Input & Output Limitations – 3

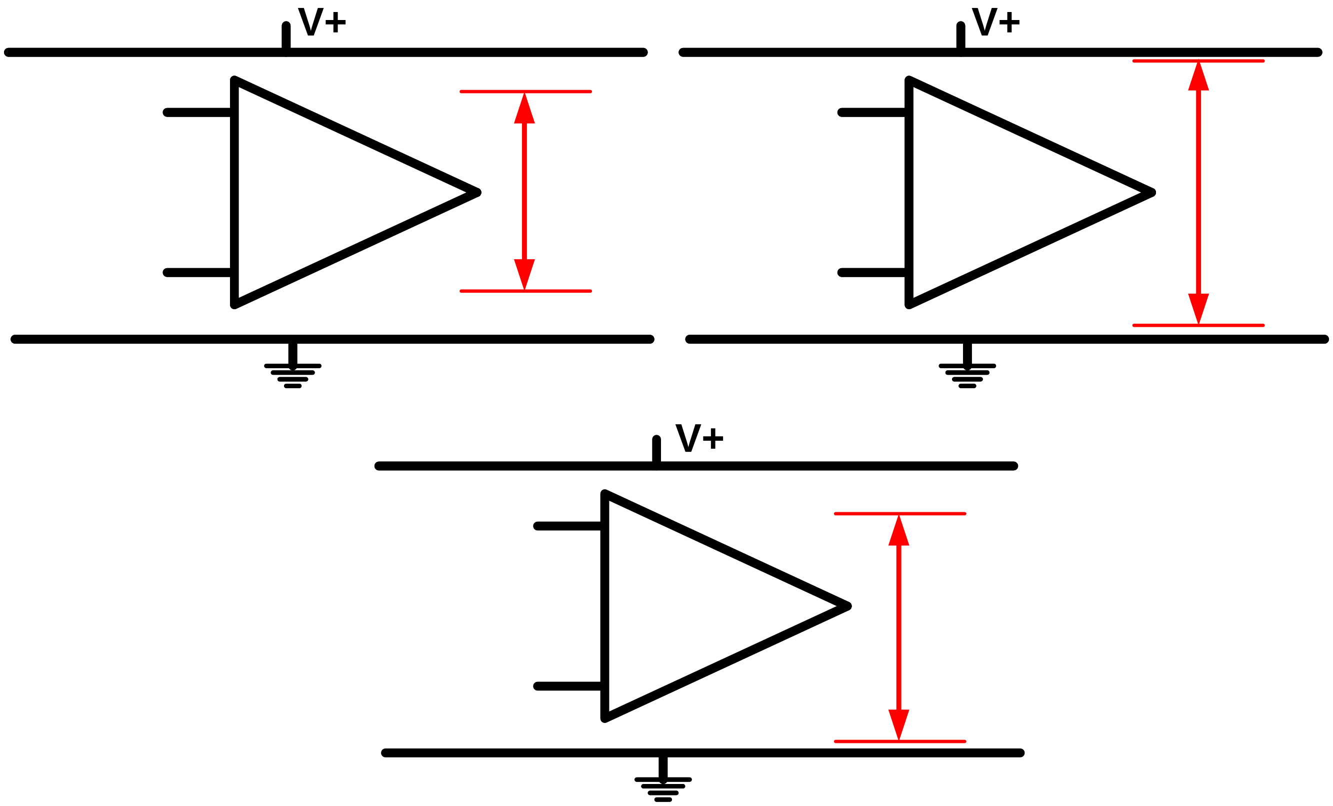
TIPL 1132
TI Precision Labs – Op Amps

Presented by Ian Williams

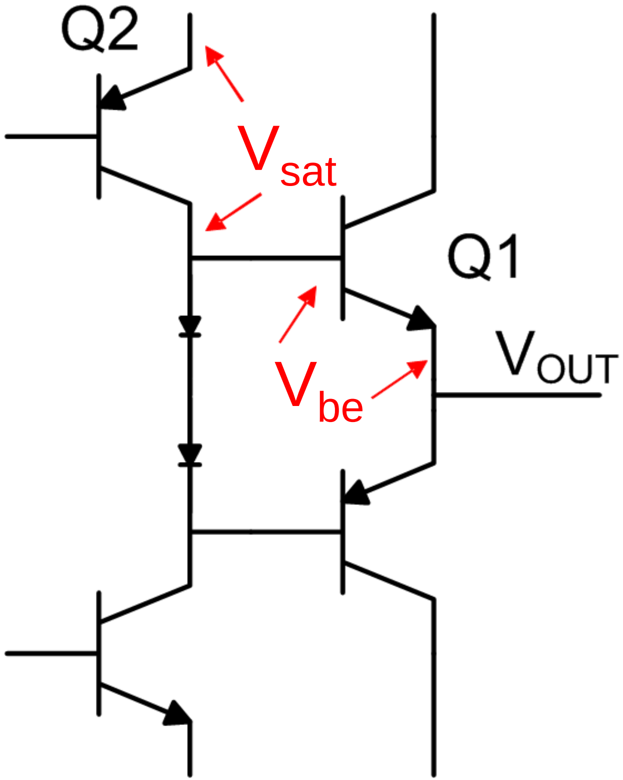
Prepared by Art Kay and Ian Williams

Prerequisites: Input & Output Limitations 1, 2
(TIPL 1130, TIPL 1131)

Real World Output Range



Classic Bipolar Output Stage

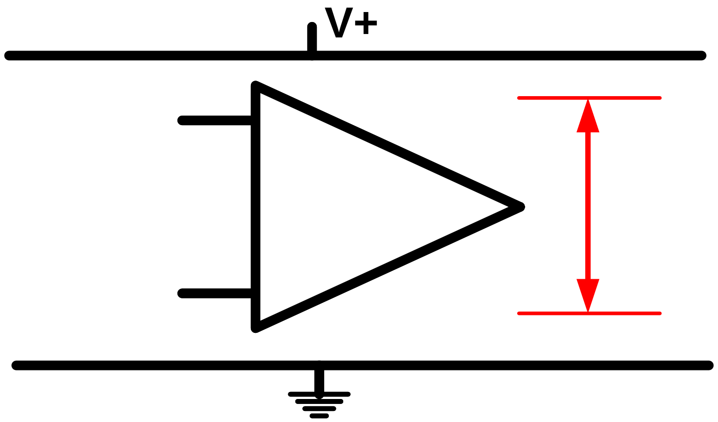


V_{OUT} swing headroom = $V_{sat} + V_{be}$

Therefore,

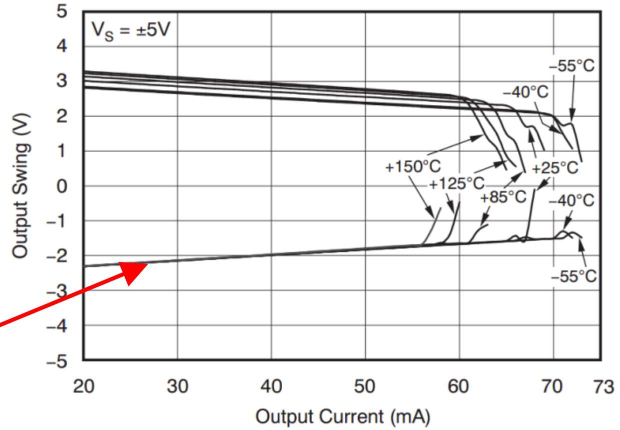
$V_{out\_max} < +V_S - V_{sat} - V_{be}$

