Chapter 3

Data and Signals

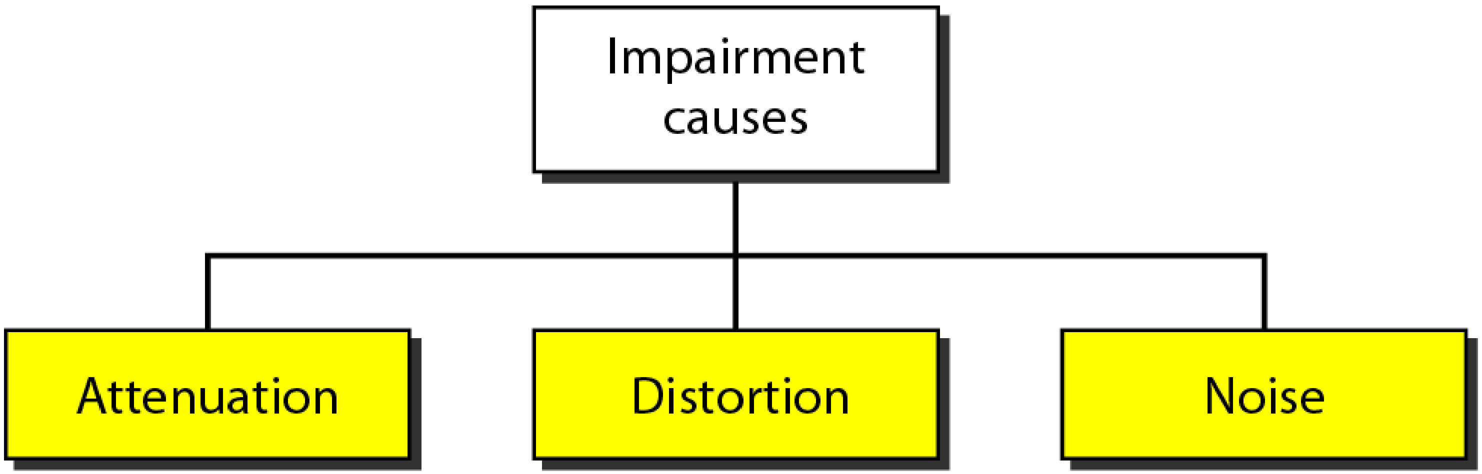
3-4 TRANSMISSION IMPAIRMENT

Signals travel through transmission media, which are not perfect. The imperfection causes signal impairment. This means that the signal at the beginning of the medium is not the same as the signal at the end of the medium. What is sent is not what is received. Three causes of impairment are attenuation, distortion, and noise.

Topics discussed in this section:

- **Attenuation**
- **Distortion**
- **Noise**

Figure 3.25 *Causes of impairment*



Attenuation

- Means loss of energy -> weaker signal
- When a signal travels through a medium it loses energy overcoming the resistance of the medium
- Amplifiers are used to compensate for this loss of energy by amplifying the signal.

