Endüstriyel Otomatik Kontrol Sistemleri
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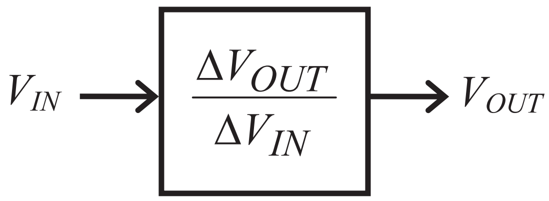
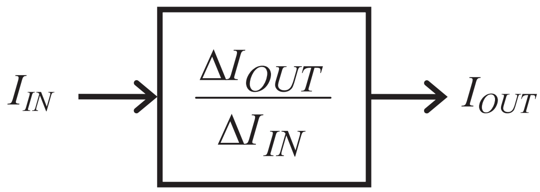
Dersin Konusu: Endüstriyel Otomatik Kontrol Sistemlerinde Kullanılan Yükselteçler ve Uygulamaları

Dersin Amacı:
Endüstriyel otomatik kontrol sistemlerinde kullanılan yükselteçlerin özellikleri, iç donanımı ve elektronik devrelerinin incelenmesi, uygulama devrelerinin analizi, incelenmesi ve tasarlanmasının öğretilmesidir.

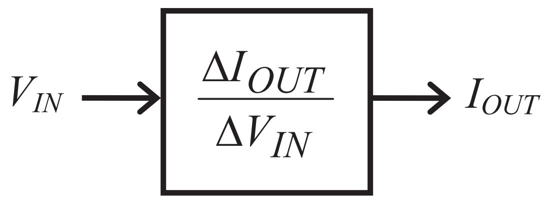
YÜKSELTEÇ TİPLERİ



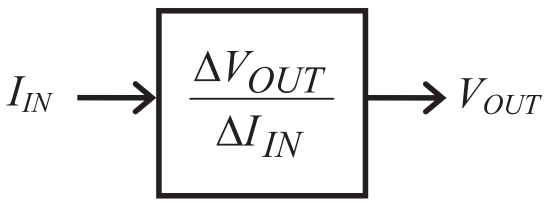
Gerilim Yükselteci



Akım Yükselteci



İletkenlik transfer Yükselteci (Transconductance)



Empedans transfer Yükselteci (Transimpedance)

Operational Amplifiers (OPAMP)

High Speed Current Feedback (CFA)

High Speed Voltage Feedback

Precision, Low Power

High Speed Comparators

Instrumentation Amplifiers

Isolation Amplifiers

Sensor Amplifiers

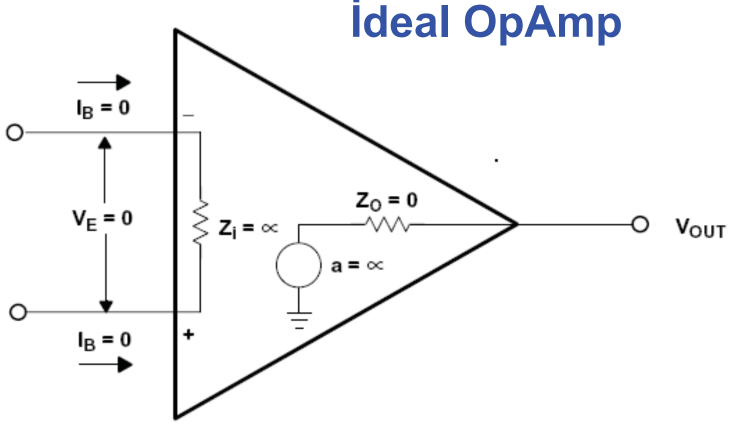
Bridge Amplifiers

Log Amplifiers

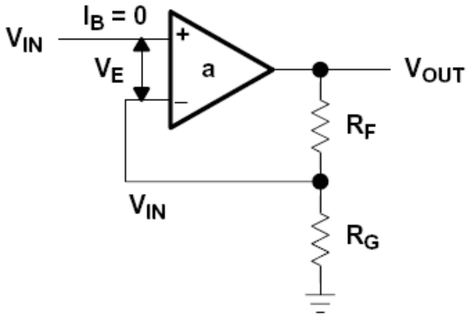
Operational Amplifiers (OPAMP)

PARAMETER NAME	PARAMETERS SYMBOL	VALUE
Input current	I_{IN}	0
Input offset voltage	V_{OS}	0
Input impedance	Z_{IN}	∞
Output impedance	Z_{OUT}	0
Gain	a	∞

İdeal OpAmp



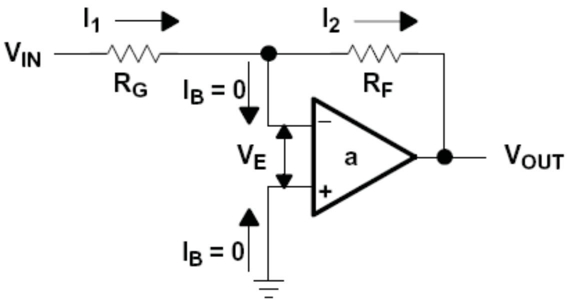
Evirmeyen Yükselteç



$$V_{IN} = V_{OUT}\frac{R_G}{R_G + R_F}$$

$$\frac{V_{OUT}}{V_{IN}} = \frac{R_G + R_F}{R_G} = 1 + \frac{R_F}{R_G}$$

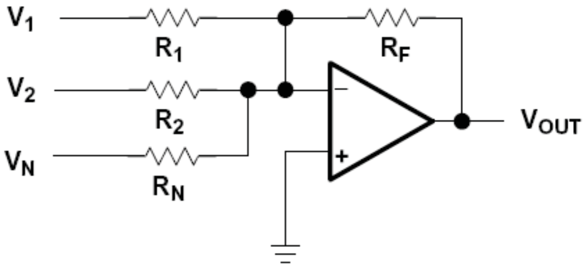
Eviren Yükselteç



$$I_1 = \frac{V_{IN}}{R_G} = -I_2 = -\frac{V_{OUT}}{R_F}$$

$$\frac{V_{OUT}}{V_{IN}} = -\frac{R_F}{R_G}$$

Toplayıcı Yükselteç



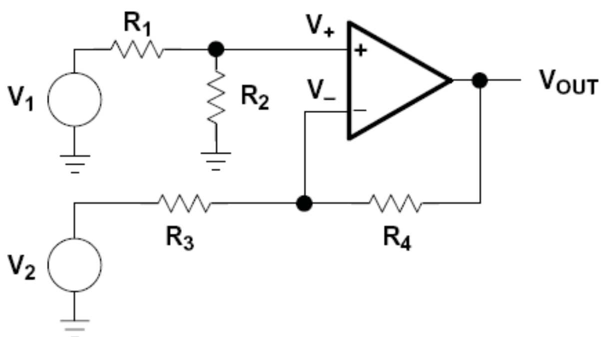
$$V_{OUTN} = -\frac{R_F}{R_N} V_N$$

$$V_{OUT1} = -\frac{R_F}{R_1} V_1$$

$$V_{OUT2} = -\frac{R_F}{R_2} V_2$$

$$V_{OUT} = -\left(\frac{R_F}{R_1} V_1 + \frac{R_F}{R_2} V_2 + \frac{R_F}{R_N} V_N\right)$$

Fark Yükselteci



$$V_{+} = V_1 \frac{R_2}{R_1 + R_2}$$

$$V_{OUT1} = V_{+}(G_{+}) = V_1 \frac{R_2}{R_1 + R_2}\left(\frac{R_3 + R_4}{R_3}\right)$$

$$V_{OUT2} = V_2\left(-\frac{R_4}{R_3}\right)$$

$$V_{OUT} = V_1 \frac{R_2}{R_1 + R_2}\left(\frac{R_3 + R_4}{R_3}\right) - V_2 \frac{R_4}{R_3} \qquad V_{OUT} = (V_1 - V_2)\frac{R_4}{R_3}$$