$V_{out\_min} > -V_S + V_{sat} + V_{be}$

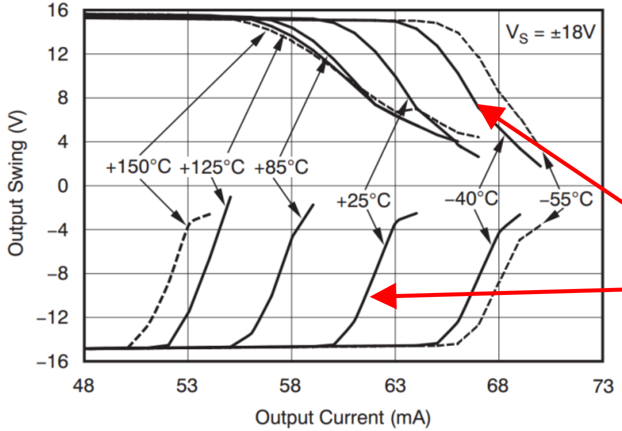


OPA827 – Classic Bipolar Output Stage

PARAMETER		CONDITIONS	STANDARD GRADE OPA827AI			UNIT
			MIN	TYP	MAX	
OUTPUT						
Voltage Output Swing		R_L = 1kΩ, A_{OL} > 120dB	(V–)+3		(V+)–3	V
Over Temperature		**R_L = 1kΩ, A_{OL} > 114dB**	**(V–)+3**		**(V+)–3**	**V**
Output Current	I_{OUT}	$\|V_S - V_{OUT}\| < 3V$		30		mA
Short-Circuit Current	I_{SC}			±65		mA



Output Saturated



Short Circuit Protection

OPA827 – Classic Bipolar Output Stage

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
OUTPUT					
Voltage Output Swing	R_L = 1kΩ, A_{OL} > 120dB	(V–)+3		(V+)–3	V

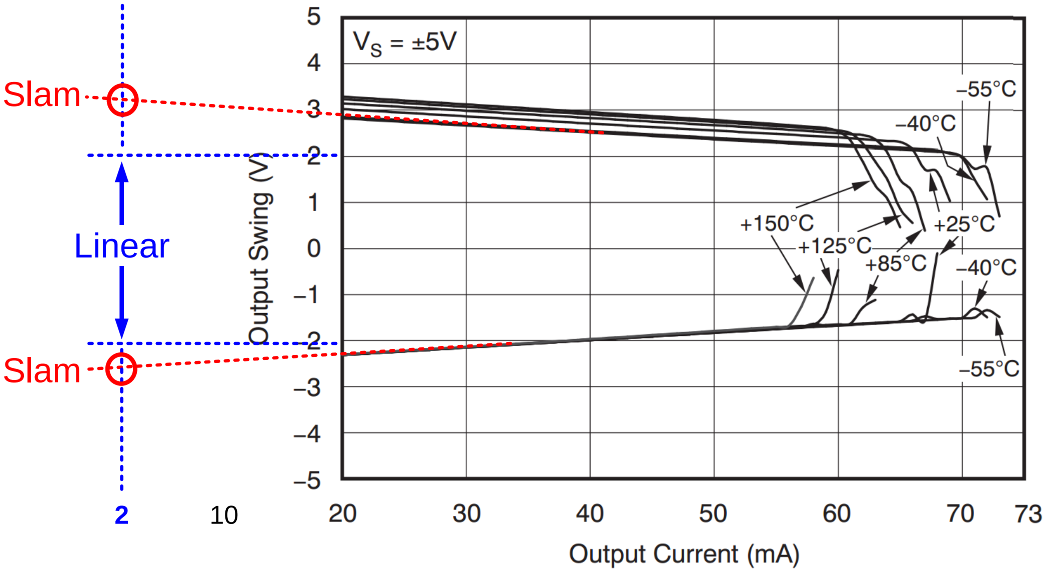
Output Swing (Specs Table)

V_{OUT} swing = 5V – 3V = ±2V

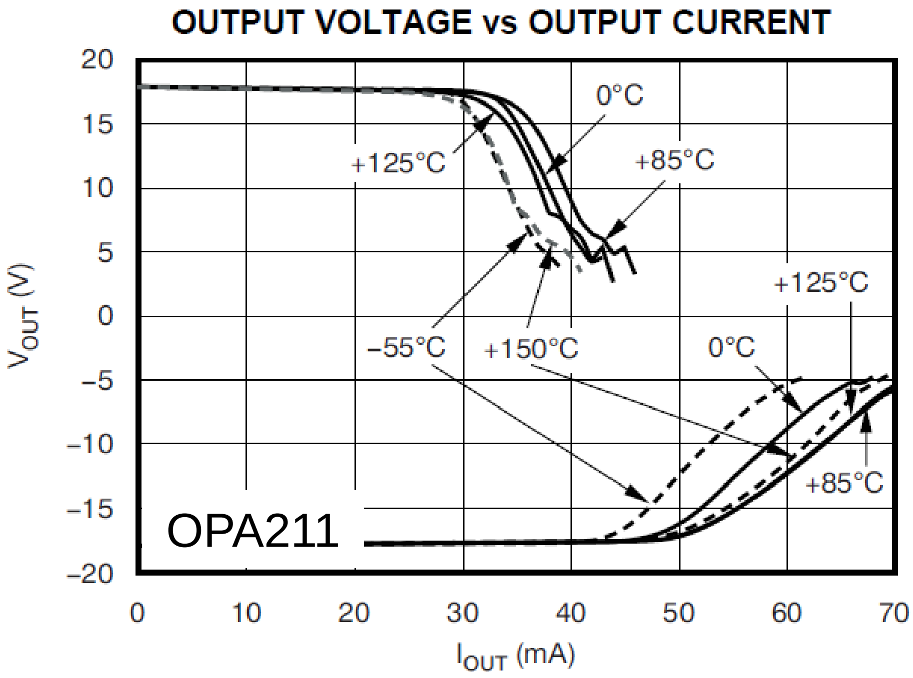
I_{OUT} = 2V / 1kΩ = 2mA

Output Swing (Claw Curve)