Measurement of Attenuation

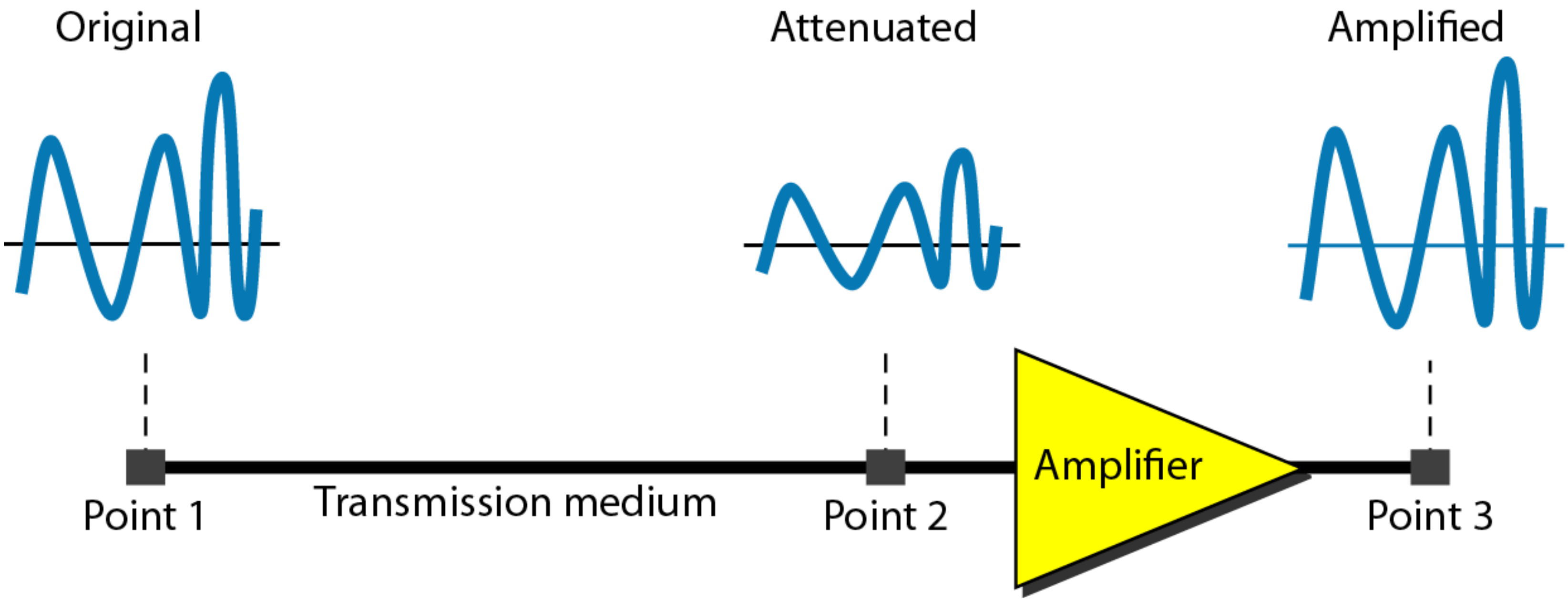
- To show the loss or gain of energy the unit "decibel" is used.

$$dB = 10\log_{10}P_2/P_1$$

P_1 - input signal

P_2 - output signal

Figure 3.26 *Attenuation*



Example 3.26

Suppose a signal travels through a transmission medium and its power is reduced to one-half. This means that P_2 is (1/2)P_1. In this case, the attenuation (loss of power) can be calculated as

$$10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{0.5 P_1}{P_1} = 10 \log_{10} 0.5 = 10(-0.3) = -3 \text{ dB}$$

A loss of 3 dB (–3 dB) is equivalent to losing one-half the power.

Example 3.27

A signal travels through an amplifier, and its power is increased 10 times. This means that $P_2 = 10P_1$. In this case, the amplification (gain of power) can be calculated as

$$10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{10P_1}{P_1}$$

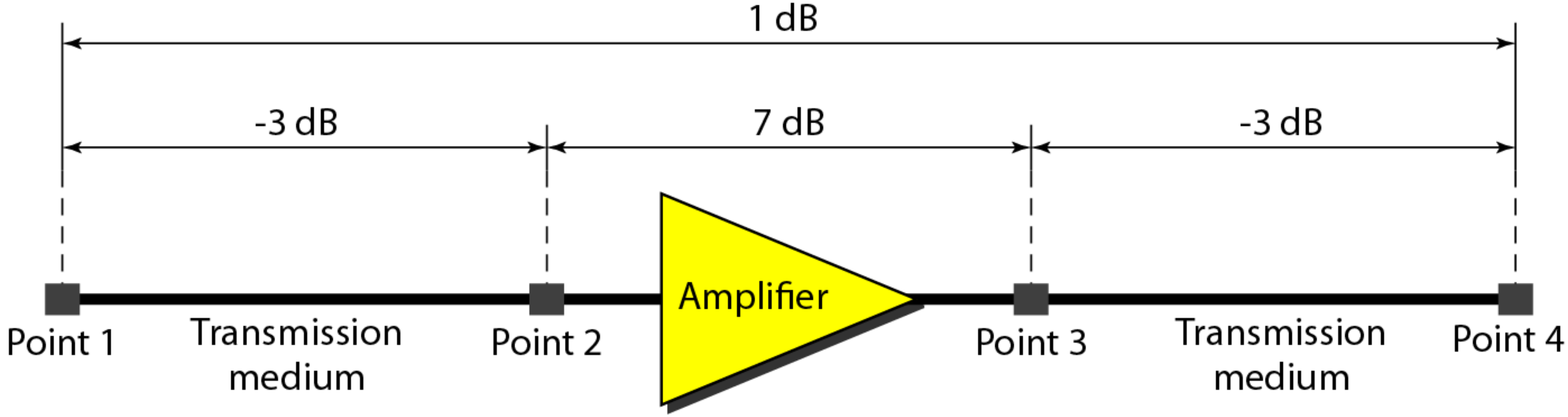
$$= 10 \log_{10} 10 = 10(1) = 10 \text{ dB}$$

