

2.996/6.971 Biomedical Devices Design Laboratory

Lecture 7: OpAmps

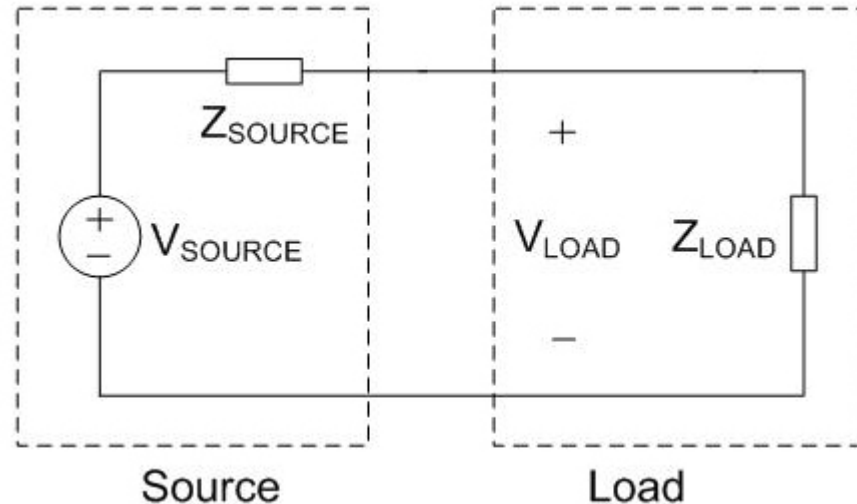
Instructor: Dr. Hong Ma

Oct. 3, 2007

Fundamental Circuit: Source and Load

Sources

Power supply
Signal Generator
Sensor
Amplifier output



Loads

Actuator
Measurement device
Amplifier input

- Optimize for Voltage: $Z_{LOAD} \gg Z_{SOURCE}$
- Optimize for Current: $Z_{LOAD} \ll Z_{SOURCE}$
- Optimize for Power: $Z_{LOAD} = Z_{SOURCE}$
- Amplifier / active circuit – impedance transform

Ideal Amplifier

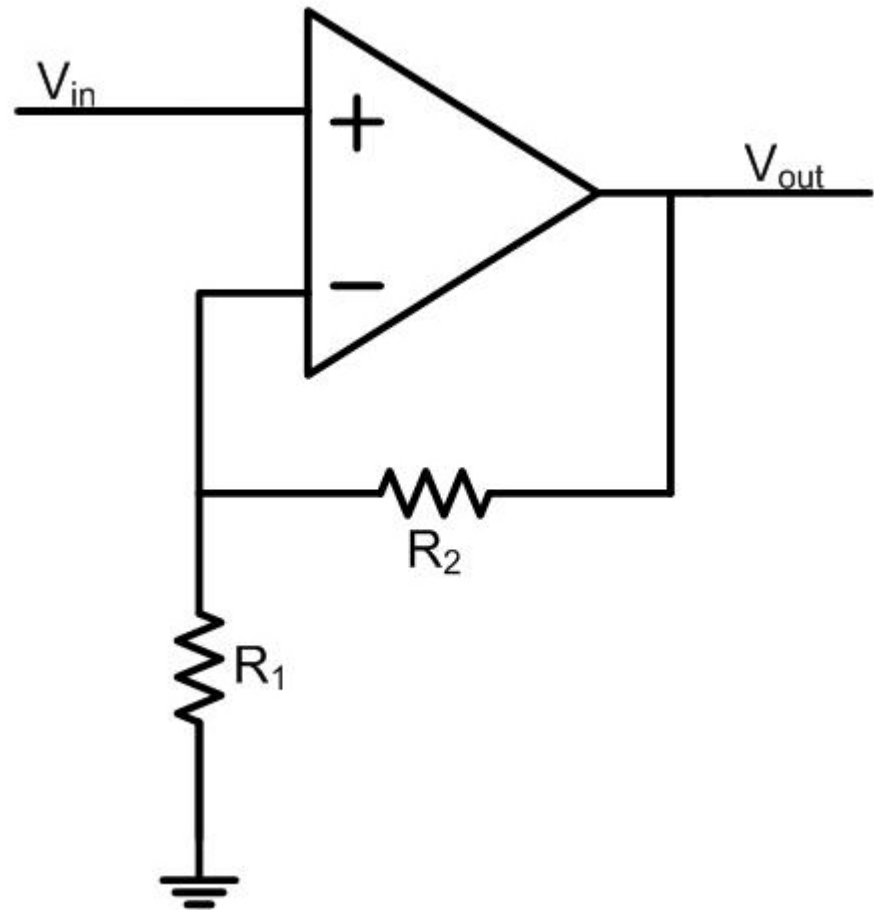
- High input impedance
- Low output impedance
- Accurate and stable gain

Operational Amplifier

- High input impedance
- Low output impedance
- Very high gain → Trade gain for accuracy

