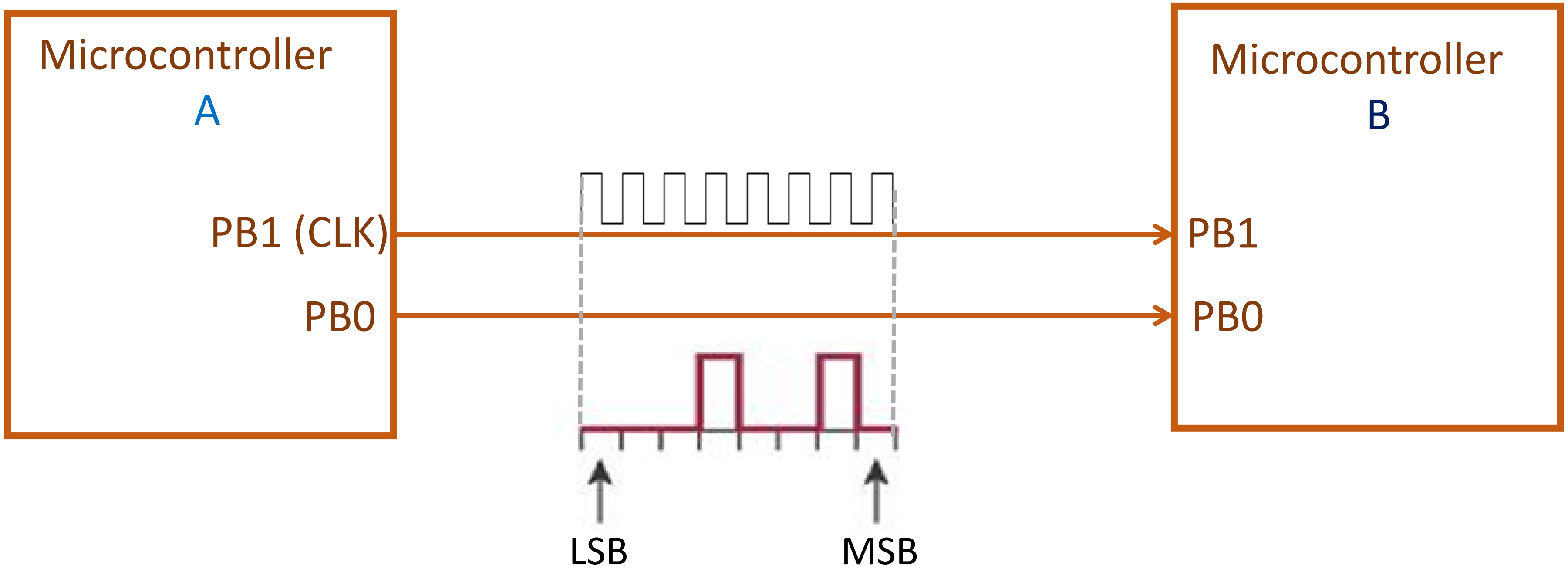


Synchronous vs Asynchronous Transmission

- A synchronous transmission system uses a separate clock line for synchronization (e.g. I2C and SPI)
- An asynchronous transmission system does not use a separate clock line.

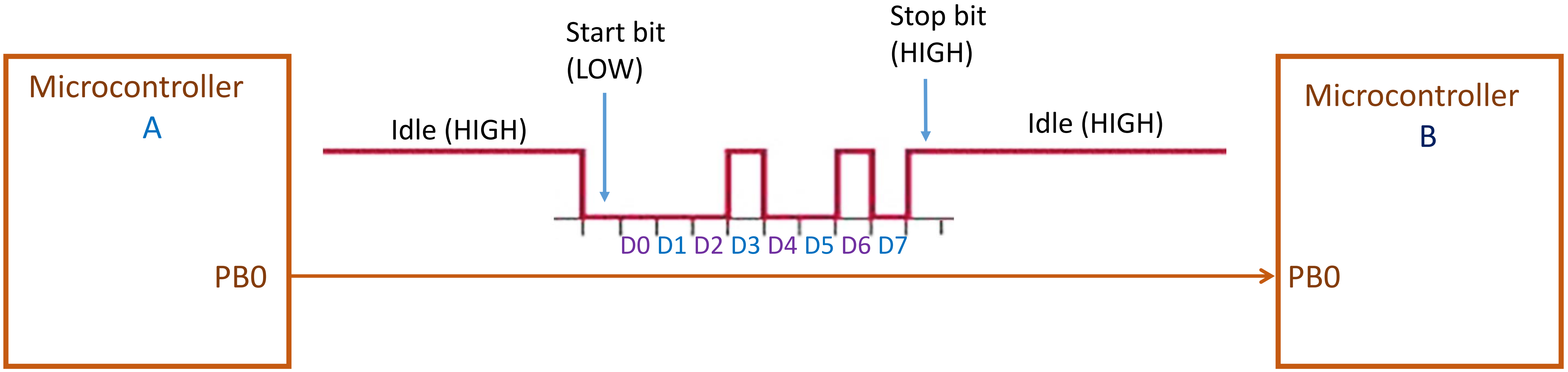
Synchronous transmission

- The data byte is sent through one line and CLK signal is sent through a separate line.
- The receiver can observe the clock signal and read the individual bits at clock transitions (either PGT or NGT).
- Advantage: high data transfer rate can be achieved (compared to asynchronous)
- Disadvantage: a dedicated CLK line is required.



Asynchronous Transmission

- There is no common clock between sender and receiver.
- The data stream contains extra synchronization information (such as start bit and stop bit)
- Sender and receiver need to agree on transfer speed (baud rate)
- Advantage: only data line is needed.
- Disadvantage: signal becomes longer (because of added synchronization information)



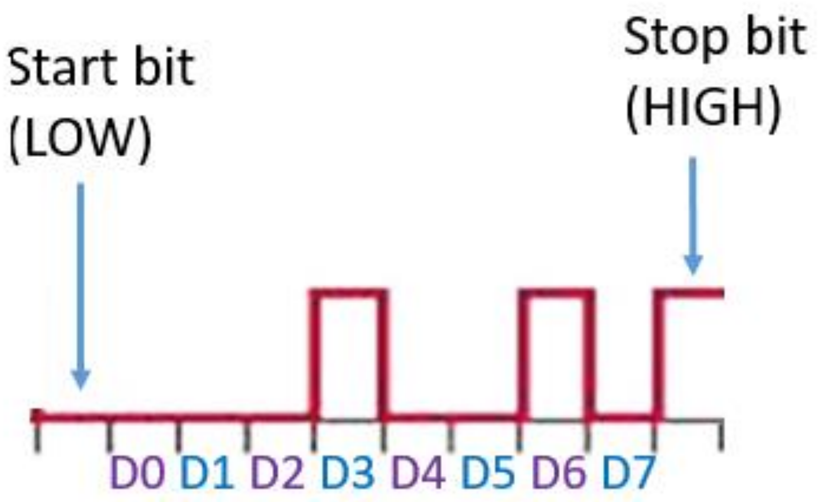
Bit vs Symbol

- 8 bits of data are represented by 10 signal elements or symbols.
- Bit refers to the smallest element of the original data
- Symbol refers to the smallest element of the transmitted signal.
- Symbol length can be shorter or longer than data length.

Example:

Data length = 8 bits

Symbol length = 10 units



Bit-rate and baud-rate

Most digital signals are not periodic, thus period and frequency are not appropriate measures.

Bit rate = number of data bits sent/received in 1 second (Unit: bps)

Baud rate = number of symbols sent/received in 1 second (Unit: Bd)

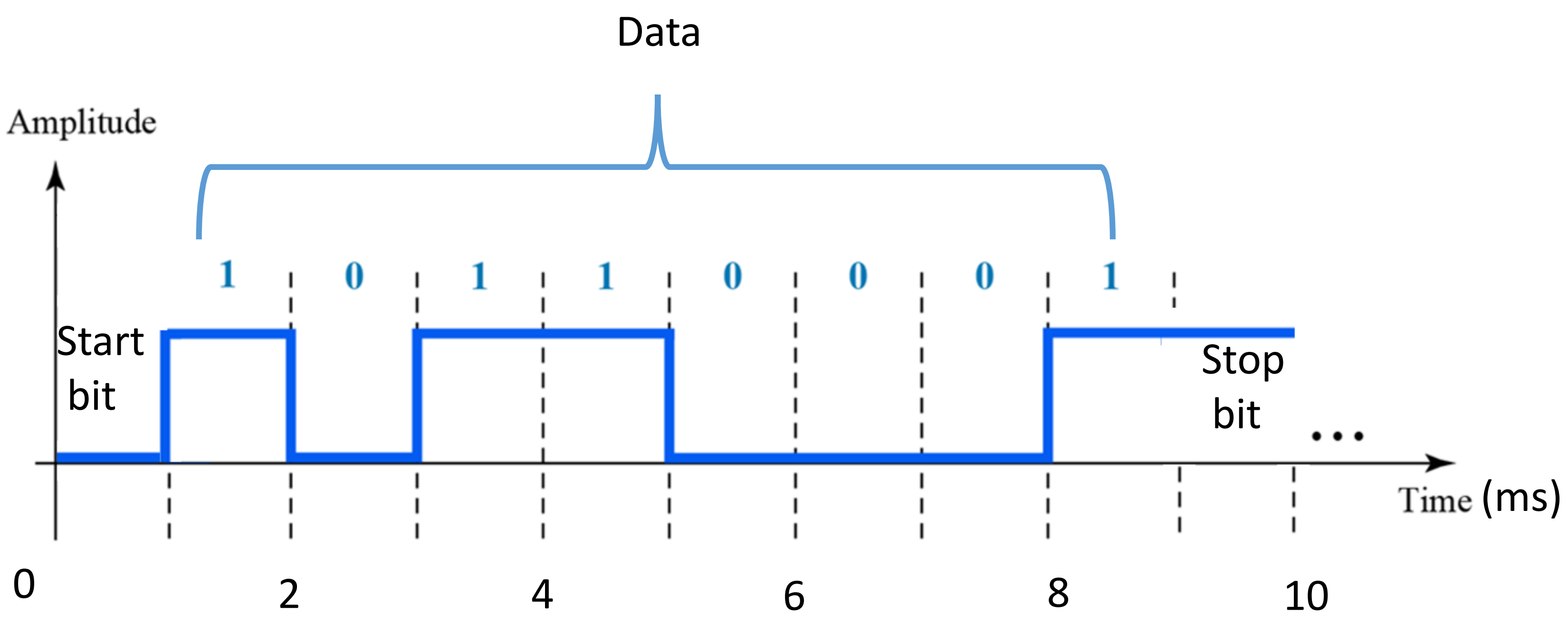
Note: Bit rate and baud rate are expressed in decimal prefix instead of binary prefix
(1Kbps = 1000 bps instead of 1024 bps)
(1KBd = 1000 Bd instead of 1024 Bd)

Example 1

Determine the bit rate and the baud rate of the following signal which contains one byte of data.

10 symbols sent in 10 ms
Therefore baud rate = 1000 Bd

8 data bits sent in 10 ms
Therefore bit rate = 800 bps



Example 2

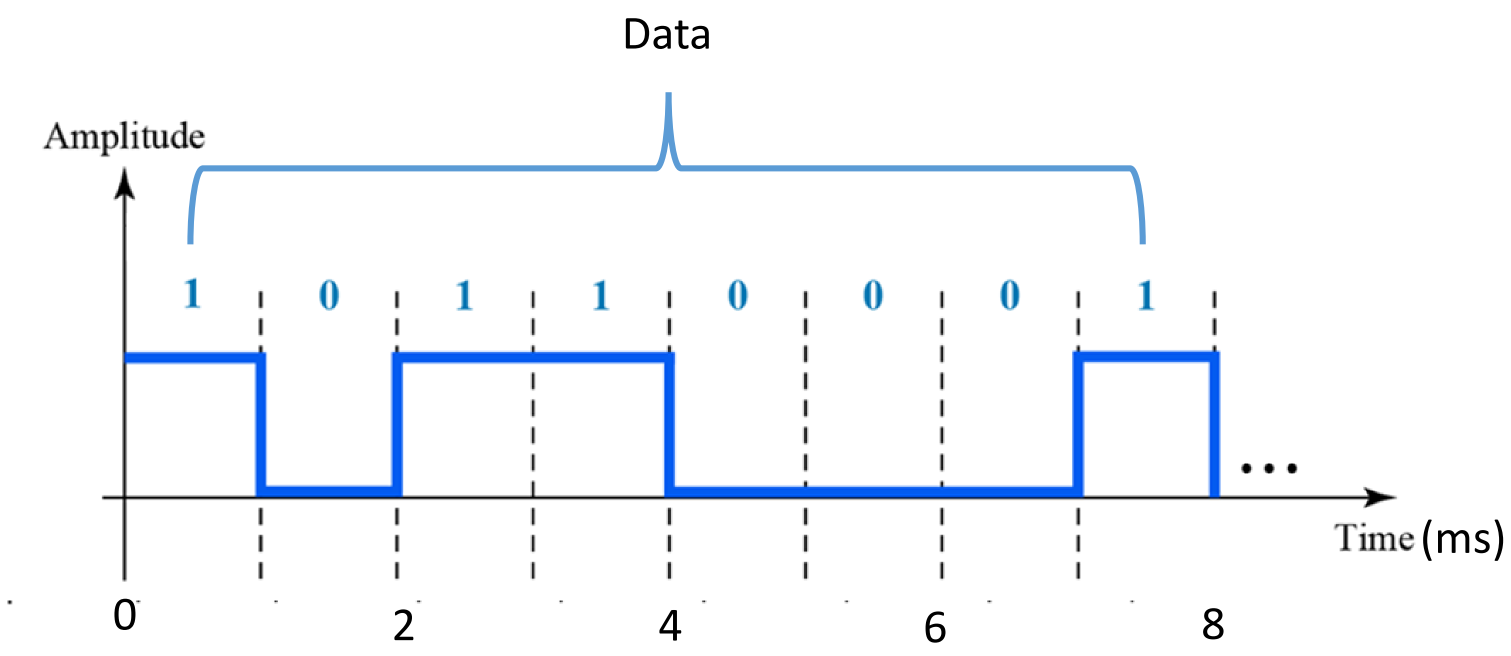
Determine the bit rate and the baud rate of the following signal which contains one byte of data.