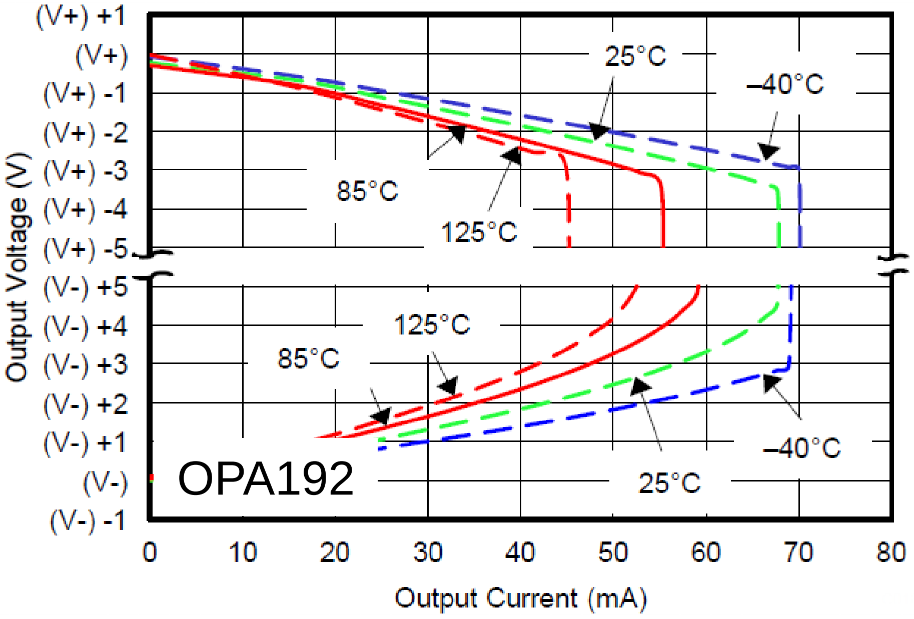
V_{OUT} swing ≈ ±3V (Slam @ 2mA)



Claw Curve – Bipolar vs. CMOS



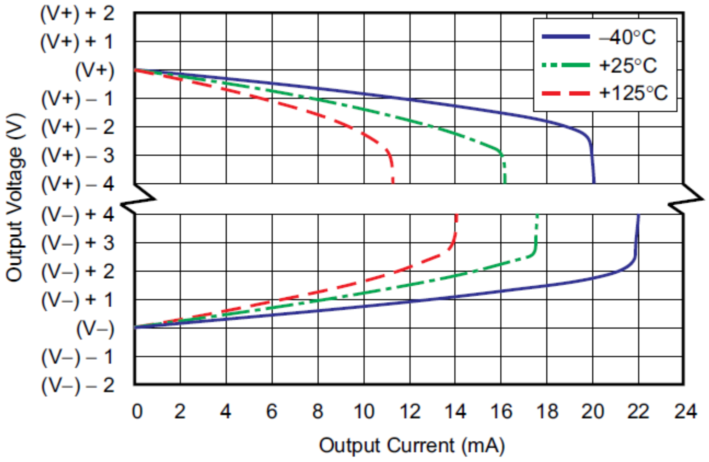
Bipolar



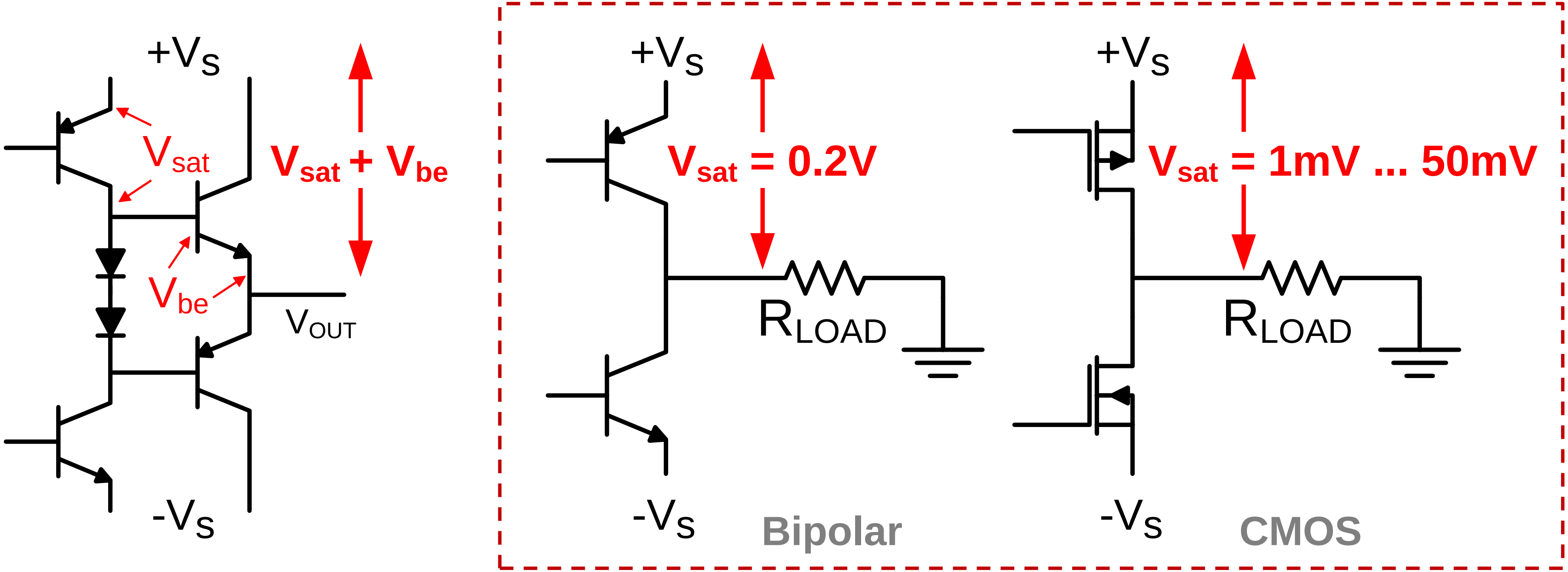
CMOS

Specs Table – Linear or Slam Voltage?

PARAMETER		CONDITIONS	MIN	TYP	MAX	UNIT
OUTPUT						
	Voltage output swing from rail	No load		6	15	mV
		R_L = 10 kΩ		220	250	mV
		T_A = –40°C to +125°C		310	350	mV
OPEN-LOOP GAIN						
A_{OL}	Open-loop voltage gain	(V–) + 0.5 V < V_O < (V+) – 0.5 V, R_L = 5 kΩ	110	120		dB
		(V–) + 0.5 V < V_O < (V+) – 0.5 V	120	130		dB

