POLITECNICO DI MILANO

Electronics – 96032

Instrumentation Amps and OA Parameters

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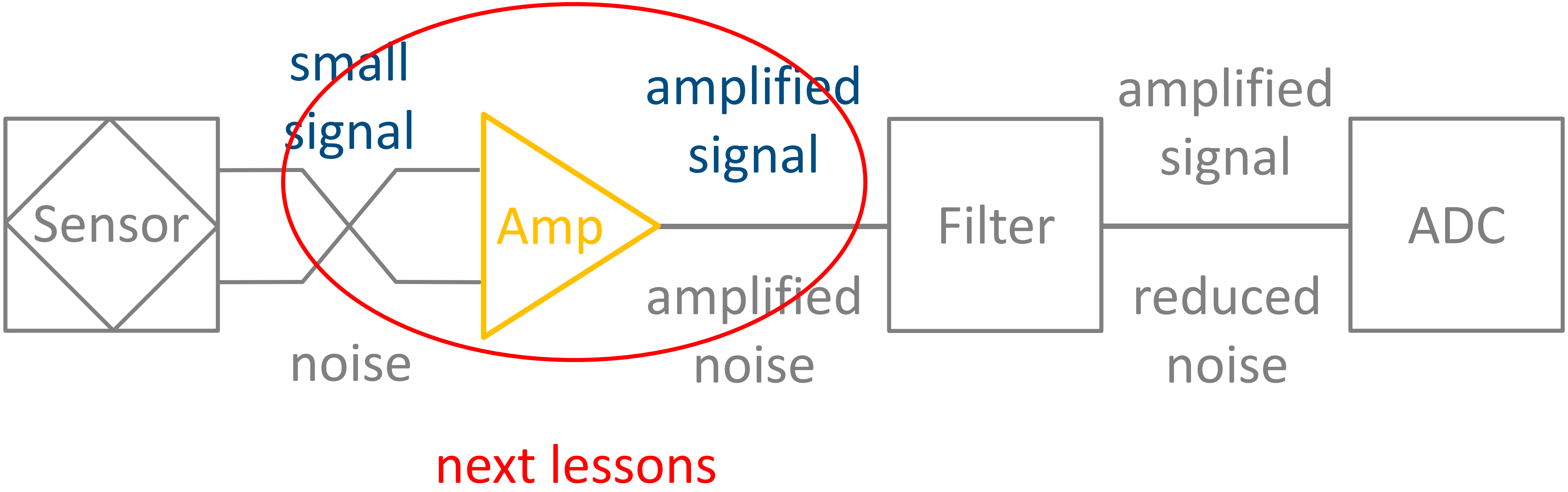
Disclaimer

Slides are supplementary material and are NOT a replacement for textbooks and/or lecture notes

Acquisition chain



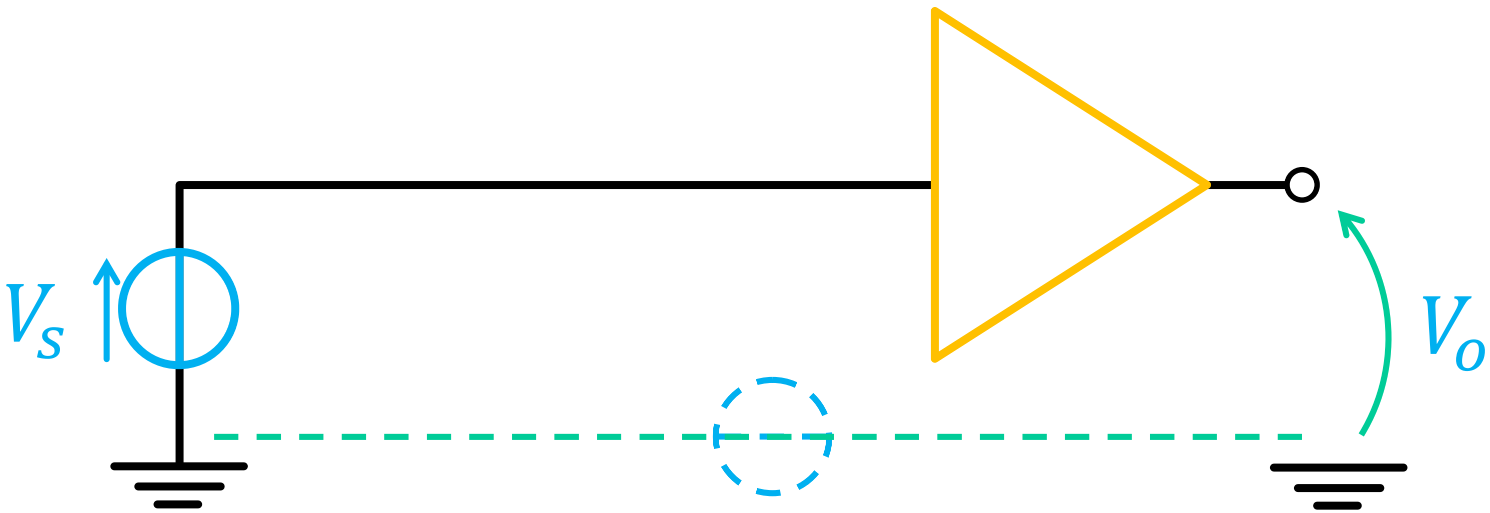
Purpose of the lesson

- We begin our study with the analysis and design of simple amplifiers
- Next lessons will deal with
  - Basic amplifier principles and the feedback amplifier concept
  - Linear applications of OpAmps
  - Feedback amplifier properties
  - Stability of feedback amplifiers
  - Instrumentation amplifiers and OpAmp parameters (this lesson)

Outline

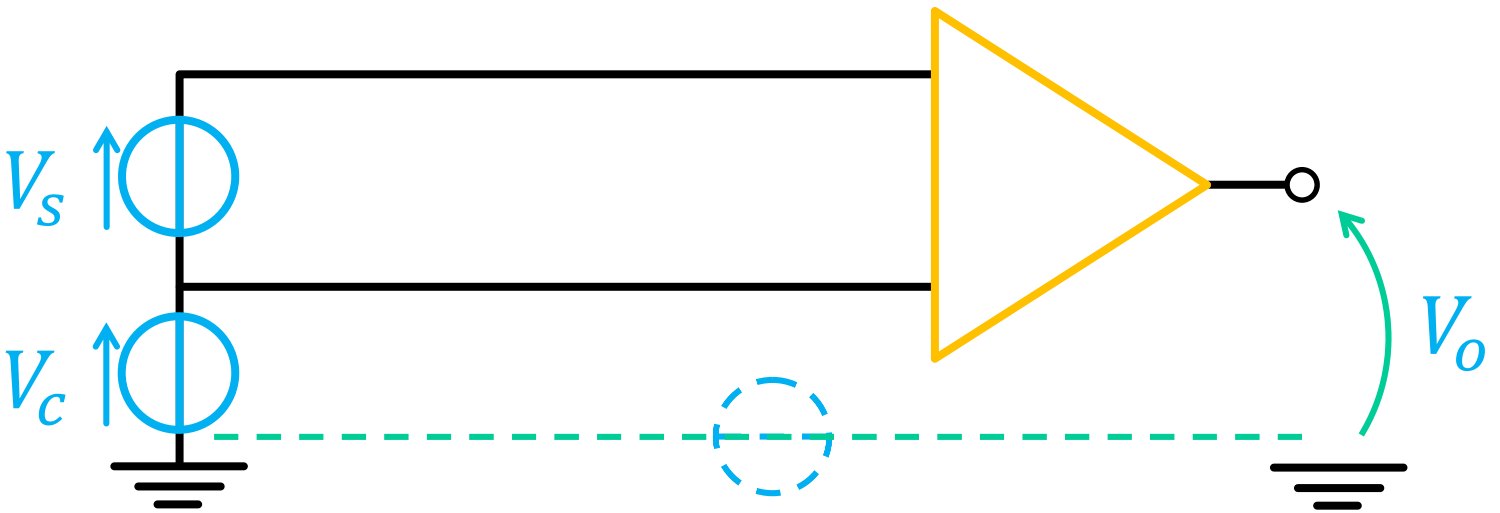
- Differential signals and CMRR
- Instrumentation amplifiers
- Other OA limitations
- Circuit simulation with Simulink
- Appendix 1: Single-supply OA circuits
- Appendix 2: OA datasheets

Single-ended signals



- Simple setup
- Sensitive to noise/interferences
- Sensitive to differences in ground potentials

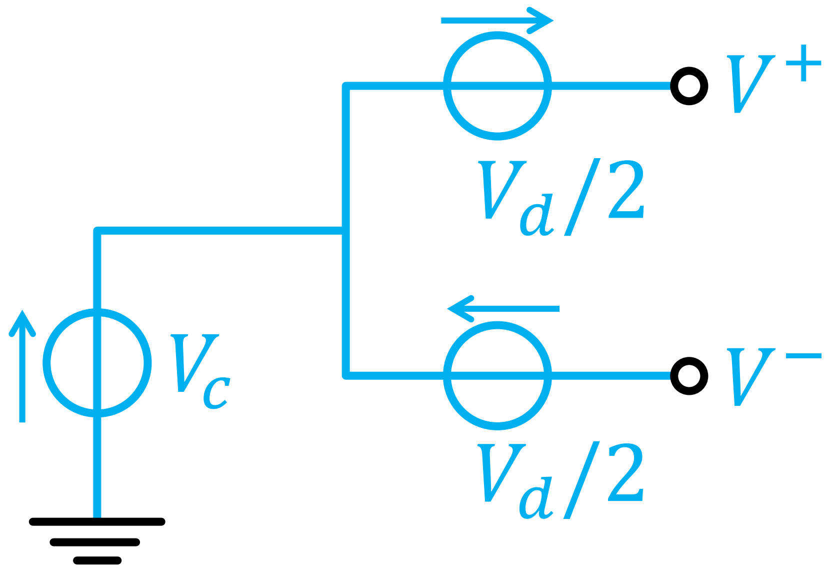
Differential signals



- Higher immunity to noise and disturbs
- Amplifier needs to reject common-mode signal/noise (incl. ground potential fluctuations)
- Can be more expensive

Common and differential modes

- Given the input voltages V^+ and V^-, we define
  - Common-mode voltage $V_c = \frac{V^+ + V^-}{2}$
  - Differential-mode voltage $V_d = V^+ - V^-$



Common mode rejection ratio

- A generic amplifier output can be written as

$$V_o = A_d V_d + A_c V_c = A_d\left(V_d + \frac{V_c}{CMRR}\right)$$

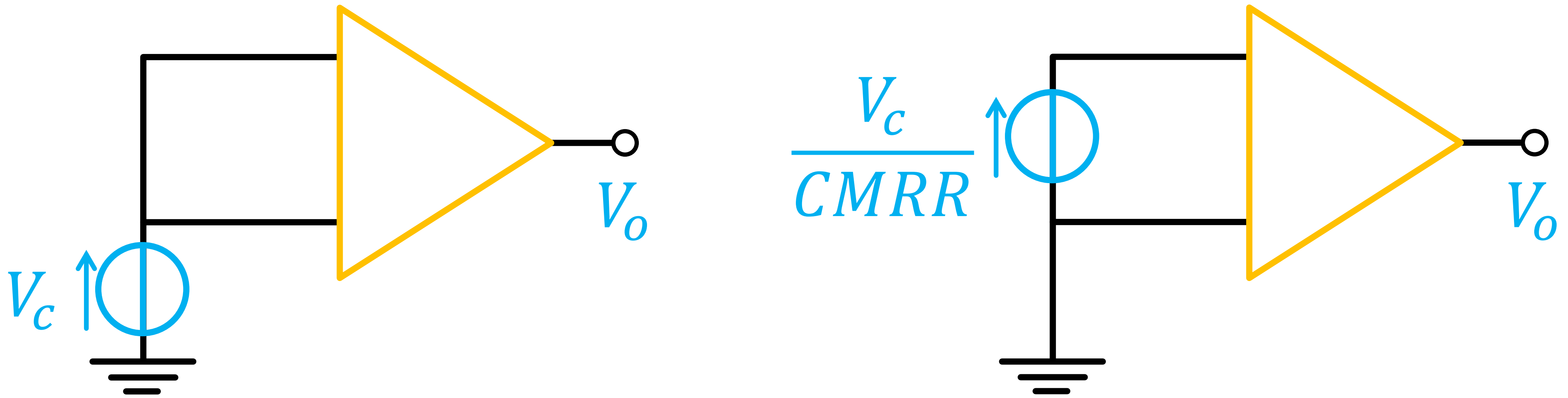
where

$$CMRR = \frac{A_d}{A_c}$$

- To have small error

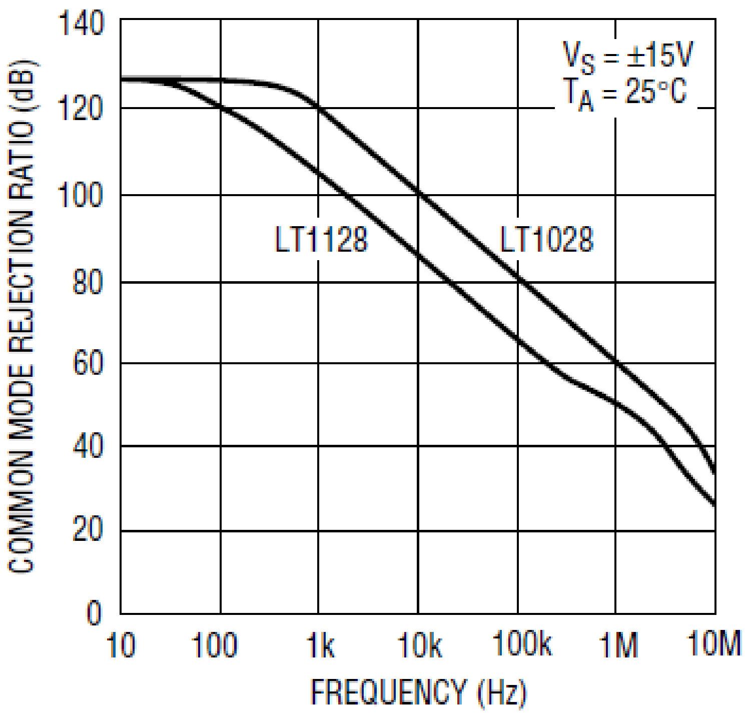
$$\frac{V_c}{CMRR} \ll V_d \Rightarrow CMRR \gg \frac{V_c}{V_d}$$

