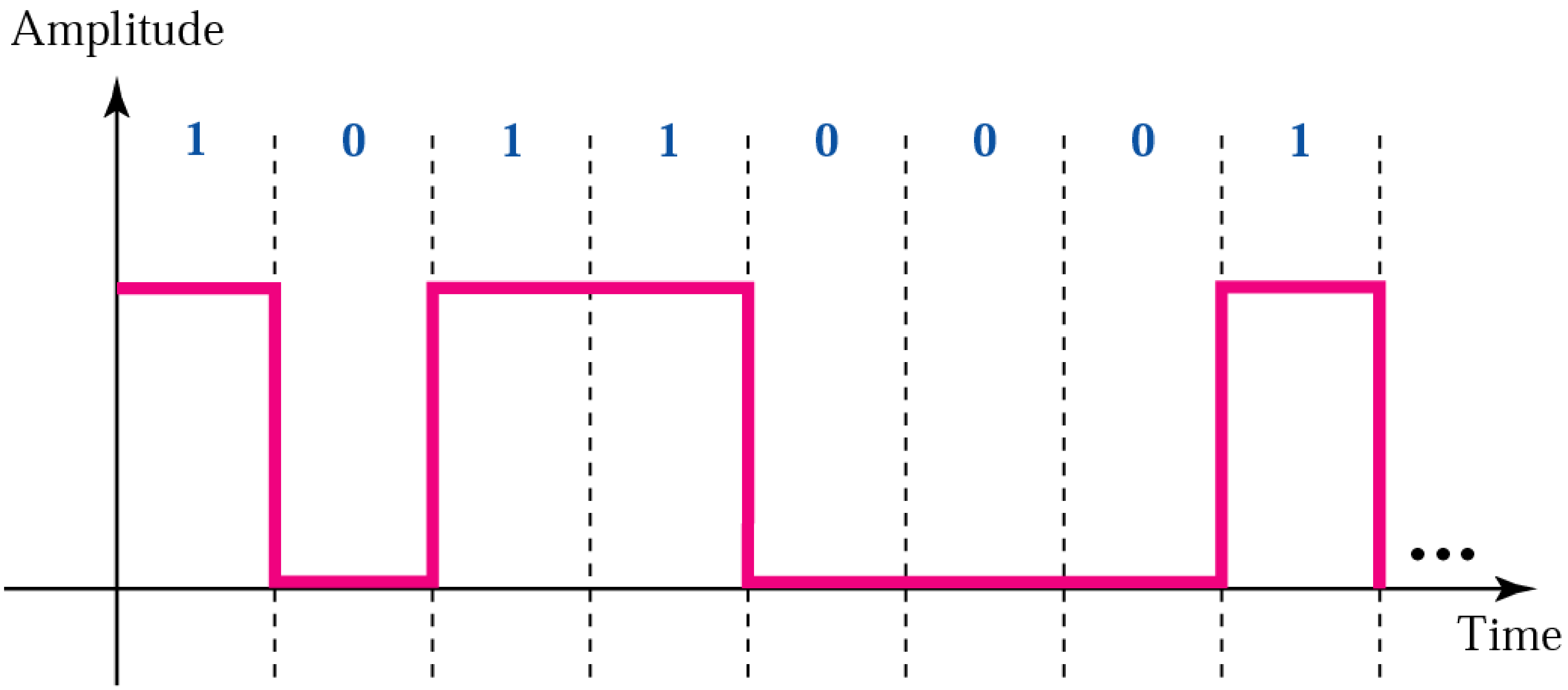
Digital Signals

Digital Signals

- Use binary (0s and 1s) to encode information
- sequence of voltage pulses (DC levels) – each pulse represents a *signal element*
- binary data are transmitted using only 2 types of signal elements

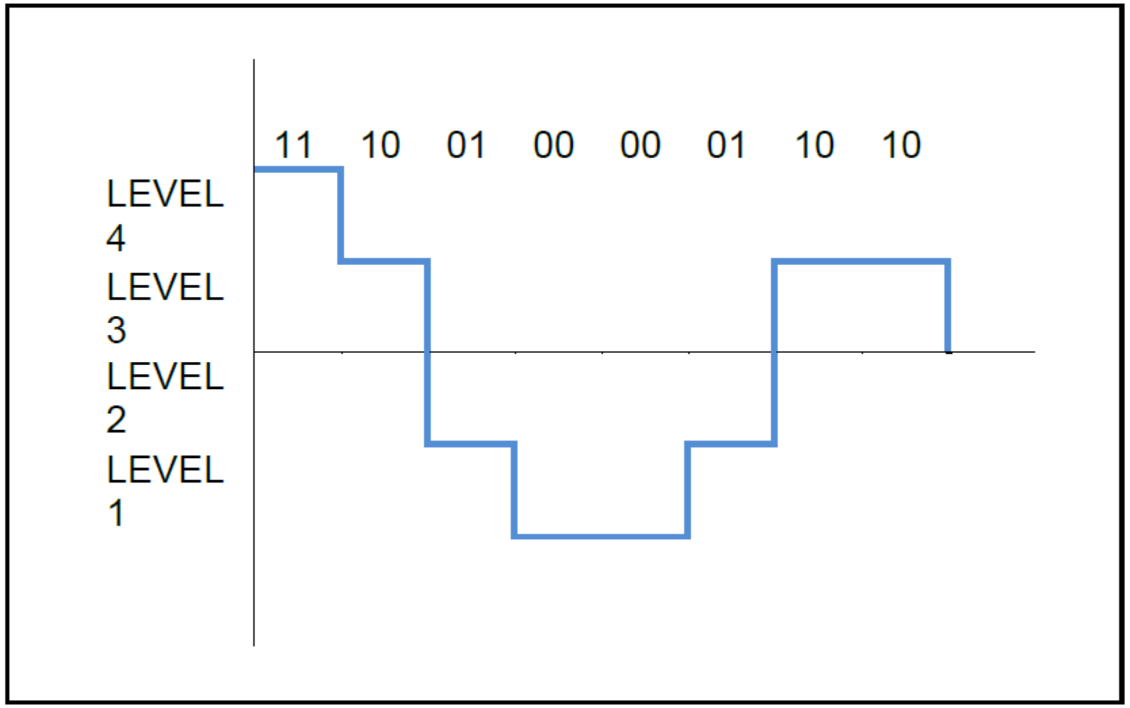
  (1 = positive voltage, 0 = negative voltage)
- Usually aperiodic; period and frequency are not appropriate
- Less affected by interference (noise); fewer errors

