Where are you joining from today?

ELEC202

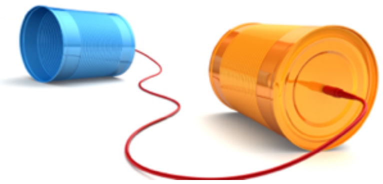
Lecture 10/12

Digital Baseband Communication

Last week…

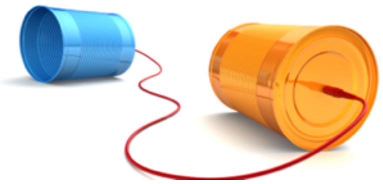
- **Digitisation: Sampling & Quantisation**
- **Nyquist-Shannon criterion**
- **Aliasing and anti-aliasing filters**
- **Quantisation and quantization error**

Questions: SMS to *02071 838 329* starting with code: *wax*
Or visit www.textwall.co.uk/post



What remains . . .

- **L10: Digital Baseband/Pulse Modulation**
- **L11 (Mon 20/4): Digital Bandpass Modulation**
- **L12 (Thu 23/4): Multiplexing**
- **Class Test 2: Thu 30/4 at 9:00am**



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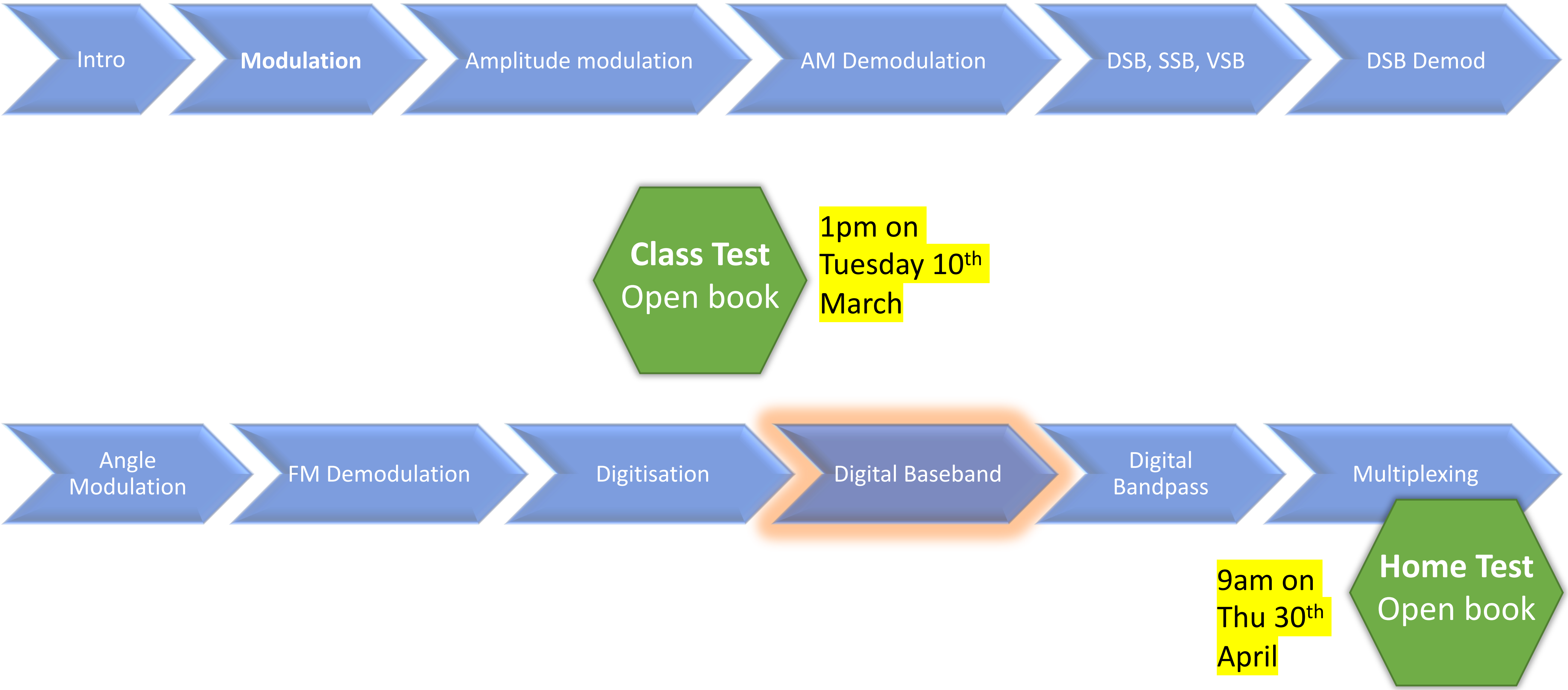
Module Pathway



~~Class~~ Home Test 2 (15%)

- 9am on Thu 30th April
- Simultaneous open-book ”home” test
- Lectures 7 to 12 included
- 15 questions
- No resit/repeat opportunity
- Practice mini-tests available