Example 3.28

One reason that engineers use the decibel to measure the changes in the strength of a signal is that decibel numbers can be added (or subtracted) when we are measuring several points (cascading) instead of just two. In Figure 3.27 a signal travels from point 1 to point 4. In this case, the decibel value can be calculated as

$$\boxed{\text{dB} = -3 + 7 - 3 = +1}$$

Figure 3.27 *Decibels for Example 3.28*



Example 3.29

Sometimes the decibel is used to measure signal power in milliwatts. In this case, it is referred to as dB_m and is calculated as $dB_m = 10 \log10 P_m$, where P_m is the power in milliwatts. Calculate the power of a signal with $dB_m = -30$.

Solution

We can calculate the power in the signal as

$$\mathrm{dB_m} = 10 \log_{10} P_m = -30$$

$$\log_{10} P_m = -3 \qquad P_m = 10^{-3}\ \mathrm{mW}$$

Example 3.30

The loss in a cable is usually defined in decibels per kilometer (dB/km). If the signal at the beginning of a cable with −0.3 dB/km has a power of 2 mW, what is the power of the signal at 5 km?

Solution

The loss in the cable in decibels is 5 × (−0.3) = −1.5 dB. We can calculate the power as

$$\text{dB} = 10 \log_{10} \frac{P_2}{P_1} = -1.5$$

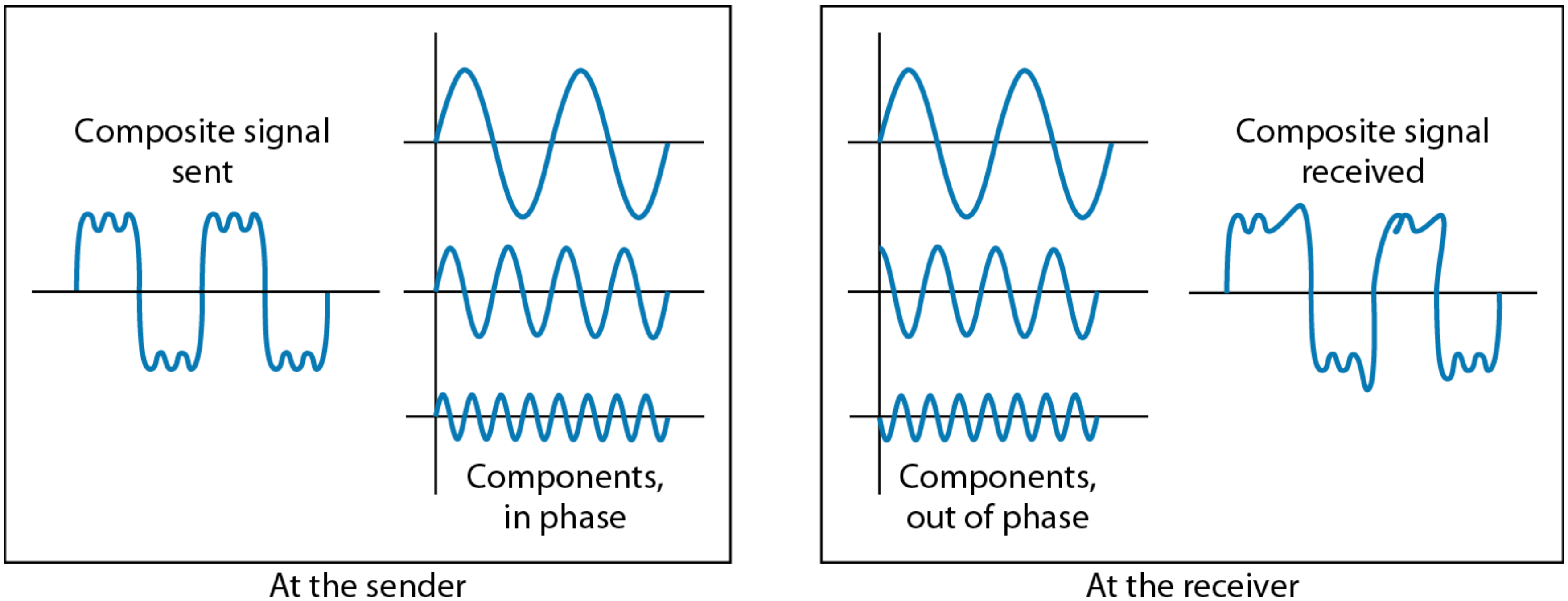
$$\frac{P_2}{P_1} = 10^{-0.15} = 0.71$$

$$P_2 = 0.71 P_1 = 0.7 \times 2 = 1.4 \text{ mW}$$

Distortion

- Means that the signal changes its form or shape
- Distortion occurs in composite signals
- Each frequency component has its own propagation speed traveling through a medium.
- The different components therefore arrive with different delays at the receiver.
- That means that the signals have different phases at the receiver than they did at the source.