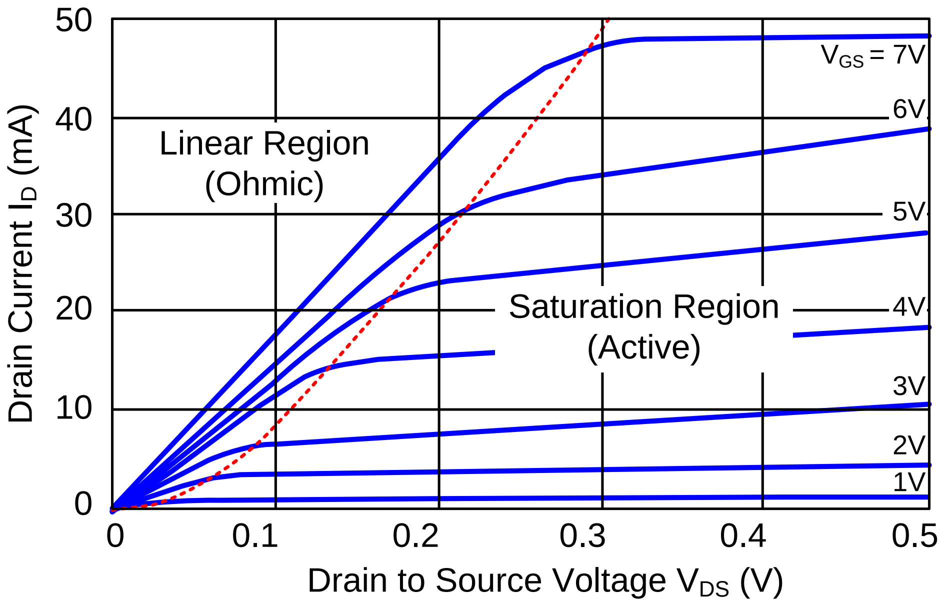


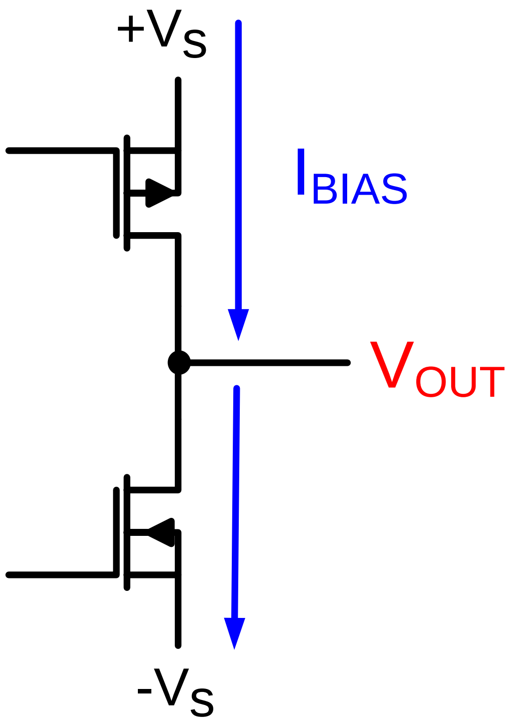
Classic Bipolar vs. Rail-to-Rail Output Stage



Classic Bipolar **Rail-to-Rail**

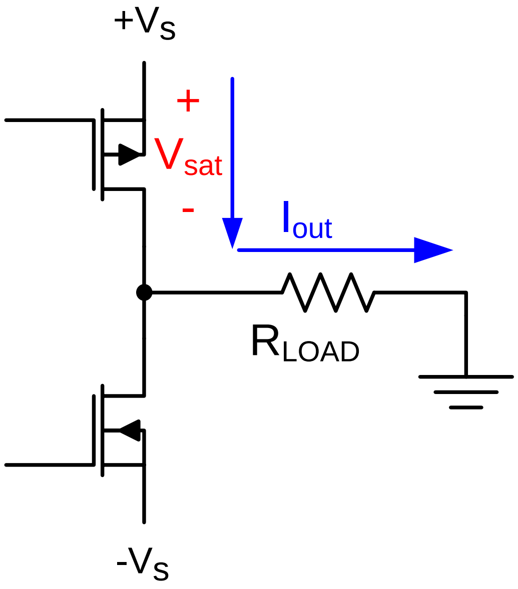
CMOS – Why No True Rail-to-Rail Output?

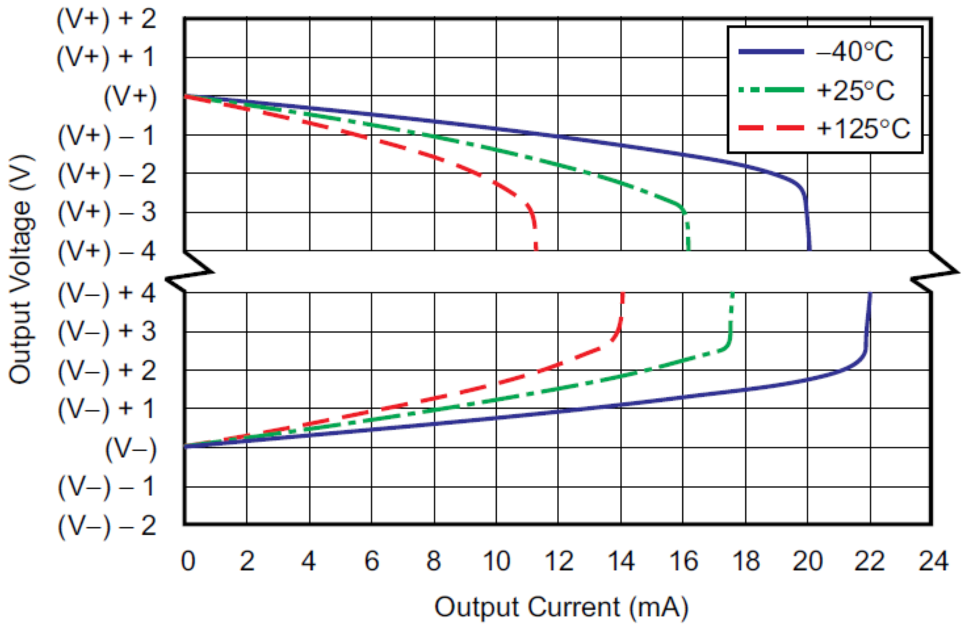




- Some minimum drain to source voltage is required!
- Increasing I_D → Increasing V_{GS}

Rail-to-Rail Output Stage vs. I_{OUT}



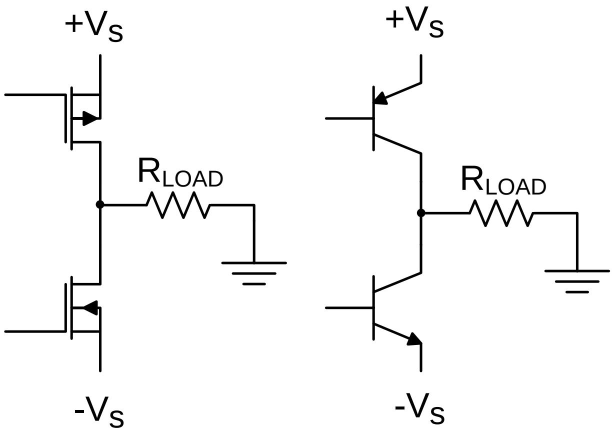


I_{out} = 0mA, V_{sat} ≈ 0V

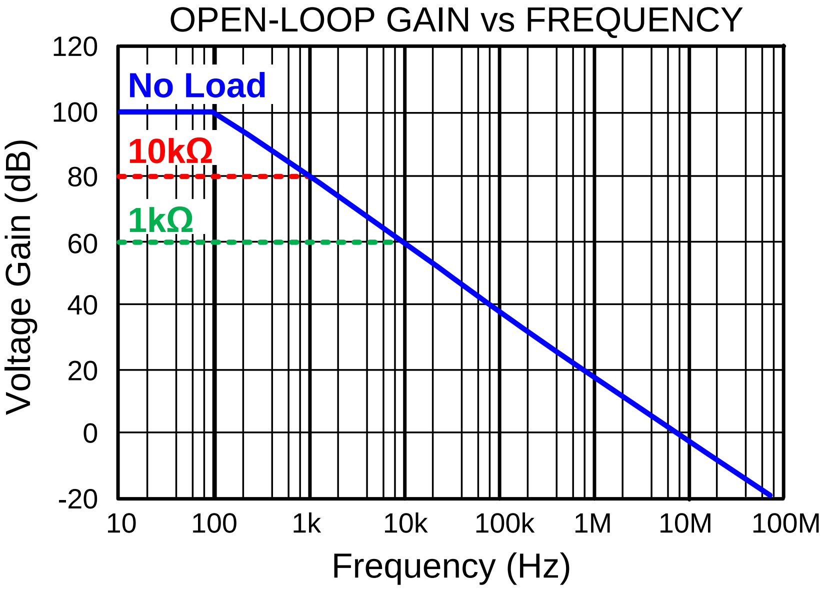
I_{out} = 8mA, V_{sat} ≈ 1V (T = 25°C) → **R_{out} = 125Ω**