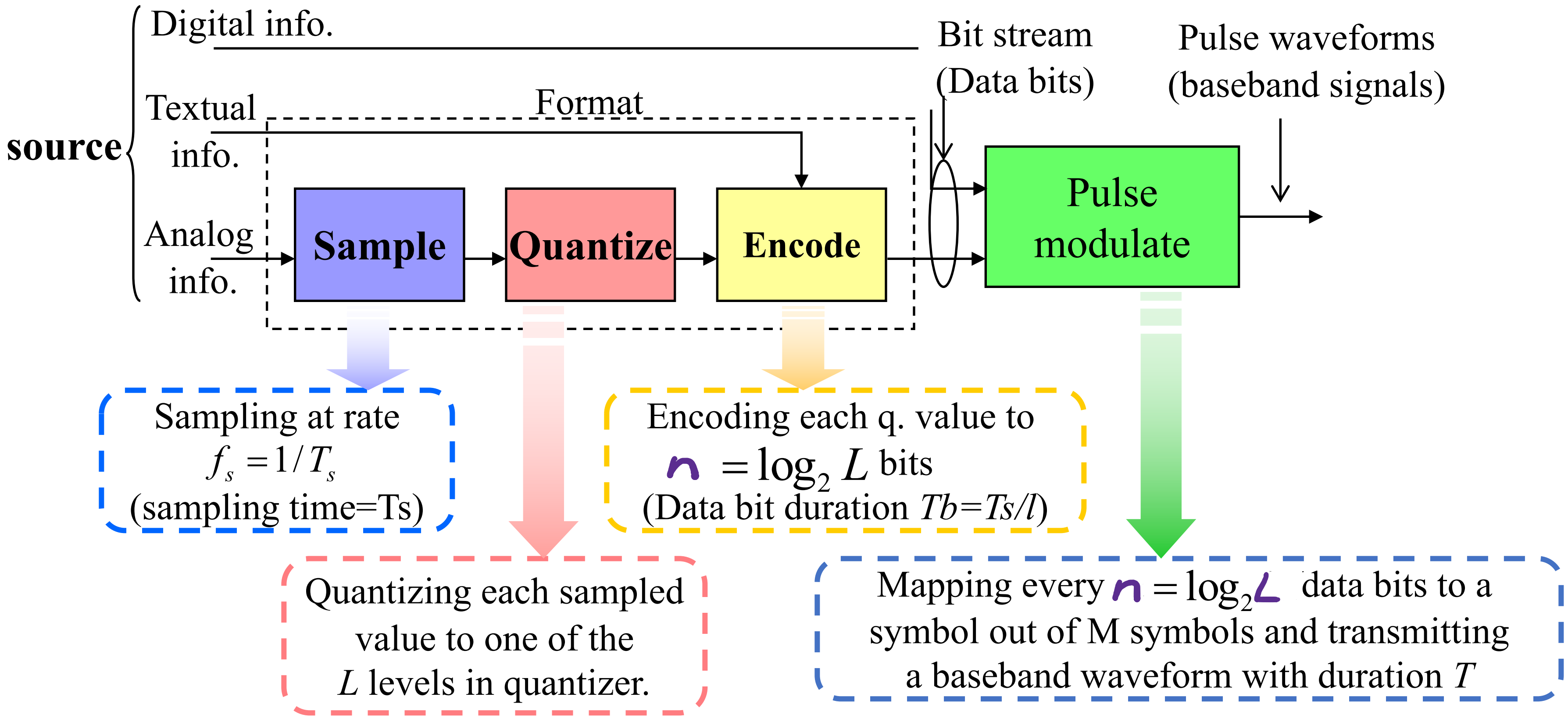
Next Steps…

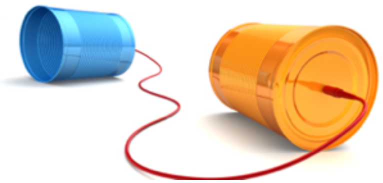
- After the signal has been sampled, quantised and encoded, it is ready for digital transmission (baseband or bandpass): today, we'll be talking about baseband transmission,

Today

- **Pulse Modulation and Pulse Code Modulation**
- **Line Coding**
- **Hartley-Shannon Law (Channel Capacity)**

Before Pulse Modulation…

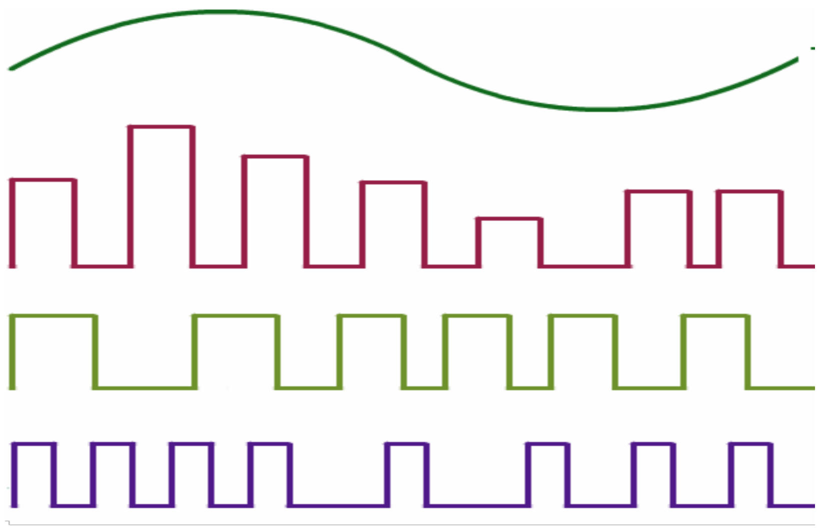


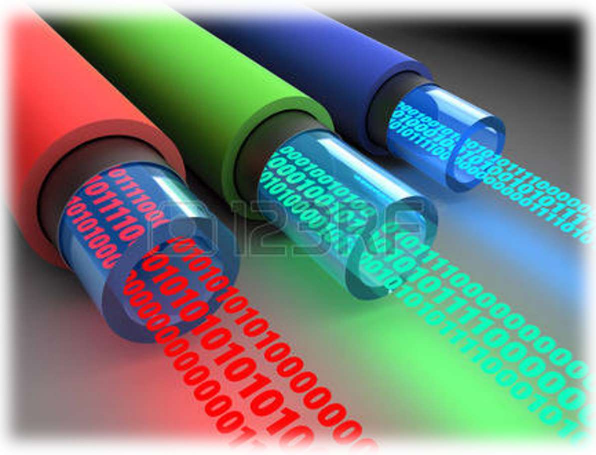


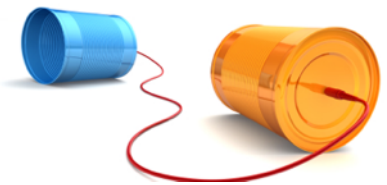
Pulse ‘Modulation’

Pulse modulation is a form of **baseband** communication.

Even though it is called “modulation”, no carrier is involved.