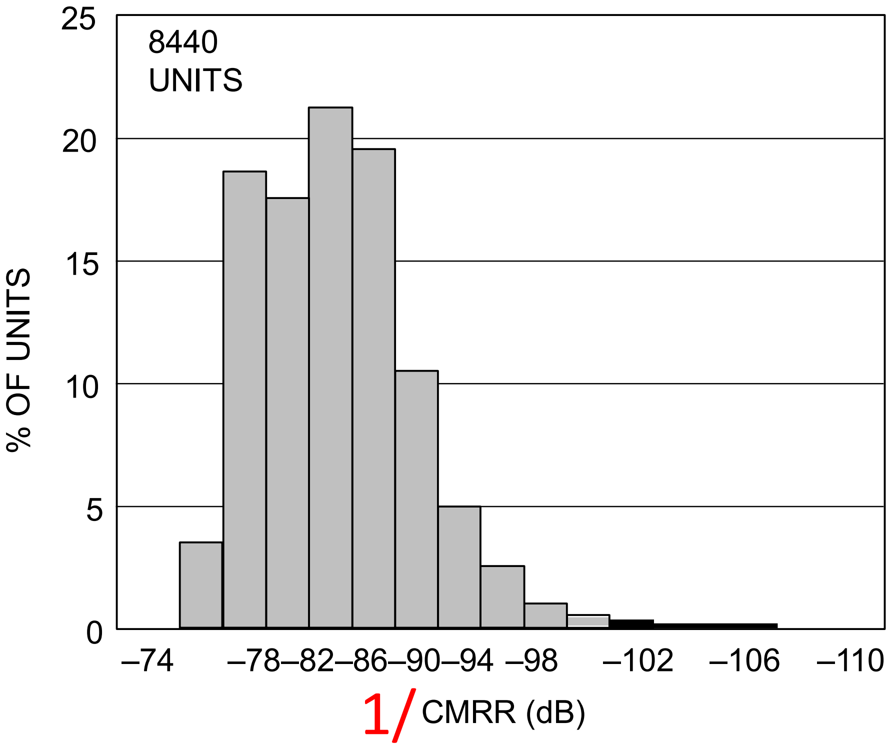
CMRR



- CMRR converts the common-mode signal into an equivalent differential signal
- Typical values for OAs are $70 - 120$ dB

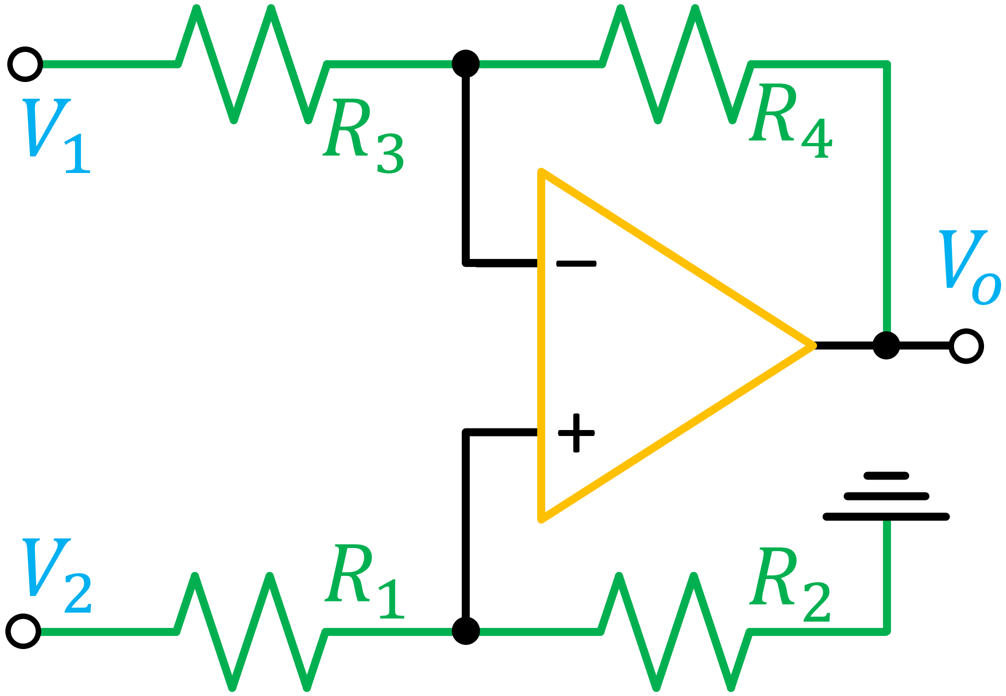
Actual values from datasheets





CMRR decreases with frequency

Subtractor circuit



- Easy to design
- Low and asymmetric Z_{in}
- Actual $CMRR$ is limited by resistor matching

Effect of resistor matching

- The common-mode gain can be expressed as

$$A_{cm} = -\frac{R_4}{R_3} + \frac{R_3 + R_4}{R_3}\frac{R_2}{R_1 + R_2} = \frac{1 - \frac{R_1}{R_2}\frac{R_4}{R_3}}{1 + R_1/R_2}$$

- Due to tolerances, $R \rightarrow\ R \pm \Delta R = R(1 \pm x)$

$$\frac{R_1}{R_2} \rightarrow \frac{R_1(1 \pm x)}{R_2(1 \mp x)} \approx \frac{R_1}{R_2}(1 \pm x)^2 \approx \frac{R_1}{R_2}(1 \pm 2x)$$

$$\frac{R_3}{R_4} \rightarrow \frac{R_3}{R_4}(1 \pm 2x)$$

Impact on CMRR

- Worst-case A_{cm} and $CMRR$ become

$$A_{cm} = \frac{1 - \dfrac{R_1}{R_2}\dfrac{R_4}{R_3}}{1 + R_1/R_2} = \frac{1 - \dfrac{1 \pm 2x}{1 \mp 2x}}{1 + R_1/R_2} \approx \frac{4x}{1 + \dfrac{R_1}{R_2}}$$

$\dfrac{R_1}{R_2} \rightarrow 1/A_{dm}$

$$CMRR = \frac{A_{dm} + 1}{4x}$$

- For discrete R, $x = 10\%$ (silver), 5% (gold), down to $1‰$ (violet)
- For a subtractor with $A_{dm} = 1$ and $x = 0.1\%$, $CMRR = 54$ dB

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- Appendix 1: Single-supply OA circuits
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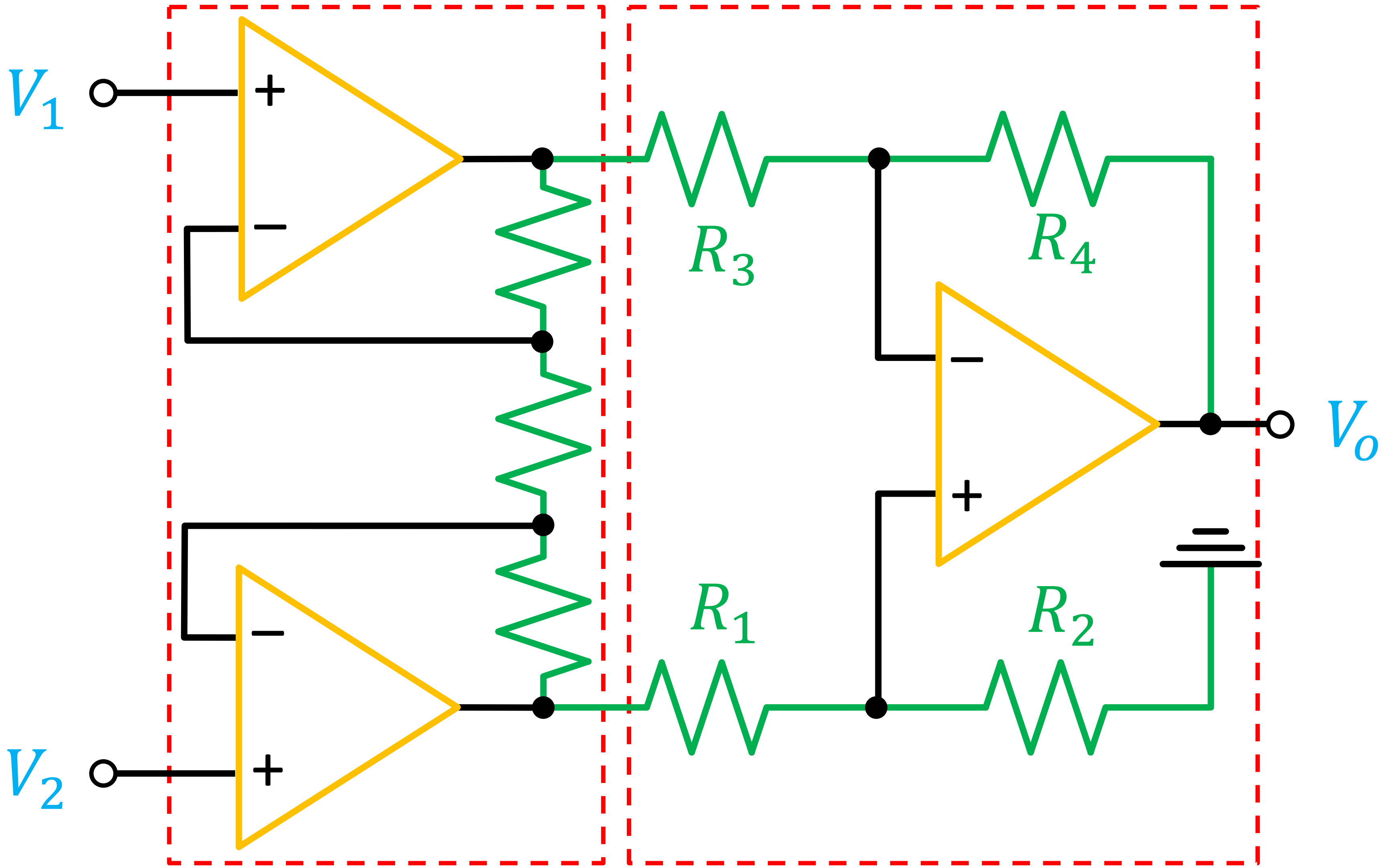
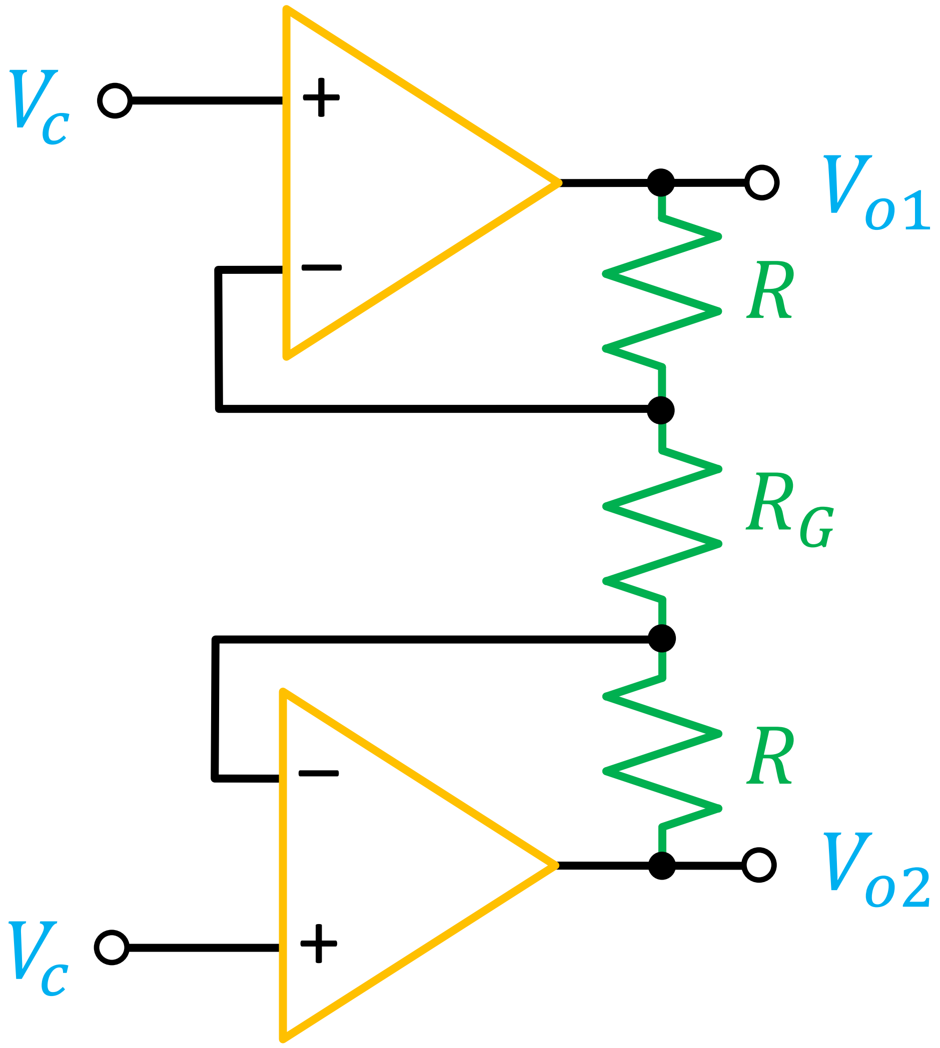
The concept



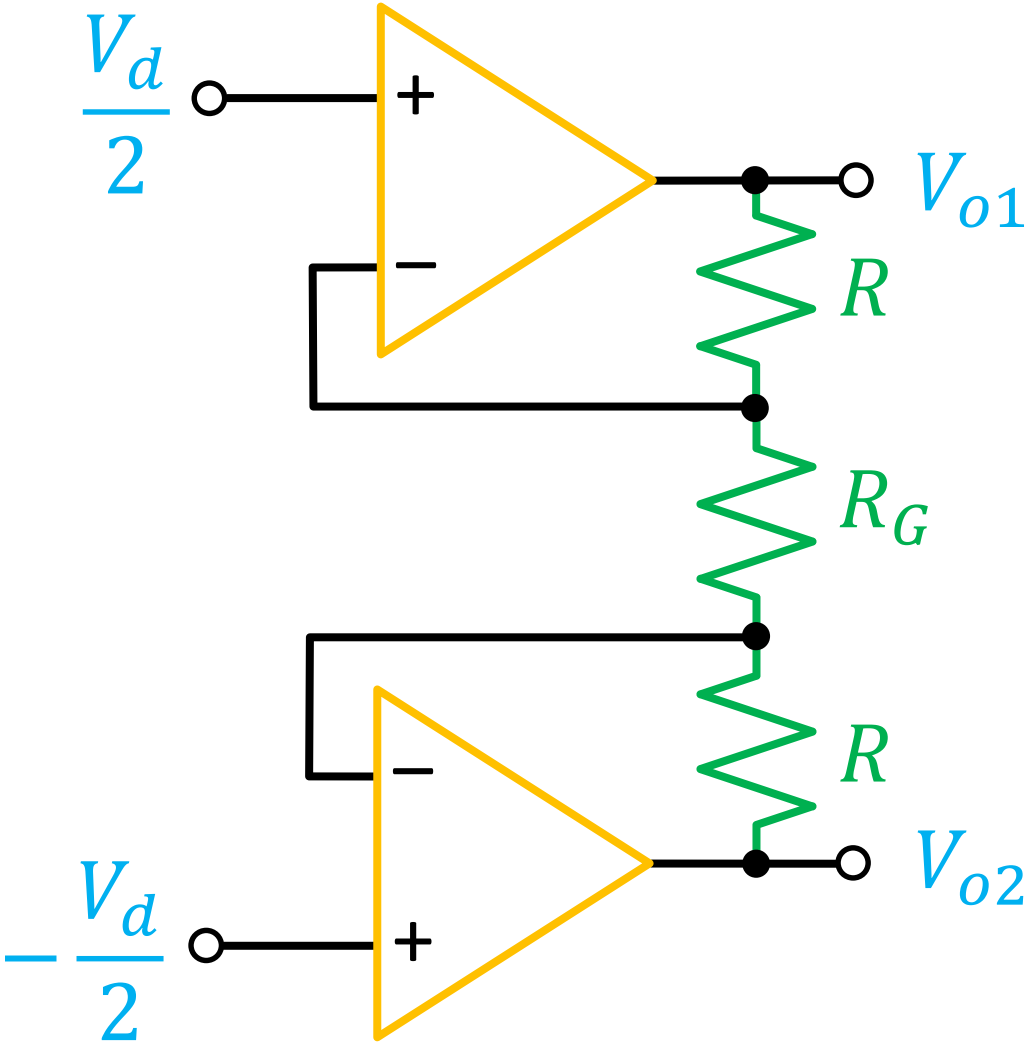
First stage – CM



$$A_{cm1} = 1$$

Independent of resistor matching!

