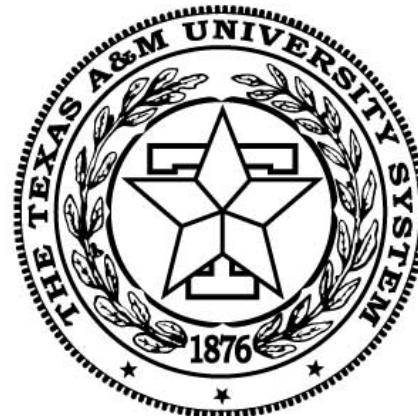


ECEN 449 – Microprocessor System Design



Pulse Modulation

Objectives of this Lecture Unit

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

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

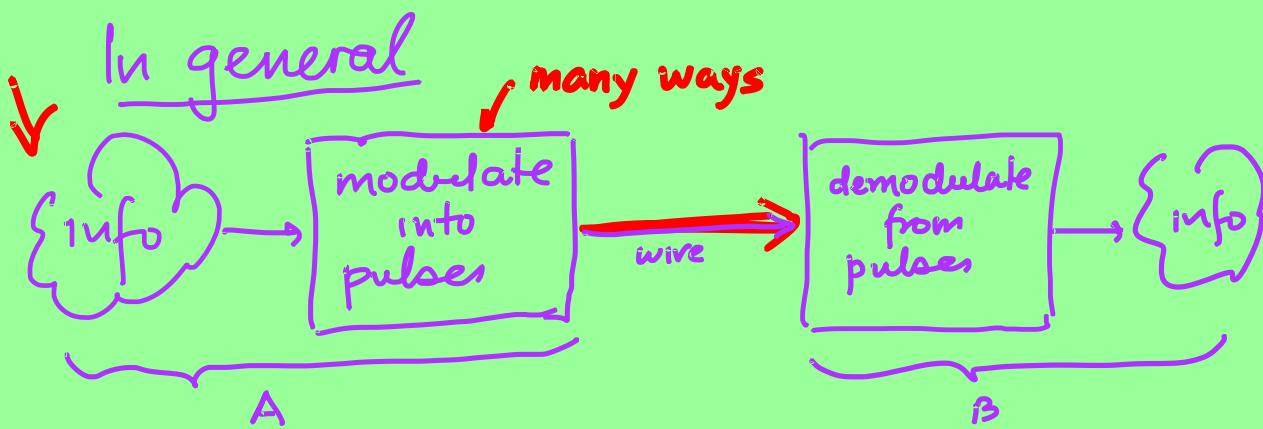
Workspace for 'pulse-modulation'

Page 1 (row 2, column 2)



3.1

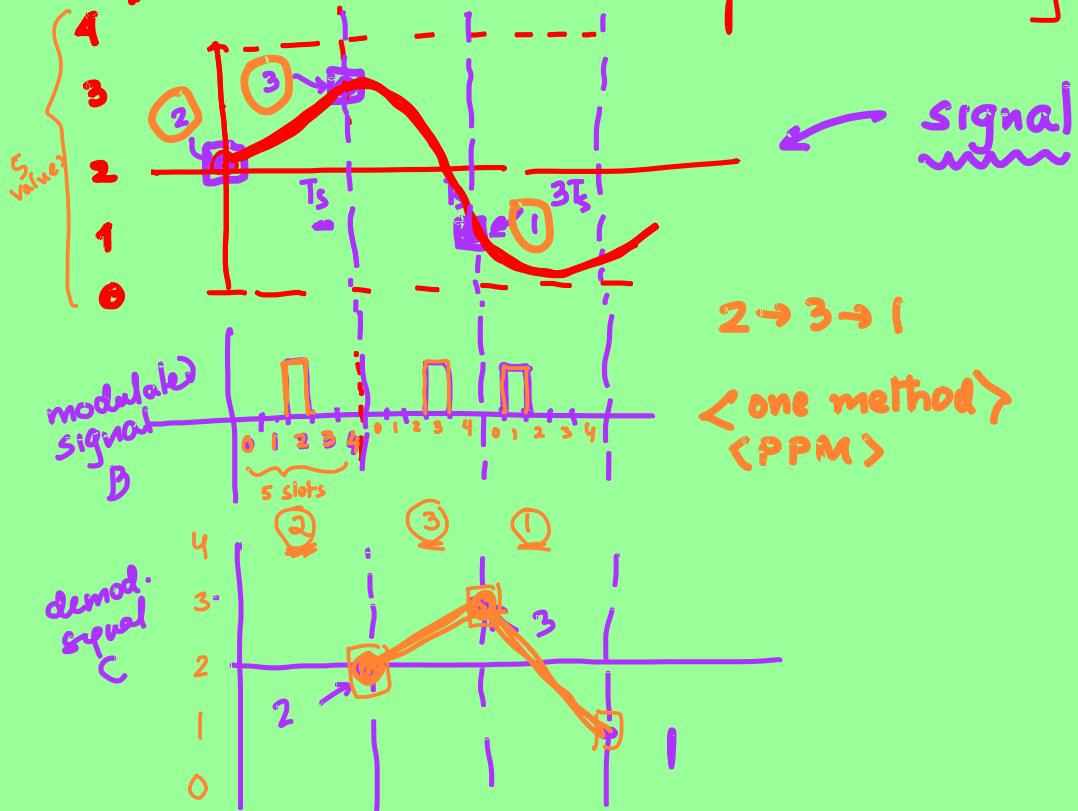
- A wants to communicate w/ B
- Using a single wire ✓
- Using a series of pulses ✓
- Sometimes (rare) use an extra clock wire also
- Sometimes the comm is bidirectional
full duplex, sometimes unidirection
from A to B (half duplex)