High Speed Current Feedback Amplifiers

High Speed Current Feedback

Differential Line Driver

High Speed Voltage Feedback Amplifiers

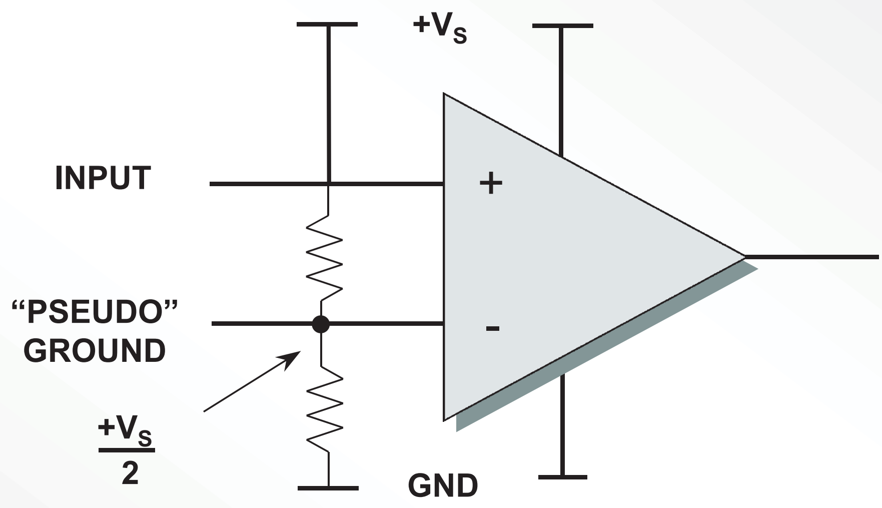
High Speed Amplifiers

Differential Input/Output

Differential Line Drivers

Rail-Rail Amplifiers

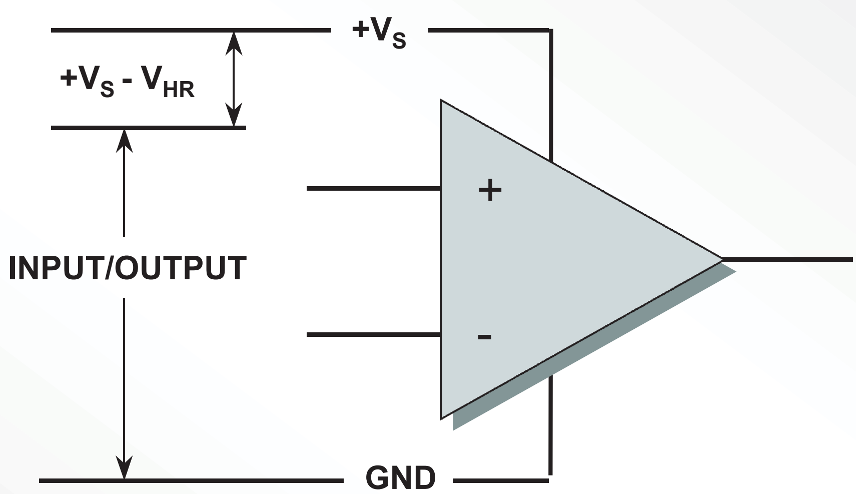
What is a Rail-Rail Amplifier?



Conventional Op Amp Used in a "Single Supply" Mode:

- Most Op Amps Can Operate From a Single Supply If Their "Ground" Is Biased Between the Positive Rail and Ground.
- Standard Op Amps Will Require 2-3 Volts of "Headroom" Between Supply Rails.

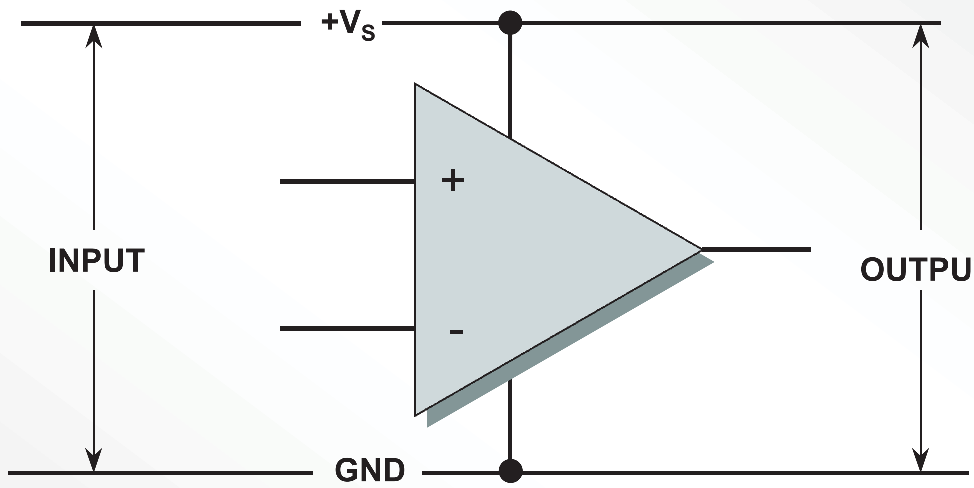
What is a Rail-Rail Amplifier ? (con't)



True "Single Supply" Op Amp

- True Single Supply Op Amps Can Operate Down to Their Negative Rail (Ground)
- Sometimes Still Require 2-3 Volts of Headroom V_{HR} Between the Positive Excursion and the Positive Rail.

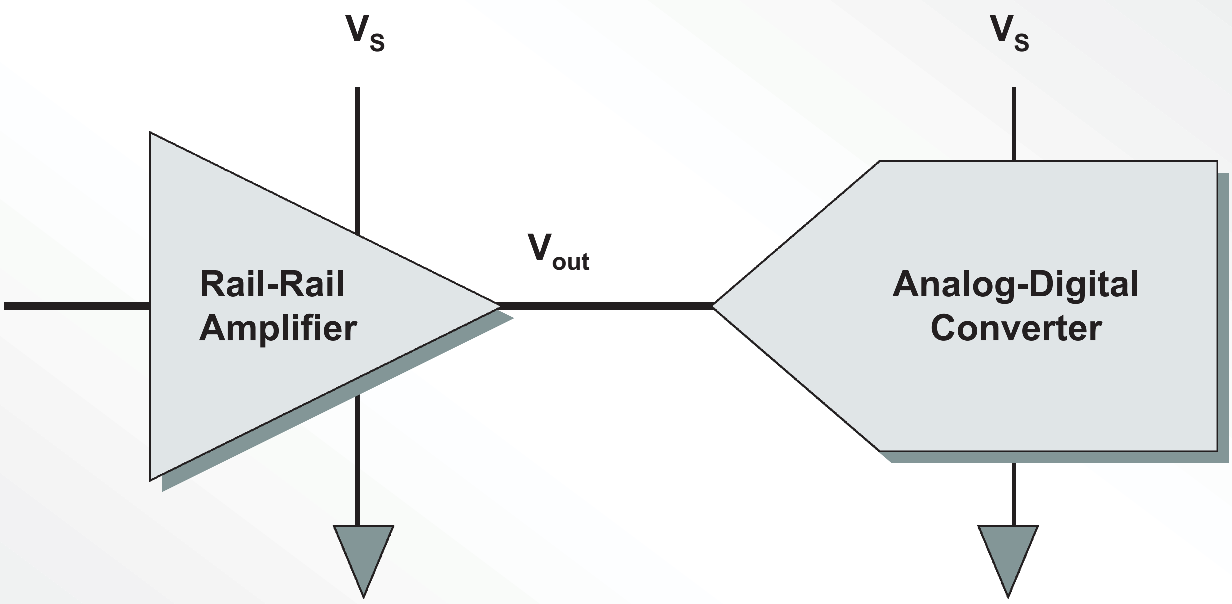
What is a Rail-Rail Amplifier ? (con't)



True Rail-Rail Op Amp

- True Rail-Rail Op Amps Can Swing to Within a Few Millivolts of Their Supply Rails, Either on the Input, the Output or Both.

Why Rail-Rail?



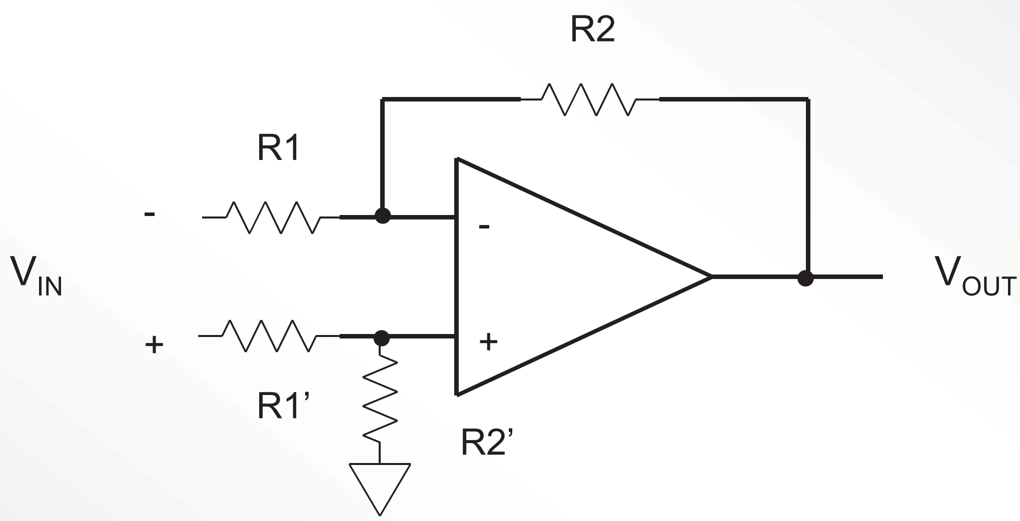
- Many New High Speed A-D Converters Operate From Single +3V to +5V Supply
- Rail-Rail Amplifiers Provide Maximum Dynamic Range