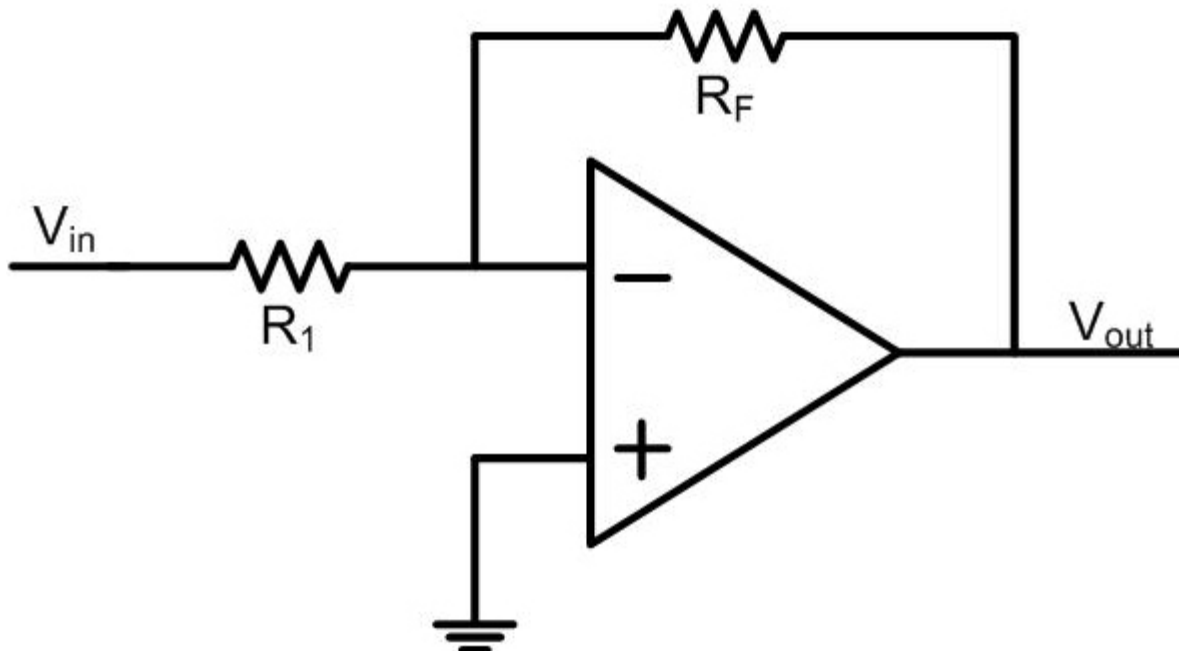
Non-inverting Amplifier

- 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

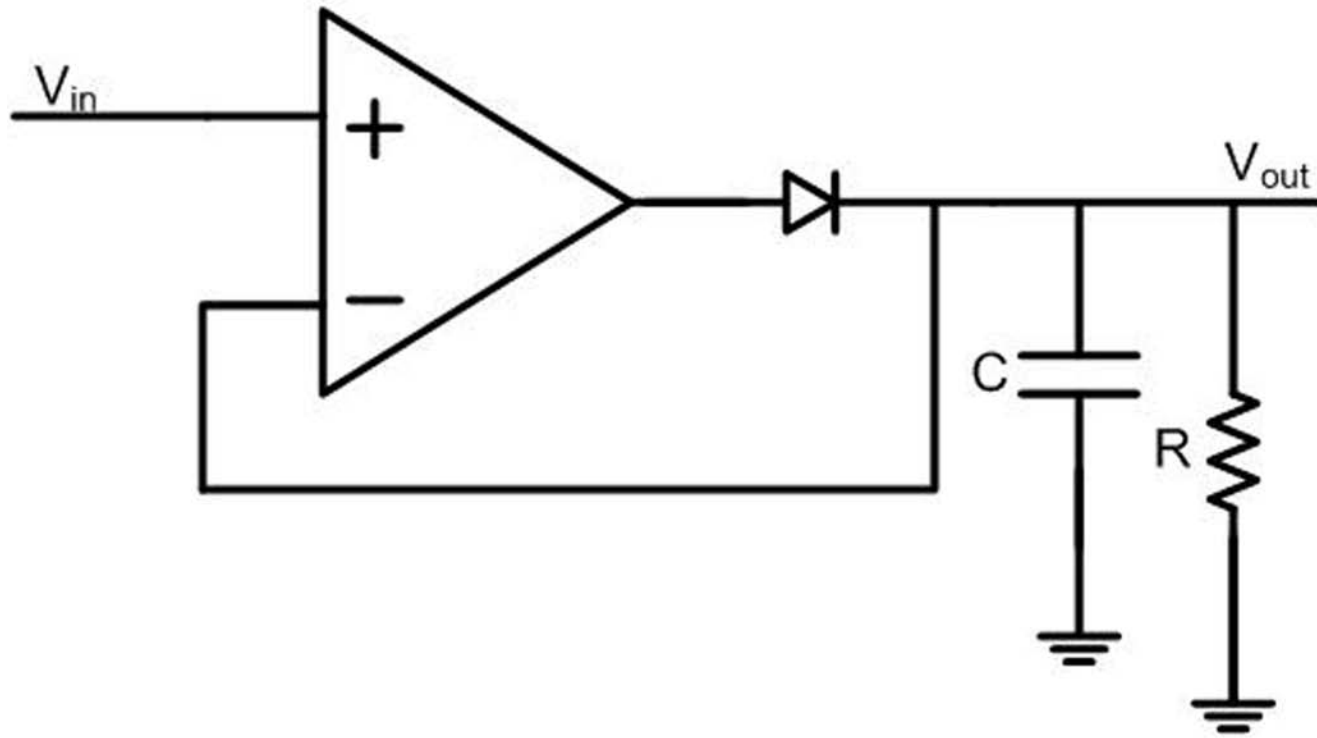
Feedback T-Network

- 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

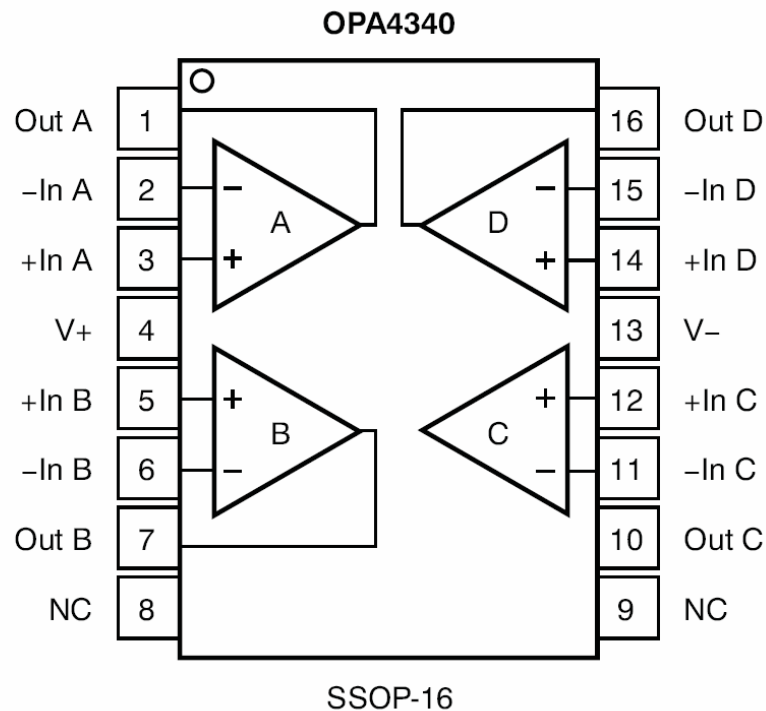
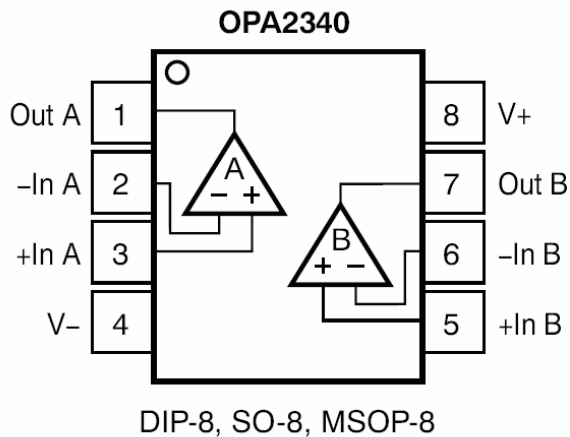
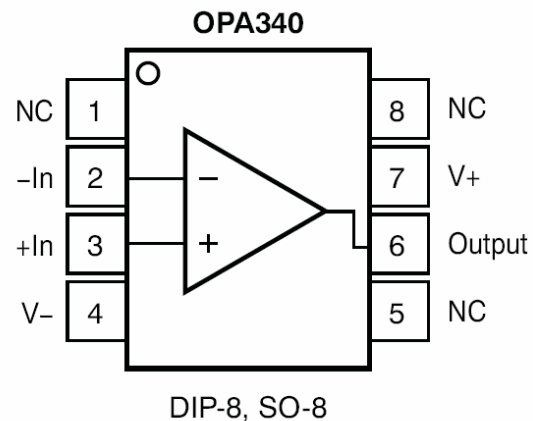
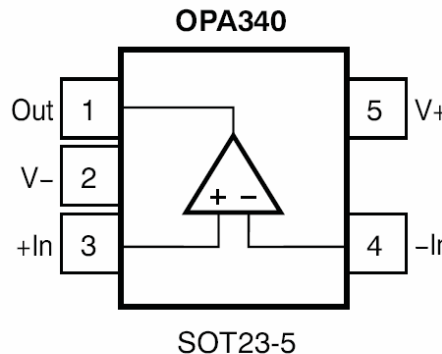


- Also: Op Amp power driver

Op Amp Packages

Examples:

- OPA374
- LT1792



Voltage Offset

- Range: $\approx 1\text{mV}$ or less
- Magnified by the gain

Chopper Stabilized Op Amp

- Periodically calibrate the offset using switches
- More noisy than standard op amps by $\sim 5x$
