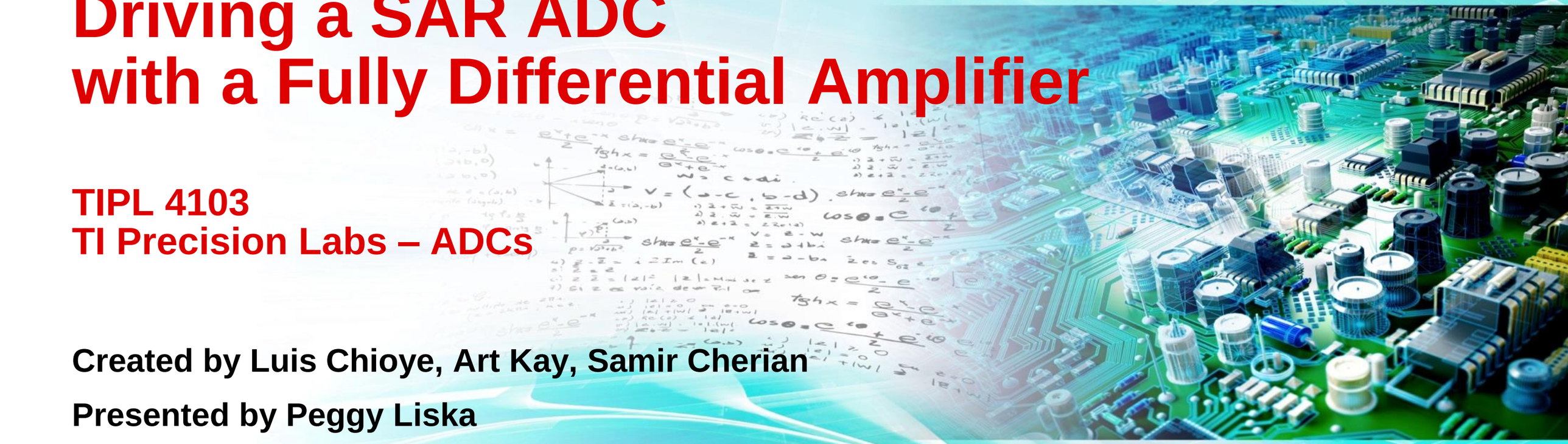
Driving a SAR ADC with a Fully Differential Amplifier