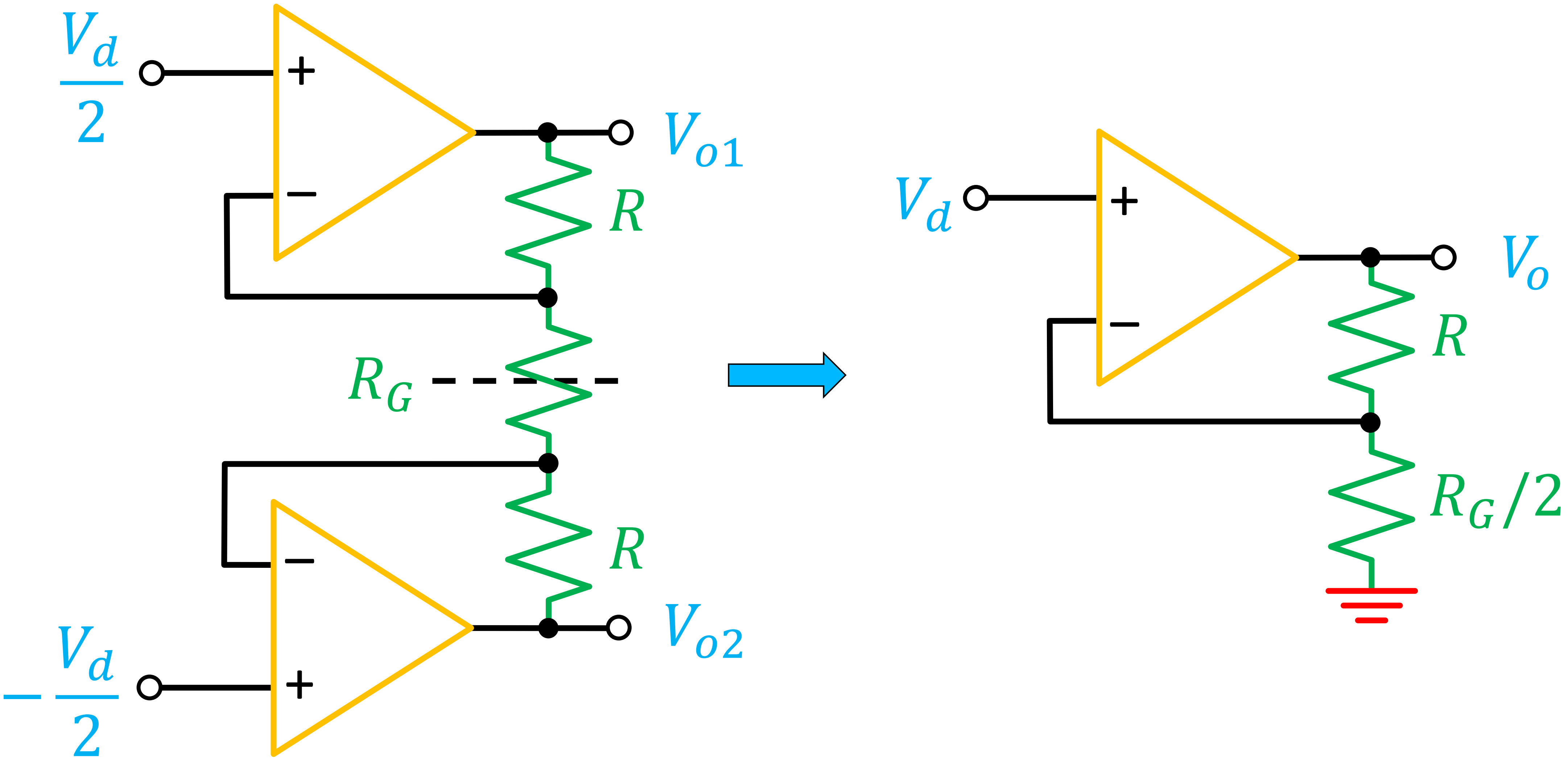
First stage – DM



$$A_{dm1} = \frac{V_{o1} - V_{o2}}{V_d} = 1 + \frac{2R}{R_G}$$

Set by the external resistor R_G

Half-circuit approach



Overall CMRR

$$CMRR = \frac{A_{dm}}{A_{cm}} = \frac{A_{dm1}A_{dm2}}{A_{cm1}A_{cm2}} = A_{dm1}CMRR_2$$

- $CMRR$ is actually limited by the OAs
- To a first appproximation, CM errors will be cancelled by the second stage $\Rightarrow$ it is the difference in OA $CMRR$s that counts!
- Can achieve $CMRR$ of $90 - 140$ dB

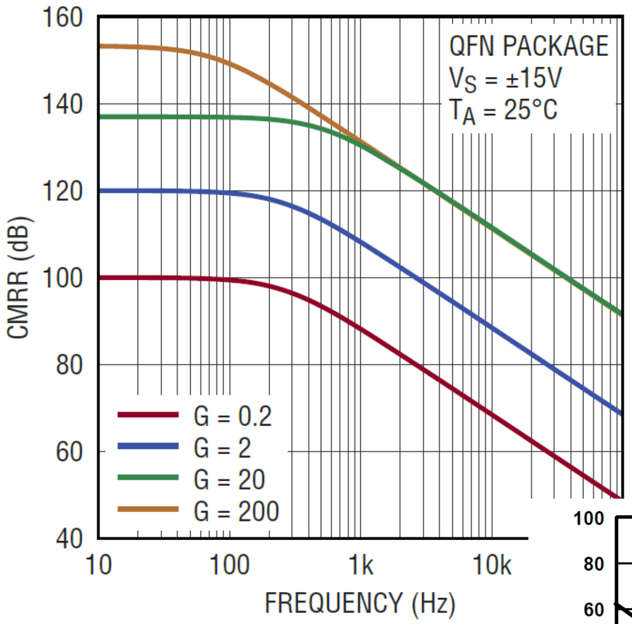
Specifications

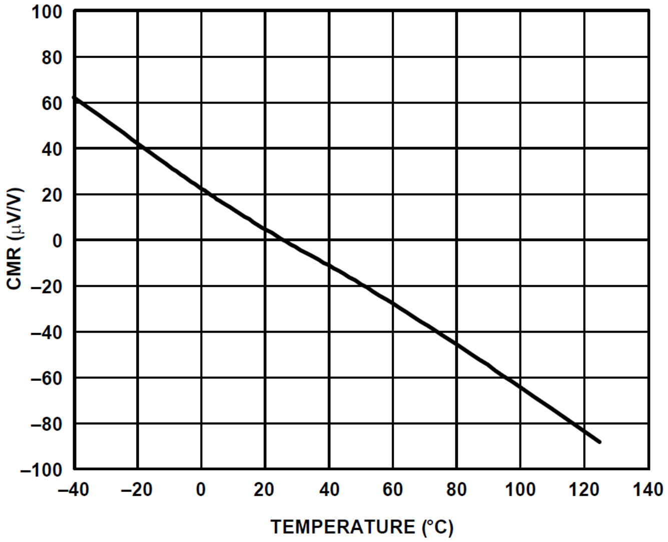
- Gain range (e.g., $1 - 1000$): the range in which device is guaranteed to work as specified
- Gain (or equation) error (e.g., 0.5%): maximum deviation from the gain equation (tolerances in R, serie resistances,…)
- Nonlinearity (e.g., 100ppm): maximum deviation from interpolating line
- Offset voltage: $V_{OS} = V_{OS1} + \frac{V_{OS2}}{G}$

Typical parameters

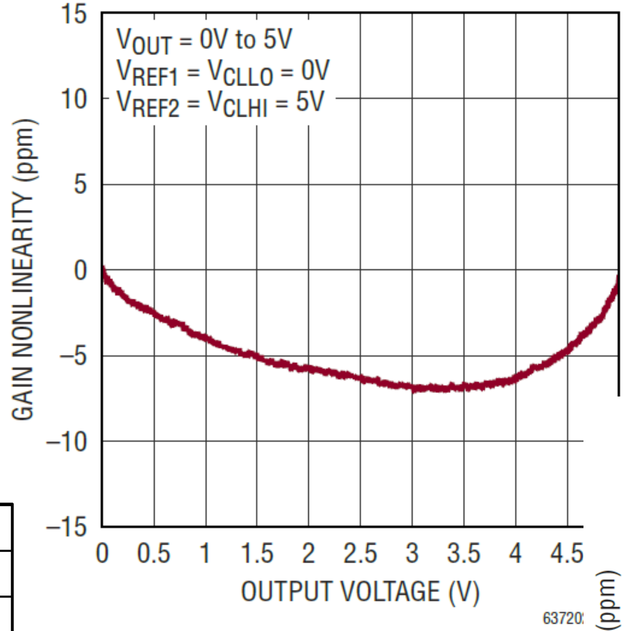
- $GBWP \approx 100$ kHz
- $V_{OS} < 500$ µV, drift < 0.5 µV/°C
- $I_B < 2$ nA
- Usually made with bipolar technology

Datasheet parameters

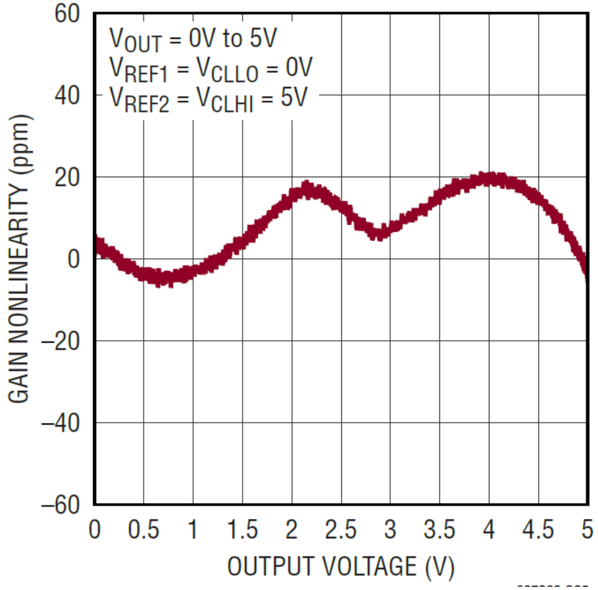




Gain Nonlinearity (G = 0.2)



Gain Nonlinearity (G = 200)



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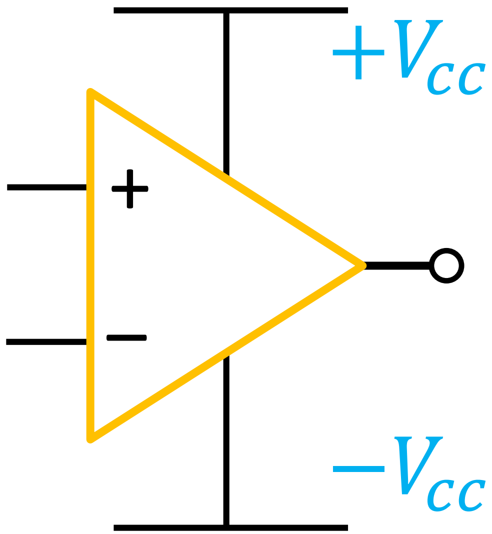
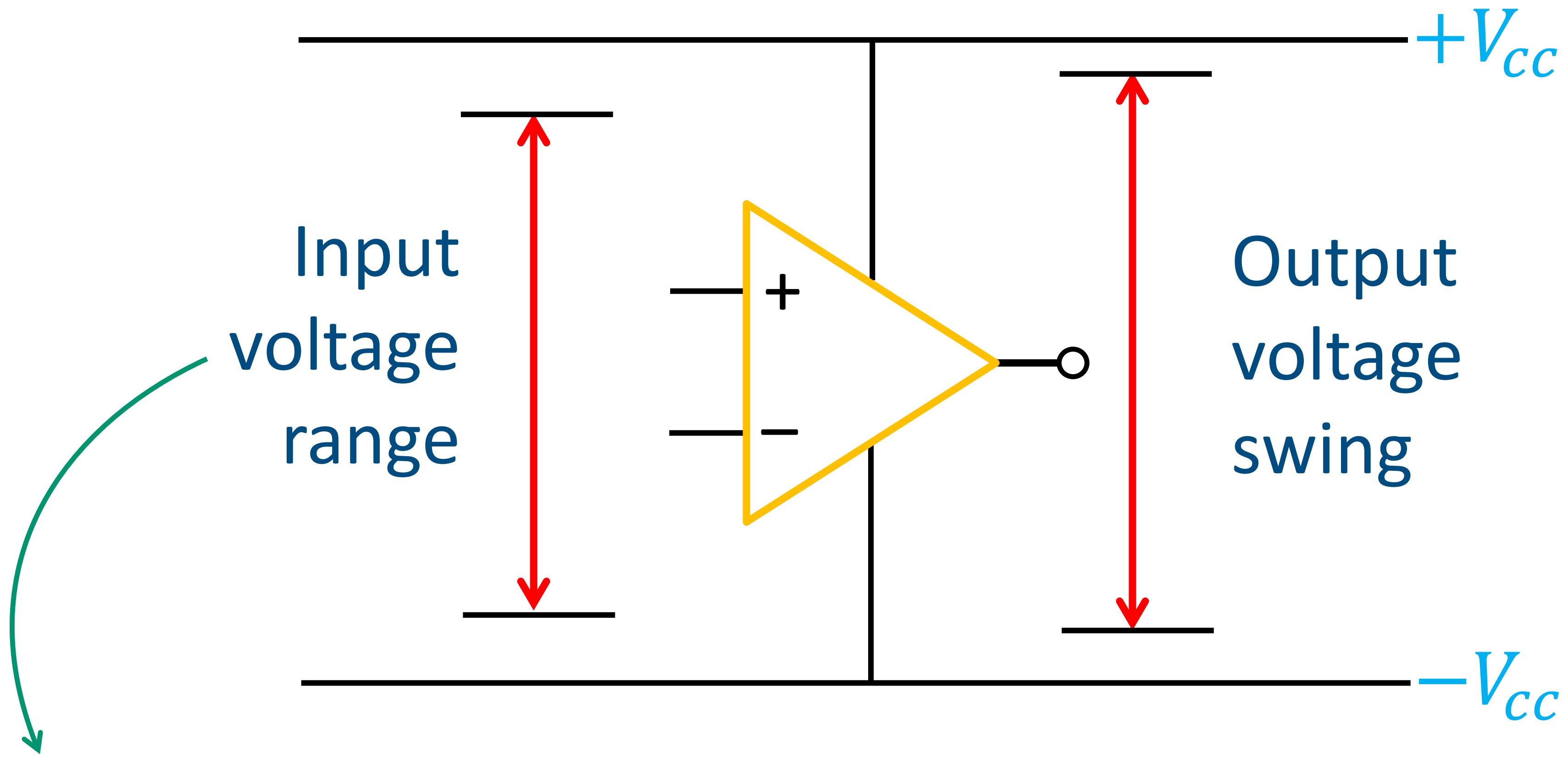
Supply voltage