- Some sacrifice in speed, performance, and cost

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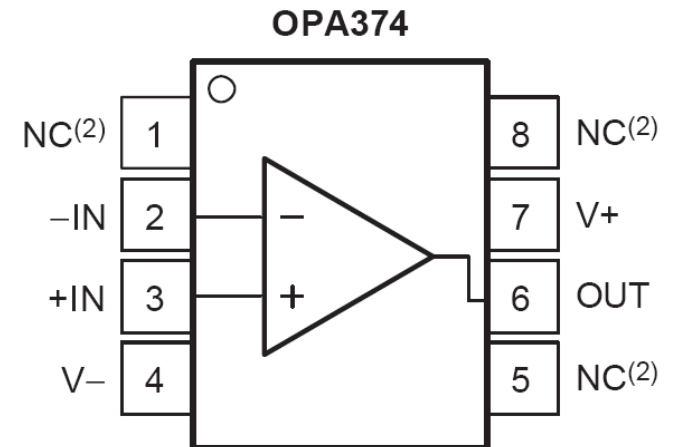
Information sheet for Linear Technology LTC1051/LTC1053 dual/quad zero-drift op amps.

Input Bias Current

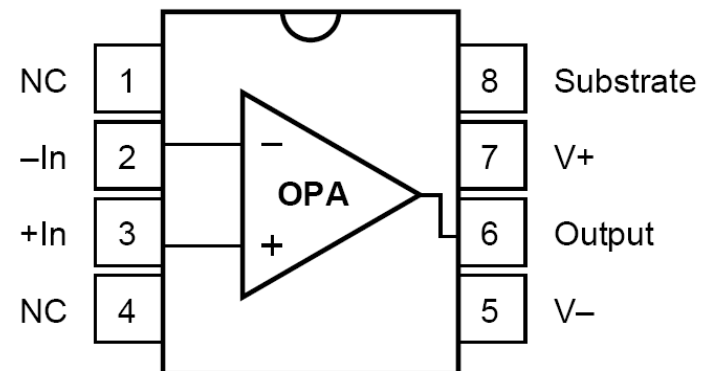
- Mismatched input \rightarrow input offset current
- Bipolar input op amps
 - Can be quite large $\rightarrow >1\text{nA}$
 - Match input impedance to reduce error
- CMOS or J-FET input op amps
 - 100fA to 1nA
 - Match input impedance is not necessary
- Increases with increasing temperature
- How to address: keep bias impedances low
- Input bias current important for measuring small current levels