8 symbols sent in 8 ms

Therefore baud rate = 1 kBd

8 data bits sent in 8 ms

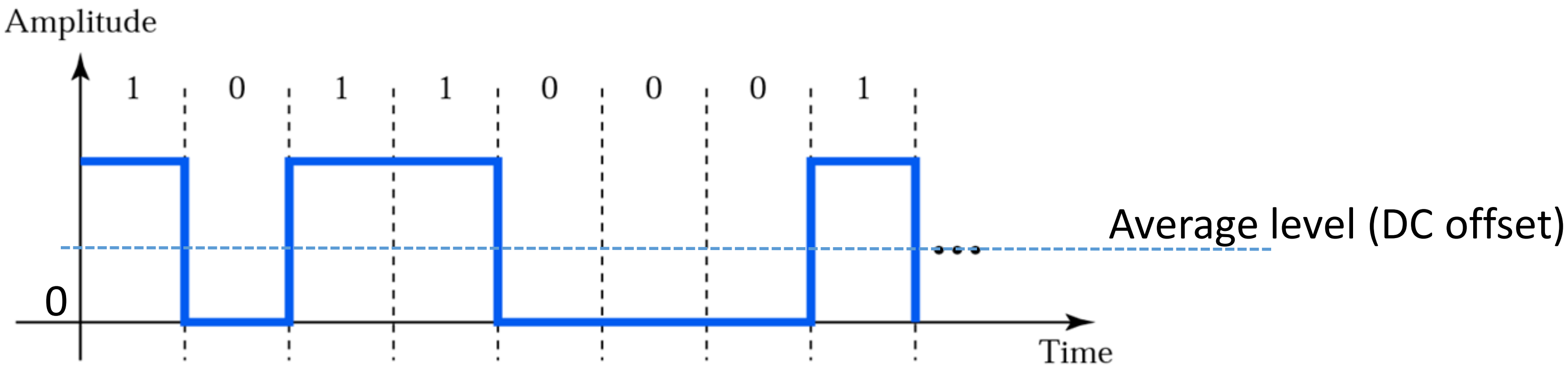
Therefore bit rate = 1 kbps



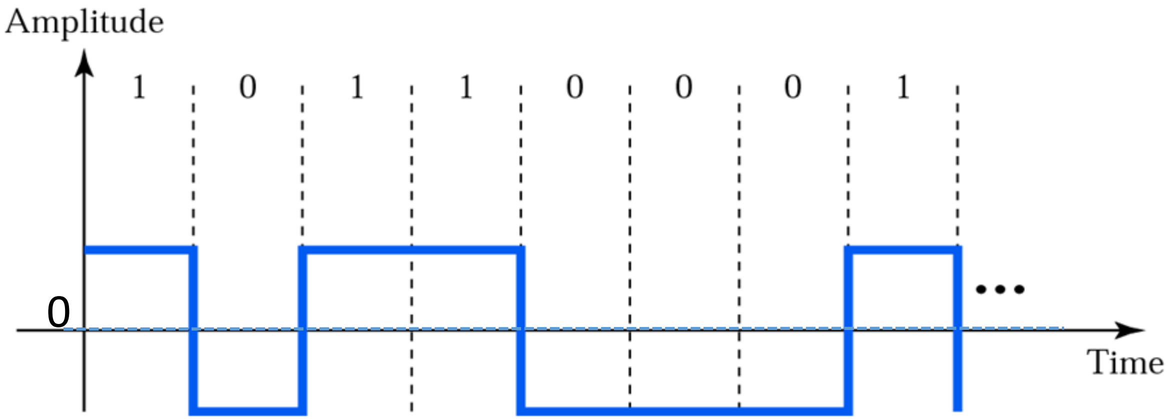
DC Component

- DC-balanced signals (with 0 DC offset) are preferred in data communication.
- Therefore, uni-polar signals are often transmitted.

Uni-polar



Bi-polar

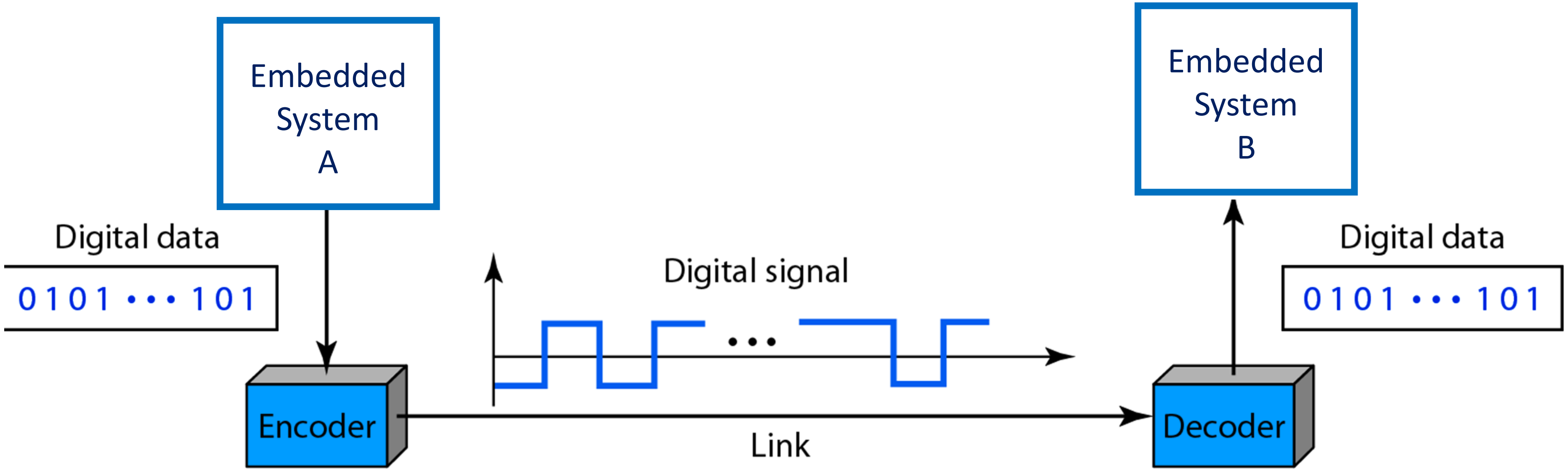


<u>Hardware Implementation:</u>

- GPIOs of ATmega328p only output 0V (LOW) and Vcc (HIGH)
- Op-amps can be used to change perform scaling and offsetting.

Line Coding

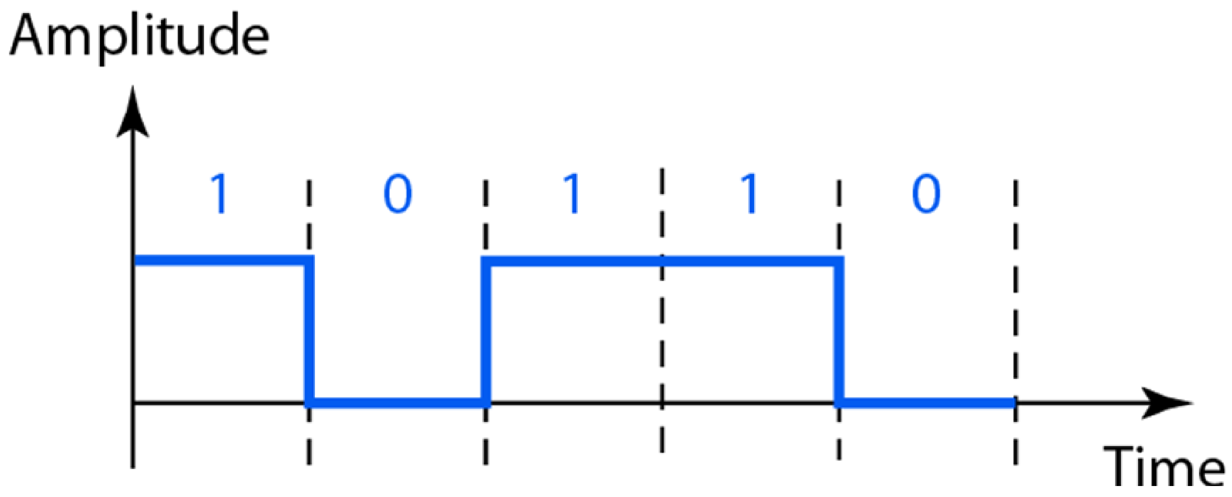
- Digital data are not usually transmitted in their native form.
- The transmitter encodes the data into some representation (which usually includes synchronization and error detection information).
- The receiver must decode it to get back the original data.



NRZ (Non-return to zero)

- 1 is represented by HIGH level and 0 is represented by LOW level.
- Very easy to implement.

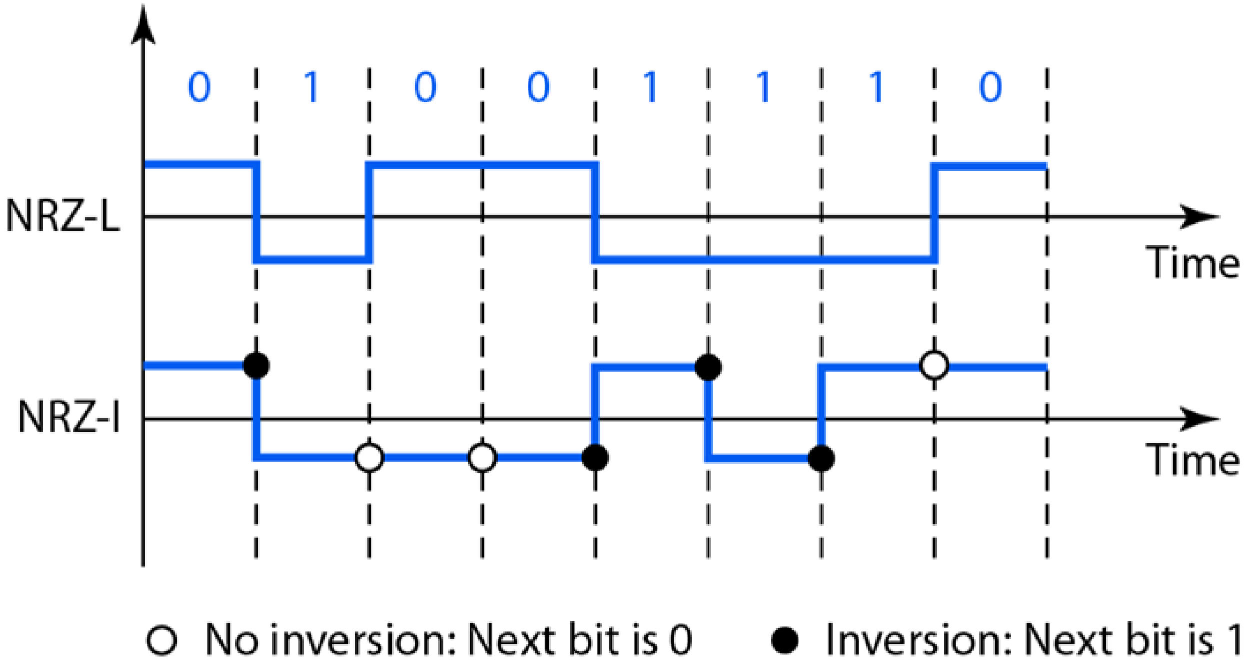
- Disadvantages: The signal contains DC component.
  Lack of synchronization information.



Each data bit is presented by one symbol

Baud rate = bit rate (if nothing else is added)

NRZ-L and NRZ-I



NRZ-L: 1 is represented by lower level and 1 is represented by higher level

NRZ-I: Whenever ‘1’ comes, invert the level of the signal.

<u>Need to know the initial level of the signal.</u>

In this example, it is assumed that the signal is initially HIGH.

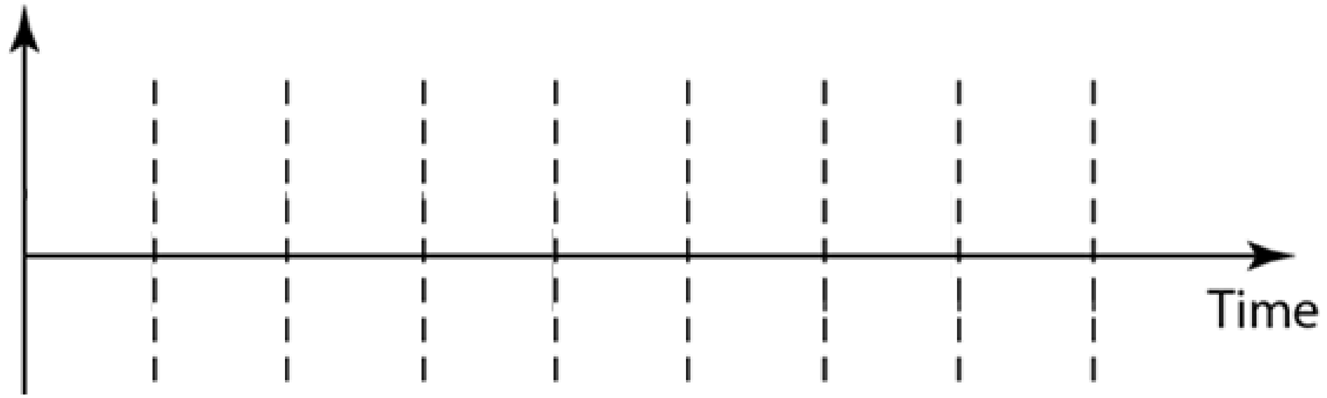
- Still contains DC component (lesser than NRZ)
- Lack of synchronization information.