- Dual symmetrical power supply is almost always used
- V_{cc} must be kept within a specified range (see Appendix 2)

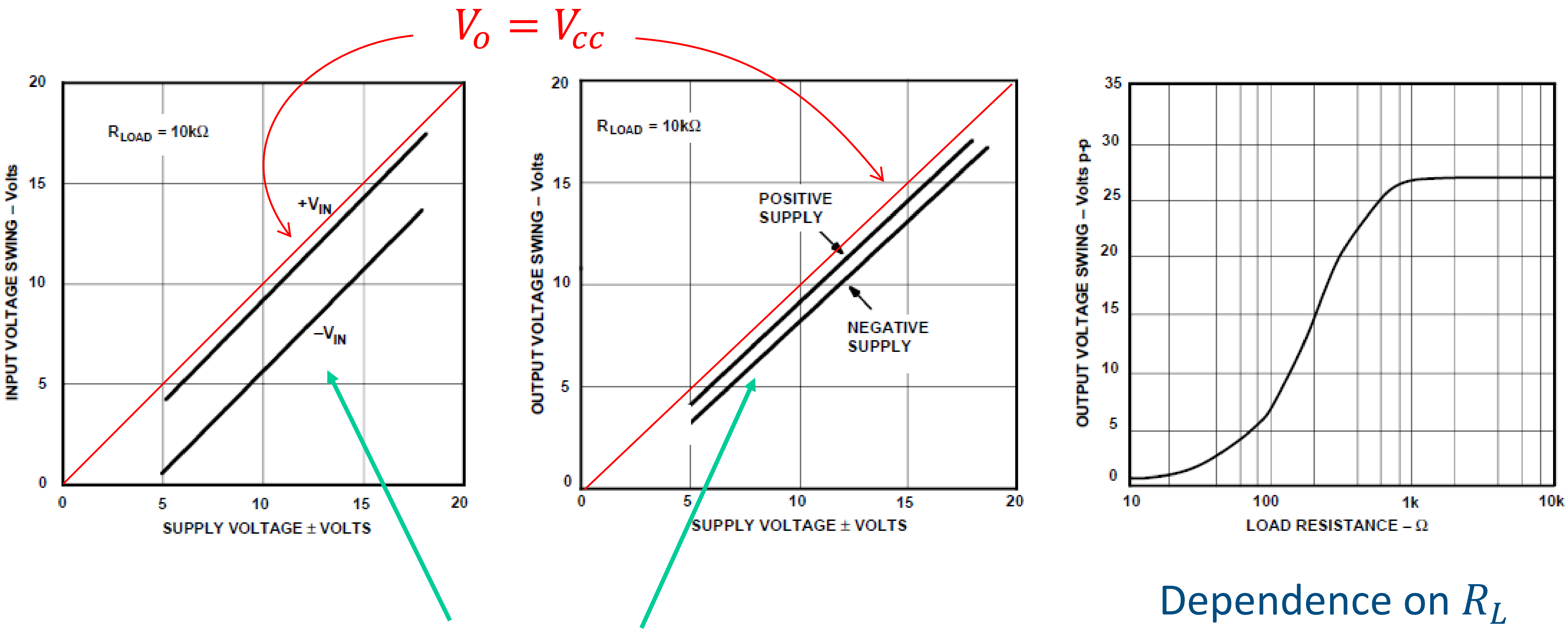


OA parameter: I/O voltage ranges/swings



A common-mode input range is also defined, related to $(V^+ + V^-)/2$

Actual values from datasheets



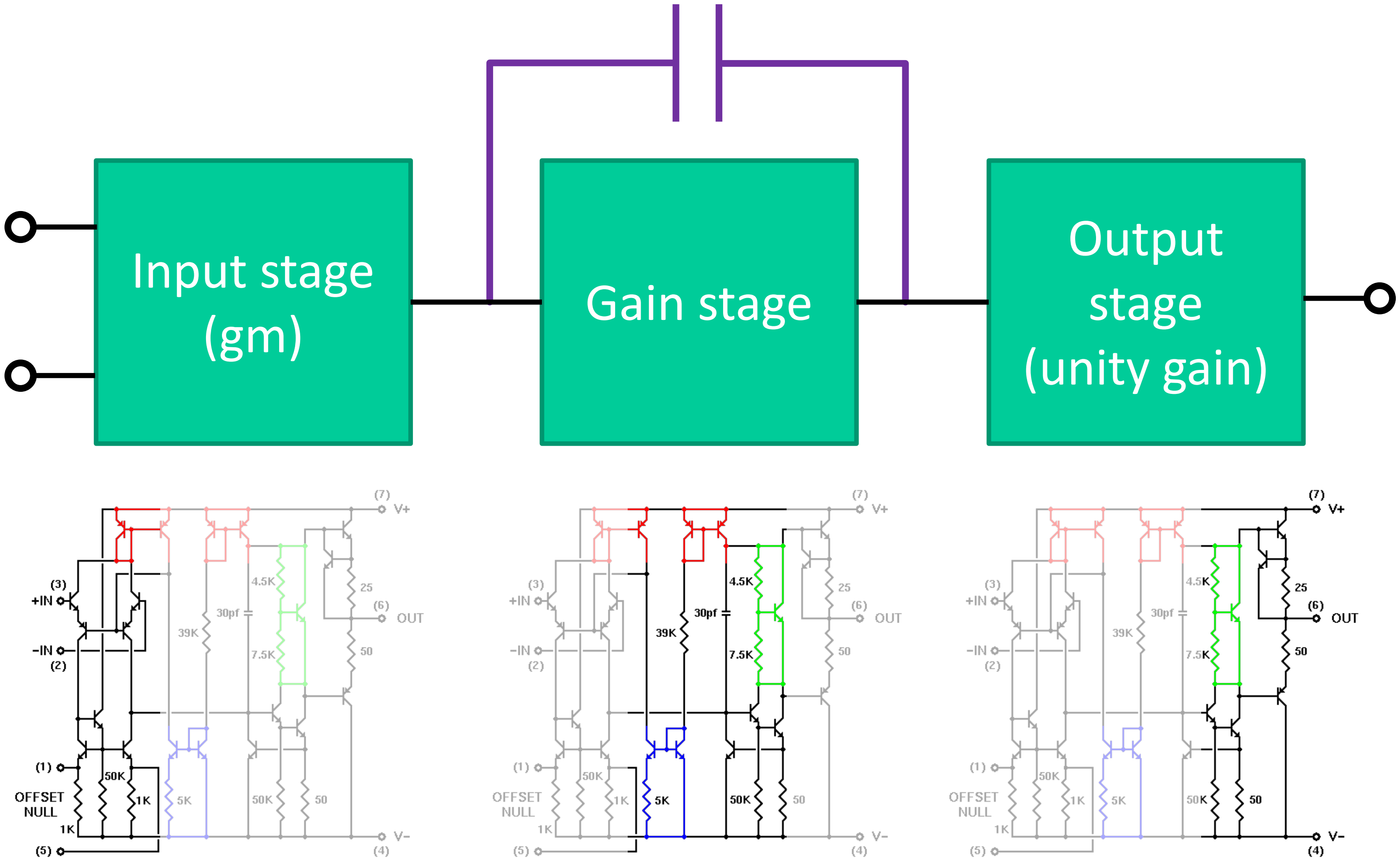
Non-symmetrical
(and a bit lower than V_{cc})

Dependence on R_L
(i.e., on delivered current)

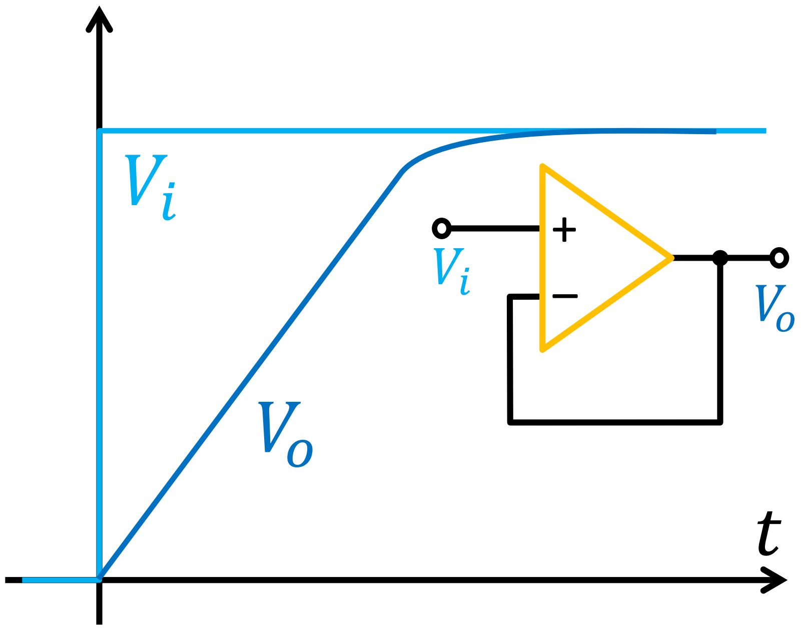
Single-supply operation

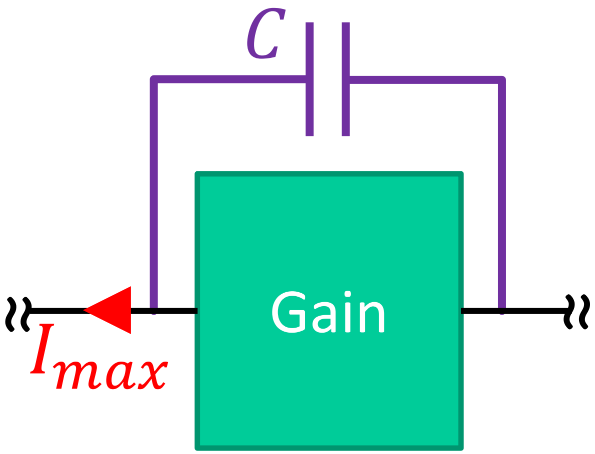
- Up to here, we always implicitly considered dual power supply, $\pm V_{CC}$
- In reality, single-supply design $(+V_{CC}, 0)$ is often needed:
  - Adopt power sources already available (e.g., 5 V logic rail)
  - Can be powered with batteries
  - Reduce costs
- Circuits must be redesigned to work with single supply (see Appendix 1)

Internal circuit (block scheme)



Slew rate

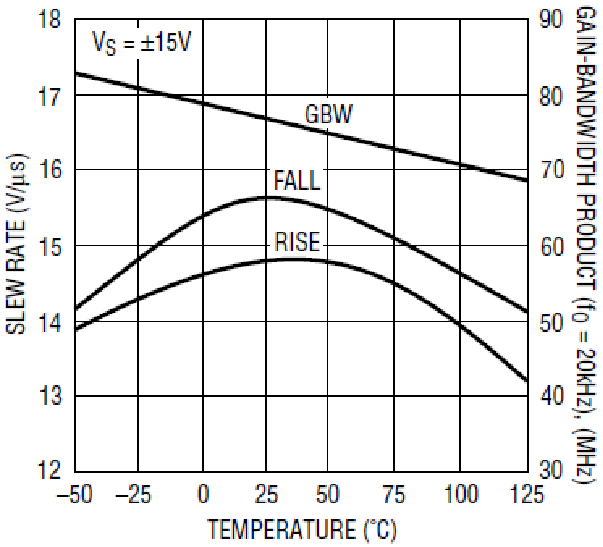


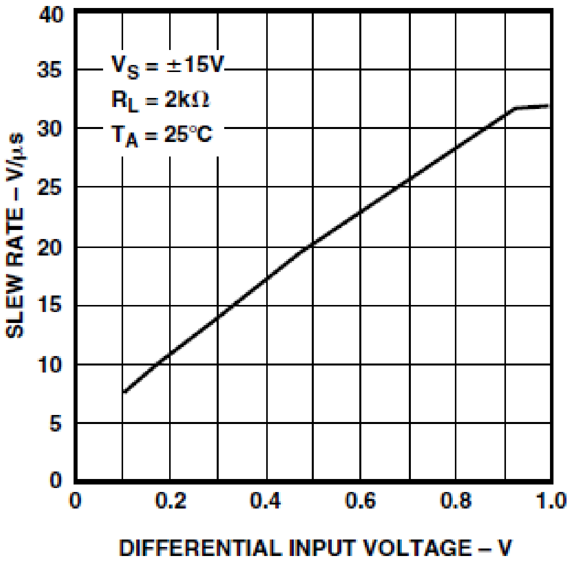


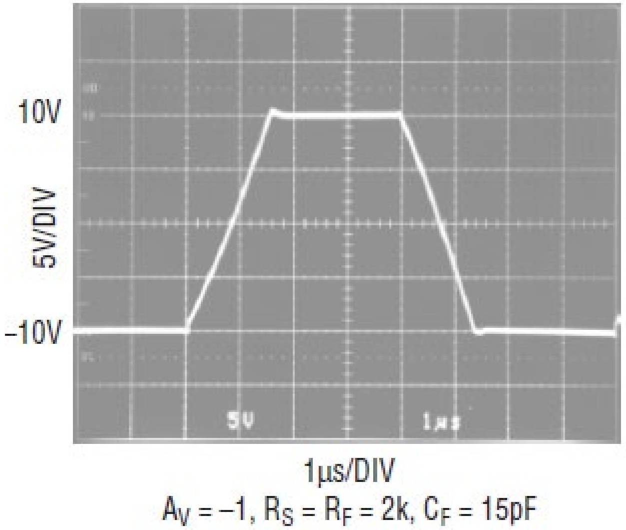
$$SR = \left.\frac{dV_o}{dt}\right|_{max} = \frac{I_{max}}{C}$$

