ECEN 449 – Microprocessor System Design

Pulse Modulation

Objectives of this Lecture Unit

- Get familiar with pulse based communication
  - Different pulse modulation schemes
  - Applicability of these to different design scenarios

sender (tx) $\xrightarrow[\text{medium}]{}$ receiver (rx)

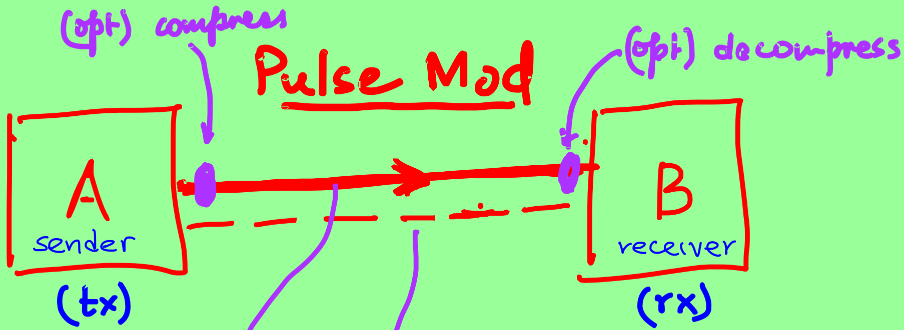
Modulation and Communication

- When we have to communicate information over a medium, we typically
  - Modulate the signal before transmission by the sender
  - Then demodulate the signal at the receiving end to retrieve the information
- Why do this?
  - The modulated signal can be transmitted with low loss
  - Interference with other communications is avoided
  - Receiving antennas can be made quite small
  - Multiple signals can be multiplexed

  desired features
- Typical modulation schemes – amplitude, frequency, phase, code

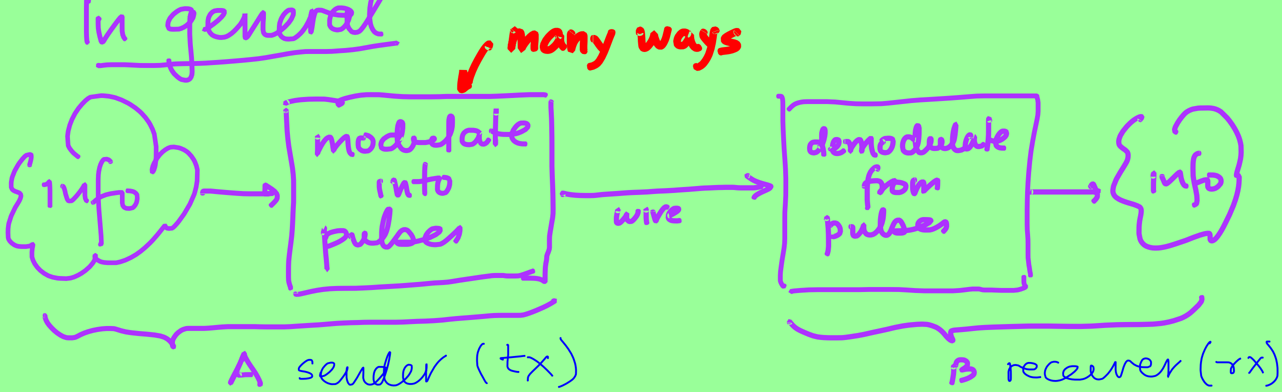
3.1

Pulse Mod



- A wants to communicate w/ B
  using a single wire
  using a series of pulses
- Sometimes (rare) use an extra clock wire also
- Sometimes the comm is bidirectional (full duplex), sometimes unidirectional from A to B (half duplex)

