Determining a SAR ADC's Linear Range when using Operational Amplifiers

TIPL 4101
TI Precision Labs – ADCs

Created by Art Kay & Dale Li

Presented by Peggy Liska

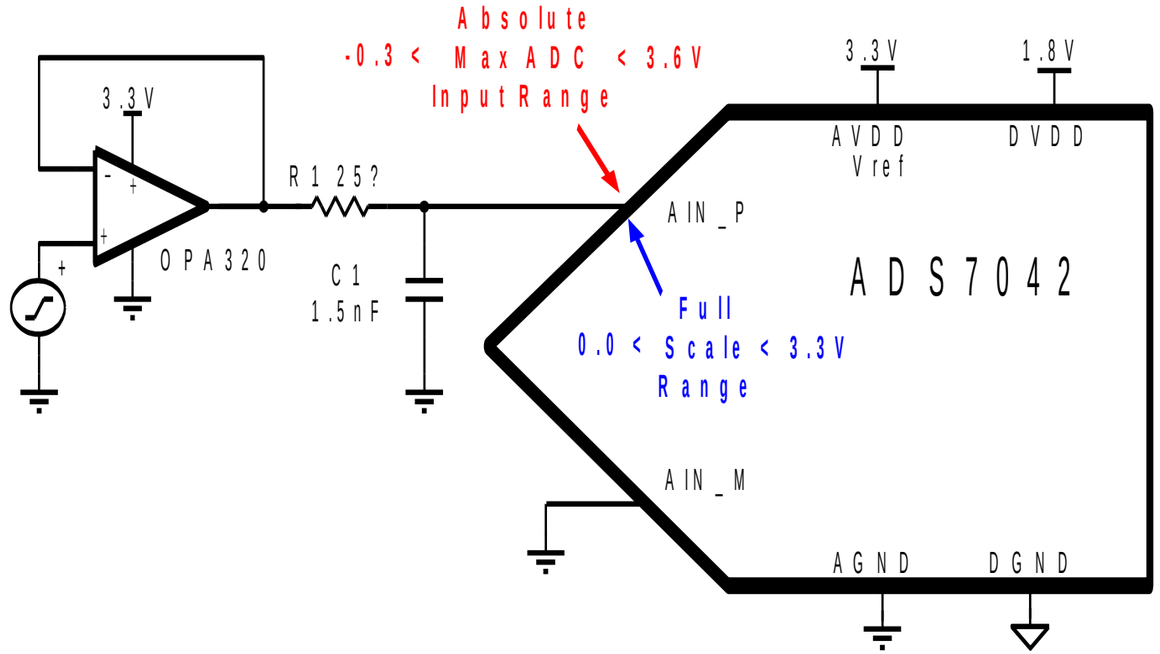
Single Ended Input: ADC Input Range Considerations

PARAMETER ADS7042		TEST CONDITION	MIN	TYP	MAX	UNIT
ANALOG INPUT						
Full-scale input voltage span			**0**		**AVDD**	
Absolute Input voltage range	AINP to GND		0		AVDD+0.1	V
	AINM to GND		-0.1		+0.1	

Absolute Maximum Ratings

ADS7042	MIN	MAX	UNIT
AVDD to GND	-0.3	3.9	V
DVDD to GND	-0.3	3.9	V
AINP to GND	**-0.3**	**AVDD + 0.3**	V
AINM to GND	-0.3	+0.3	V

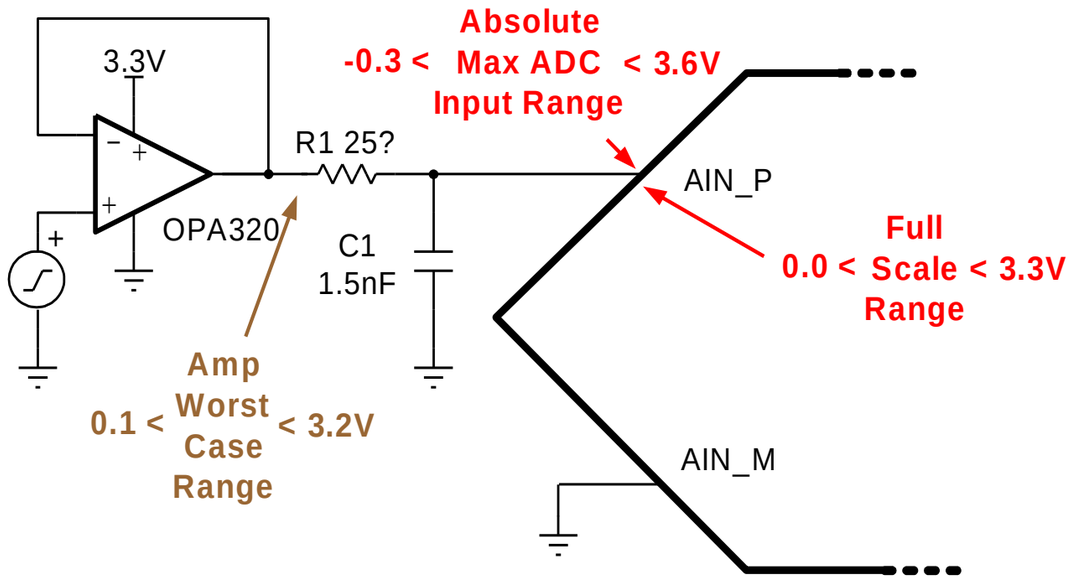
AVDD+0.3 = 3.3V + 0.3V = 3.6V



Single Ended Input: OPA320 Linear Range

PARAMETER OPA320		TEST CONDITION	MIN	TYP	MAX	UNIT
INPUT VOLTAGE						
Common-mode voltage range	V_{cm}		(V-) - 0.1		(V+)+0.1	V
OUTPUT						
Voltage swing from both rails	V_O	RL = 10kΩ		10	20	mV
		RL = 2kΩ		25	35	
OPEN-LOOP GAIN						
Open-loop gain	A_{OL}	0.1 < Vo < (V+)-0.1V, R_L = 10kΩ	114	132		dB
		0.2 < Vo < (V+)-0.2V, R_L = 2kΩ	108	123		

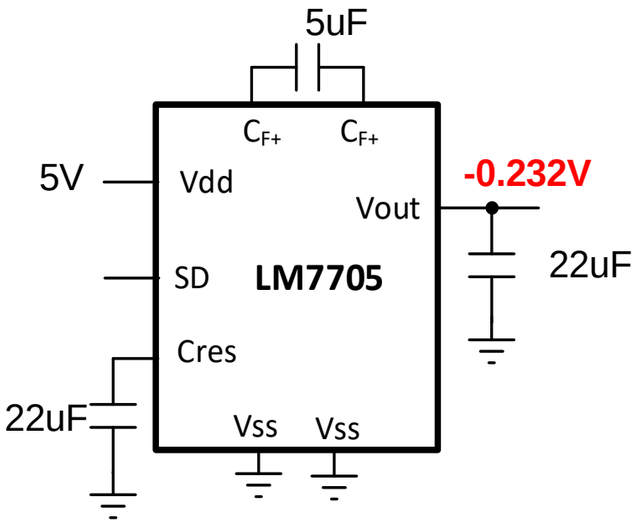
Amplifier Input Range	$-0.1V < V_{cm} < 3.4V$
Amplifier Output Range	$0.02 < V_O < 3.28V$
Amplifier Linear Range	$0.1 < V_O < 3.2V$
Worst Case Range	**$0.1 < V_O < 3.2V$**