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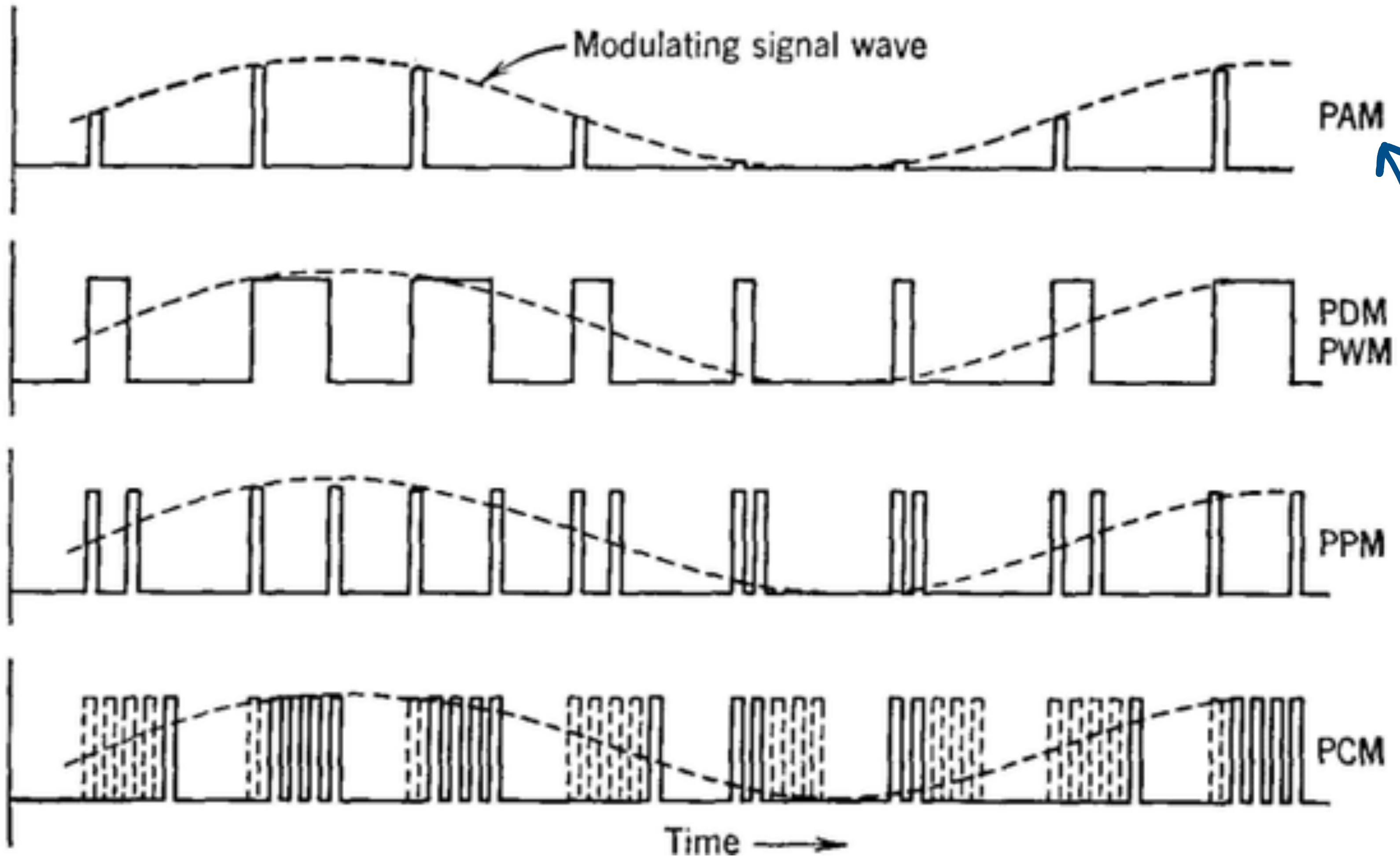
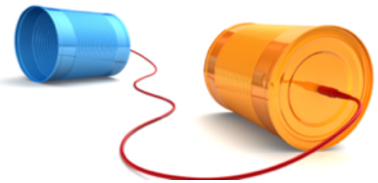
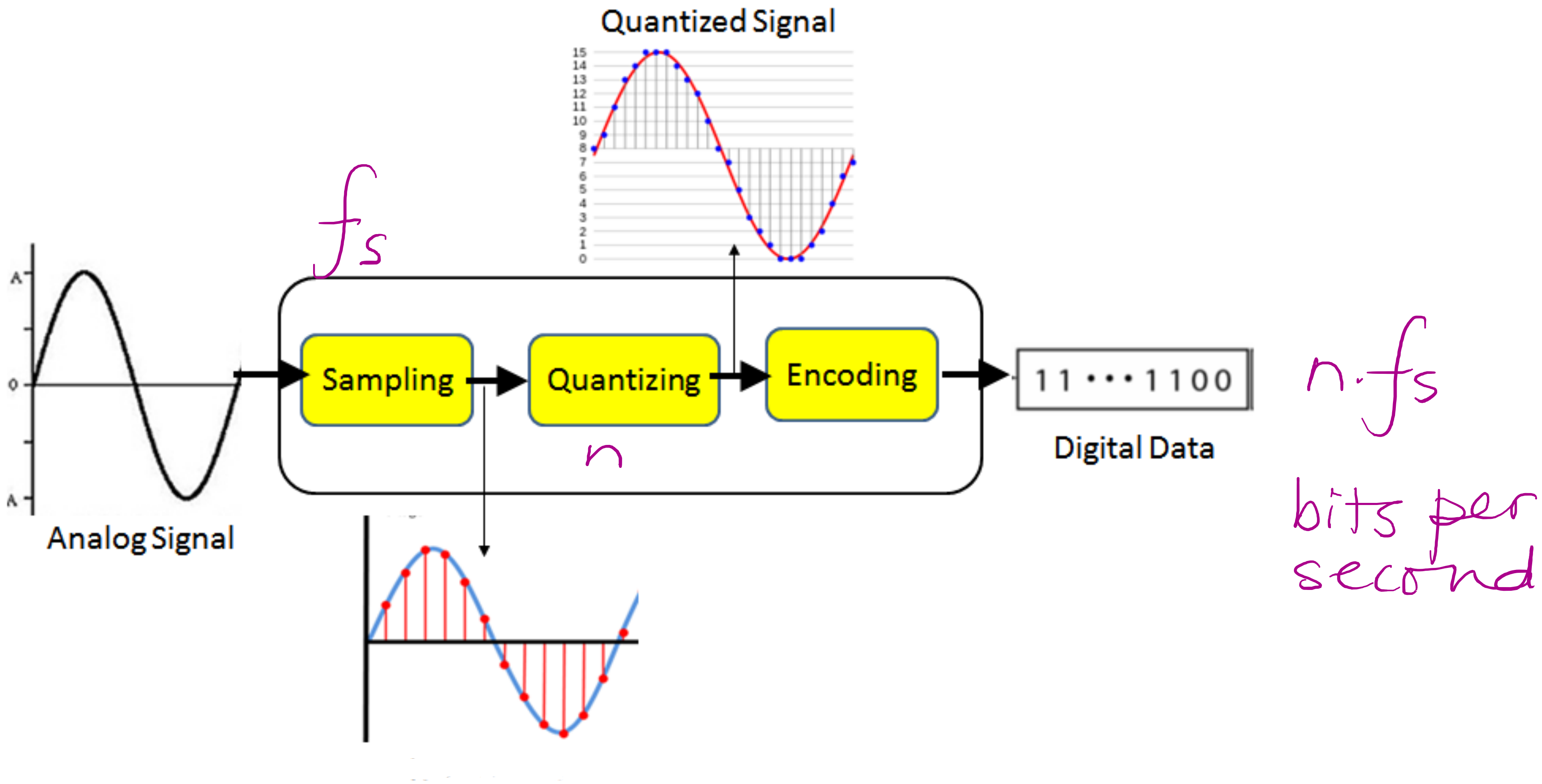
Pulse Modulation Schemes