(3.2)

Trick

- mod | • sample the signal every T_s seconds - \rightarrow many
- demod | • encode the sample into pulses <transmit the pulses>
- demod | • decode the pulses to extract the sample
- demod | • recover the signal from the extracted samples every T_s



(3.3)

- How to choose T_s

- Nyquist sampling theorem

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

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

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

→ What is B ?

- signal ≡ its max freq component is B



3.4

Human voice $B \leq 20\text{ kHz}$

f_s for human voice $\geq 40\text{ kHz}$

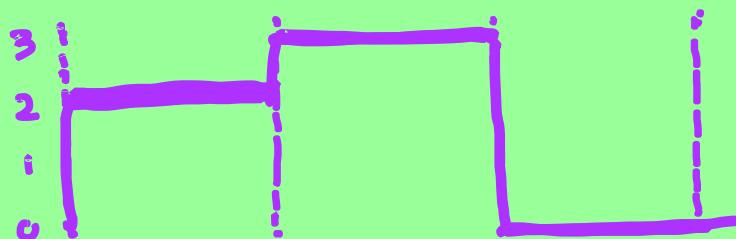
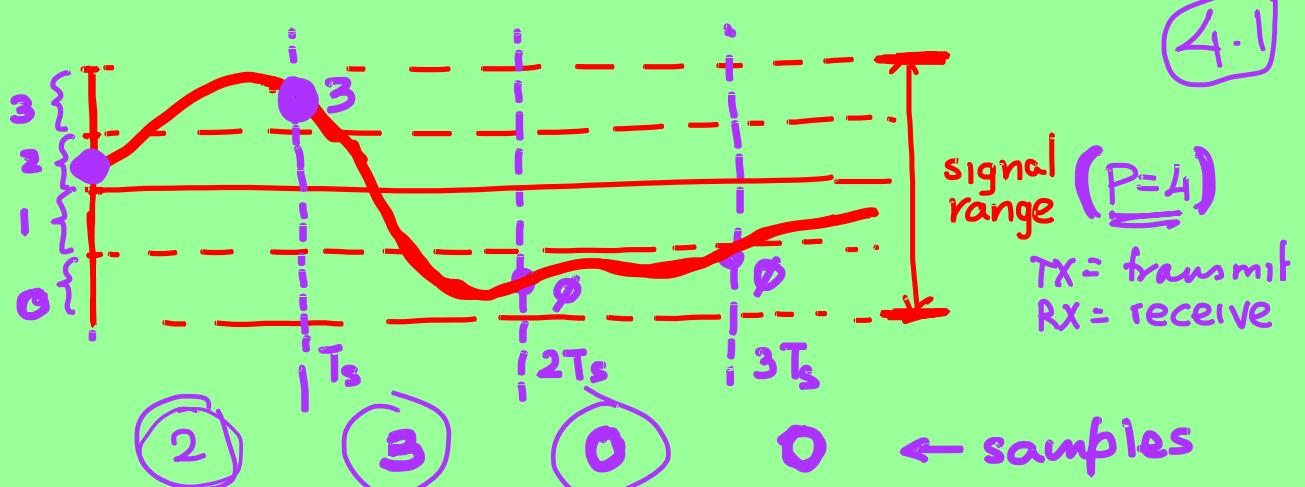
CD audio uses 44.1 kHz

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

Workspace for 'pulse-modulation'

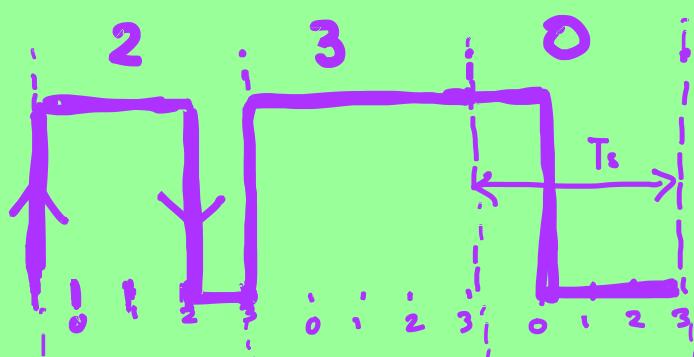
Page 9 (row 2, column 6)