Precision, Low Power Amplifiers

High Speed Comparators

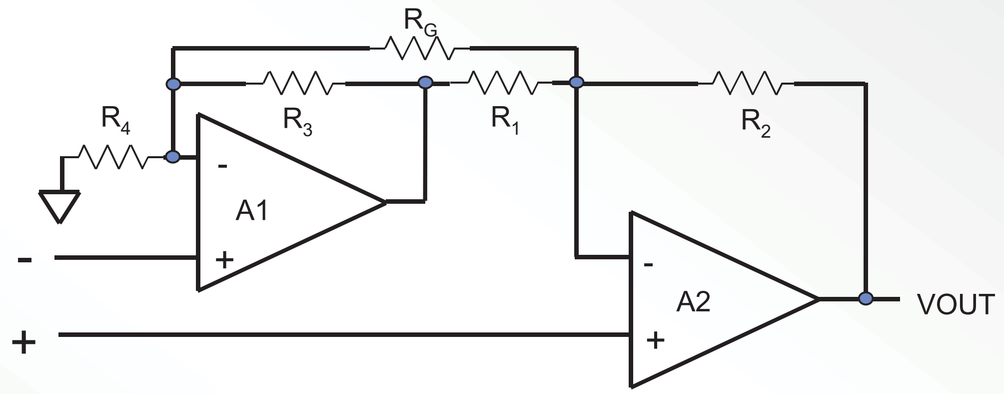
Instrumentation Amplifiers

A "Differential" Amplifier



- For Balanced Gain, G = R2/R1 = R2'/R1'
- For Balanced Input Z, R1'+ R2' = R1
- Common Mode Rejection Depends on Resistor Ratio Matching

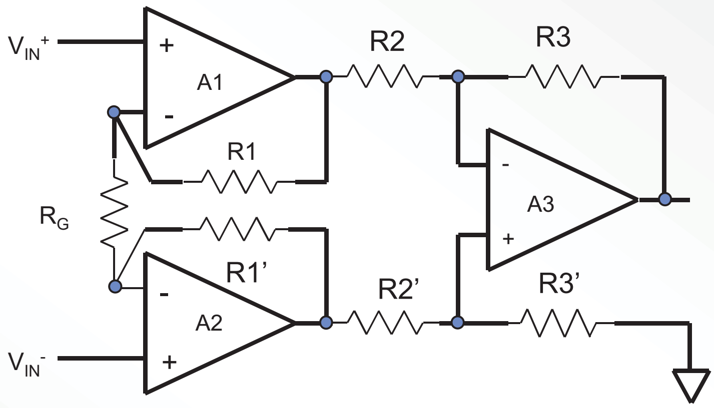
2 Op Amp Design



$$\frac{V_{OUT}}{V_{IN}} = 1 + \frac{R_2}{R_1} + \frac{2R_2}{R_G}$$

- **Advantages:**
  - **Requires Only 2 Op Amps**
  - **High Input Impedance**
- **Disadvantages:**
  - **Input Common Mode Voltage Range Is Gain-Dependent**
  - **A1 Amplifies Common Mode by (R3+R4)/R4**

3 Op Amp Design



$$\frac{VOUT}{VIN} = \left(\frac{2R1}{RG} + 1\right)\left(\frac{R3}{R2}\right)$$

- **Advantages:**
  - **Fully Differential Inputs**
  - **Very High Input Impedance**
  - **Input Common Mode Voltage Range Is No Longer Gain-Dependent**
- **Disadvantage : Extra Amplifier**

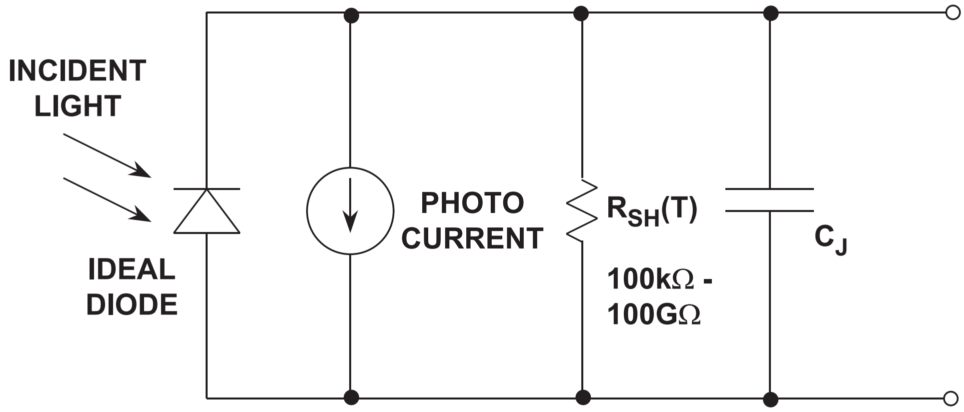
HIGH IMPEDANCE SENSORS

- Photodiode Preamplifiers
- Piezoelectric Sensors
  - Accelerometers
  - Hydrophones
- Humidity Monitors
- pH Monitors
- Chemical Sensors
- Smoke Detectors
- Charge Coupled Devices and Contact Image Sensors for Imaging

PHOTODIODE APPLICATIONS

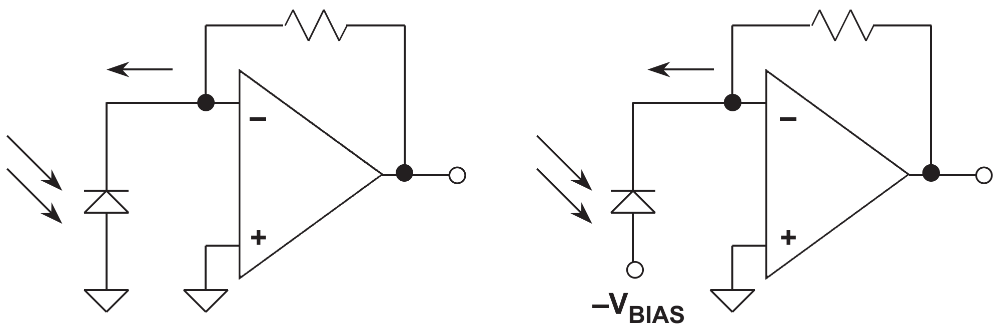
- Optical: Light Meters, Auto-Focus, Flash Controls
- Medical: CAT Scanners (X-Ray Detection), Blood Particle Analyzers
- Automotive: Headlight Dimmers, Twilight Detectors
- Communications: Fiber Optic Receivers
- Industrial: Bar Code Scanners, Position Sensors, Laser Printers

PHOTODIODE EQUIVALENT CIRCUIT



NOTE: R_{SH} HALVES EVERY 10°C TEMPERATURE RISE

PHOTODIODE MODES OF OPERATION



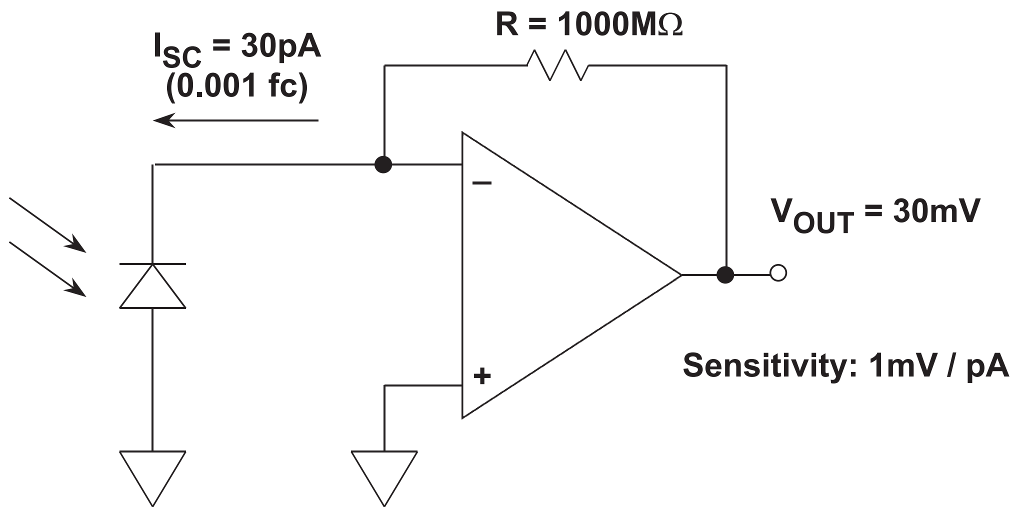
PHOTOVOLTAIC

- Zero Bias
- No "Dark" Current
- Linear
- Low Noise (Johnson)
- Precision Applications

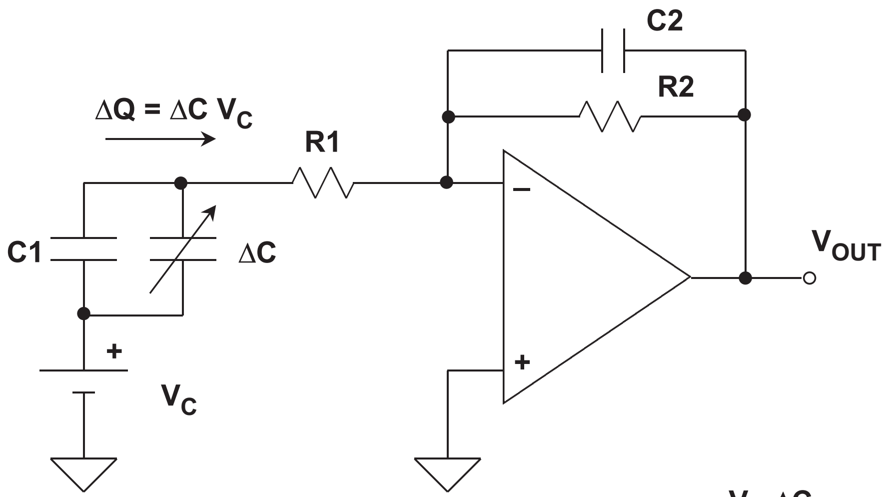
PHOTOCONDUCTIVE

- Reverse Bias
- Has "Dark" Current
- Nonlinear
- Higher Noise (Johnson + Shot)
- High Speed Applications