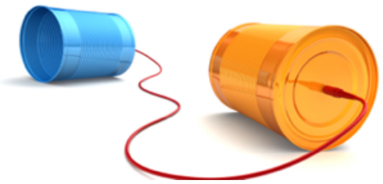


could also be analogue



PCM Generation





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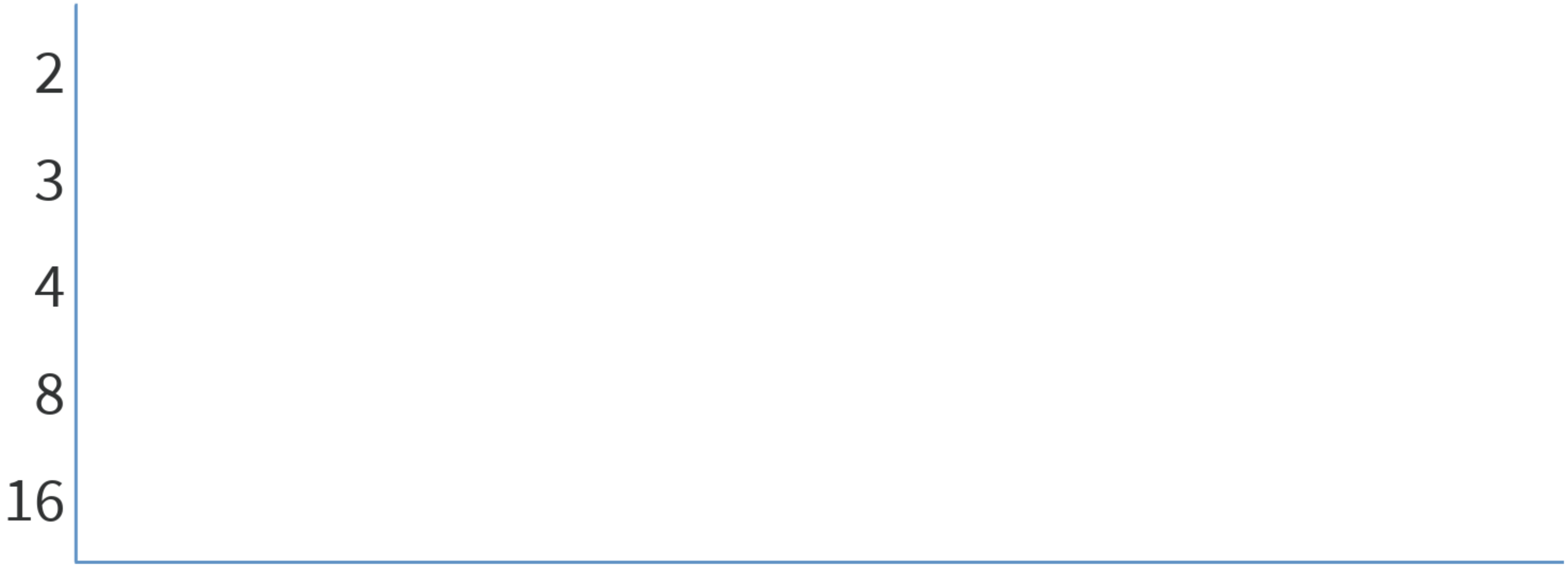
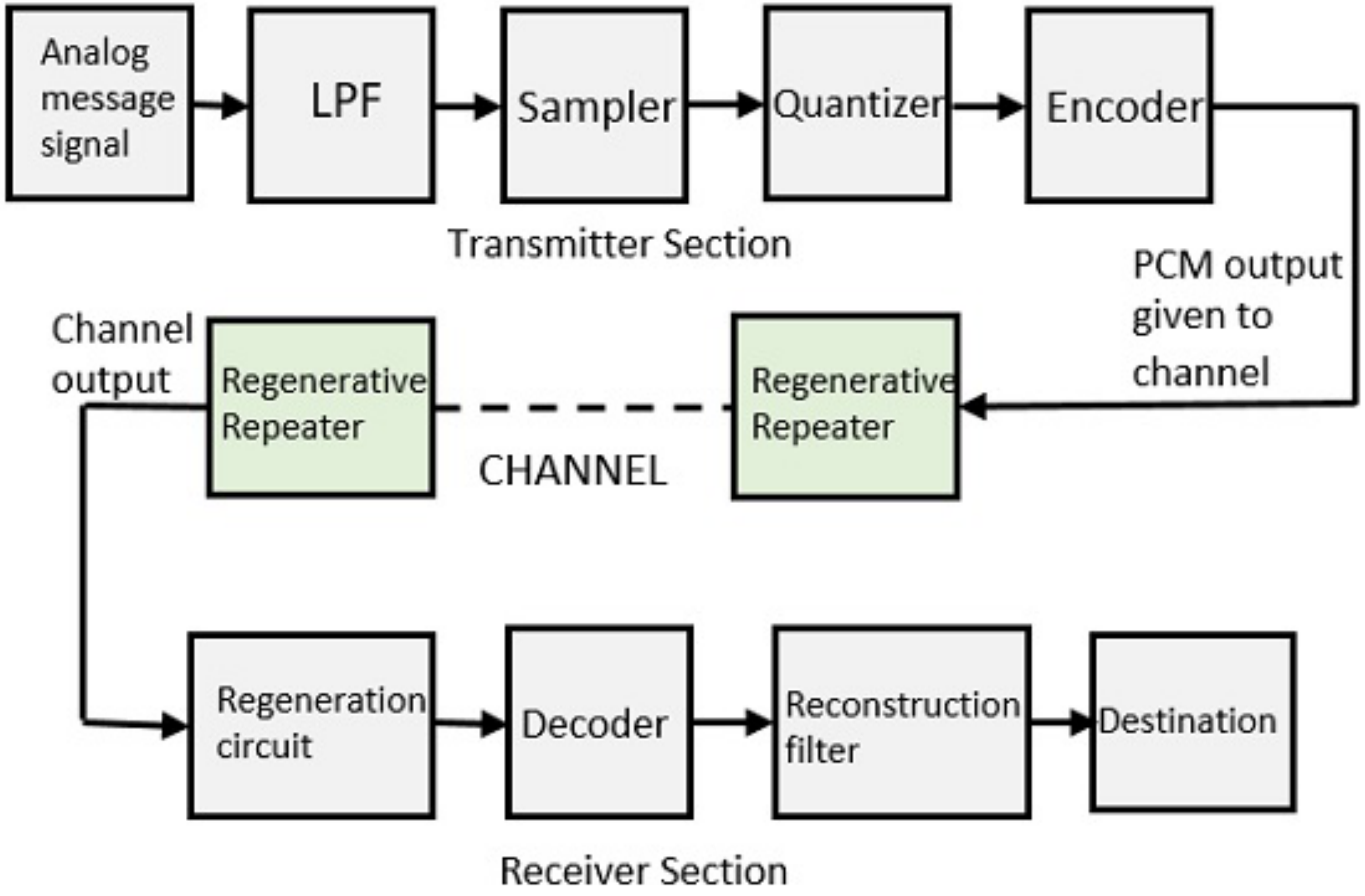
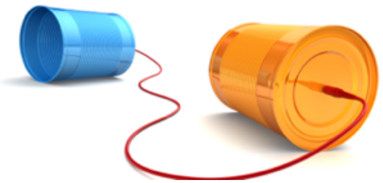
A signal is encoded using PCM with 16 levels. How many bits per sample are needed?