Digital signal



- Information in a digital signal can be represented in the form of voltage levels.
- A Signal can have more than two levels
- if a signal has L levels then, each level need Log_2L bits

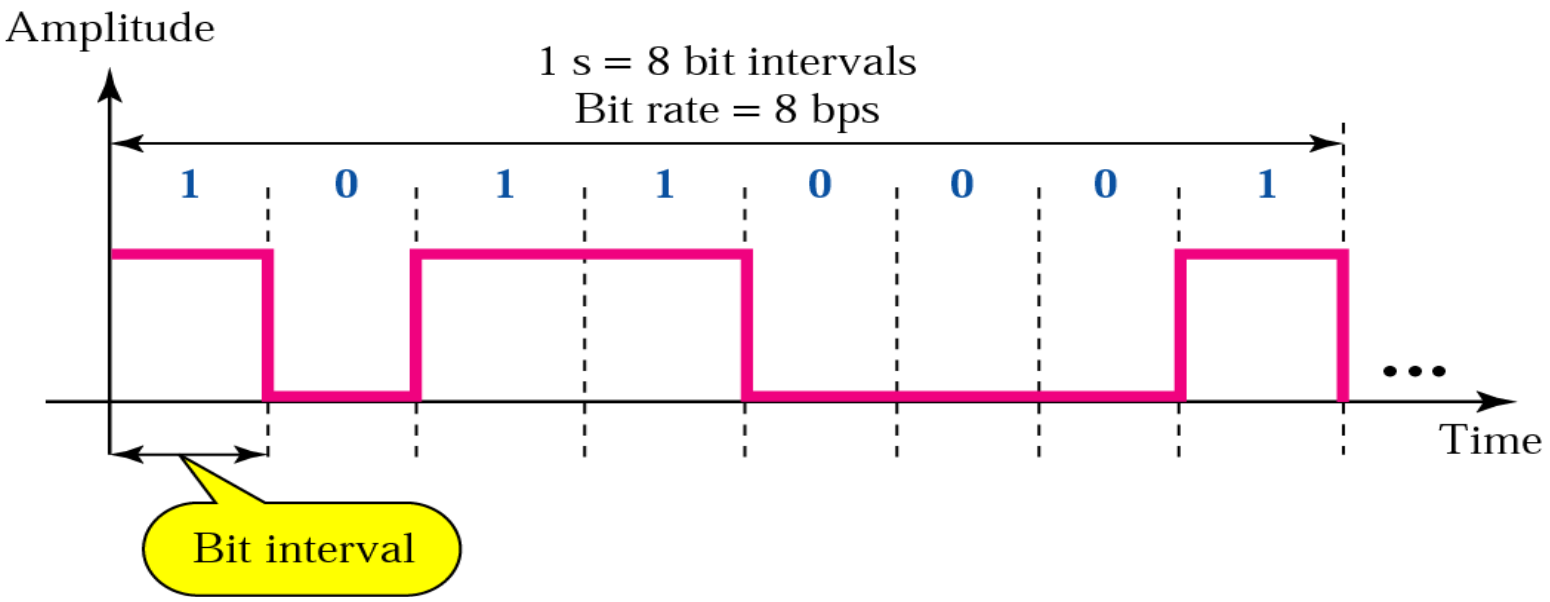
A digital signal with four levels



Bit Interval and Bit Rate

Digital signals are described by

- Bit interval or Bit length– time required to send one single bit
  - Bit Length = propagation speed * bit duration
- Bit rate – number of bit intervals per second, usually expressed as *bits per second* (bps)
- Bit rate = 1 / Bit interval