Ultra Low Input Bias Current: OPA129

Conventional Pin-Out



OPA129 Pin-Out



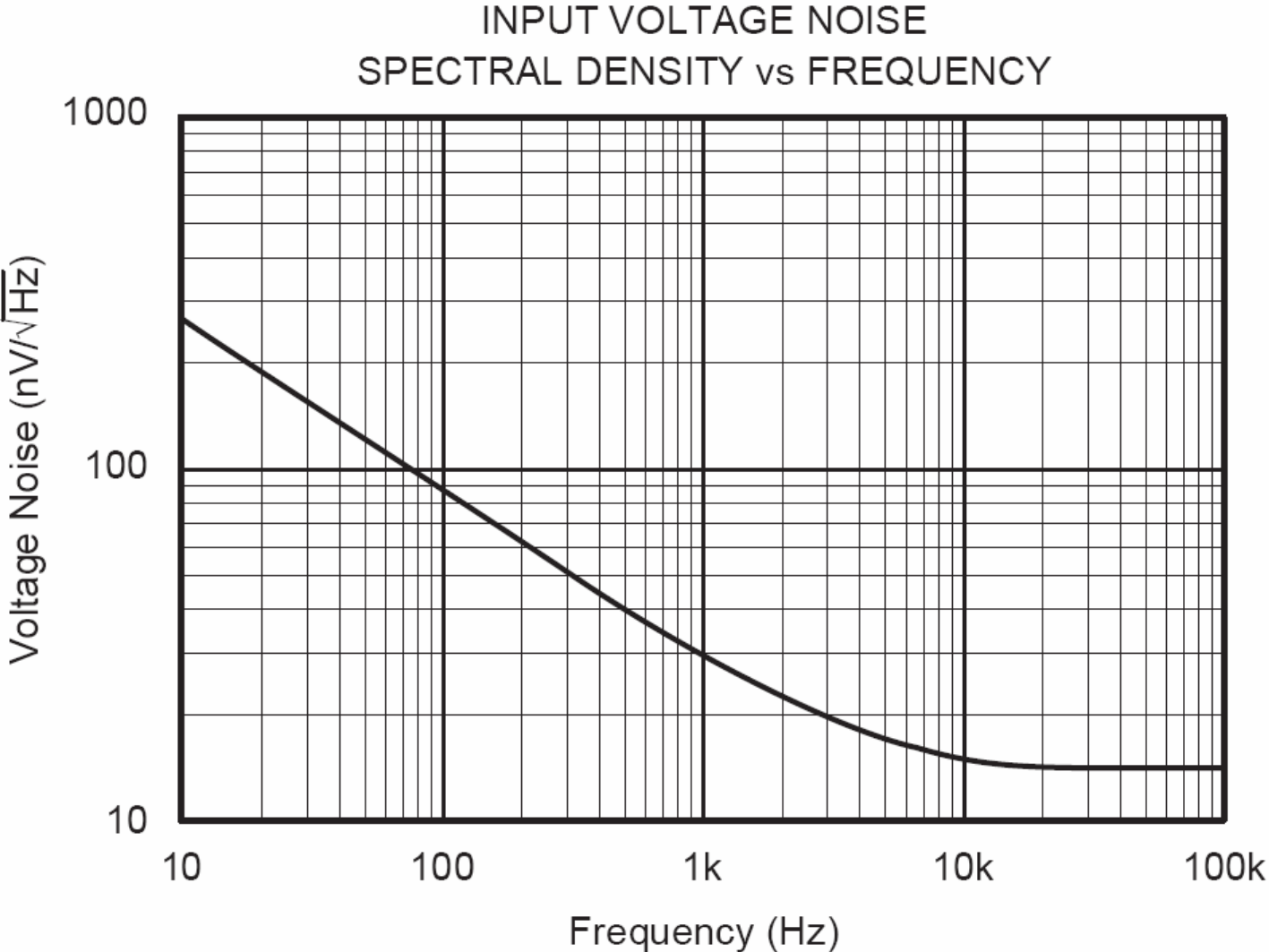
- ± 100 fA maximum
- Intended Purpose:
 - Capacitive sensing
 - Photodiode preamp

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Information sheet for Burr-Brown OPA129 op amp.

Op Amp Noise

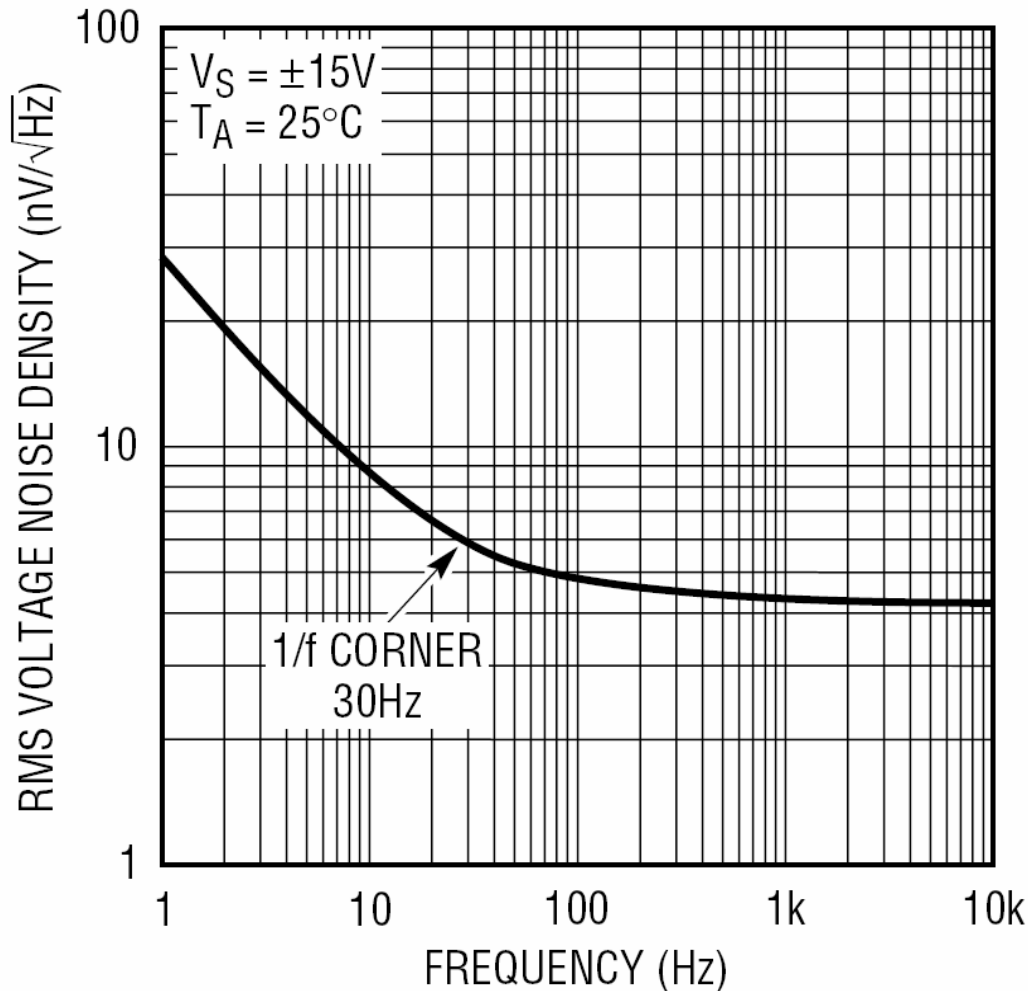
- Frequency dependent
 - $1/f$ characteristic at low frequencies
 - Devices specify $1/f$ corner
- Specified in μV over some frequency range
- Or as spectral density ($\text{nV} / \text{Hz}^{0.5}$)
- Include both noise voltage and noise current
- Analysis is the same as the offsets