I_{out} = 13mA, Vsat ≈ 2V (T = 25°C) → **R_{out} = 154Ω**

Rail-to-Rail Output Stage

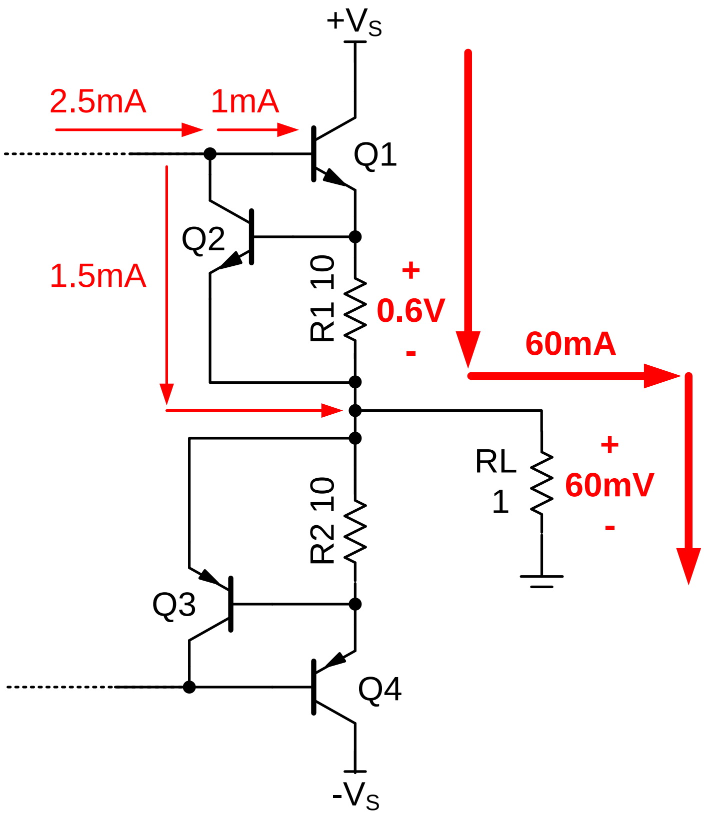


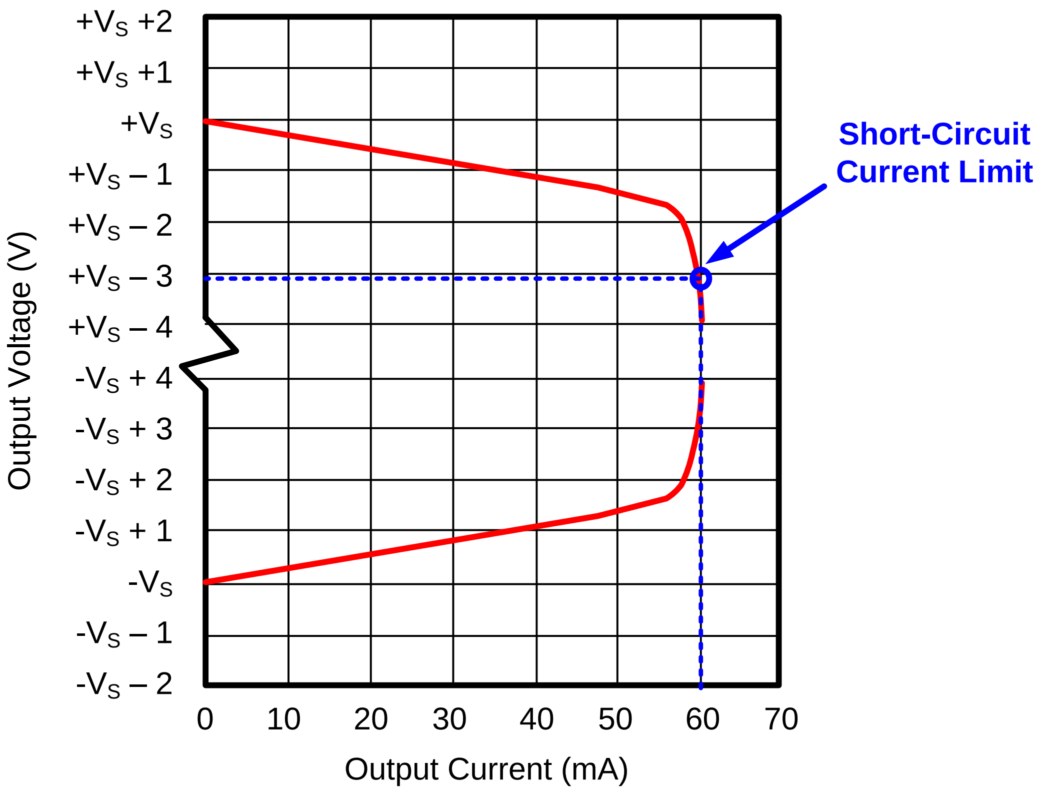
CMOS **Bipolar**



- R_{LOAD} affects A_{OL} and output swing
- $R_{out} = R_{LOAD} \parallel R_o$, where R_o = output resistance
- Gain in the last stage is set by R_{out} / g_m
- R_{out} decreases with loading

Output Short Circuit Current Limit



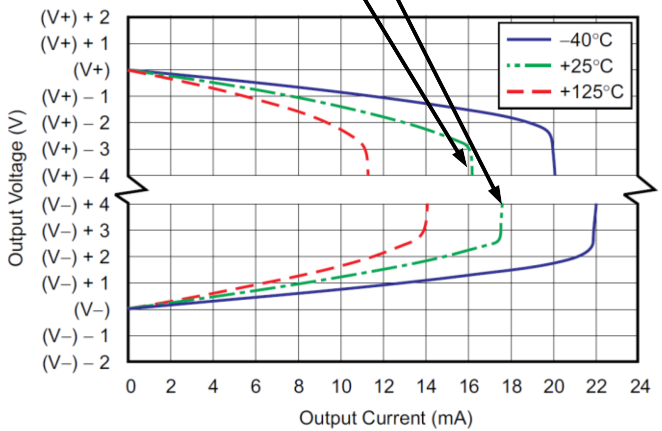


Short Circuit Limit – Specs Table vs. Curve

ELECTRICAL CHARACTERISTICS:
High-Voltage Operation, V_S = ±4 V to ±18 V (V_S = +8 V to +36 V) (continued)

At T_A = +25°C, R_L = 10 kΩ connected to V_S / 2[(1)], and V_{CM} = V_{OUT} = V_S / 2[(1)], unless otherwise noted.

