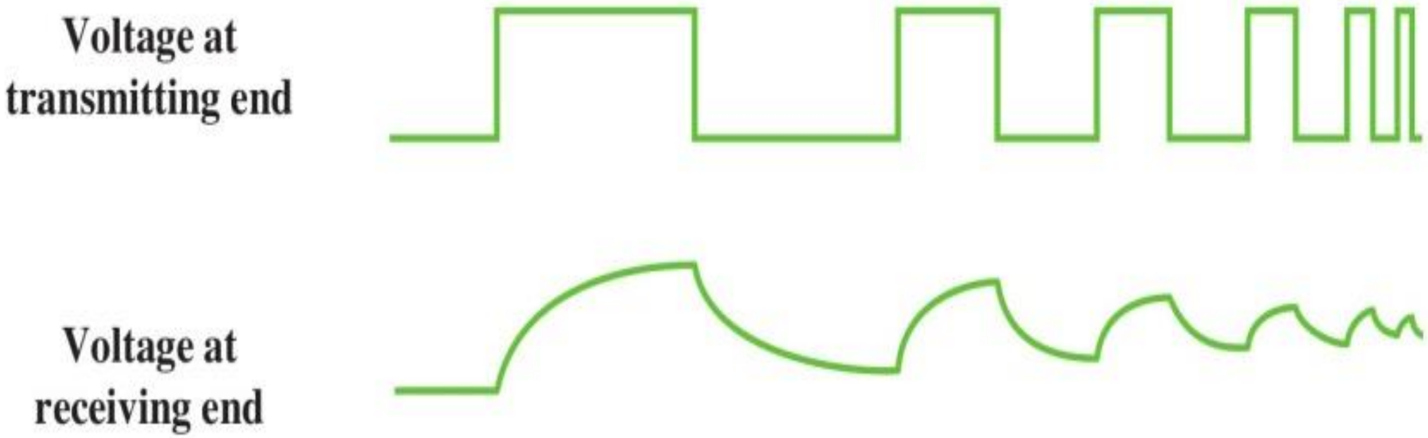
Recap Concepts

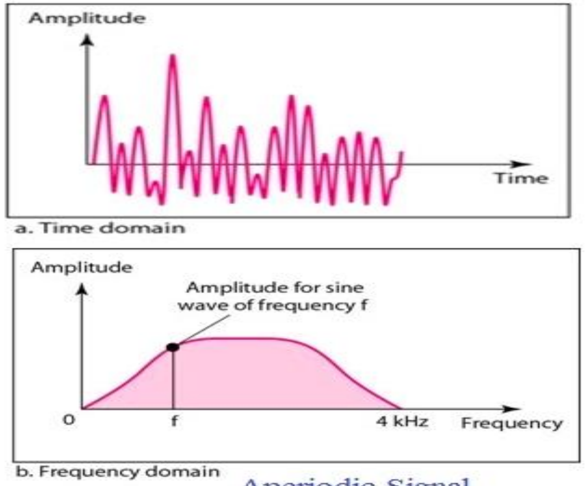
Analog vs Digital Signals

- Electric or electromagnetic representations of data.
- Analog signal : continuously varying electromagnetic wave.
- Digital signal : sequence of voltage pulses.



Data Communication Concepts

- Communication Model and Tasks
- Types of Data and Signals
- Time Domain Concepts
- Frequency Domain Concepts
- Representation in Time and Frequency Domain: Advantages
- Sine wave equation
- Fundamental and Harmonic Frequency: Frequency Components of a square wave.
- DC Component