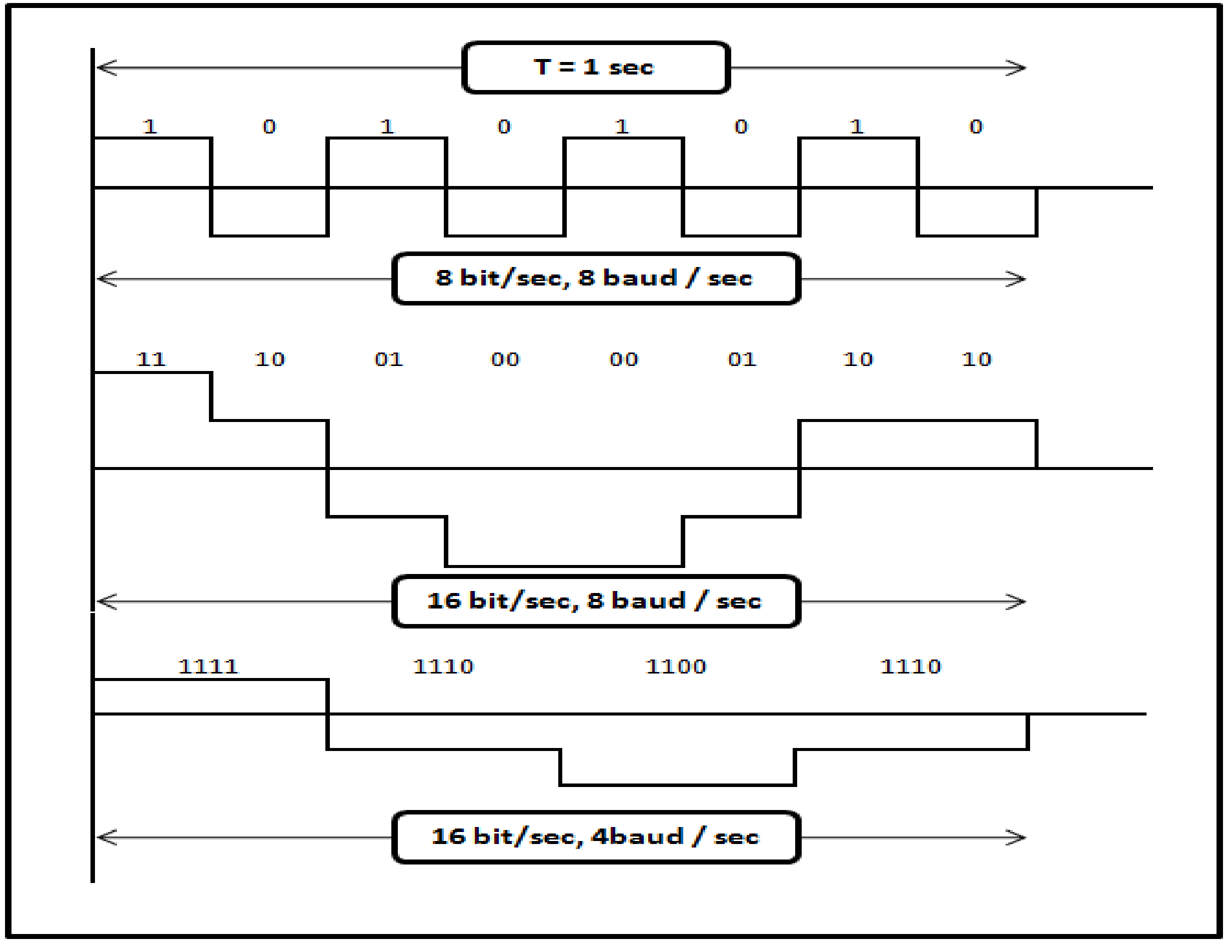


Baud Rate

- It is the rate of Signal Speed, i.e. the rate at which the signal changes.
- A digital signal with two levels ‘0‘ & ‘1‘ will have the same baud rate and bit rate

Three signals with different bit rates and baud rates

a)Signal with a bit rate of 8 bits/ sec and baud rate of 8 baud/sec
b) Signal with a bit rate of 16 bits/ sec and baud rate of 8 baud/sec
c) Signal with a bit rate of 16 bits/ sec and baud rate of 4 baud/sec



Digital signal As a Composite Analog Signal

- Digital signal, with all its sudden changes, is actually a composite analog signal having an infinite number of frequencies
- The bandwidth of a digital signal is infinite i.e. A digital signal is a composite signal with an infinite bandwidth.

Digital signal through a wide bandwidth medium

- if a medium has a wide bandwidth, a digital signal can be sent through it
- Some frequencies will be weakened or blocked by medium; still, enough frequencies will be passed to preserve a decent signal shape
- Such as a coaxial cable to send a digital signal through a LAN