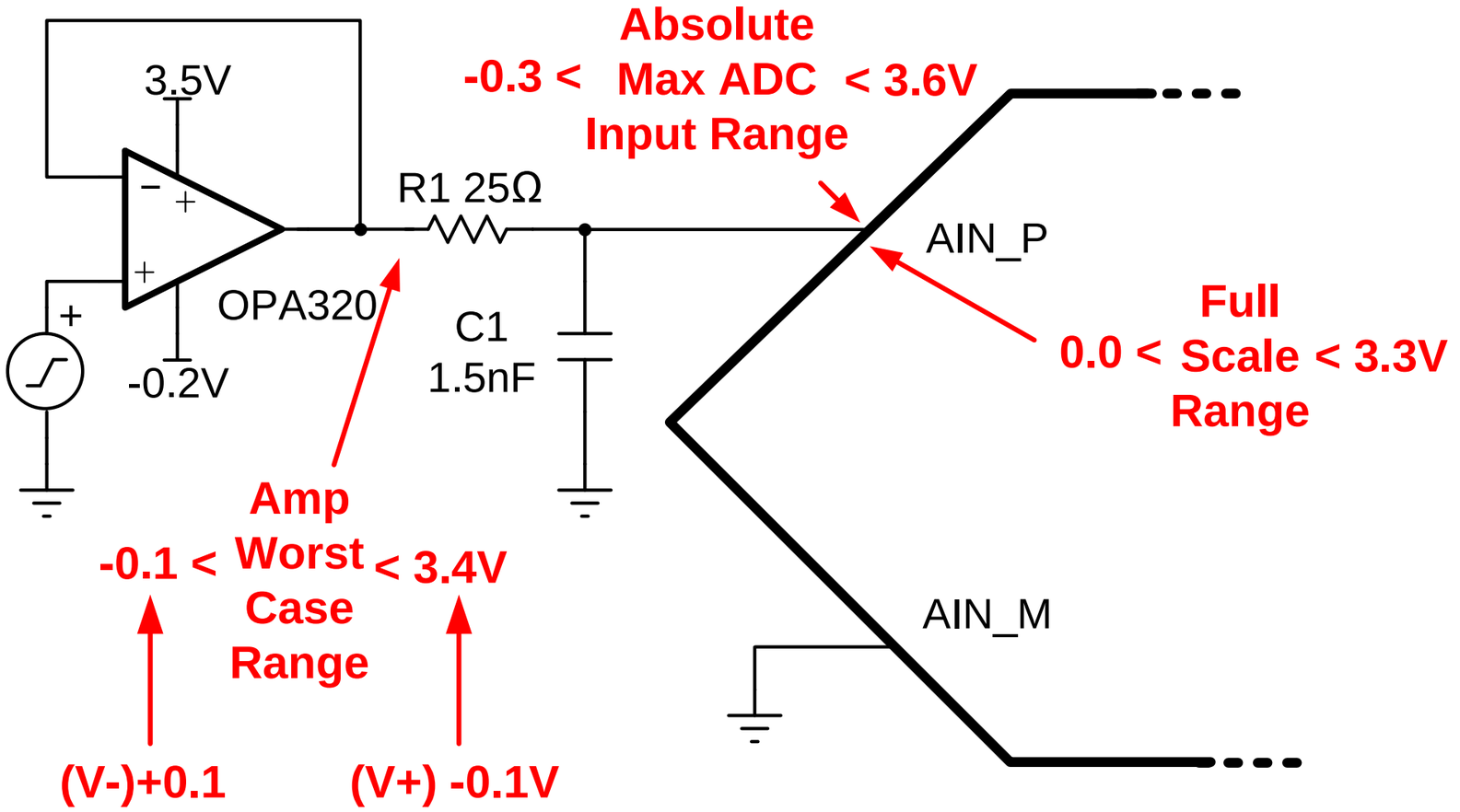


Single Ended Input: Extending the Op Amp Range

Low Noise Negative Bias Generator

- Regulated Output Voltage −0.232 V
- Output Voltage Tolerance 5%
- Output Voltage Ripple 4 mV_{PP}
- Maximum Output Current 26 mA

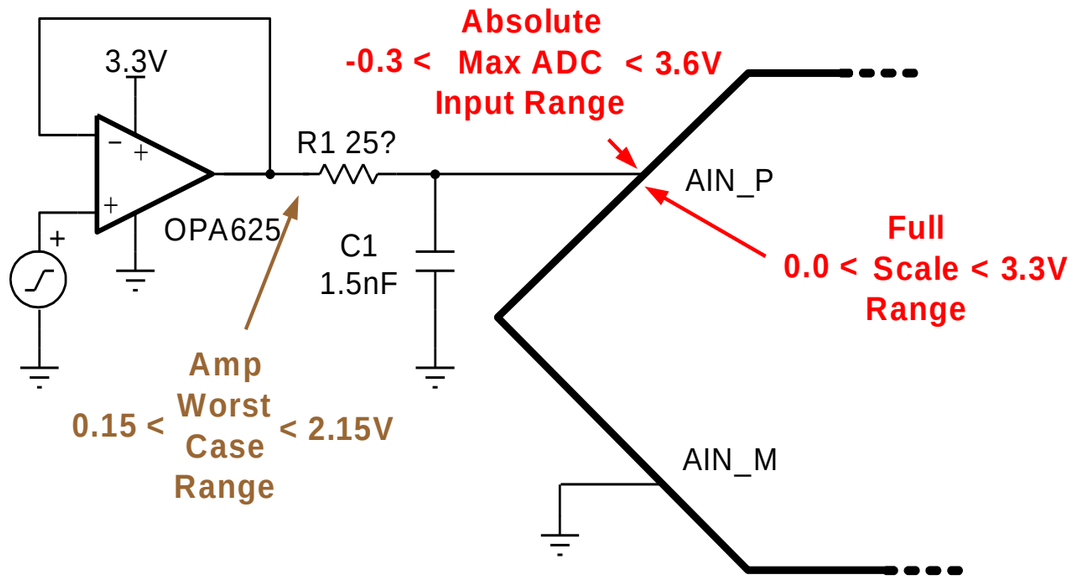




Single Ended Input: OPA625

PARAMETER OPA320		TEST CONDITION	MIN	TYP	MAX	UNIT
INPUT VOLTAGE						
Common-mode voltage range	V_{cm}		(V-)		(V+) - 1.15	V
OUTPUT						
Voltage swing from both rails	V_O	RL = 10kΩ		20	**35**	mV
		RL = 600Ω		60	80	
OPEN-LOOP GAIN						
Open-loop gain	A_{OL}	**0.15 < Vo < (V+) - 0.15V, R_L = 10kΩ**	110	132		dB
		0.2 < Vo < (V+) - 0.2V, R_L = 600Ω	106	128		

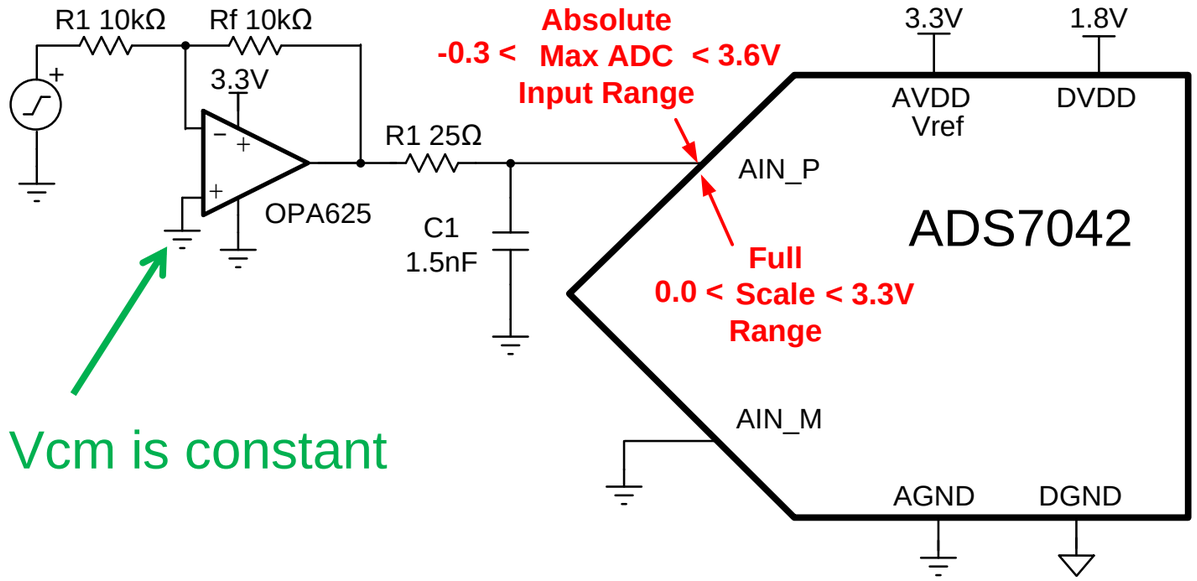
Amplifier input range	$0.0V < V_{cm} < 2.15V$
Amplifier output range	$0.035 < V_O < 3.265V$
Amplifier Linear Range	$0.15 < V_O < 3.15V$
Worst Case Range	**$0.15 < V_O < 2.15V$**



Inverting amplifier: Eliminate Common mode issue

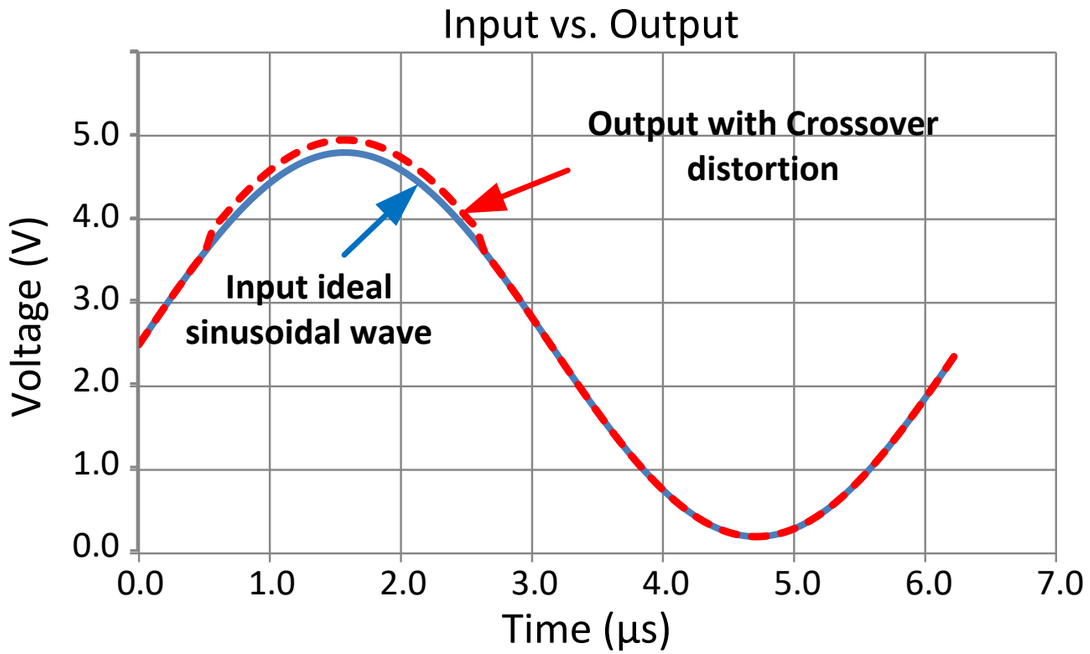
PARAMETER OPA625		TEST CONDITION	MIN	TYP	MAX	UNIT
INPUT VOLTAGE						
Common-mode voltage range	V_{cm}		(V-)		(V+) - 1.15	V
OUTPUT						
Voltage swing from both rails	V_O	RL = 10kΩ		20	**35**	mV
		RL = 600Ω		60	80	
OPEN-LOOP GAIN						
Open-loop gain	A_{OL}	0.15 < Vo < (V+) - 0.15V, R_L = 10kΩ	110	132		dB
		0.2 < Vo < (V+) - 0.2V, R_L = 600Ω	106	128		