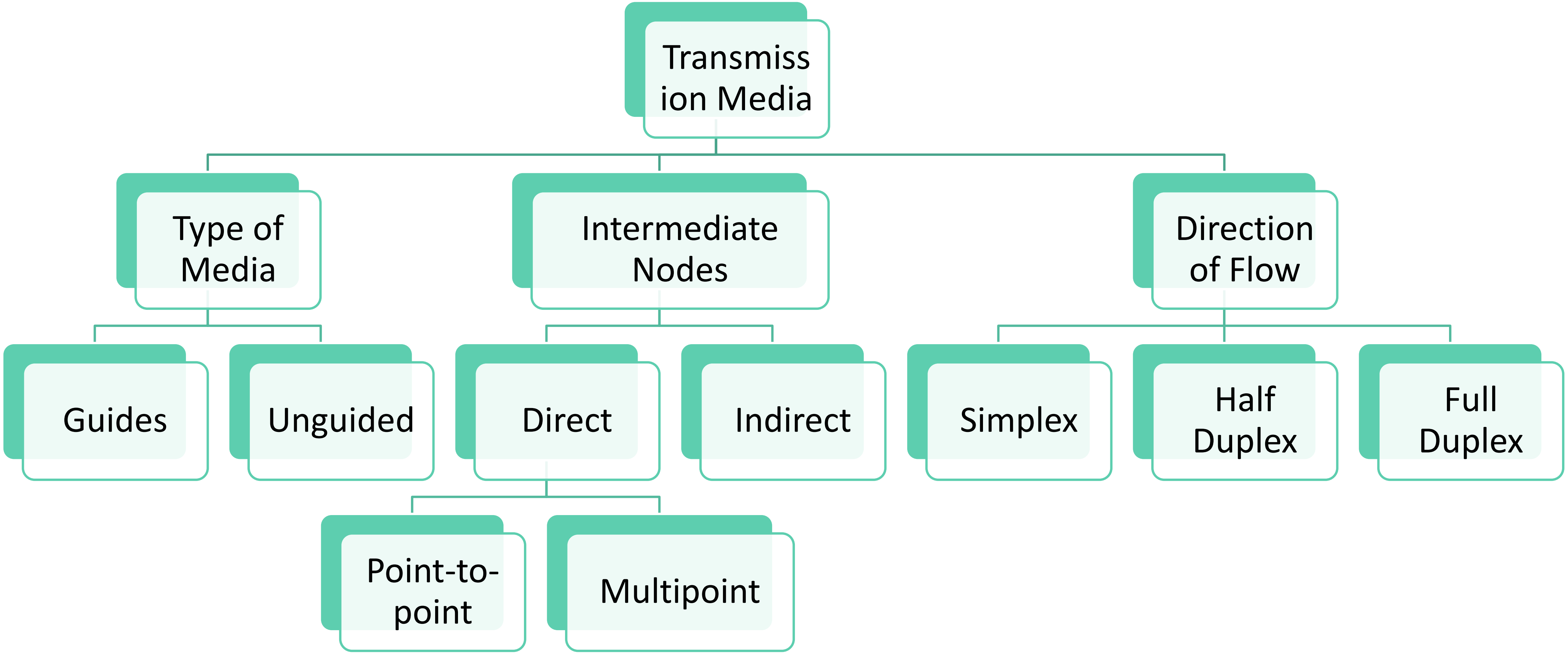


Aperiodic Signal

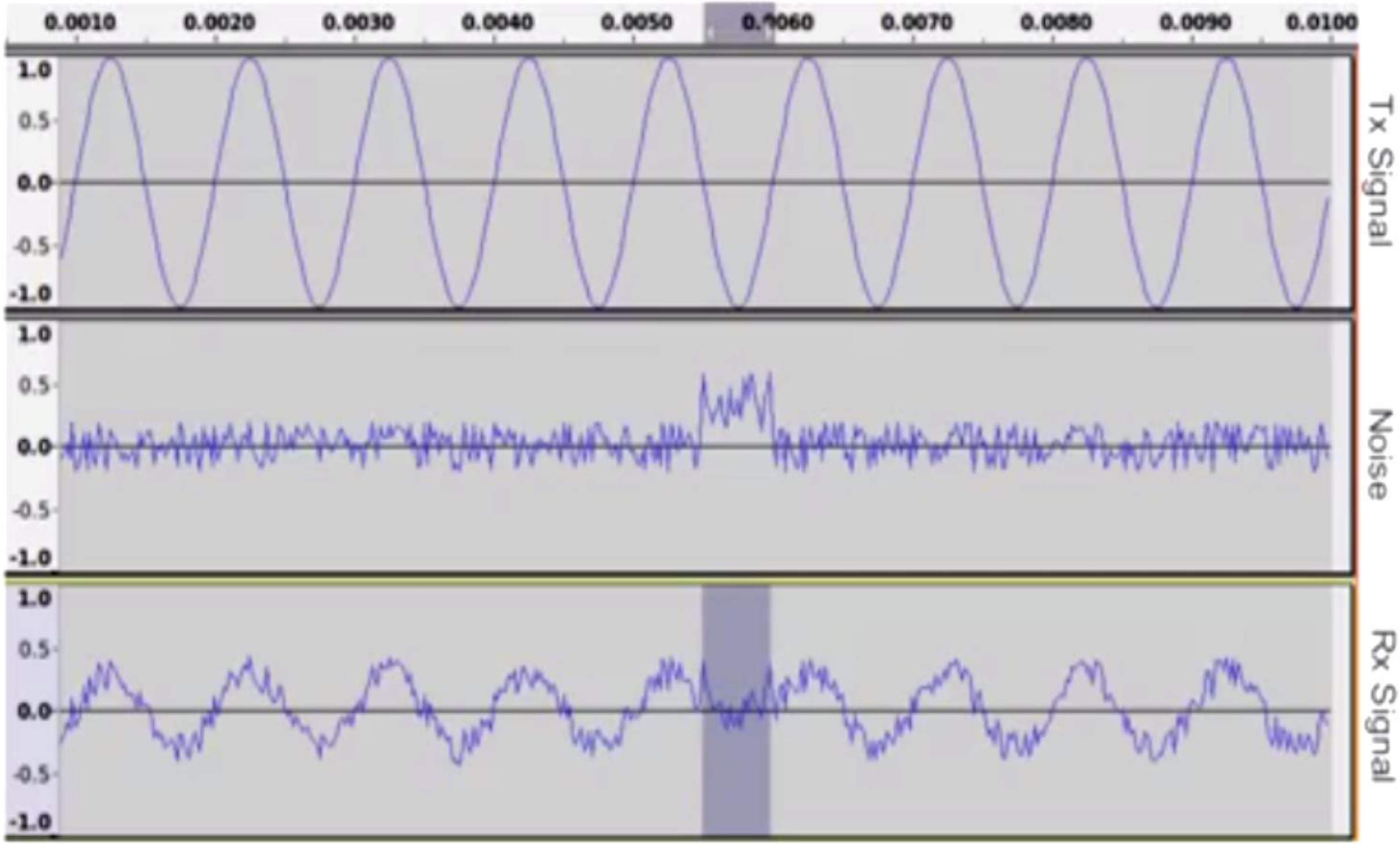
Data Communication Concepts

- Data Rate and Bandwidth
- Digital Signal Concepts
- Data, Signals, Transmission: Analog and Digital (Modem, Codec)
- Transmission Media
- Transmission Impairments
- Channel Capacity: Nyquist BW, Shannon Formula

