Lecture 3 Outline:
Analog-to-Bits and Back
Sampling with Zero-Order Hold

- Announcements:
  - HW 1 posted, due 4pm Fri 4/13 (HWs will be posted Fri, not Wed)
  - Matlab review session Monday, bring laptops with Matlab if you can

- Review of Last Lecture

- Digital to Analog Conversion (DAC)

- Quantization

- Analog to Bits and Back

- Sampling with Zero-Order Hold
Review of Last Lecture

- **Sampling (Time):** \[ x(t) \sum_{n=-\infty}^{\infty} \delta(t - nT_s) = x_s(t) \]

- **Sampling (Frequency):** \[ x(t)y(t) \leftrightarrow X(j\omega)Y(j\omega)/(2\pi) \]

  \[ X(j\omega) \ast \frac{2\pi}{T_s} \sum_n \delta(\omega - (2\pi n/T_s)) = X_s(j\omega) \]

  \[ X_s(j\omega) = \sum \frac{1}{T_s} \]

- **Nyquist:** recover \( x(t) \) with LPF if \( T_s \leq \pi/W \)

  Corrrects lecture 2 ppt

- **ADC:** Setting \( x_d[n] = x(nT_s) \) yields \( X_d(e^{j\Omega}) \) with \( \Omega = \omega T_s \)

  Corrects lecture 2 ppt
Digital-to-Analog Conversion

If $x_d[n] = x(nT_s)$, $T_s \leq \pi/W$, then $X_r(j\omega) = X(j\omega)$
Quantization

- Divide amplitude range \([-A,A]\) into \(2^N\) levels, \([-A+k\Delta]\), \(k=0,...,2^N-1\)
- Map \(x(t)\) amplitude at each \(T_s\) to closest level, yields \(x^Q(nT_s)=x^Q[n]\)
- Convert \(k\) to its binary representation (\(N\) bits); converts \(x^Q[n]\) to bits
Analog to Bits and Back

**Analog to Bits**

Continuous-Time Unquantized $x(t)$ → Anti-Aliasing Lowpass Filter → Bandlimits $x(t)$ to prevent aliasing

Discrete-Time Sampler

$\frac{x_d[n]}{x(t)} |_{t=nT}$

Quantizer → Discrete-Time Quantized Representation of $x_d[n]$

**Bits to Analog**

Digital Storage, Transmission, Signal Processing, … → Discrete-Time Quantized $y[n]$ → Reconstruction System → Continuous-Time $y(t)$
Sampling with Zero-Order Hold

- Ideal sampling not possible in practice
  - delta function train cannot be realized
- In practice, ADC uses zero-order hold to produce $x_d[n]$ from $x_0(t)$
  - Design uses switch, capacitor and resistors
- Reconstruction of $x(t)$ from $x_0(t)$ removes $h_0(t)$ distortion
  - Multiplication in frequency domain by $1/H_0(j\omega)$
- Also use zero-order hold for reconstruction in practice
Main Points

- Digital-to-Analog Conversion converts a discrete-time signal into a continuous-time signal by treating it as continuous-time samples.

- Quantization converts a discrete-time signal to bits by mapping its values to a finite number of levels, which introduces noise.

- ADC/DAC with quantization maps an analog signal to bits and back.

- Sampling and reconstruction in practice uses a zero-order hold, whose distortion can be completely removed.