Digital signal through a band-limited medium

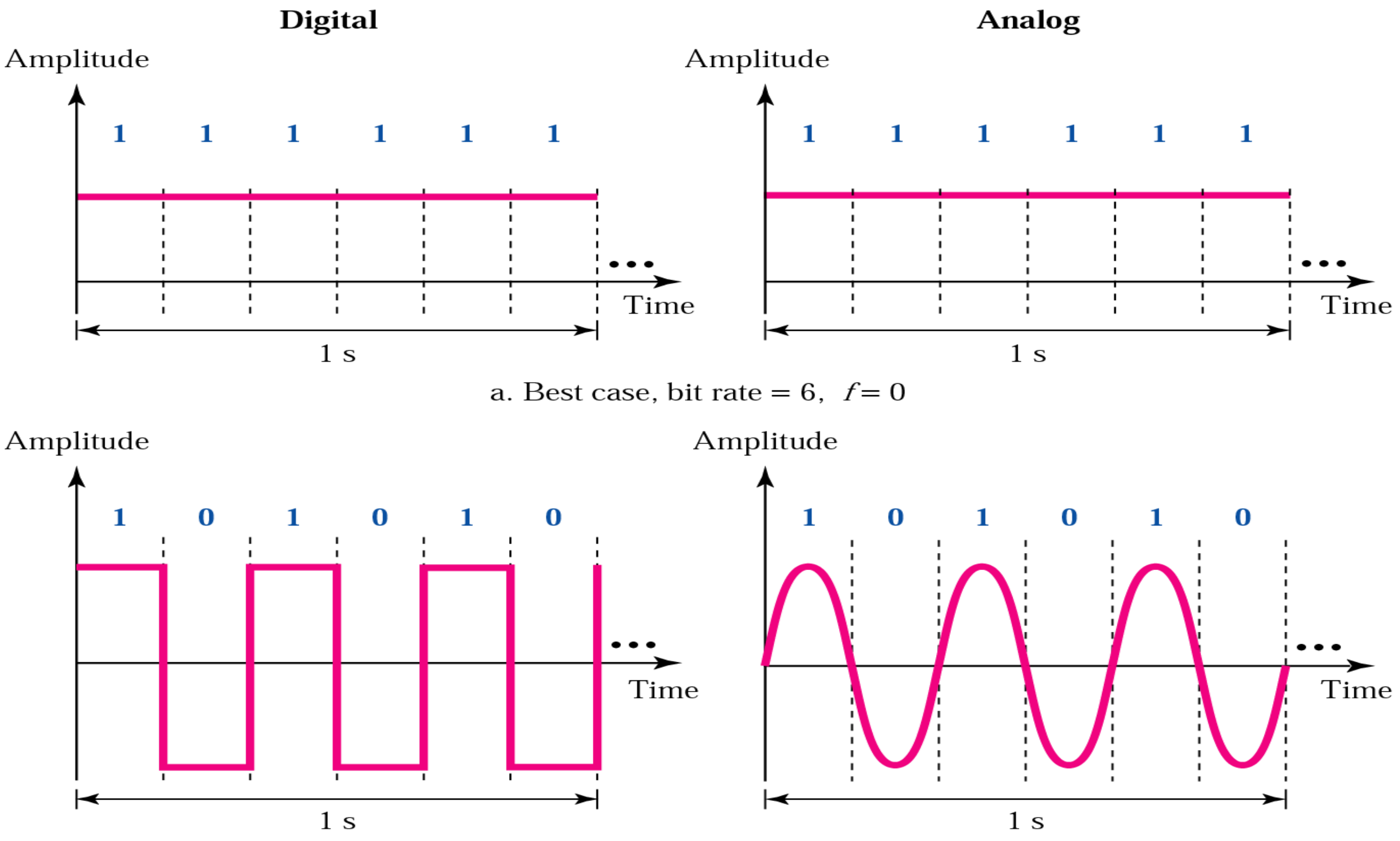
- the Internet via telephone line
- The relationship between bite rate (n) and the required bandwidth (B)
- Using only one harmonic

$$\left(B = \frac{n}{2}\right)$$

- Using more harmonic

$$\left(B >= \frac{n}{2}\right) or \;\; n <= 2E$$

Using only one harmonic (Digital versus Analog)



a. Best case, bit rate = 6, $f = 0$

b. Worst case, bit rate = 6, $f = 3$

TYPES OF CHANNELS

Each composite signal has a lowest possible(minimum) frequency and a highest possible (maximum) frequency.

From the point of view of transmission, there are two types of channels:

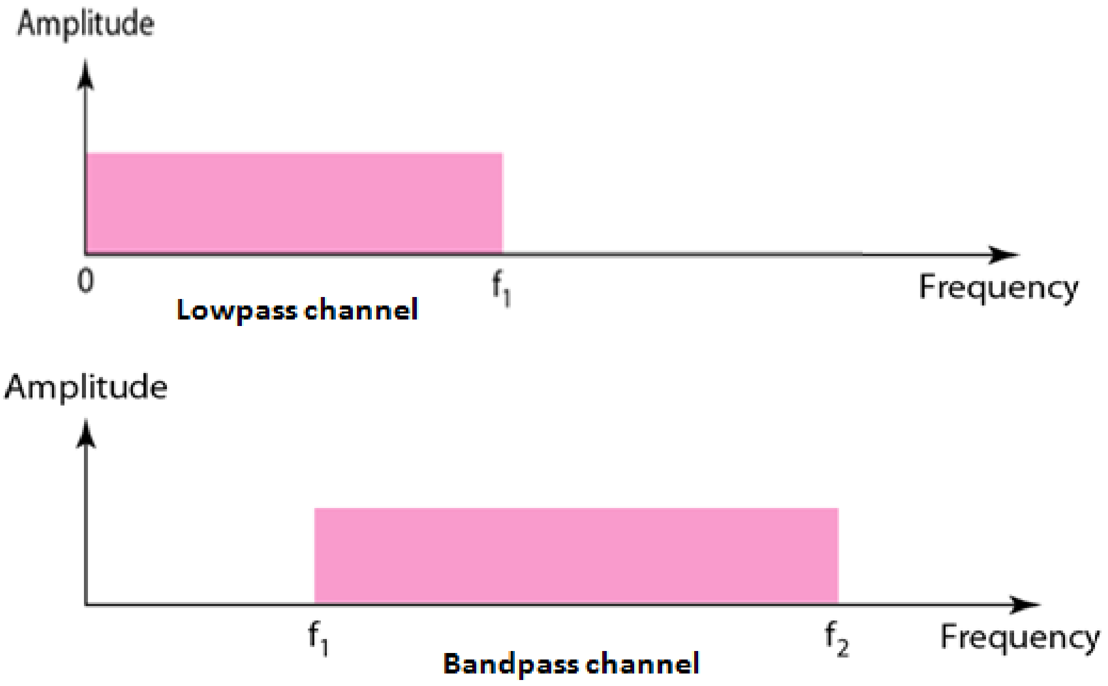
Low pass Channel

- This channel has the lowest frequency as ‘0‘ and highest frequency as some non-zero frequency ‘f1‘.
- This channel can pass all the frequencies in the range 0 to f1.

Band pass channel

- This channel has the lowest frequency as some non-zero frequency ‘f1‘ and highest frequency as some non-zero frequency ‘f2‘.
- This channel can pass all the frequencies in the range f1 to f2.

Lowpass Channel & Bandpass Channel



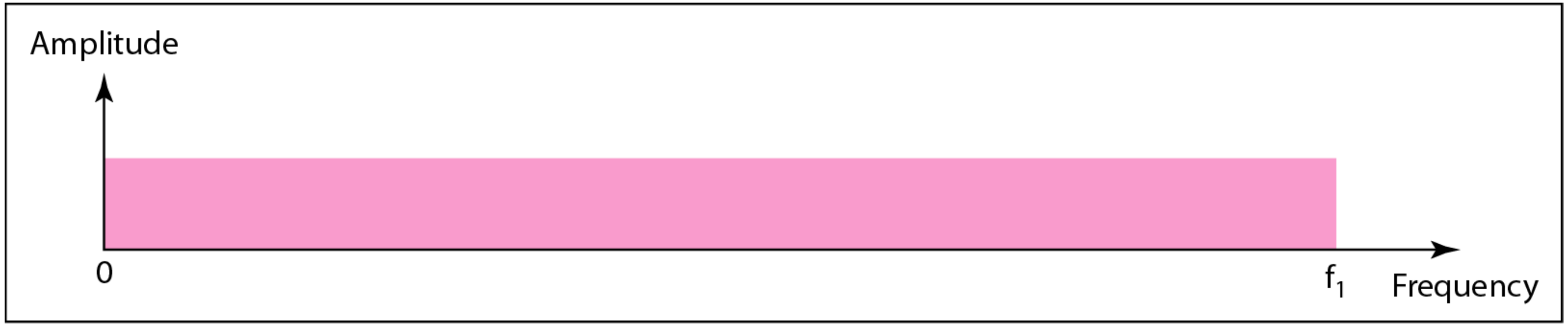
Transmission of Digital signal

Digital signal can be transmitted in the following two ways:

Baseband Transmission

- the signal is transmitted without making any change to it
- sending a digital signal over a channel without changing the digital signal to an analog signal i.e. without modulation
- Requires that we have a low-pass channel, a channel with a bandwidth that starts from zero.
- This is the case if we have a dedicated medium with a bandwidth constituting only one channel.
- In baseband transmission, the bandwidth of the signal to be transmitted has to be less than the bandwidth of the channel.

- Ex. Consider a Baseband channel with lower frequency 0Hz and higher frequency 100Hz, hence its bandwidth is 100 Hz
- We can easily transmit a signal with frequency below 100Hz, such a channel whose bandwidth is more than the bandwidth of the signal is called **Wideband** channel
- Logically a signal with frequency say 120Hz will be blocked resulting in loss of information, such a channel whose bandwidth is less than the bandwidth of the signal is called **Narrowband** channel