CURRENT-TO-VOLTAGE CONVERTER (SIMPLIFIED)

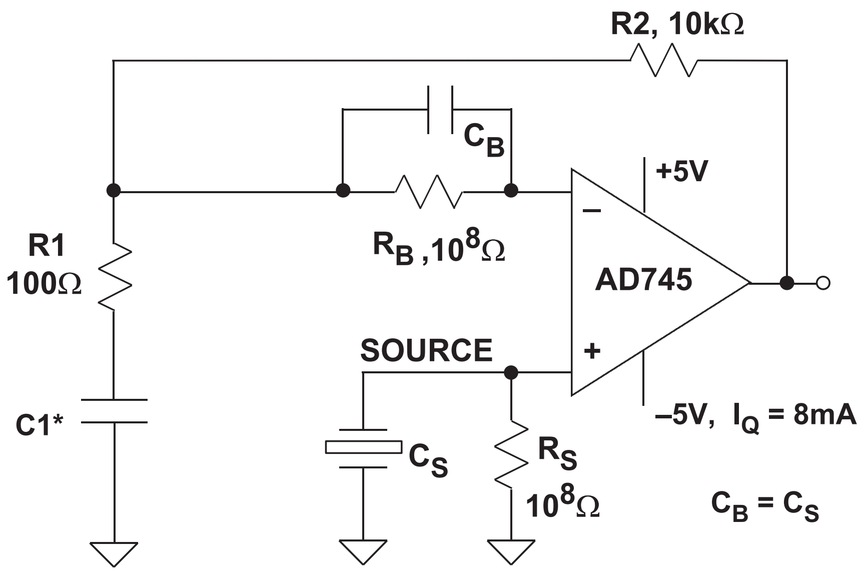


CHARGE AMPLIFIER FOR CAPACITIVE SENSOR



- FOR CAPACITIVE SENSORS: $\Delta V_{OUT} = \dfrac{-V_C\ \Delta C}{C2}$
- FOR CHARGE-EMITTING SENSORS: $\Delta V_{OUT} = \dfrac{-\Delta Q}{C2}$
- UPPER CUTOFF FREQUENCY $= f_2 = \dfrac{1}{2\pi\ R2\ C2}$
- LOWER CUTOFF FREQUENCY $= f_1 = \dfrac{1}{2\pi\ R1\ C1}$

GAIN OF 100 PIEZOELECTRIC SENSOR AMPLIFIER



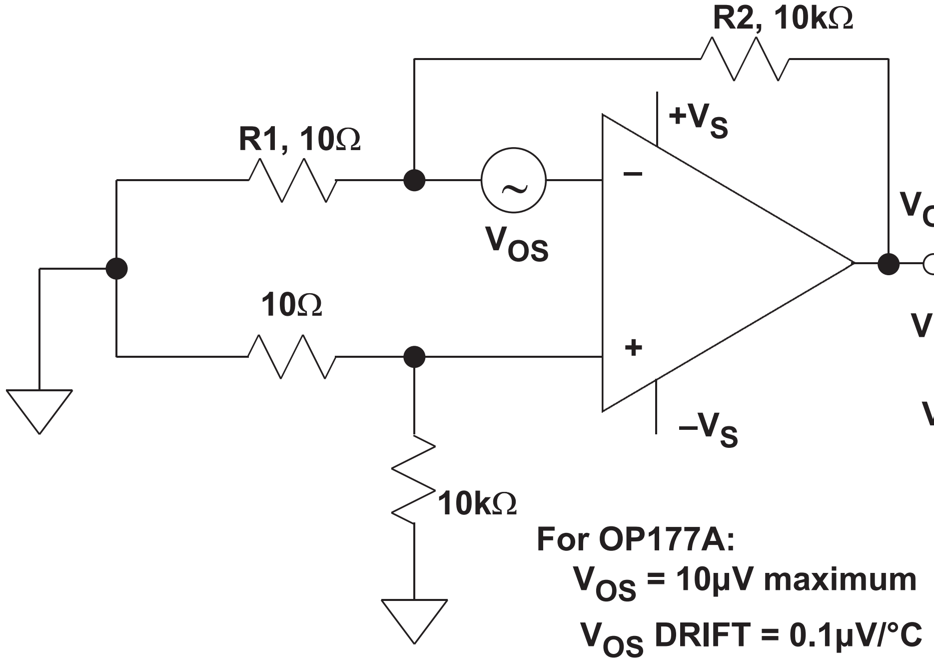
- ±5V Power Supplies Reduce I_B for 0°C to +85°C Operation, P_D = 80mW
- C1 Allows –55°C to +125°C Operation

AMPLIFIERS FOR SIGNAL CONDITIONING

Input Offset Voltage	<100µV
Input Offset Voltage Drift	<1µV/°C
Input Bias Current	<2nA
Input Offset Current	<2nA
DC Open Loop Gain	>1,000,000
Unity Gain Bandwidth Product, f_u	500kHz - 5MHz
Always Check Open Loop Gain at Signal Frequency!	
1/f (0.1Hz to 10Hz) Noise	<1µV p-p
Wideband Noise	<10nV/√Hz
CMR, PSR	>100dB

- Single Supply Operation
- Power Dissipation

MEASURING INPUT OFFSET VOLTAGE



$$V_{OUT} = \left[1 + \frac{R2}{R1}\right] V_{OS}$$

$$V_{OUT} = 1001 \cdot V_{OS}$$

$$V_{OS} = \frac{V_{OUT}}{1001}$$

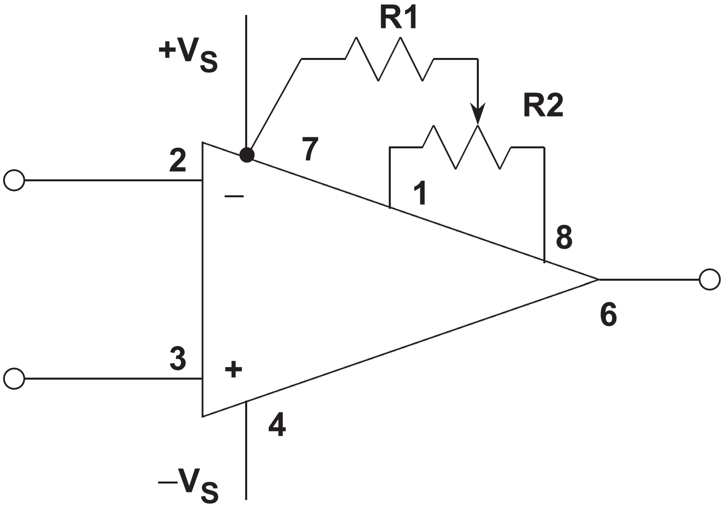
For OP177A:

V_{OS} = 10µV maximum

V_{OS} DRIFT = 0.1µV/°C maximum

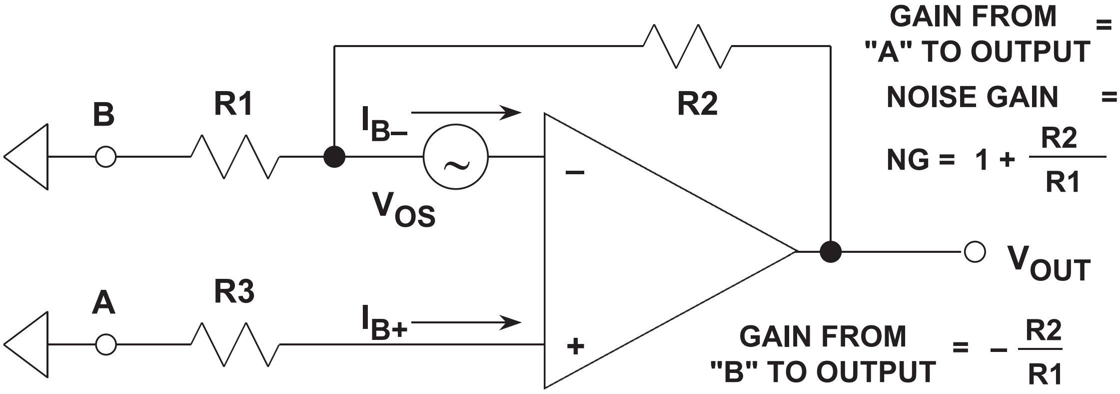
V_{OS} STABILITY = 0.2µV/month typical

OP177/AD707 OFFSET ADJUSTMENT PINS



- R1 = 10kΩ, R2 = 2kΩ , OFFSET ADJUST RANGE = 200µV
- R1 = 0, R1 = 20kΩ , OFFSET ADJUST RANGE = 3mV

OP AMP TOTAL OFFSET VOLTAGE MODEL



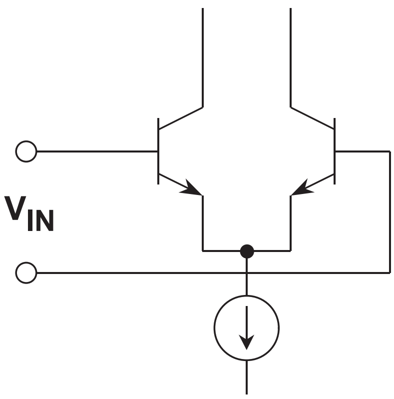
- OFFSET (RTO) $= V_{OS}\left[1 + \frac{R2}{R1}\right] + I_{B+} \cdot R3 \left[1 + \frac{R2}{R1}\right] - I_{B-} \cdot R2$
- OFFSET (RTI) $= V_{OS} + I_{B+} \cdot R3 - I_{B-}\left[\frac{R1 \cdot R2}{R1 + R2}\right]$

