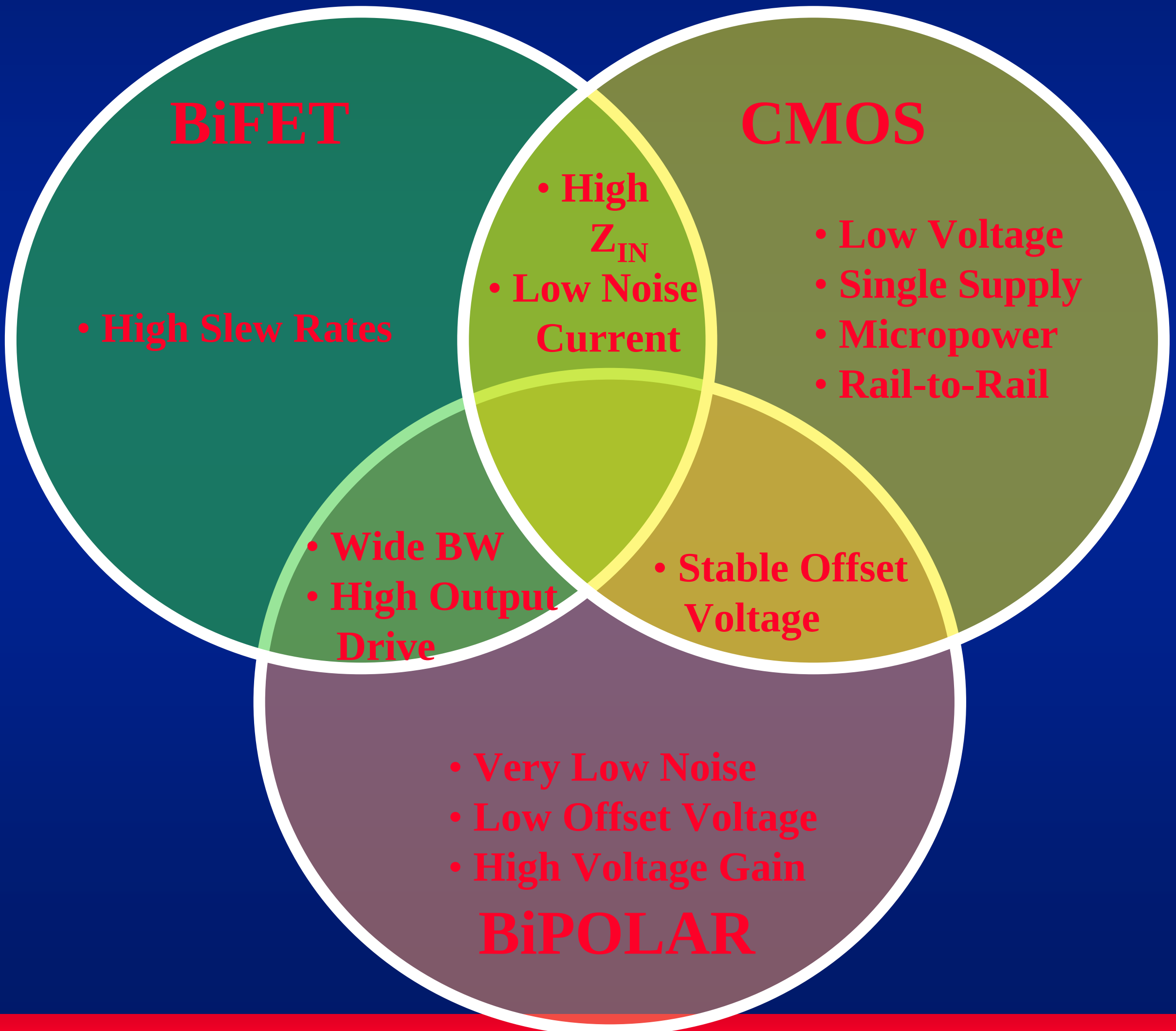
Mechatronics WIB
OP Amp

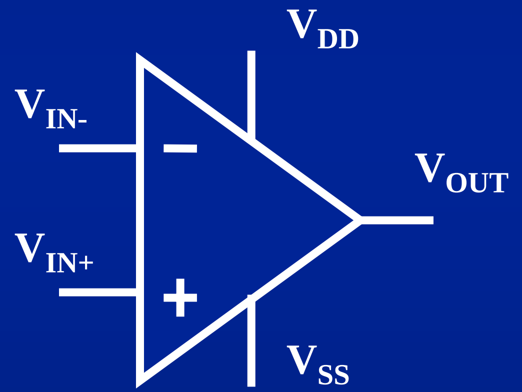
Low Power Options
Process Tradeoffs



Ideal Op Amp Specs

POWER SUPPLY
- No min or max Voltage
- I_{SUPPLY} = 0 Amps
- Power Supply Rejection = ∞

INPUT
- Input Current (I_B) = 0
- Input Impedance (Z_{IN}) = ∞
- Input Voltage (V_{IN}) → no limits
- Zero Noise
- Zero DC error
- Common-Mode Rejection = ∞

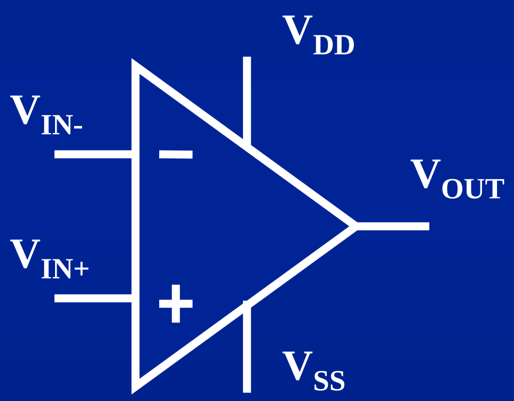


OUTPUT
- V_{OUT} = V_{SS} to V_{DD}
- I_{OUT} = ∞
- Slew Rate = ∞

SIGNAL TRANSFER
- Open Loop Gain = ∞
- Bandwidth = 0 → ∞
- Zero Harmonic Distortion

$0.00

Non-Ideal DC Op Amp Model



POWER SUPPLY

- **Limited by IC Process**
- **I_{SUPPLY} : Standard → mAs per op amp**
  Low Power →100s of uAs per op amp
  Micropower →10s of uA per op amp
- **Power Supply Rejection : typical spec 100uV/V**

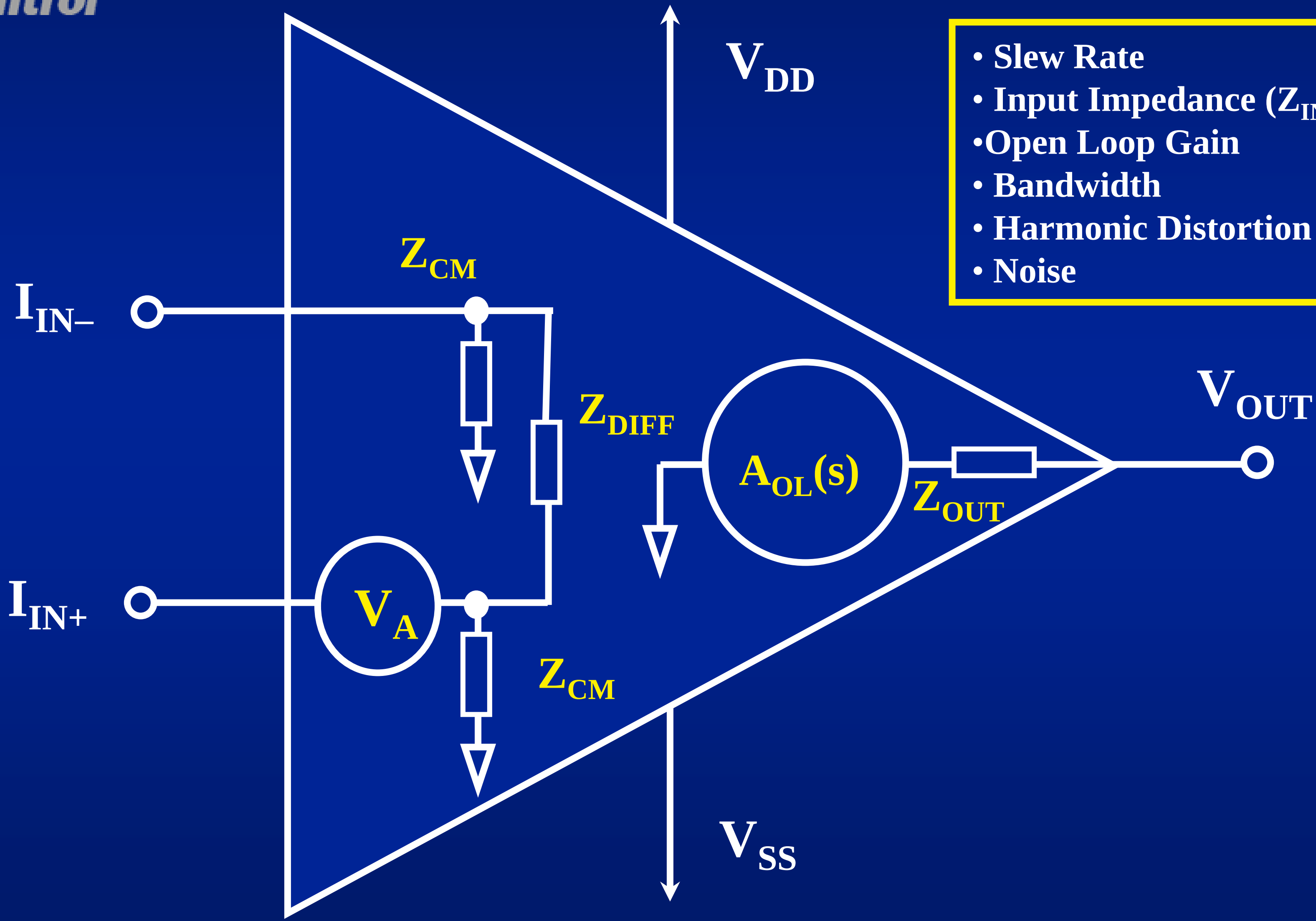
INPUT

- **Input Current (I_B)**
  □→ nA for BiPolar
  □→ pA for CMOS
- **Input Voltage (V_{IN}) → Supply Limited**
- **Significant Offset Error**
- **Common-Mode Rejection : typical spec 75dB**

OUTPUT

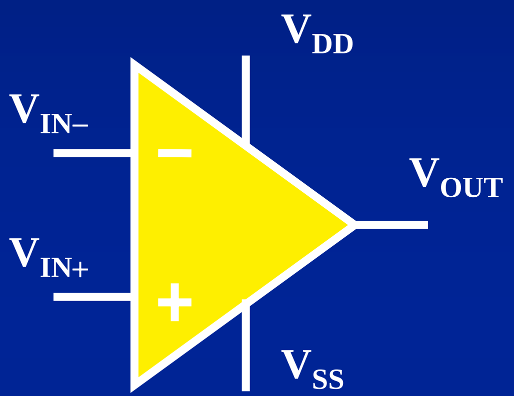
- **V_{OUT} = V_{SS} to V_{DD}**
- **I_{OUT}: limited by thermal properties of package**

Non-Ideal AC Op Amp Model



- Slew Rate
- Input Impedance (Z_{IN})
- Open Loop Gain
- Bandwidth
- Harmonic Distortion
- Noise