OPA374 Voltage Noise Spectrum



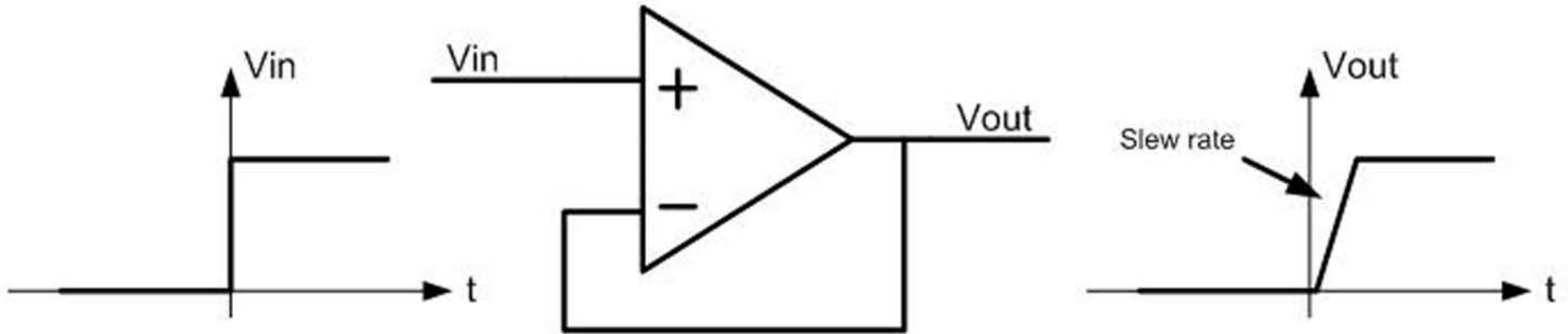
LT1792 Voltage Noise Spectrum

Voltage Noise vs Frequency



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

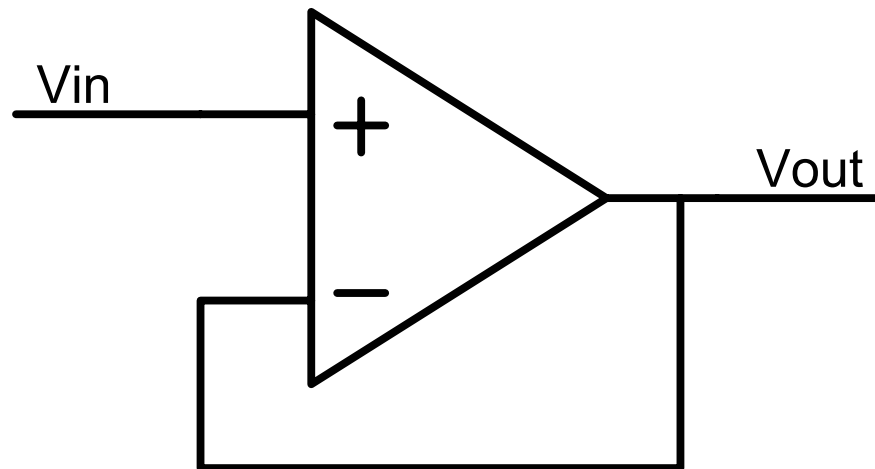
Slew Rate



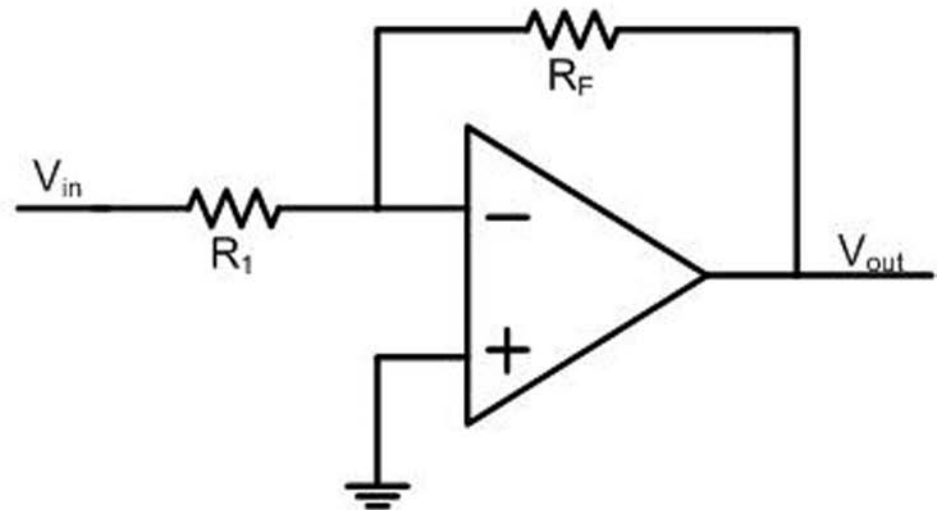
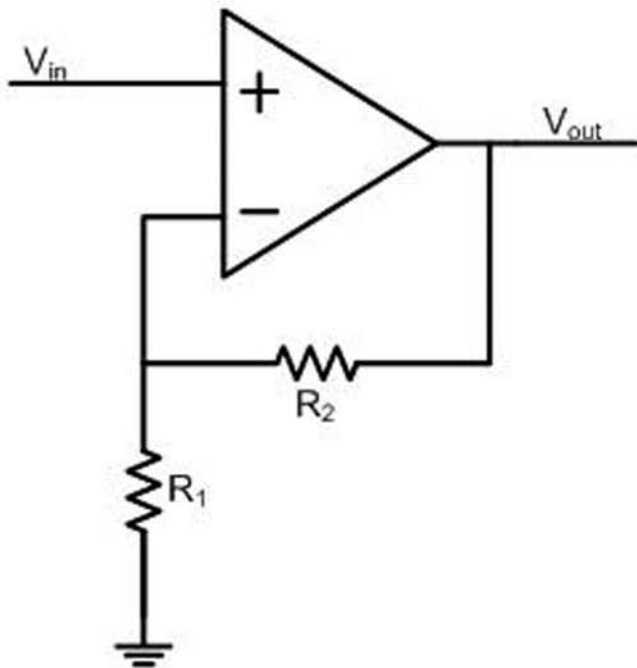
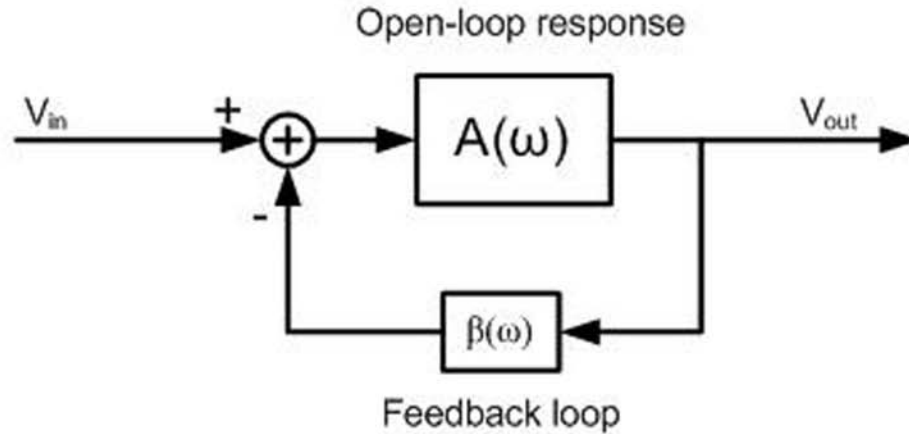
- Example 1: Multiplexed input
- Example 2: Rectifier