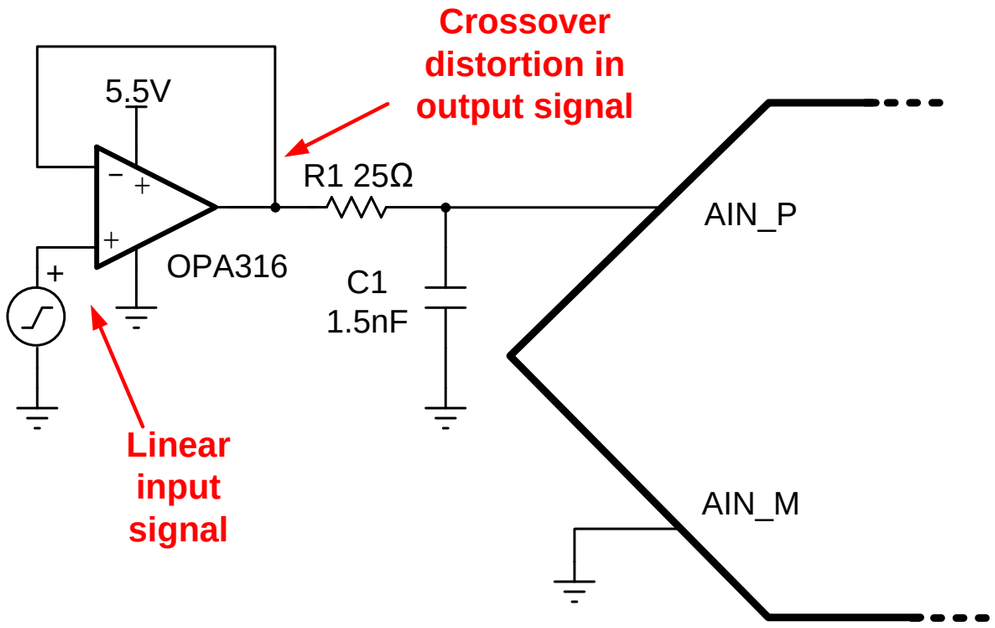
Amplifier input range	No Vcm limit
Amplifier output range	$0.035 < V_O < 3.265V$
Amplifier Linear Range	$0.15 < V_O < 3.15V$
Worst Case Range	**$0.15 < V_O < 3.15V$**



Input Crossover Distortion in Rail-to-Rail Inputs

PARAMETER OPA316		TEST CONDITIONS	MIN	TYP	MAX	UNIT
INPUT VOLTAGE RANGE						
V_{CM}	Common mode voltage range	TA = -40C to 85C	-0.2		(V+)+0.1	V
CMRR	Common mode Rejection	Vs = 5V, -0.1V<Vcm< 3.6V	76	90		dB
		Vs = 5V, -0.1V<Vcm<5.2V	65	80		dB

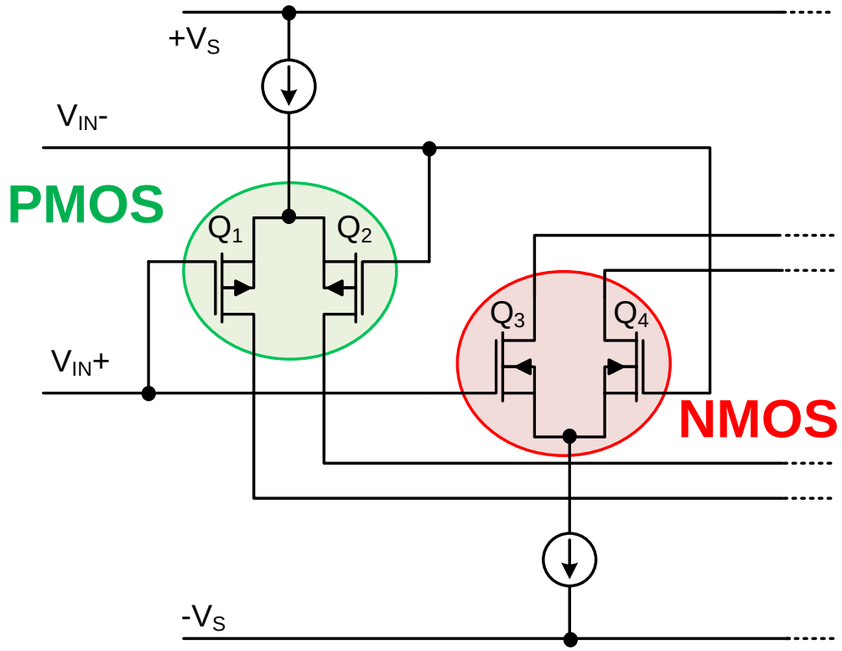


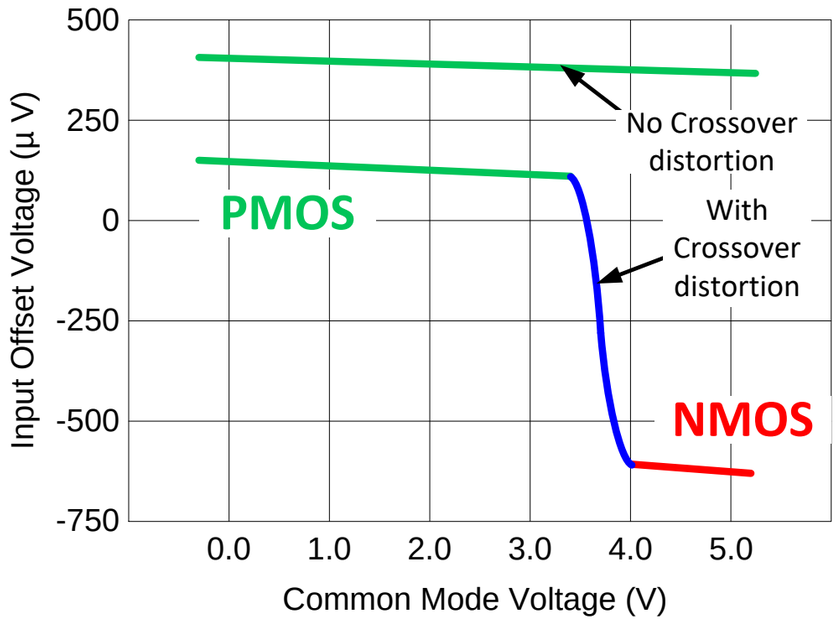


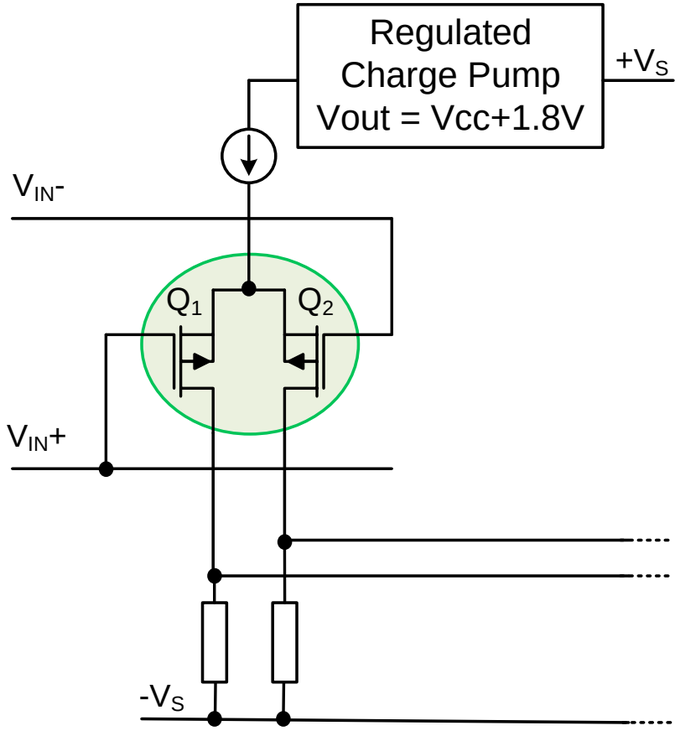
Input Cross-Over distortion vs Zero Cross-Over

PARAMETER: OPA350 – Has Crossover		MIN	TYP	MAX	UNIT
INPUT VOLTAGE RANGE					
V_{CM}	Common mode voltage range	(V-)-0.1		(V+)+0.1	V
CMRR	Common mode Rejection -0.1V<Vcm<5.6V	74	90		dB

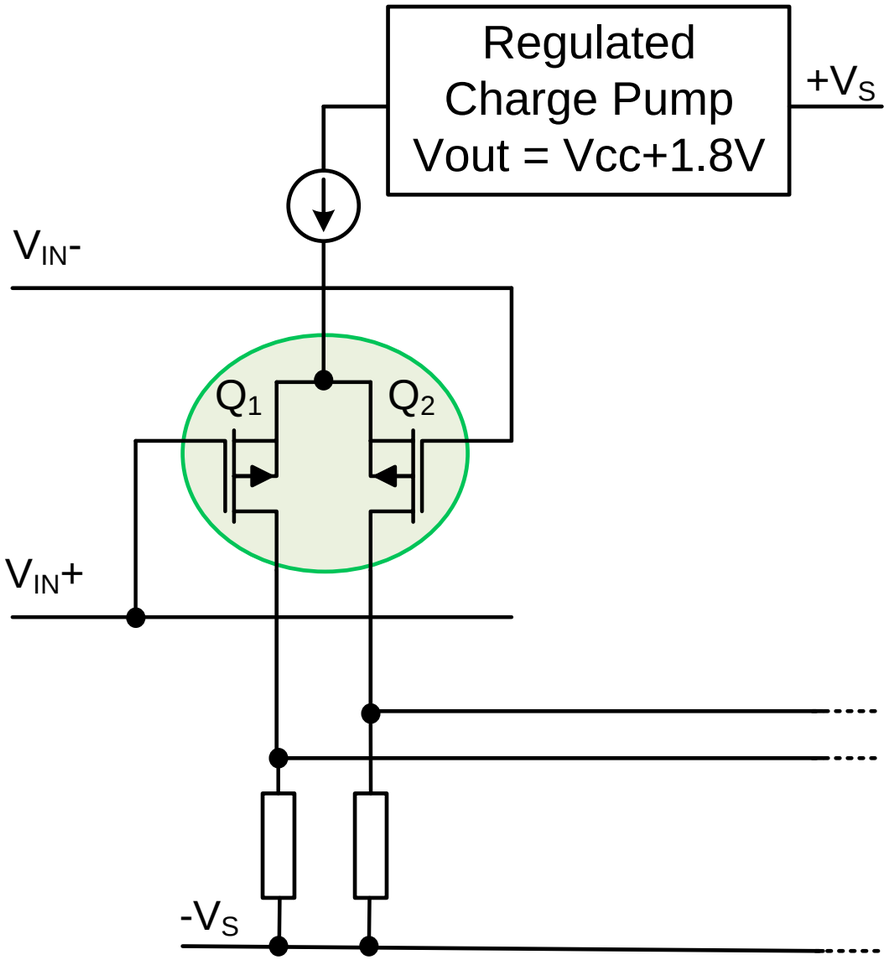
PARAMETER: OPA320 – Zero Cross-Over		MIN	TYP	MAX	UNIT
INPUT VOLTAGE RANGE					
V_{CM}	Common mode voltage range	(V-)-0.1		(V+)+0.1	V
CMRR	Common mode Rejection -0.1V<Vcm<5.6V	100	114		dB