FOR BIAS CURRENT CANCELLATION:

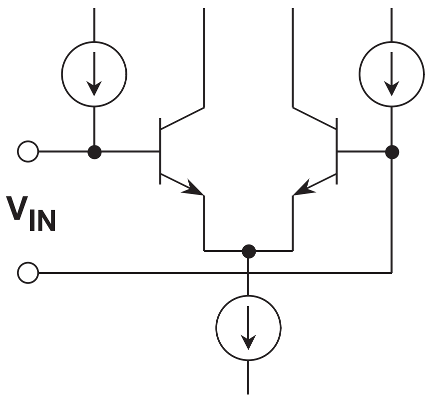
OFFSET (RTI) $= V_{OS}$ IF $I_{B+} = I_{B-}$ AND $R3 = \frac{R1 \cdot R2}{R1 + R2}$

INPUT BIAS CURRENT COMPENSATED OP AMPS

UNCOMPENSATED



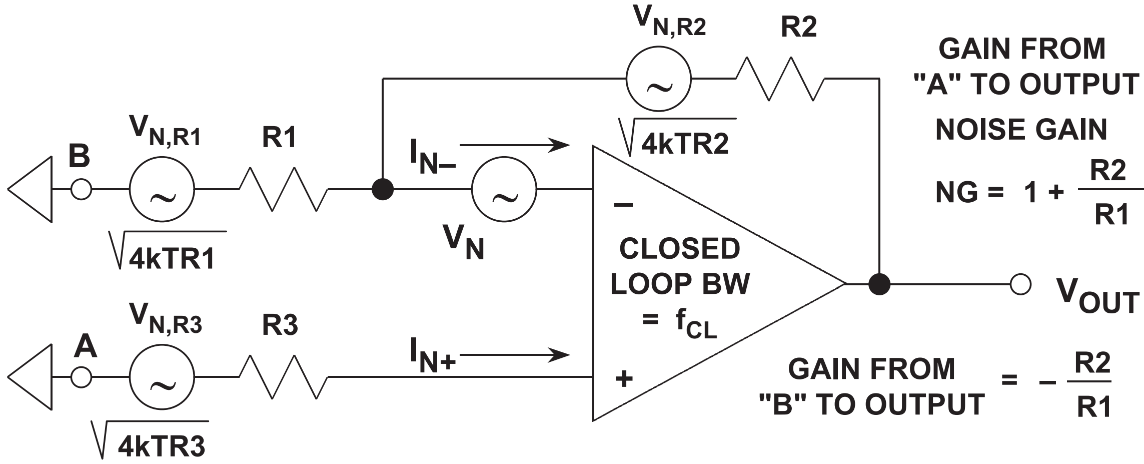
COMPENSATED



- MATCHED BIAS CURRENTS
- SAME SIGN
- 50nA - 10µA
- 50pA - 5nA (Super Beta)
- $I_{OFFSET} << I_{BIAS}$

- LOW, UNMATCHED BIAS CURRENTS
- CAN HAVE DIFFERENT SIGNS
- 0.5nA - 10nA
- HIGHER CURRENT NOISE
- $I_{OFFSET} \approx I_{BIAS}$

OP AMP NOISE MODEL



GAIN FROM "A" TO OUTPUT = NOISE GAIN =

$$NG = 1 + \frac{R2}{R1}$$

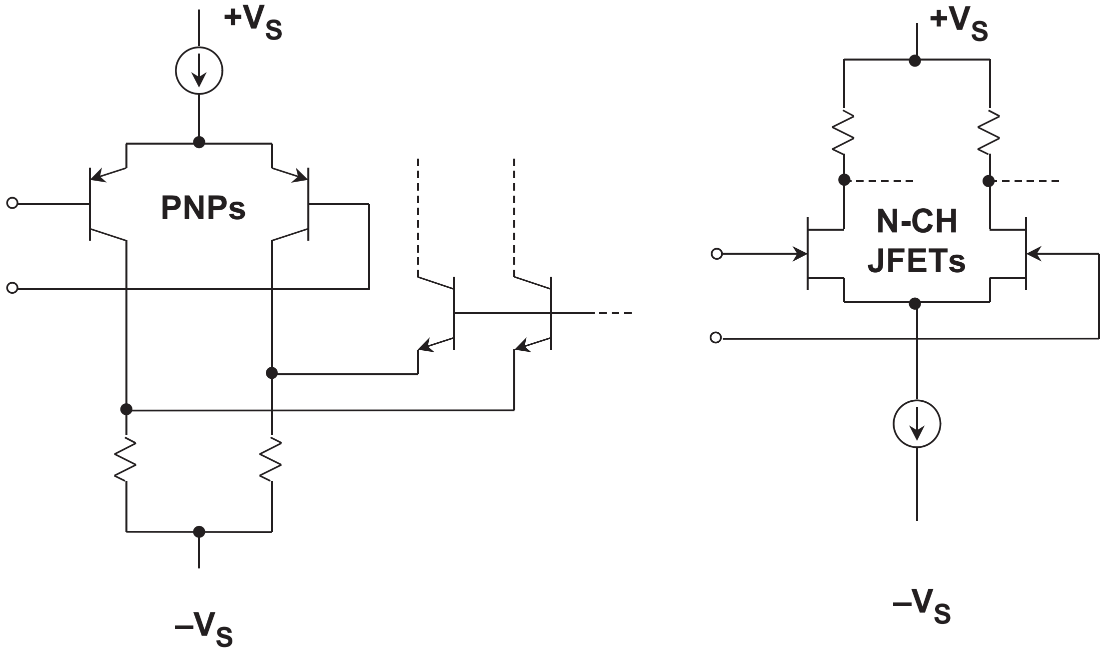
GAIN FROM "B" TO OUTPUT $= -\frac{R2}{R1}$

- RTI NOISE $= \sqrt{BW} \cdot \sqrt{V_N^2 + 4kTR3 + 4kTR1\left[\frac{R2}{R1+R2}\right]^2 + I_{N+}^2R3^2 + I_{N-}^2\left[\frac{R1 \cdot R2}{R1+R2}\right]^2 + 4kTR2\left[\frac{R1}{R1+R2}\right]^2}$
- RTO NOISE = NG • RTI NOISE
- BW = 1.57 f_{CL}

SINGLE SUPPLY AMPLIFIERS

- Single Supply Offers:
  - Lower Power
  - Battery Operated Portable Equipment
  - Requires Only One Voltage
- Design Tradeoffs:
  - Reduced Signal Swing Increases Sensitivity to Errors Caused by Offset Voltage, Bias Current, Finite Open-Loop Gain, Noise, etc.
  - Must Usually Share Noisy Digital Supply
  - Rail-to-Rail Input and Output Needed to Increase Signal Swing
  - Precision Less than the best Dual Supply Op Amps but not Required for All Applications
  - Many Op Amps Specified for Single Supply, but do not have Rail-to-Rail Inputs or Outputs

PNP OR N-CHANNEL JFET STAGES ALLOW INPUT SIGNAL TO GO TO THE NEGATIVE RAIL



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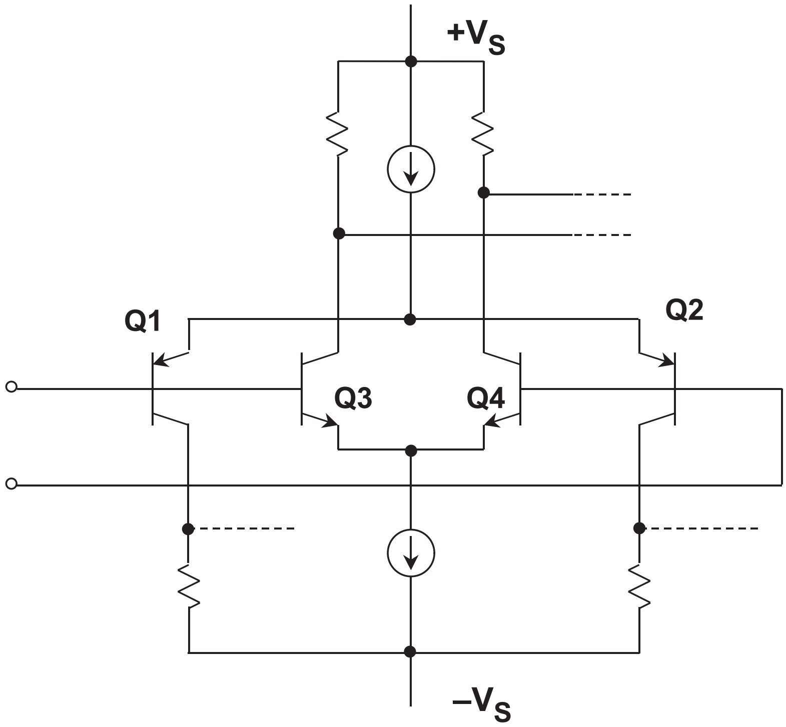
TRUE RAIL-TO-RAIL INPUT STAGE