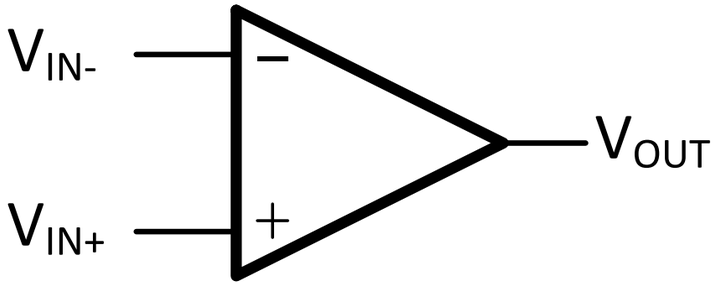


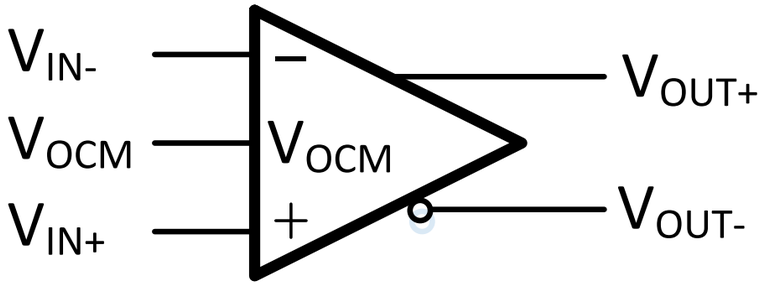
TIPL 4103
TI Precision Labs – ADCs

Created by Luis Chioye, Art Kay, Samir Cherian

Presented by Peggy Liska

Fully Differential Amplifier or FDA





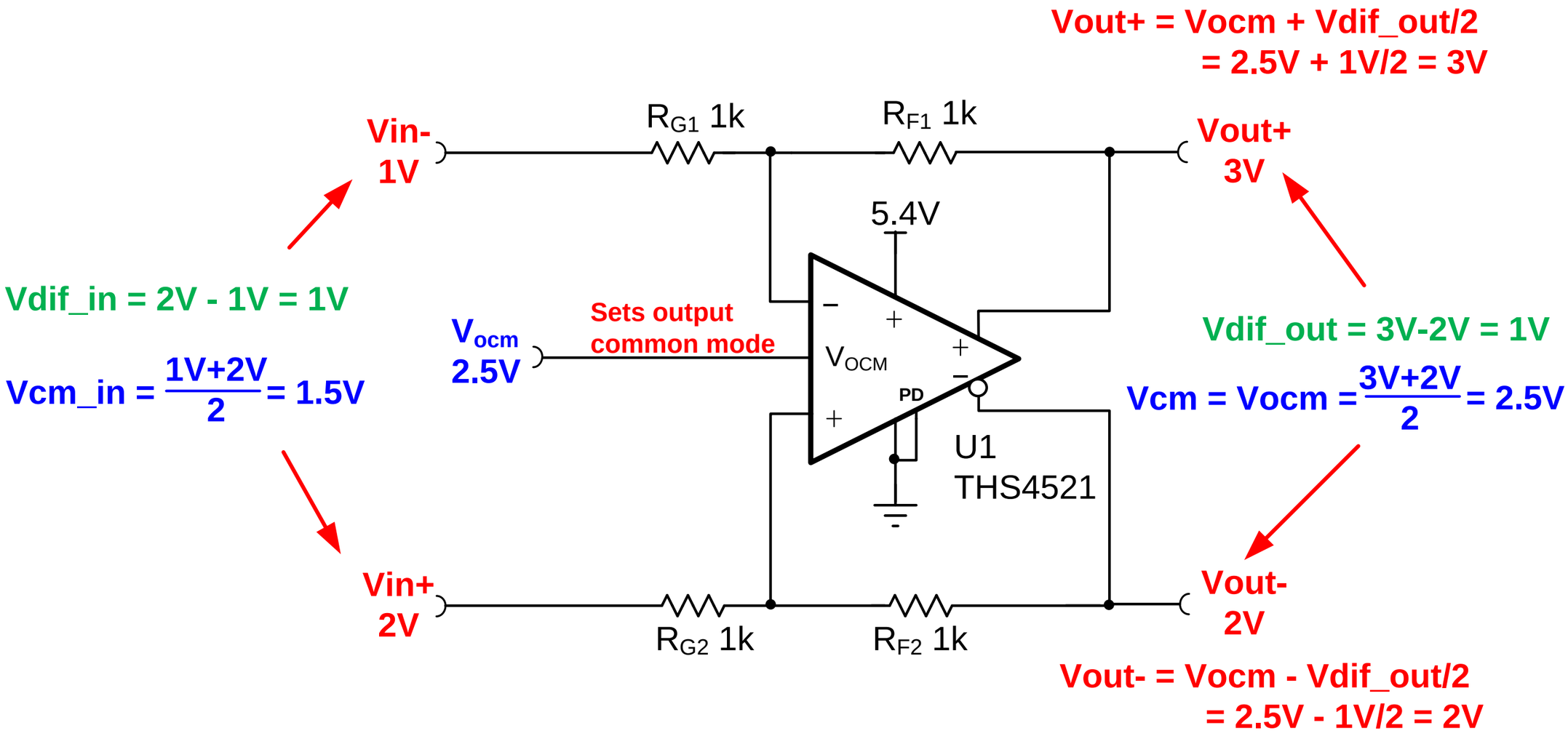
Standard Operational Amplifier

- Differential in
- Single-ended out
- Output Common Mode is Vout
- Single feedback paths

