DATA AND SIGNALS

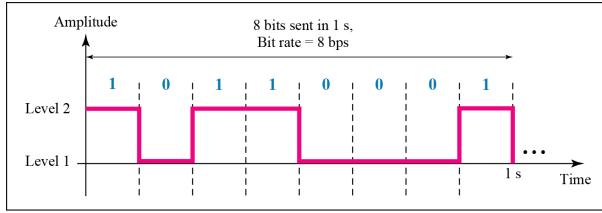
CSE306

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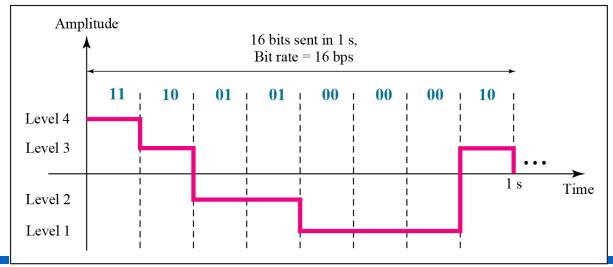
DIGITAL SIGNALS

In addition to being represented by an analog signal, information can also be represented by a digital signal. For example, a 1 can be encoded as a positive voltage and a 0 as zero voltage. A digital signal can have more than two levels. In this case, we can send more than 1 bit for each level.

Figure Two digital signals: one with two signal levels and the other with four signal levels



a. A digital signal with two levels



POLL 1

A digital Signal can be represented by

- a) Two levels only
- b) 4 levels only
- c) Finite levels in the power of 2 only
- d) Finite levels

Example

A digital signal has eight levels. How many bits are needed per level? We calculate the number of bits from the formula

Number of bits per level = $log_2 8 = 3$

Each signal level is represented by 3 bits.



A digital signal has nine levels. How many bits are needed per level? We calculate the number of bits by using the formula. Each signal level is represented by 3.17 bits. However, this answer is not realistic. The number of bits sent per level needs to be an integer as well as a power of 2. For this example, 4 bits can represent one level.

Bit Rate

- Most Digital Signals are non-periodic. Therefore, period and frequency are not appropriate characteristics.
- Bit rate is used.
- Bit rate is number of bits sent in 1s. Expressed in **bps**.

POLL 2

- A digital signal is represented in bps because
- a) It is a non-periodic signal
- b) It is a periodic signal



Assume we need to download text documents at the rate of 100 pages per minute. What is the required bit rate of the channel?

Solution

A page is an average of 24 lines with 80 characters in each line. If we assume that one character requires 8 bits, the bit rate is

 $100 \times 24 \times 80 \times 8 = 1,636,000 \text{ bps} = 1.636 \text{ Mbps}$



A digitized voice channel is made by digitizing a 4-kHz bandwidth analog voice signal. We need to sample the signal at twice the highest frequency (two samples per hertz). We assume that each sample requires 8 bits. What is the required bit rate?

- *a*) 64 kbps
- b) 12 kbps
- c) 32 kbps



A digitized voice channel is made by digitizing a 4-kHz bandwidth analog voice signal. We need to sample the signal at twice the highest frequency (two samples per hertz). We assume that each sample requires 8 bits. What is the required bit rate?

Solution

The bit rate can be calculated as

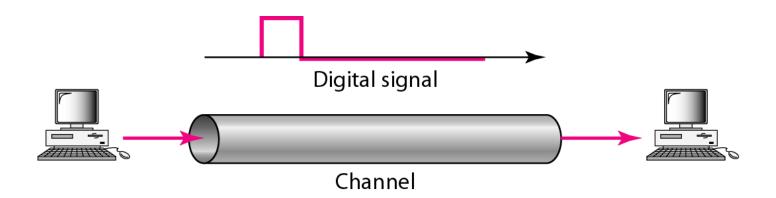
 $2 \times 4000 \times 8 = 64,000 \text{ bps} = 64 \text{ kbps}$

Bit Length

• Bit length is distance one bit occupies on transmission medium.