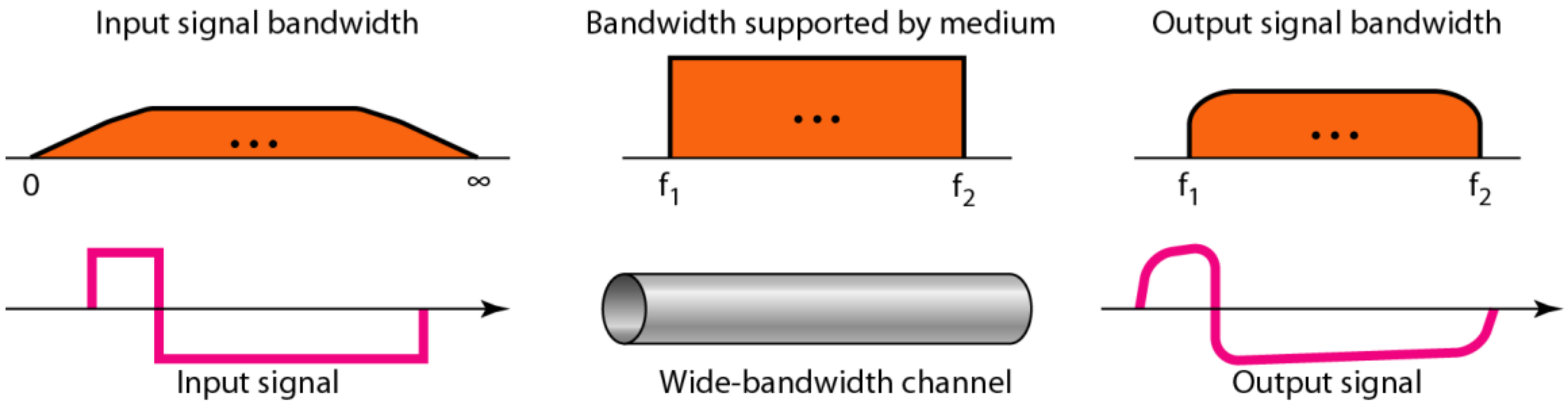


a. Low-pass channel, wide bandwidth

b. Low-pass channel, narrow bandwidth

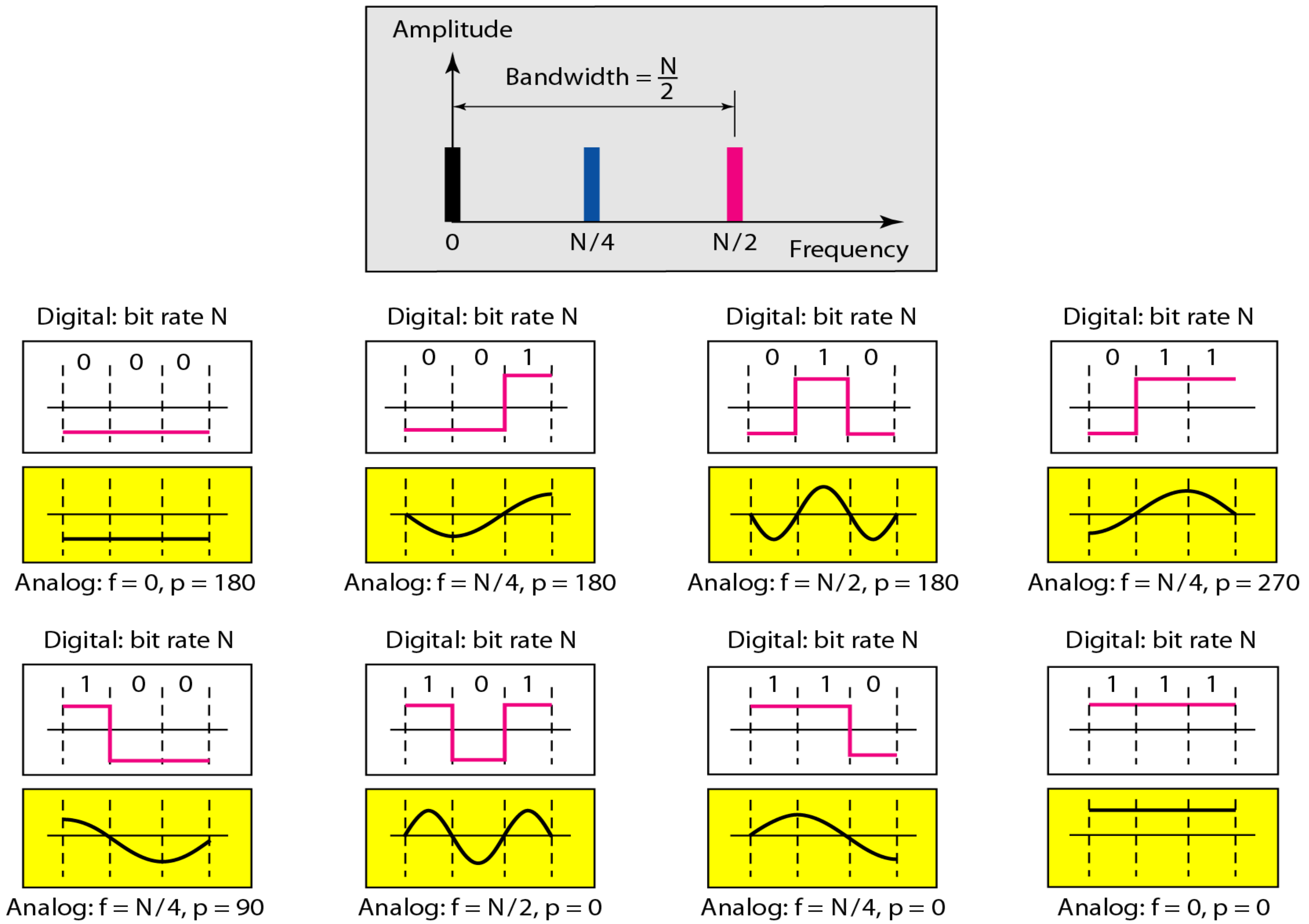
Low-Pass Channel with Wide Bandwidth

- To preserve the exact form of a nonperiodic digital signal with vertical segments vertical and horizontal segments horizontal, we need to send the entire spectrum, the continuous range of frequencies between zero and infinity.
- This is possible if we have a dedicated medium with an infinite bandwidth between the sender and receiver that preserves the exact amplitude of each component of the composite signal.
- If a coaxial cable or fiber optic, with a very wide bandwidth is used, then two stations can communicate by using digital signals with very good accuracy.