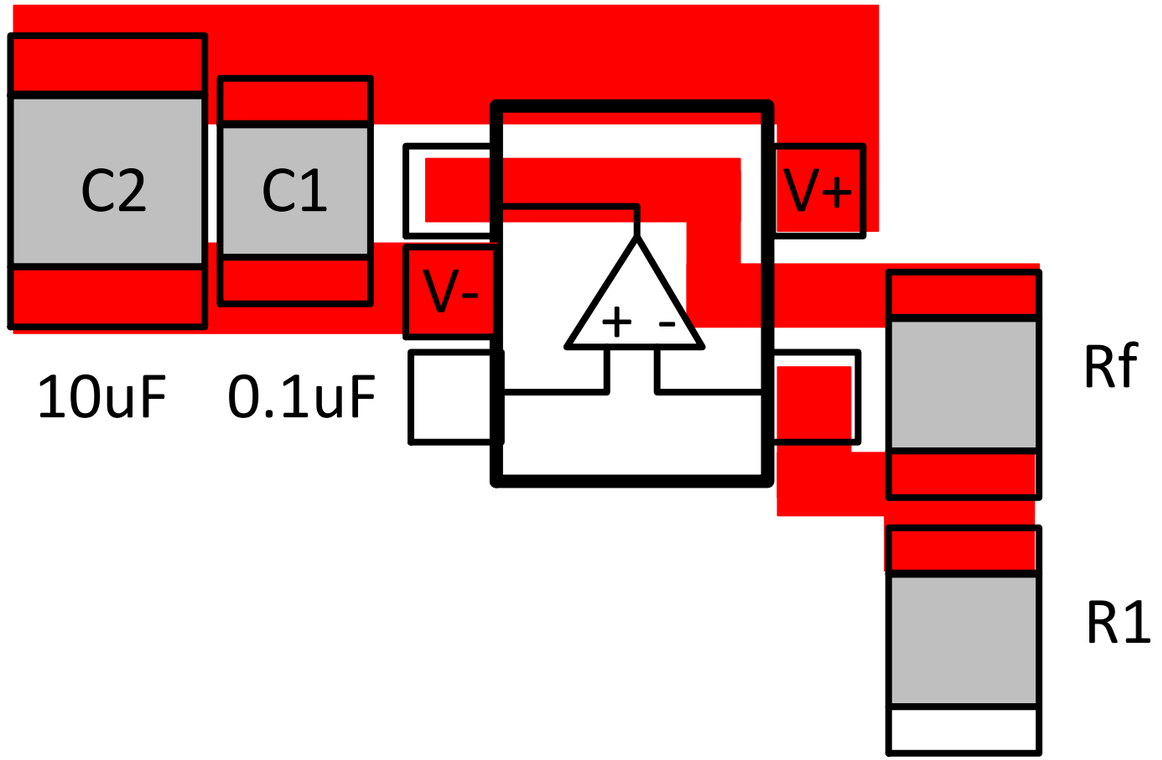




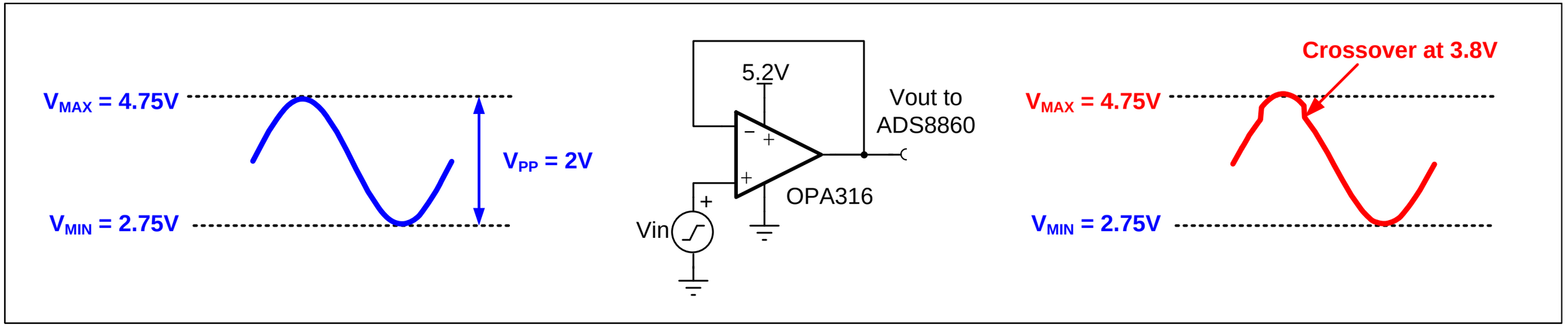
Optimize bypass for internal charge pump op amps

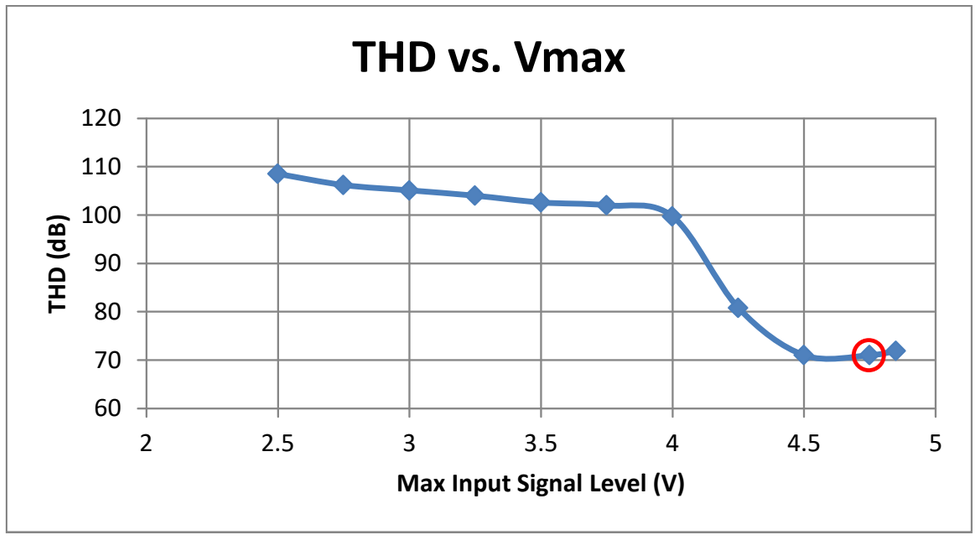


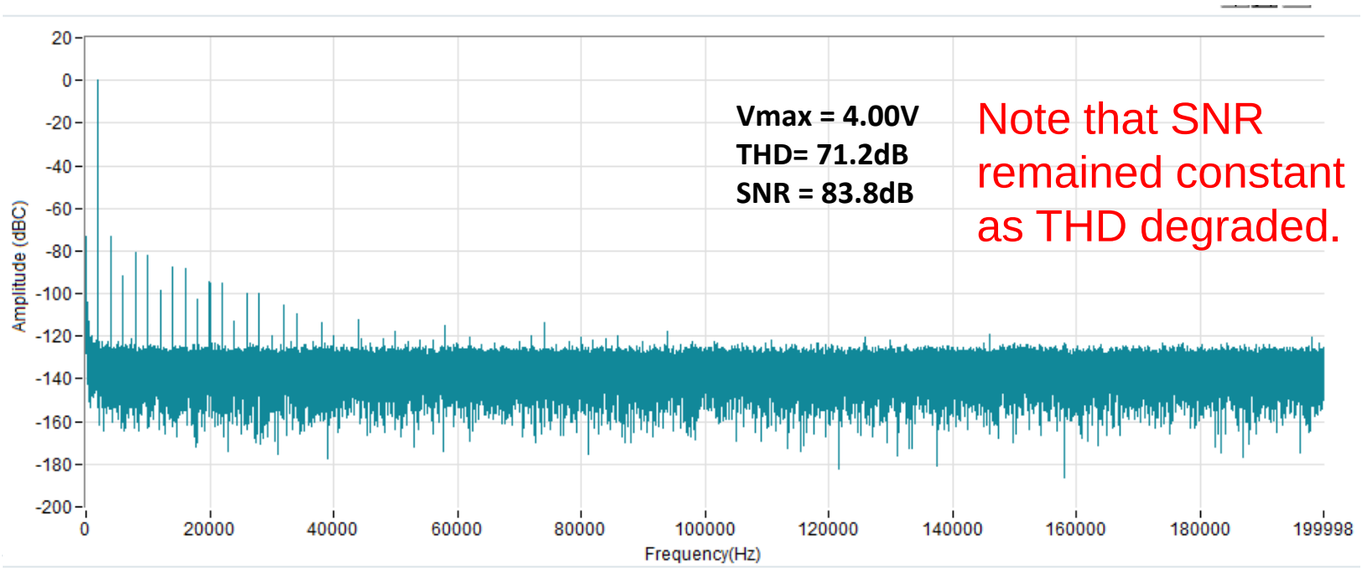
Short direct connections from supply to decoupling