In general



3,2

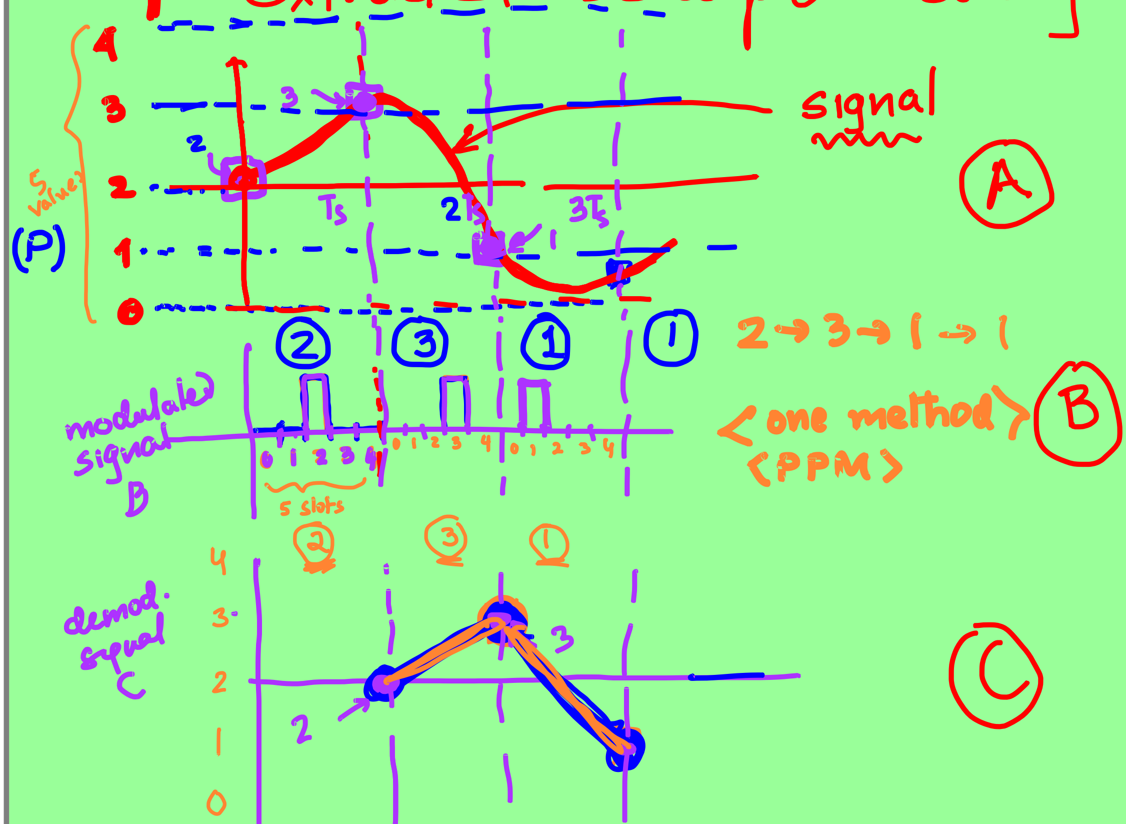
Trick

A modulate
- Sample the signal every T_s seconds.
- encode the sample into one or more pulses

B transmit

< transmit the pulses >

C demodulat
- decode the pulses to extract the sample
- recover the signal from the extracted samples every T_s



3.3

- How to choose T_s
  - Nyqst sampling theorem

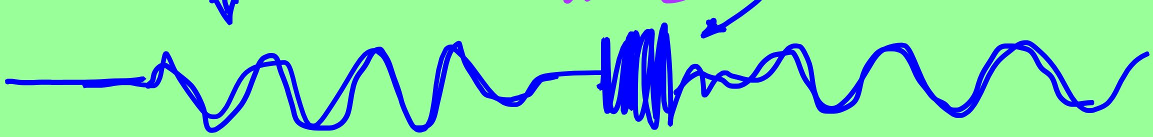
→ if I want to sample a signal of bandwidth B then I should use a sampling frequency f_s, ST

$$\frac{1}{T_s} = f_s \geq 2B$$

$$\frac{1}{T_s} \geq 2B \; ; \; T_s \leq \frac{1}{2B}$$

→ what is B?

- signal ≡ its max freq component is B



Workspace for 'pulse-modulation'
Page 4 (row 2, column 5)