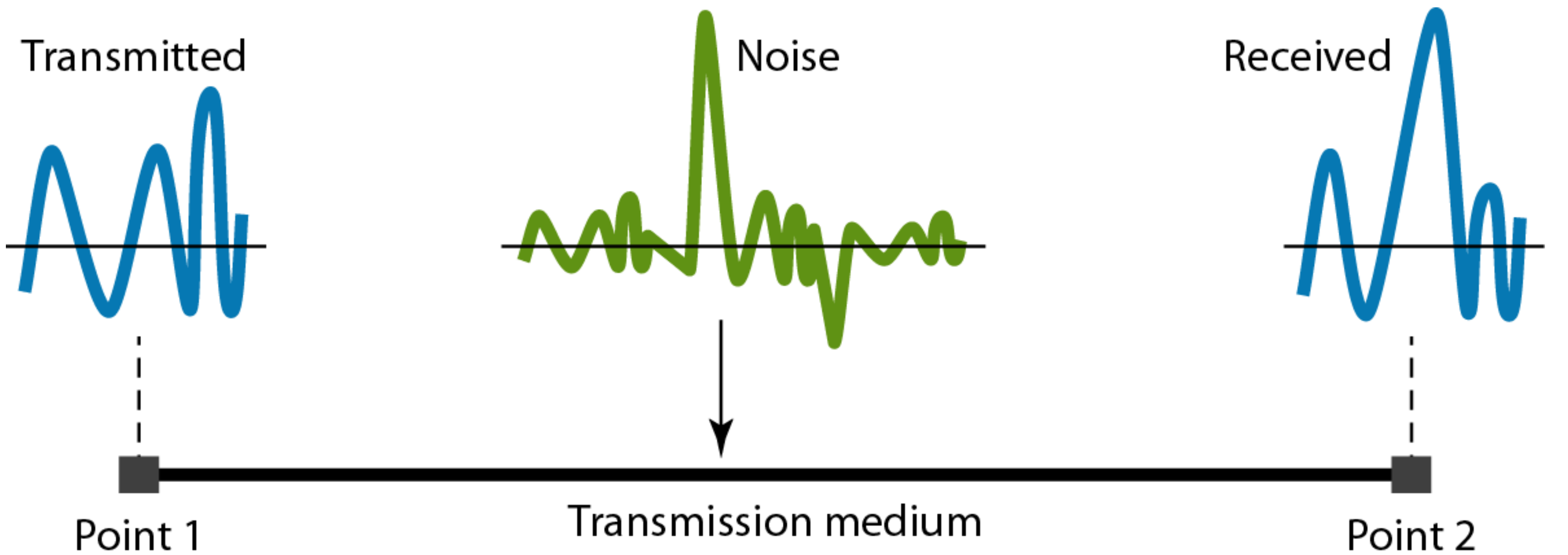
Figure 3.28 *Distortion*



Noise

- There are different types of noise
  - Thermal - random noise of electrons in the wire creates an extra signal
  - Induced - from motors and appliances, devices act are transmitter antenna and medium as receiving antenna.
  - Crosstalk - same as above but between two wires.
  - Impulse - Spikes that result from power lines, lighning, etc.

Figure 3.29 *Noise*



Signal to Noise Ratio (SNR)

- To measure the quality of a system the SNR is often used. It indicates the strength of the signal wrt the noise power in the system.
- It is the ratio between two powers.
- It is usually given in dB and referred to as SNR_{dB}.

Formula

The **Signal-to-Noise Ratio (SNR)** can be calculated in two main ways, depending on whether you want it as a **ratio** or in **decibels (dB)**.

---

1. Ratio form (unitless)

$$\mathrm{SNR} = \frac{P_{\text{signal}}}{P_{\text{noise}}}$$

Where:

- P_{signal} = average signal power
- P_{noise} = average noise power

2. In decibels (most common in communications)

$$\mathrm{SNR}_{\text{dB}} = 10\log_{10}\left(\frac{P_{\text{signal}}}{P_{\text{noise}}}\right)$$

Example 3.31

The power of a signal is 10 mW and the power of the noise is 1 μW; what are the values of SNR and SNR_{dB}?