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

Pulse Amplitude
Modulation 5-6

- dialup modem
- ethernet



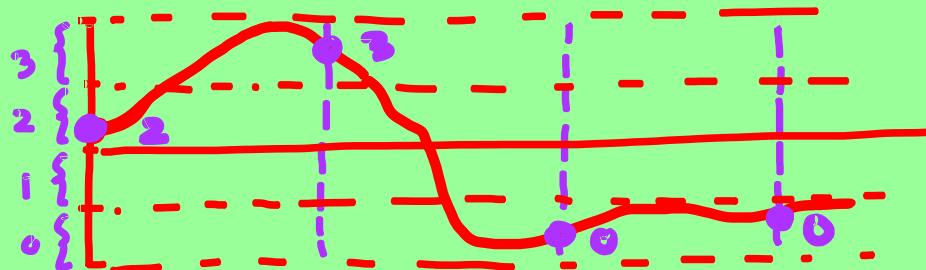
mod: sawtooth & comparator
 demod: counter & DAC :
 Tx clk period = T_s/P

Pulse Width
Modulation 7-8

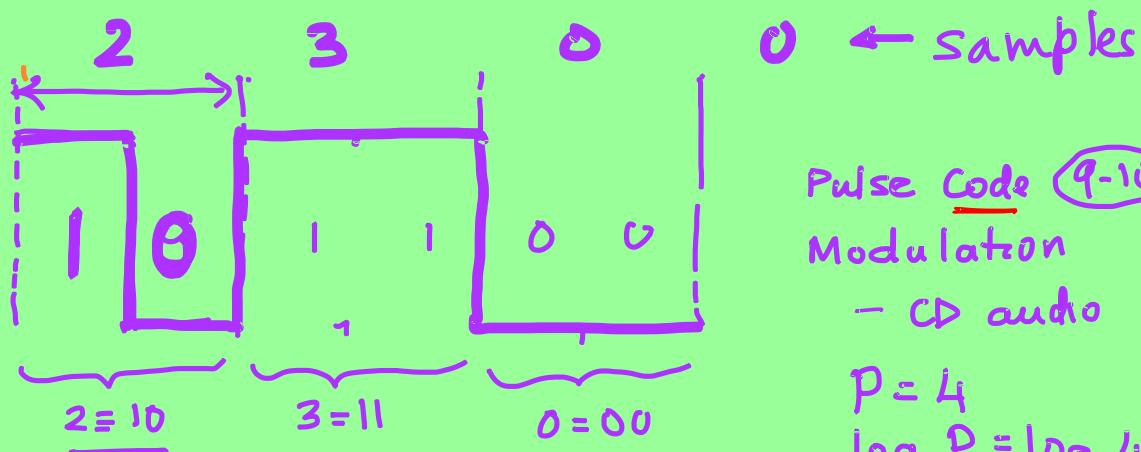
- Volt. regulator
- Class D amp

Workspace for 'pulse-modulation'

Page 10 (row 3, column 6)



4.2



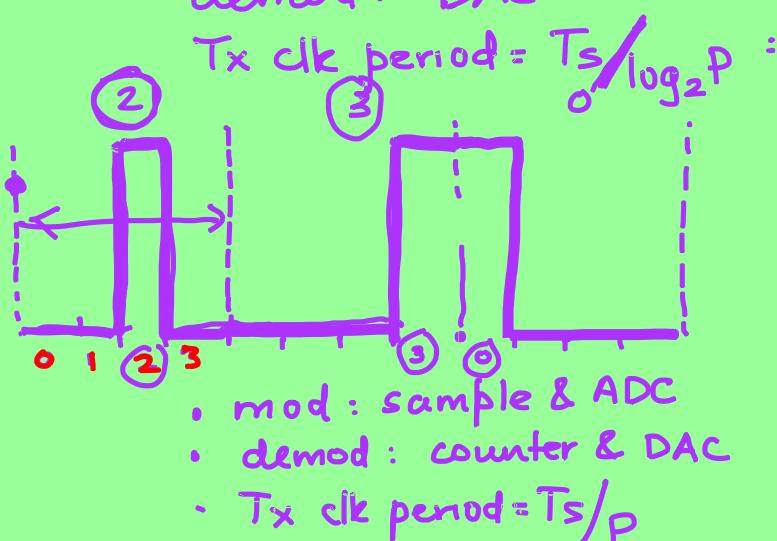
Pulse Code (9-10)

Modulation

- CD audio

$$P = 4$$

$$\underline{\log_2 P} = \underline{\log_2 4} = 2b$$



(11-12)

Pulse Position Modulation

- RC toys (low end)

- optic fiber comm
(non-coherent)

(4.3)

Comparing the schemes

- one way to compare them is 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 $T_s \leftarrow \text{best}$. BUT PAM needs amplitude comparison

PWM T_s/P for demod, unlike the other 3.

PCM $T_s/\log_2 P \leftarrow \text{runner up}$. BUT doesn't need to compare pulse

PPM T_s/P amplitudes, so it is preferred

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 let's compare the info transfer rate of our 4 P*M schemes

PAM: $\frac{\log_2 P}{T_s} \rightarrow$ P amplitudes

4.5

PWM : $\frac{\log_2 P}{T_s} \rightarrow P$ widths

PCM : $\frac{\log_2 P}{T_s} \rightarrow$ we literally send $\log_2 P$ bits

PPM : $\frac{\log_2 P}{T_s} \rightarrow$ we send one of P positions.