3.4

Human voice $B = 20$ kHz

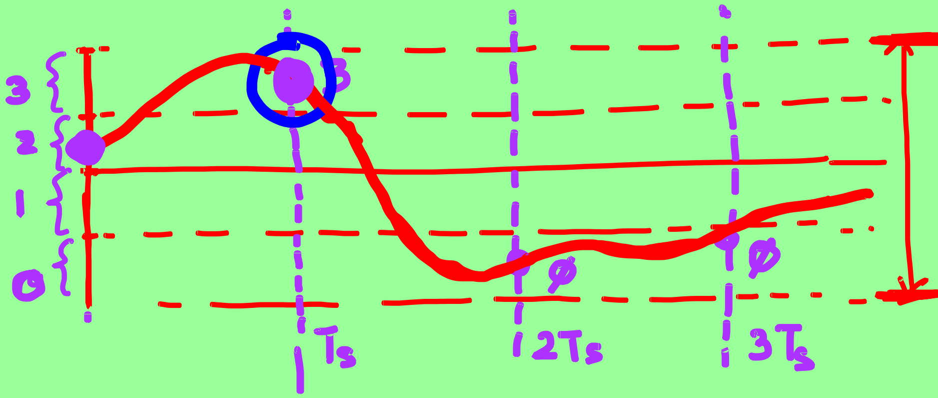
f_s for human voice ≥ 40 kHz

CD audio uses 44.1 kHz

What is Pulse Modulation

- Pulse modulation involves communication using a train of recurring pulses.
- Common means of modulating data in digital communication
  - Key advantage is that I can send multiple signals using Time Division Multiplexing
- There are several pulse modulation techniques
  - Pulse Amplitude Modulation
  - Pulse Width Modulation
  - Pulse Code Modulation
  - Pulse Position Modulation

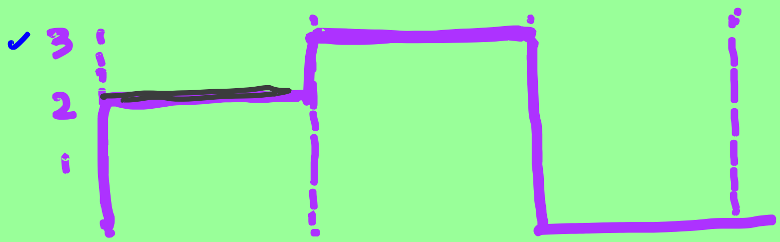
4.1



signal range (P=4)

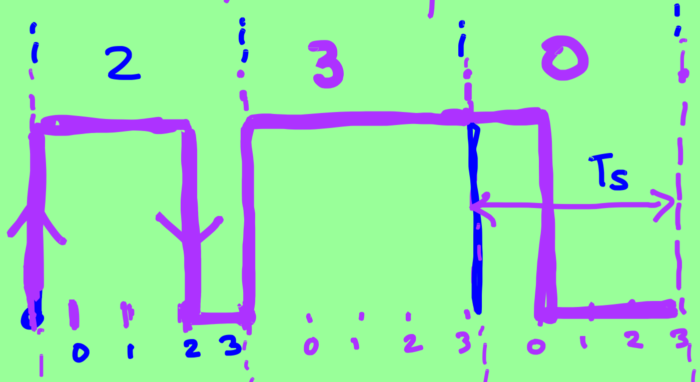
TX = transmit
RX = receive

2 3 0 0 ← samples



Pulse Amplitude Modulation (5-6)
→ dialup modem
→ ethernet PAM5 (10Mbps)

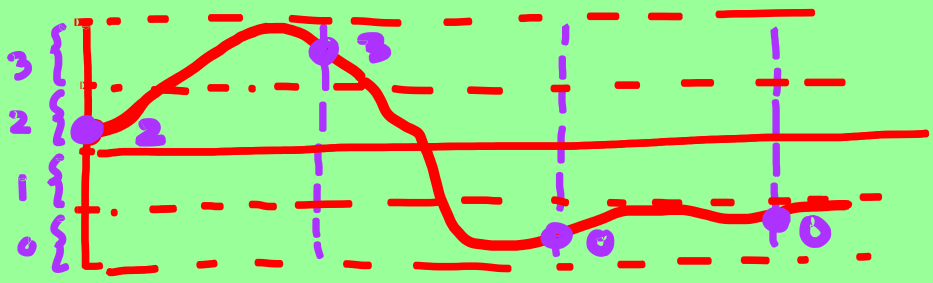
mod: sample and hold
demod: filter (RC)
Tx clock period = Ts