Op Amp in Feedback

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

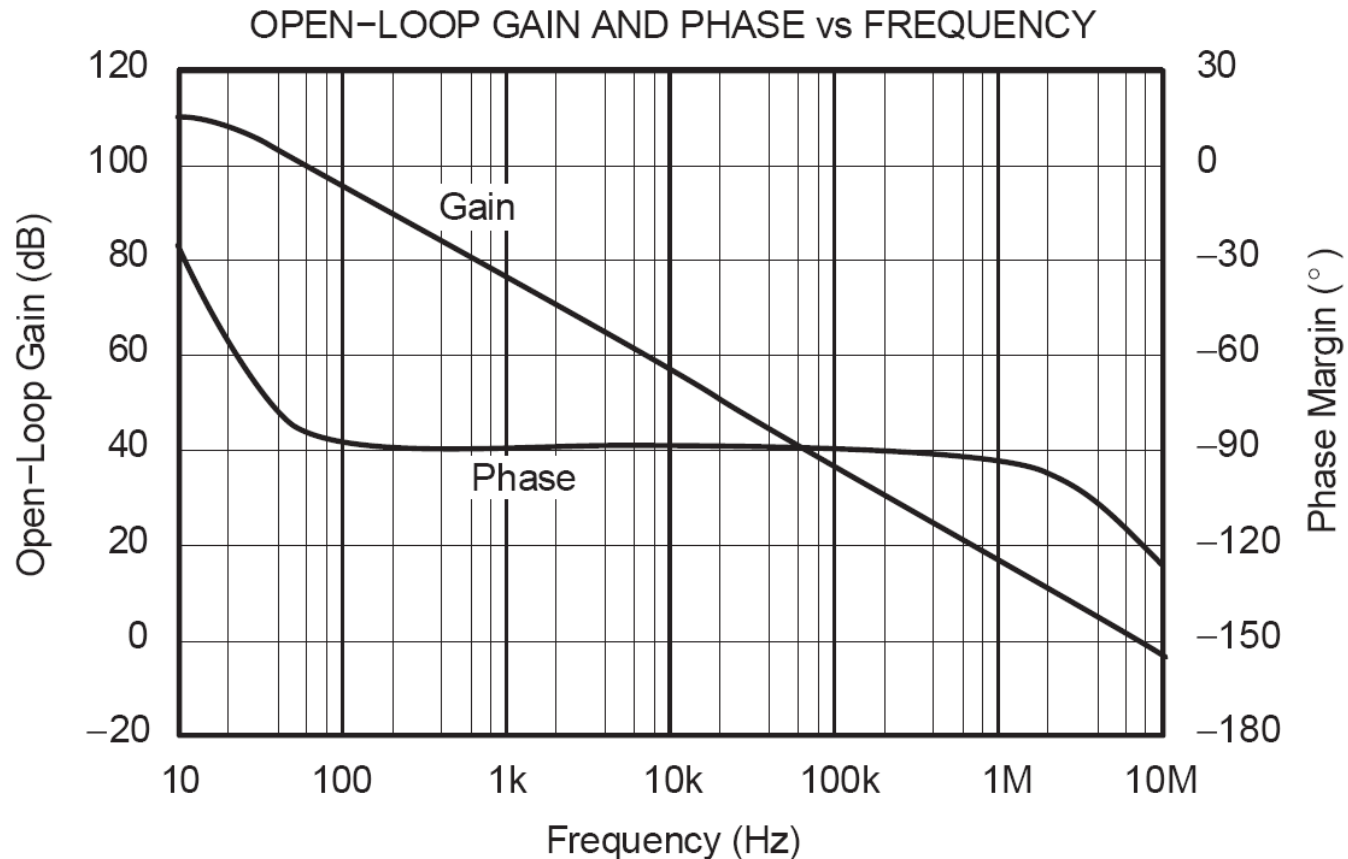


Review of Feedback Systems



Op Amp Frequency Response

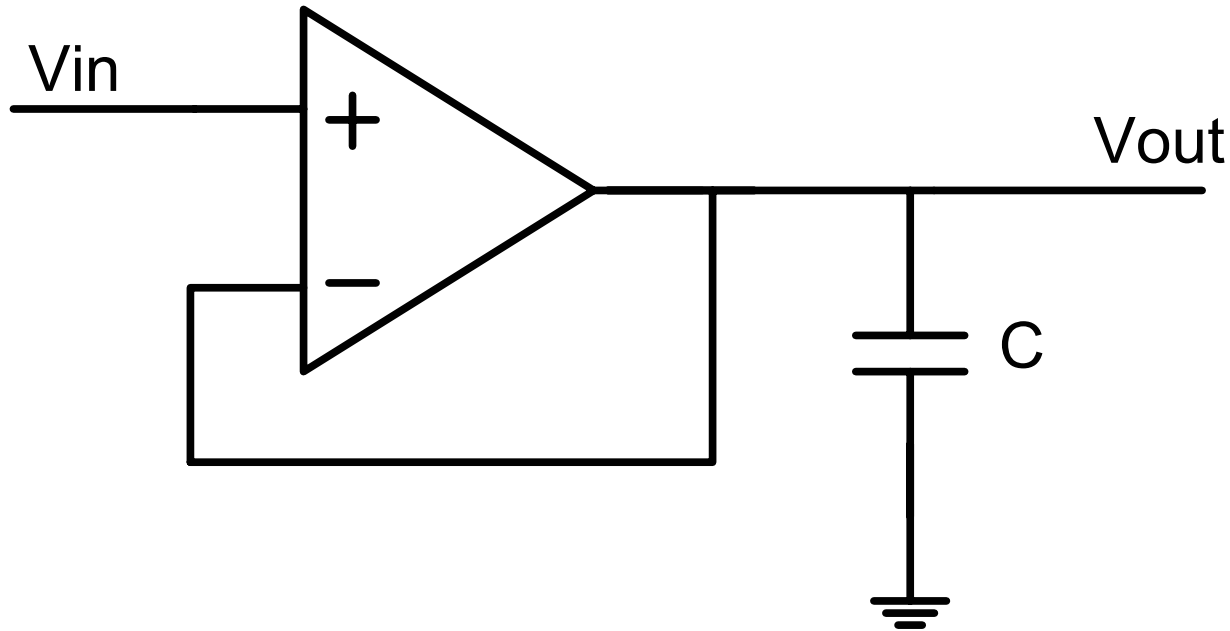
- Open-loop frequency response
- Gain-Bandwidth (GBW) product



Review of 2nd Order Systems

- If loop gain has 2 poles or more:
 - 180° phase shift turns negative FB into positive FB
 - potential for instability
- Phase margin (180° - loop phase shift when gain=1)
 - 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



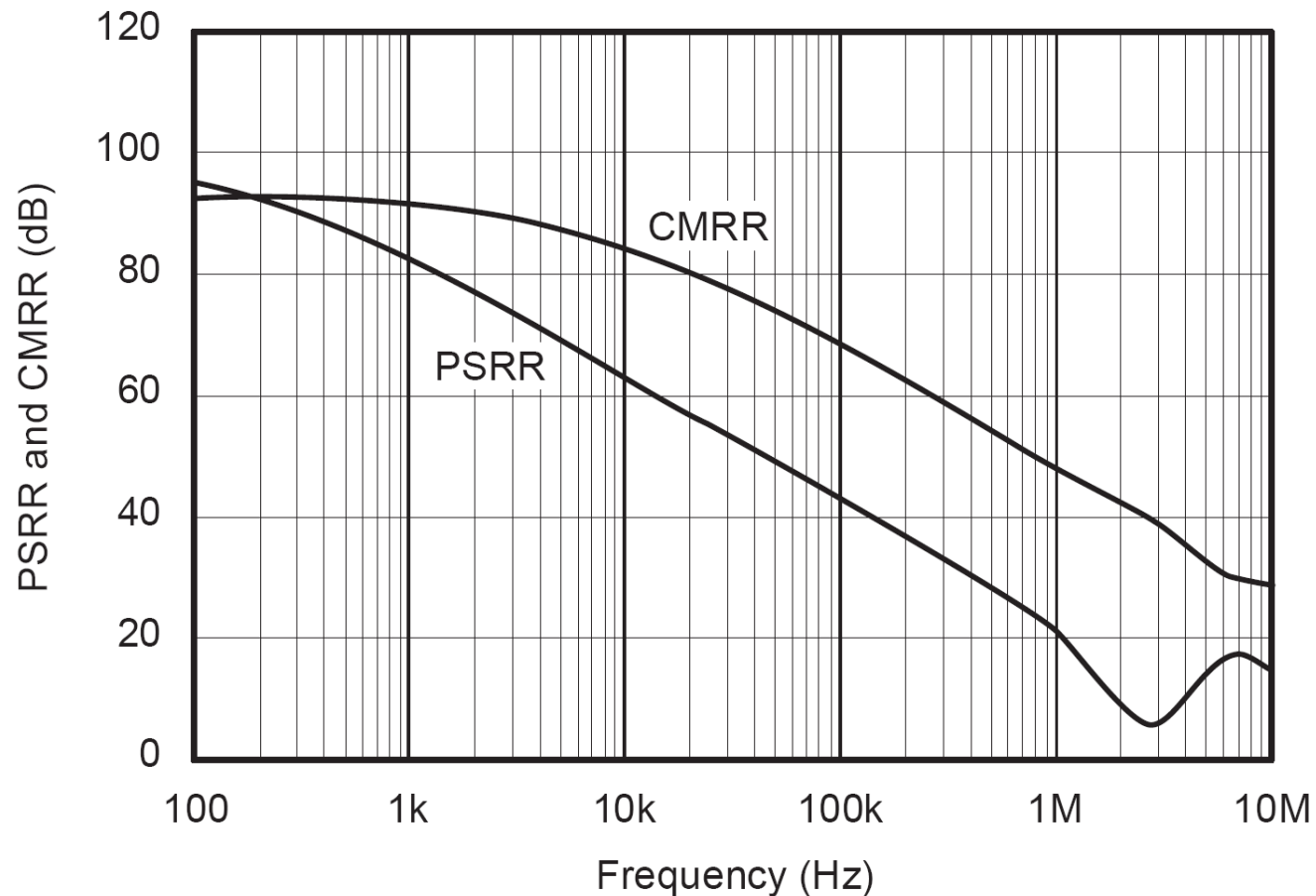
- Possible instability when driving purely capacitive loads
- Cause: op amp output resistance $\sim 20\Omega$