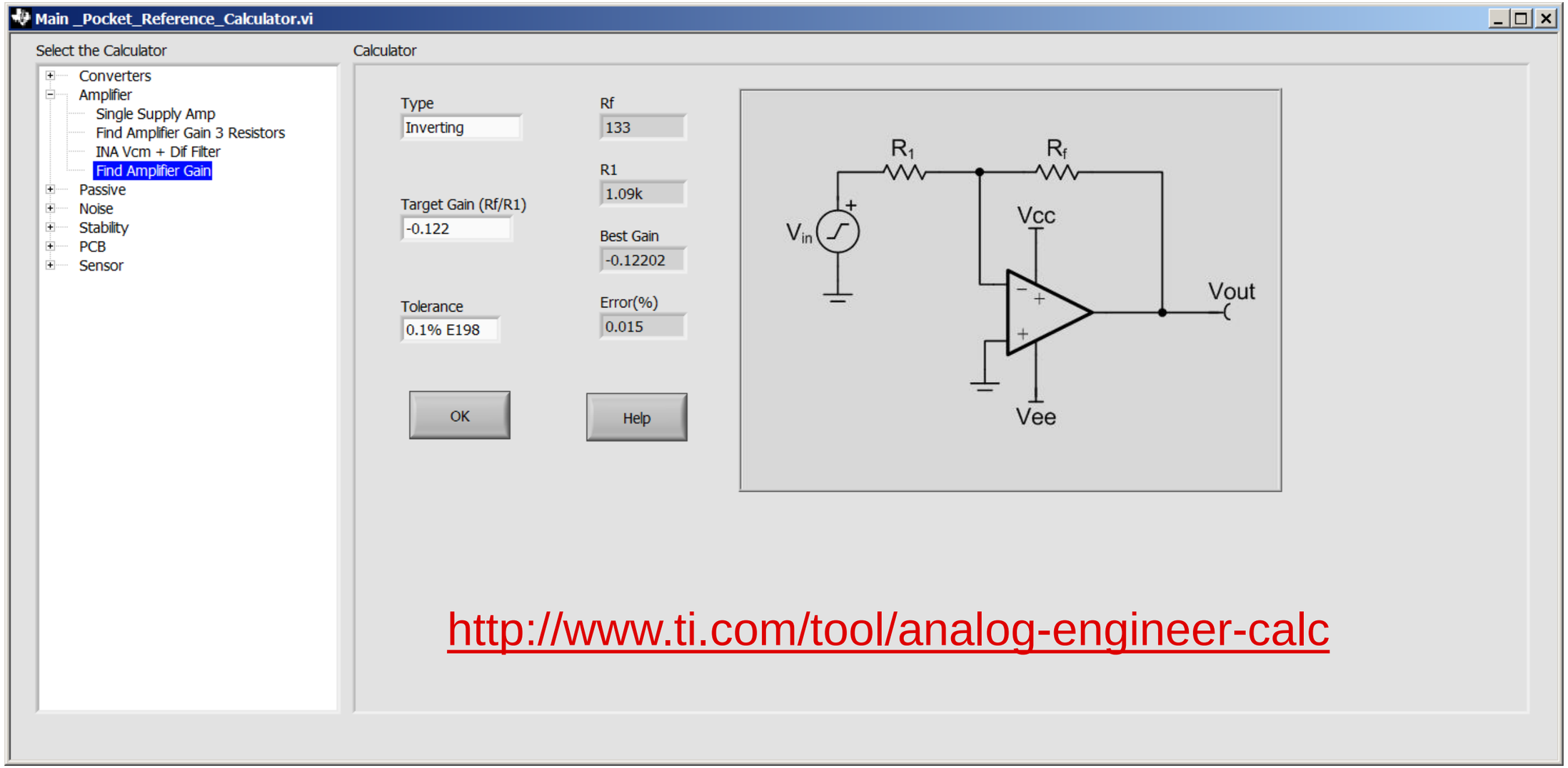
THD vs. Input Crossover Distortion







Finding standard resistors for unusual gains



http://www.ti.com/tool/analog-engineer-calc

Thanks for your time!
Please try the quiz.

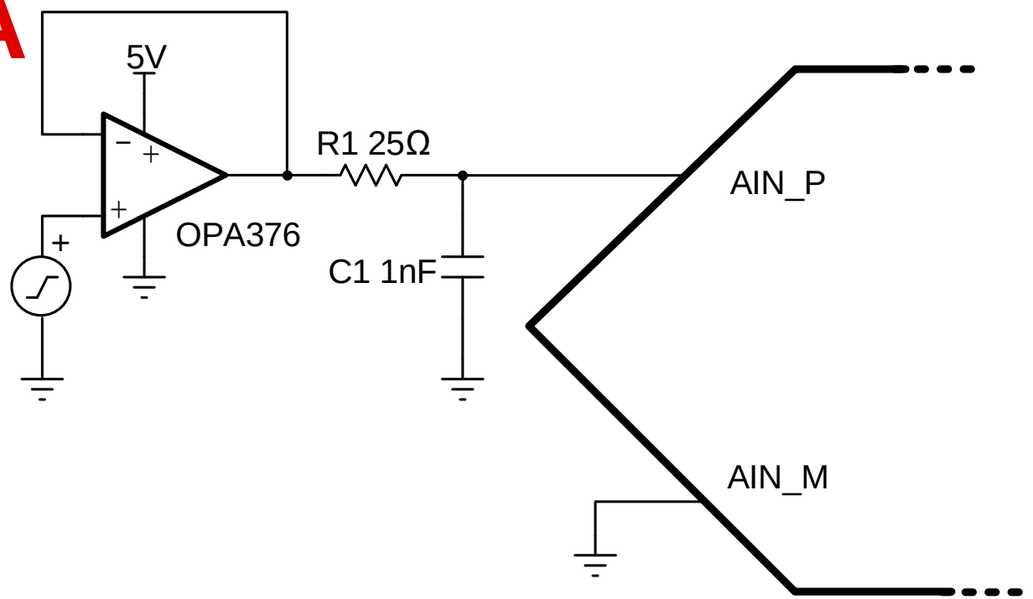
Quiz: Determining a SAR ADC's Linear Range when using Operational Amplifiers

TIPL 4101
TI Precision Labs – ADCs

Created by Art Kay

Quiz: Linear Range ADC + OPA

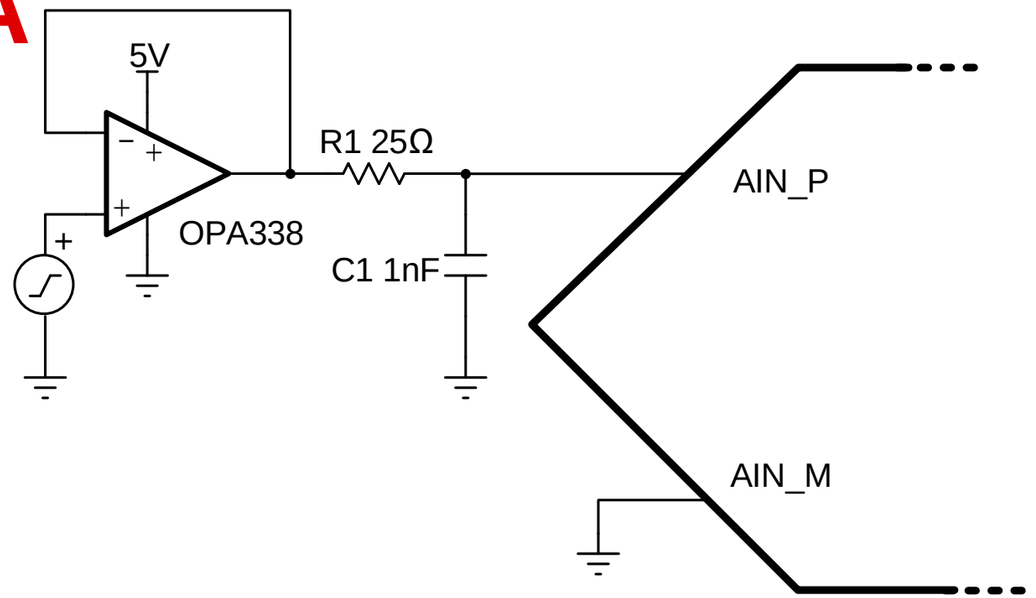
1. What is the worst case output range for the amplifier below.



PARAMETER OPA376		TEST CONDITION	MIN	TYP	MAX	UNIT
INPUT VOLTAGE						
Common-mode voltage range	V_{cm}		(V-) - 0.1		(V+)+0.1	V
OUTPUT						
Voltage swing from both rails	V_O	RL = 10kΩ		10	20	mV
		RL = 2kΩ		20	30	
OPEN-LOOP GAIN						
Open-loop gain	A_{OL}	50mV < Vo < (V+)-50mV, R_L = 10kΩ	120	134		dB
		0.1 < Vo < (V+)-0.1V, R_L = 2kΩ	120	126		

Quiz: Linear Range ADC + OPA

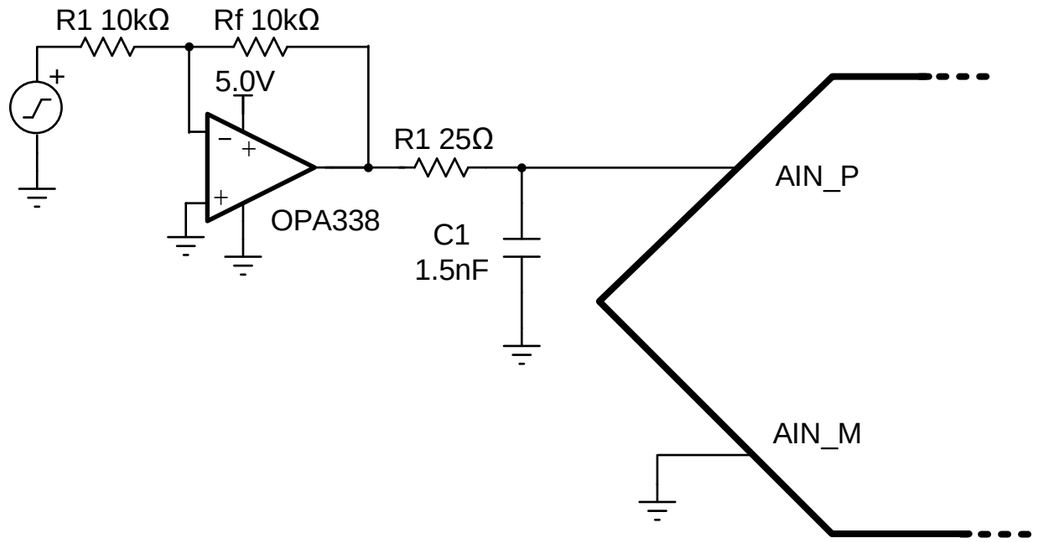
2. What is the worst case output range for the amplifier below.