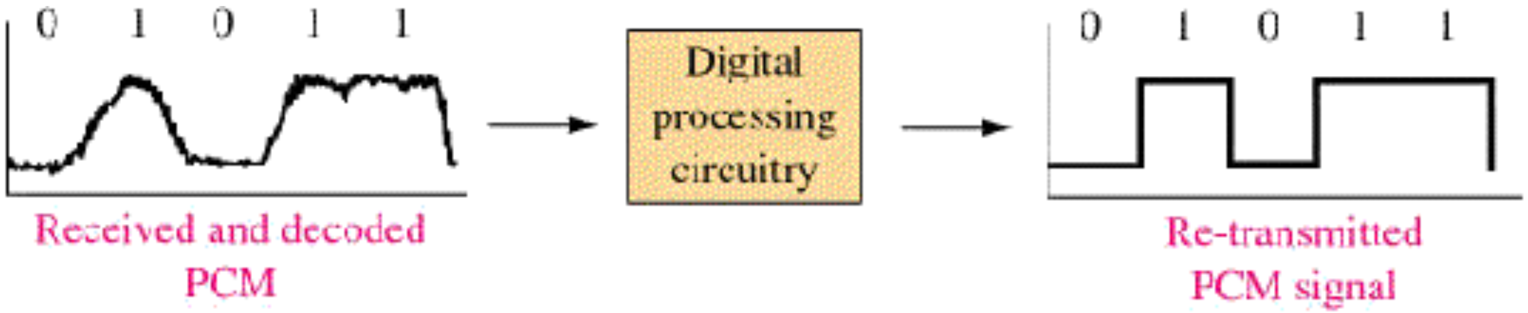


PCM System


Analog message signal
LPF
Sampler
Quantizer
Encoder
Transmitter Section
PCM output given to channel
Channel output
Regenerative Repeater
CHANNEL
Regenerative Repeater
Regeneration circuit
Decoder
Reconstruction filter
Destination
Receiver Section

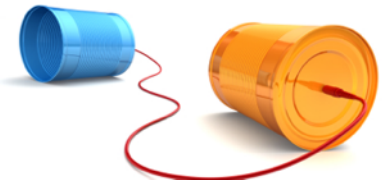


Pulse Regeneration



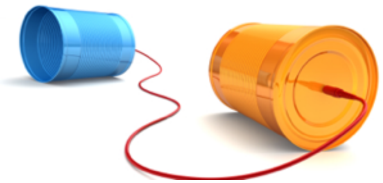
Noise added by the channel etc. is removed by regenerating a fresh signal. This is done by a ***regenerator***.

Some errors can nevertheless appear



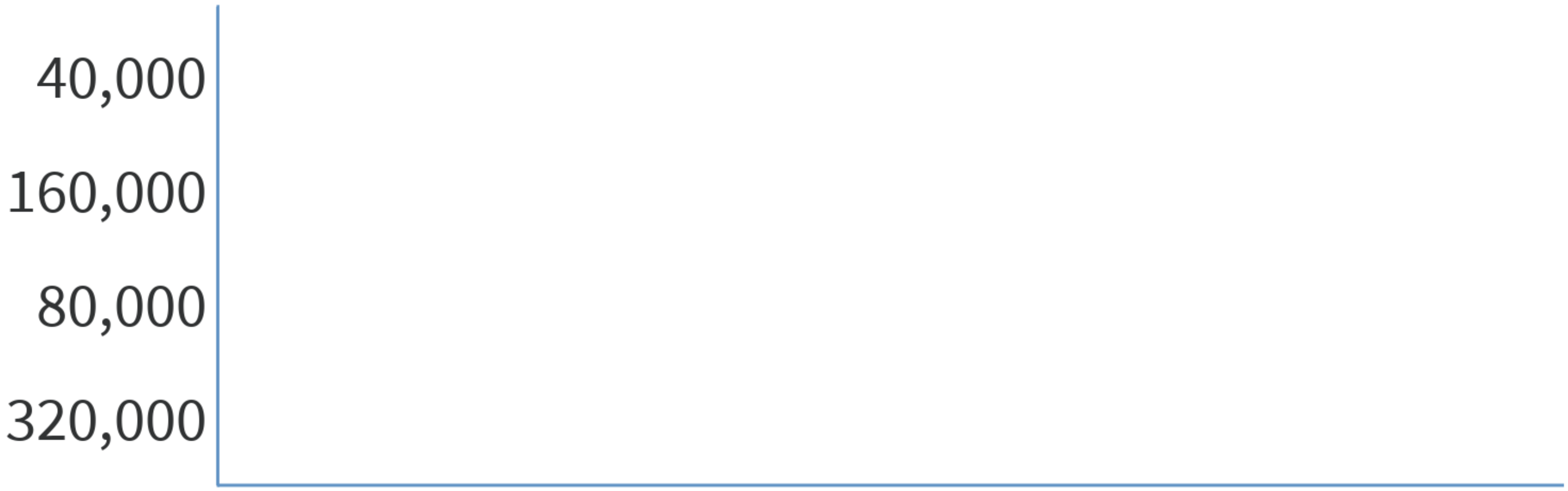
PCM Bandwidth

- For a sample rate of f_s samples per second …
- and $L=2^n$ quantiser levels, n = bits per sample
- Bit rate at quantiser output is $f_s n$ bits/sec
- Optimum pulse shaping : **2** bits per second per Hertz
- Min. PCM bandwidth with optimum pulse shaping ∴ $f_s n / 2$ Hz