Each data bit is presented by one symbol

Baud rate = bit rate (if nothing else is added)

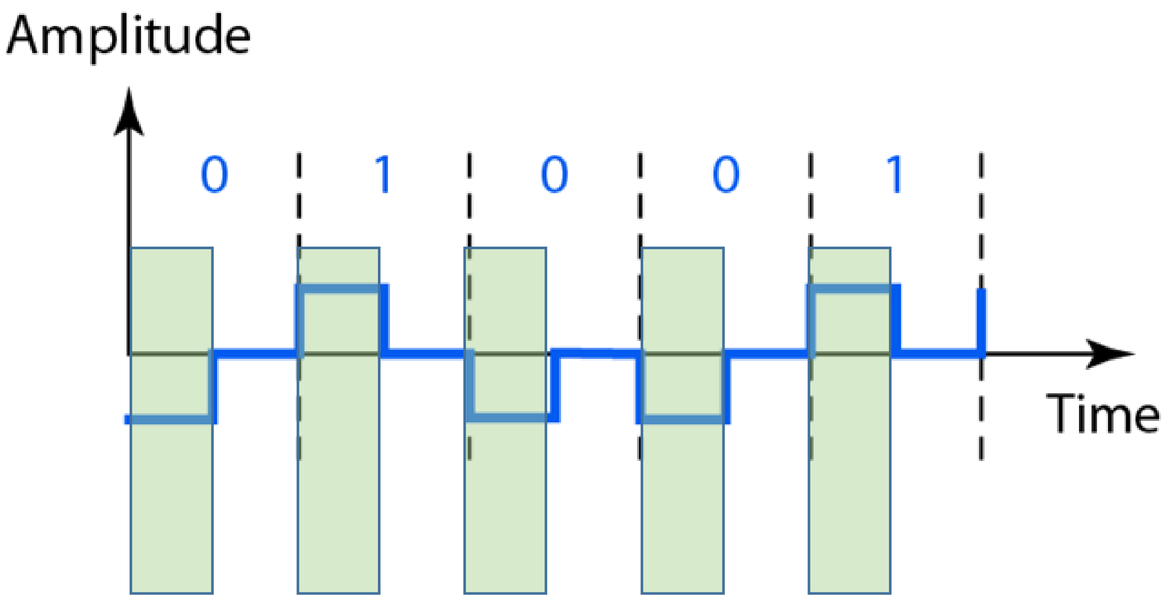
Example 3

Encode 1010 1101 in NRZ-I



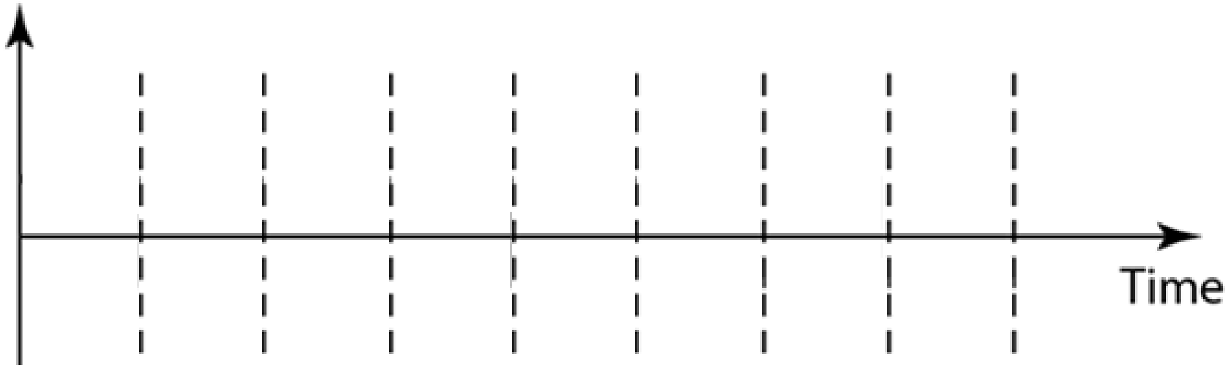
RZ (Return to Zero)

- 1 data bit is represented by 2 symbols.
    - The first symbol contains the actual data (higher level for ‘1’ and lower level for ‘0’)
    - The second symbol bit is used for synchronization
- Advantage: every bit has synchronization information.
- Disadvantage: difficult to implement (requires 3 voltage levels)
- Baud rate = 2 × bit rate



Example 4

Encode 1010 1101 in RZ

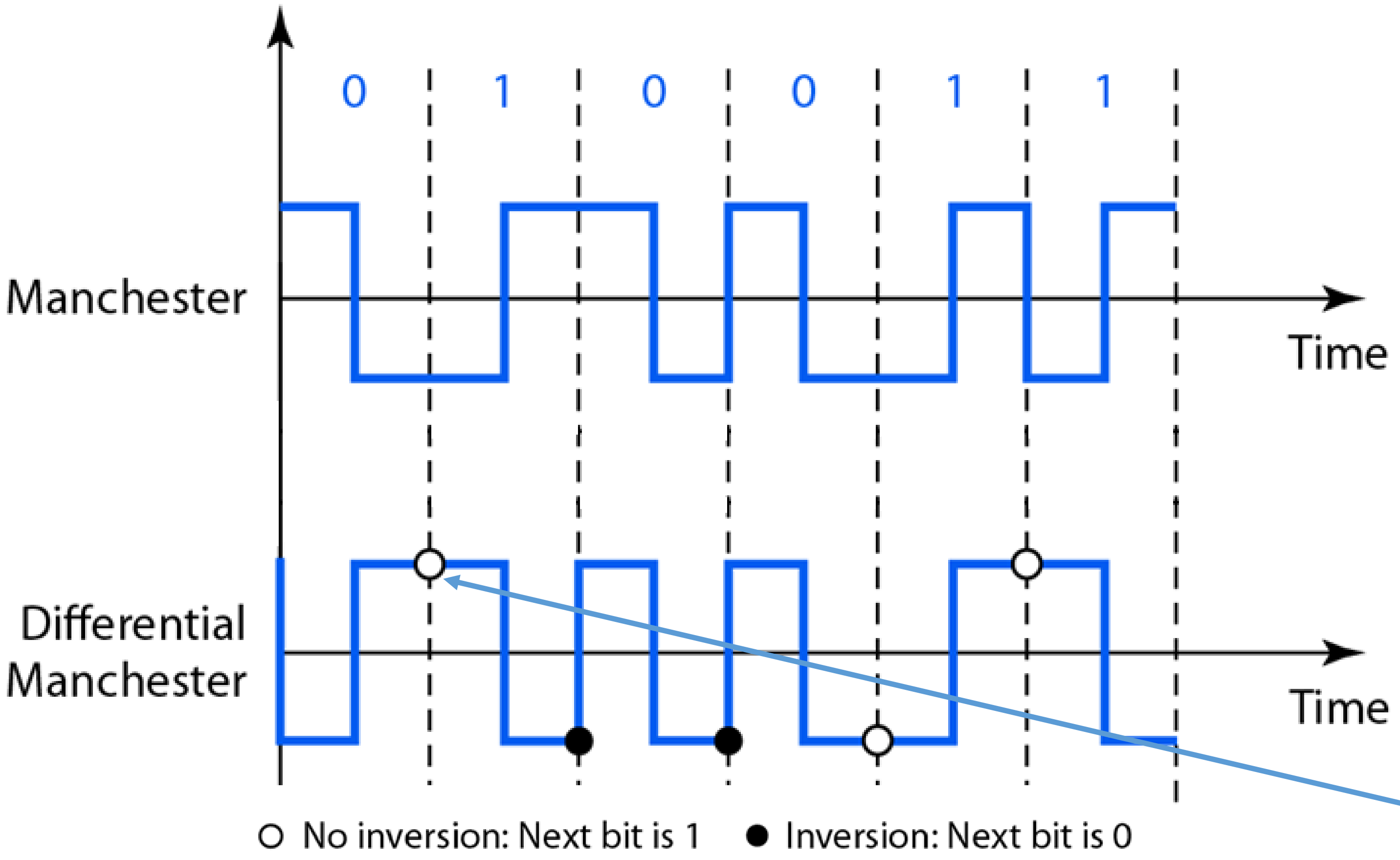


If the bit-rate of the signal is 10Mbps, determine the baud rate of transmission.

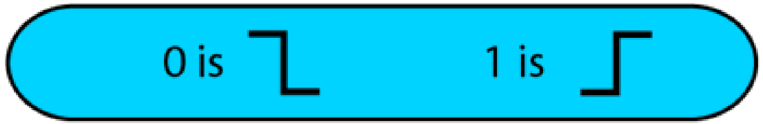
Answer: 20 MBd

Manchester and Differential Manchester

- Manchester and Differential Manchester schemes achieve the same thing as NRZ (using only two voltage levels)
- Differential Manchester is a combination of Manchester and NRZ-I.



In Manchester scheme,



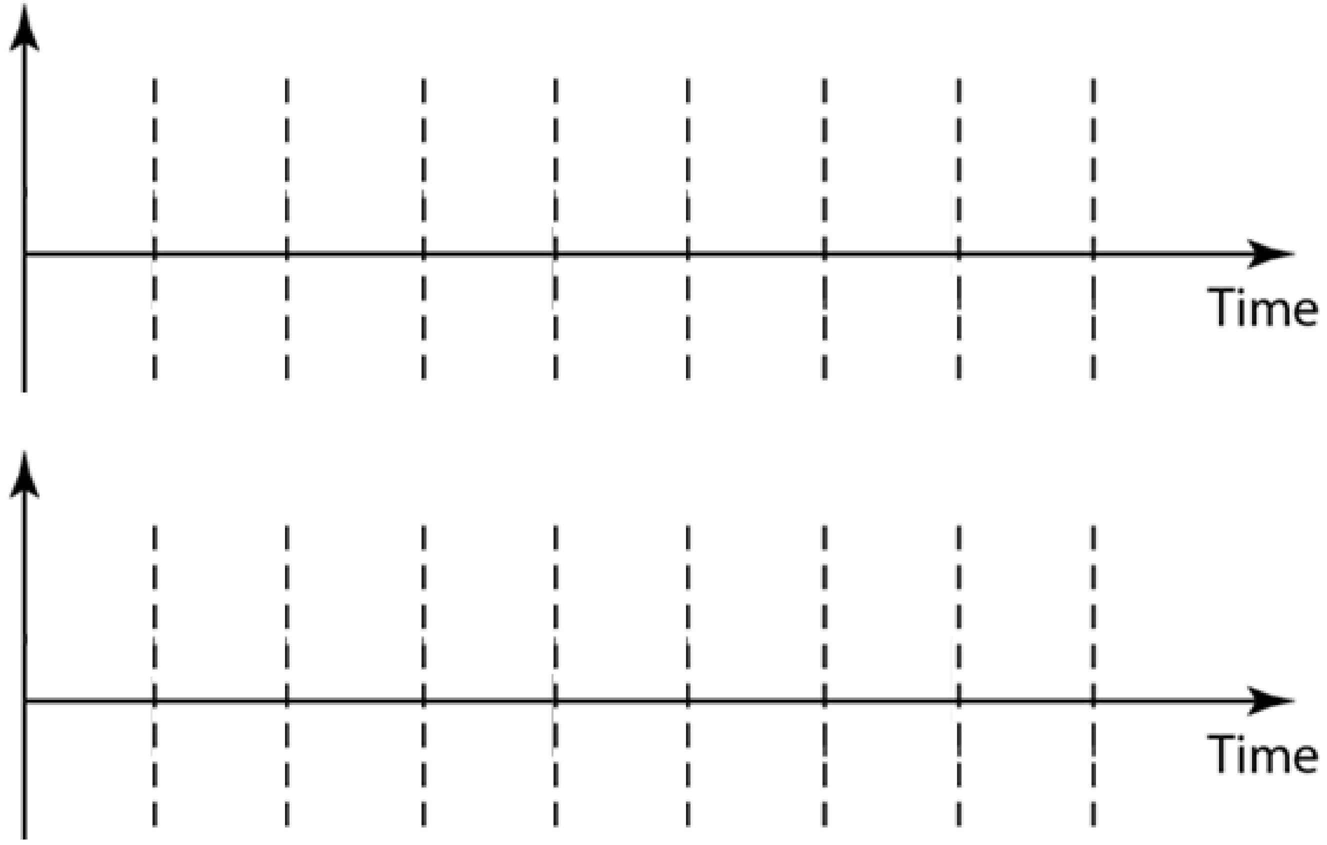
Differential Manchester

Need to know the initial level of the signal. In this example, it is assumed HIGH.

Example:
Current signal level = HIGH. Next data bit = HIGH
Therefore, no change

Example 5

Encode 1010 1101 in Manchester and Differential Manchester.



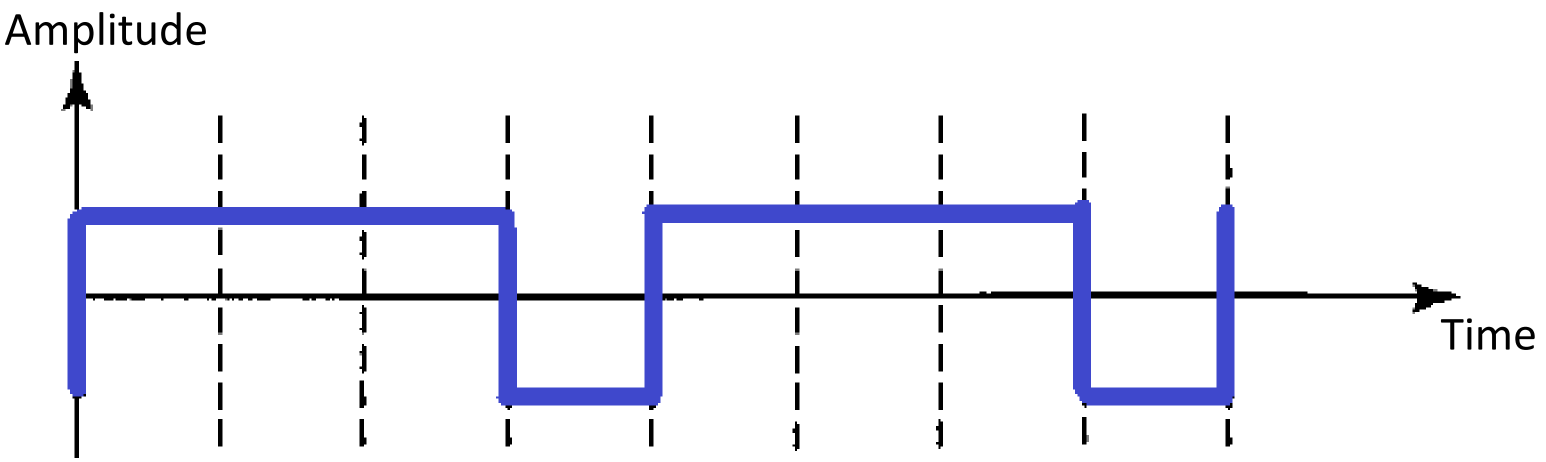
Example 6

Find the 8-bit data stream for each case depicted in the figures below.