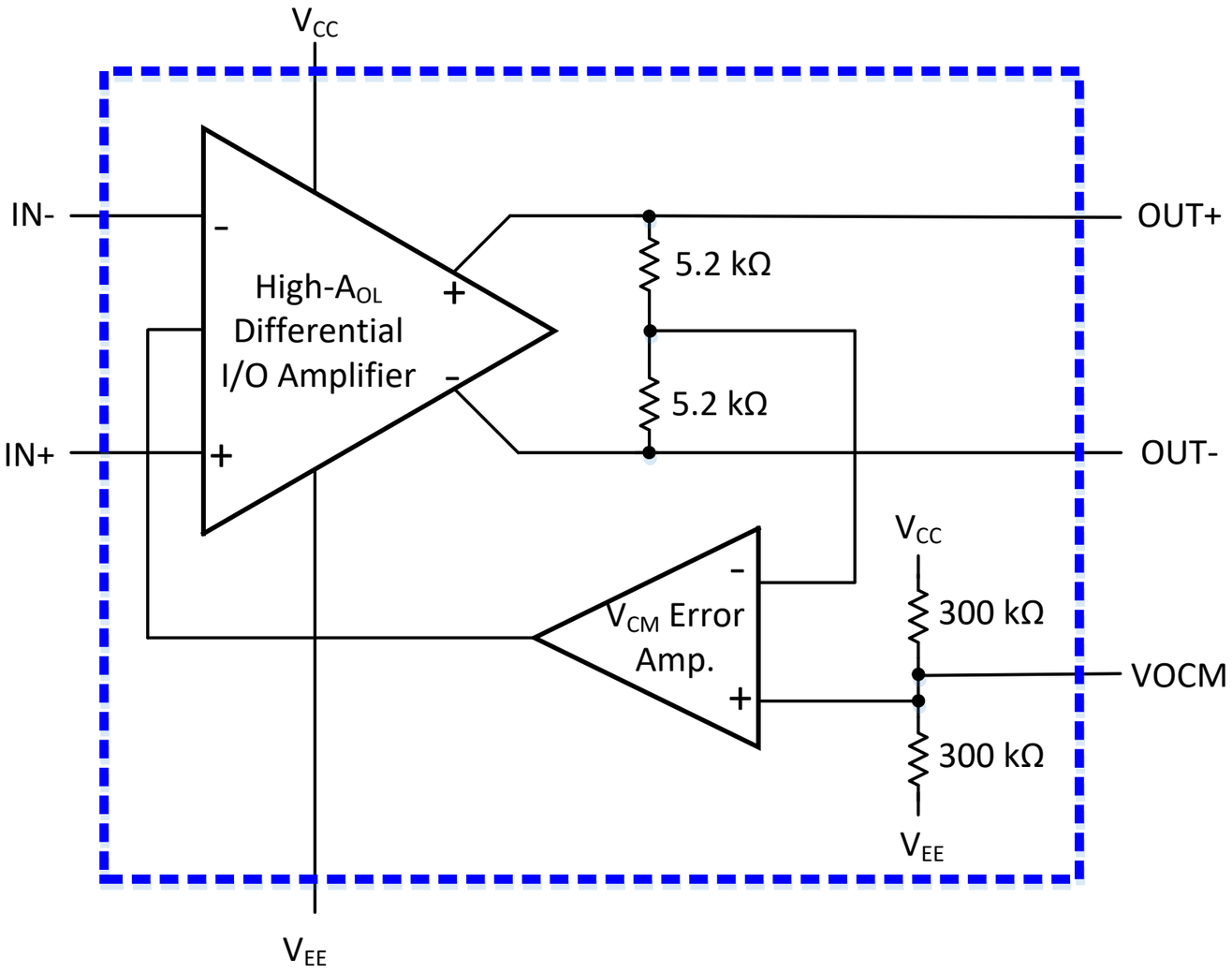
Fully-Differential Amplifier

- Differential in
- Differential out
- Output Common-mode set by Vocm
- Multiple feedback paths
- Double the dynamic range of amplifier
- Even order harmonic distortion canceled