Specifications
DC and AC



DC

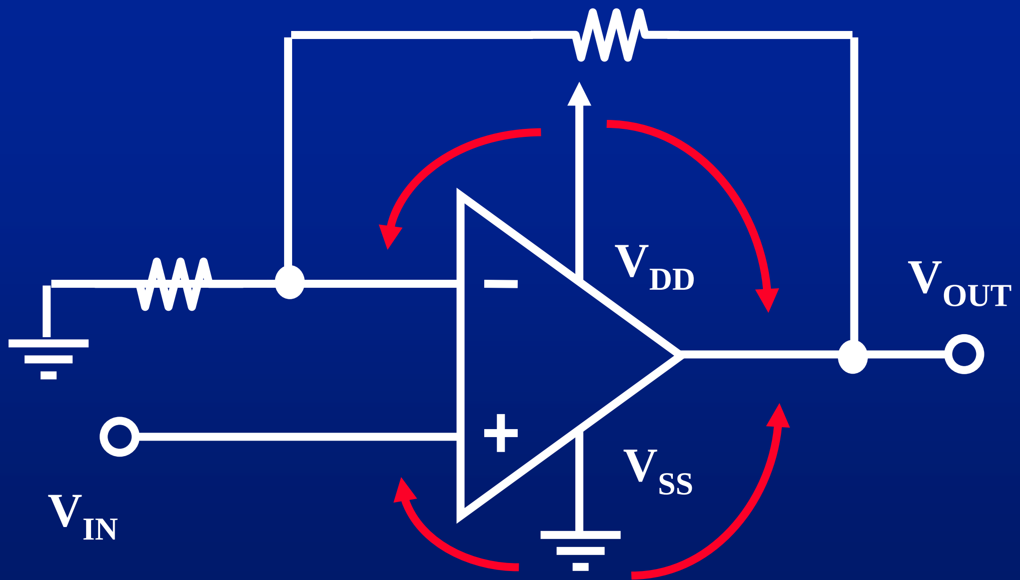
Input Offset Voltage
Input Bias Current
Input Voltage Swing
Open Loop Gain
Power Supply Rejection
Common-mode Rejection
Output Voltage Swing
Power Supply Current and Voltage
Operating rating
Absolute Maximum rating

AC

Gain Bandwidth Product (GBWP)
Slew Rate (SR)
Settling Time
Input Voltage Noise
Input Current Noise

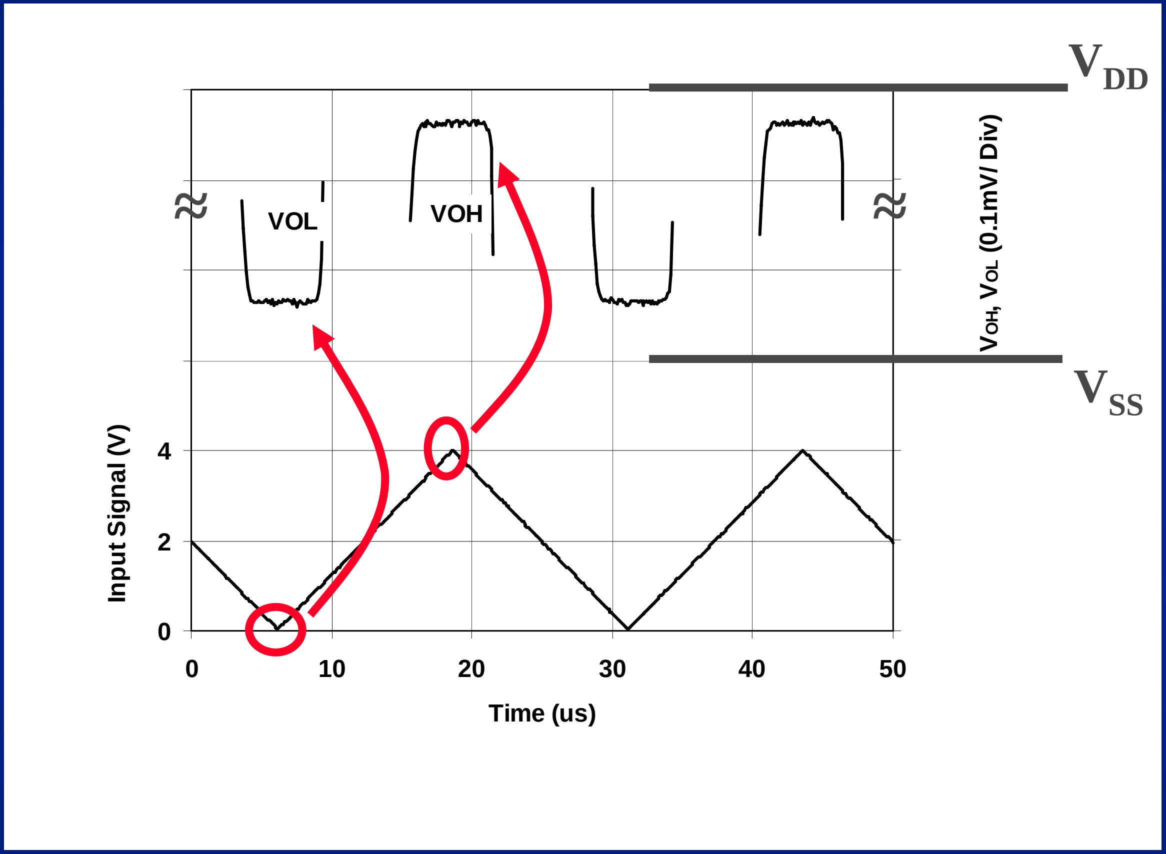
DC Specifications
Power Supply Voltage

- Limits Input and Output Swing Range
- Typical Amplifier Single Supply Ranges
  - V_{DD} = 2.7V to 5.5V
  - V_{DD} = 2.5V to 5.5V
  - V_{DD} = 1.8V to 5.5V



DC Specifications
Output Swing Limitations

- Open Loop Gain Spec
  - DC test
  - Linear region
- V_{OH}, V_{OL} Spec
  - DC test
  - Output is Over Driven

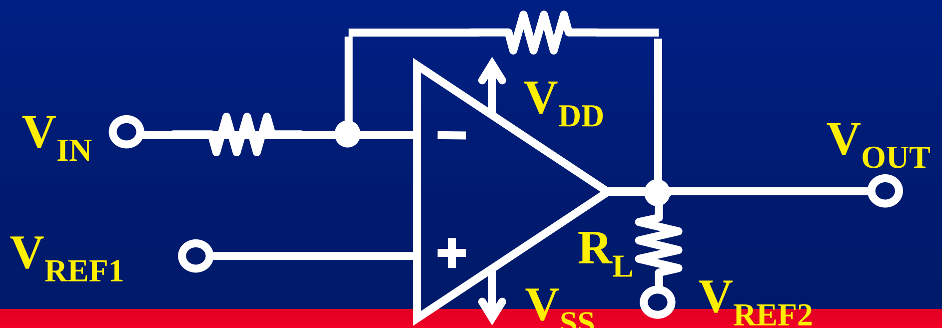


G = +2V/V,
Input Frequency = 40kHz

DC Specifications

About Output Swing and Drive

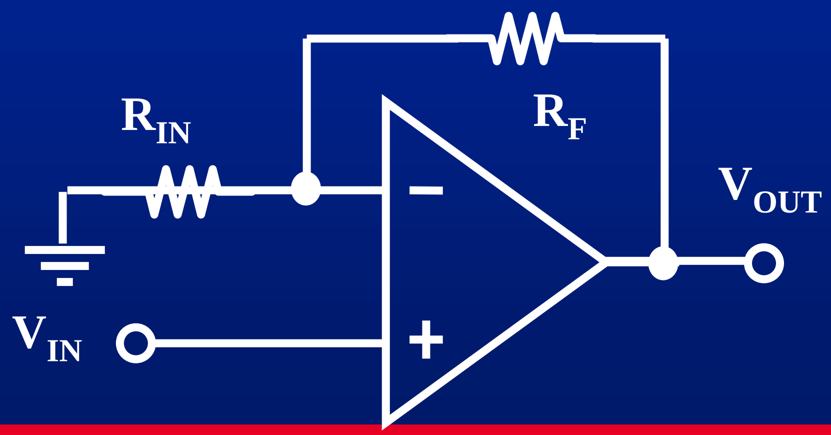
Output Voltage Swing	Test Conditions		Measured Output Swing above V_{SS} (mV)	Measured Output Swing below V_{DD} (mV)
	Load Conditions, R_L	V_{REF2}		
High, to V_{DD}	10kΩ	$(V_{DD} - V_{SS})/2 + V_{SS}$	-	11.2
High, to V_{DD}	10kΩ	V_{SS}	-	20.4
High, to V_{DD}	10kΩ	V_{DD}	-	1.95
High, to V_{DD}	100µA Source	-	-	3.8
Low, to V_{SS}	10kΩ	$(V_{DD}-V_{SS})/2 + V_{SS}$	11.6	-
Low, to V_{SS}	10kΩ	V_{SS}	3.7	-
Low, to V_{SS}	10kΩ	V_{DD}	25.5	-
Low, to V_{SS}	100µA Sink	-	8.1	-



Rail-to-Rail Output Amplifier

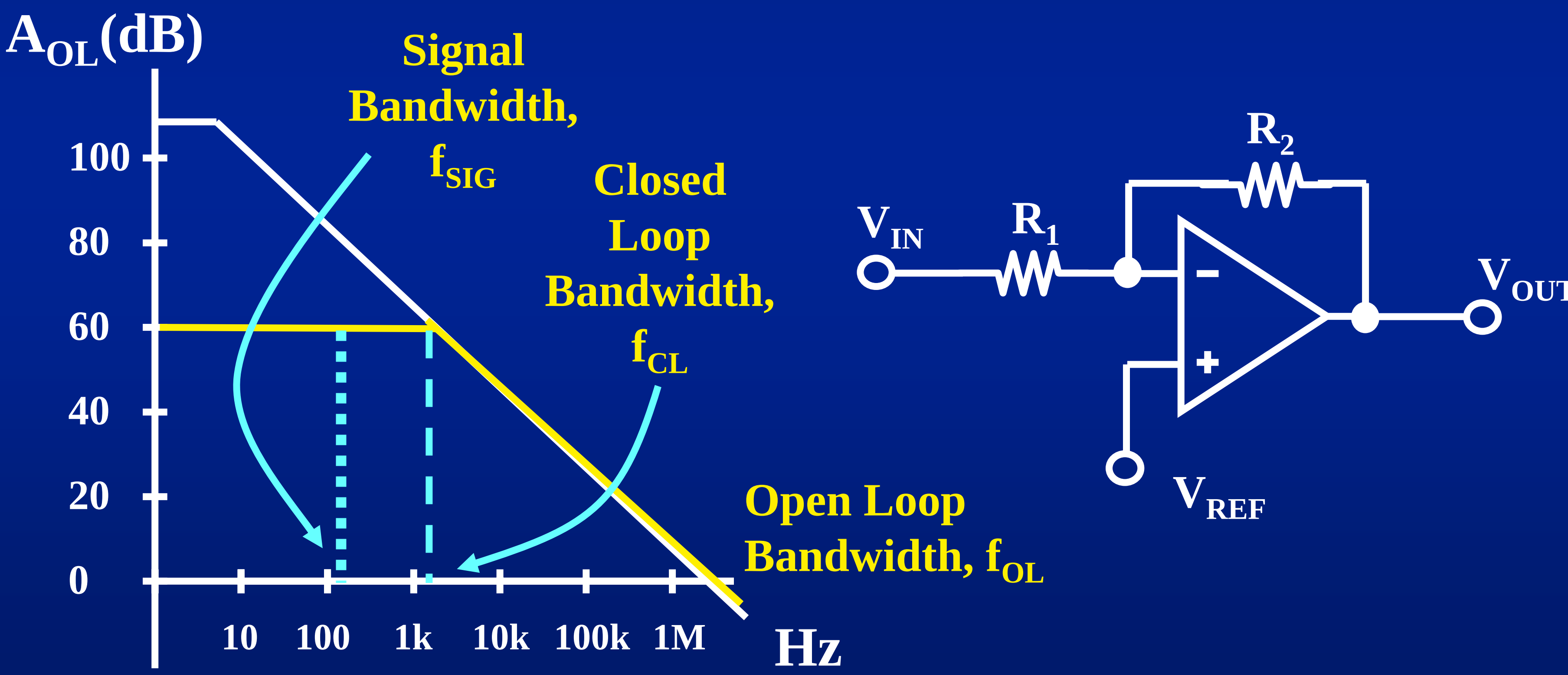
DC Specifications
Input swing

- Input swing Dependant on Type of Transistors at the Input of Op Amp
- Typical Input Limits from Positive Rail
  - $V_{DD} - 2.3$
  - V_{DD}
- Typical Input Range Limits from Negative Rail
  - $V_{SS} - 0.3V$
  - V_{SS}



