Lecture 7: OpAmps

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Fundamental Circuit: Source and Load

**Sources**
- Power supply
- Signal Generator
- Sensor
- Amplifier output

**Loads**
- Actuator
- Measurement device
- Amplifier input

- Optimize for Voltage: $Z_{LOAD} >> Z_{SOURCE}$
- Optimize for Current: $Z_{LOAD} << Z_{SOURCE}$
- Optimize for Power: $Z_{LOAD} = Z_{SOURCE}$

- Amplifier / active circuit – impedance transform
Ideal Amplifier

- High input impedance
- Low output impedance
- Accurate and stable gain
Operational Amplifier

- High input impedance
- Low output impedance
- Very high gain → Trade gain for accuracy
Op Amp in Feedback

• Rules:
  – Inputs draw no current
  – Output will do whatever is necessary to make the voltage difference between the inputs zero
Non-inverting Amplifier

- High input impedance
Inverting Amplifier

- Input impedance defined by $R_1$
- Can be used for current input
- Can be used as an adder
Op Amp Circuits

• Level shifters
• Simple filters
Feedback T-Network

• Measuring small currents
• Use Thevenin-Norton to analyze more complex feedback networks
Differential Amplifier

• Differential Amplifier
• Instrumentation Amp (Buffered differential amp)
• 2-op amp instrumentation amp
Accurate Peak Detector

- Also: Op Amp power driver
Op Amp Packages

Examples:
- OPA374
- LT1792
Voltage Offset

• Range: ≈ 1mV or less
• Magnified by the gain
Chopper Stablized Op Amp

• Periodically calibrate the offset using switches
• More noisy than standard op amps by ~5x
• Some sacrifice in speed, performance, and cost
Input Bias Current

- Mismatched input → input offset current
- Bipolar input op amps
  - Can be quite large → >1nA
  - Match input impedance to reduce error
- CMOS or J-FET input op amps
  - 100fA to 1nA
  - Match input impedance is not necessary
- Increases with increasing temperature
- How to address: keep bias impedances low
- Input bias current important for measuring small current levels
Ultra Low Input Bias Current: OPA129

- ±100 fA maximum
- Intended Purpose:
  - Capacitive sensing
  - Photodiode preamp

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Information sheet for Burr-Brown OPA129 op amp.
Op Amp Noise

• Frequency dependent
  – 1/f characteristic at low frequencies
  – Devices specify 1/f corner

• Specified in µV over some frequency range

• Or as spectral density (nV / Hz^{0.5})

• Include both noise voltage and noise current

• Analysis is the same as the offsets
OPA374 Voltage Noise Spectrum

INPUT VOLTAGE NOISE
SPECTRAL DENSITY vs FREQUENCY

Voltage Noise (nV/√Hz)

Frequency (Hz)
LT1792 Voltage Noise Spectrum

- Much lower 1/f corner!
- Trade-off:
  - OPA374 input capacitance ~ 3pF
  - LT1792 input capacitance ~ 27pF
Slew Rate

• Example 1: Multiplexed input
• Example 2: Rectifier
Op Amp Frequency Response

- Open-loop frequency response
- Gain-Bandwidth (GBW) product
Review of Feedback Systems

Open-loop response

Feedback loop

\[ V_{in} \rightarrow A(\omega) \rightarrow V_{out} \]

\[ \beta(\omega) \]

\[ V_{in} \rightarrow V_{out} \]

\[ V_{in} \rightarrow R_1 \rightarrow V_{out} \]

\[ V_{in} \rightarrow R_F \rightarrow V_{out} \]
Review of 2\textsuperscript{nd} Order Systems

- If loop gain has 2 poles or more:
  - 180° phase shift turns negative FB into positive FB
  - potential for instability
- Phase margin and gain margin
  - Settling time
  - Overshoot
  - Possibility for oscillation
- Rule of thumb for phase margin
  - aim for 60°
  - minimum 45°
- Check datasheets for PM at various gains
Driving Capacitive Loads

- Possible instability when driving purely capacitive loads
- Cause: op amp output resistance ~ 20Ω
Common Mode Rejection Ratio
Power Supply Rejection Ratio

- \( \text{CMRR} = \frac{A_{\text{DIFF}}}{A_{\text{CM}}} \)
- \( \text{PSRR} = \frac{V_{\text{CC}}}{V_{\text{OS}}} \)
More on the Power Supply: The Op Amp is a 5 Terminal Device!

- Output cannot exceed the power supply!
- Traditional op amps need 1-2V head room
- Dual supply vs. Single supply
- ‘Single-supply op amp’ \( \rightarrow \) accept input down to \( V_{S^-} \)
Rail-to-Rail (R-R) Op Amps

• Overused industry buzzword
• Can be R-R input or R-R output or both
• R-R output = low output impedance near supplies
• ‘Single-supply op amp’ = half of a R-R input op amp
• R-R input op amps $\rightarrow$ cross-over distortion
Cross-over Distortion

- Bias current has a similar error
- Remedy: Avoid cross-over distortion
- OPA386 R-R op amp with no cross-over distortion
Check List for Selecting Op Amps

1. Power supply: range, rail-to-rail
2. Gain-Bandwidth
3. Cost
4. Voltage offset
5. Stability at the intended gain, settling time
6. Output current
7. Noise
8. Special functions: e.g. shut-down pin
Op Amps Types (Industry Jargon)

• Precision Amplifier - Could be any of the following:
  – Low offset
  – Low input bias current
  – Low noise
• Zero-drift amplifier ➔ chopper stablized, poor noise
• Low power ➔ Low bandwidth
• Video Amps ➔ High speed, poor DC characteristics
• Audio Amps ➔ Low distortion, poor DC characteristics
• Current Feedback Amps ➔ High speed, poor DC, cannot be used as a conventional voltage FB amplifier
• Differential / Instrumentation amplifiers
• High voltage / high current