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

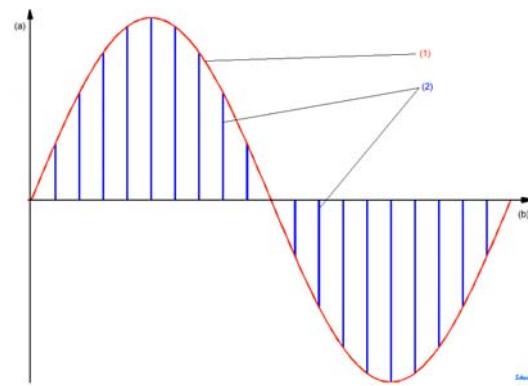
→ PCM transmits exponentially more information !!

→ Why? Because info transfer rates are:

$$\text{PWM } \left. \begin{array}{l} \\ \end{array} \right\} : \frac{\log_2 P}{T_s}$$

$$\text{PPM} \quad : \frac{\log_2 P}{T_s} \quad \text{PCM} : \frac{P}{T_s} : \text{this is exponentially more than}$$

Pulse Amplitude Modulation (PAM)



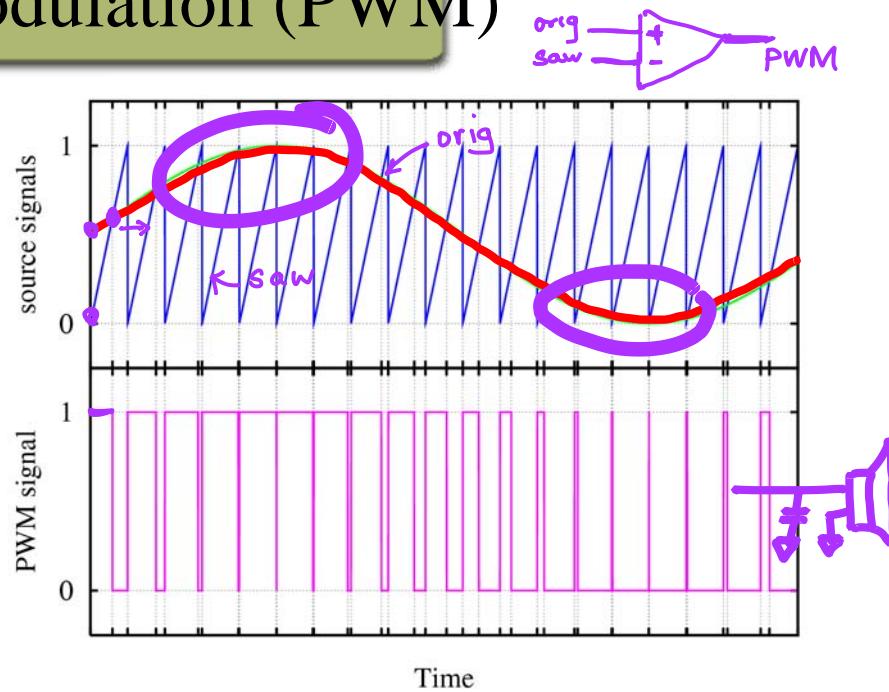
- Message information encoded in the form of the amplitude of pulses.
- Pulse transmitted every T_s seconds, amplitude of the pulse is quantized to Q values, for PAM-Q.
- Example shown above is the PAM encoded (blue) signal corresponding to a sinusoidal (red) input.

Pulse Amplitude Modulation

- 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.

"baud"

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.