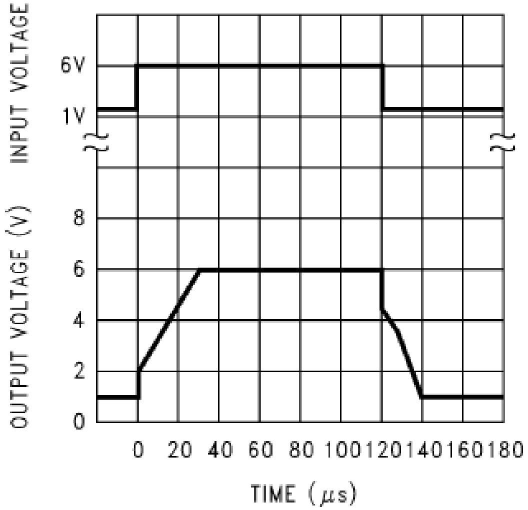
Typical values are 1 V/μs – 100 V/μs or more

Slew rate (large signal response)









Full-power Bandwidth

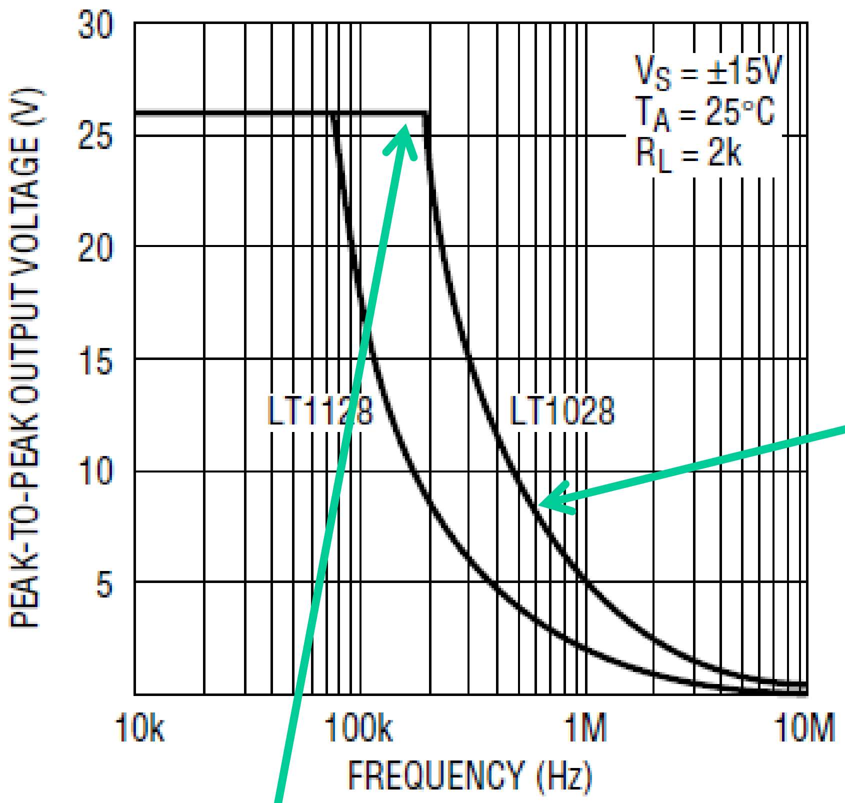
$$V_o = V_M \sin(\omega t)$$

$$\left.\frac{dV_o}{dt}\right|_{max} = \omega V_M < SR$$

The OA can work at the maximum swing, V_o^{max}, without being limited by SR if

$$f \leq \frac{SR}{2\pi V_o^{max}} = FPBW$$

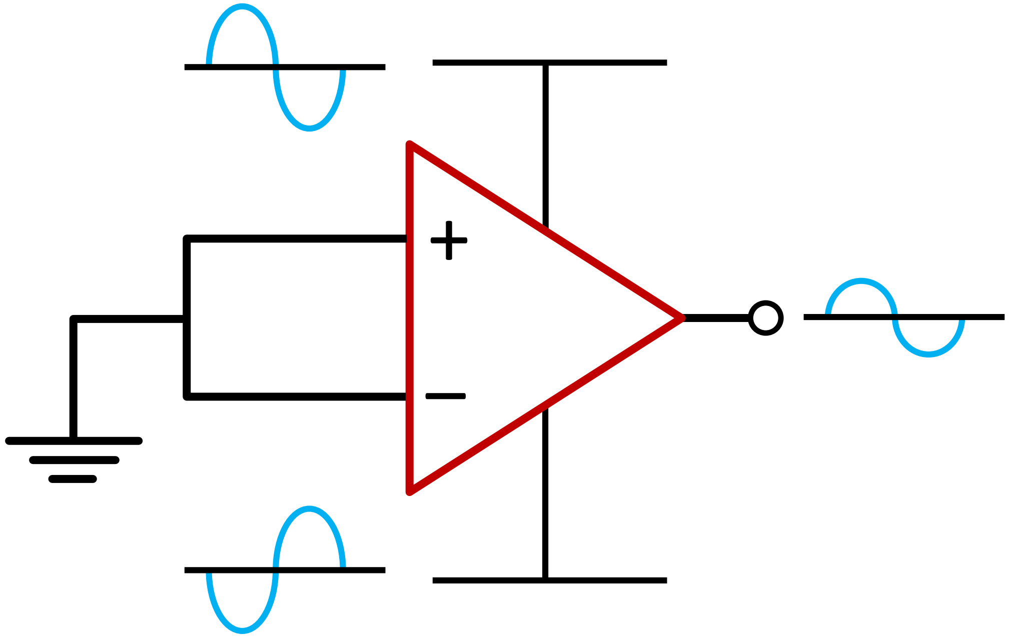
Full-power bandwidth

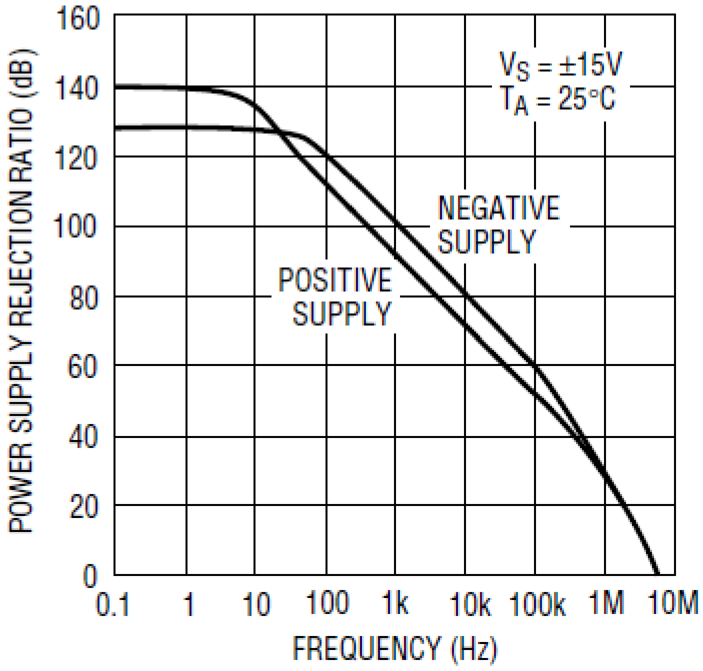


$$2\pi f V_o = SR$$

$$FPBW = \frac{SR}{2\pi V_o^{max}}$$

Power supply rejection ratio





- PSRR is the ratio between the PS disturbs and the differential signal that gives the same output
- Typical values are 80 – 100 dB (decreasing at high frequency)

Outline

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Circuit simulation

- Numerical simulation is always used to refine the initial draft project
- Many tools are available, supporting all stages of the design process for both ICs and discretes
- Here we will briefly discuss how to use Simulink (a Matlab tool) to simulate our circuits
  - Matlab is freely available to PoliMI students

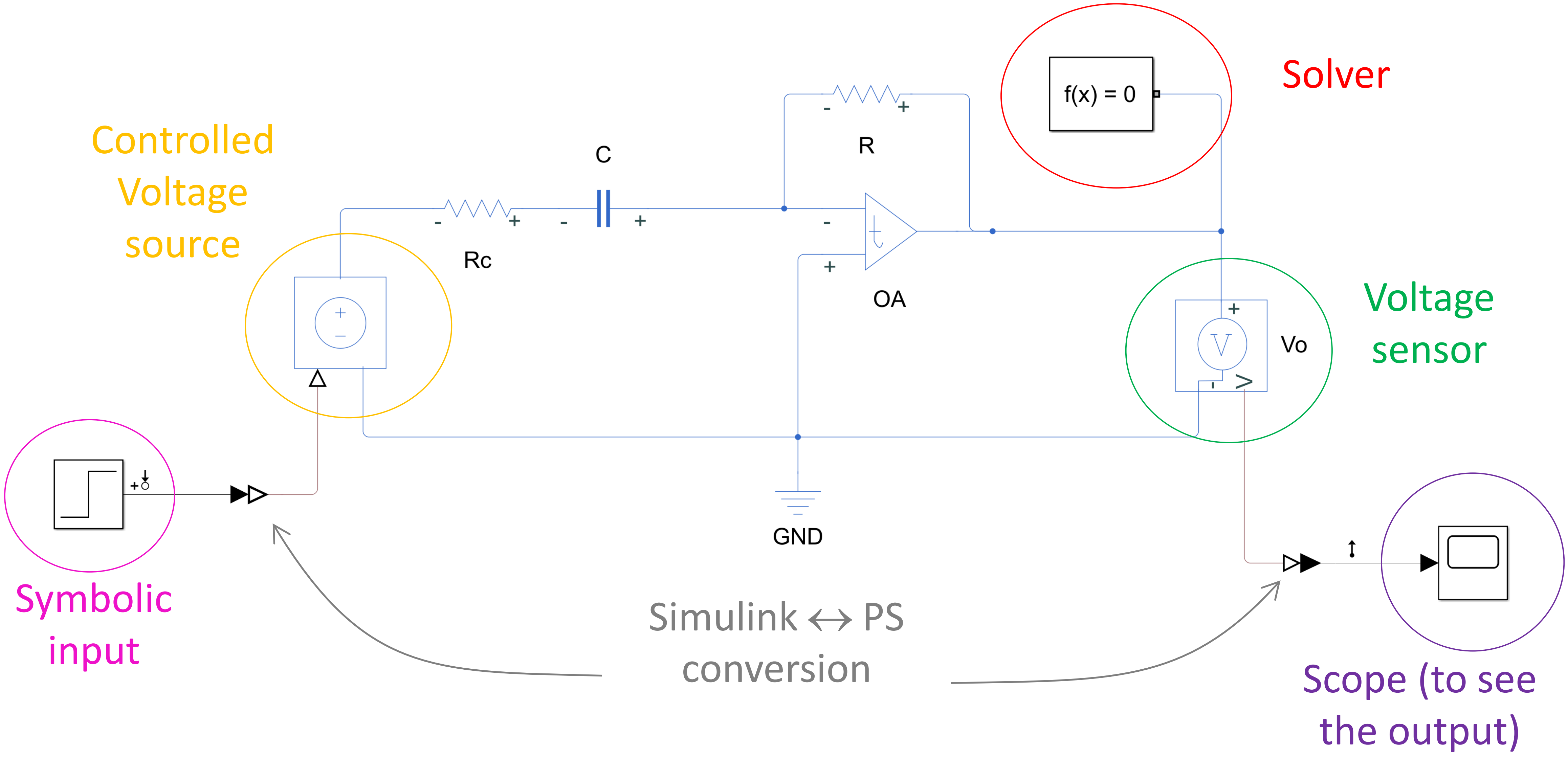
The basics

- To start a new project:
  - Matlab ⇒ Simulink ⇒ New ⇒ From Template ⇒ Model ⇒ Simscape ⇒ Electrical
- To add a component:
  - Library Browser ⇒ Simscape
    - Foundation Library ⇒ Electrical
    - Electrical

Library content

Library	Main Submenu	Main Content
Foundation Library ⇒ Electrical	Electrical Sources	AC/DC V/I sources, controlled V/I sources
	Electrical Elements	R, L, C, ground, ideal OA
	Electrical Sensors	V/I sensors
Electrical	Sources	Positive/negative supply rails, piecewise linear V/I sources, pulse V/I sources
	Passive	R, L, C, and more…
	Integrated Circuits	Band-limited OA, Fully-differential OA, logic

Typical circuit (taken from Drill #2)



Linear analysis

- Start the linearization tool:
  - APPS (or Linearization) $\Rightarrow$ Model Linearizer $\Rightarrow$
    - Step
    - Bode
    - Impulse
- Note: this performs a linear analysis $\Rightarrow$ non-linear effects such as those resulting from slew-rate, output voltage saturation and so on are NOT included

Non-linear analysis (transient)

- Replace the input with – say – a piecewise linear V/I source (no conversion needed) and set its parameters
- Set the simulation time and click Run
- Double-click on the Scope to see the output