Assume the initial state of the signals are LOW.

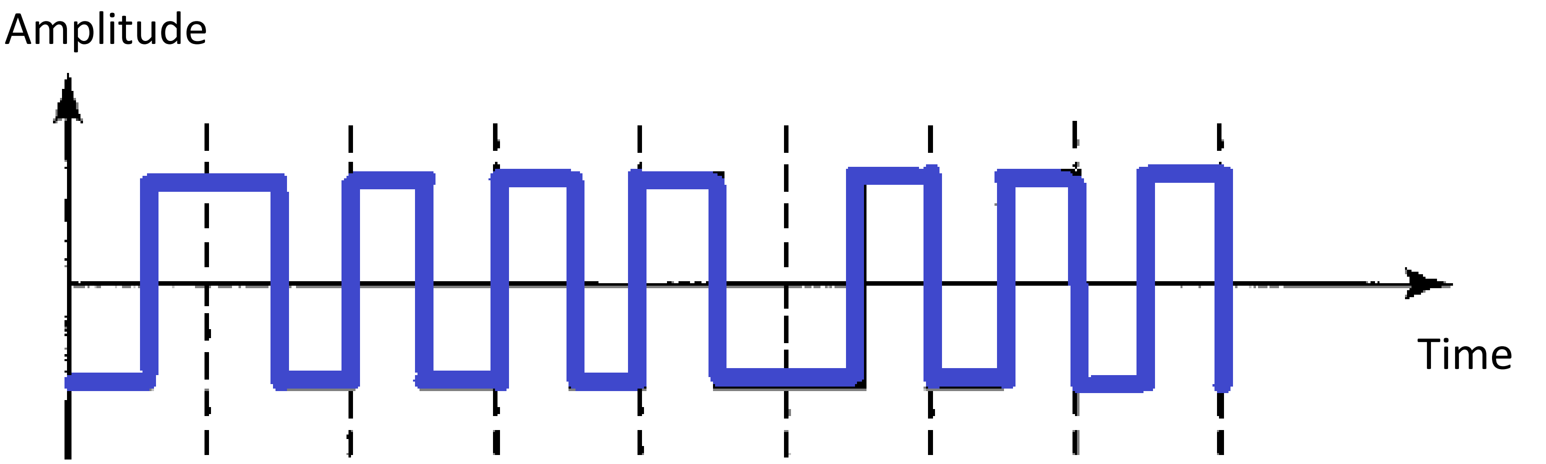
1001 1001

NRZ-I



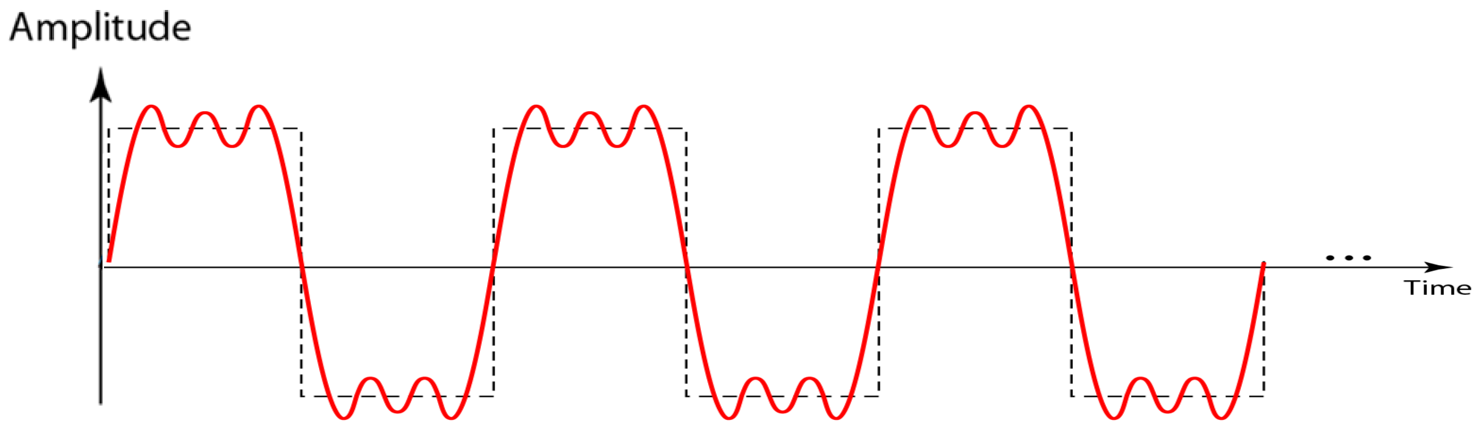
1100 0100

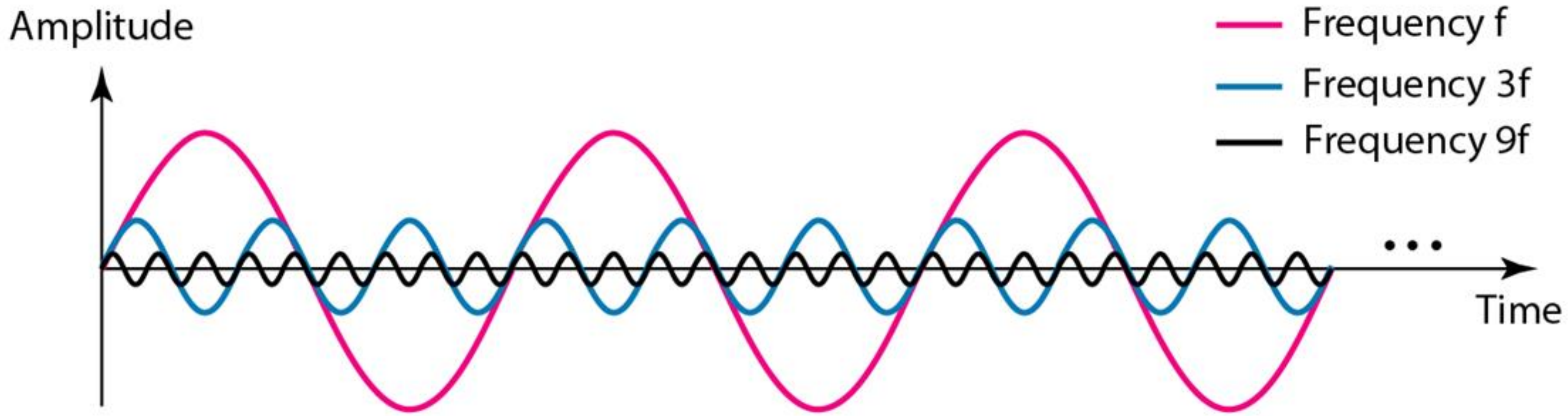
Differential Manchester

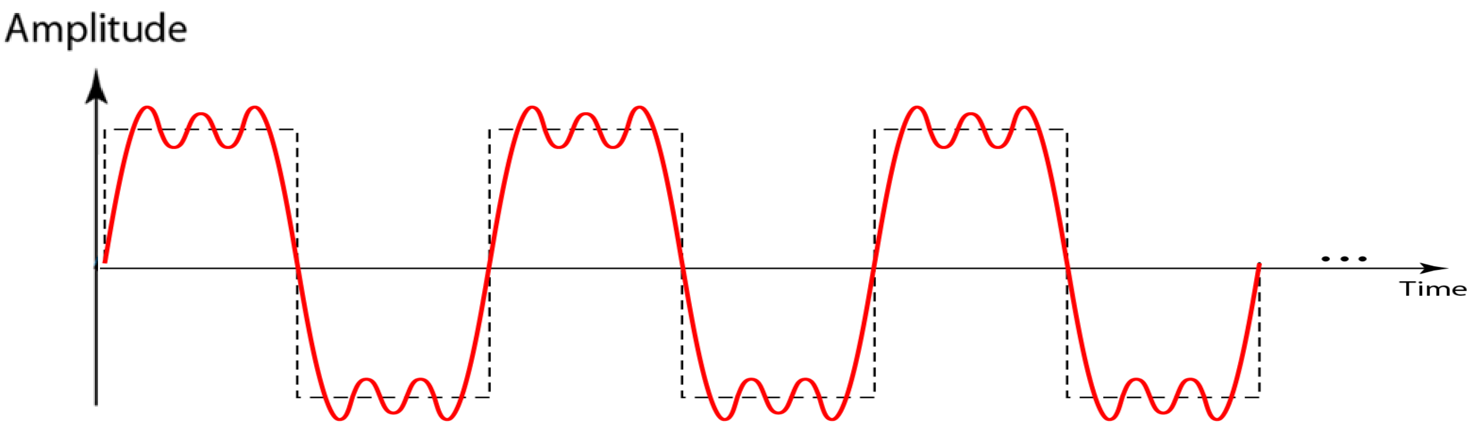


Review on Frequency domain

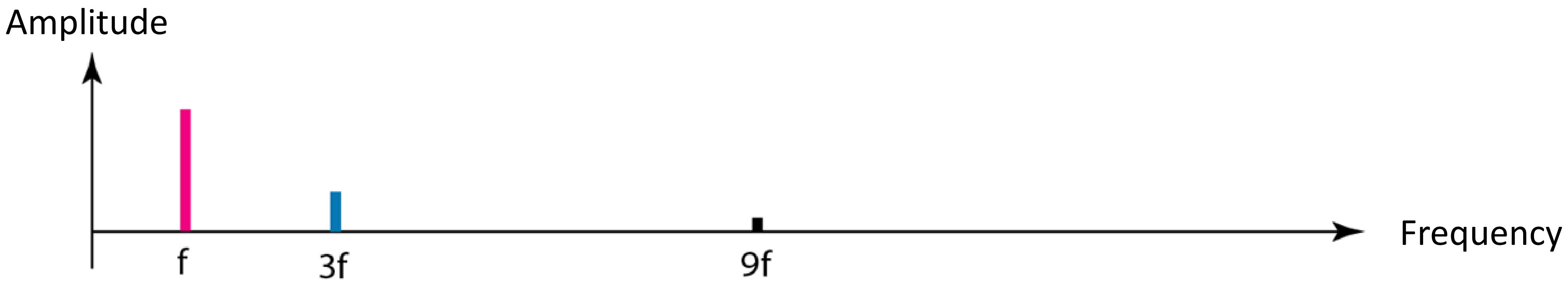
Any signal can be decomposed into a sum of sinusoidal signals.