Closed Loop versus Open Loop Gain

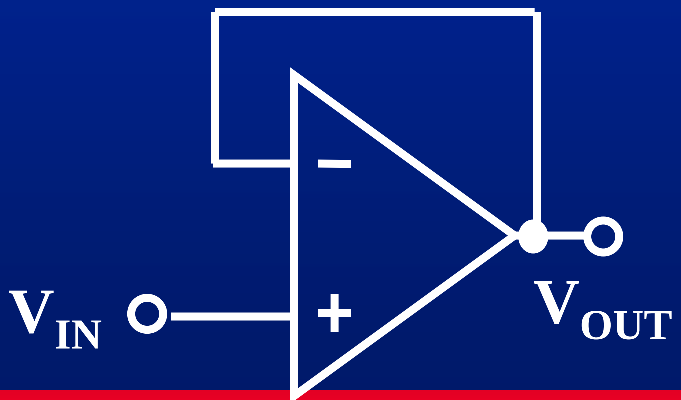
- Close Loop f_{CL} > 10x Signal Bandwidth, f_{SIG}
- The f_{OL} of Op Amp is Usually Higher than f_{CL}

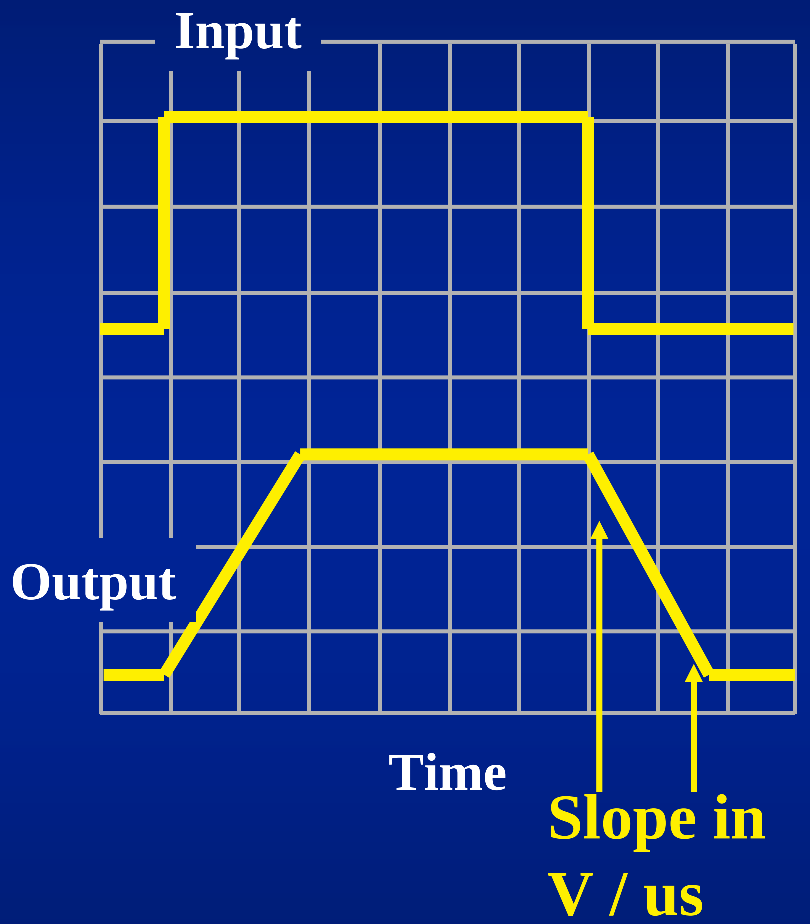


AC Specifications
Slew Rate

- Ability of Amplifier to “keep up” with Fast Input Signals
- Defined Between 10% to 90% of Output Swing in V/us
- Maximum rate of change of output voltage per unit time
- Expressed in V/uS
- Basically say how fast the out can follow input signal

$V_{OUT} = V_{IN}$

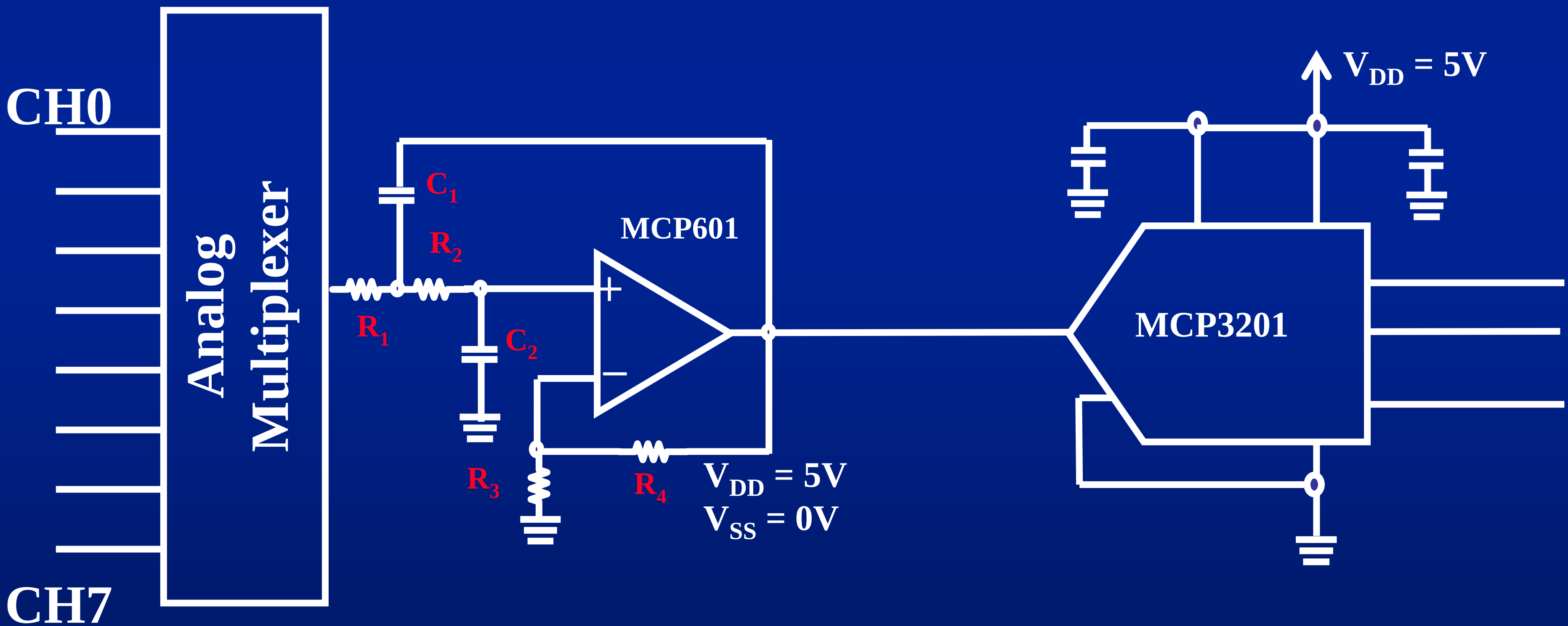




SR = ΔVout/Δt

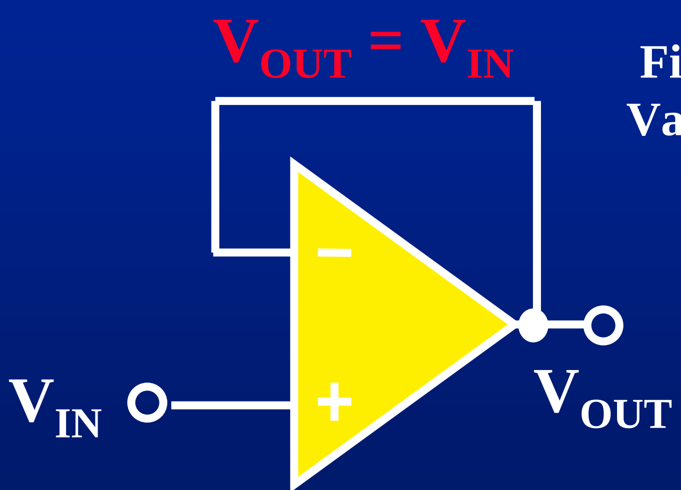
Critical Application
Slew Rate

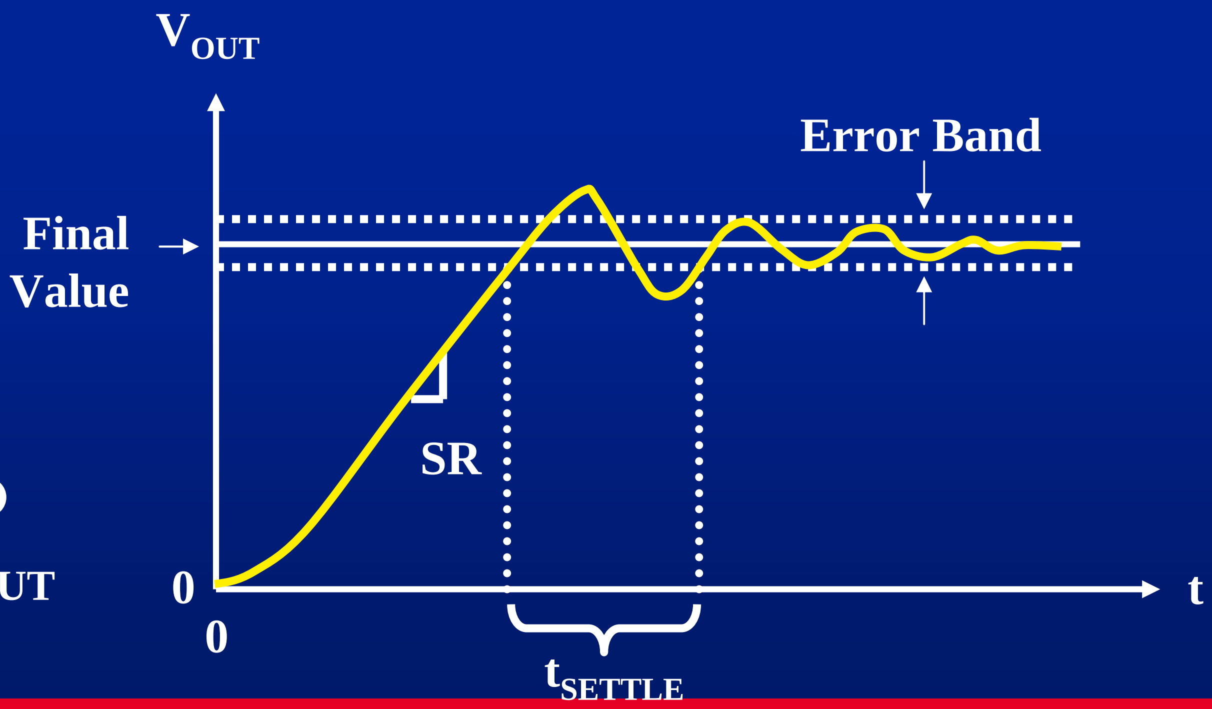
- The Amplifier's Ability to go from Zero to Full-Scale can Limit the Sampling Speed of the A/D Converter