Input signal bandwidth
Bandwidth supported by medium
Output signal bandwidth
0
∞
f1
f2
f1
f2
Input signal
Wide-bandwidth channel
Output signal

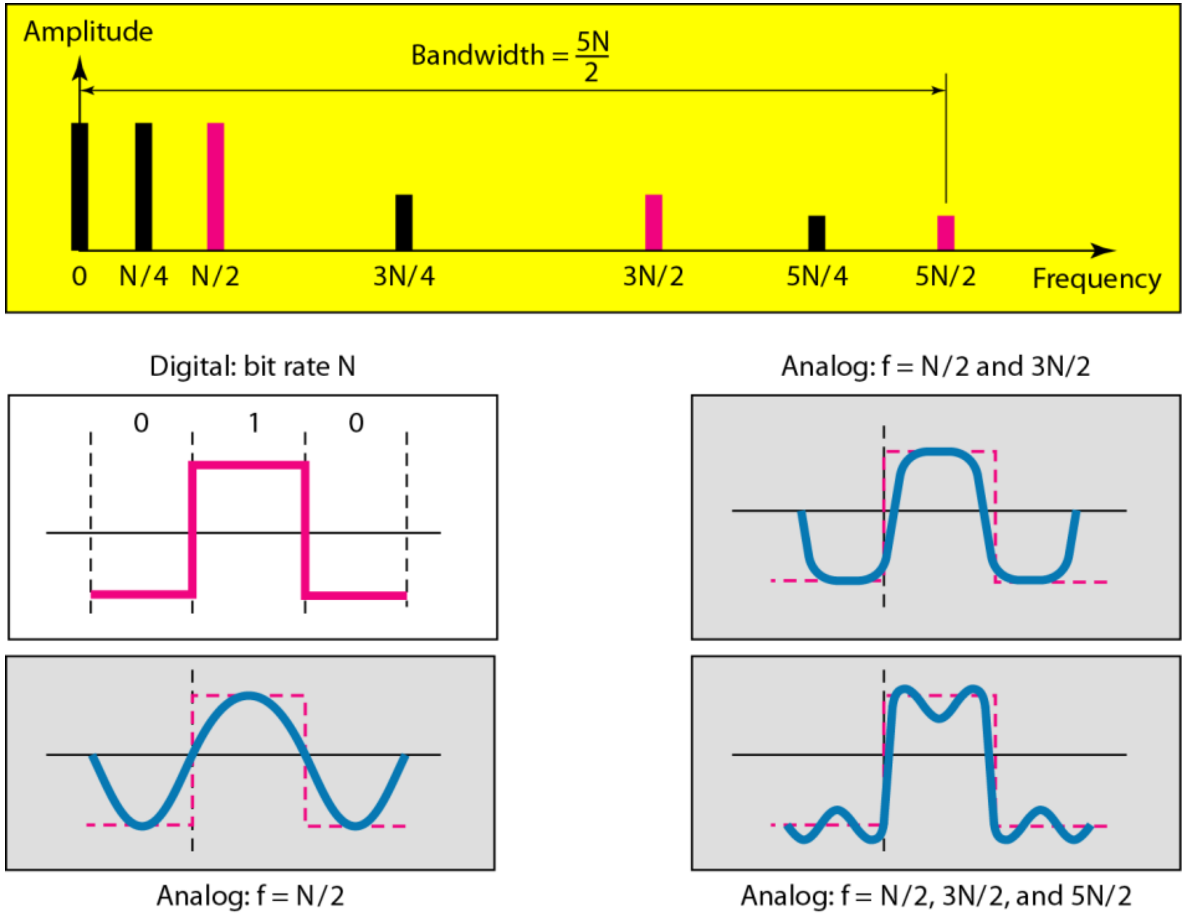
Low-Pass Channel with Limited Bandwidth

- In a low-pass channel with limited bandwidth, we approximate the digital signal with an analog signal.
- The level of approximation depends on the bandwidth available.
- **Rough Approximation**
- Assume that we have a digital signal of bit rate *N*.
- Consider the worst case, a maximum number of changes in the digital signal.
  - sequence 01010101 ... or the sequence 10101010…..
  - To simulate these two cases, we need an analog signal of frequency $f = N/2$.


Amplitude
Bandwidth = N/2
0
N/4
N/2
Frequency
Digital: bit rate N
0 0 0
Analog: f = 0, p = 180
Digital: bit rate N
0 0 1
Analog: f = N/4, p = 180
Digital: bit rate N
0 1 0
Analog: f = N/2, p = 180
Digital: bit rate N
0 1 1
Analog: f = N/4, p = 270
Digital: bit rate N
1 0 0
Analog: f = N/4, p = 90
Digital: bit rate N
1 0 1
Analog: f = N/2, p = 0
Digital: bit rate N
1 1 0
Analog: f = N/4, p = 0
Digital: bit rate N
1 1 1
Analog: f = 0, p = 0

- The two similar cases (000 and 111) are simulated with a signal with frequency f =0 and a phase of 180° for 000 and a phase of 0° for 111.
- The two worst cases (010 and 101) are simulated with an analog signal with frequency =*N/2* and phases of 180° and 0°.
- The other four cases can only be simulated with an analog signal with f = N/4 and phases of 180°, 270°, 90°, and 0°.
- In other words, we need a channel that can handle frequencies 0, N/4, and N/2. This rough approximation is referred to as using the first harmonic (N/2) frequency.