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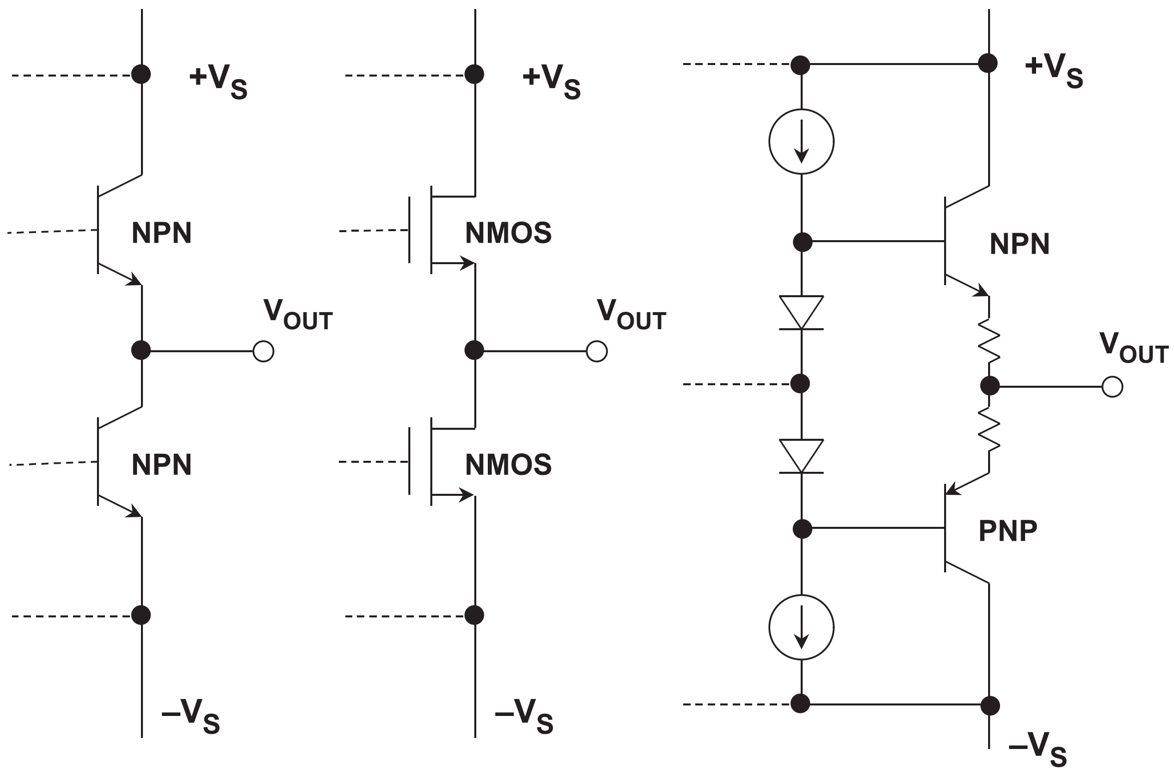
TRADITIONAL OUTPUT STAGES



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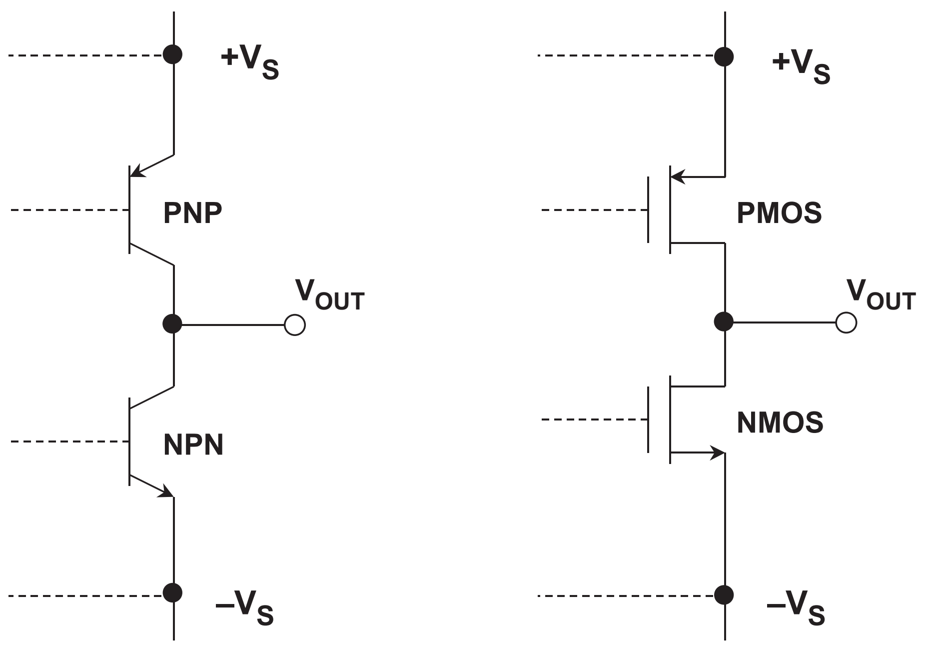
"ALMOST" RAIL-TO-RAIL OUTPUT STRUCTURES



SWINGS LIMITED BY SATURATION VOLTAGE

SWINGS LIMITED BY FET "ON" RESISTANCE

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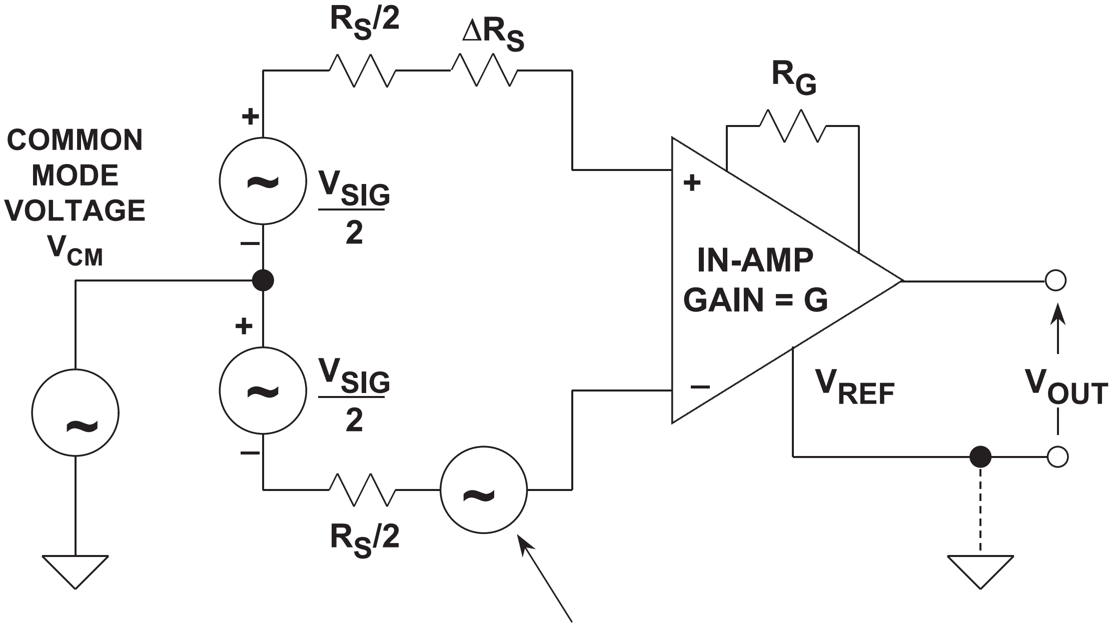
OP AMP PROCESS TECHNOLOGY SUMMARY

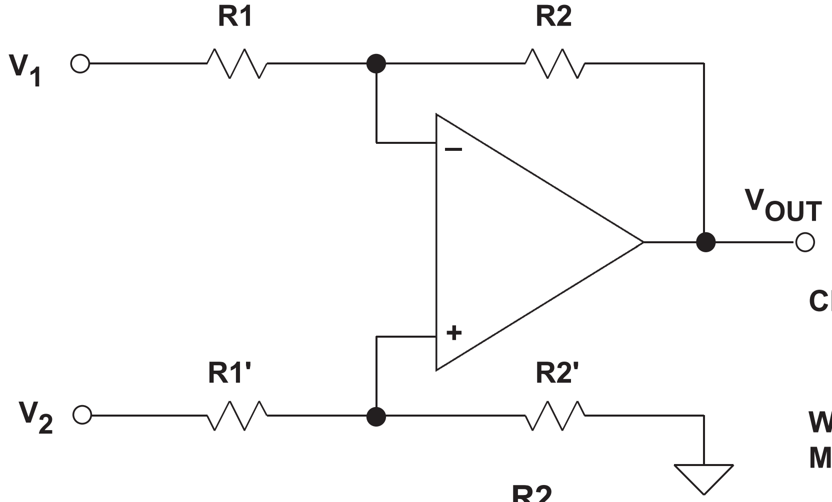
- BIPOLAR (NPN-BASED): This is Where it All Started!!
- COMPLEMENTARY BIPOLAR (CB): Rail-to-Rail, Precision, High Speed
- BIPOLAR + JFET (BiFET): High Input Impedance, High Speed
- COMPLEMENTARY BIPOLAR + JFET (CBFET): High Input Impedance, Rail-to-Rail Output, High Speed
- COMPLEMENTARY MOSFET (CMOS): Low Cost, Non-Critical Op Amps
- BIPOLAR + CMOS (BiCMOS): Bipolar Input Stage adds Linearity, Low Power, Rail-to-Rail Output
- COMPLEMENTARY BIPOLAR + CMOS (CBCMOS): Rail-to-Rail Inputs, Rail-to-Rail Outputs, Good Linearity, Low Power