AC Specs
Settling Time

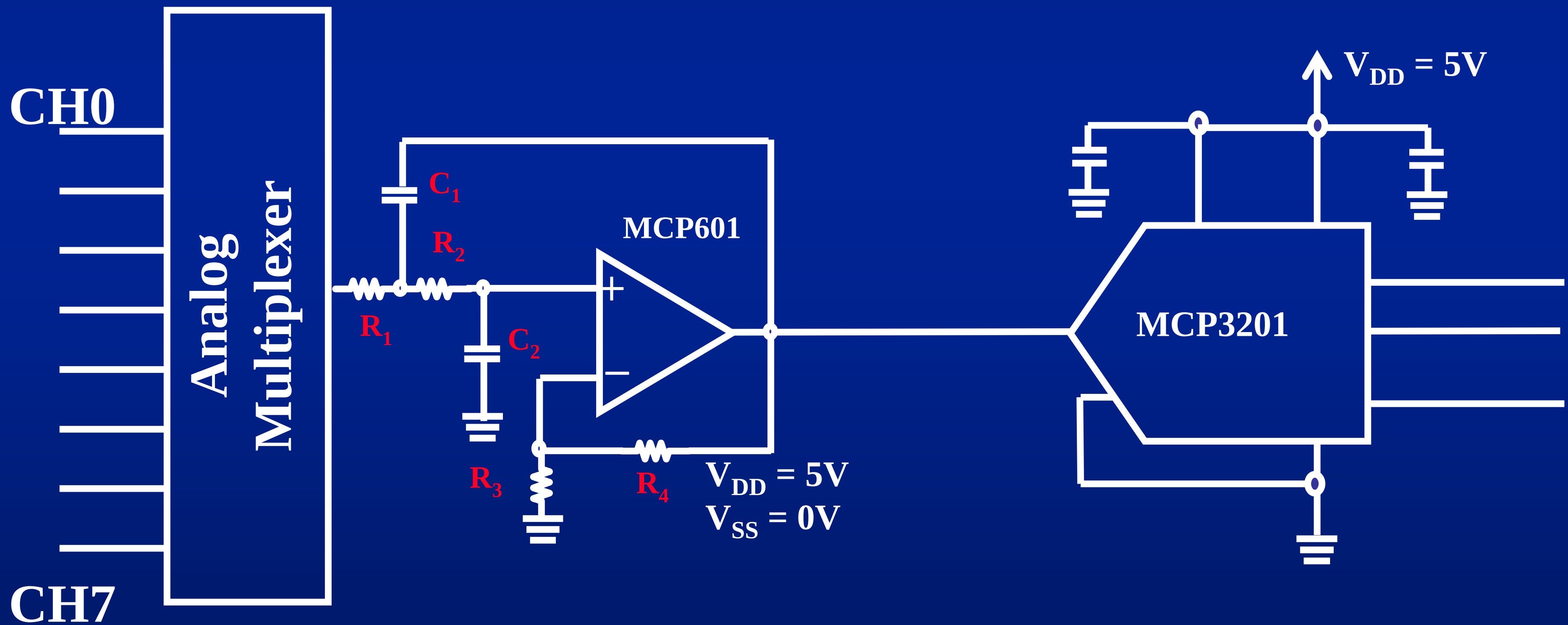
- Amount of Time Amplifier Requires to “Settle” within a Specified Error Band. The input of the amplifier is driven with a large signal square wave.
- MCP60x = 8us to 0.01%





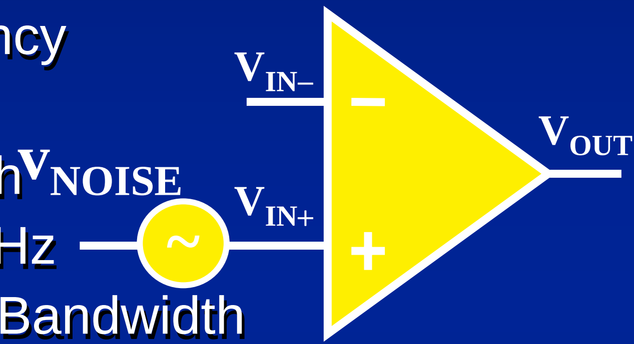
Settling Time

- The Amount of Time it Takes the Op Amp to Settle can Limit the Sampling Speed of the A/D Converter



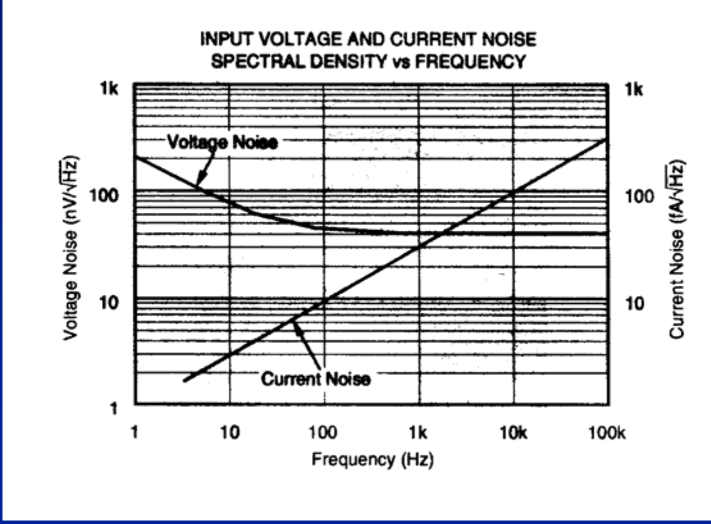
AC Specs
Noise

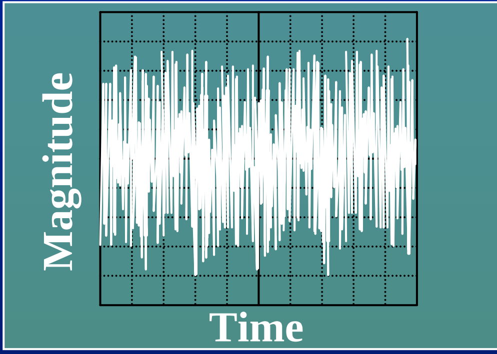
- Amplifier Specifications for Noise
  - Voltage Noise :
    - nV / rt Hz at a Specific Frequency
      - ie, 22nV / rt Hz at 1kHz
    - rms over a Specified Bandwidth
      - ie, 2uV rms 100Hz to 10kHz
    - peak-to-peak over a Specified Bandwidth
      - ie, 1.3uV p-p 0.1Hz to 10Hz
  - Current Noise :
    - Similar Specifications but in Amperes
      - pA / rt Hz at Specified Frequency; ie,15pA / rt Hz at 1kHz
- Always Referred Input of the Amplifier (RTI)
- CMOS and BiFet Amp. have lower Current Noise
- Bipolar Amplifiers have lower Voltage Noise



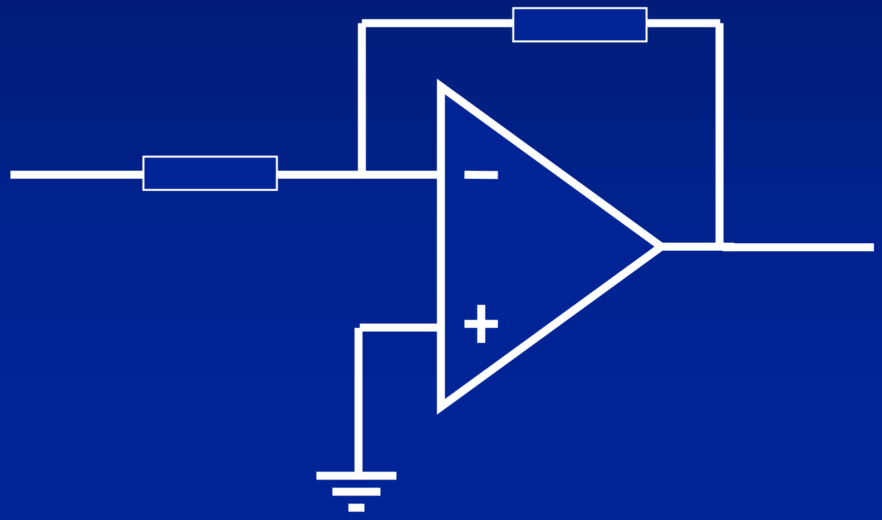
Specifications and Calculations

- Units of Measure
  - nV/ $\sqrt{Hz}$ == spot noise taken over a 1Hz Bandwidth
  - rms == $\sqrt{v_1^2 + v_2^2 + v_3^2 + \ldots + v_n^2}$
- Probability Specifications
  - Peak-to- Peak (p-p)
    - == Calculated from several thousand samples
    - == rms noise * 2 * crest factor
  - Noise Free == also know as p-p
  - Crest Factor ==
    - Probability factor of occurring inside a specified limit
    - Industry uses a crest factor of 3.3 to project that 99.9% of all samples will be within specified limits





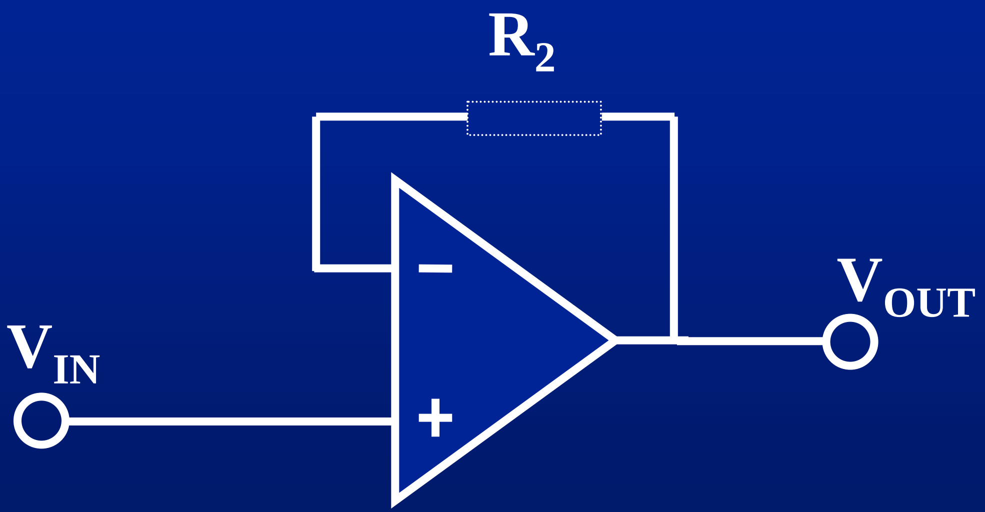
Dual Supply vs Single: Critical Specs



- Dual Supply
  - **Power Consumption**
  - **Good SNR**
  - **Wider Bandwidths**
- Single Supply
  - **Power supply**
  - **Voltage Output Swing**
  - **Voltage Input Range**
  - **Offset Voltage**
  - **Noise**