Fully Differential Amplifier or FDA

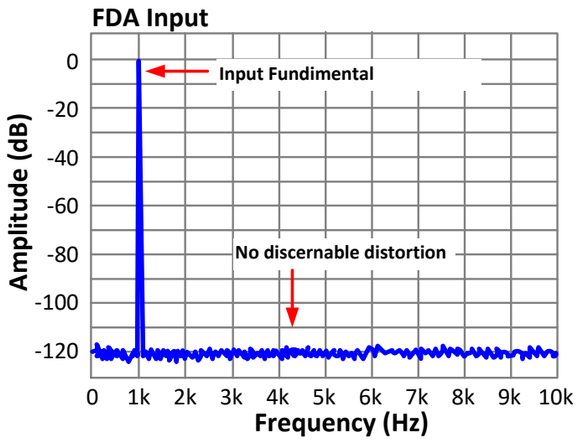


Integrated FDA – THS4551 block diagram



- Integrated fully-differential, high A_{OL} amplifier
- Integrated wide-bandwidth, common-mode feedback, error amplifier
- Integrated resistors to detect the average output common-mode voltage
- Integrated mid-supply, common mode setting resistors

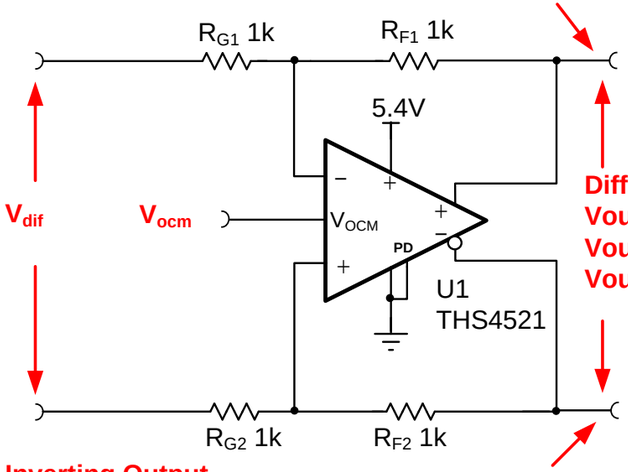
FDA Distortion Considerations



Non-Inverting Output

$g_a(x) = a_0 + a_1 \cdot x + a_2 \cdot x^2 + a_3 \cdot x^3 + a_4 \cdot x^4 + a_5 \cdot x^5 + \ldots$

$Vout\_pos = a_0 + a_1 \cdot (V_{dif}) + a_2 \cdot (V_{dif})^2 + a_3 \cdot (V_{dif})^3 + a_4 \cdot (V_{dif})^4 + a_5 \cdot (V_{dif})^5 + \ldots$

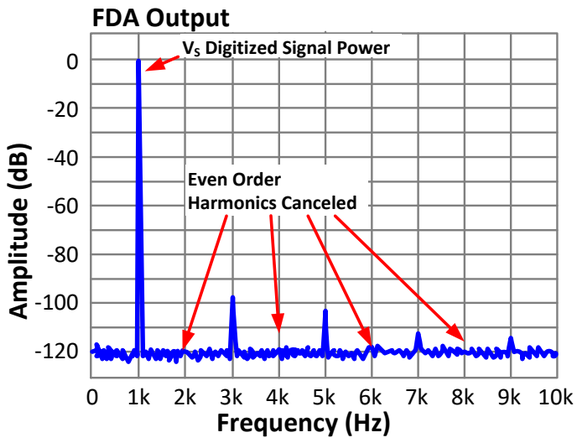


Inverting Output

$g_b(x) = b_0 + b_1 \cdot x + b_2 \cdot x^2 + b_3 \cdot x^3 + b_4 \cdot x^4 + b_5 \cdot x^5 + \ldots$

$Vout\_neg = b_0 + b_1 \cdot (-V_{dif}) + b_2 \cdot (-V_{dif})^2 + b_3 \cdot (-V_{dif})^3 + b_4 \cdot (-V_{dif})^4 + b_5 \cdot (-V_{dif})^5 + \ldots$

