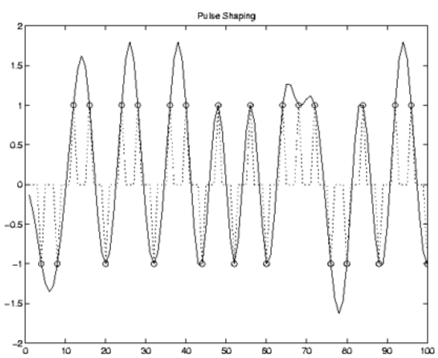
Lecture13 Digital Pulse Amplitude Modulation

Notes by Jenna May

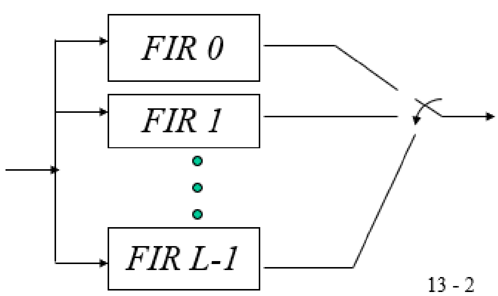
March 23, 2026

Review of midterm #1 exam
- Graded exams on Canvas on the midterm #1 page
- Solution set for midterm #1 is available online
- Blue text in solutions is additional information, not required for student answers

Digital Pulse Amplitude Modulation (PAM)
- PAM transmitter/receiver Implemented in Lab 5 this week and the next two weeks
- Historic uses of PAM
  - Voiceband dial-up modems (56 kbps) connecting sounds and explanation
  - (Symmetric) High-Speed Digital Subscriber Line 2 modems (1.544 Mbps)
- In modern systems, used as a part of Quadrature Amplitude Modulation (QAM) in Wi-Fi, cellular, and cable modems (covered in Lab 6 and later lectures)
- Baseband PAM Transmitter converts a stream of bits to a continuous-time analog signal (shown below) which is later processed by the analog/RF front and transmitted

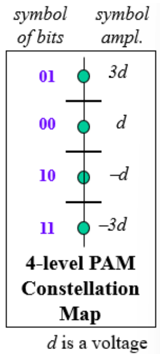


- For the interpolation in the baseband PAM transmitter, we'll use a filter bank for computational efficiency

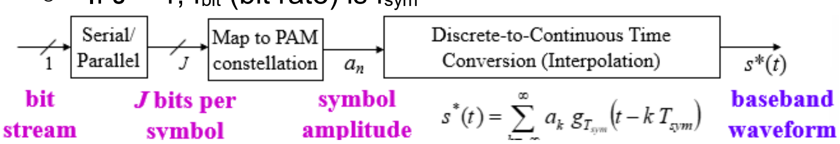


Intro
- Digital communications converts a stream of bits to a stream of pulses
  - Group stream of bits into symbols of J bits each

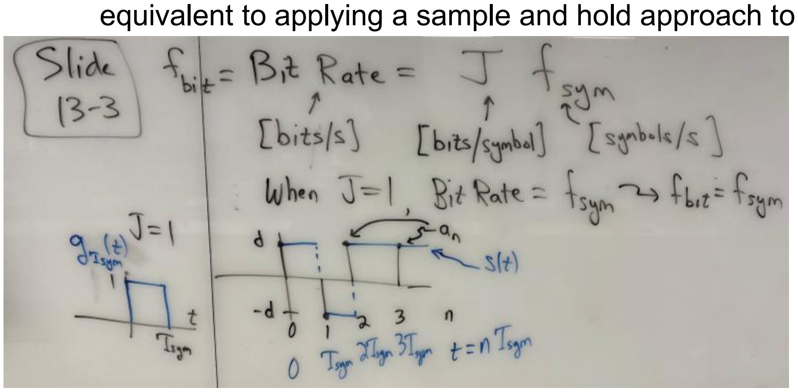
- ○ Uniquely map each symbol of bits to real-valued symbol amplitude via a constellation map



- M-level PAM referred to as M-PAM
  - Above figure is 4-PAM
  - M = 2^J i.e. 2^(# bits)
- Symbol period T_{sym}, $f_{sym} = 1/T_{sym}$
- Symbol rate is also known as the baud rate
- f_{bit} (bit rate) is $J*f_{sym}$
  - f_{bit} (bits/sec) = J (bits/symbol) * f_{sym} (symbols/sec)
  - If J = 1, f_{bit} (bit rate) is f_{sym}



- Discrete-time to Continuous-Time Conversion
  - Convolution of discrete-time signal a_n and continuous-time pulse shape $g_{Tsym}(t)$
  - Shown below is the discrete-time to continuous-time conversion for a pulse shape that is a rectangular pulse lasting T_{sym} seconds for J = 1 bit/symbol– the result is a staircase approximation of the discrete-time signal a_n which is equivalent to applying a sample and hold approach to a_n.



2-PAM Transmission

- Truncated sinc pulse with peak of 1
- From the plot, we estimate that d = 1 and T_{sym} = 4 ms. Over 100ms, there are 25 symbol periods. The symbol amplitude values are +1 and -1 and hence d = 1.

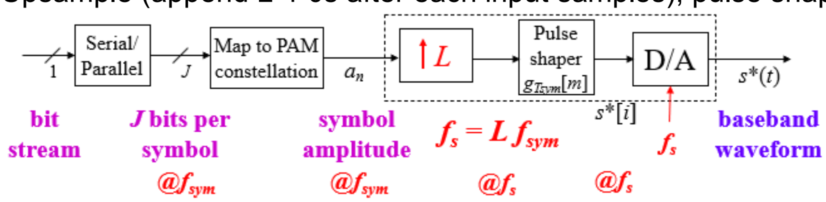
- Amplitudes of the analog continuous-time baseband PAM transmission signal are between -2 times the max symbol amplitude and 2 times the max symbol amplitude, which is helpful in scaling the signal when inputting into a D/A converter to use the full range of the amplitude values supported by the D/A converter (as you did in lab 2 for generating cosine and sine signals)

<u>4-PAM Transmission</u>

- Truncated since pulse with peak of 1
- From the plot of a 4-PAM baseband transmission signal,
    - we estimate d = 2 because the symbol amplitudes are -6, -2, 2, and 6.
    - want symbol amplitudes to be centered at origin and equally spaced, e.g. -3d, -d, d, 3d for 4-PAM
    - Can find d by finding minimum sample amplitude or ½ * distance between observed symbol amplitudes
    - We estimatie T_{sym} = 3 ms. The signal lasts for 60 ms and has 20 symbol periods.
    - Max amplitude is again less than twice max symbol amplitude

<u>Discrete to Continuous Time Conversion</u>

- Upsample (append L-1 0s after each input samples), pulse shape, D/A converter



- Pulse shaping filter should be LPF, should preserve amplitude of original samples
    - Receiver will expect original amplitudes at original sample time
    - Time and frequency domain constraints on pulse shape are met by rectangular pulses, triangular pulses, truncated sinc pulses, truncated raised cosine pulses