PARAMETER OPA338		TEST CONDITION	MIN	TYP	MAX	UNIT
INPUT VOLTAGE						
Common-mode voltage range	V_{cm}		(V-) - 0.2		(V+)-1.2	V
OUTPUT						
Voltage swing from both rails	V_O	RL = 25kΩ		40	125	mV
		RL = 5kΩ		150	500	
OPEN-LOOP GAIN						
Open-loop gain	A_{OL}	125mV < Vo < (V+)-125mV, R_L = 25kΩ	100	120		dB
		500mV < Vo < (V+)-500mV, R_L = 5kΩ	100	114		

Quiz: Linear Range ADC + OPA

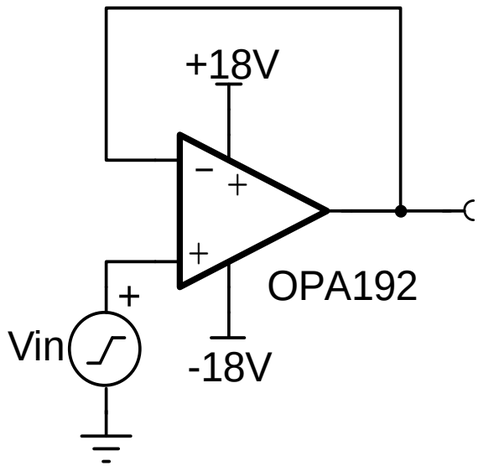
3. What is the worst case output range for the amplifier below.



PARAMETER OPA338		TEST CONDITION	MIN	TYP	MAX	UNIT
INPUT VOLTAGE						
Common-mode voltage range	V_{cm}		(V-) - 0.2		(V+)-1.2	V
OUTPUT						
Voltage swing from both rails	V_O	RL = 25kΩ		40	125	mV
		RL = 5kΩ		150	500	
OPEN-LOOP GAIN						
Open-loop gain	A_{OL}	125mV < Vo < (V+)-125mV, R_L = 25kΩ	100	120		dB
		500mV < Vo < (V+)-500mV, R_L = 5kΩ	100	114		

Quiz: Linear Range ADC + OPA

4. The amplifier shown below _____.
   a. Would have poor power supply rejection.
   b. Would show crossover distortion if the input signal is greater than 15Vpk.
   c. Would not show crossover distortion.
   d. Would have a low input impedance.



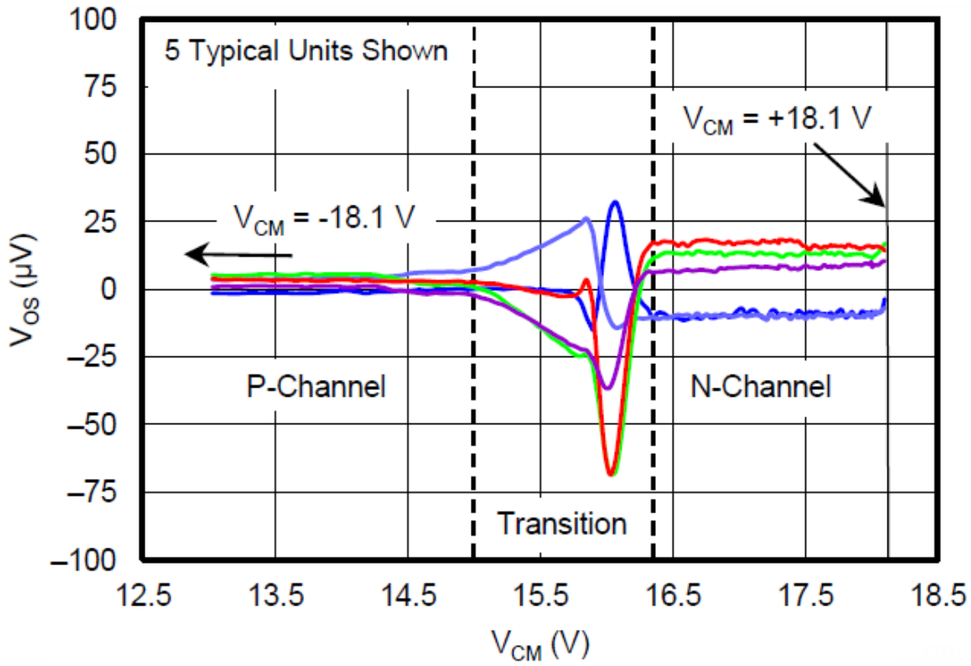
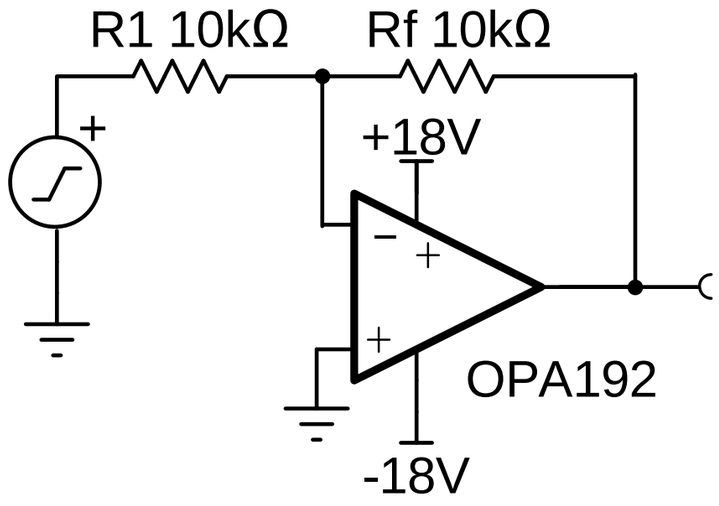


Figure 13: Offset Voltage vs. Common-Mode Voltage

Quiz: Linear Range ADC + OPA

5. The amplifier shown below _____.
   a. Would have poor power supply rejection.
   b. Would show crossover distortion if the input signal is greater than 15Vpk.
   c. Would not show crossover distortion.



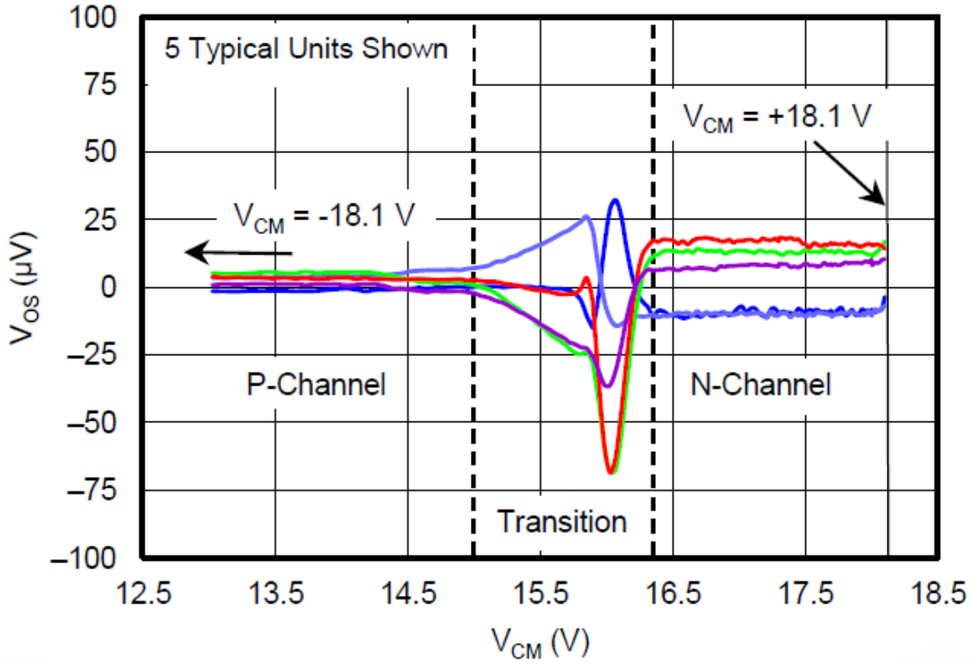
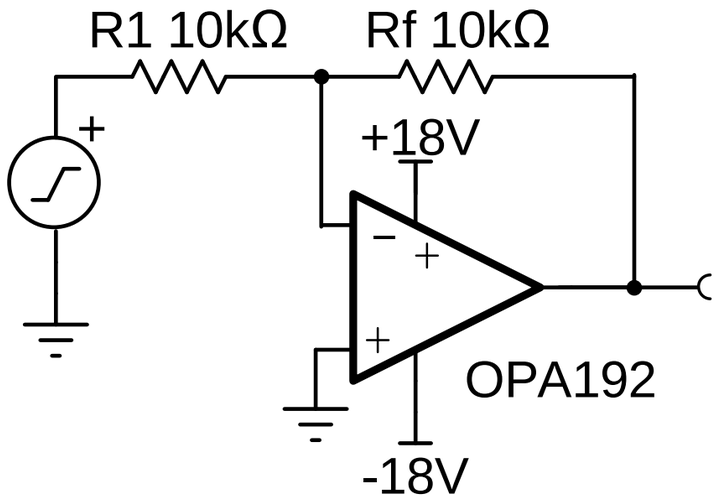