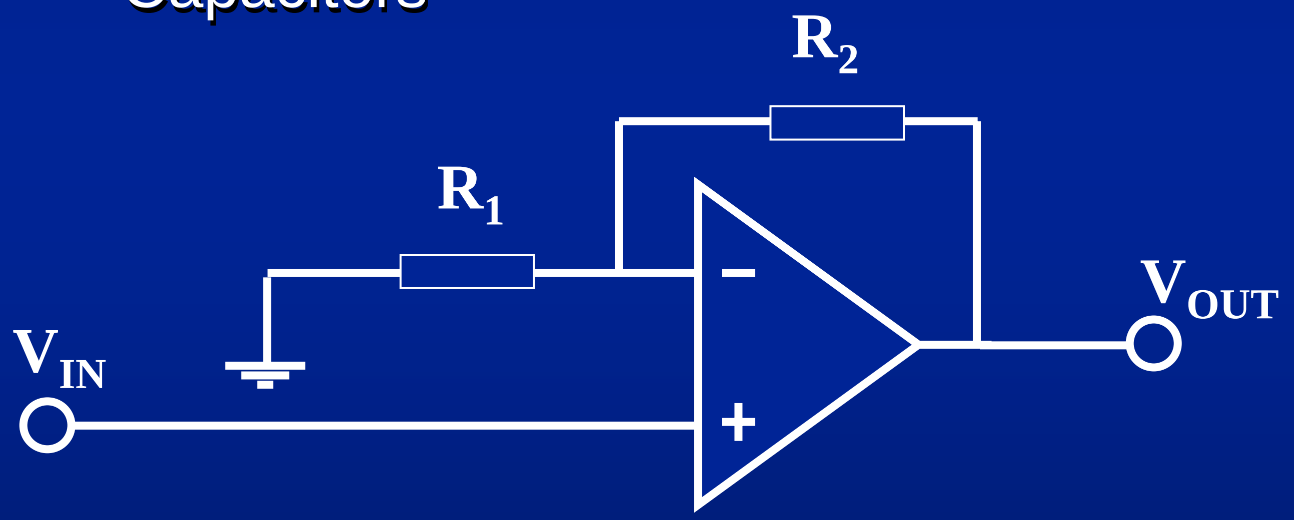
Voltage Follower (or Buffer)

- Buffer Amplifier
  - $V_{OUT} / V_{IN} = +1V/V$
  - Can not implement a filter with this configuration
- Challenging to Use in Single Supply Circuits
  - Input Swing
  - Output Swing



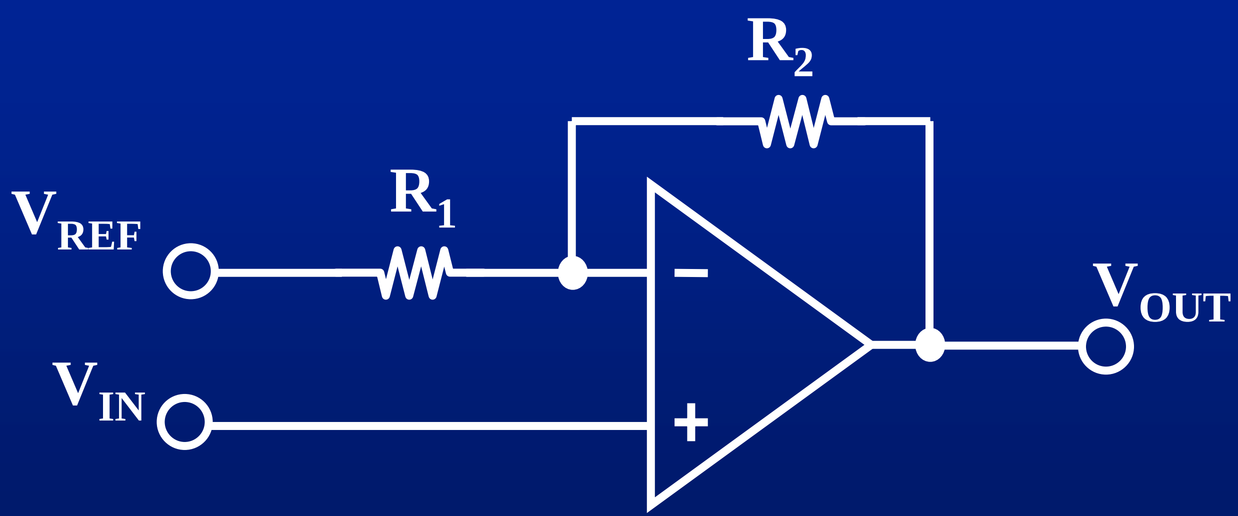
Non-Inverting Gain

- $V_{OUT} / V_{IN} = 1 + R_2 / R_1$
- Easy to use in Single Supply Environments
- Filter can be Implemented with Additional Capacitors



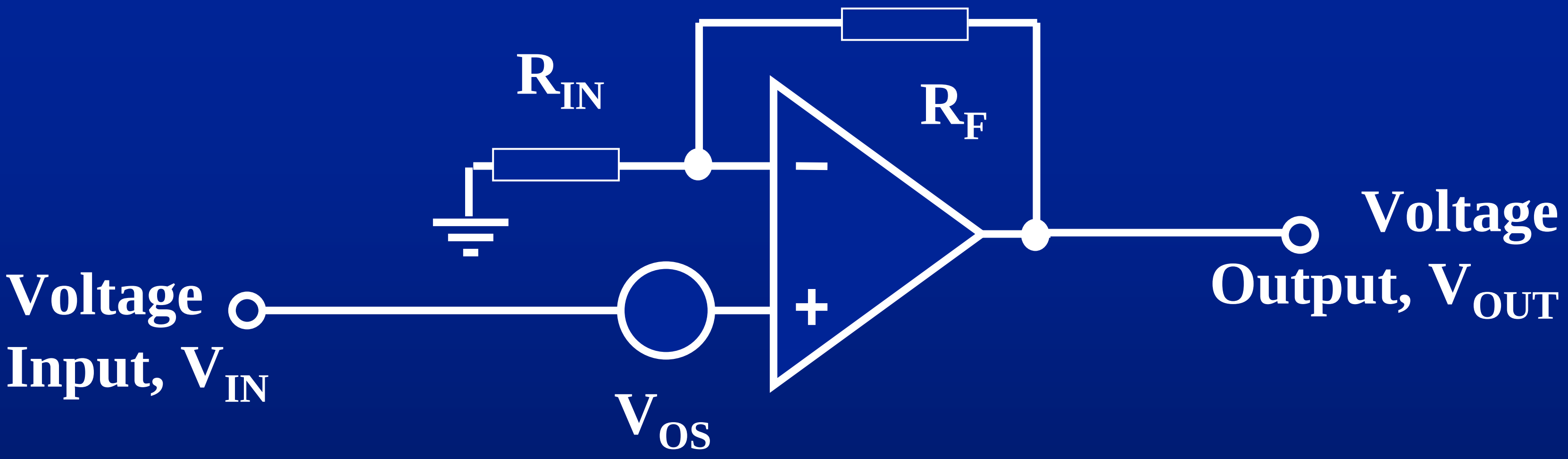
Non-Inverting Amp
Adding the Reference

- Single Supply Environments Require V_{REF}
- V_{REF} is
  - Negated
  - Gained
- $V_{OUT} = V_{IN} (1 + R_2 / R_1) - V_{REF} (R_2 / R_1)$



Critical Application for Single Supply

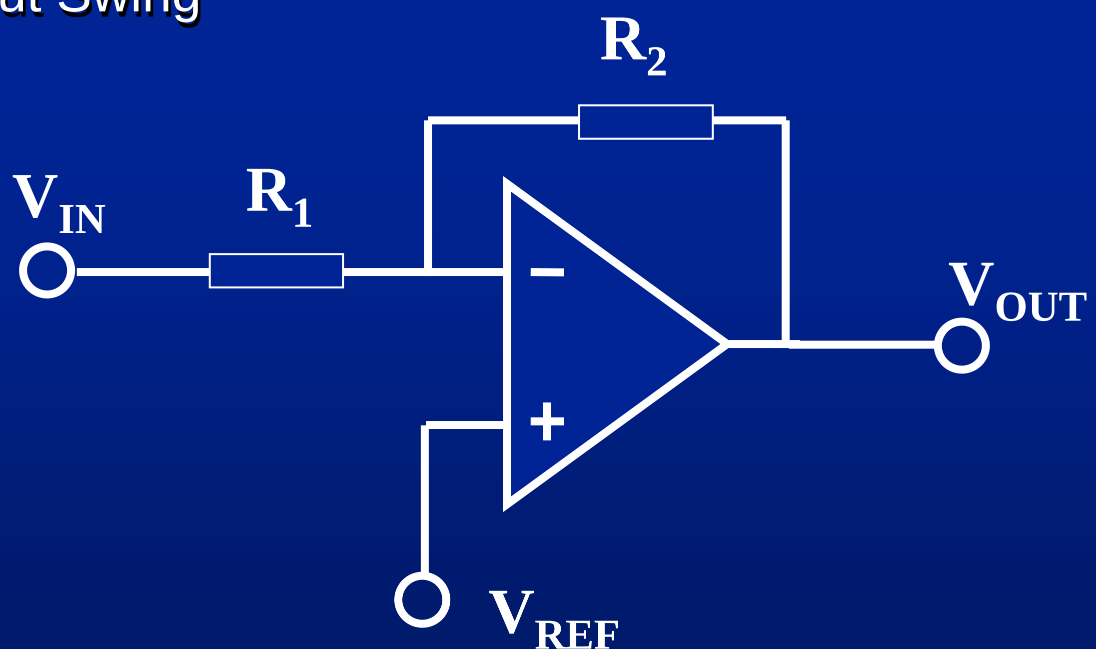
- Operation Amplifier Configured for a High Gain (Closed Loop)
  - Let R_{IN} = 100Ω, R_F = 10kΩ and V_{OS} = 1mV,
  - if V_{IN} = 0V what is the Output Voltage, V_{OUT}?