PARAMETER		CONDITIONS	MIN	TYP	MAX	UNIT
OUTPUT						
	Voltage output swing from rail	No load		6	15	mV
		R_L = 10 kΩ		220	250	mV
		T_A = –40°C to +125°C		310	350	mV
I_{SC}	Short-circuit current	Sinking		-18		mA
		Sourcing		+16		mA



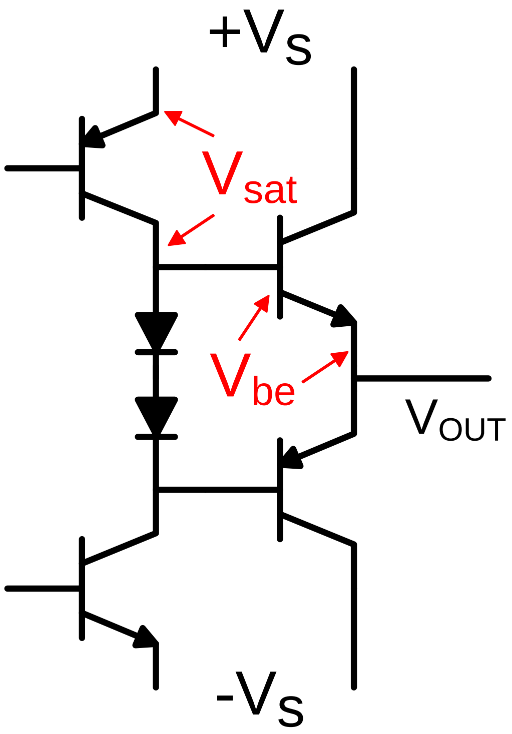
Thanks for your time! Please try the quiz.

Input & Output Limitations – 3

Multiple Choice Quiz
TI Precision Labs – Op Amps

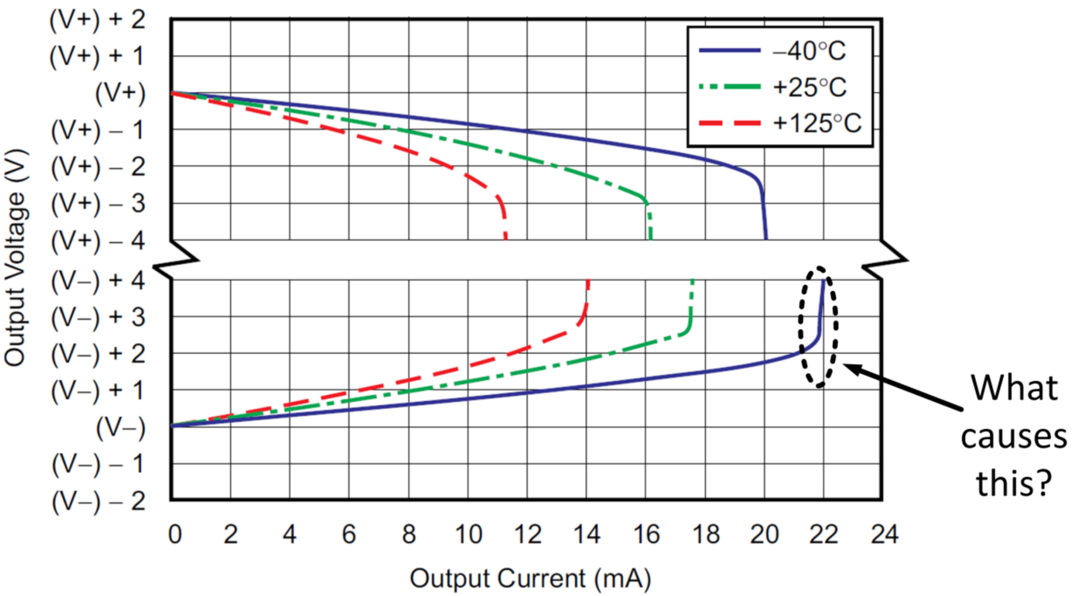
Quiz: Input & Output Limitations – 3

1. The figure below shows a classic bipolar output stage. Which of the following is true?
   a. This is a rail-to-rail output.
   b. Connecting a load to the output will cause A_{OL} to shift.
   c. The output swing limit will be about 1V from the supply rail.
   d. The RF immunity for the op amp will be limited.



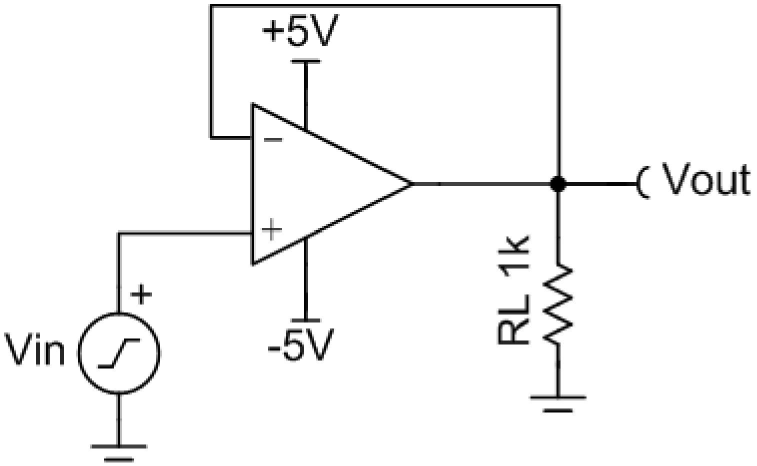
Quiz: Input & Output Limitations – 3

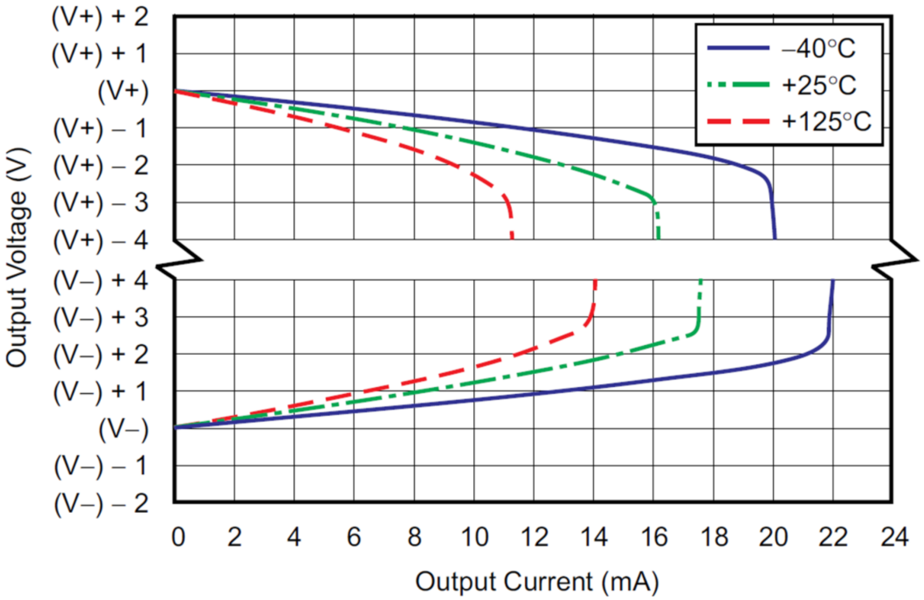
2. In the claw curve below, the region at the end of the curve is circled. What causes this bend in the curve?
   a. The amplifier short circuit limit is turning on.
   b. The resistance of the output transistors is causing voltage to decrease.
   c. The amplifier is going into thermal overload.
   d. The saturation and cutoff of the input stage is causing common mode limitations.