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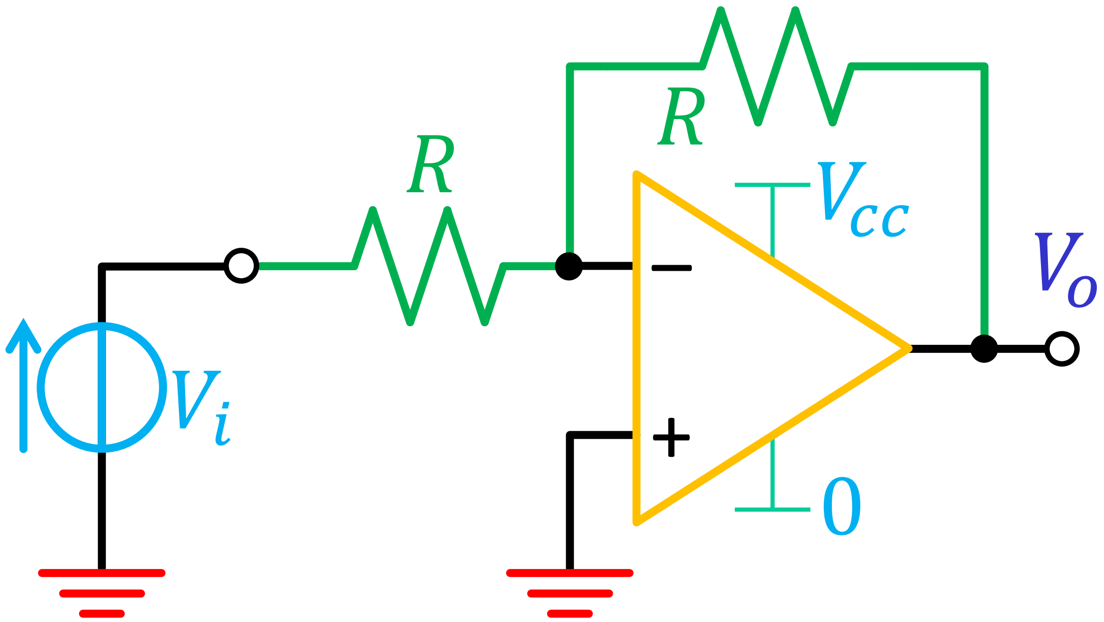
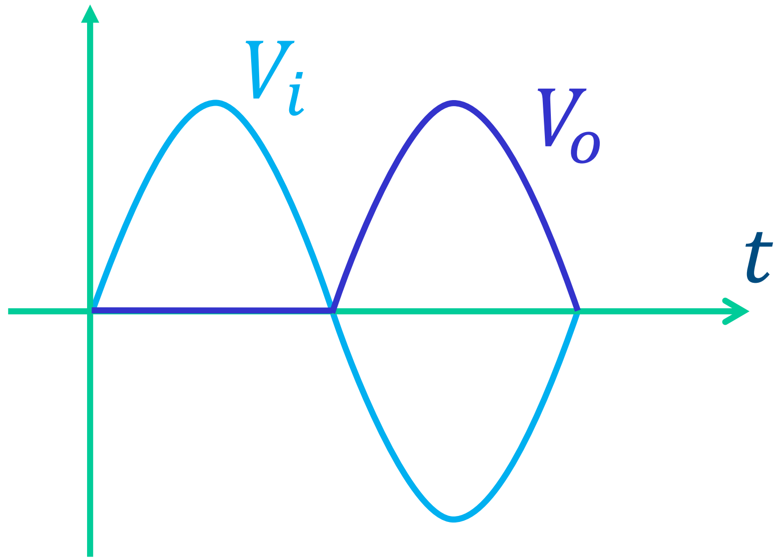
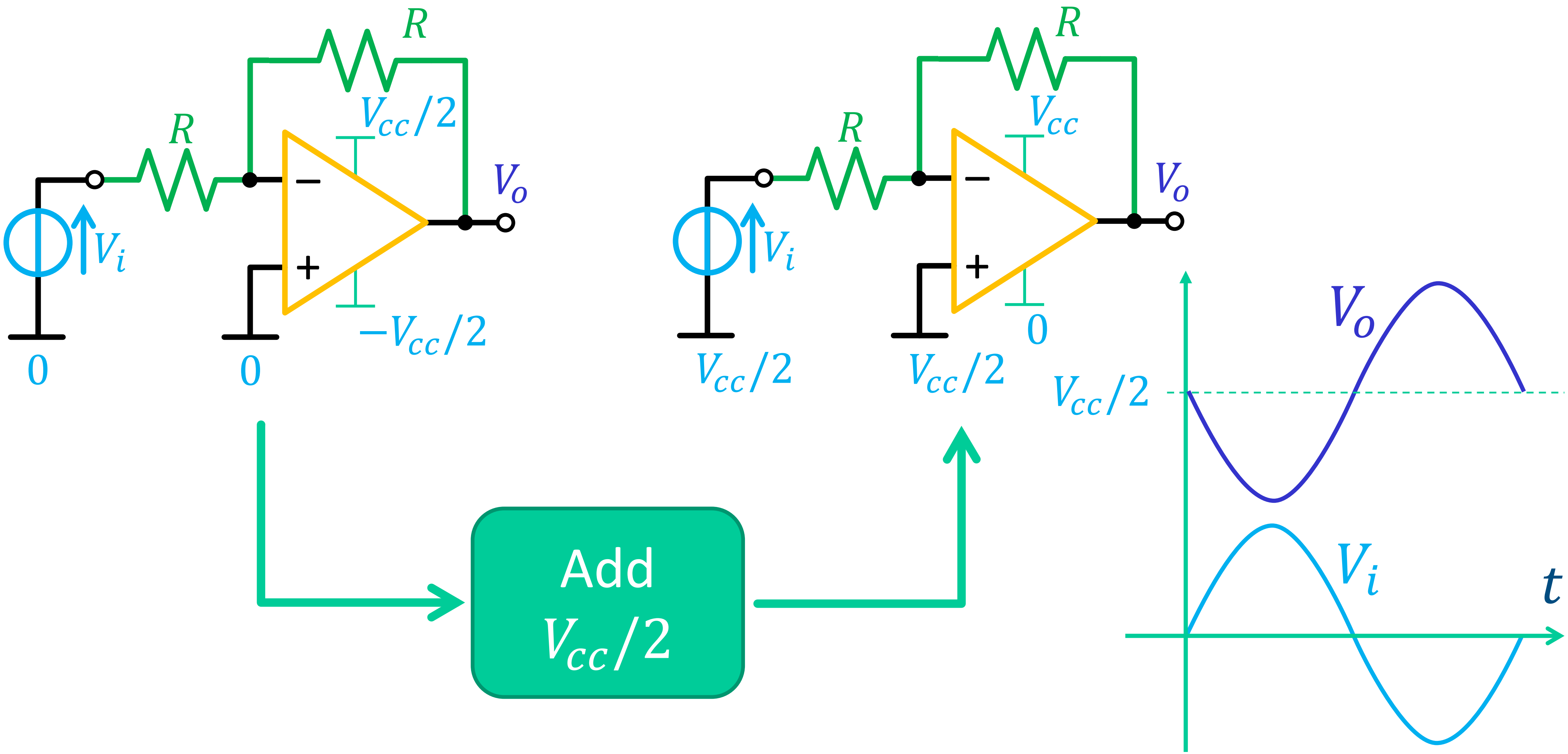
Example: inverting amplifier





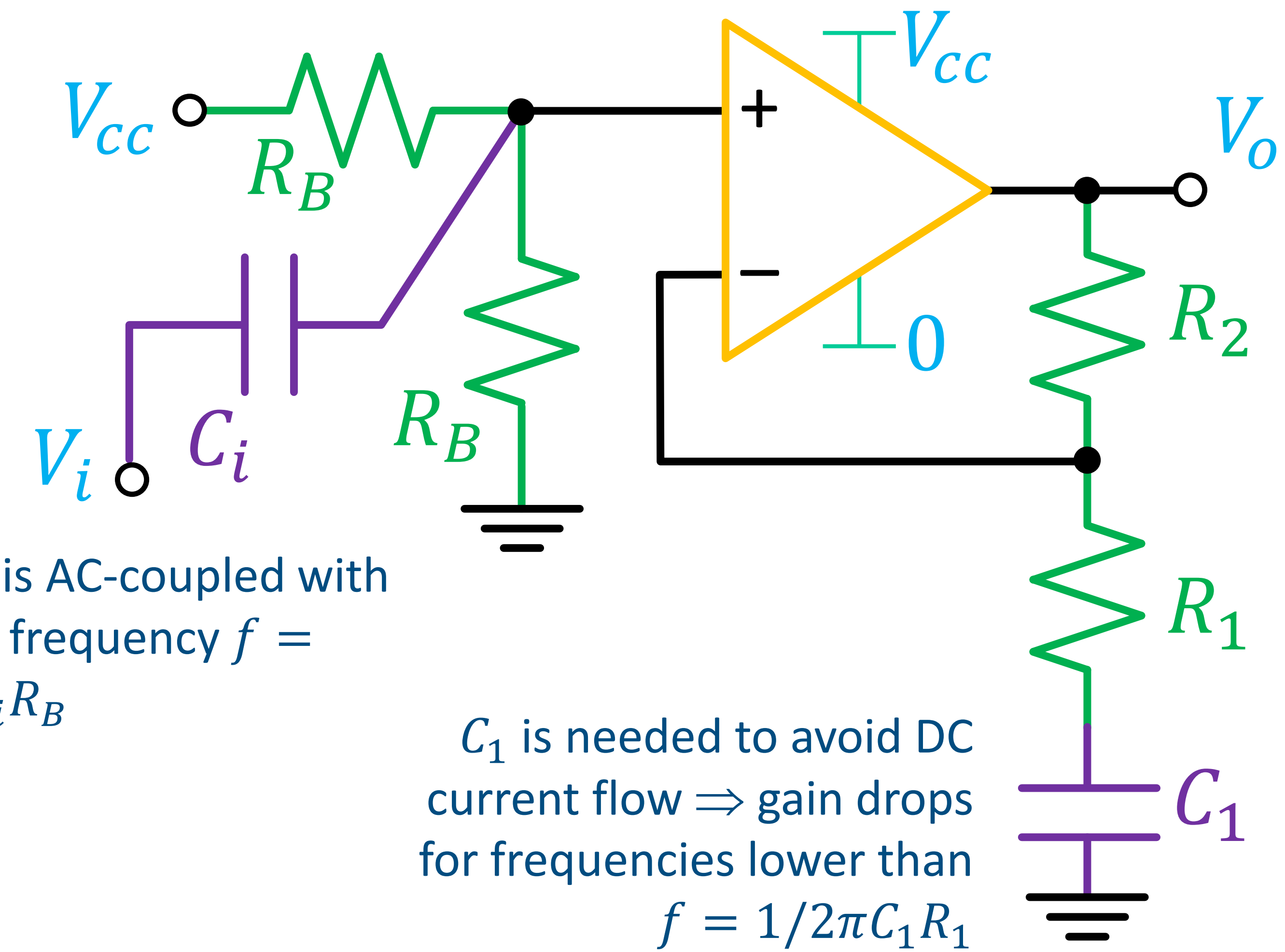
- V_o cannot drop below the lower power supply
- Even negative values of V_i can undermine proper operation
- A new voltage reference point must be chosen for single-supply operation

Voltage reference point



Actual scheme (non-inverting amplifier)

Rejection of PS disturbs can be an issue

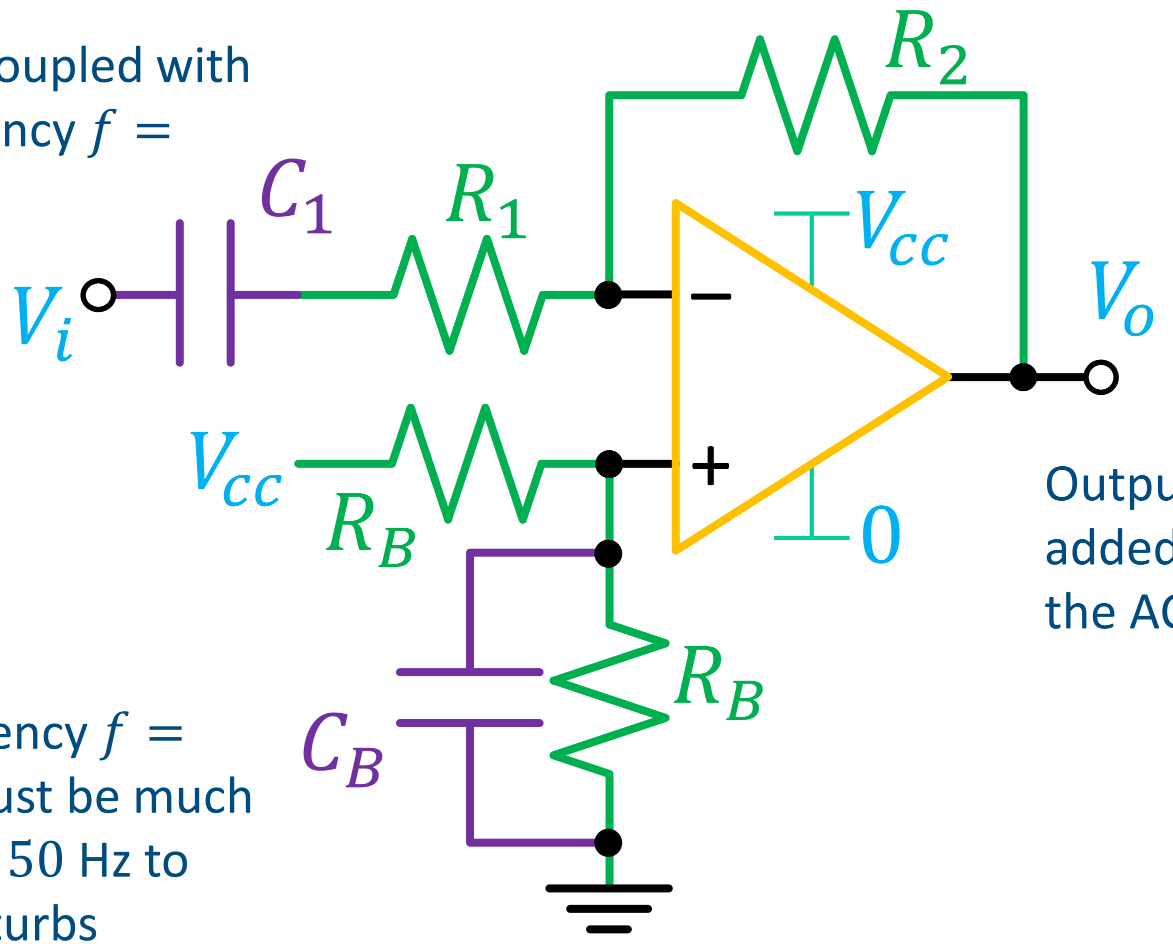


Input is AC-coupled with lower frequency $f = 1/\pi C_i R_B$

C_1 is needed to avoid DC current flow ⇒ gain drops for frequencies lower than $f = 1/2\pi C_1 R_1$

Actual scheme (inverting amplifier)