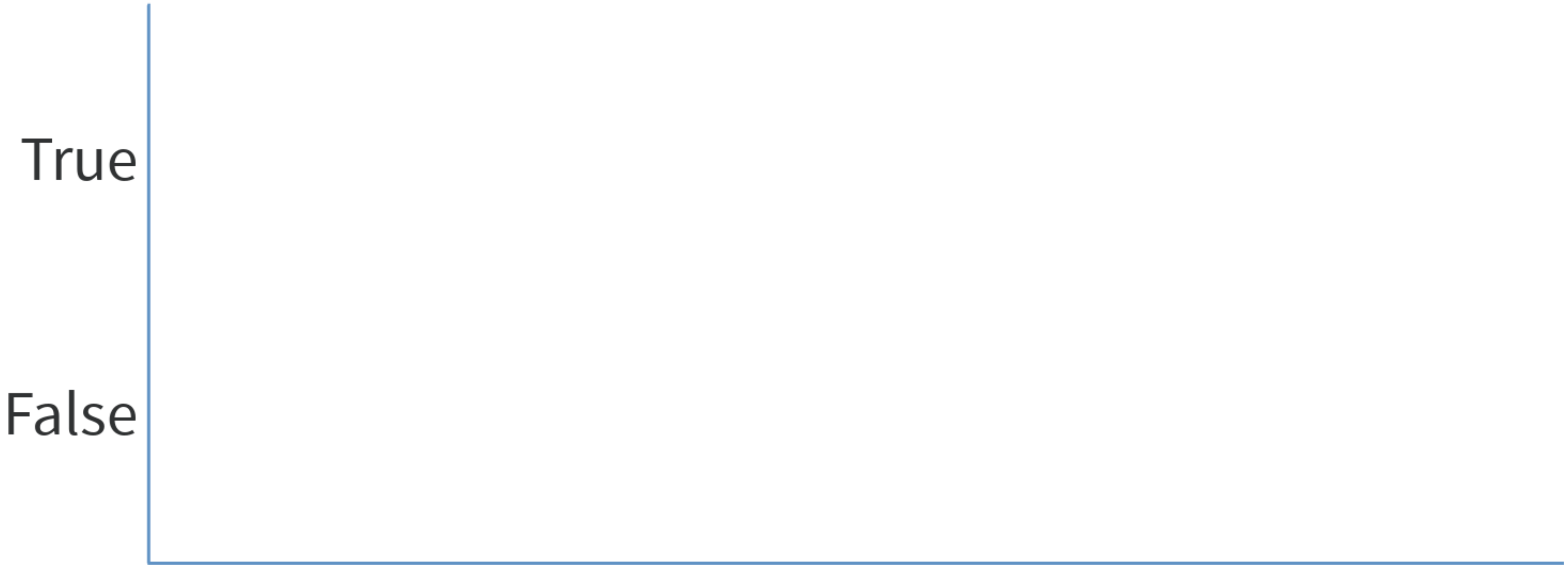


A signal is sampled at 10kHz and encoded using PCM with 16 levels.

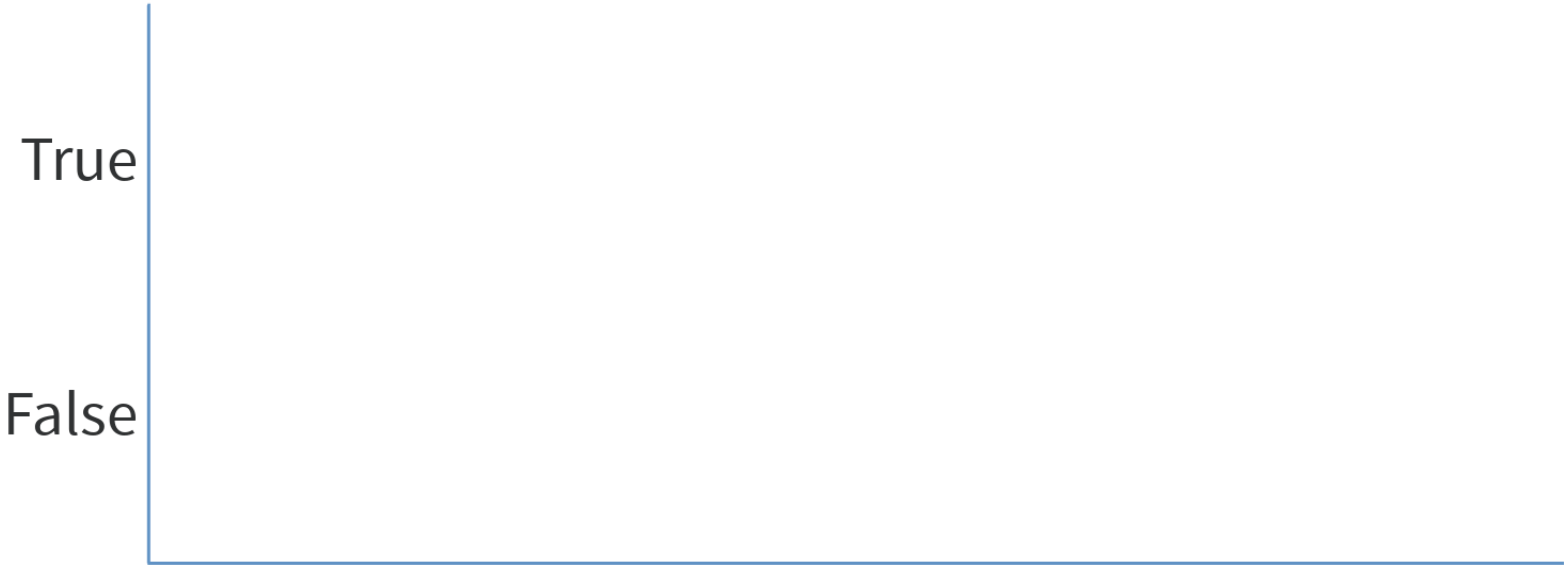
How many bits per second are needed?