INSTRUMENTATION AMPLIFIER



COMMON MODE ERROR (RTI) = $\frac{V_{CM}}{CMRR}$

OP AMP SUBTRACTOR



$$CMR = 20 \log_{10}\left[\frac{1+\frac{R2}{R1}}{Kr}\right]$$

Where Kr = Total Fractional Mismatch of R1 - R2

- $V_{OUT} = (V_2 - V_1)\,\frac{R2}{R1}$
- $\frac{R2}{R1} = \frac{R2'}{R1'}$ CRITICAL FOR HIGH CMR
- EXTREMELY SENSITIVE TO SOURCE IMPEDANCE IMBALANCE
- 0.1% TOTAL MISMATCH YIELDS $\approx$ 66dB CMR FOR R1 = R2

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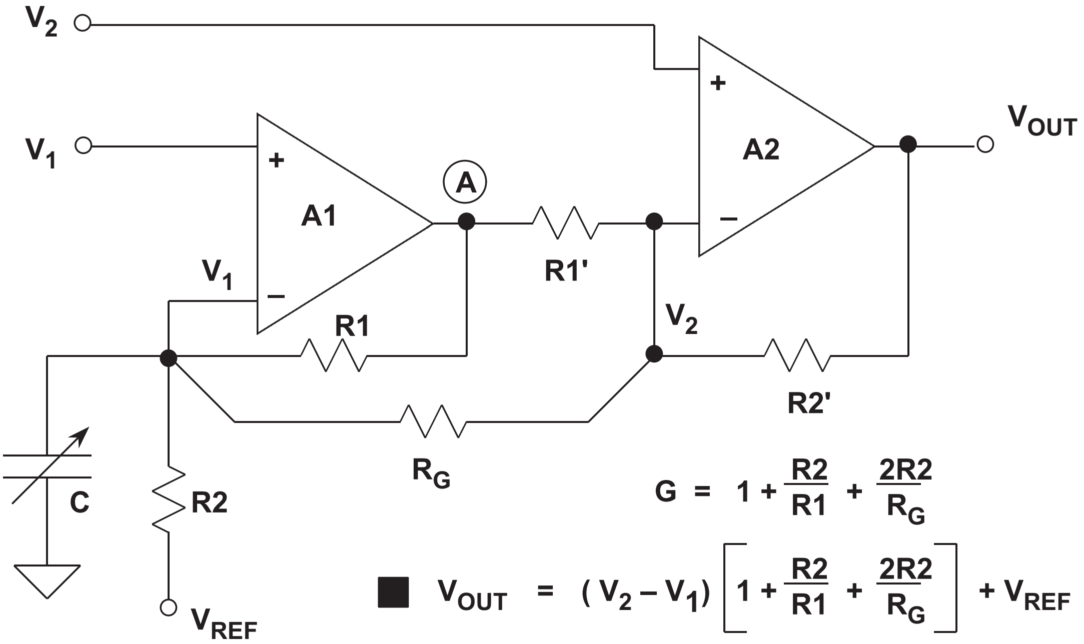
TWO OP AMP INSTRUMENTATION AMPLIFIER



$$G = 1 + \frac{R2}{R1} + \frac{2R2}{R_G}$$

- $V_{OUT} = (V_2 - V_1)\left[1 + \frac{R2}{R1} + \frac{2R2}{R_G}\right] + V_{REF}$
- $\frac{R2}{R1} = \frac{R2'}{R1'}$
- $CMR \leq 20\log\left[\frac{GAIN \times 100}{\%\ MISMATCH}\right]$

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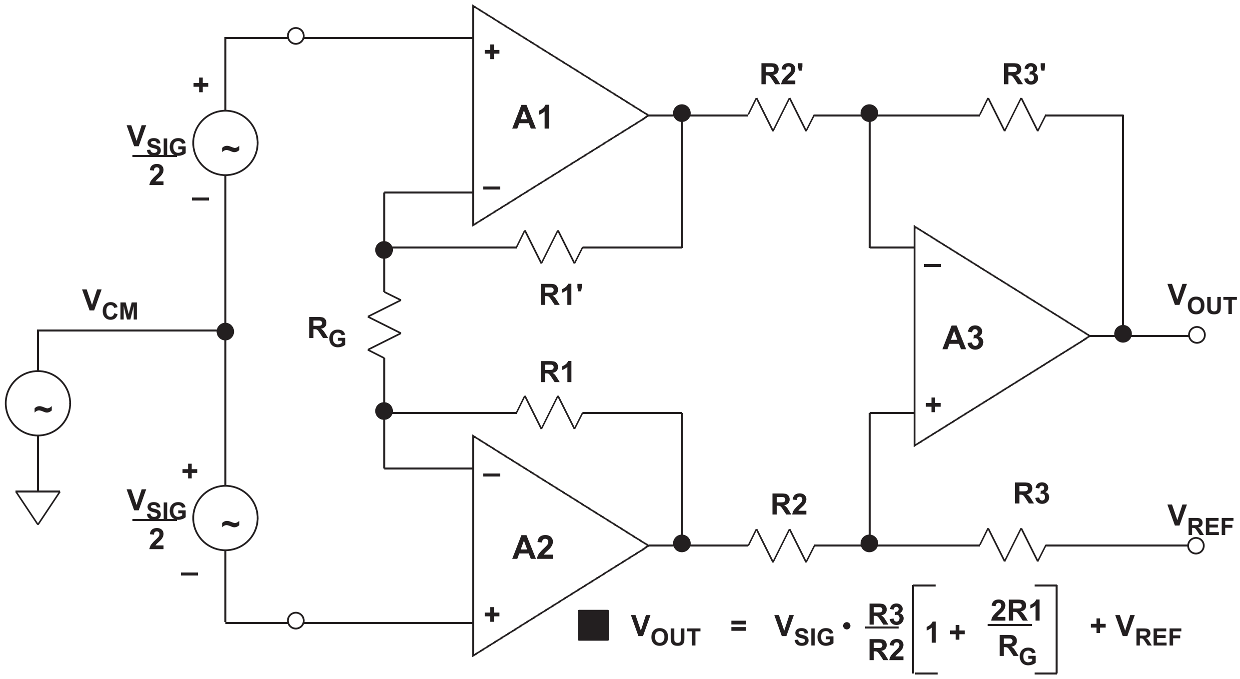
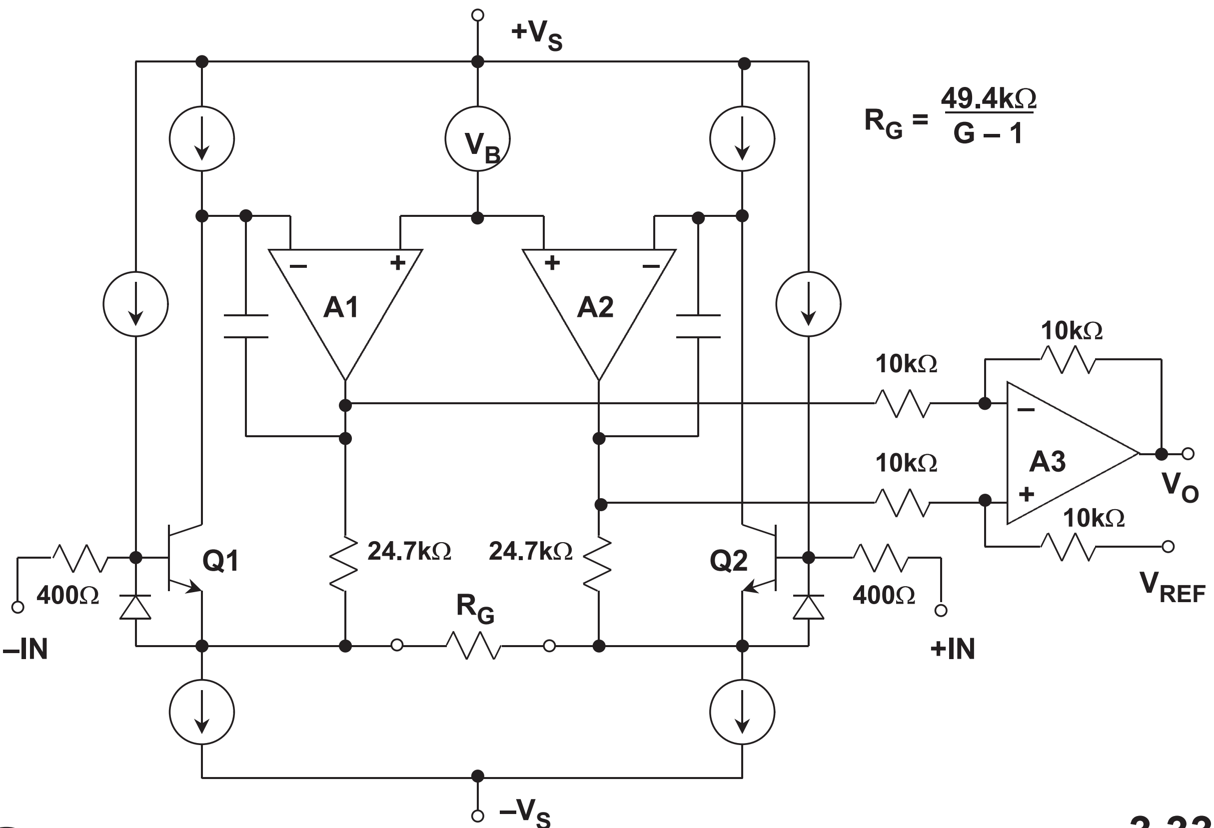
THREE OP AMP INSTRUMENTATION AMPLIFIER