Input is AC-coupled with lower frequency $f = 1/2\pi C_1 R_1$



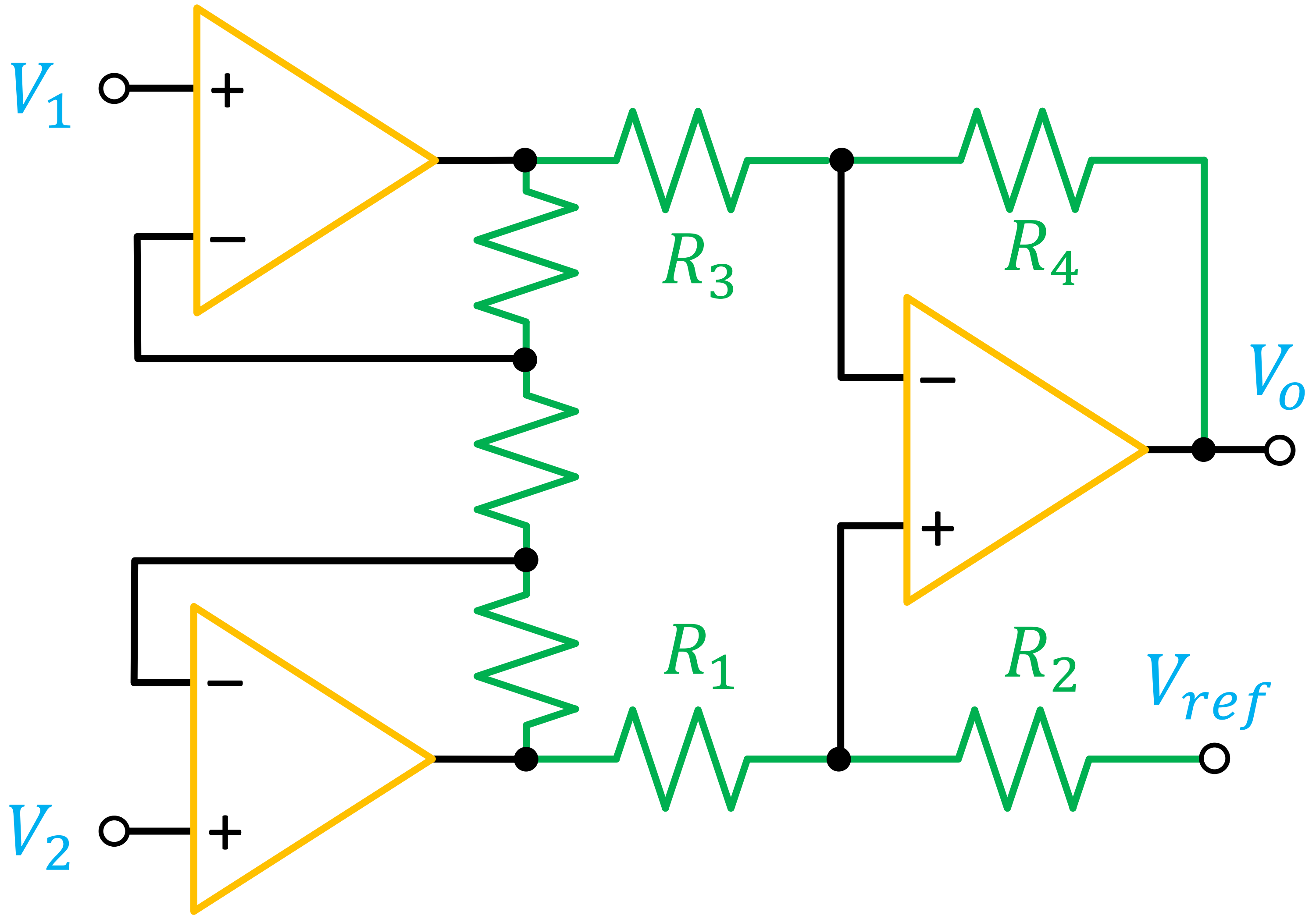
Cutoff frequency $f = 1/\pi C_B R_B$ must be much smaller than 50 Hz to reject PS disturbs

Output capacitor can be added if interested in the AC signal only

Comments

- R_B should minimize power dissipation (high values) and bias/offset current errors (low values)
- Zener-diode biasing or linear voltage regulators are often used to provide the $V_{cc}/2$ reference
- In the NI scheme, the input can be decoupled to the $V_{cc}/2$ reference via an additional resistor and capacitor (see [3] for discussion)

Single-supply INA



An additional input is provided, which sets the reference output voltage. This is usually grounded for dual-supply operation, but should be set at around $V_{CC}/2$ for single supply

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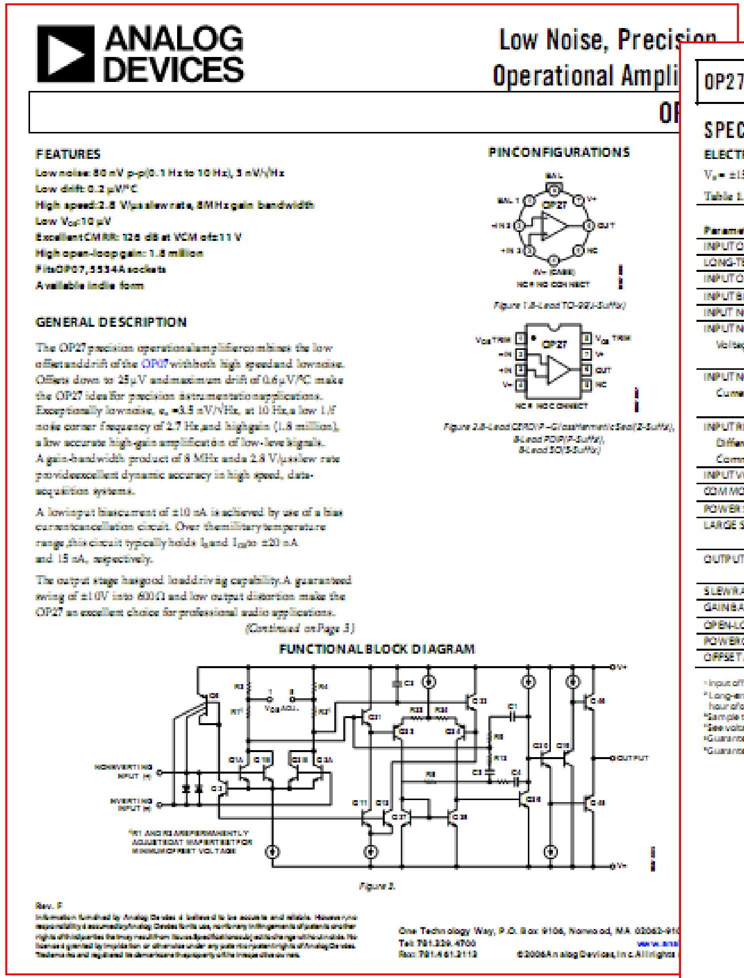
OA datasheets


ANALOG DEVICES

Low Noise, Precision Operational Ampli[fier]

OP[27]

FEATURES

Low noise: 80 nV p-p (0.1 Hz to 10 Hz), 3 nV/√Hz
Low drift: 0.2 µV/°C
High speed: 2.8 V/µs slew rate, 8 MHz gain bandwidth
Low V_{OS}: 10 µV
Excellent CMRR: 126 dB at VCM of ±11 V
High open-loop gain: 1.8 million
Fits OP07, 5534A sockets
Available in die form

GENERAL DESCRIPTION

The OP27 precision operational amplifier combines the low offset and drift of the OP07 with both high speed and low noise. Offsets down to 25 µV and maximum drift of 0.6 µV/°C make the OP27 ideal for precision instrumentation applications. Exceptionally low noise, e_n = 3.5 nV/√Hz, at 10 Hz, a low 1/f noise corner frequency of 2.7 Hz, and high gain (1.8 million), allow accurate high-gain amplification of low-level signals. A gain-bandwidth product of 8 MHz and a 2.8 V/µsec slew rate provides excellent dynamic accuracy in high speed, data-acquisition systems.

A low input bias current of ±10 nA is achieved by use of a bias current cancellation circuit. Over the military temperature range, this circuit typically holds I_B and I_{OS} to ±20 nA and 15 nA, respectively.

The output stage has good load driving capability. A guaranteed swing of ±10 V into 600 Ω and low output distortion make the OP27 an excellent choice for professional audio applications.

(Continued on Page 3)

PIN CONFIGURATIONS

Figure 1. 8-Lead TO-99 (J-Suffix)

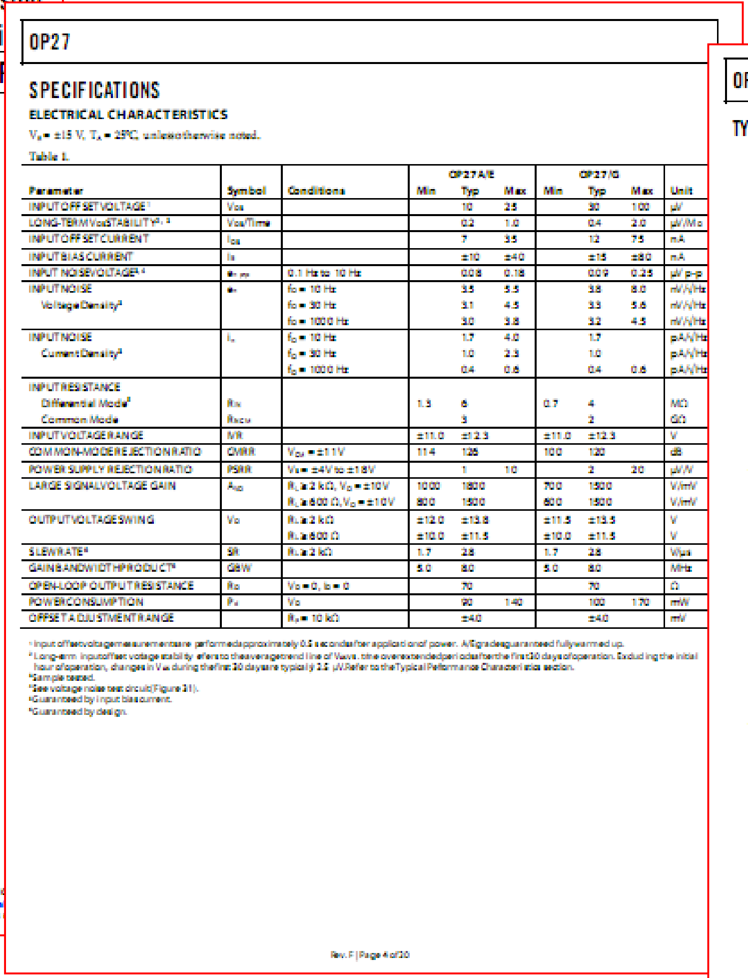
Figure 2. 8-Lead CERDIP – Glass Hermetic Seal (Z-Suffix), 8-Lead PDIP (P-Suffix), 8-Lead SOIC (S-Suffix)

FUNCTIONAL BLOCK DIAGRAM

Figure 3.

Rev. F

One Technology Way, P.O. Box 9106, Norwood, MA 02062-91[06]
Tel: 781.329.4700
Fax: 781.461.3113


OP27

SPECIFICATIONS

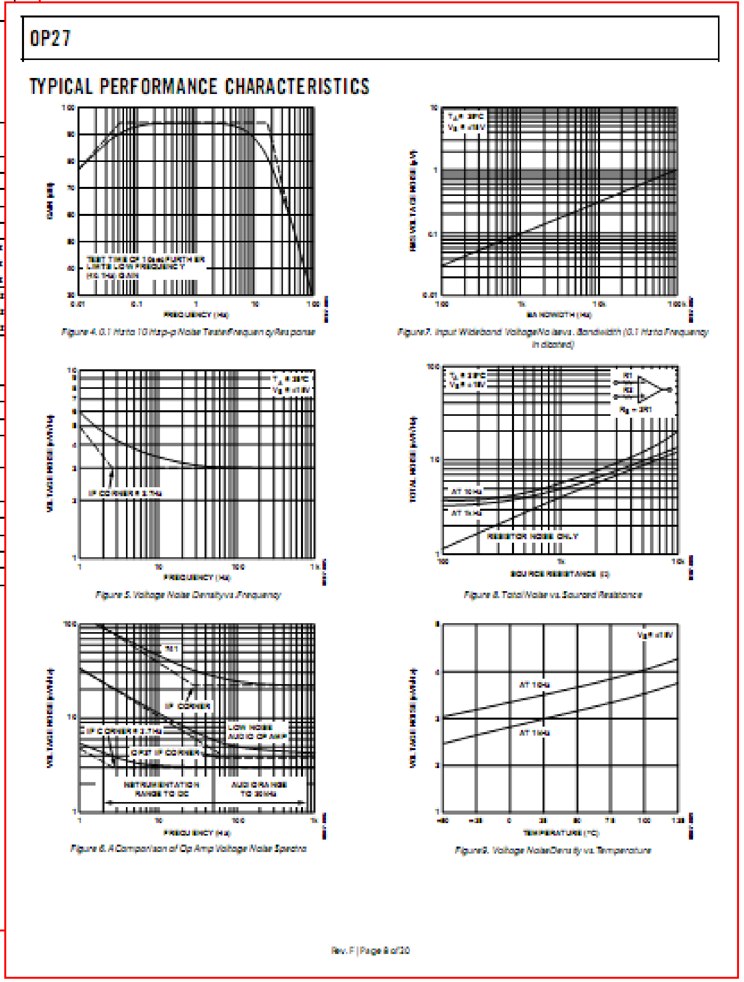
ELECTRICAL CHARACTERISTICS

V_S = ±15 V, T_A = 25°C, unless otherwise noted.

Table 1.