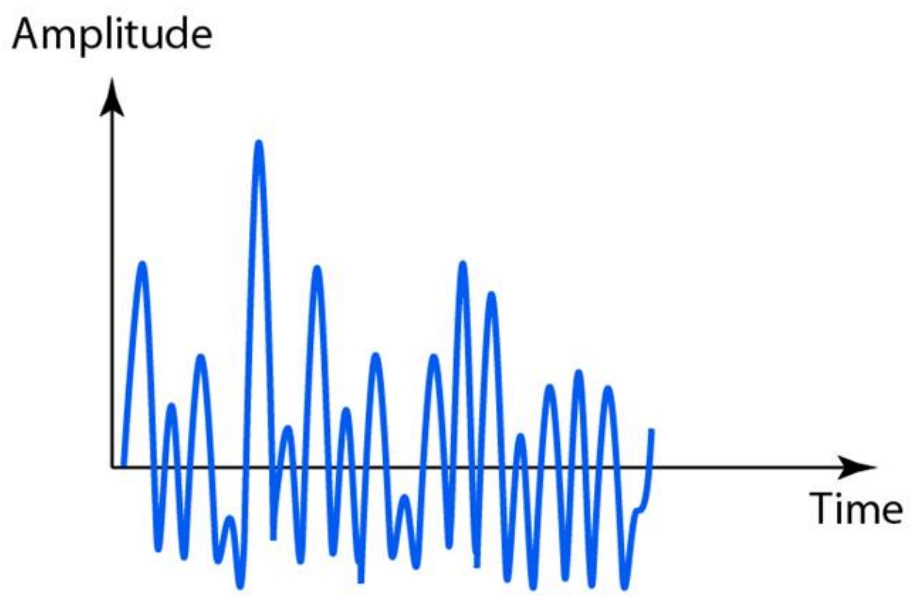


Frequency spectrum

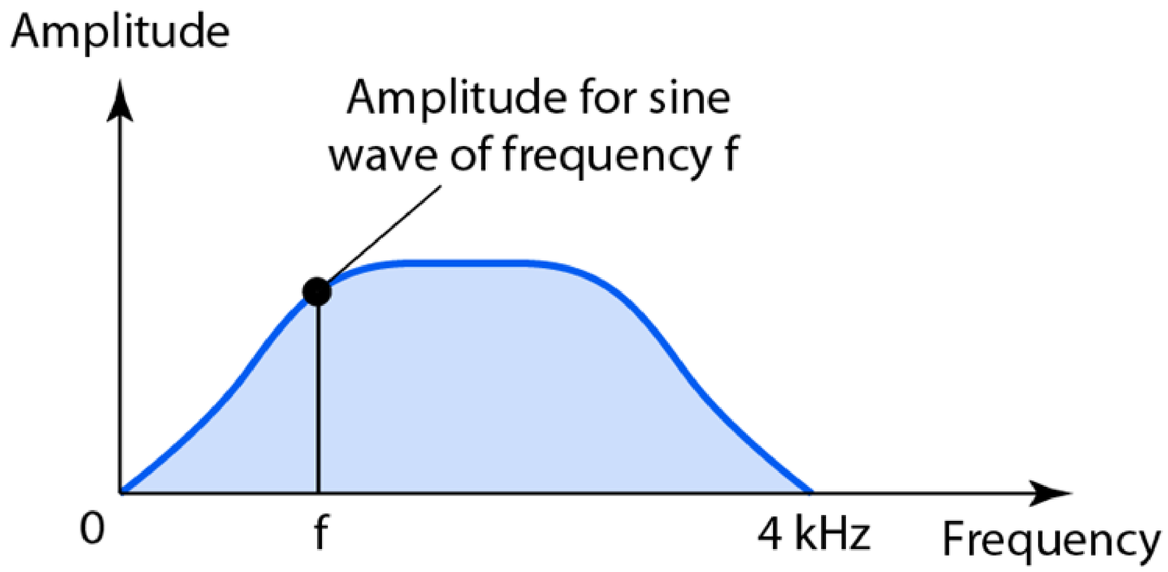


Frequency spectrum of a non-periodic signal

Time domain



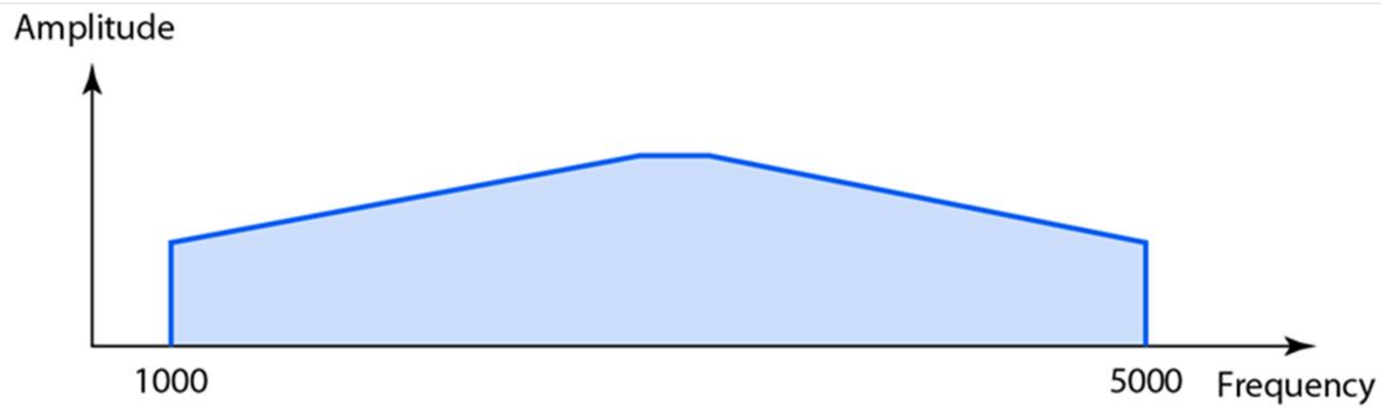
Frequency domain

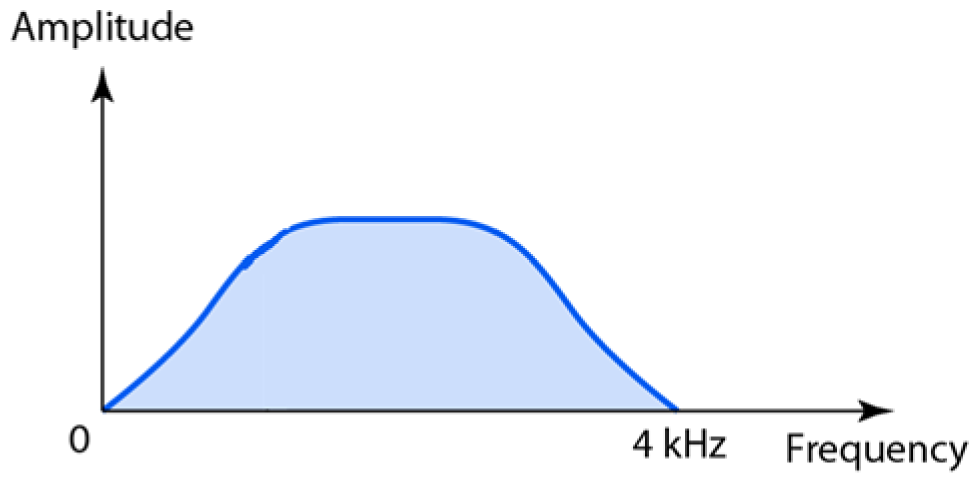


Bandwidth

The bandwidth of a signal is the difference between the highest and lowest frequency contained in the signal.

Bandwidth = 5kHz – 1kHz = 4kHz



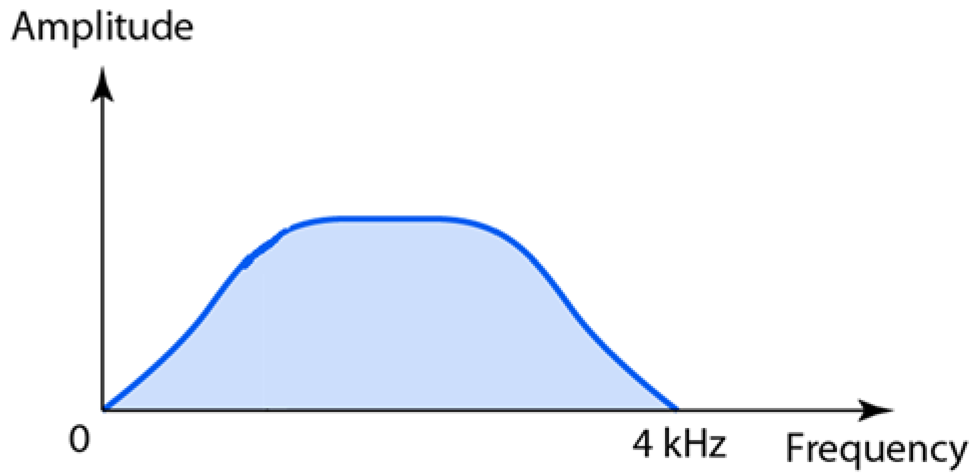


Bandwidth = 4kHz – 0 = 4kHz

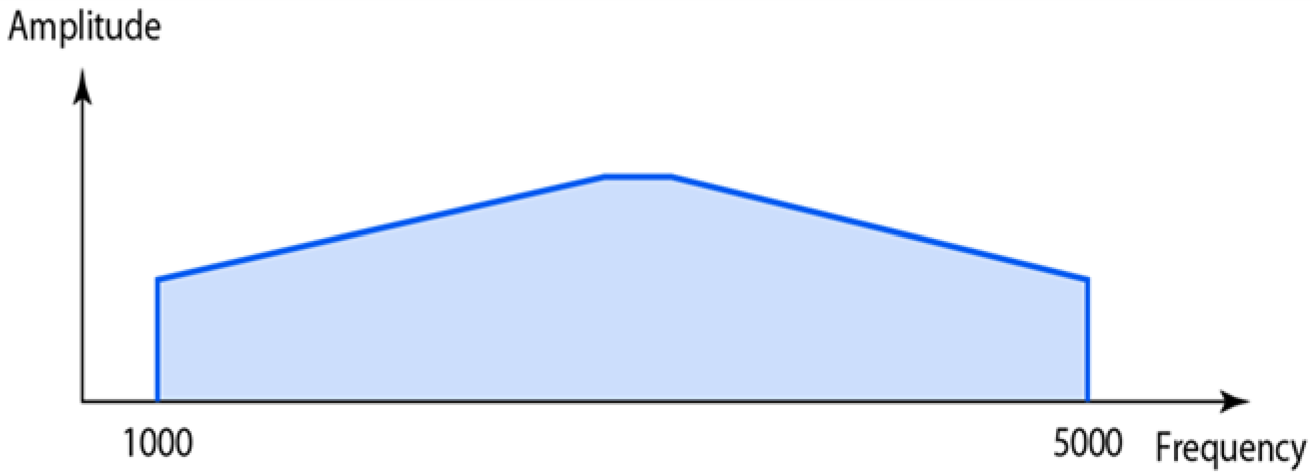
Baseband signal

- A baseband signal is a signal whose frequency spectrum ranges 0 Hz (or close to it) . It is called baseband because it occupies the base (the lowest range of the spectrum)
- Example: human voice (<5Khz)

Base-band signal

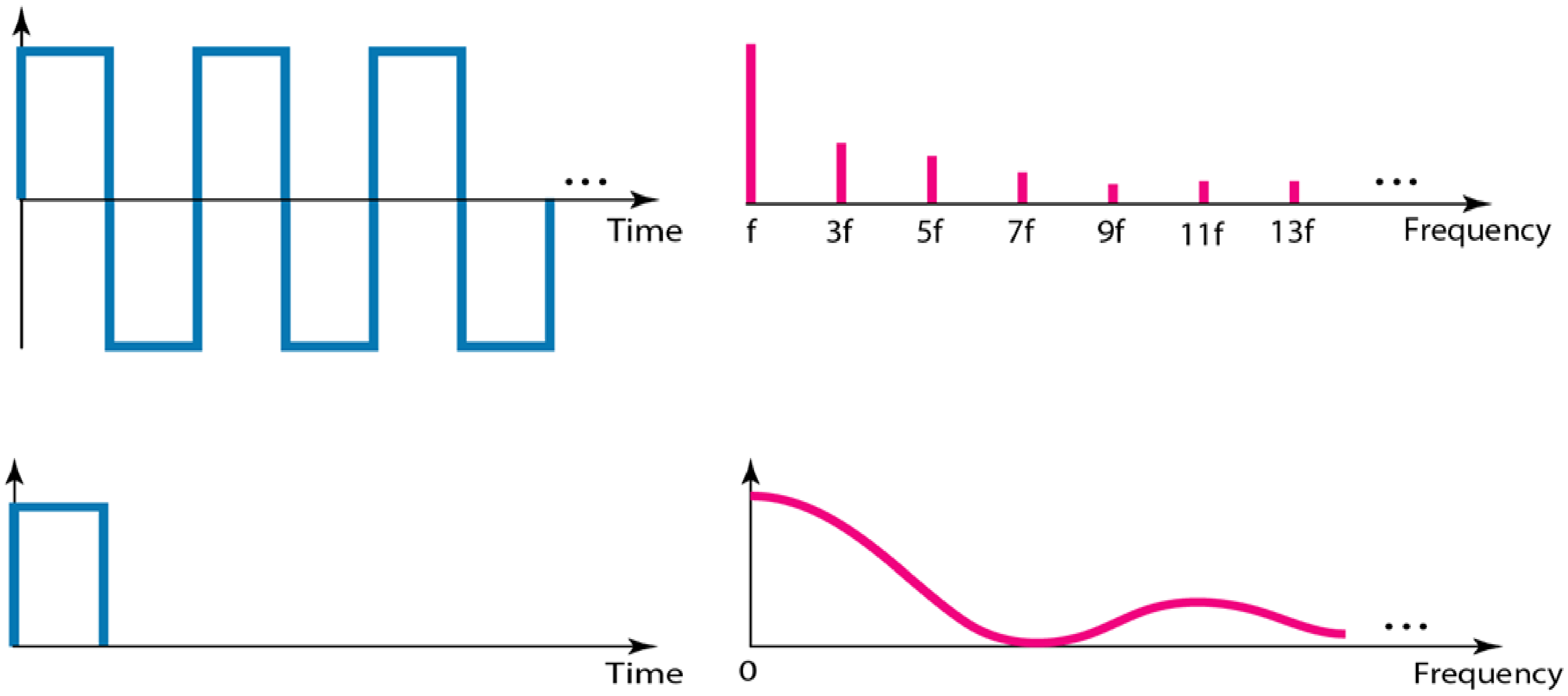


Broad-band signal



Bandwidth of Digital Signals

Digital signals have infinite bandwidth.