• Bit length= propagation speed* bit duration

Figure Baseband transmission

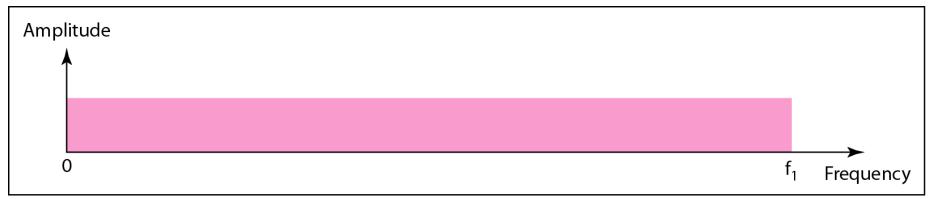




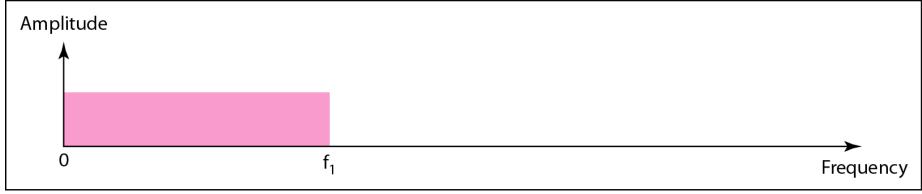
Note

A digital signal is a composite analog signal with an infinite bandwidth.

Figure Bandwidths of two low-pass channels

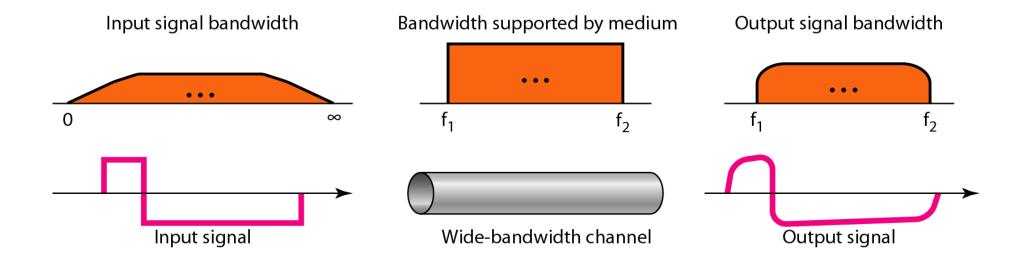


a. Low-pass channel, wide bandwidth



b. Low-pass channel, narrow bandwidth

Figure Baseband transmission using a dedicated medium





Note

Baseband transmission of a digital signal that preserves the shape of the digital signal is possible only if we have a low-pass channel with an infinite or very wide bandwidth.



Note

In baseband transmission, the required bandwidth is proportional to the bit rate; if we need to send bits faster, we need more bandwidth. Bit rate is twice the bandwidth required.



What is the required bandwidth of a low-pass channel if we need to send 1 Mbps by using baseband transmission?

Solution

The minimum bandwidth, is B = bit rate / 2, or 500 kHz.



We have a low-pass channel with bandwidth 100 kHz. What is the maximum bit rate of this channel?

- a) 100 kbps
- b) 200 kbps
- c) 400 kbps

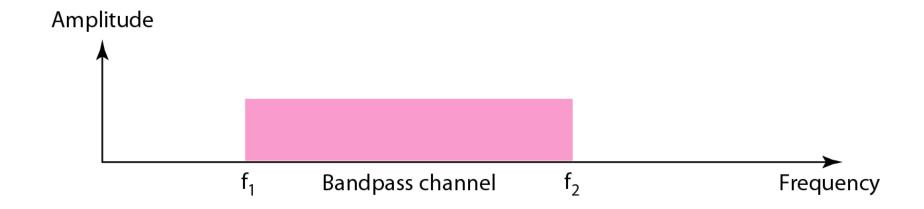


We have a low-pass channel with bandwidth 100 kHz. What is the maximum bit rate of this channel?

Solution

The maximum bit rate can be achieved if we use the first harmonic. The bit rate is 2 times the available bandwidth, or 200 kbps.