$Vout\_neg = b_0 - b_1 \cdot (V_{dif}) + b_2 \cdot (V_{dif})^2 - b_3 \cdot (V_{dif})^3 + b_4 \cdot (V_{dif})^4 - b_5 \cdot (V_{dif})^5 + \ldots$



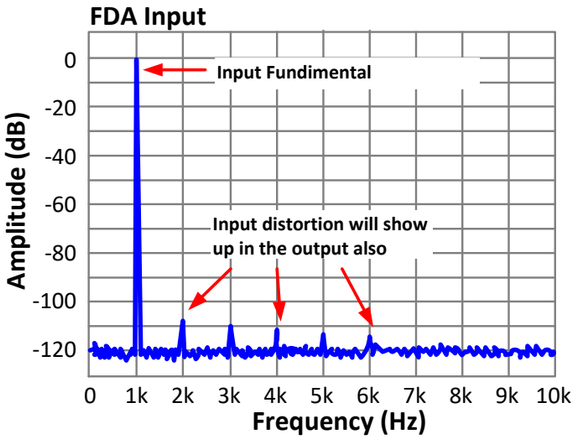
Differential Output

$Vout\_dif = Vout\_pos - Vout\_neg$

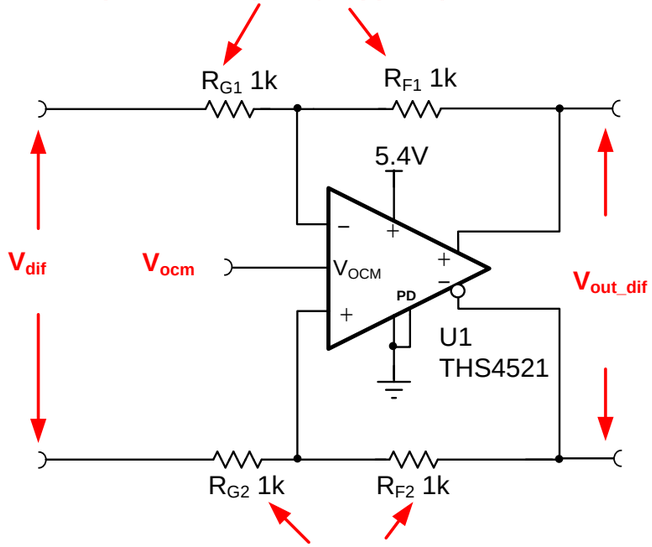
$Vout\_dif = a_0 + b_0 + (a_1 + b_1) \cdot (V_{dif}) + (a_2 - b_2) \cdot (V_{dif})^2 + (a_3 + b_3) \cdot (V_{dif})^3 + (a_4 - b_4) \cdot (V_{dif})^4 + (a_5 + b_5) \cdot (V_{dif})^5 + \ldots$

$Vout\_dif = a_0 + b_0 + (a_1 + b_1) \cdot (V_{dif}) + 0.0 + (a_3 + b_3) \cdot (V_{dif})^3 + 0.0 + (a_5 + b_5) \cdot (V_{dif})^5 + \ldots$