To make the shape of the analog signal look more like that of a digital signal, we need to add more harmonics of the frequencies.
i.e. to increase the bandwidth to 3N/2, 5N/2, 7N/2, and so on.

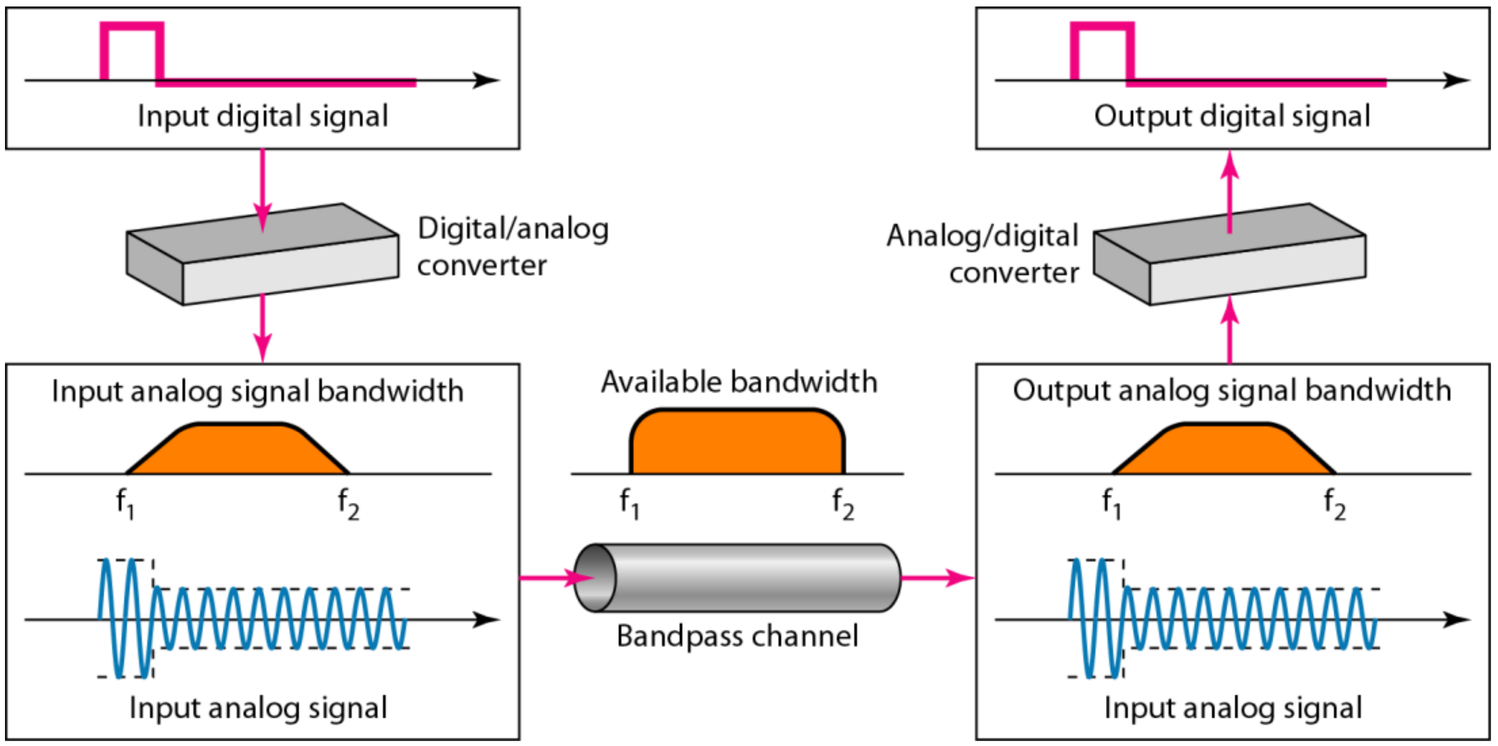


Broad band Transmission

- Given a bandpass channel, a digital signal cannot be transmitted directly through it
- In broadband transmission we use modulation, i.e. we change the signal to analog signal before transmitting it.
- Modulation allows us to use a bandpass channel-a channel with a bandwidth that does not start from zero.

- The digital signal is first converted to an analog signal, since we have a bandpass channel we cannot directly send this signal through the available channel.
- Ex. Consider the bandpass channel with lower frequency 50Hz and higher frequency 80Hz, and the signal to be transmitted has frequency 10Hz.
- To pass the analog signal through the bandpass channel, the signal is modulated using a carrier frequency. Ex. The analog signal (10Hz) is modulated by a carrier frequency of 50Hz resulting in an signal of frequency 60Hz which can pass through our bandpass channel.
- The signal is demodulated and again converted into an digital signal at the other end

Modulation of a digital signal



- A digital signal is converted to a composite analog signal with the help of carrier.
- At the receiver, the received analog signal is converted to digital, and the result is a replica of what has been sent.

Broadband Transmission Involving Modulation & Demodulation