[10:30 – 10:50am] Interpolation & Pulse Shaping (Slides 7-10, 7-14, 7-16)

Review and takeaways from Lecture 7 Interpolation & Pulse Shaping

- Discrete-time to continuous-time conversion requires interpolation
- Interpolation is a filtering operation
- It is convenient to use an FIR filter, but IIR could be used as well
- Interpolation filter has lowpass frequency selectivity
- Common pulse shapes:
  - Infinite two-sided sinc (IIR)
  - Truncated sinc (FIR)
  - Rectangular (FIR)
  - Triangular (FIR)
  - Raised cosine (IIR)
  - Truncated raised cosine (FIR)
- Pulse shape for discrete-time to continuous-time conversion (interpolation):
  - Desired frequency range is $-\frac{1}{2} f_s < f < \frac{1}{2} f_s$
  - Zero crossings at multiples of T_s (except origin)
- Pulse shape for discrete-time to discrete-time conversion (interpolation):
  - Desired frequency range is $-\frac{\pi}{L} < \omega < \frac{\pi}{L}$
  - Zero crossings at multiples of L (except origin)

[10:50am – 11:05am] Announcements: Spectrum Regulation and Auctions

http://users.ece.utexas.edu/~bevans/courses/realtime/lectures/13_Digital_PAM/announcements.html

[11:05am – 11:25am] Digital Pulse Amplitude Modulation (Slide 13-3)

Goal: convert bit stream to analog pulses.

- Serial-to-parallel conversion: group stream of bits into symbols
- Constellation maps symbol of bits to amplitude
- A symbol of J bits requires 2^J levels in constellation
- The symbol of bits can be thought of as index into lookup table

4-PAM Example

Symbol of Bits	Symbol Amplitude
00	d
01	$3d$
10	$-d$
11	$-3d$

M-level PAM:

- M is the number of symbol amplitudes: $M = 2^J$
- The symbols are separated by a period $T_{\text{sym}} = 1/f_{\text{sym}}$
- $\underbrace{\text{Bit Rate}}_{\text{bits/second}} = \underbrace{J}_{\text{bits/symbol}} \times \underbrace{f_{\text{sym}}}_{\text{symbols/second}}$

Binary phase shift keying (BPSK) is equivalent to 2-PAM

Q: What is the reasoning behind the ordering in the constellation map?

A: Different orderings are possible. An alternative example is:

Two's complement	Symbol of Bits	Symbol Amplitude
1	01	$3d$
0	00	d
-1	11	$-d$
-2	10	$-3d$

Q: Are the amplitude values in the constellation in analog units?

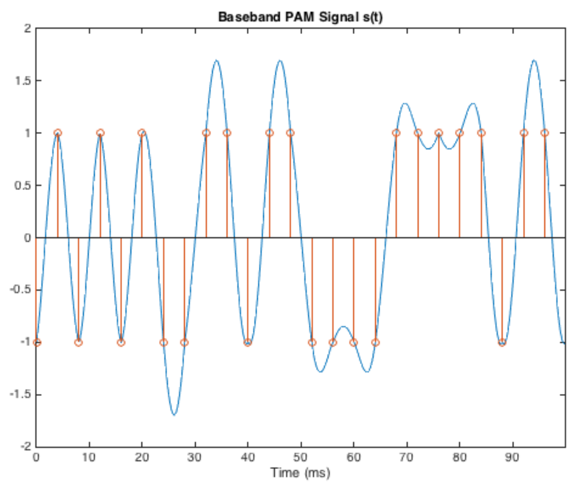
A: Yes, they represent amplitudes of the continuous-time analog waveform.

[11:33am – 11:43am] BPSK/2-PAM Example (Slide 13-4)

Symbol amplitudes marked as circles. For 2-PAM, amplitudes are -d and +d.

- $d = 1$ Volt
- $T_{\text{sym}} = 4 \text{ ms} = \dfrac{100 \text{ ms}}{25 \text{ periods}}$

The maximum symbol amplitude is $(M-1)d = d$. The maximum amplitude in the baseband PAM signal is less than $2(M-1)d = 2$

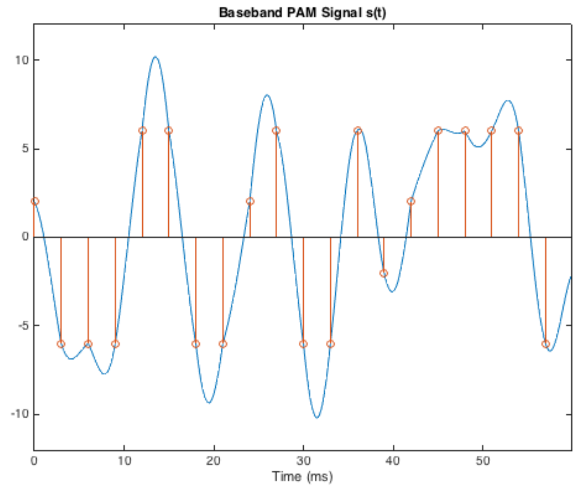


[11:43am – 11:45am] 4-PAM Example (Slide 13-6)

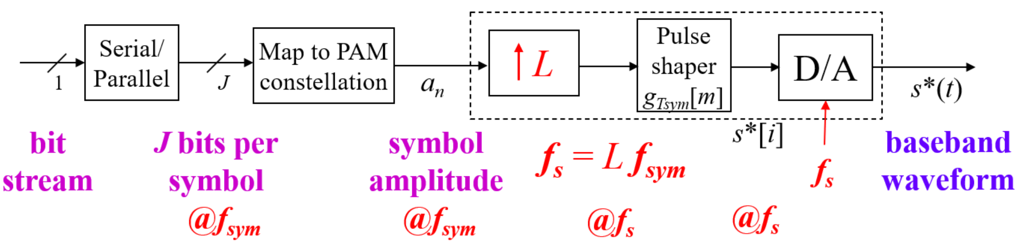
Symbol amplitudes marked as circles. For 4-PAM, symbol amplitudes are -3*d*, -*d*, +*d*,+3*d*.

- $d = 2$ Volt
- $T_{\text{sym}} = 3 \text{ ms} = \frac{60 \text{ ms}}{20 \text{ periods}}$

The maximum symbol amplitude is $(M-1)d$. The maximum amplitude in the baseband PAM signal is less than $2(M-1)d = 6$



[11:40am – 11:50am] PAM Transmission (Slide 13-7)



[11:50am – 11:55am] Digital Interpolation Example (Slide 13-8)

Example: increase sampling rate from 44.1 kHz to 176.4 kHz

- Upsample by 4
- Apply FIR lowpass filter to "fill in" inserted zeros

The input CD audio signal sampled at $f_{s_1} = 44.1$ kHz . The maximum frequency $f_{\max}$ that could be captured is $f_{max} = \frac{1}{2} f_{s_1} = 22.05$ kHz .

Upsampling by L increases the sampling rate by a factor of L, i.e. $f_s = L\, f_{s_1}$. Any frequency content at or above f_{max} are artifacts introduced by upsampling. The interpolation filter should attenuate frequencies at or above f_{max} which corresponds to discrete-time freq.

$$\omega_{max} = 2\pi \frac{f_{max}}{f_s} = 2\pi \frac{f_{max}}{L\, f_{s_1}} = 2\pi \frac{f_{max}}{2\, L\, f_{max}} = \frac{\pi}{L}$$