A PCM signal with 16 levels needs half the bandwidth of a PCM signal with 32 levels (assuming same sample rate)

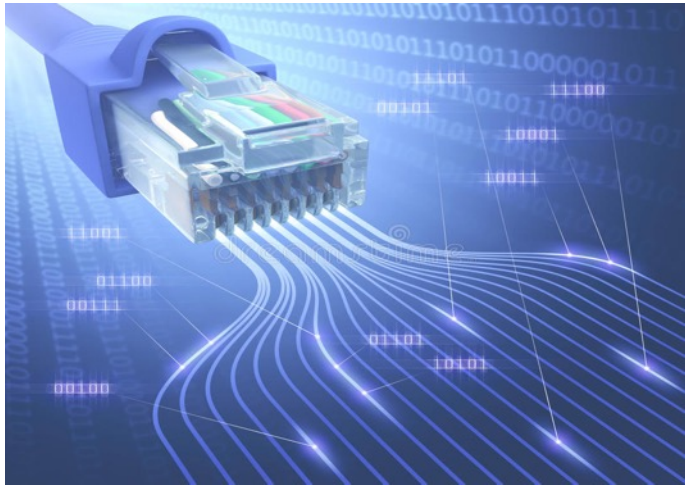


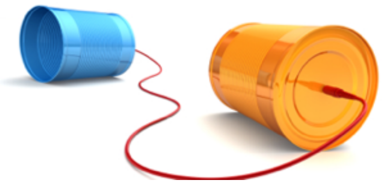
A PCM signal with 17 levels needs twice the bandwidth of a PCM signal with 16 levels (assume same sample rate)



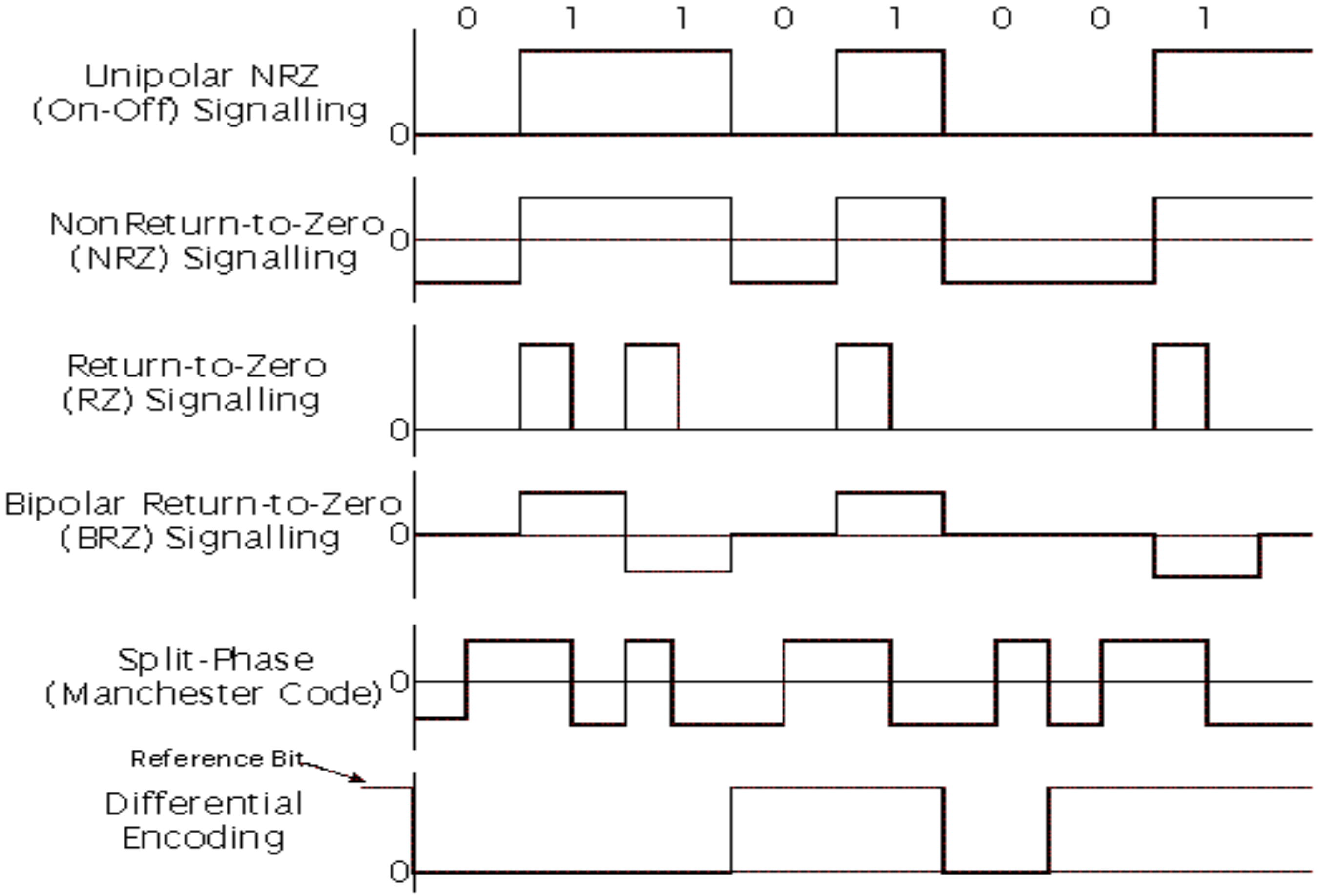
Line coding

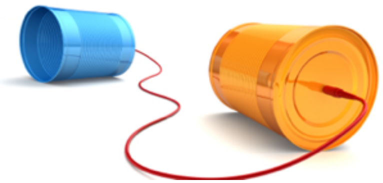
- Line coding is the process of converting digital data into digital pulses for transmission onto a physical medium (the channel).
- There re many different line coding formats.





Common line codes



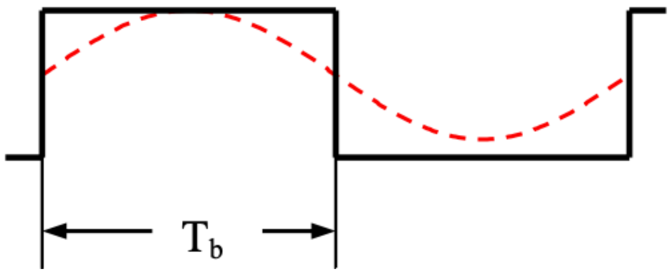


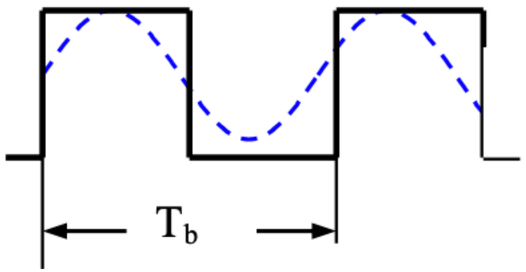
Bandwidth Requirements

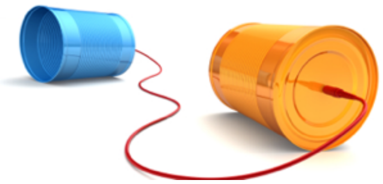
NRZ schemes can transmit 2 bits per level-change : 2 bits per second per Hertz

RZ schemes can transmit one bit per level-change : 1 bit per second per Hertz

No. of bits per second per Hertz = **Bandwidth Efficiency**







PCM bandwidth (again)

Consider a binary PCM system using L quantisation levels.