Solution

The values of SNR and SNR_{dB} can be calculated as follows:

$$\text{SNR} = \frac{10{,}000\ \mu\text{W}}{1\ \text{mW}} = 10{,}000$$

$$\text{SNR}_{\text{dB}} = 10 \log_{10} 10{,}000 = 10 \log_{10} 10^4 = 40$$

Where, 1 mW = 1000 μW

Example 3.32

The values of SNR and SNR_{dB} for a noiseless channel are

$$\mathrm{SNR} = \frac{\text{signal power}}{0} = \infty$$

$$\mathrm{SNR_{dB}} = 10 \log_{10} \infty = \infty$$

We can never achieve this ratio in real life; it is an ideal.

3-5 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)*

Topics discussed in this section:

Noiseless Channel: Nyquist Bit Rate
Noisy Channel: Shannon Capacity

Noiseless Channel: Nyquist Bit Rate

- ***BitRate = 2 x bandwidth x $\log_2 L$***
- ***L is the number of levels used to represent data***
- ***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***

$$\boxed{\text{BitRate} = 2 \times 3000 \times \log_2 2 = 6000 \text{ bps}}$$

Note

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

- A noiseless channel has bandwidth B = 4 kHz and uses binary signaling (L = 2). Find the maximum bit rate according to Nyquist.

- **Solution**
- Write the formula: $\text{BitRate} = 2 \times B \times \log_2(L)$.
- Substitute: $\text{BitRate} = 2 \times 4000 \times \log_2(2)$.
- Since $\log_2(2) = 1$, $\text{BitRate} = 2 \times 4000 \times 1 = 8000$ bps.
- Therefore, the maximum bit rate is 8 kbps.

- A noiseless channel with bandwidth $B = 5$ kHz employs 8-level signaling ($L = 8$). Compute the Nyquist maximum bit rate.

- **Solution**
- Use $\text{BitRate} = 2 \times B \times \log_2(L)$.
- Compute $\log_2(8) = 3$.
- $\text{BitRate} = 2 \times 5000 \times 3 = 30{,}000$ bps.
- Hence, the maximum bit rate is 30 kbps.

- A noiseless channel of bandwidth B = 4 kHz must support a bit rate of C= 96 kbps. What is the required number of signal levels L?
- **Solution**
- Start with BitRate = 2 × B × $\log_2(L)$.
- Rearrange: $\log_2(L)$ = BitRate / (2B) = 96,000 / (2 × 4000) = 96,000 / 8,000 = 12.
- Therefore, L = 2^{12} = 4096 levels.

If you know $\log_2(L)$ and want to find L, you use the **inverse logarithm:**

$$L = 2^{\log_2(L)}$$

Noisy Channel: Shannon Capacity

- ***In reality, there is no noiseless channel; the channel is always noisy.***
- ***Shannon capacity determines the theoretical highest data rate for a noisy channel***
- ***Capacity = bandwidth x $\log_2(1+SNR)$***
- ***SNR is the signal-to-noise ratio.***

Example 3.37

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

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

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.

- A noisy channel has bandwidth $B = 3$ kHz and an SNR of 15 (linear). Find the channel capacity C.

Solution

1. Formula: $C = B \times \log_2(1 + SNR)$
2. Substitute: $C = 3000 \times \log_2(1 + 15)$
3. $1 + 15 = 16$, and $\log_2(16) = 4$
4. $C = 3000 \times 4 = 12{,}000$ bps

Answer: $C = 12$ kbps

A channel has bandwidth B = 4 kHz and an SNR of 20 dB. Find the Shannon capacity C.

Solution

$$\boxed{\mathrm{SNR}_{\mathrm{dB}} = 10\log_{10}(\mathrm{SNR}_{\mathrm{linear}})}$$

$$\boxed{\mathrm{SNR}_{\mathrm{linear}} = 10^{\frac{\mathrm{SNR}_{\mathrm{dB}}}{10}}}$$

1. Convert SNR from dB to linear: SNR_linear = 10^(20/10) = 100
2. C = 4000 × $\log_2$(1 + 100)
3. 1 + 100 = 101; $\log_2$(101) ≈ 6.6582
4. C ≈ 4000 × 6.6582 ≈ 26,632.8 bps

Answer: C ≈ 26.63 kbps

Note

The Shannon capacity gives us the upper limit; the Nyquist formula tells us how many signal levels we need.