Common Mode Rejection Ratio

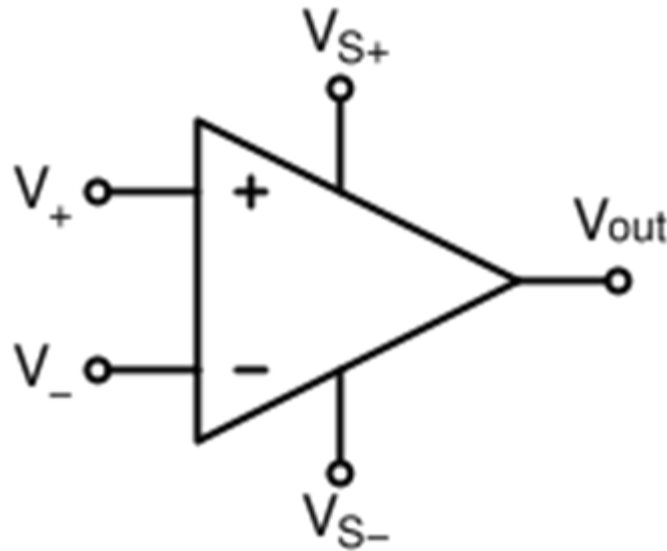
Power Supply Rejection Ratio

- $CMRR = A_{DIFF} / A_{CM}$
- $PSRR = V_{CC} / V_{OS}$

POWER-SUPPLY AND COMMON-MODE
REJECTION RATIO vs FREQUENCY



More on the Power Supply: The Op Amp is a 5 Terminal Device!

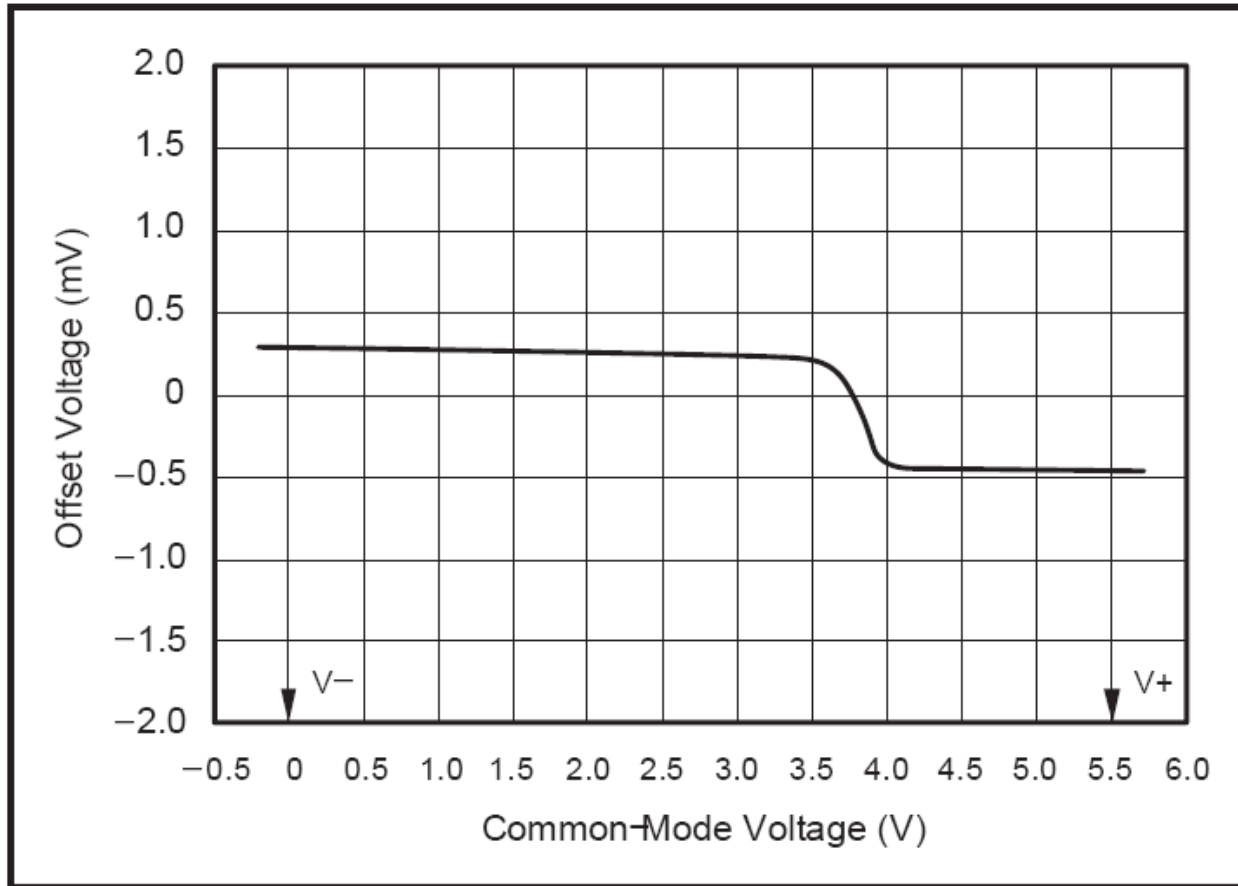


- Output cannot exceed the power supply!
- Traditional op amps need 1-2V head room
- Dual supply vs. Single supply
- 'Single-supply op amp' → accept input down to V_{S-}

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 → 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 stabilized, 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