Figure 13: Offset Voltage vs. Common-Mode Voltage

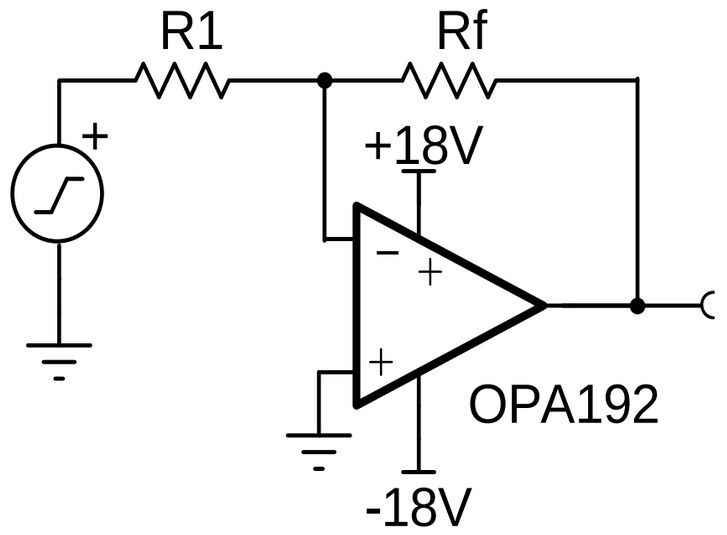
Quiz: Linear Range ADC + OPA

6. Which of the following applies to an inverting amplifier topology.
   a. Gain error is determined by resistor tolerance.
   b. The input impedance is relatively low (10kΩ in this case).
   c. The circuit will not have crossover distortion issues.
   d. Common mode rejection would be eliminated
   e. The output will be loaded by the feedback network (10kΩ in this case).
   f. All the statements apply to the inverting topology.
   g. None of the statements apply to the inverting topology.



Quiz: Linear Range ADC + OPA

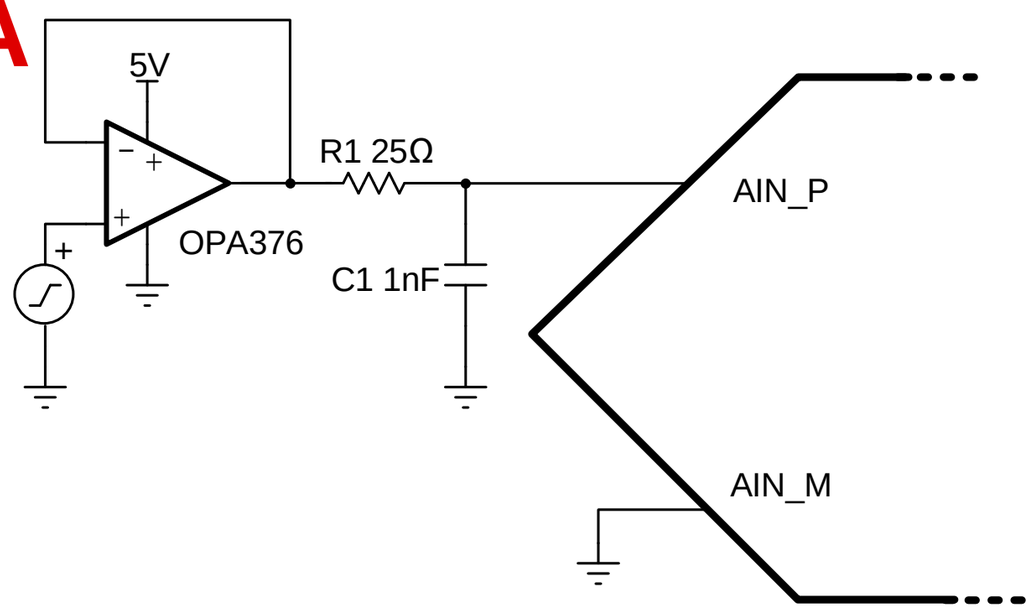
7. Select 0.1% and 1% standard value resistors for the circuit below to set the gain to -0.188.



Solutions

Quiz: Linear Range ADC + OPA

1. What is the worst case output range for the amplifier below.

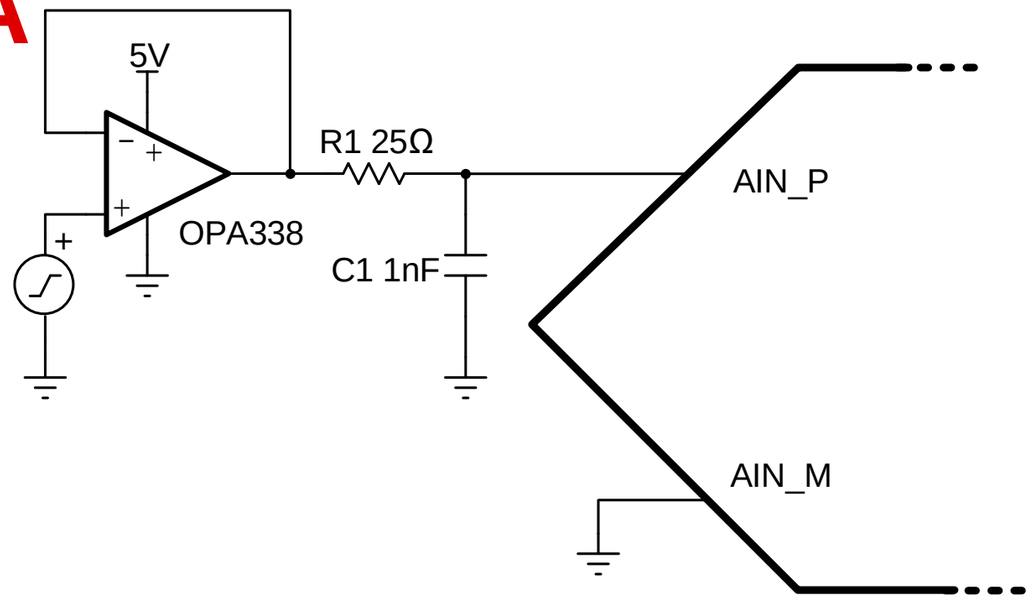


Amplifier input range	$-0.1V < V_{cm} < 5.1V$
Amplifier output range	$0.02 < V_O < 4.98V$
Amplifier Linear Range	$0.05 < V_O < 4.95V$
Worst Case Range	$0.05 < V_O < 4.95V$

PARAMETER OPA376		TEST CONDITION	MIN	TYP	MAX	UNIT
INPUT VOLTAGE						
Common-mode voltage range	V_{cm}		(V-) - 0.1		(V+)+0.1	V
OUTPUT						
Voltage swing from both rails	V_O	RL = 10kΩ		10	20	mV
		RL = 2kΩ		20	30	
OPEN-LOOP GAIN						
Open-loop gain	A_{OL}	50mV < Vo < (V+)-50mV, R_L = 10kΩ	120	134		dB
		0.1 < Vo < (V+)-0.1V, R_L = 2kΩ	120	126		

Quiz: Linear Range ADC + OPA

2. What is the worst case output range for the amplifier below.



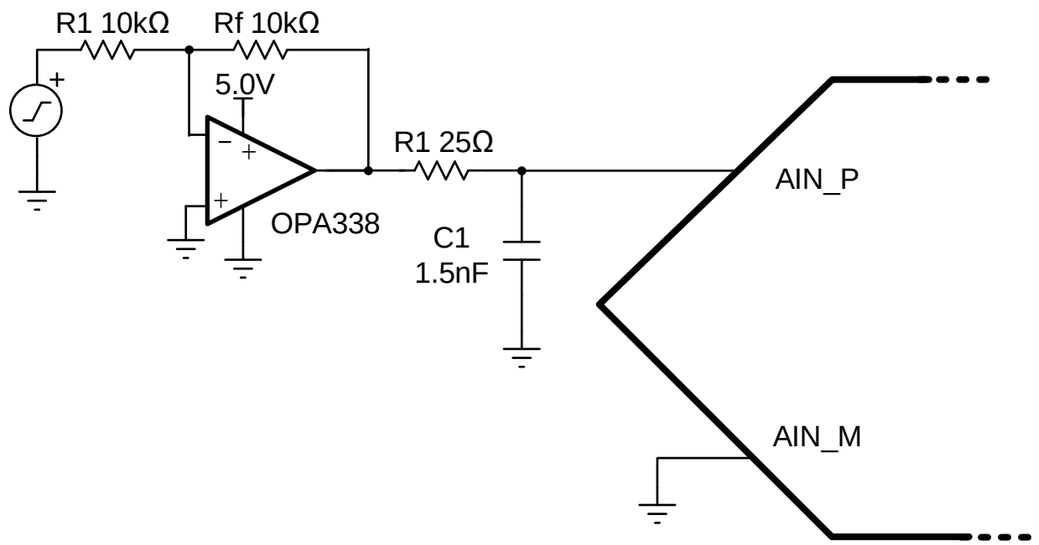
Amplifier input range	$-0.2V < V_{cm} < 3.8V$
Amplifier output range	$0.02 < V_O < 4.875V$
Amplifier Linear Range	$0.125 < V_O < 4.875V$
Worst Case Range	$0.125 < V_O < 3.8V$

PARAMETER OPA338		TEST CONDITION	MIN	TYP	MAX	UNIT
INPUT VOLTAGE						
Common-mode voltage range	V_{cm}		(V-) - 0.2		(V+)-1.2	V
OUTPUT						
Voltage swing from both rails	V_O	RL = 25kΩ		40	125	mV
		RL = 5kΩ		150	500	
OPEN-LOOP GAIN						
Open-loop gain	A_{OL}	125mV < Vo < (V+)-125mV, R_L = 25kΩ	100	120		dB
		500mV < Vo < (V+)-500mV, R_L = 5kΩ	100	114		