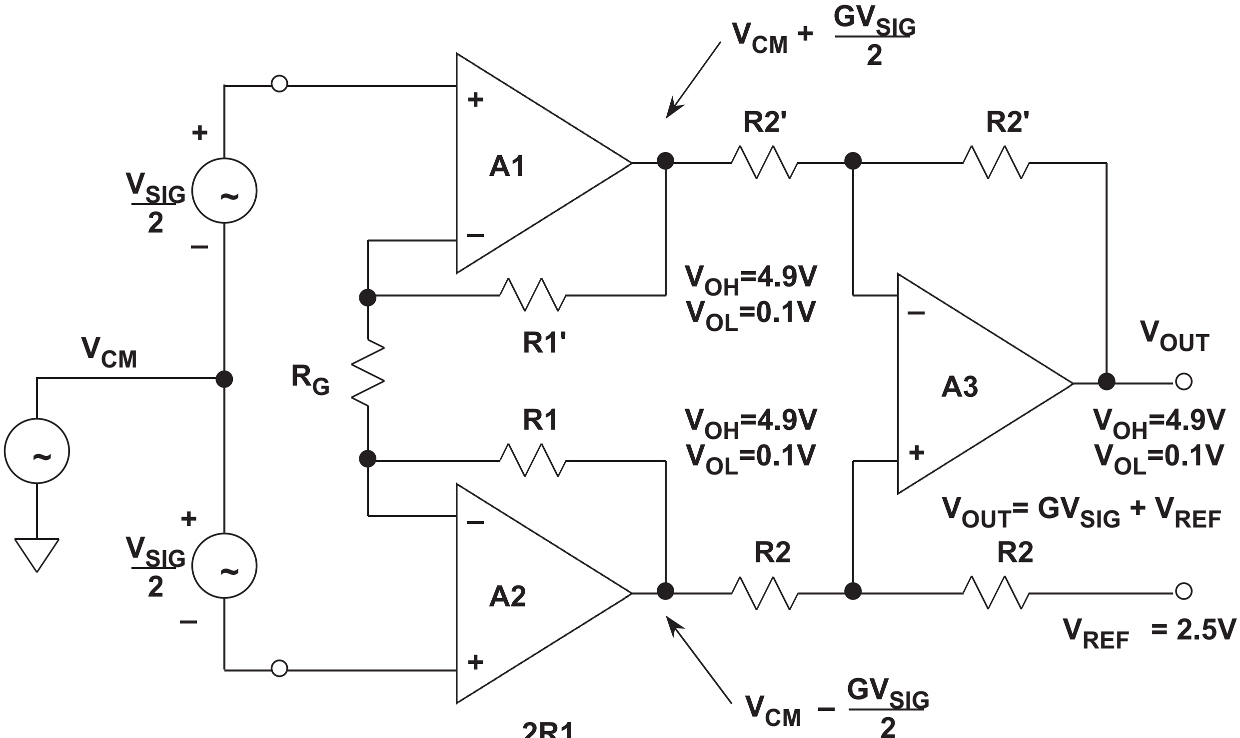
- $V_{OUT} = V_{SIG} \cdot \frac{R3}{R2}\left[1 + \frac{2R1}{R_G}\right] + V_{REF}$
- $CMR \leq 20\log\left[\frac{GAIN \times 100}{\%\ MISMATCH}\right]$
- IF R2 = R3, $G = 1 + \frac{2R1}{R_G}$

AD620 IN-AMP SIMPLIFIED SCHEMATIC



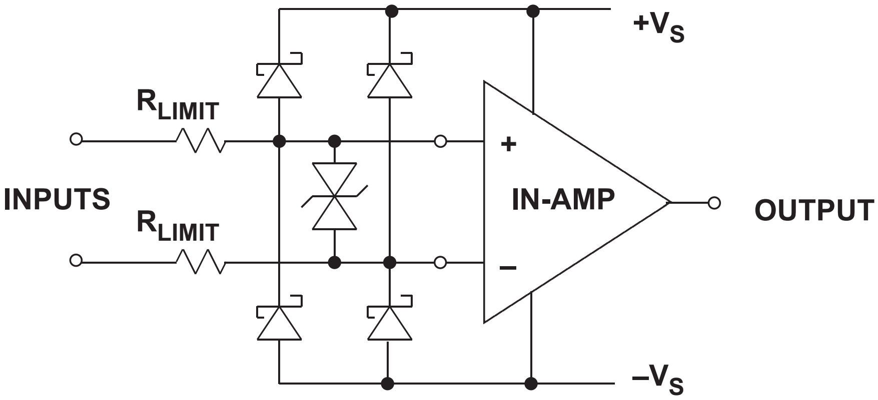
$R_G = \frac{49.4k\Omega}{G - 1}$

THREE OP AMP IN-AMP
SINGLE +5V SUPPLY RESTRICTIONS



$$G = 1 + \frac{2R1}{R_G}$$

INSTRUMENTATION AMPLIFIER
INPUT OVERVOLTAGE CONSIDERATIONS

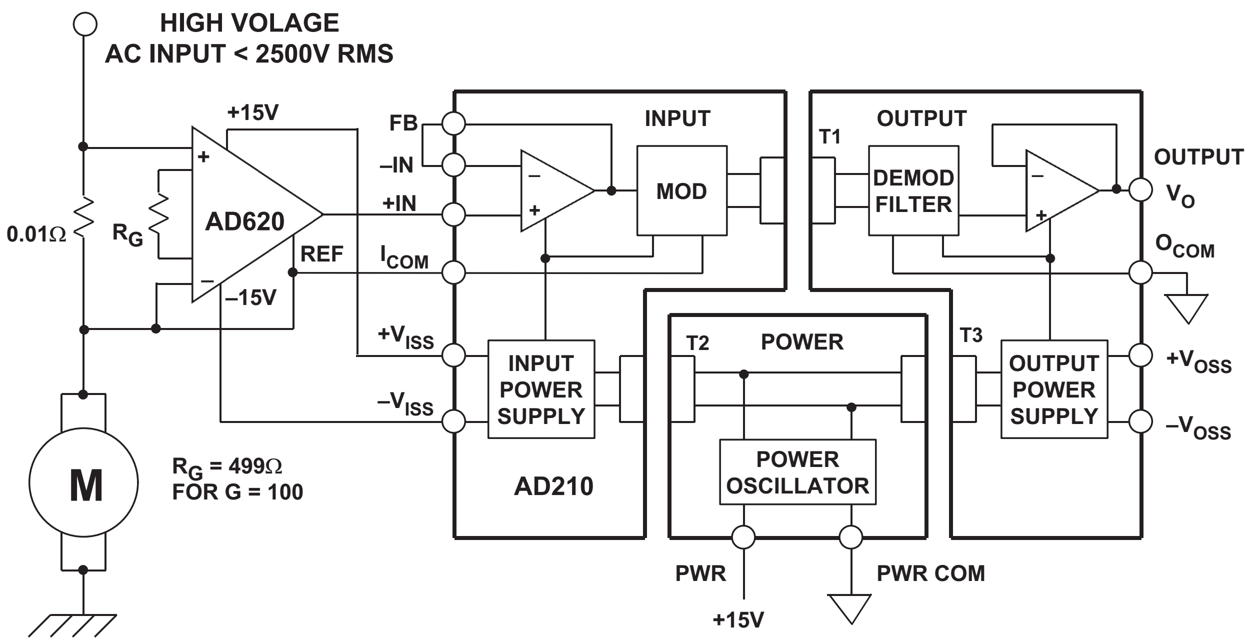


- Always Observe Absolute Maximum Data Sheet Specs!
- Schottky Diode Clamps to the Supply Rails Will Limit Input to Approximately $\pm V_S$ ±0.3V, TVSs Limit Differential Voltage
- External Resistors (or Internal Thin-Film Resistors) Can Limit Input Current, but will Increase Noise
- Some In-Amps Have Series-Protection Input FETs for Lower Noise and Higher Input Over-Voltages (up to ±60V, Depending on Device)

APPLICATIONS FOR ISOLATION AMPLIFIERS

- Sensor is at a High Potential Relative to Other Circuitry (or may become so under Fault Conditions)
- Sensor May Not Carry Dangerous Voltages, Irrespective of Faults in Other Circuitry (e.g. Patient Monitoring and Intrinsically Safe Equipment for use with Explosive Gases)
- To Break Ground Loops

MOTOR CONTROL CURRENT SENSING



KAYNAKLAR

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