Transmission of Digital Signals

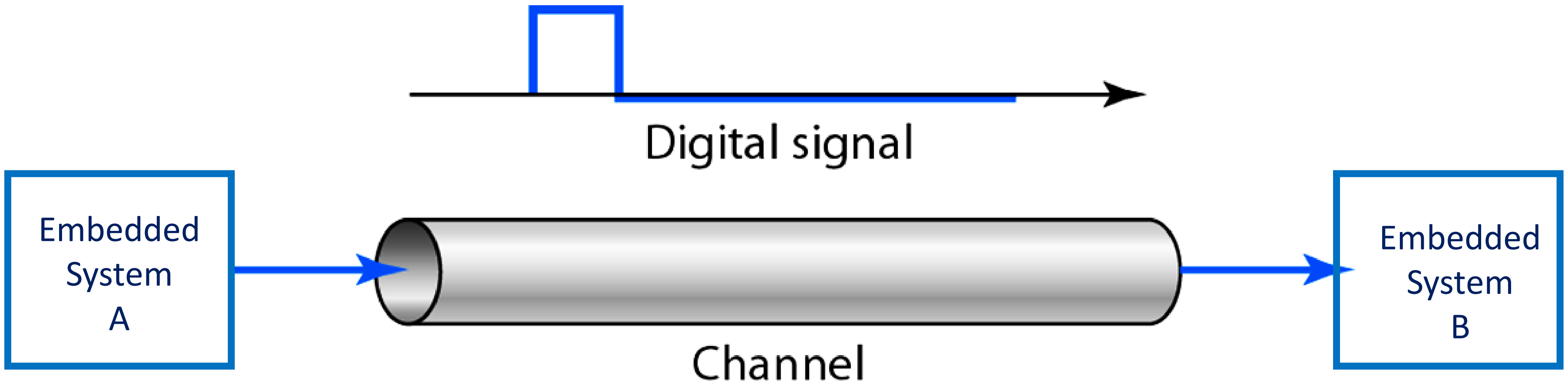
Digital signals can be transmitted using

1. Baseband transmission
   - Transmit digital signal digitally
   - Example: 100BASE-TX (Fast Ethernet)

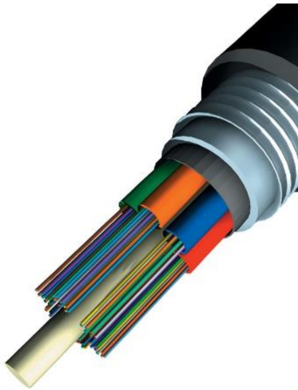
2. Broadband transmission
   - Transmit digital signal by transforming it into an analog signal.
   - Modulation is involved

Baseband Transmission

- Transmit encoded data digitally
- Normally used in wired communication

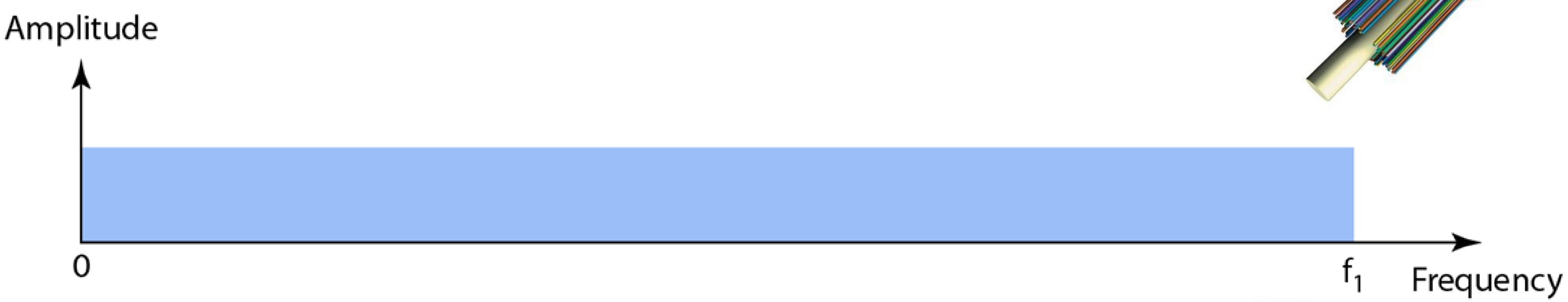


Every channel has a finite bandwidth.



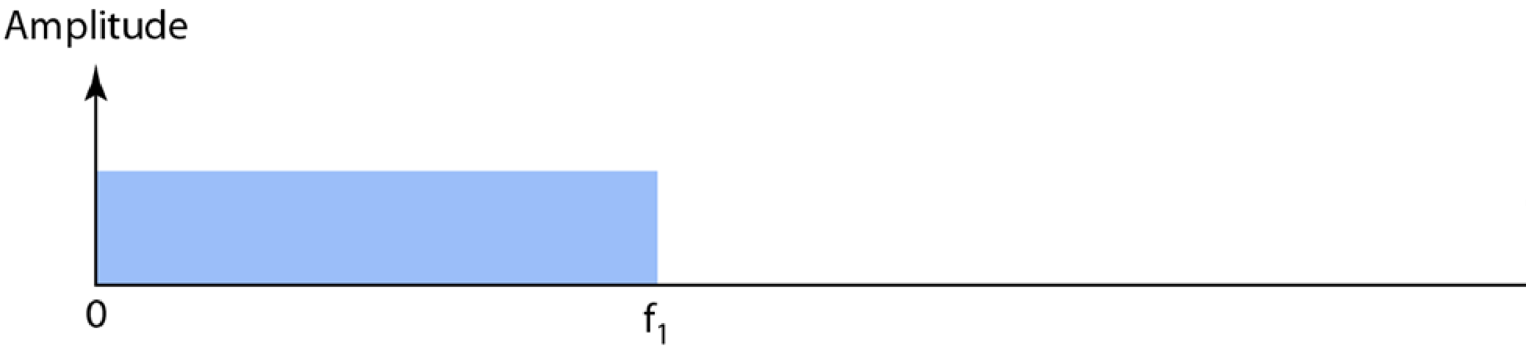
Channel with wide bandwidth

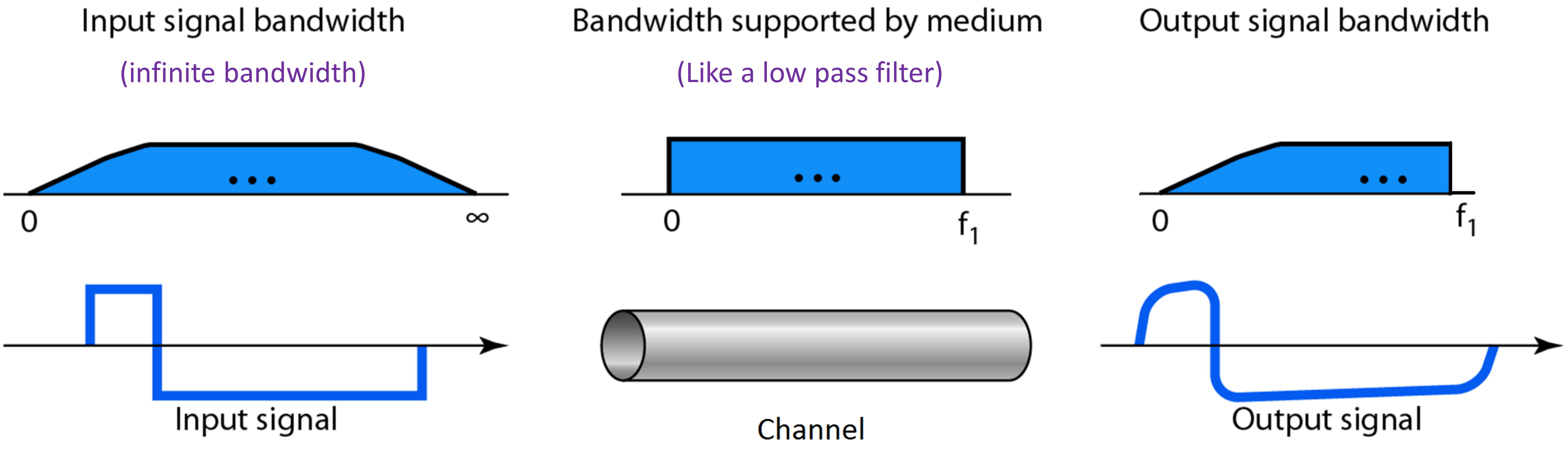
(Thick cable with good quality)

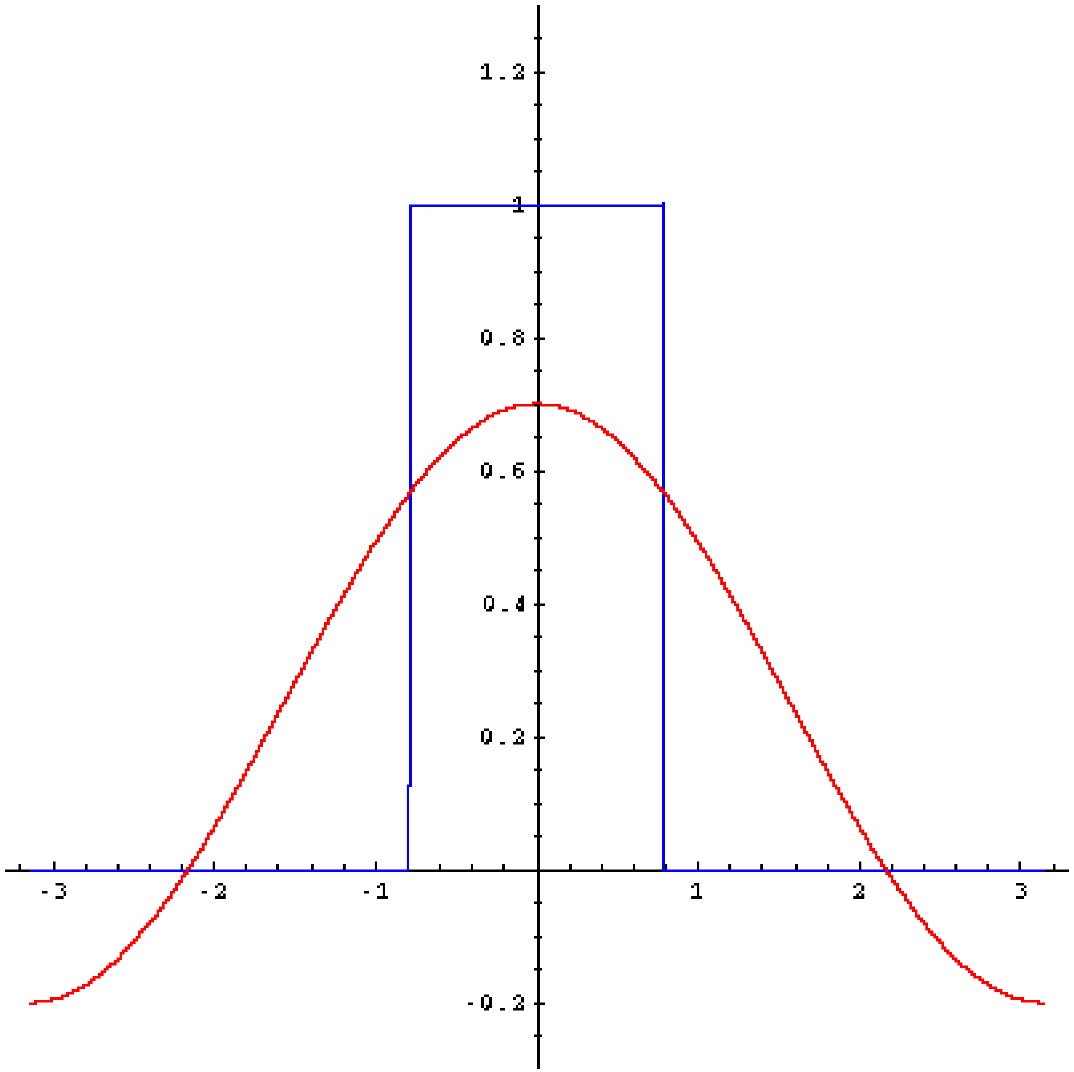


Channel with narrow bandwidth

(Thin cable with poor quality)




Input signal bandwidth
(infinite bandwidth)
0
∞
Input signal
Bandwidth supported by medium
(Like a low pass filter)
0
f_1
Channel
Output signal bandwidth
0
f_1
Output signal



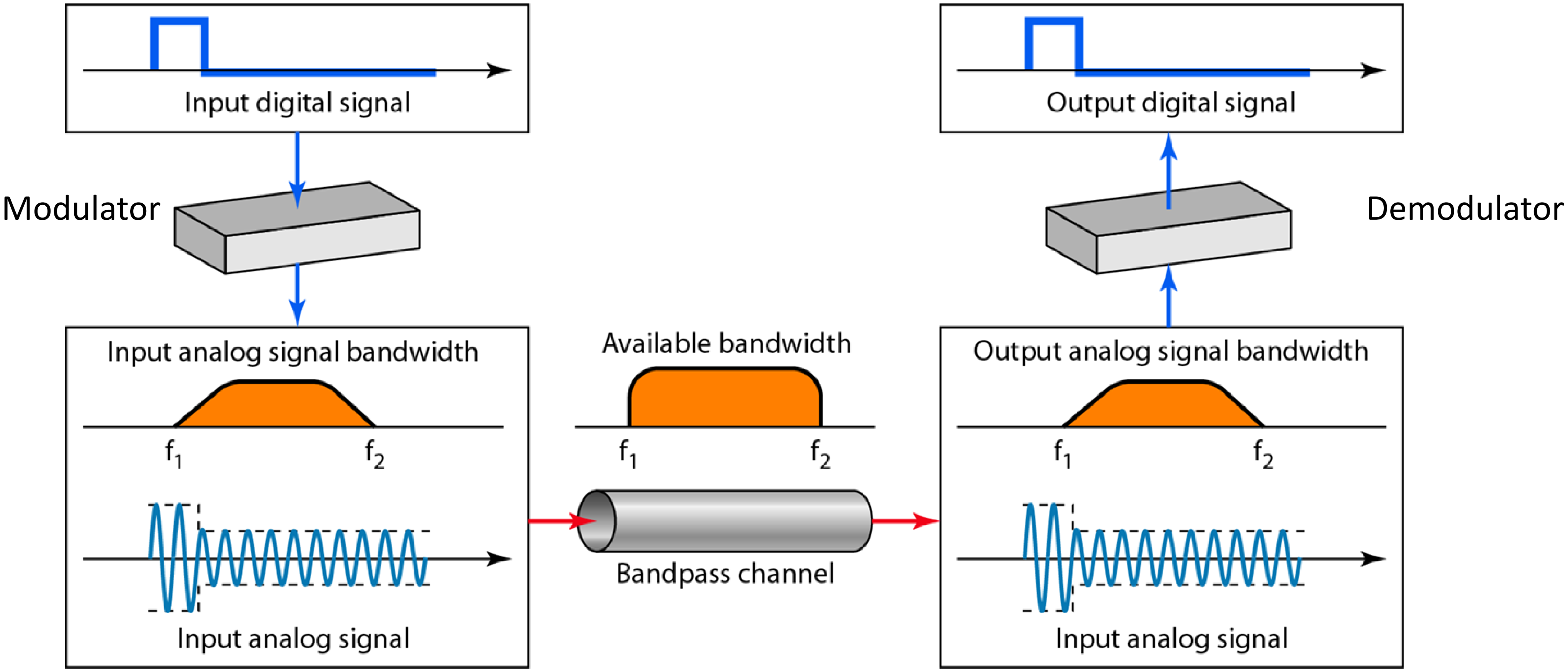
Using a channel with a very narrow bandwidth

Blue square wave = Transmitted signal

Red sine wave = Received signal.