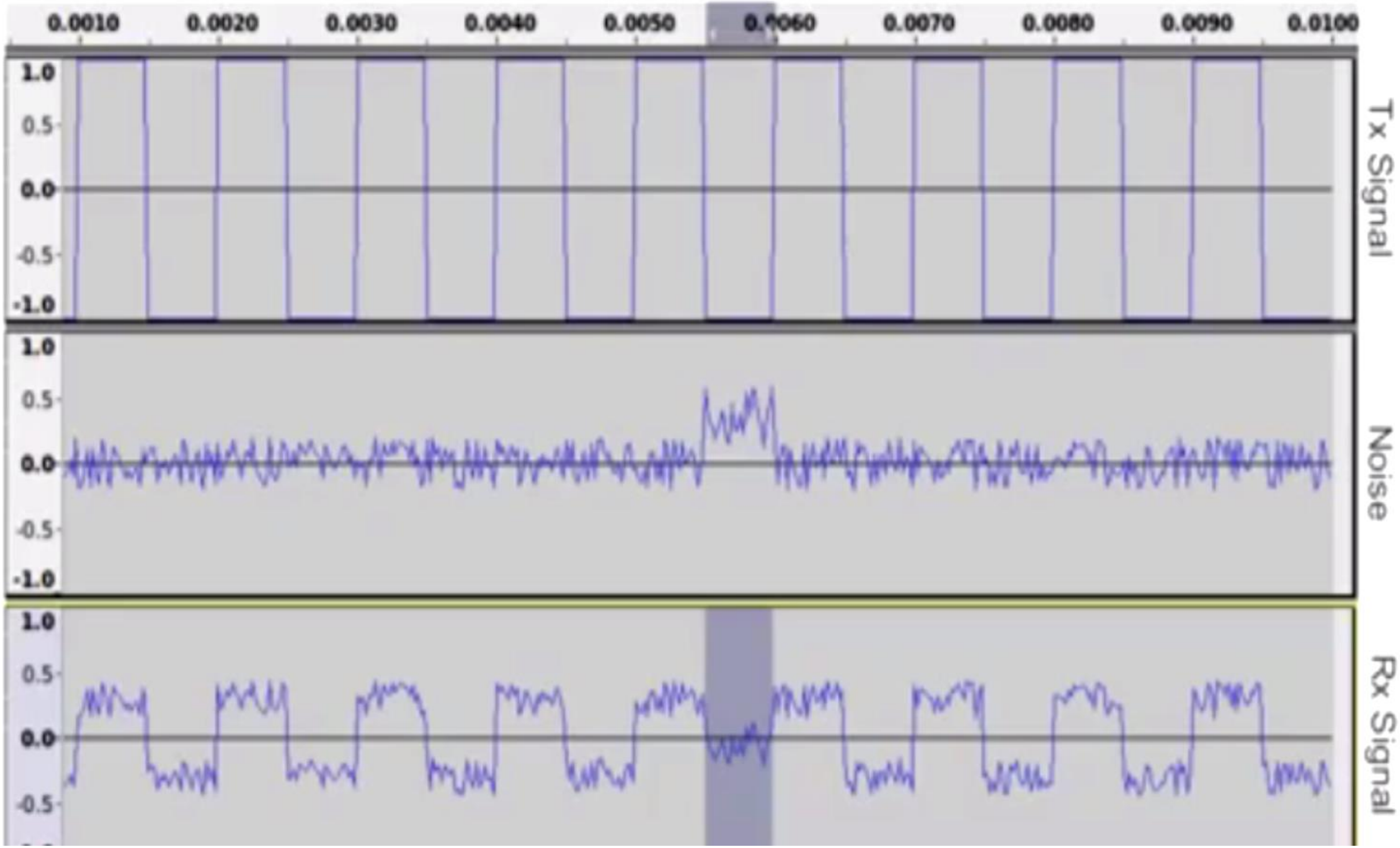
Transmission Media



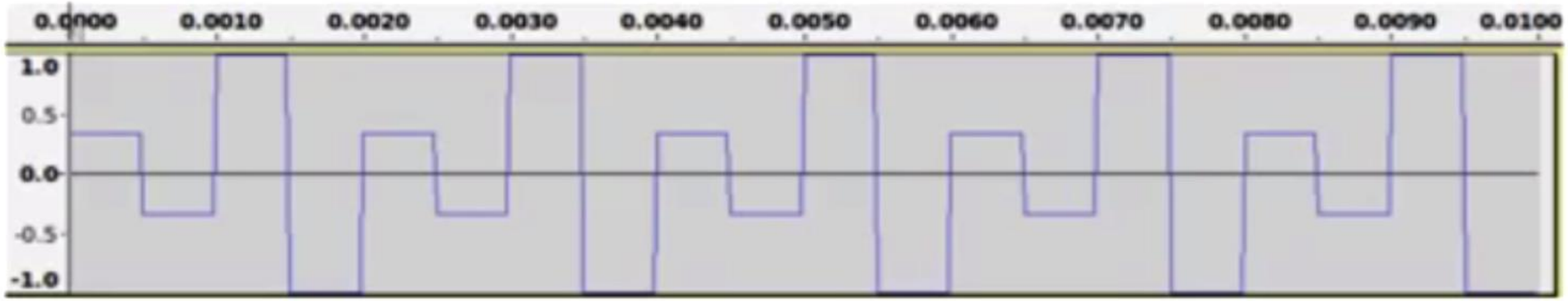
Tx Signal: 1000 Hz sine wave; Attenuation; Random noise with 0.5ms spike