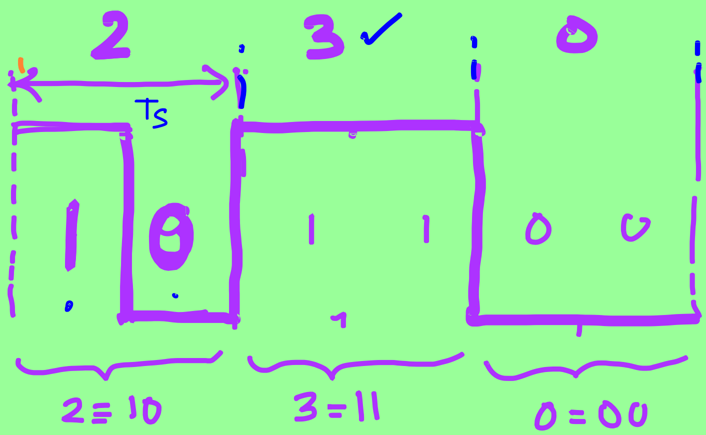


Pulse Width Modulation (7-8)
- Volt. regulator
- Class D amp

mod: sawtooth & comparator
demod: counter & DAC
Tx clk period = Ts/P

4.2



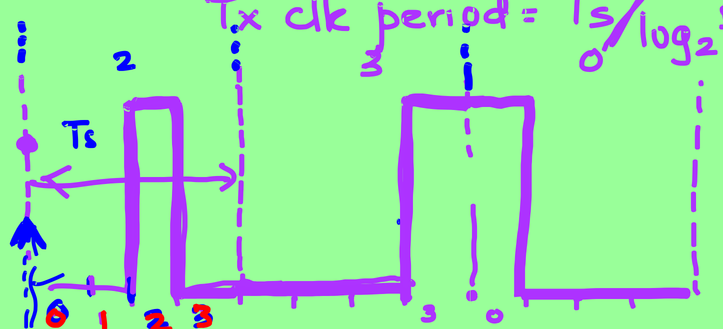


← samples

Pulse Code (9-10)
Modulation
- CD audio

$P = 4$
$\log_2 P = \log_2 4 = 2b$

mod : sample & ADC
demod : DAC
Tx clk period = $T_s / \log_2 P$



Pulse Position (11-12)
Modulation
- RC toys (low end)
- optic fiber comm
(non-coherent)

- mod : sample & ADC & ctr
- demod : counter & DAC
- Tx clk period = T_s / P

4.3

Comparing the schemes

- one way to compare them is by by comparing the Tx clock frequency (or period). Obviously, a lower frequency (higher period) is preferred

We will assume that the signal is discretized into P values, and the sample period is T_s.

Scheme	Tx Clk period	
PAM	T_s	← best. BUT PAM needs amplitude comparison for demod, unlike the other 3.
PWM	T_s/P	
PCM	$T_s/\log_2 P$	← runner up. BUT doesn't need to compare pulse amplitudes, so it is preferred
PPM	T_s/P	

4.4

Information transfer rate

Q: Suppose I send you one of 5 colored flags every T seconds. What is the information transfer rate?

A: Info. transfer rate = $\frac{\text{info transferred}}{\text{time}}$

Information transferred is measured in bits. Since I send you 5 colored flags, the information transferred is
$= \log_2 5$

So the info transfer rate is $\frac{\log_2 5}{T}$

Now lets compare the info transfer rate of our 4 P*M schemes

PAM: $\frac{\log_2 Q}{T_s}$ ⟶ Q amplitudes (assume they all use Q slots)

(4.5)

PWM : $\frac{\log_2 Q}{T_s}$ → Q widths

PCM : $\frac{Q}{T_s}$ → exponentially more info than others

[same # of slots]

PPM : $\frac{\log_2 Q}{T_s}$ → we send one of Q positions.

So if we use the same Tx clock period for PWM, PCM and PPM, (and T_s is same for them)

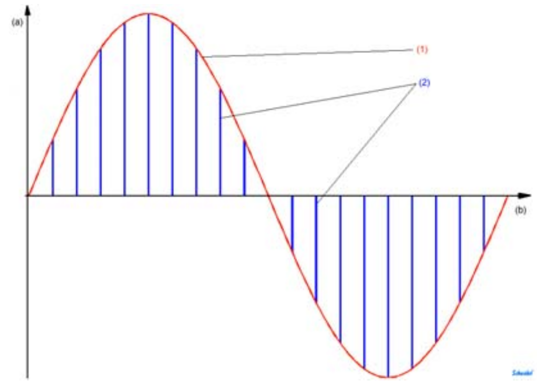
→ PCM transmits exponentially more information!!