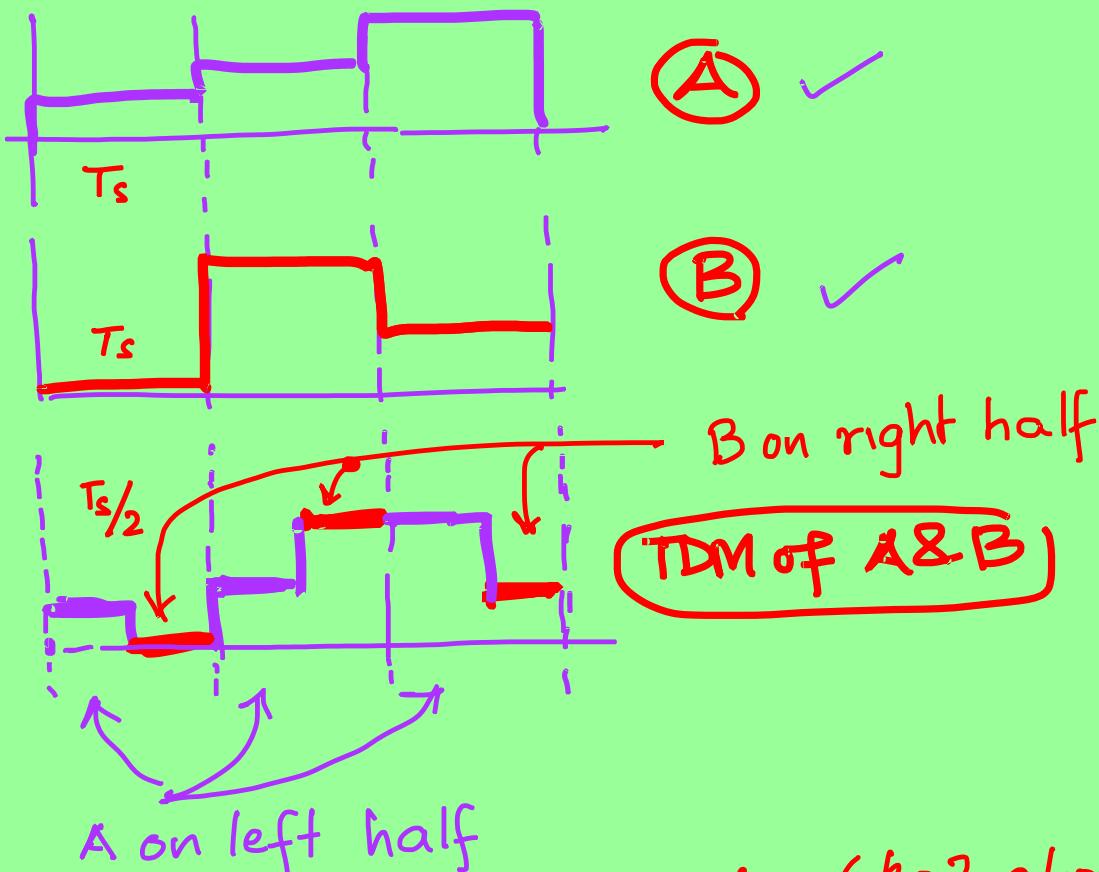
Pulse Code Modulation (PCM)

- 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

Consider 2 PAM 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)

P values

- Suppose I want to send one of ~~M message bits~~ every ~~T_s~~ seconds.
- PPM modulates the message by transmitting a single pulse in one of ~~2^M~~ time slots
 - Each time slot is ~~T/2^M~~ 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)
 → called coherent receiver **(PLL)**

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

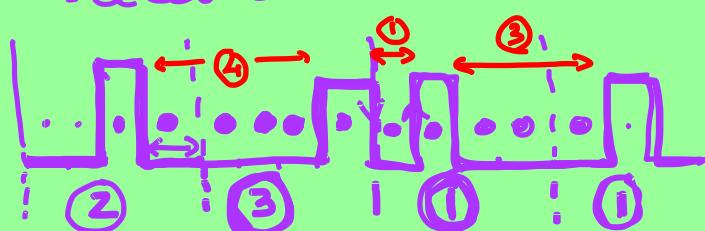
→ So we use codes that always wiggle the modulated signal

eg $\begin{array}{ll} \text{(want)} & \text{(send)} \\ 00 & 001 \\ 01 & 010 \\ 10 & 101 \\ 11 & 110 \end{array}$ for PCM

① training pattern
 ② encoding

2b3b
 8b10b

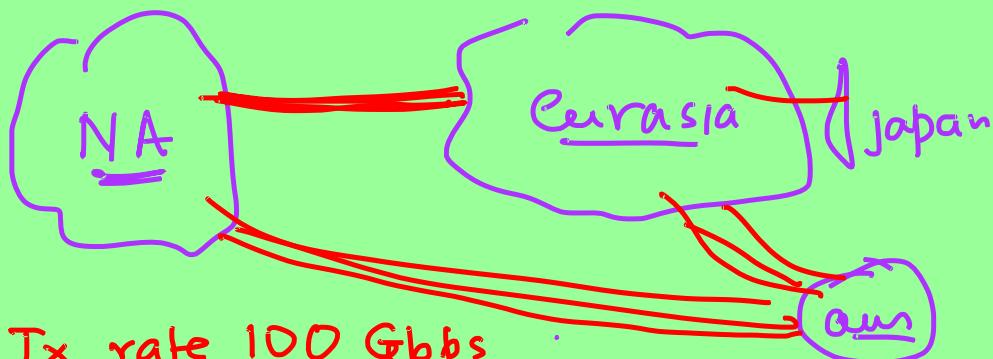
→ But PPM does not need coherent receiver



(12.2)

PPM is used in optic fiber comm.

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



- Tx rate 100 Gbps
 - say 100 "colors"
- $$\begin{aligned} \text{effective tx rate} &= 100 \times 100 \text{ Gbps} \\ &= 10^{13} \text{ b/s} \end{aligned}$$

- Phone call $BW = 8 \text{ kHz}$, $F_s = 2 \cdot BW = \underline{16 \text{ kHz}}$
- suppose 8 bit/sample, so call (nyqvst)
- needs $16 \text{ k samples/s} \times 8 \text{ b/sample} = 128 \text{ kb/s}$
- Since calls are full duplex, double this
- One call = 256 kb/s

(12-3)

of calls on one fiber is:

$$1 \text{ call} \rightarrow \frac{256\,000}{10^{13}} \text{ b/s}$$

$$x = 39 \times 10^6$$

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.