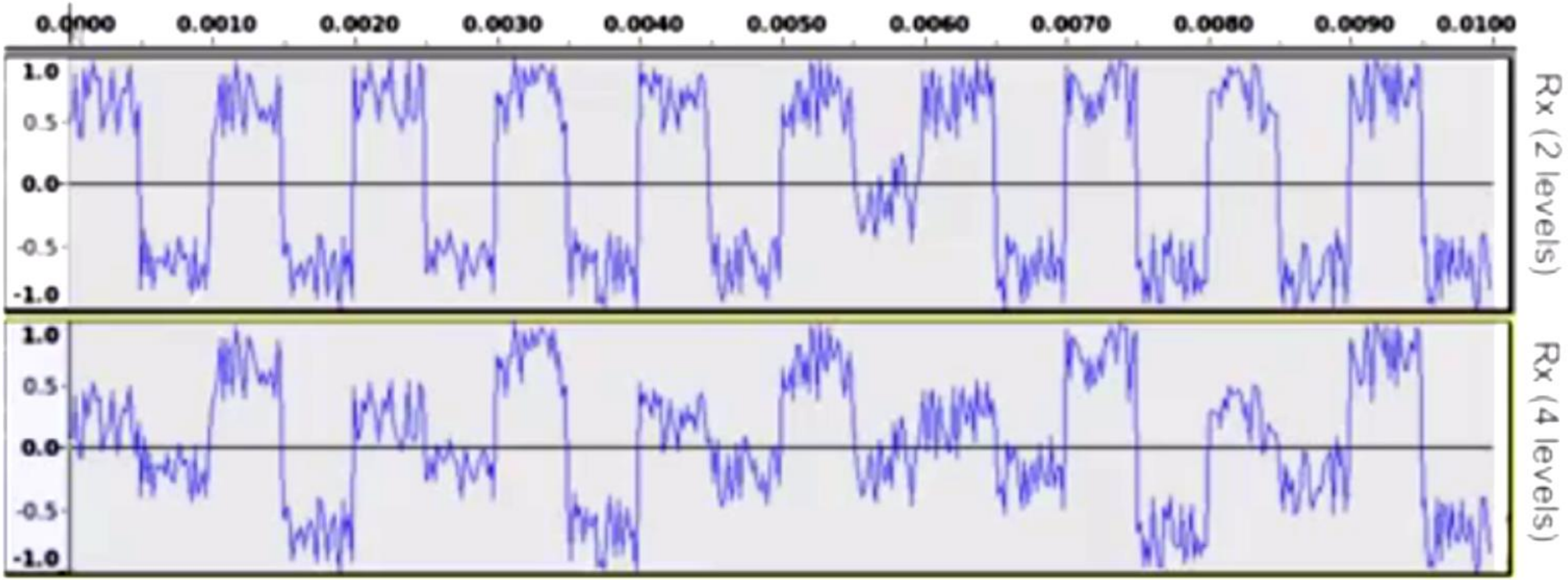


Tx Signal: 1000 Hz square wave; Attenuation; Random noise with 0.5ms spike



What about a signal with 2 levels vs a signal with 4 levels: which one will have more bit errors for some given noise?




0.0000
0.0010
0.0020
0.0030
0.0040
0.0050
0.0060
0.0070
0.0080
0.0090
0.0100
1.0
0.5
0.0
-0.5
-1.0
Rx (2 levels)
Rx (4 levels)

Trade-Offs for Channel Capacity

Increase Bandwidth		
Increase Levels in a Signal		
Increase Bandwidth		
Increase Signal		
Increase Noise		

What we want:

To get as **high a data rate** as possible at a particular **limit of error rate** for a **given bandwidth**.

Trade-offs for Nyquist Capacity

- Increase the bandwidth, increases the data rate
- Increase the signal levels, increases the data rate
- Increase the signal levels, harder for receiver to interpret the bits (practical limit to M)

Trade-offs : Shannon Capacity

- Increase bandwidth or signal power, increases data rate.
- Increase of noise, reduces data rate,
- Increase bandwidth, allows more noise.
- Increase signal power, causes increased intermodulation noise.

Terminologies

- **Data rate:** The rate, in bits per second (bps), at which data can be communicated.
- **Bandwidth:** The bandwidth of the transmitted signal as constrained by the transmitter and the nature of the transmission medium, expressed in cycles per second, or Hertz.
- **Noise:** The average level of noise over the communications path.
- **Error rate:** The rate at which errors occur, where an error is the reception of a 1 when a 0 was transmitted or the reception of a 0 when a 1 was transmitted.

Nyquist Capacity

- Given a bandwidth of *B*, the highest signal rate that can be carried is 2*B*.
- This limitation is because **of intersymbol interference** (similar to delay distortion).
- **Where is this result useful?**
- In the development of digital-to-analog encoding schemes.

Shannon's Capacity

- Assume a given level of noise. For that same level of noise, how can the receiver's ability to receive data correctly be improved?
  - If we have a greater signal strength.
- What are the repercussions of increasing signal strength?
  - Effect of **non-linearities** in the system will increase=> Increase in intermodulation noise.
- Where is SNR measured and why?
  - At the receiver, because the signal is processed here to recover the data.
- Present technology still can not achieve Shannon capacity. Why?
  - Shannon's formula does not account all other noises. Moreover, encoding issues (coding length and complexity) is an add-on concern.

- *If the actual information rate on a channel is less than the error-free capacity, then it is **theoretically possible** to use a suitable **signal code** to achieve error-free transmission through the channel.*

Concept of gain and loss.

$$SNR_{dB} = 10 \log_{10} \frac{\text{signal power}}{\text{noise power}}$$

- Power vs Voltage (signal Levels)
- Decibels, dB.
- G_{dB} : gain in decibels.
- Gain, $G = P_{out} / P_{in}$

Question

Q: We have a bandwidth of 300Hz between a dialup modem and an ISP. If M=2, what is the maximum data rate we can achieve using this modem? If we want a speed of 56Kbps, what needs to be done?

Question

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

$265000 = 2*20000 * \log_2 L$

$\Rightarrow L = 2^{6.625} = 98.7$ levels (theoretical)

Generally, we need levels that is a power of 2.

We may either increase the number of levels or reduce the bit rate.

If we have 128 levels, bit rate is 280Kbps.

Or, Bit rate becomes 240 Kbps, if we make the number of levels=64.