Broadband Transmission

- Broadband transmission involves changing the digital signal into an analog signal using a modulator.
- The frequency spectrum of the modulated signal does not start from 0 (not baseband)



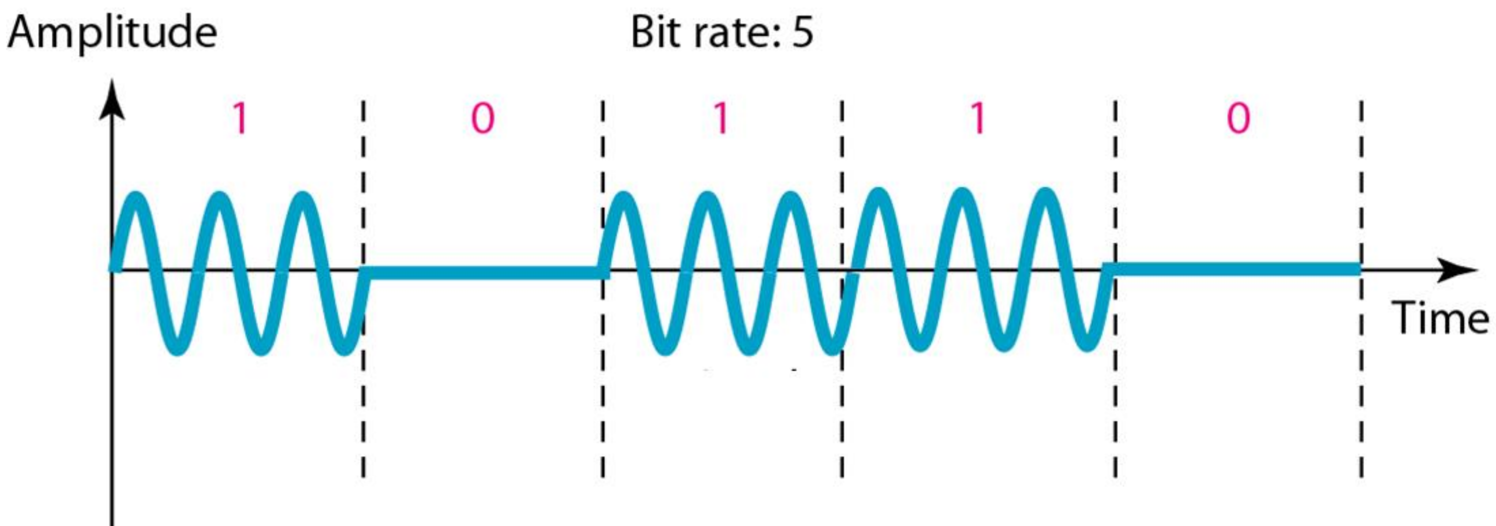
- The receiver demodulates the received signal back to digital signal.
- Wireless transmission is generally broadband

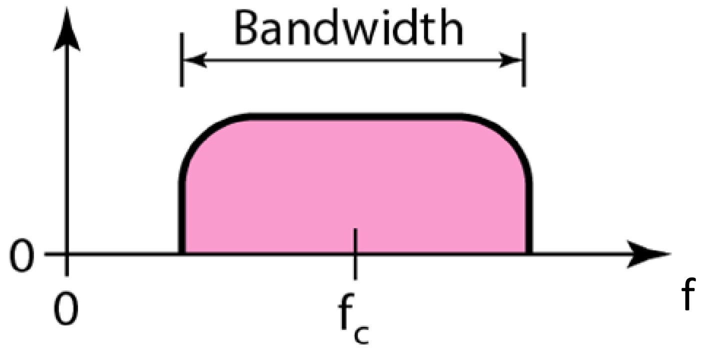
There are at least four techniques to transmit digital data in analog form

1. Amplitude Shift Keying (ASK)
2. Frequency Shift Keying (FSK)
3. Phase Shift Keying (PSK)
4. Quadrature Amplitude Modulation (QAM)

Amplitude Shift Keying

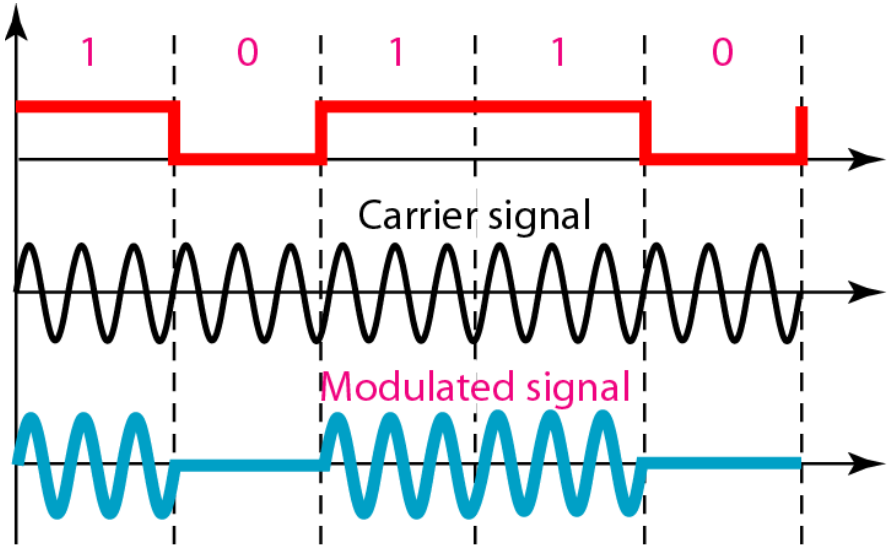
- The carrier signal has frequency f_c.
- 0 is represented by 0 amplitude.
- 1 is represented by the amplitude of the carrier signal.
- Disadvantage: noise can affect amplitude

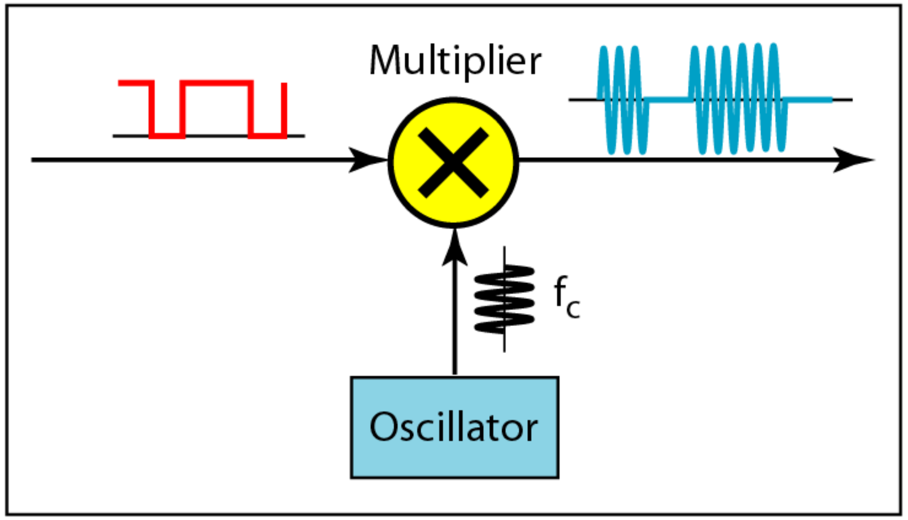




Implementation

If the digital data are represented in unipolar NRZ, the digital signal can simply be multiplied with the output of an oscillator with frequency $f_{c.}$