Quiz: Input & Output Limitations – 3

3. For the circuit below, estimate the output swing (slam limit).
   a. -4.9 < Vout < +4.9V
   b. -4.2 < Vout < +4.0V
   c. -3.5< Vout < +3.5V
   d. -3.0< Vout < +3.0V





Quiz: Input & Output Limitations – 3

4. (T/F) The claw curve represents the linear output swing range for an op amp vs. output current.
   a. True
   b. False

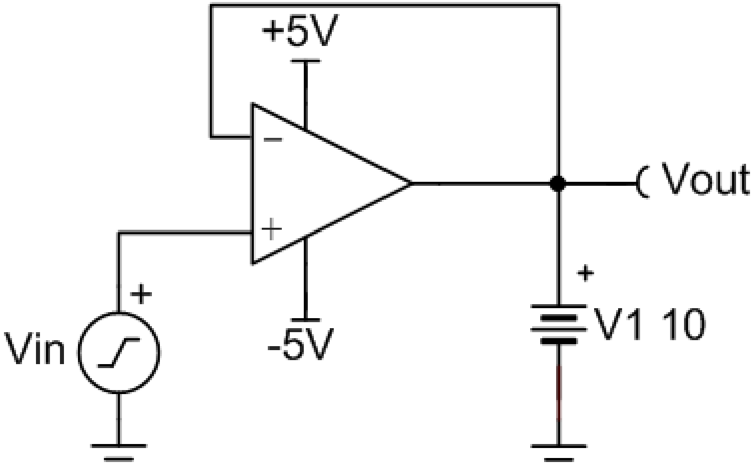
5. The DC A_{OL} for some amplifiers will be affected by loading. Which amplifier types are most susceptible to the effect?
   a. Rail-to-rail
   b. Classic bipolar

6. What output swing limitation would you expect with a bipolar rail-to-rail amplifier?
   a. A few millivolts from the rail
   b. 50mV from the rail
   c. 300mV from the rail
   d. 1V from the rail

7. (T/F) If the output is shorted to the negative supply, the short circuit limit will limit the output current and protect the device from damage.
   a. True
   b. False

Quiz: Input & Output Limitations – 3

8. The circuit's output is accidentally shorted to a 10V supply as shown below. Will the short circuit protection, prevent damage?
   a. Yes
   b. No



Quiz: Input & Output Limitations – 3

9. Based on the data sheet excerpt below, at 125°C, the worst case linear output swing is ___________.
    a. 30mV from the rail.
    b. 50mV from the rail.
    c. 70mV from the rail.
    d. 100mV from the rail.

At T_A = +25°C, R_L = 10 kΩ connected to V_S / 2, V_{CM} = V_S / 2, and V_{OUT} = V_S / 2, unless otherwise noted.

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
OPEN-LOOP GAIN						
A_{OL}	Open-loop voltage gain	(V–) + 100 mV < V_O < (V+) – 100 mV, R_L = 10 kΩ, T_A = –40°C to +125°C	106	130		dB
OUTPUT						
	Voltage output swing from rail	R_L = 10 kΩ		30	50	mV
		R_L = 10 kΩ, T_A = –40°C to +125°C			70	mV
I_{SC}	Short-circuit current			±5		mA

Quiz: Input & Output Limitations – 3

10. For the data sheet excerpt below, the typical short circuit current is set to turn on at +30mA (sourcing) and -45mA (sinking). These limits are for room temperature only. How could you estimate the variation of short circuit current over temperature?
    a. ±20%
    b. ±50%
    c. Use the claw curves

11. For the data sheet excerpt below, the typical short circuit current is set to turn on at +30mA (sourcing) and -45mA (sinking). These limits indicate typical performance only. How could you estimate the worst case?
    a. ±20%
    b. ±50%
    c. Use the claw curves

PARAMETER		CONDITIONS	Standard Grade OPA211AI, OPA2211AI			High Grade OPA211I[1]			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	
OUTPUT									
Voltage Output	V_{OUT}	**R_L = 10kΩ, A_{OL} ≥ 114dB**	**(V–) + 0.2**		**(V+) – 0.2**	**(V–) + 0.2**		**(V+) – 0.2**	**V**
		R_L = 600Ω, A_{OL} ≥ 110dB	(V–) + 0.6		(V+) – 0.6	(V–) + 0.6		(V+) – 0.6	V
		I_O < 15mA, A_{OL} ≥ 110dB	**(V–) + 0.6**		**(V+) – 0.6**	**(V–) + 0.6**		**(V+) – 0.6**	**V**
Short-Circuit Current	I_{SC}			+30/–45			+30/–45		mA

Input & Output Limitations – 3

Multiple Choice Quiz: Solutions
TI Precision Labs – Op Amps

Solutions: Input & Output Limitations – 3

1. The figure below shows a classic bipolar output stage. Which of the following is true?
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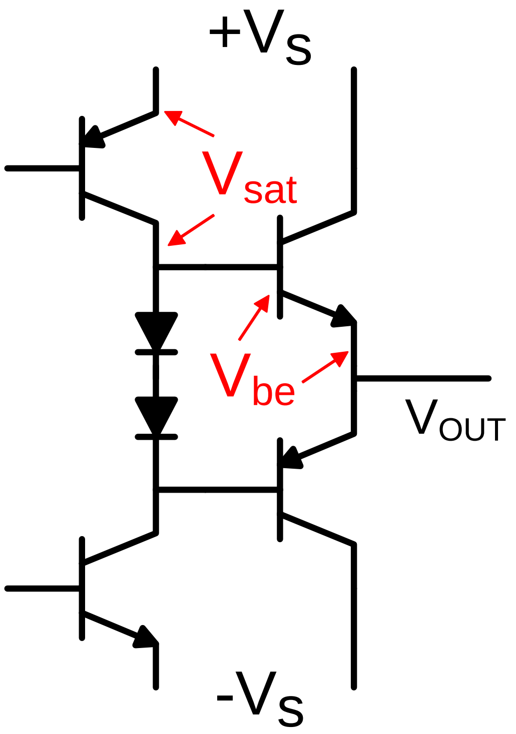