→ Why? Because info transfer rates are:

PWM, PPM } : $\frac{\log_2 P}{T_s}$

PCM : $\frac{P}{T_s}$: this is exponentially more than

Pulse Amplitude Modulation (PAM)



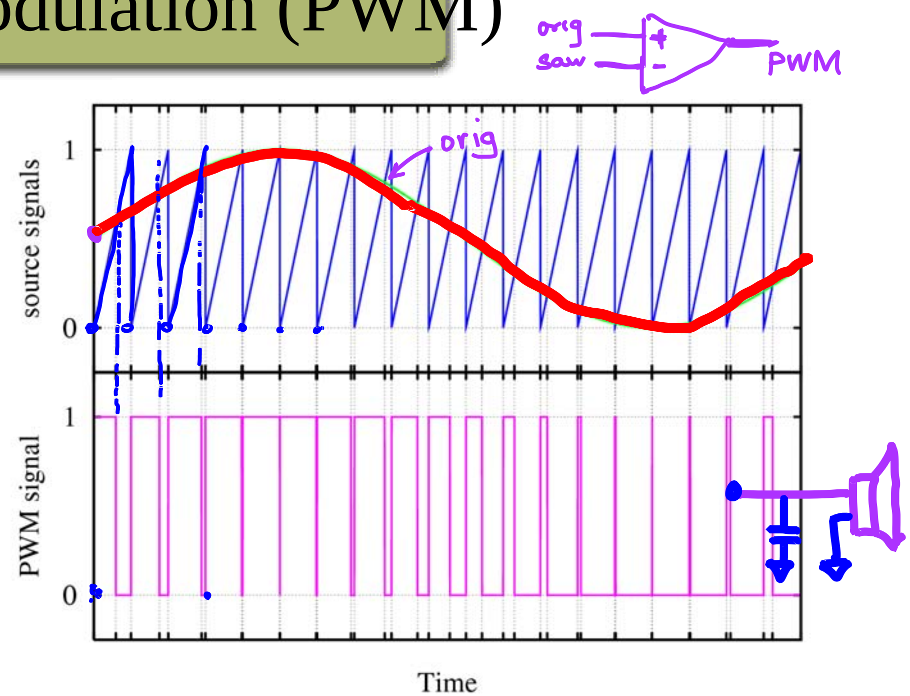
- Message information encoded in the form of the amplitude of pulses.
- Pulse transmitted every T_s seconds, amplitude of the pulse is quantized to Q values, for PAM-Q.
- Example shown above is the PAM encoded (blue) signal corresponding to a sinusoidal (red) input.

Pulse Amplitude Modulation

"baud"

- Examples:
  - Telephone modems faster than 300 bits/sec use PAM
  - Ethernet uses PAM.
    - 100BASE-T2 as well as 1000BASE-T use PAM-5
- To achieve full-duplex operation, we can do one of two things
  - Use some kind of carrier sensing (as in Ethernet, which uses Carrier Sense Multiple Access)
  - Or use some flavor of Time Division Multiple Access.

Pulse Width Modulation (PWM)



- Here we modulate the width of pulses (or their duty cycle) to convey information.
- Example above shows the PWM signal (bottom picture) corresponding to a sinusoidal signal (top picture). The PWM signal is typically generated using a sawtooth waveform and a comparator

Pulse Width Modulation

- Popular in digital circuits
  - Generation of PWM signal easy, demodulation typically uses counters and digital-to-analog converters (DACs)
- Three flavors of PWM
  - Pulse center is in the center of the time window
  - Pulse leading edge coincides with leading edge of time window, and the trailing edge is modulated
  - Pulse trailing edge coincides with trailing edge of the time window, and the leading edge is modulated
- Applications
  - Voltage regulators
  - Class D audio amplifiers (feed PWM signal to speaker after filtering to block carrier), which are highly efficient.