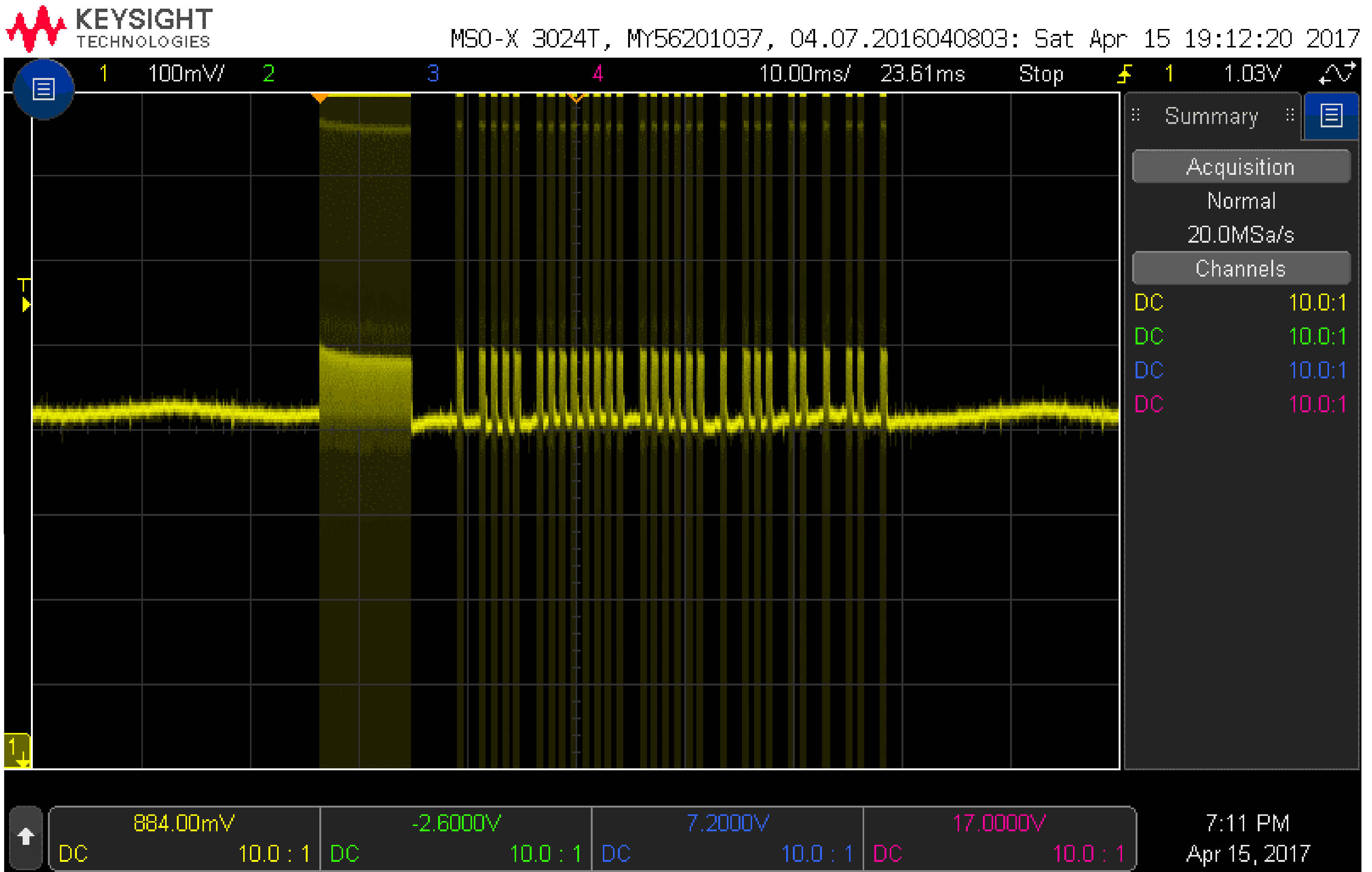




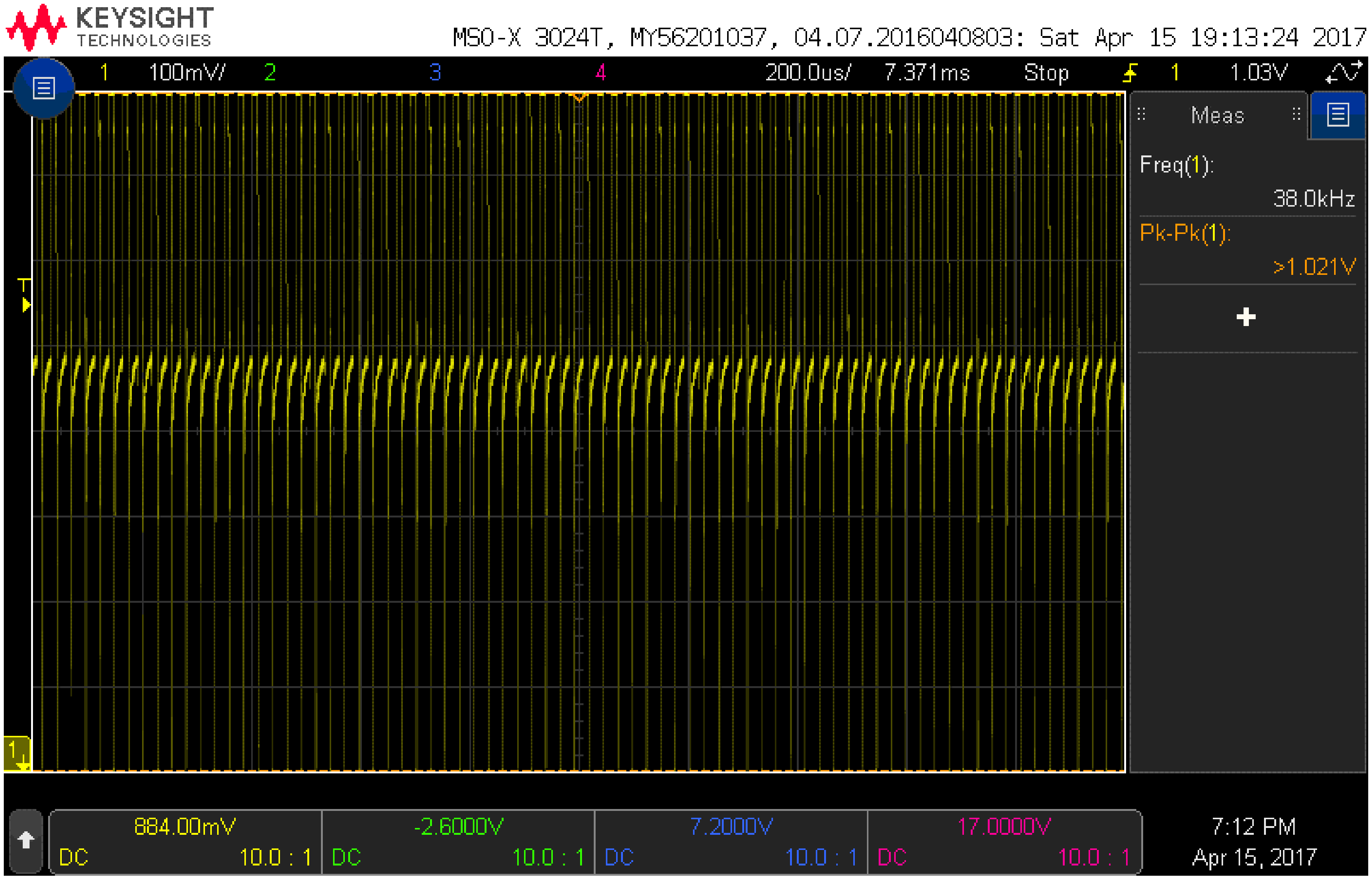
Example: LG aircon remote control

It uses a form of ASK

The waveform shows the voltage across the IR LED when a button is pressed

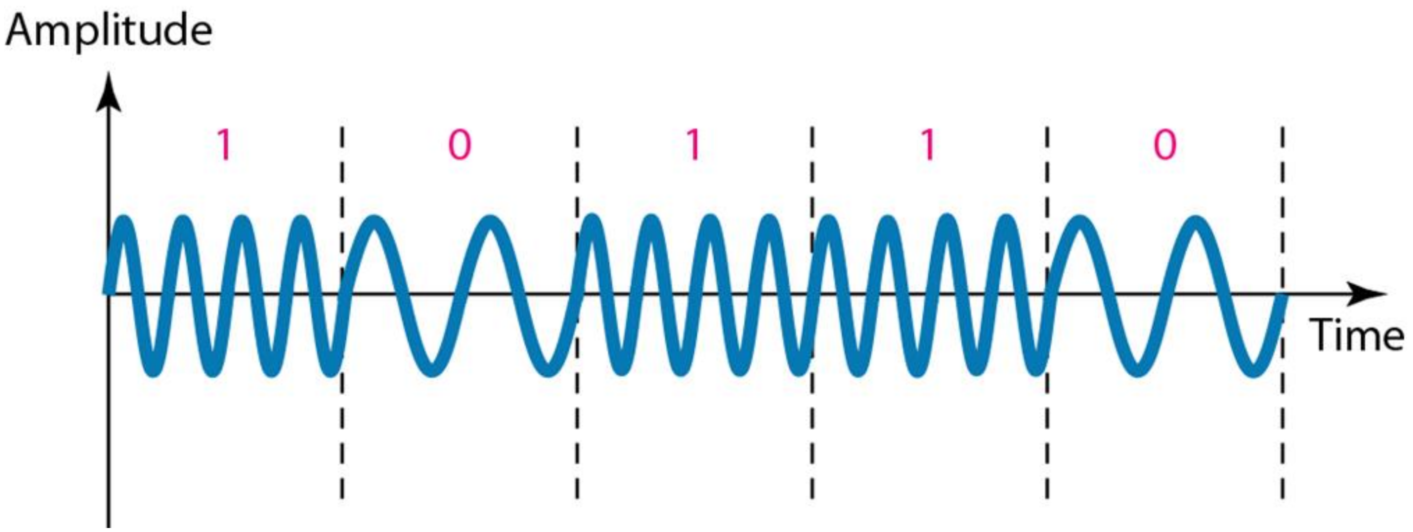


The modulation frequency is 38kHz

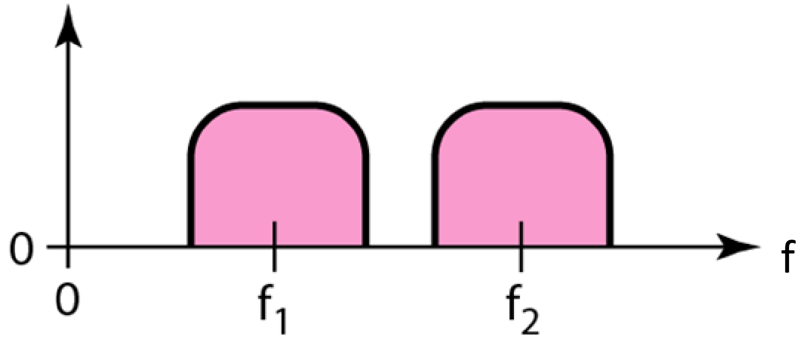


Frequency Shift Keying

- There are two carrier frequencies f_1 and f_2 $(f_2 > f_1)$
- Amplitude and phase are fixed.
- 0 is represented by frequency f_1
- 1 is represented by frequency f_2
- Disadvantage: wide bandwidth (two carrier frequencies are required)



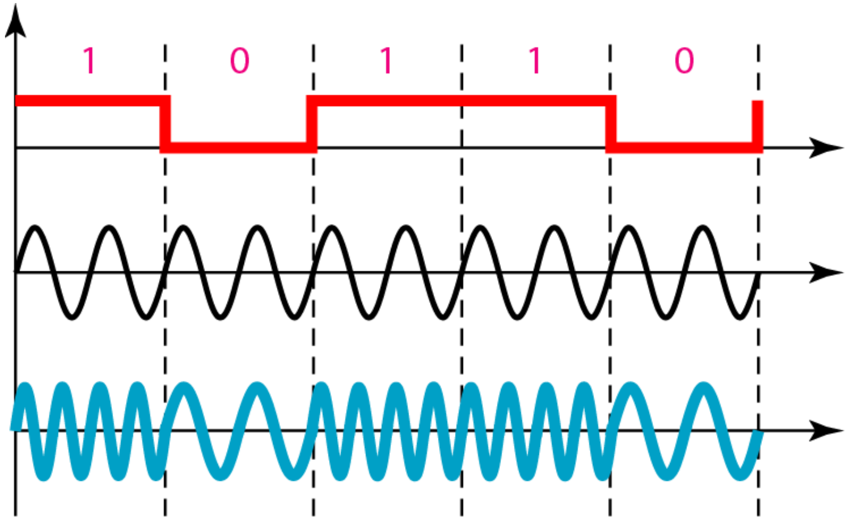
Bandwidth

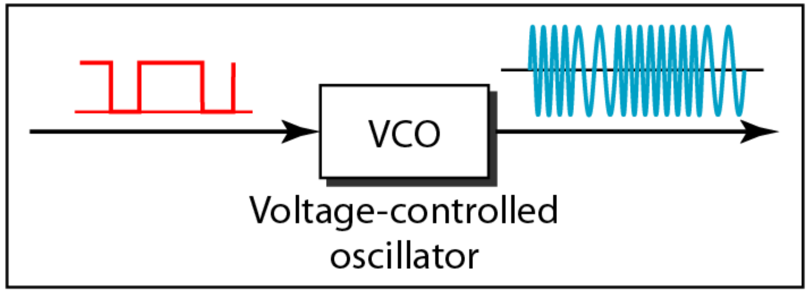


Bandwidth

Implementation

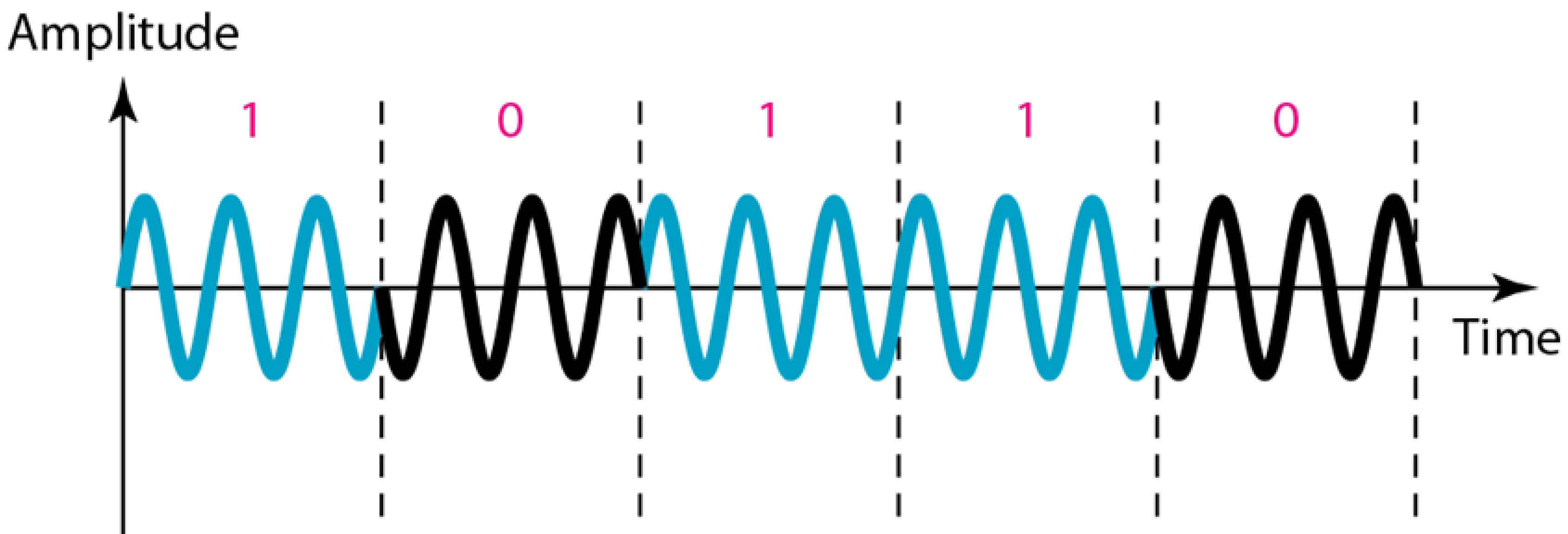
If the digital data are represented in unipolar NRZ, the digital signal can simply be passed through a voltage-controller oscillator to produce modulated signal.

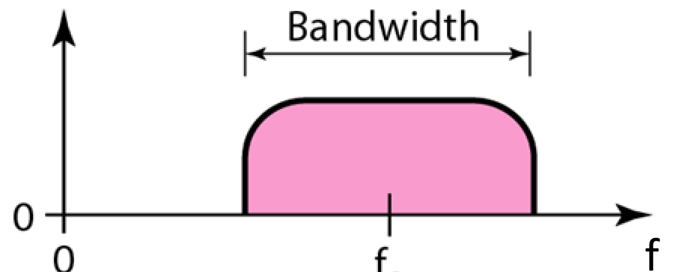




Phase Key Shifting

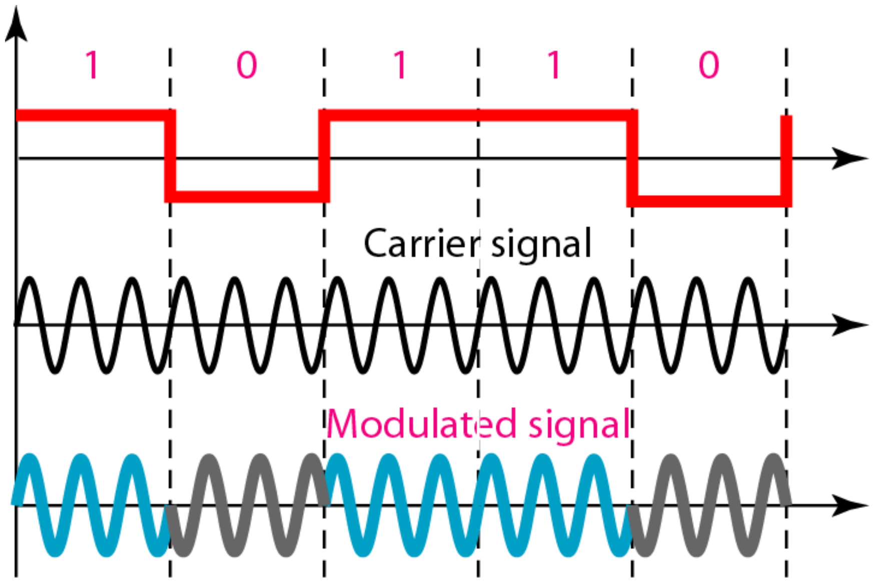
- The carrier signal has frequency f_c.
- One logic level is represented by a phase of 0°.
- The other logic level is represented by a phase of 180°.
- Less susceptible to noise then ASK. Uses lesser bandwidth than FSK.
- Variations of PSK are used for wireless LANs, biometric passports, RFID and Bluetooth

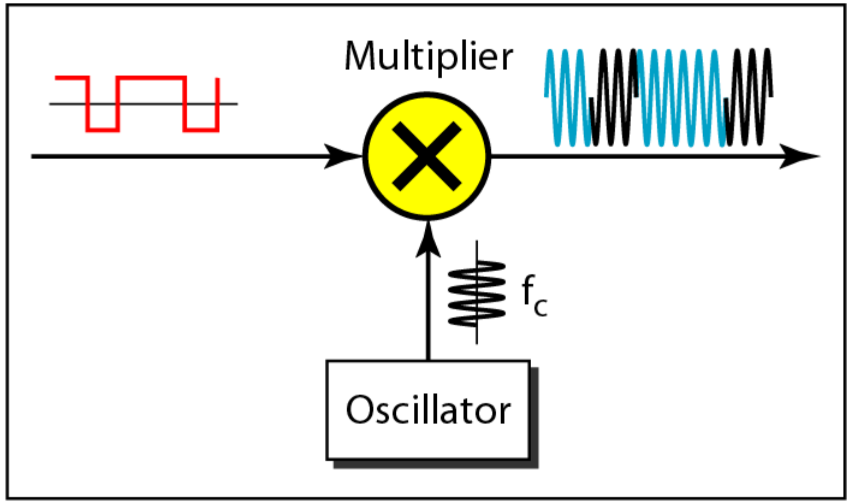




Implementation

If the digital data are represented in polar NRZ, the digital signal can simply be multiplied with the output of an oscillator with frequency f_c.





Quadrature Amplitude Modulation

- QAM combines ASK and PSK to increase the bit rate by at least a factor of 2 (for a given baud rate).

Bit rate = $2 \times$ baud rate