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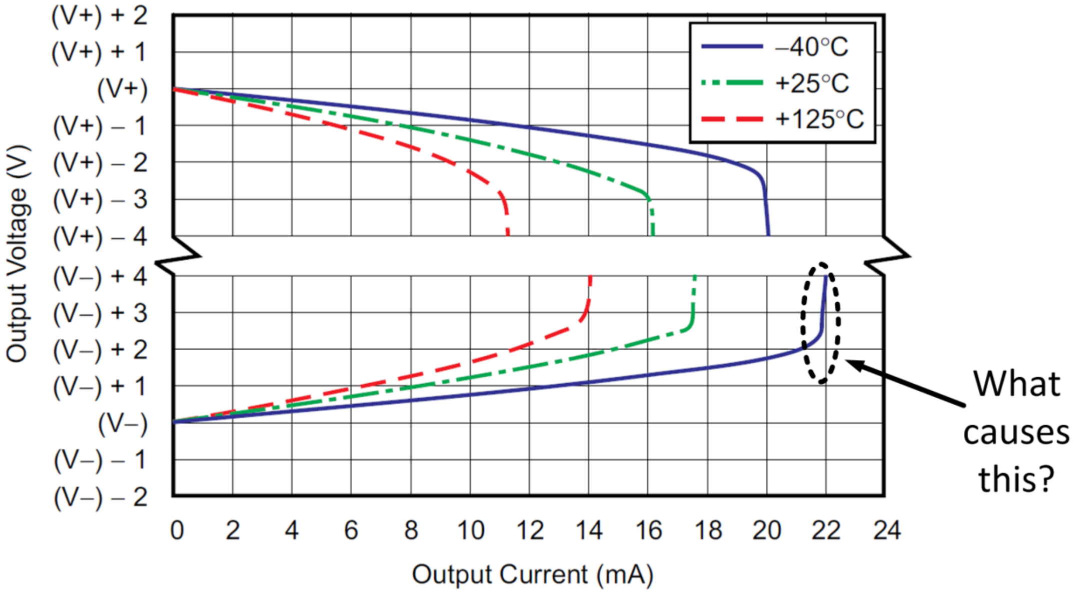

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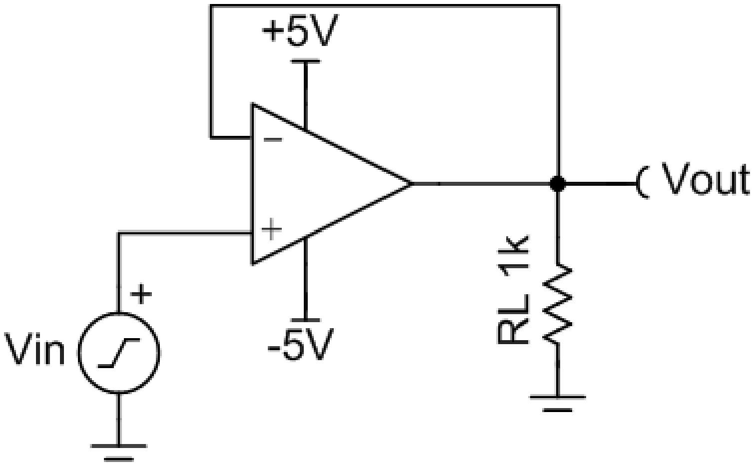

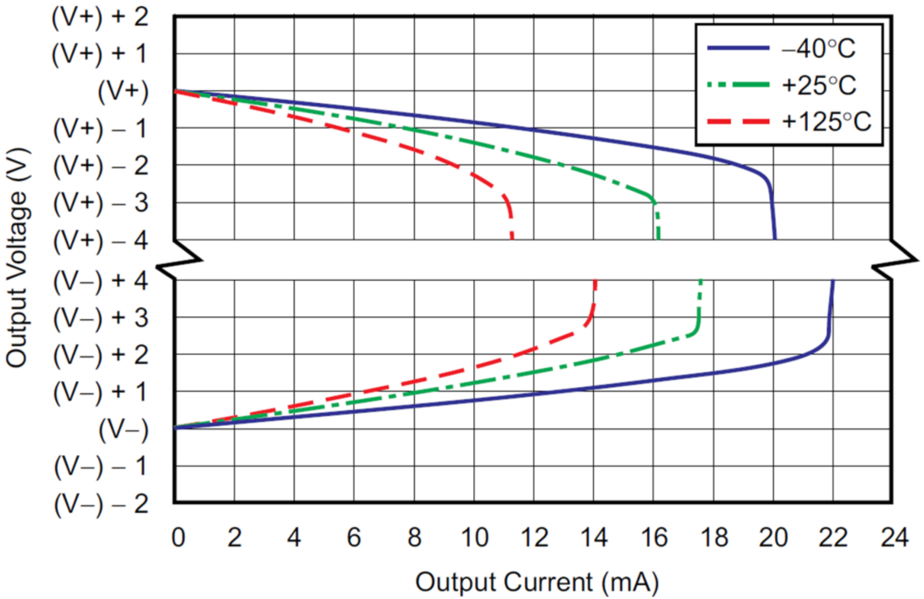

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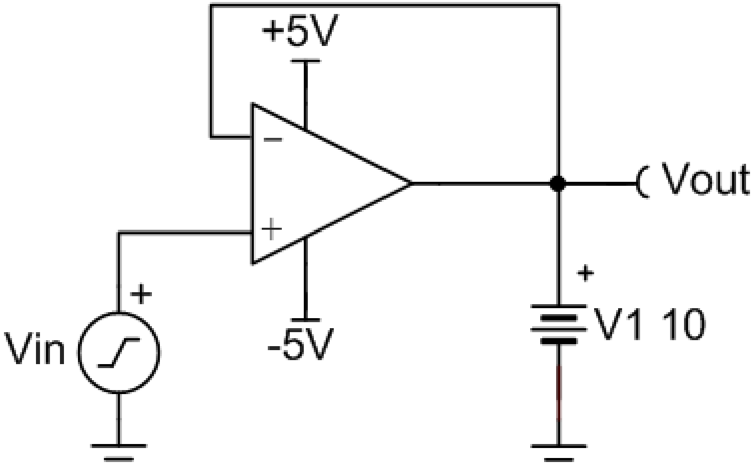

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PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
OPEN-LOOP GAIN						
A_{OL}	Open-loop voltage gain	(V–) + 100 mV < V_O < (V+) – 100 mV, R_L = 10 kΩ, T_A = –40°C to +125°C	106	130		dB
OUTPUT						
	Voltage output swing from rail	R_L = 10 kΩ		30	50	mV
		R_L = 10 kΩ, T_A = –40°C to +125°C			70	mV
I_{SC}	Short-circuit current			±5		mA

Solutions: Input & Output Limitations – 3

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PARAMETER		CONDITIONS	Standard Grade OPA211AI, OPA2211AI			High Grade OPA211I[1]			UNIT
			MIN	TYP	MAX	MIN	TYP	MAX	
OUTPUT									
Voltage Output	V_{OUT}	**R_L = 10kΩ, A_{OL} ≥ 114dB**	**(V–) + 0.2**		**(V+) – 0.2**	**(V–) + 0.2**		**(V+) – 0.2**	**V**
		R_L = 600Ω, A_{OL} ≥ 110dB	(V–) + 0.6		(V+) – 0.6	(V–) + 0.6		(V+) – 0.6	V
		I_O < 15mA, A_{OL} ≥ 110dB	**(V–) + 0.6**		**(V+) – 0.6**	**(V–) + 0.6**		**(V+) – 0.6**	**V**
Short-Circuit Current	I_{SC}			+30/–45			+30/–45		mA