Lecture 9: Analog Signal Processing

Important Dates
In-class presentations: Dec. 5 and 10
Journal articles due: Dec. 12
Presentations at MGH: March 4 and 11 (4-6pm)
Active Filters

• Common Filter Tasks
  – LPF – Reduce high frequency noise
  – LPF – Smooth out an envelop
  – HPF – Block DC signal
  – BPF – Remove out-of-band noise
  – Notch filter – Remove interference signal

• Ideal filter characteristics
  – Flat passband gain
  – Infinite stop band attenuation

• 1\textsuperscript{st} order filter $\rightarrow$ 20 dB per decade attenuation

• What if we want more?
Filter Roll-off Characteristics

- **Butterworth**
  - Maximum passband flatness

- **Bessel**
  - Constant phase dispersion
  - Some pass-band attenuation
  - Slow roll-off

- **Tschebyscheff**
  - Maximum roll-off steepness
  - Passband ripples
  - Tables available for 1, 2, and 3dB passband ripple

Figure 11. Transient Response of the Three Filters
The Sallen-Key LPF
(Equal component value form)

\[ A(s) = \frac{A_0}{1 + \omega_c RC (3 - A_0) s + (\omega_c RC)^2 s^2} \]

\[ A_0 = 1 + \frac{R_4}{R_3} \]

\[ \omega_c = \frac{1}{RC} \]

2nd Order filter coefficients (Ref: Op Amps for Everyone, R. Mancini, pp 277)

<table>
<thead>
<tr>
<th></th>
<th>Bessel</th>
<th>Butterworth</th>
<th>Tschebyscheff (3dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R4/R3</td>
<td>0.268</td>
<td>0.568</td>
<td>0.234</td>
</tr>
<tr>
<td>Q</td>
<td>0.58</td>
<td>0.71</td>
<td>1.3</td>
</tr>
</tbody>
</table>
2nd Order HPF and BPF

- Sallen-Key HPF
- Multiple Feedback BPF
LTC1563-x Series Pre-packaged LPF

- Two internal opamps
- Integrated capacitors → better accuracy
- ~$2 in quantity

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LTC1062 – DC Accurate 5th order LPF

• Switched cap filter; ~$3 each in quantity

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Synchronous Detection

• What is it for?
  – Measuring small signals in a noisy environment

• How does it work?
  – Modulate the excitation signal
  – Demodulate the sensor output
  – Isolate signal from noise using the frequency and phase

• When to use it?
  – Avoiding interference
  – Sensor noise at DC (1/f noise)
  – AC excitation

  • Remember: DC-coupled sensors are susceptible to drift errors
Synchronous Detection

• Phase shift attenuates the signal by a cosine factor!
Analog Multipliers

**FEATURES**
- 4-Quadrant Multiplication
- Low Cost 8-Lead Package
- Complete—No External Components Required
- Laser-Trimmed Accuracy and Stability
- Total Error within 2% of FS
- Differential High Impedance X and Y Inputs
- High Impedance Unity-Gain Summing Input
- Laser-Trimmed 10 V Scaling Reference

**APPLICATIONS**
- Multiplication, Division, Squaring
- Modulation/Demodulation, Phase Detection
- Voltage Controlled Amplifiers/Attenuators/Filters

**PRODUCT DESCRIPTION**
The AD633 is a functionally complete, four-quadrant, analog multiplier. It includes high impedance, differential X and Y inputs and a high impedance summing input (Z). The low impedance output voltage is a nominal 10 V full scale provided by a buried Zener. The AD633 is the first product to offer these features in modestly priced 8-lead plastic DIP and SOIC packages. The AD633 is laser calibrated to a guaranteed total accuracy of 2% of full scale. Nonlinearity for the Y input is typically less than 0.1% and noise referred to the output is typically less than

**CONNECTION DIAGRAMS**
8-Lead Plastic DIP (N) Package

**PRODUCTS**
- ~$5 each
- ±15V Supply
- More expensive versions with better BW and accuracy
All Pass Filter

- Unity gain for all frequencies
- Phase shift = 180° for $\omega \to 0$
- Phase shift = 90° for $\omega \to \infty$
- Phase shift = 135° at $\omega = 1/RC$
- Switch R and C to get 0-90° phase shift

\[ \omega \to \infty \]
\[ \omega \to 0 \]
\[ \omega = 1/RC \]
Microprocessor-based Sync. Det.

- +1/-1 buffers must have low settling time!
Analog-to-Digital Converters (ADC)

• Fundamental tradeoff between resolution and speed (samples per second)
Analog-to-Digital Converters

• Comparators
  – Differences between a comparator and an Op Amp
  – Hysteresis

• Architectures
  – Flash
  – SAR
  – Sigma-Delta
  – Pipelined

• How to use SAR ADC
  – Flywheel capacitor

• How to use a sigma-delta ADC
Comparators

- A high gain amplifier without feedback
- Hysteresis
ADC Topologies
SAR ADCs

• Free-wheel capacitor
Sigma-Delta ADCs