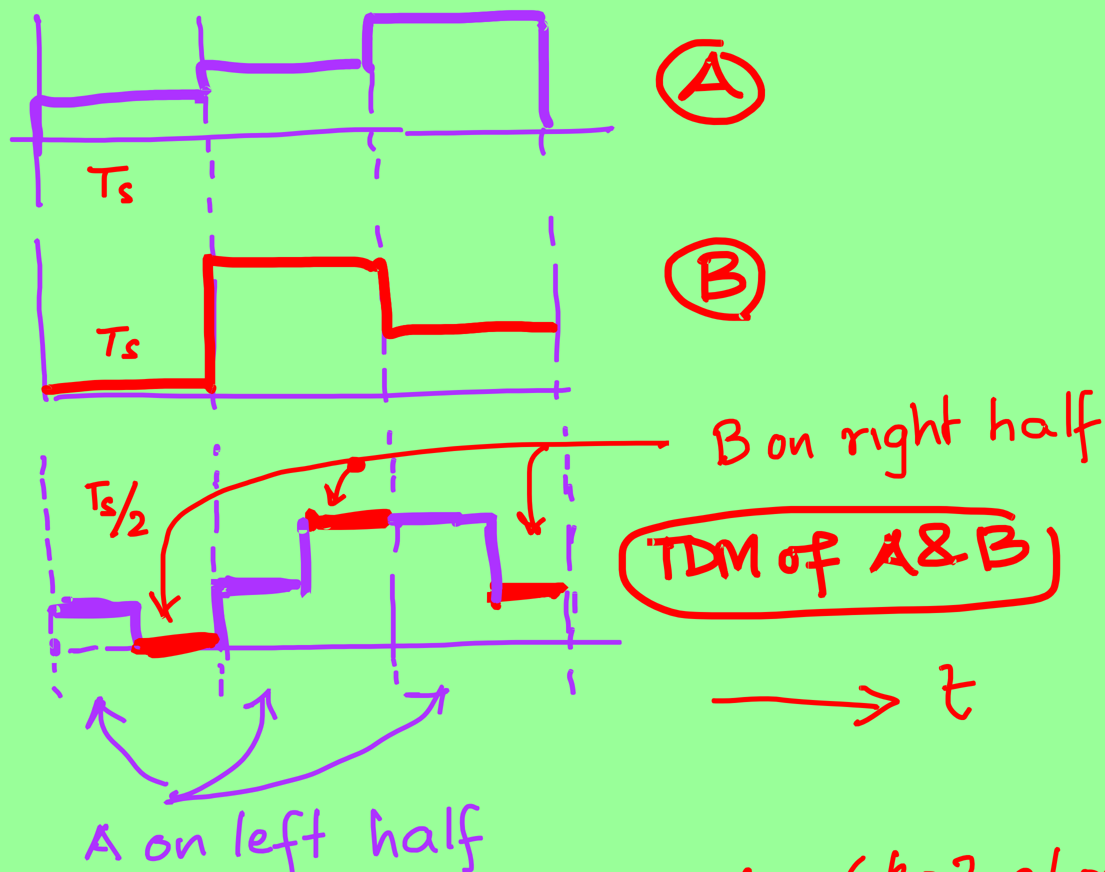
Pulse Code Modulation (PCM)

- Means to represent an analog signal in a digital manner
- Sample the analog signal every T_s seconds, into P values.
  - P is usually a power of two.
- Transmit $\log_2 P$ bits every T_s seconds (can do compression also)
- Typically sampling is done via an ADC (Analog to Digital Converter).
- Many such PCM datastreams can be multiplexed on to a high bandwidth medium in a Time Division Multiplexing (TDM) fashion.
  - Example voice signals sent over a phone network, or data sent over an optic fiber

9

Time division multiplexing (TDM)

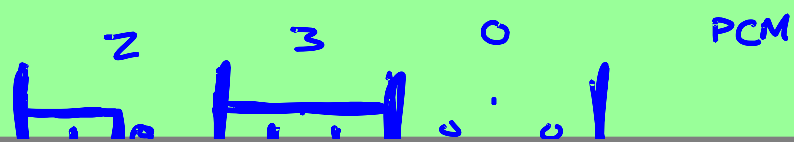
Consider 2 PXM streams A&B
– assume PAM for example



→ can send k signals (k=2 above)

→ frequency = k times higher

→ use this to do full duplex



Pulse Code Modulation

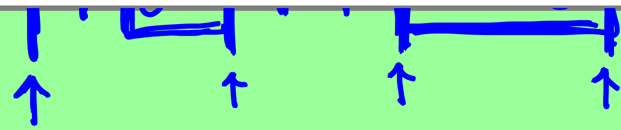
- Demodulation is done by collecting $\log_2 P$ entries, and feeding them to a Digital to Analog Converter (DAC).
  - Possibly need to do decompression before this.
- Applications
  - Digital audio in computers and CDs
  - Straight PCM not used in video standards (DVD, DVR) since it needs a high bitrate.
- Some PCM techniques transmit the difference between two adjacent samples, rather than the raw sample values. This effectively compresses the transmitted data.