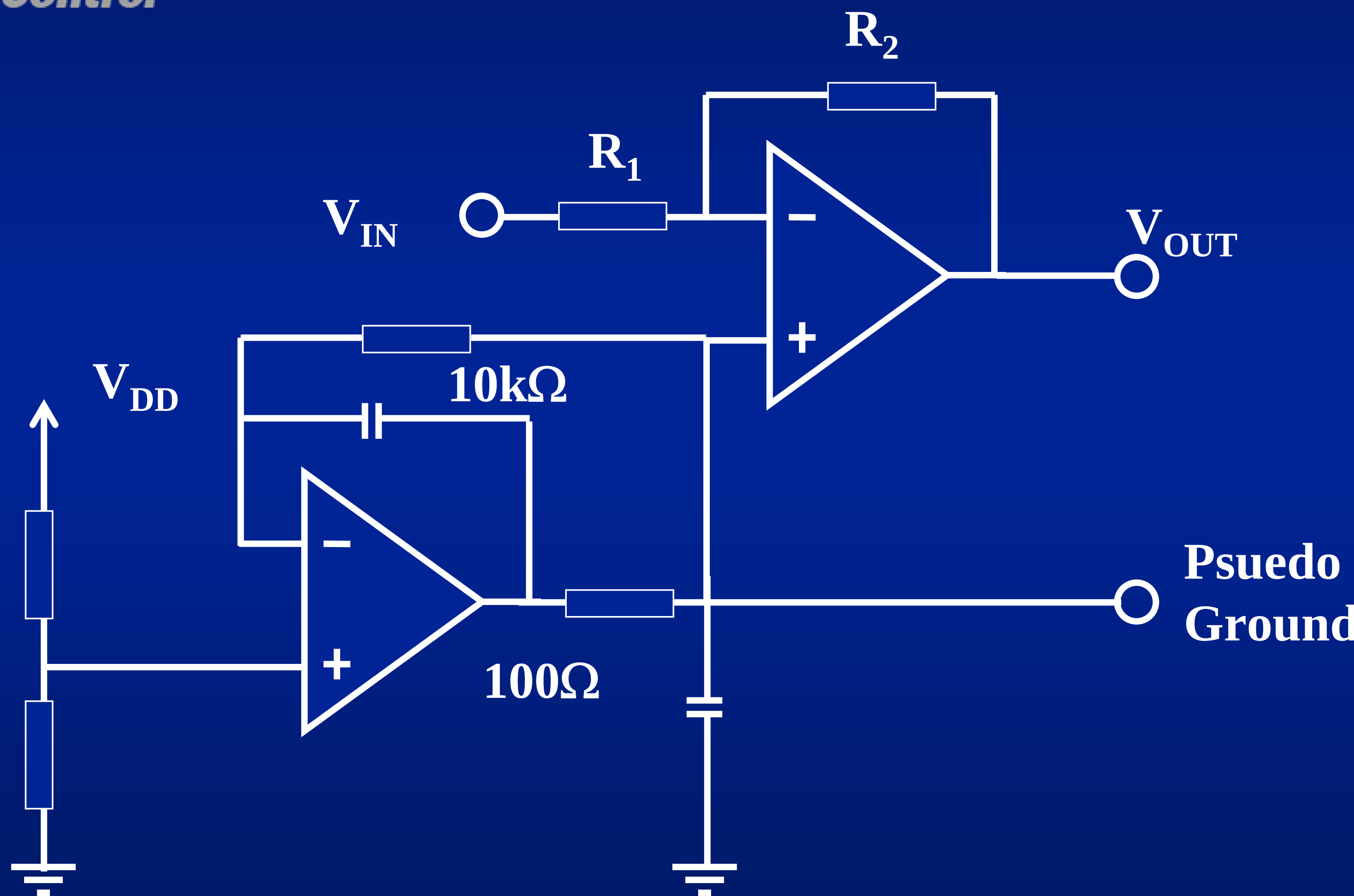
$$V_{OUT} = (1 + R_F / R_{IN}) (V_{IN} + V_{OS})$$

Inverting Gain

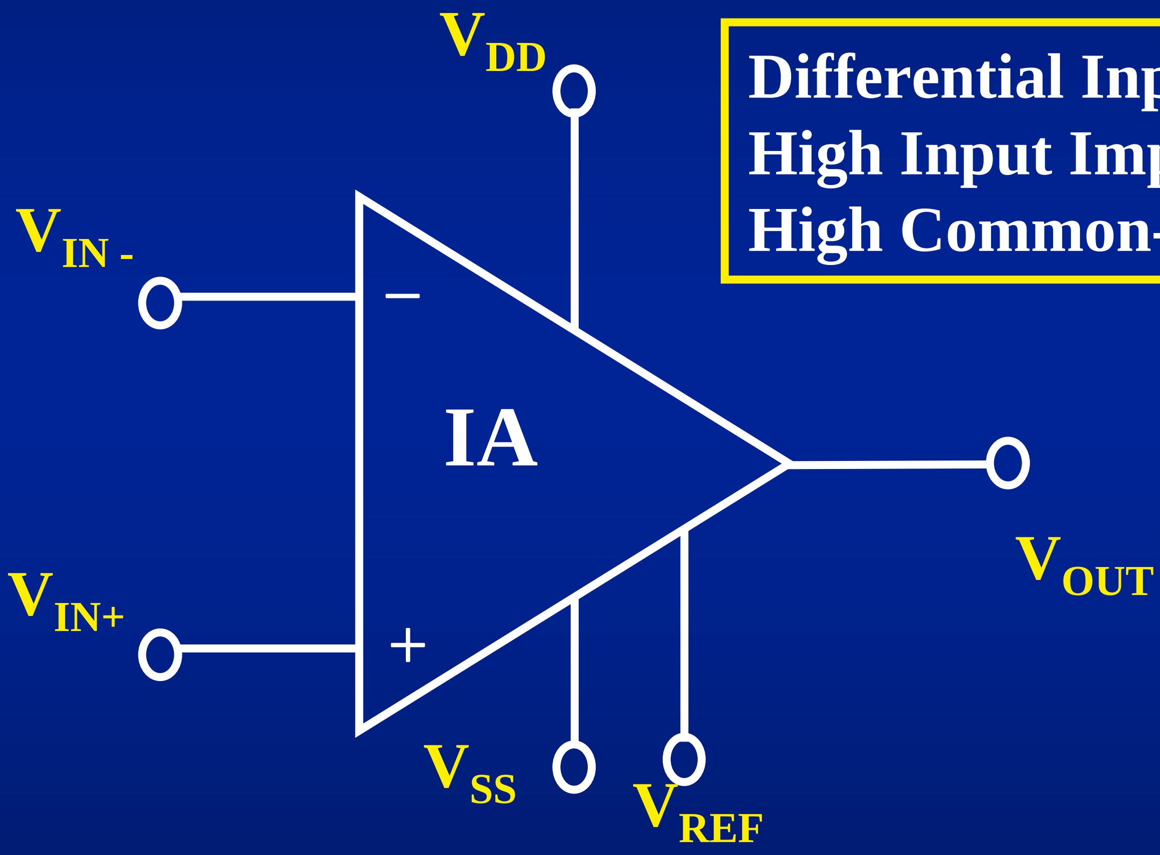
- $V_{OUT} = -V_{IN}(R_2 / R_1) + V_{REF}(1 + R_2 / R_1)$
- $V_{OUT} = (-V_{IN} + V_{REF})(R_2 / R_1) + V_{REF}$
- Challenging to Use in Single Supply Circuits
  - Input Swing
  - Output Swing
  - V_{REF}