Broadband Transmission: Bandwidth of a bandpass channel

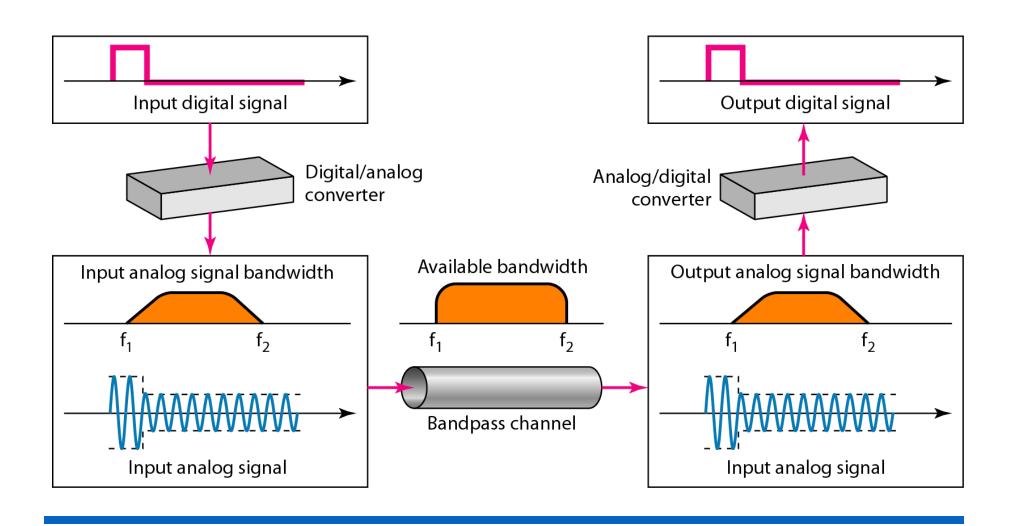




Note

If the available channel is a bandpass channel, we cannot send the digital signal directly to the channel; we need to convert the digital signal to an analog signal before transmission.

Figure Modulation of a digital signal for transmission on a bandpass channel





example of broadband transmission modulation is the sending of computer data through a telephone subscriber line, the line connecting a resident to the central telephone office. These lines are designed to carry voice with a limited bandwidth. The channel is considered a bandpass channel. We convert the digital signal from the computer to an analog signal, and send the analog signal. We can install two converters to change the digital signal to analog and vice versa at the receiving end. The converter, in this case, is called a modem

DATA RATE LIMITS

A very important consideration in data communications is how fast we can send data, in bits per second, over a channel. Data rate depends on three factors:

- 1. The bandwidth available
- 2. The level of the signals we use
- 3. The quality of the channel (the level of noise)

Noiseless Channel: Nyquist Bit Rate Noisy Channel: Shannon Capacity Using Both Limits



Note

Increasing the levels of a signal may reduce the reliability of the system.

Noiseless Channel: Nyquist Bit Rate

Bit Rate= 2 * bandwidth * log₂ L

Example

Consider a noiseless channel with a bandwidth of 3000 Hz transmitting a signal with two signal levels. The maximum bit rate can be calculated as

BitRate = $2 \times 3000 \times \log_2 2 = 6000$ bps



Consider the same noiseless channel transmitting a signal with four signal levels (for each level, we send 2 bits). The maximum bit rate will be

- A) 6000 bps
- B) 4000 bps
- C) 12000 bps

Example

Consider the same noiseless channel transmitting a signal with four signal levels (for each level, we send 2 bits). The maximum bit rate can be calculated as

BitRate = $2 \times 3000 \times \log_2 4 = 12,000$ bps



We need to send 265 kbps over a noiseless channel with a bandwidth of 20 kHz. How many signal levels do we need?

Solution

We can use the Nyquist formula as shown:

$$265,000 = 2 \times 20,000 \times \log_2 L$$

 $\log_2 L = 6.625$ $L = 2^{6.625} = 98.7$ levels

Since this result is not a power of 2, we need to either increase the number of levels or reduce the bit rate. If we have 128 levels, the bit rate is 280 kbps. If we have 64 levels, the bit rate is 240 kbps.

Noisy Channel: Shannon Capacity

Capacity= Bandwidth * log₂(1+SNR)



Consider an extremely noisy channel in which the value of the signal-to-noise ratio is almost zero. In other words, the noise is so strong that the signal is faint. For this channel the capacity C is calculated as

$$C = B \log_2 (1 + \text{SNR}) = B \log_2 (1 + 0) = B \log_2 1 = B \times 0 = 0$$

This means that the capacity of this channel is zero regardless of the bandwidth. In other words, we cannot receive any data through this channel.

Example

We can calculate the theoretical highest bit rate of a regular telephone line. A telephone line normally has a bandwidth of 3000. The signal-to-noise ratio is usually 3162. For this channel the capacity is calculated as

$$C = B \log_2 (1 + \text{SNR}) = 3000 \log_2 (1 + 3162) = 3000 \log_2 3163$$

= $3000 \times 11.62 = 34,860 \text{ bps}$

This means that the highest bit rate for a telephone line is 34.860 kbps. If we want to send data faster than this, we can either increase the bandwidth of the line or improve the signal-to-noise ratio.

Example

The signal-to-noise ratio is often given in decibels. Assume that $SNR_{dB} = 36$ and the channel bandwidth is 2 MHz. The theoretical channel capacity can be calculated as

$$SNR_{dB} = 10 \log_{10} SNR$$
 \longrightarrow $SNR = 10^{SNR_{dB}/10}$ \longrightarrow $SNR = 10^{3.6} = 3981$ $C = B \log_2 (1 + SNR) = 2 \times 10^6 \times \log_2 3982 = 24 \text{ Mbps}$