Quiz: Linear Range ADC + OPA

3. What is the worst case output range for the amplifier below.

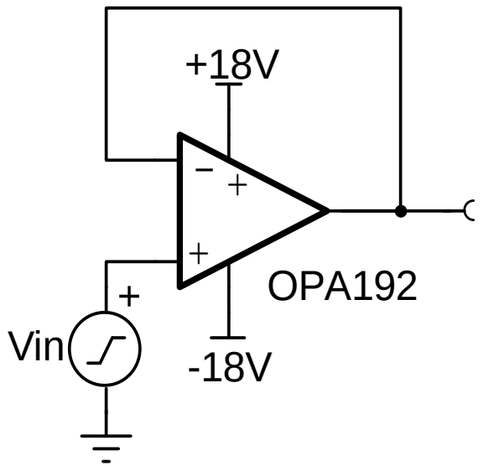
Amplifier input range	No limit, Vcm = 0V
Amplifier output range	$0.02 < V_O < 4.875V$
Amplifier Linear Range	$0.125 < V_O < 4.875V$
Worst Case Range	$0.125 < V_O < 4.875V$



PARAMETER OPA338		TEST CONDITION	MIN	TYP	MAX	UNIT
INPUT VOLTAGE						
Common-mode voltage range	V_{cm}		(V-) - 0.2		(V+)-1.2	V
OUTPUT						
Voltage swing from both rails	V_O	RL = 25kΩ		40	125	mV
		RL = 5kΩ		150	500	
OPEN-LOOP GAIN						
Open-loop gain	A_{OL}	125mV < Vo < (V+)-125mV, R_L = 25kΩ	100	120		dB
		500mV < Vo < (V+)-500mV, R_L = 5kΩ	100	114		

Quiz: Linear Range ADC + OPA

4. The amplifier shown below _____.
   a. Would have poor power supply rejection.
   b. Would show crossover distortion if the input signal is greater than 15Vpk.
   c. Would not show crossover distortion.
   d. Would have a low input impedance.



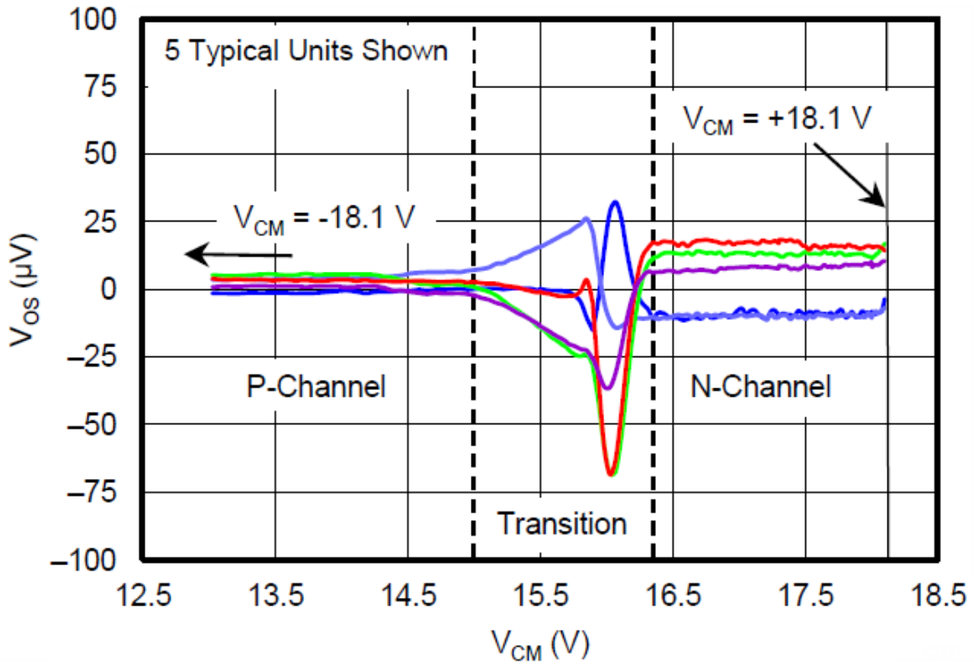
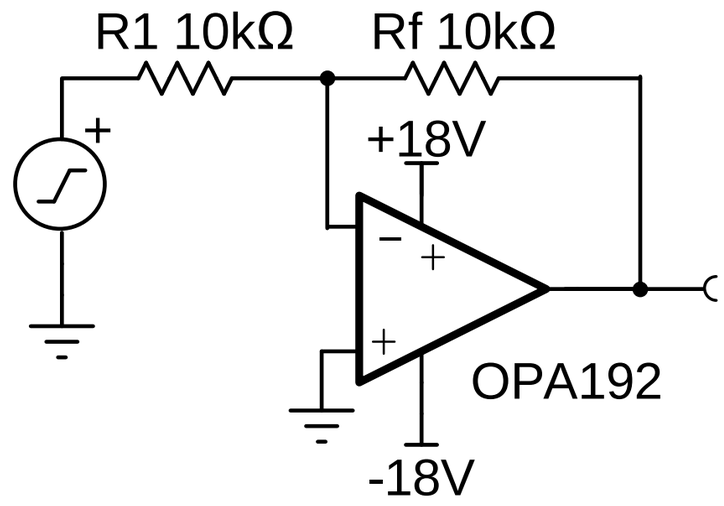


Figure 13: Offset Voltage vs. Common-Mode Voltage

Quiz: Linear Range ADC + OPA

5. The amplifier shown below _____.
   a. Would have poor power supply rejection.
   b. Would show crossover distortion if the input signal is greater than 15Vpk.
   c. Would not show crossover distortion.



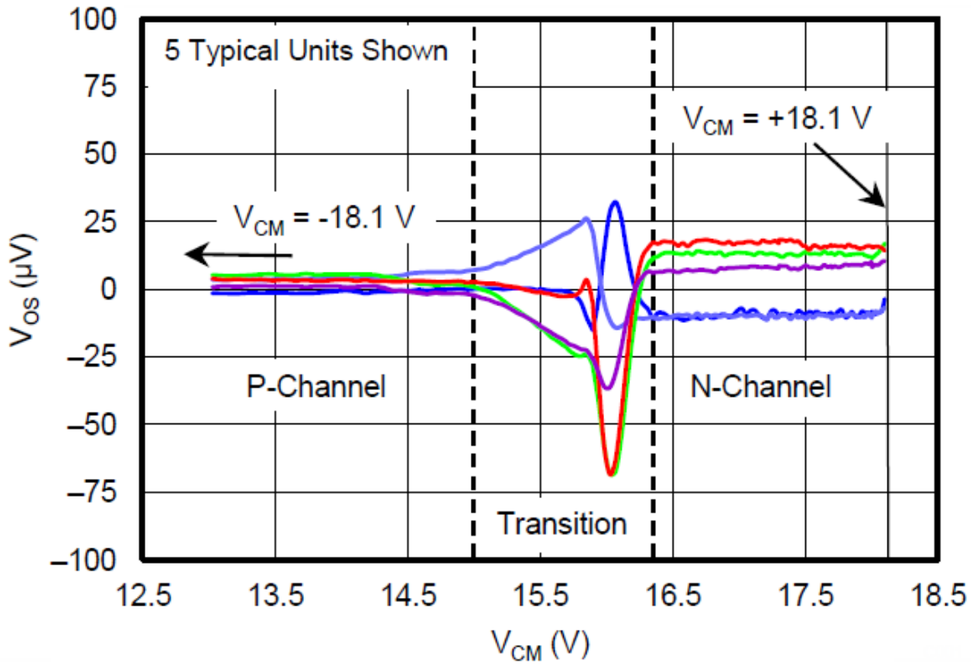
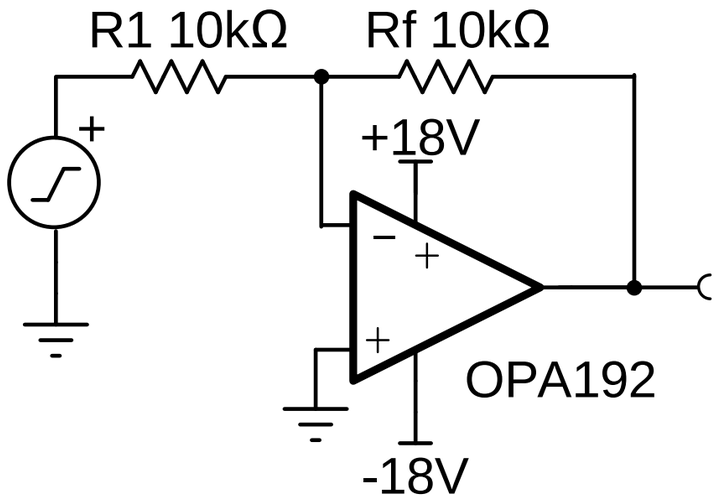


Figure 13: Offset Voltage vs. Common-Mode Voltage

Quiz: Linear Range ADC + OPA

6. Which of the following applies to an inverting amplifier topology.
   a. Gain error is determined by resistor tolerance.
   b. The input impedance is relatively low (10kΩ in this case).
   c. The circuit will not have crossover distortion issues.
   d. Would have a low input impedance.
   e. The output will be loaded by the feedback network (10kΩ in this case).
   f. All the statements apply to the inverting topology.
   g. None of the statements apply to the inverting topology.



Quiz: Linear Range ADC + OPA

7. Select 0.1% and 1% standard value resistors for the circuit below to set the gain to -0.188. Use the “Analog Engineer’s calculator”.

For 0.1%: Rf = 2.67kΩ, R1 = 14.2k Ω (or another power of 10 multiple).

For 1.0%: Rf = 2.21kΩ, R1 = 11.8k Ω (or another power of 10 multiple).