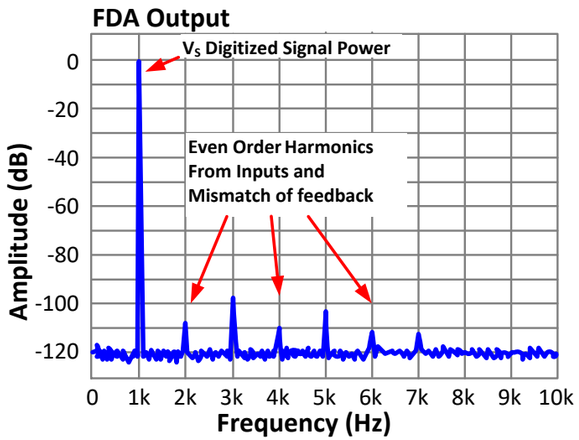
FDA Distortion Considerations



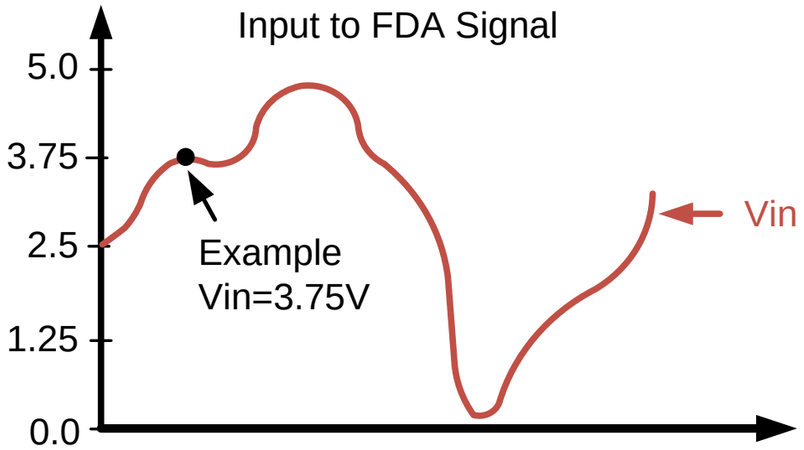
Make sure you use accurate low drift resistors for optimal THD (0.1%, 20ppm/C)