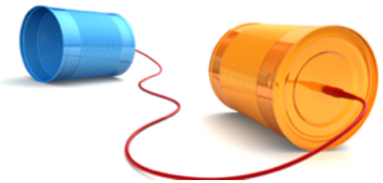
Number of bits per sample is $n = \lceil \log_2 L \rceil$ (ceiling function: next highest integer)

Sample rate is $f_s = 1/T$.

Number of bits per second is $\lceil \log_2 L \rceil / T$.

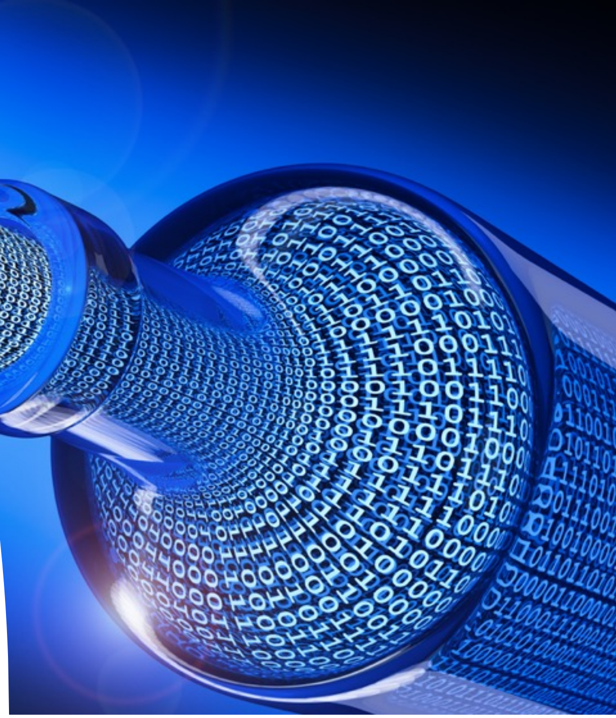
Bandwidth Efficiency of NRZ code is 2 bps/Hz

$\therefore$ Minimum bandwidth = $\lceil \log_2 L \rceil / 2T$



How fast can we send data down a channel?

- The data rate (in bits/sec) is limited by the slowest link in the communication system, the so-called bottleneck.
- This rate of information transfer is limited by a theoretical upper limit called the **channel capacity**.

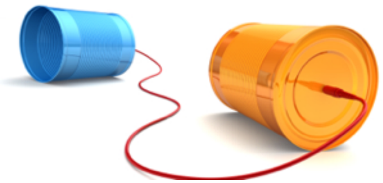


Hartley-Shannon Law

Channel capacity of a white band-limited gaussian channel is

$$C = B \log_2(1 + S/N) \qquad \text{bps}$$

where *B* is the channel bandwidth and *S/N* is mean-square signal-to-noise ratio.



Hartley-Shannon : Example

What bandwidth is needed to transmit 2.3 Mbits/sec on a channel with S/N ratio of 70 dB?

S/N as a ratio is obtained from

$$70 = 10\ \mathrm{Log}_{10}(S/N)$$

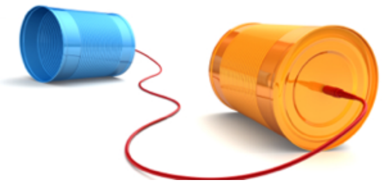
$$S/N = 10^7$$

Channel capacity is 2.3 Mbits/sec

$$C = B\ \log_2(1+10^7) = 2{,}300{,}000\ \text{bps}$$

Bandwidth

$$\begin{aligned} B &= 2{,}300{,}000 / \log2(10{,}000{,}001) \\ &= 2{,}300{,}000 / (\log_{10}(10{,}000{,}001)/\log_{10}(2)) \\ &= 2{,}300{,}000 / 23 \\ &= 100{,}000\ \text{Hz.} \end{aligned}$$



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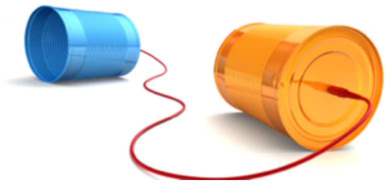
Hartley-Shannon : Example

A television picture consists of **3×10^5** pixels, each equiprobable among **10** brightness levels. **30** frames are transmitted every second.

Calculate the minimum bandwidth required to transmit the video signal assuming that a **30** dB SNR is necessary for picture reproduction.

(Stremler Ch. 9)

Answer : approx 3 MHz)

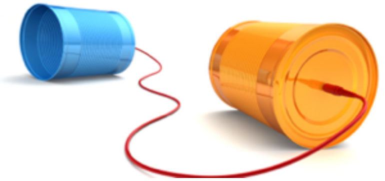


Hartley-Shannon : Example

What is the minimum time required for the facsimile (fax) transmission of one picture over a standard telephone line. There are about **2.25x10^6** picture elements to be transmitted and **12** equiprobable brightness levels to be used for good reproduction. The telephone circuit has a **3** kHz bandwidth and a SNR of **30** dB.

(Stremler Ch. 9)

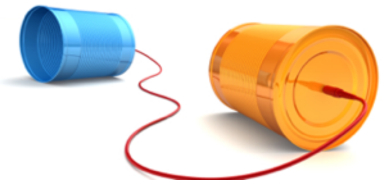
(Answer : 4.5 min)



Summary

- **Pulse Modulation**
- **Pulse Code Modulation**
- **Line Coding**
- **Hartley-Shannon Law (Channel Capacity)**

- **After Easter: Digital Bandpass Modulation**



Module Pathway

Intro → **Modulation** → Amplitude modulation → AM Demodulation → DSB, SSB, VSB → DSB Demod

Class Test
Open book

1pm on Tuesday 10th March

Angle Modulation → FM Demodulation → Digitisation → Pulse Baseband → Digital Bandpass → Multiplexing

Home Test
Open book

9am on Thu 30th April

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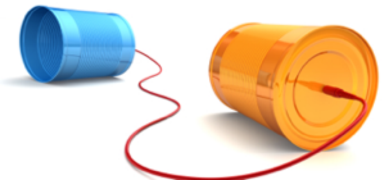

How was today's lecture?