Workspace for 'pulse-modulation'

Page 8 (row 4, column 5)

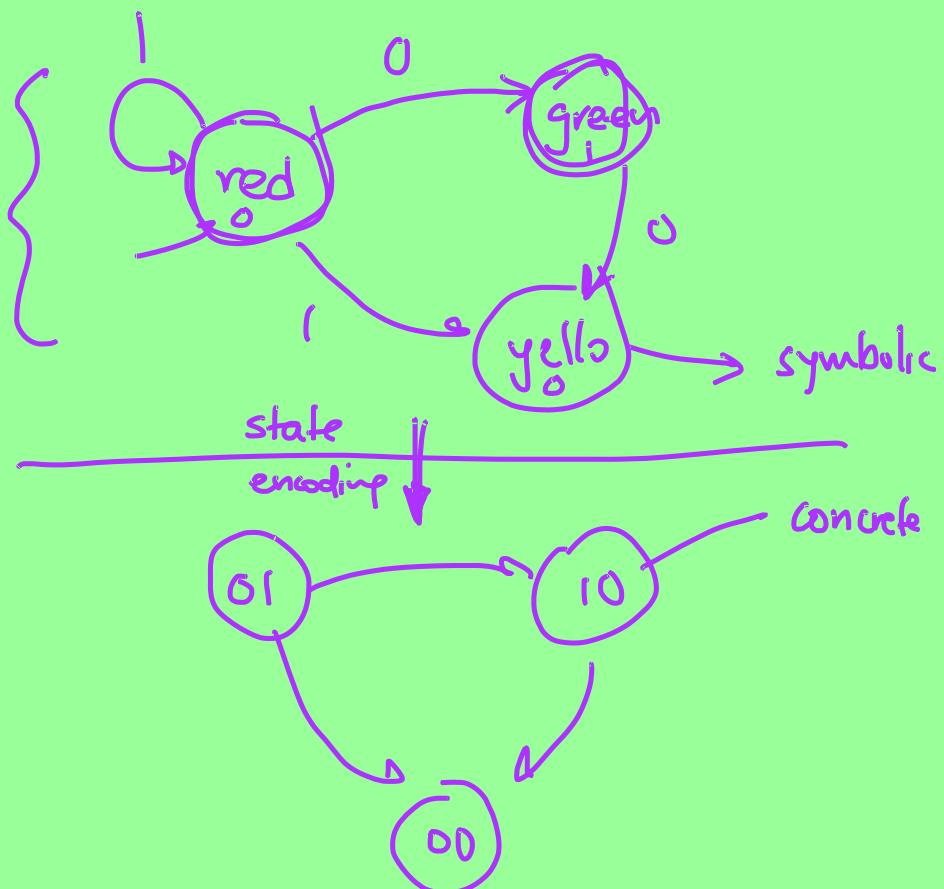
(Q3, HW 3)

OH

FSM

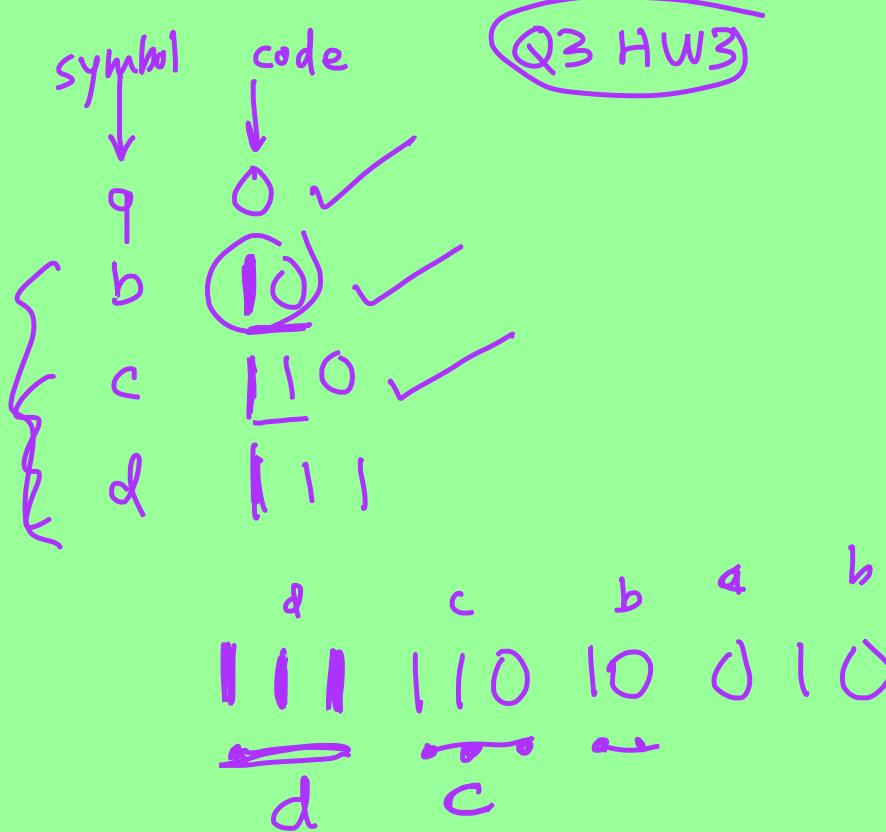
State
transition
graph
(STG)
moore

nodes \equiv states
edges \equiv transition



Workspace for 'pulse-modulation'