Parameter	Symbol	Conditions	OP27A/E Min	OP27A/E Typ	OP27A/E Max	OP27G Min	OP27G Typ	OP27G Max	Unit
INPUT OFFSET VOLTAGE[1]	V_{OS}			10	25		30	100	µV
LONG-TERM V_{OS} STABILITY[2, 3]	V_{OS}/Time			0.2	1.0		0.4	2.0	µV/Mo
INPUT OFFSET CURRENT	I_{OS}			7	35		12	75	nA
INPUT BIAS CURRENT	I_B			±10	±40		±15	±80	nA
INPUT NOISE VOLTAGE[3, 4]	$e_{n\,p\text{-}p}$	0.1 Hz to 10 Hz		0.08	0.18		0.09	0.25	µV p-p
INPUT NOISE Voltage Density[3]	e_n	f_O = 10 Hz		3.5	5.5		3.8	8.0	nV/√Hz
		f_O = 30 Hz		3.1	4.5		3.3	5.6	nV/√Hz
		f_O = 1000 Hz		3.0	3.8		3.2	4.5	nV/√Hz
INPUT NOISE Current Density[3]	i_n	f_O = 10 Hz		1.7	4.0		1.7		pA/√Hz
		f_O = 30 Hz		1.0	2.3		1.0		pA/√Hz
		f_O = 1000 Hz		0.4	0.6		0.4	0.6	pA/√Hz
INPUT RESISTANCE Differential Mode[5]	R_{IN}		1.3	6		0.7	4		MΩ
Common Mode	R_{INCM}			3			2		GΩ
INPUT VOLTAGE RANGE	IVR		±11.0	±12.3		±11.0	±12.3		V
COMMON-MODE REJECTION RATIO	CMRR	V_{CM} = ±11 V	114	126		100	120		dB
POWER SUPPLY REJECTION RATIO	PSRR	V_S = ±4 V to ±18 V		1	10		2	20	µV/V
LARGE SIGNAL VOLTAGE GAIN	A_{VO}	R_L ≥ 2 kΩ, V_O = ±10 V	1000	1800		700	1500		V/mV
		R_L ≥ 600 Ω, V_O = ±10 V	800	1500		600	1500		V/mV
OUTPUT VOLTAGE SWING	V_O	R_L ≥ 2 kΩ	±12.0	±13.8		±11.5	±13.5		V
		R_L ≥ 600 Ω	±10.0	±11.5		±10.0	±11.5		V
SLEW RATE[6]	SR	R_L ≥ 2 kΩ	1.7	2.8		1.7	2.8		V/µs
GAIN BANDWIDTH PRODUCT[6]	GBW		5.0	8.0		5.0	8.0		MHz
OPEN-LOOP OUTPUT RESISTANCE	R_O	V_O = 0, I_O = 0		70			70		Ω
POWER CONSUMPTION	P_d	V_O		90	140		100	170	mW
OFFSET ADJUSTMENT RANGE		R_P = 10 kΩ		±4.0			±4.0		mV

[1] Input offset voltage measurements are performed approximately 0.5 seconds after application of power. A/E grades guaranteed fully warmed up.
[2] Long-term input offset voltage stability refers to the average trend line of V_{OS} vs. time over extended periods after the first 30 days of operation. Excluding the initial hour of operation, changes in V_{OS} during the first 30 days are typically 2.5 µV. Refer to the Typical Performance Characteristics section.
[3] Sample tested.
[4] See voltage noise test circuit (Figure 31).
[5] Guaranteed by input bias current.
[6] Guaranteed by design.


OP27

TYPICAL PERFORMANCE CHARACTERISTICS

Figure 4. 0.1 Hz to 10 Hz p-p Noise Tester Frequency Response

Figure 7. Input Wideband Voltage Noise vs. Bandwidth (0.1 Hz to Frequency Indicated)

Figure 5. Voltage Noise Density vs. Frequency

Figure 8. Total Noise vs. Source Resistance

Figure 6. A Comparison of Op Amp Voltage Noise Spectra

Figure 9. Voltage Noise Density vs. Temperature

Datasheet anatomy

- *Features & General description* (sometimes with *Block diagram*, *Schematic* and *Applications*)
- *Absolute maximum ratings*
- *Electrical characteristics*
- *Typical performance characteristics*
- Other info (dimensions, package and ordering info, etc.)

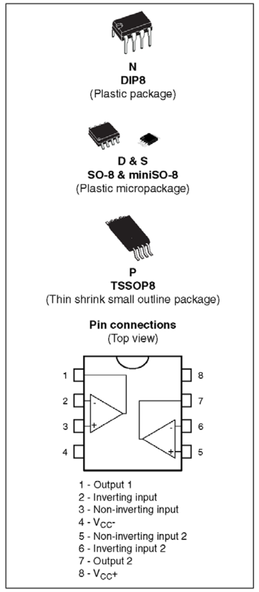
Features/Description

LM158-LM258-LM358

Low power dual operational amplifiers

Features

- Internally frequency-compensated
- Large DC voltage gain: 100 dB
- Wide bandwidth (unity gain): 1.1 MHz (temperature compensated)
- Very low supply current per operator essentially independent of supply voltage
- Low input bias current: 20 nA (temperature compensated)
- Low input offset voltage: 2 mV
- Low input offset current: 2 nA
- Input common-mode voltage range includes negative rails
- Differential input voltage range equal to the power supply voltage
- Large output voltage swing 0 V to (V_{CC}^{+} - 1.5V)



Description

These circuits consist of two independent, high-gain, internally frequency-compensated op-amps, which are specifically designed to operate from a single power supply over a wide range of voltages. The low-power supply drain is independent of the magnitude of the power supply voltage.

Application areas include transducer amplifiers, DC gain blocks and all the conventional op-amp circuits, which can now be more easily implemented in single power supply systems. For example, these circuits can be directly supplied with the standard +5 V, which is used in logic systems and will easily provide the required interface electronics with no additional power supply.

In linear mode, the input common-mode voltage range includes ground and the output voltage can also swing to ground, even though operated from only a single power supply voltage.

August 2008 Rev 8

www.st.com

LT1028/LT1128

Ultralow Noise Precision High Speed Op Amps

FEATURES

- Voltage Noise
  1.1nV/√Hz Max at 1kHz
  0.85nV/√Hz Typ at 1kHz
  1.0nV/√Hz Typ at 10Hz
  35nV$_{P-P}$ Typ, 0.1Hz to 10Hz
- Voltage and Current Noise 100% Tested
- Gain-Bandwidth Product
  LT1028: 50MHz Min
  LT1128: 13MHz Min
- Slew Rate
  LT1028: 11V/µs Min
  LT1128: 5V/µs Min
- Offset Voltage: 40µV Max
- Drift with Temperature: 0.8µV/°C Max
- Voltage Gain: 7 Million Min
- Available in 8-Pin SO Package

APPLICATIONS

- Low Noise Frequency Synthesizers
- High Quality Audio
- Infrared Detectors
- Accelerometer and Gyro Amplifiers
- 350Ω Bridge Signal Conditioning
- Magnetic Search Coil Amplifiers
- Hydrophone Amplfiers

DESCRIPTION

The LT®1028(gain of –1 stable)/LT1128(gain of +1 stable) achieve a new standard of excellence in noise performance with 0.85nV/√Hz 1kHz noise, 1.0nV/√Hz 10Hz noise. This ultralow noise is combined with excellent high speed specifications (gain-bandwidth product is 75MHz for LT1028, 20MHz for LT1128), distortion-free output, and true precision parameters (0.1µV/°C drift, 10µV offset voltage, 30 million voltage gain). Although the LT1028/LT1128 input stage operates at nearly 1mA of collector current to achieve low voltage noise, input bias current is only 25nA.

The LT1028/LT1128's voltage noise is less than the noise of a 50Ω resistor. Therefore, even in very low source impedance transducer or audio amplifier applications, the LT1028/LT1128's contribution to total system noise will be negligible.

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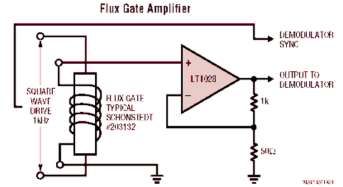
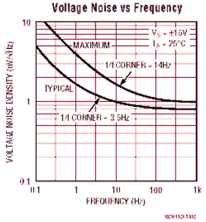
TYPICAL APPLICATION

Flux Gate Amplifier



Voltage Noise vs Frequency



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OA families

- General purpose
- High speed
- Precision
- Low bias current
- Low noise
- Low power
- Other (zero drift, rail-to-rail, high voltage, high output current,…)

Absolute maximum ratings

OP275

ABSOLUTE MAXIMUM RATINGS[1]

Supply Voltage	±22 V
Input Voltage[2]	±22 V
Differential Input Voltage[2]	±7.5 V
Output Short-Circuit Duration to GND[3]	Indefinite
Storage Temperature Range	
P, S Packages	–65°C to +150°C
Operating Temperature Range	
OP275G	–40°C to +85°C
Junction Temperature Range	
P, S Packages	–65°C to +150°C
Lead Temperature Range (Soldering, 60 sec)	300°C

Package Type	θ_{JA}[4]	θ_{JC}	Unit
8-Lead Plastic DIP (P)	103	43	°C/W
8-Lead SOIC (S)	158	43	°C/W

NOTES

[1]Absolute maximum ratings apply to packaged parts, unless otherwise noted.

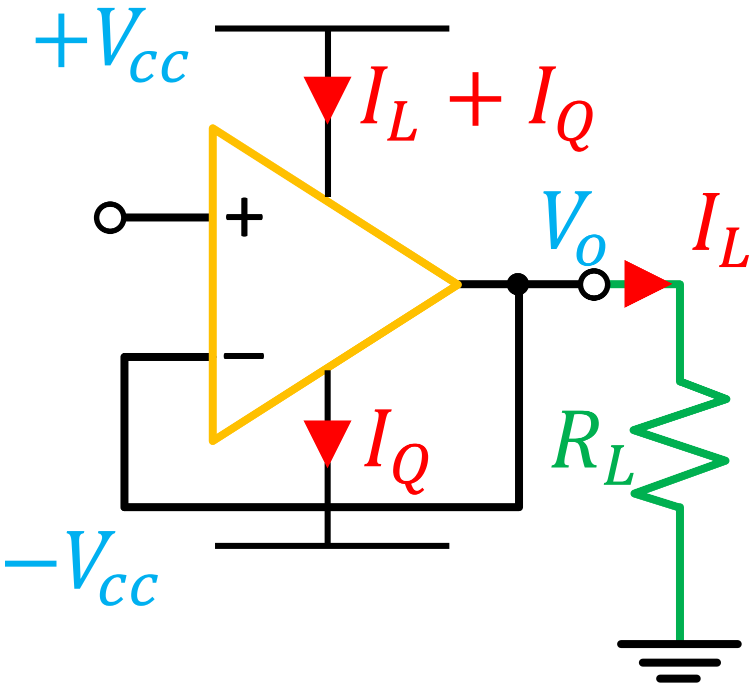
[2]For supply voltages greater than ±22 V, the absolute maximum input voltage is equal to the supply voltage.

[3]Shorts to either supply may destroy the device. See data sheet for full details.

[4]θ_{JA} is specified for the worst-case conditions, i.e., θ_{JA} is specified for device in socket for PDIP packages; θ_{JA} is specified for device soldered in circuit board for SOIC packages.

AMRs are the maximum values of few key parameters that the OA can safely tolerate. Operation beyond them leads to permanent damage

Power dissipation calculation



$$P_{R_L} = V_o I_L$$

$$P_{OA} = 2V_{cc}I_Q + (V_{cc} - V_o)I_L$$

Example: $V_{cc} = 10$ V, $V_o = 2$ V, $R_L = 500\ \Omega \Rightarrow I_L = 4$ mA

$P_{R_L} = 8$ mW, $P_{OA} \approx 32$ mW

- I_Q is a quiescent current always flowing when the OA is powered. Indicative values are 0.5 µA – 0.5 mA
- Do not confuse it with the supply current (its maximum value)

Power dissipation and temperature

- The increase in junction temperature limits the power dissipation

$$P_{max} = \frac{T_{Jmax} - T_A}{\theta_{JA}}$$

- Data from previous sheet: $T_{Jmax} = 150°\text{C}$, $\theta_{JA} = 103°\text{C/W}$. For $T_A = 25°\text{C}$, $P_{max} = 1.2\ \text{W}$
- Power OAs can reach several tens of W

Operating conditions

Table 2. Operating conditions

Symbol	Parameter	Value	Unit
V_{CC}	Supply voltage	3 to 30	V
V_{icm}	Common mode input voltage range[1]	V_{CC}^{-} -0.3 to V_{CC}^{+} -1.5	V
T_{oper}	Operating free air temperature range LM158 LM258 LM358	 -55 to +125 -40 to +105 0 to +70	°C

1. When used in comparator, the functionality is guaranteed as long as at least one input remains within the operating common mode voltage range.

Simply, the intervals that guarantee that the OA works as specified

Electrical characteristics

- Show the most important properties of the OA
- Typical, maximum and minimum values at the operating conditions are usually reported

Example

LT1028/LT1128

ELECTRICAL CHARACTERISTICS $V_S = \pm15V$, $T_A = 25°C$, unless otherwise noted.

SYMBOL	PARAMETER	CONDITIONS	LT1028AM/AC LT1128AM/AC MIN	TYP	MAX	LT1028M/C LT1128M/C MIN	TYP	MAX	UNITS
V_{OS}	Input Offset Voltage	(Note 2)		10	40		20	80	μV
$\frac{\Delta V_{OS}}{\Delta Time}$	Long Term Input Offset Voltage Stability	(Note 3)		0.3			0.3		μV/Mo
I_{OS}	Input Offset Current	$V_{CM} = 0V$		12	50		18	100	nA
I_B	Input Bias Current	$V_{CM} = 0V$		±25	±90		±30	±180	nA
e_n	Input Noise Voltage	0.1Hz to 10Hz (Note 4)		35	75		35	90	nV_{P-P}
	Input Noise Voltage Density	f_O = 10Hz (Note 5) f_O = 1000Hz, 100% tested		1.00 0.85	1.7 1.1		1.0 0.9	1.9 1.2	nV/√Hz nV/√Hz
I_n	Input Noise Current Density	f_O = 10Hz (Note 4 and 6) f_O = 1000Hz, 100% tested		4.7 1.0	10.0 1.6		4.7 1.0	12.0 1.8	pA/√Hz pA/√Hz
	Input Resistance Common Mode Differential Mode			300 20			300 20		MΩ kΩ
	Input Capacitance			5			5		pF
	Input Voltage Range		±11.0	±12.2		±11.0	±12.2		V
CMRR	Common Mode Rejection Ratio	$V_{CM} = \pm11V$	114	126		110	126		dB
PSRR	Power Supply Rejection Ratio	$V_S = \pm4V$ to $\pm18V$	117	133		110	132		dB
A_{VOL}	Large-Signal Voltage Gain	$R_L \geq 2k$, $V_O = \pm12V$ $R_L \geq 1k$, $V_O = \pm10V$ $R_L \geq 600\Omega$, $V_O = \pm10V$	7.0 5.0 3.0	30.0 20.0 15.0		5.0 3.5 2.0	30.0 20.0 15.0		V/μV V/μV V/μV
V_{OUT}	Maximum Output Voltage Swing	$R_L \geq 2k$ $R_L \geq 600\Omega$	±12.3 ±11.0	±13.0 ±12.2		±12.0 ±10.5	±13.0 ±12.2		V V
SR	Slew Rate	$A_{VCL} = -1$ LT1028 $A_{VCL} = -1$ LT1128	11.0 5.0	15.0 6.0		11.0 4.5	15.0 6.0		V/μs V/μs
GBW	Gain-Bandwidth Product	f_O = 20kHz (Note 7) LT1028 f_O = 200kHz (Note 7) LT1128	50 13	75 20		50 11	75 20		MHz MHz
Z_O	Open-Loop Output Impedance	$V_O = 0$, $I_O = 0$		80			80		Ω
I_S	Supply Current			7.4	9.5		7.6	10.5	mA

Voltage and temperature are usually specified

References

1. http://www.analog.com/media/en/technical-documentation/application-notes/AN-244.pdf
2. http://www.analog.com/en/education/education-library/dh-designers-guide-to-instrumentation-amps.html
3. http://www.analog.com/en/analog-dialogue/articles/avoiding-op-amp-instability-problems.html