Psuedo Ground Using a Supply Splitter



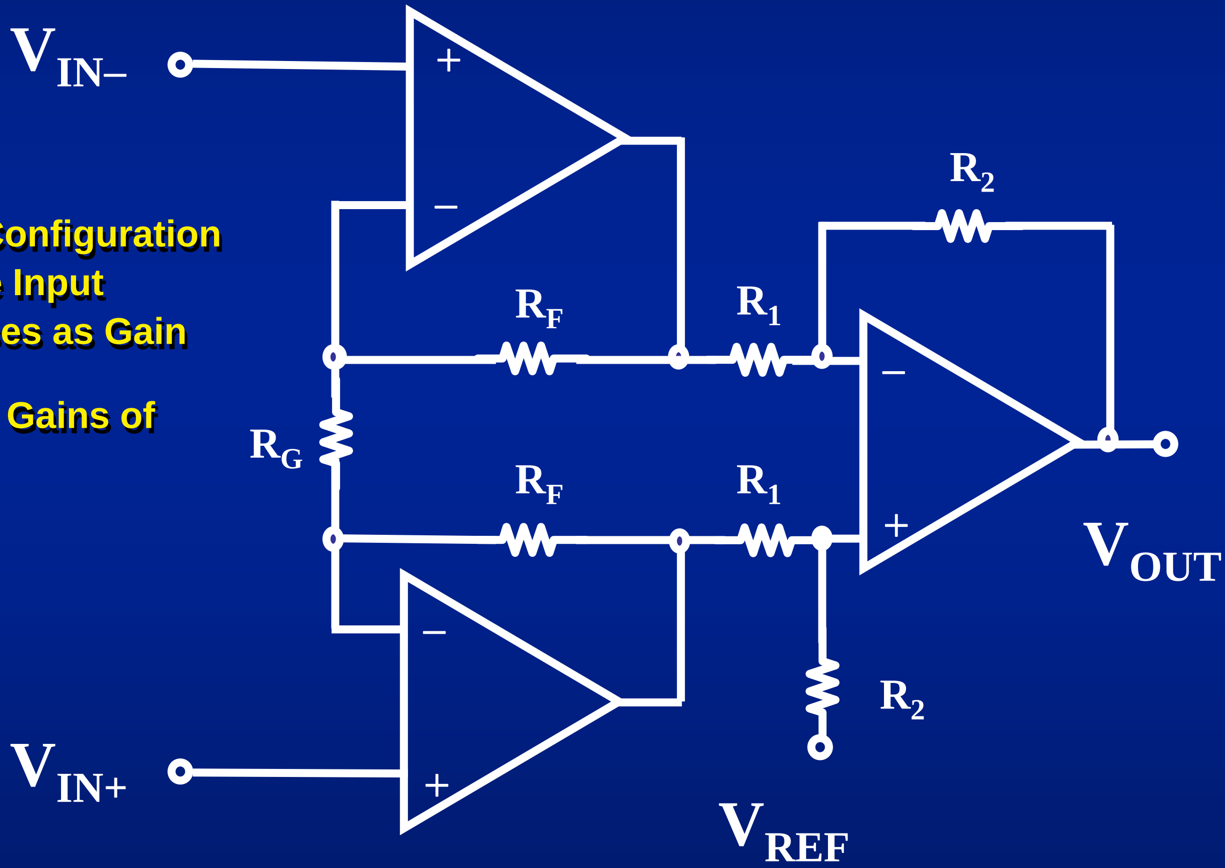
Instrumentation Amps Circuits



Differential Input
High Input Impedance
High Common-Mode Rejection

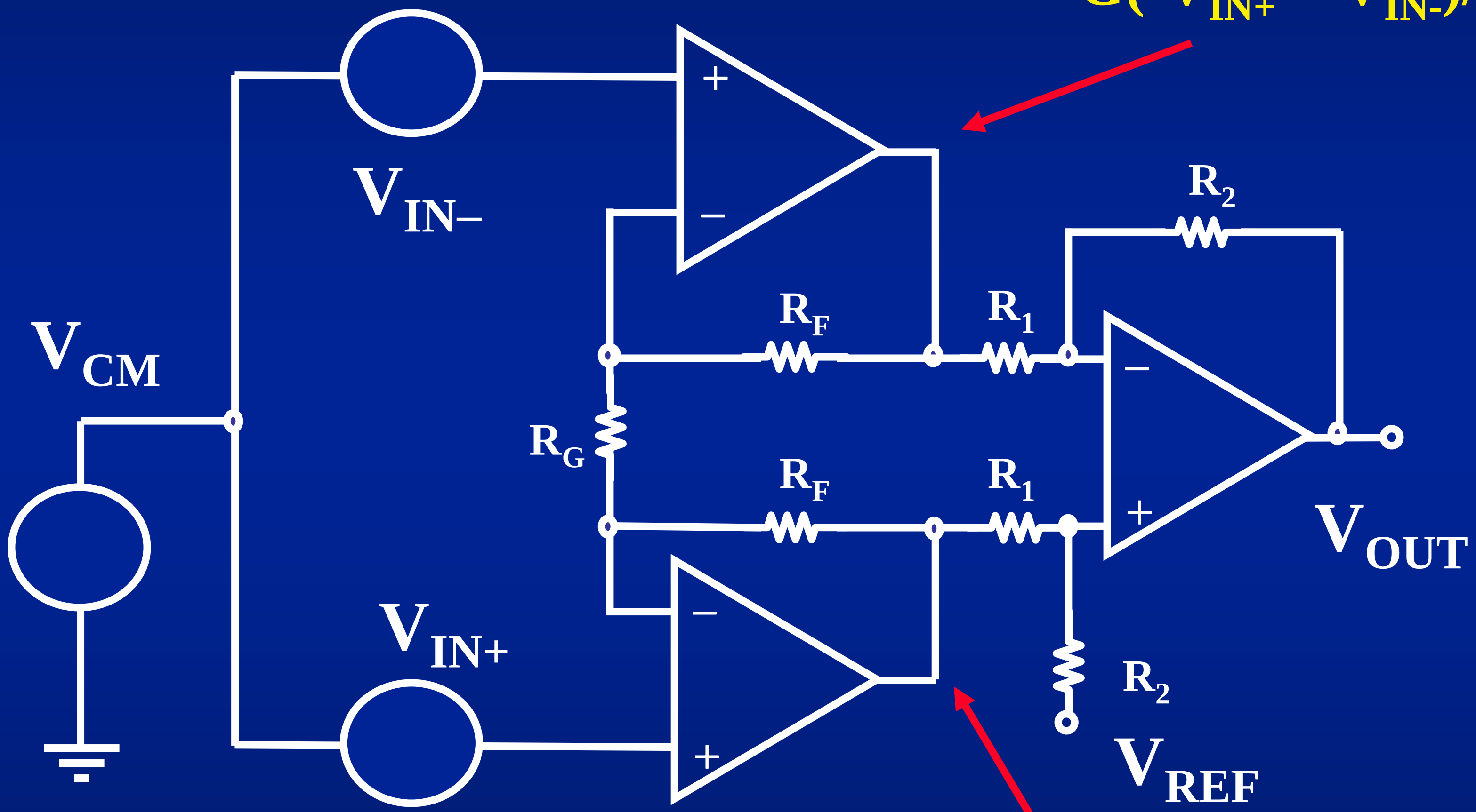
Three Op Amp IA

- **Features**
  - Most Popular Configuration
  - Common-Mode Input Range Decreases as Gain Increases
  - Can be used in Gains of 1V/V or higher



First Stage Output Limitations

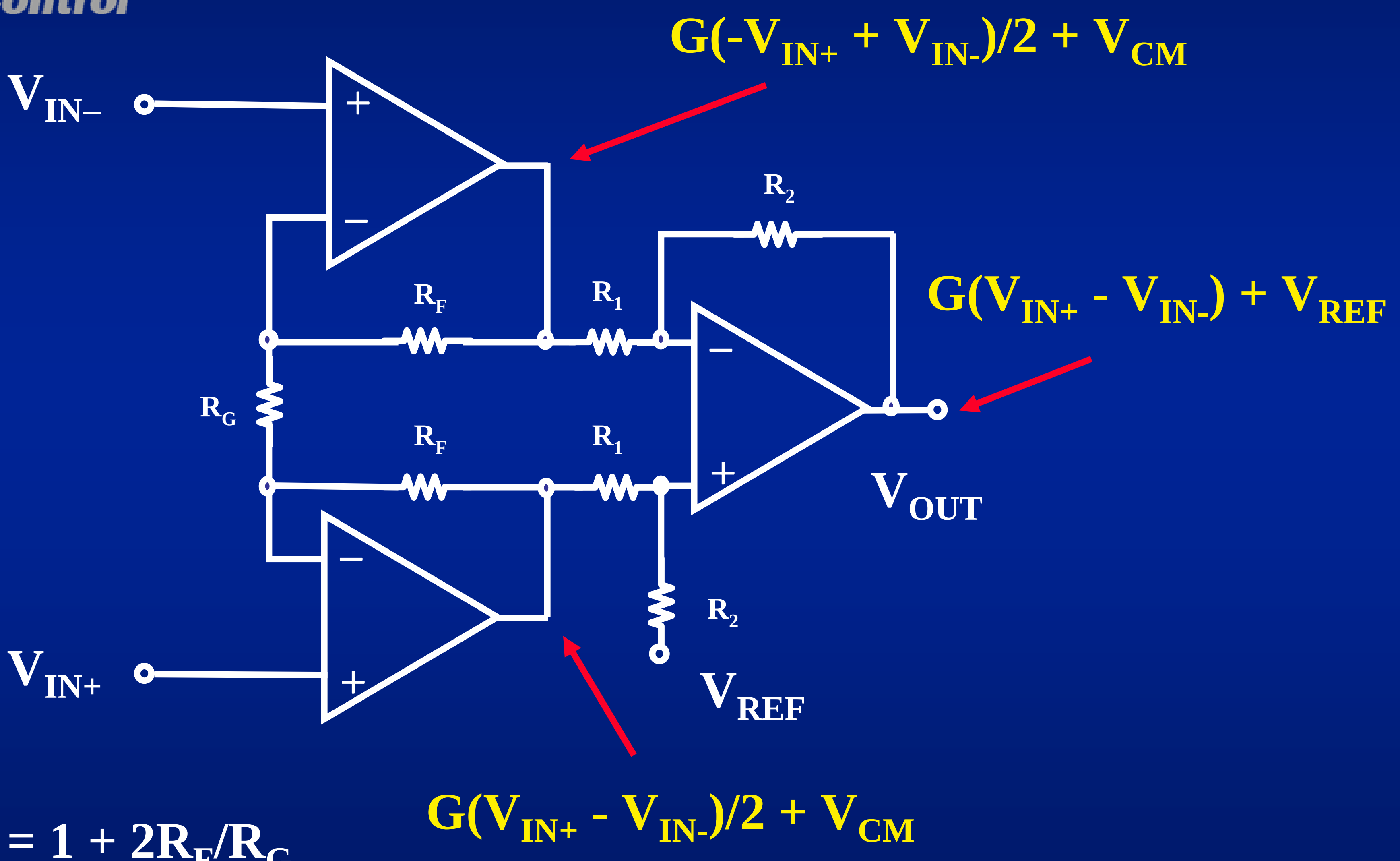
$G(-V_{IN+} + V_{IN-})/2 + V_{CM}$



$G(V_{IN+} - V_{IN-})/2 + V_{CM}$

$G = 1 + 2R_F/R_G$

Level Shift with Voltage Reference

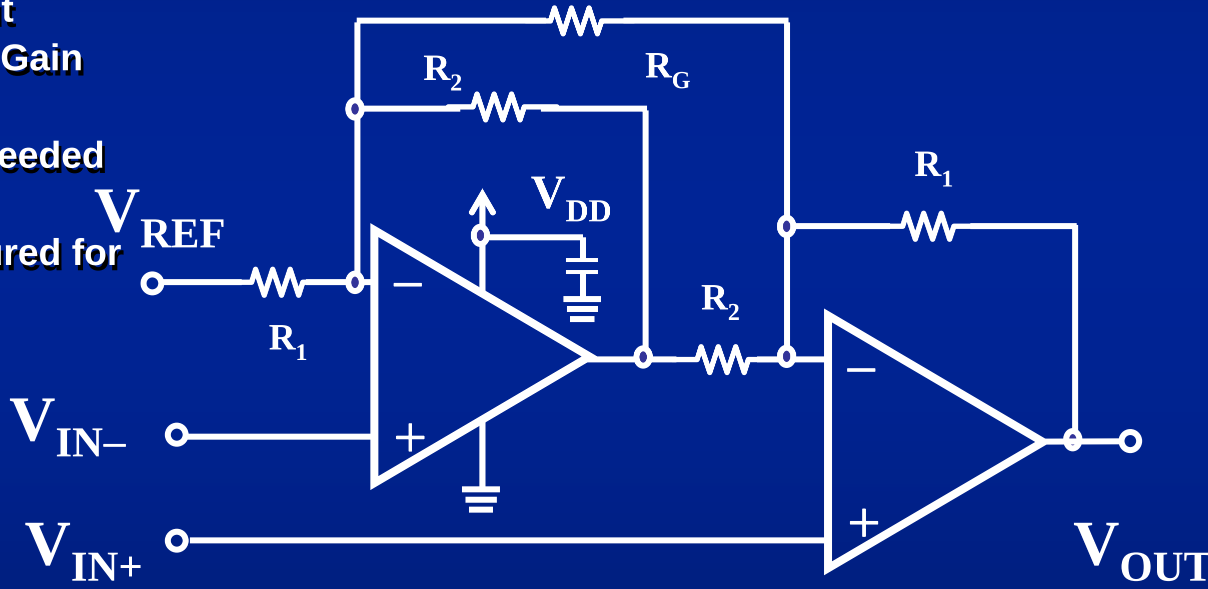


$$G = 1 + 2R_F/R_G$$

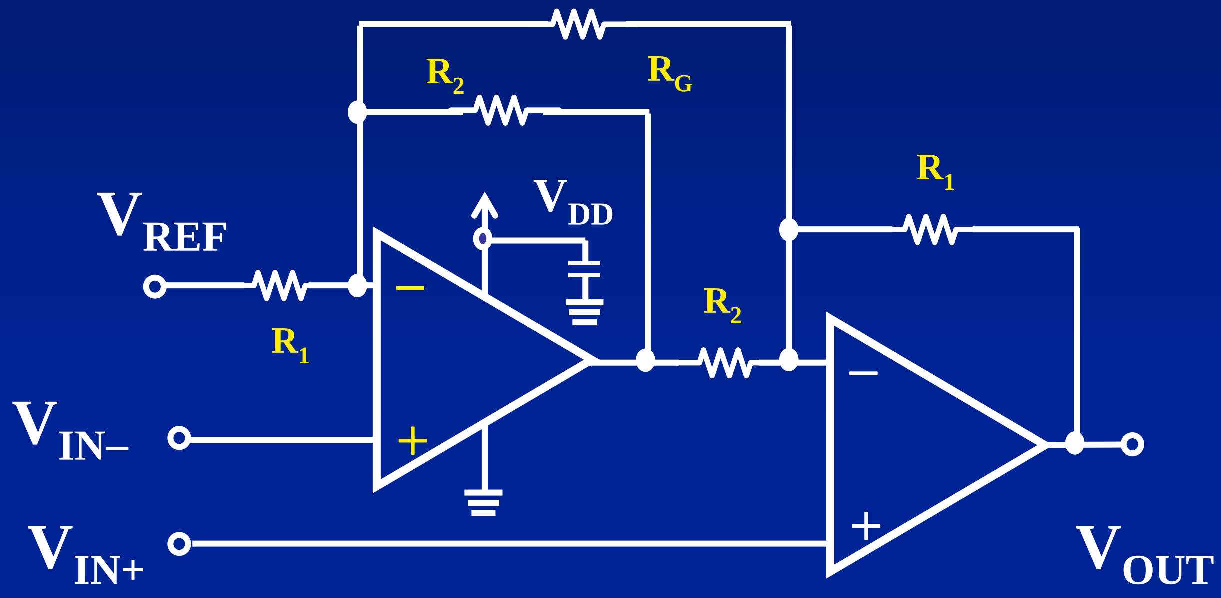
Two Op Amp IA

Features

- More Popular in Low Power Applications
- Common-Mode Input Range Decreases as Gain Decreases
- If Swing to GND is needed R1 / R2 > 2
- Can only be Configured for a Gain of +2V/V or higher