Page 11 (row 4, column 6)



Workspace for 'pulse-modulation'

Page 14 (row 4, column 7)

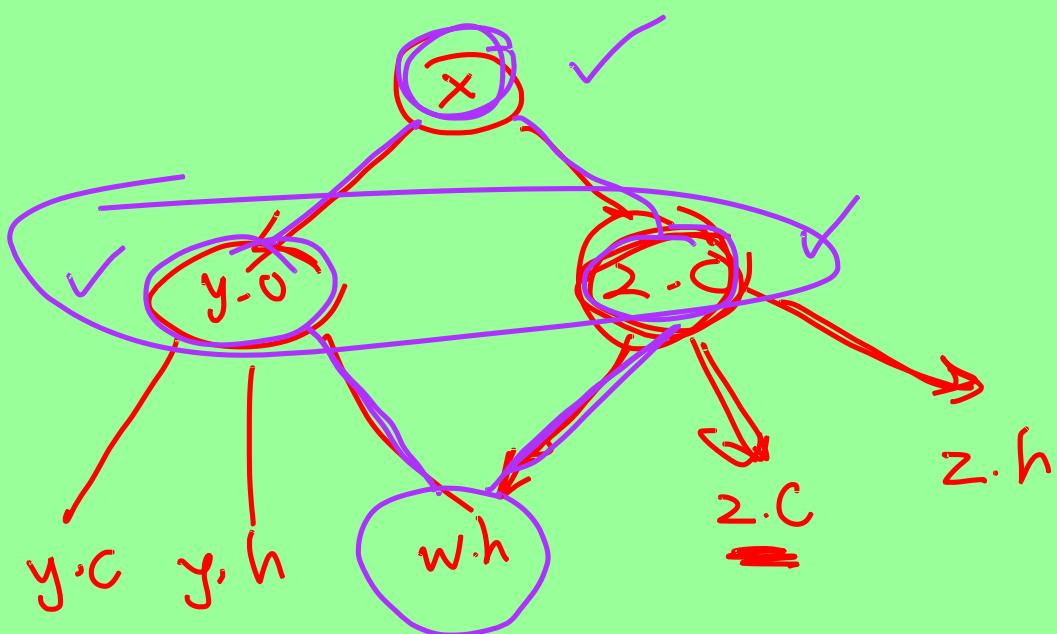
Q4

OH

x.0: y.0 z.0

y.0: y.c. y.h w.h

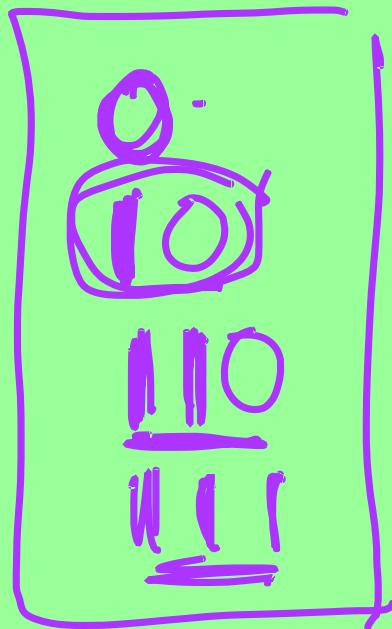
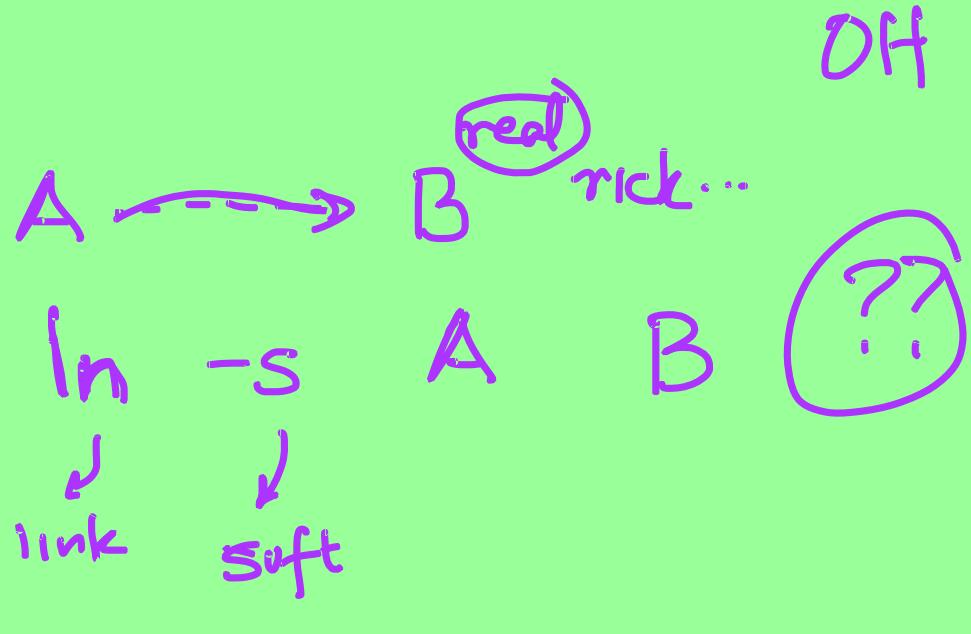
z.0: z.c. w.h z.h
cc z.c