Pulse Position Modulation (PPM)

- Suppose I want to send one of ~~M message bits~~ P values every T_s seconds.
- PPM modulates the message by transmitting a single pulse in one of $\cancel{2^M}$ P time slots
  - Each time slot is $\cancel{T/2^M}$ T_s/P seconds long
- Problematic for communication media where multi-path interference dominates
  - Urban environments
  - Media which exhibit frequency-dependent fading

Pulse Position Modulation

- Commonly used in communication over optic fibers
  - Multi-path fading is minimal
  - No need for Phase-Locked Loop at the receiver (i.e. can use non-coherent receiver). Coherent receivers are prohibitively expensive for optical communication systems.
- Also used in communication for RC aircraft/cars etc.
  - The demodulation is very simple and easy, allowing for a low-cost receiver.
  - Fancier RC systems use PCM (more expensive)



12.1

Coherent Receivers

→ Receiver extracts transmitter's clock (using Phase Locked Loop) (CDR)
→ called coherent receiver (PLL)

→ But if Tx sends 3-3-3-3
then PAM PWM, PCM signal is constant.
→ can't extract a clock!

→ So we use codes that always wiggle the modulated signal

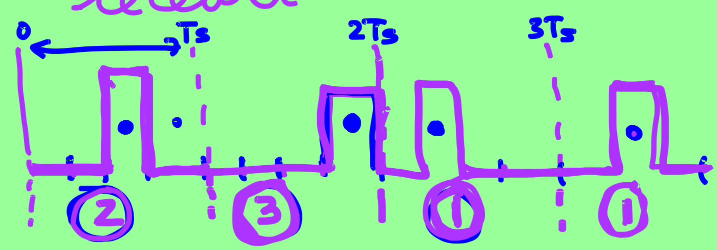
e.g.

want		send
00	→	001
01	→	010
10	→	101
11	→	110

for PCM

1. training pattern
2. encoding
   2b3b
   8b10b
3. use GPS

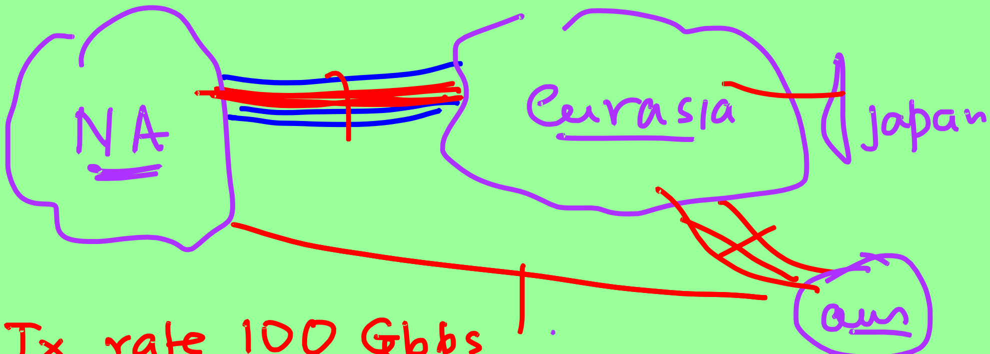
→ But PPM does not need coherent receiver



12.2

PPM is used in optic fiber comm.

- Tx rate ≅ 100 Gbps (optical pulses)
- too fast for a PLL circuit, so need non-coherent receiver!



- Tx rate 100 Gbps
- say 100 "colors" (wavelenghts)

  effective tx rate = 100 × 100 Gbps

  $= 10^{13}$ b/s

- Phone call BW = 8 khz, $F_s = 2 \cdot BW = 16$ kHz (nyqvst)
- Suppose 8bit/sample, so call needs 16 k sample/s * 8b/sample = 128 kb/s
- Since calls are full duplex, double this
- One call = 256 kb/s

12.3

# of calls on one fiber is:

1 call $\longrightarrow$ 256 000 b/s

x $\longrightarrow$ 10^{13} b/s

$x = 39 \times 10^6$

39 Million : WOW

Pulse Frequency Modulation (PFM)

- Conceptually, we could do PFM as well.
- Pulses of constant amplitude are generated, at a rate which is modulated by the signal frequency.
- Problem: arrival rate of pulses is random, and hence demodulation is hard.
- Therefore PFM is mostly a curiosity.