Lecture 6 Outline:
Zero-Order Hold Sampling, Upsampling

- Announcements:
  - HW 2 posted
  - Please respond to HW poll, including time on analysis questions vs. Matlab; may affect HW 2 (4 units~12 hours/wk), also keep track of time spent on HW2

- Review of Last Lecture

- Sampling and Reconstruction with Zero-Order Hold

- Discrete-Time Upsampling and Reconstruction
Review of Last Lecture

- Digital to Analog Conversion

\[
\begin{align*}
\text{DAC} & \quad x_d[n] \quad x_d(nT_s) \quad \text{LPF} \quad x_r(t) \\
\end{align*}
\]

- Quantization

\[
\begin{align*}
A & \quad x(t) & \quad 111 & \quad 110 \\
-A+k\Delta & \quad x^Q(nT_s) & \quad 101 & \quad 100 \\
-A+2\Delta & \quad \vdots & \quad 011 & \quad 010 \\
-A+\Delta & \quad \vdots & \quad 001 & \quad 000 \\
-A & & & \\
0 & T_s & 2T_s & \\
\end{align*}
\]
Sampling and Reconstruction with Zero-Order Hold

- Ideal sampling not possible in practice
  - delta function train cannot be realized

- In practice, sampling done with zero-order hold to produce sampled signal $x_0(t)$
  - Implementation uses switch, capacitor and resistors

- Reconstruction removes distortion of $h_0(t)$
  - Multiplication in frequency domain by $1/H_0(j\omega)$
Discrete-Time Upsampling

- Increases sampling rate above Nyquist by a factor of $L$ to simplify reconstruction
  - Inserts $L-1$ zeros between each $x_d[n]$ value, yielding $x_e[n]$
  - Compresses $X_d(e^{j\Omega})$ by $L$ in the $\Omega$ domain, repeats $2\pi/L$
  - For $x_d[n]=x(nT_s)$, equivalent to sampling $x(t)$ at rate $T_s/L$; *much easier to add zeros!*

- Less stringent requirements on reconstruction filter than an ideal LPF: zero-order hold often used
Main Points

- Sampling in practice uses a zero-order hold, whose distortion can be completely removed
  - Zero order hold easily implemented with a switch, capacitor, and resistors
  - Higher-order holds provide better performance in practice

- Can also use a zero-order hold in DAC for reconstruction
  - Allows for perfect recovery of original sampled signal with ideal filters
  - In practice, use filters that approximate ideal filter but are easier to implement

- Upsampling of a discrete-time signal by L compresses its Fourier Transform by 1/L
  - Equivalent to sampling L times faster if original sampling rate above Nyquist; much easier to add zeros!!!!
  - Allows less stringent requirements on reconstruction filter than an ideal LPF
  - A zero-order hold is often used for the reconstruction