Workspace for 'pulse-modulation'

Page 16 (row 4, column 8)

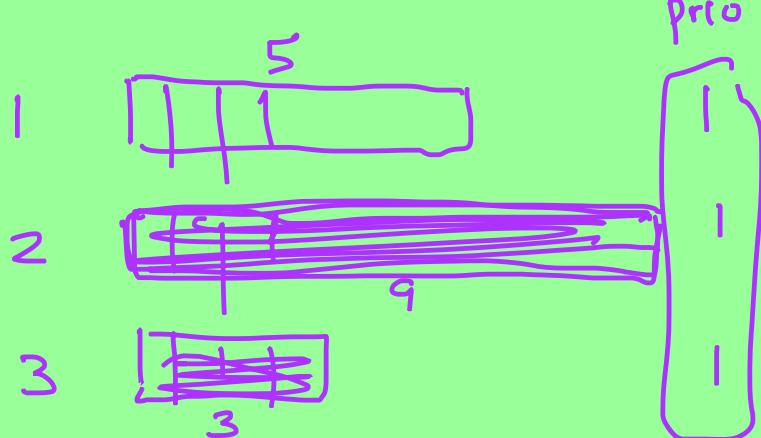
Q2e



α is
prefix
of β

Workspace for 'pulse-modulation'

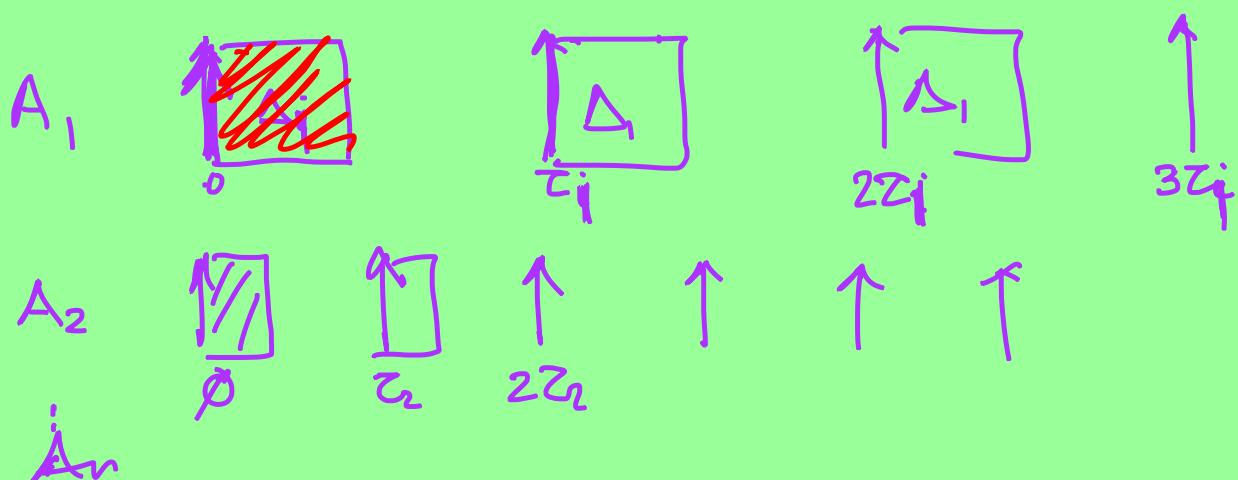
Page 18 (row 4, column 9)



$$\frac{\text{task 2}}{\text{task 3}} \quad \frac{9}{3}$$

RTOS ✓ hard real time sched

Liu Leyland

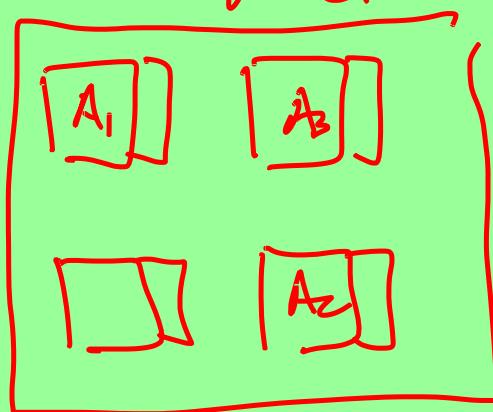


(6H.2)

N tasks reach w/ period T_i
each w/ WCET Δ_i

- $\sum \frac{\Delta_i}{T_i} < 1$

- today $\frac{BCET}{WCET} \sim 100\times$



Workspace for 'pulse-modulation'

Page 20 (row 4, column 11)