Two Op Amp IA
Transfer Function

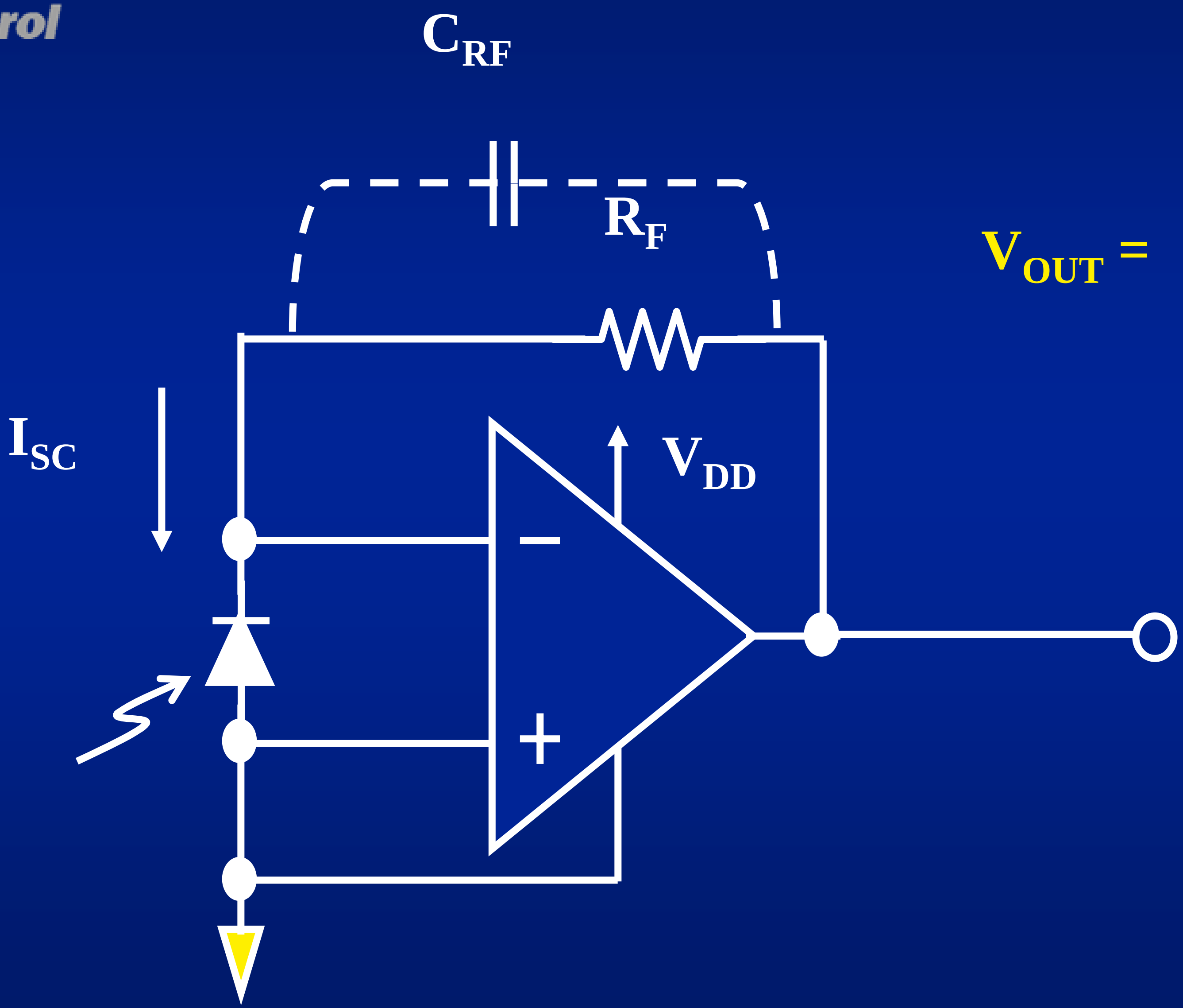


IA output = (Δ Input) * (Gain) + level shift voltage

for $R_1 = 30k\Omega$ and $R_2 = 10k\Omega$

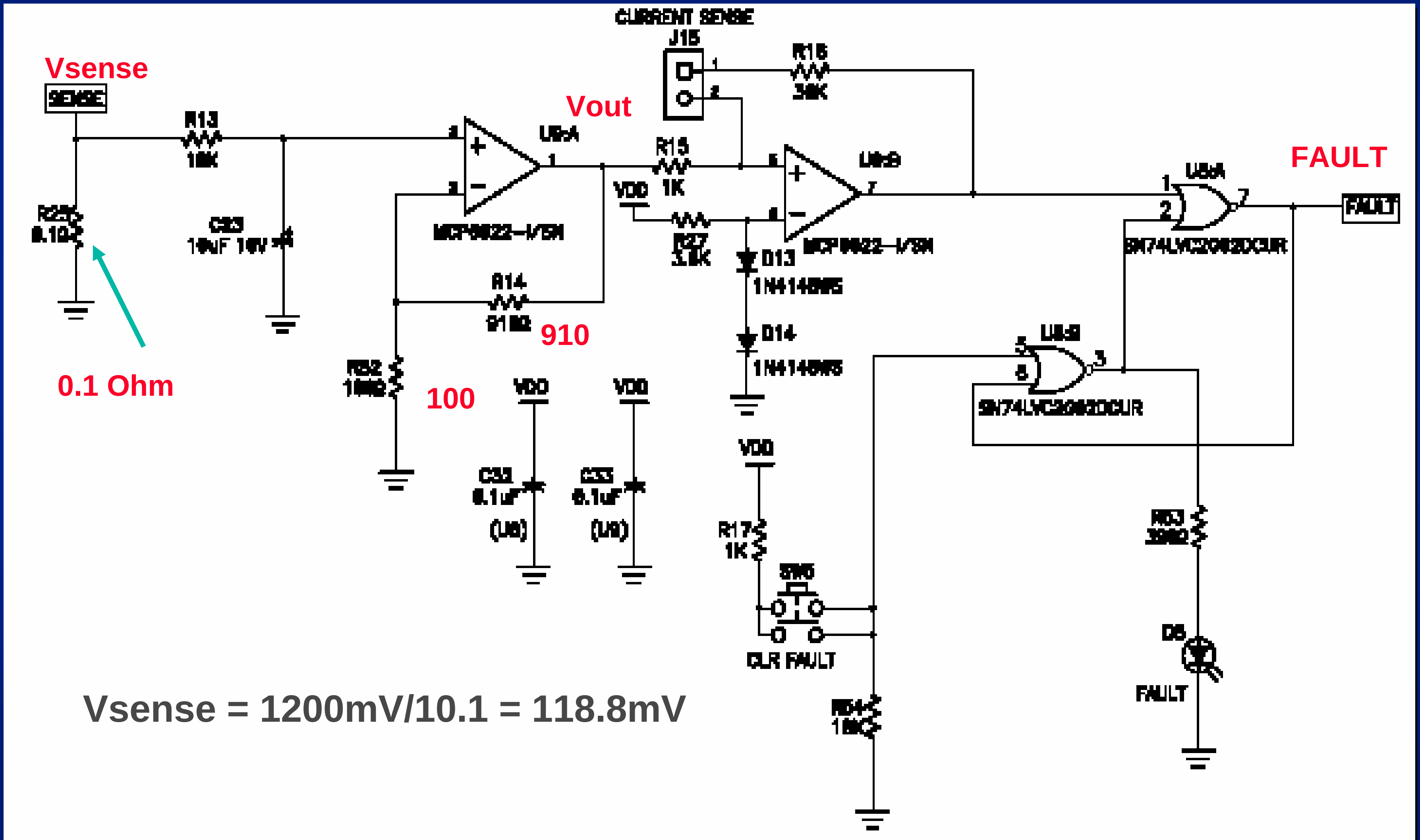
$V_{OUT} = (V_{IN+} - V_{IN-}) * (4 + 60k / R_G) + V_{REF}$

Photo Diode Pre-amp



$$V_{OUT} = + I_{SC} R_F$$

Current Limit



Vsense = 1200mV/10.1 = 118.8mV

OP Amp Quick Selection

	Low Cost	Low Iq	Low Noise	Low Supply Voltage	Low Offset Voltage	Small Package
Low Cost	MCP6001/2/3/4	MCP6231/2/4 MCP6241/2/4	MCP6291/2/3/4	MCP6001/2/4	MCP606/7/8/9 MCP616/7/8/9 MCP6021/2/3/4	MCP6001 SOT-23
High GBWP	MCP6291/2/3/4 10MHz	MCP6281/2/3/4 5MHz	MCP6291/2/3/4 MCP6021/2/3/4 10MHz	MCP6291/2/3/4 MCP6021/2/3/4 10MHz	MCP6021/2/3/4 10MHz	MCP6291 MCP6021 SOT-23
Low Offset Voltage	MCP606/7/8/9 MCP616/7/8/9 MCP6021/2/3/4	MCP606/7/8/9 MCP616/7/8/9	MCP6021/2/3/4	MCP606/7/8/9 MCP616/7/8/9 MCP6021/2/3/4	TC913	MCP606 MCP6021 SOT-23
Small Package	MCP6001 SOT-23	MCP6041/6141 TC1034/5 SOT-23	MCP6291 MCP6021 SOT-23	MCP6001 MCP6231/41 SC-70	MCP606 MCP6021 SOT-23	MCP6001 MCP6231/6241 SC-70
General Purpose	MCP601/2/3/4	MCP6271/2/3/4 MCP6241/2/4	MCP6271/2/3/4 MCP6281/2/3/4 MCP6291/2/3/4	MCP6271/2/3/4 MCP6241/2/4	MCP601/2/3/4	MCP6271 MCP601 SOT-23
(The Lowest)	(Inexpensive) MCP6001	(600nA) MCP6041/2/3/4 MCP6141/2/3/4	(8.7nV/rtHz) MCP6291/2/3/4 MCP6021/2/3/4	(1.4 to 5.5V) MCP6041/2/3/4 MCP6141/2/3/4	(15microvolts) TC913	(SC-70) MCP6001 MCP6231/6241

OP Amp Products Offering

	GBWP	Supply Voltage	V_{OS}	I_Q
Rail to Rail Output				
MCP601/2/3/4	2.8 MHz	2.7 to 5.5 V	2.0 mV	230 µA
MCP606/7/8/9	155 kHz	2.5 to 5.5 V	0.25 mV	19 µA
MCP616/7/8/9	190 kHz	2.3 to 5.5 V	0.15 mV	19 µA
Rail to Rail Input/Output				
MCP6001/2/3/4	1 MHz	1.8 to 5.5 V	7.0 mV	100 µA
MCP6021/2/3/4	10 MHz	2.5 to 5.5 V	0.5 mV	1100 µA
MCP6041/2/3/4	14 kHz	1.4 to 5.5 V	3.0 mV	0.6 µA
MCP6141/2/3/4	120 kHz	1.4 to 5.5 V	3.0 mV	0.6 µA
MCP6231/2/4	200 kHz	1.8 to 5.5 V	7.0 mV	20 µA
MCP6241/2/4	500 kHz	1.8 to 5.5 V	7.0 mV	50 µA
MCP6271/2/3/4/5	2 MHz	2.0 to 5.5 V	3.0 mV	170 µA
MCP6281/2/3/4/5	5 MHz	2.2 to 5.5 V	3.0 mV	450 µA
MCP6291/2/3/4/5	10 MHz	2.4 to 5.5 V	3.0 mV	1000 µA
TC1029/30/34/35	90 kHz	1.8 to 5.5 V	1.5 mV	6.0 µA

BACK