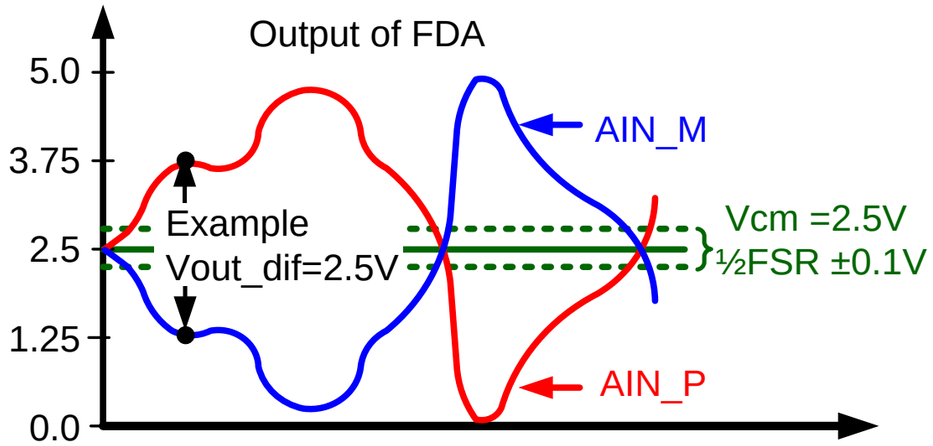


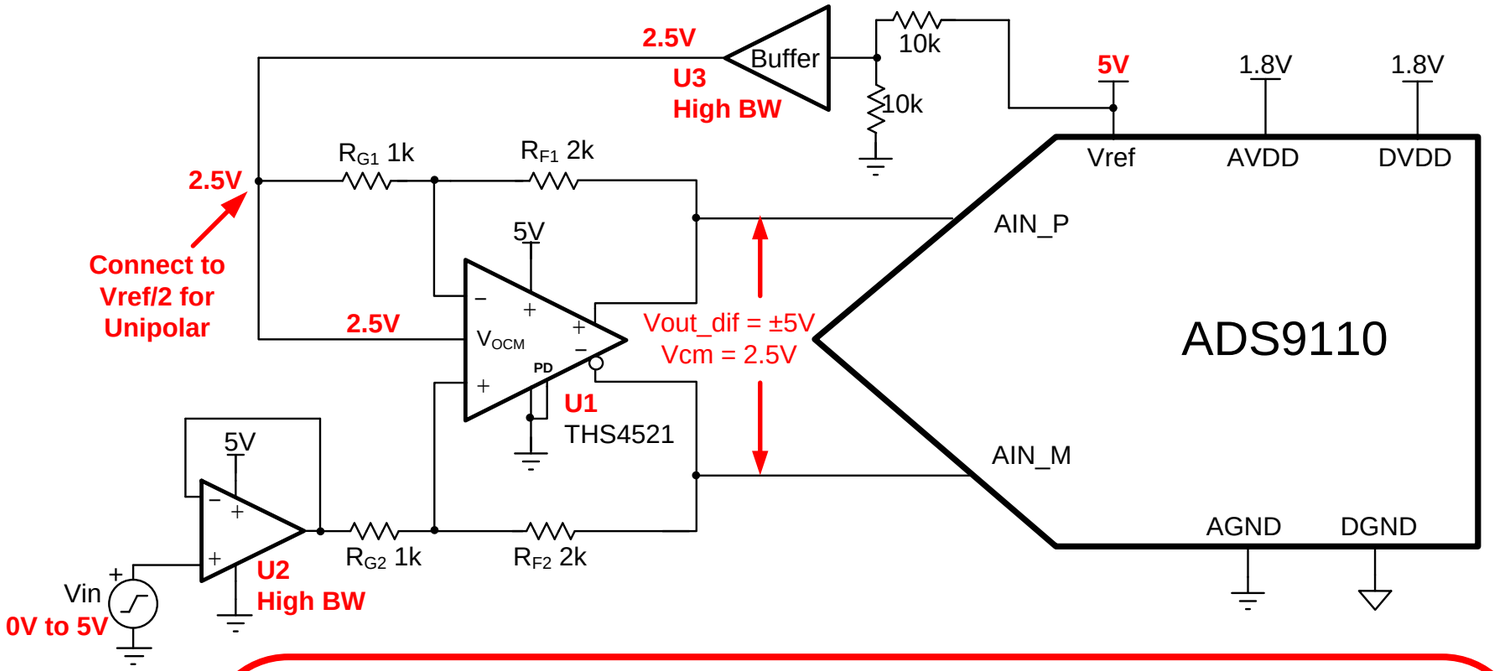
Any mismatch in resistors will introduce distortion



FDA – Single Ended Unipolar to Differential







Equations for this Configuration

$$A_{vdif} = \frac{R_F}{R_G}$$

$$V_{OutP} = \left(\frac{A_{vdif}}{2}\right) \cdot (V_{in} - V_{OCM}) + V_{OCM}$$

$$V_{OutN} = -\left(\frac{A_{vdif}}{2}\right) \cdot (V_{in} - V_{OCM}) + V_{OCM}$$

$$V_{OutDif} = A_{vdif} \cdot (V_{in} - V_{OCM})$$

Example Calculation: $V_{in} = 3.75V$

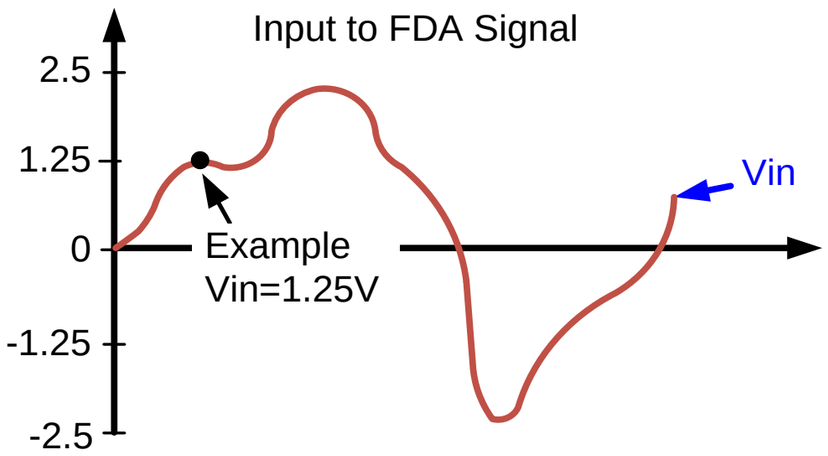
$$A_{vdif} = \frac{R_F}{R_G} = \frac{2k\Omega}{1k\Omega} = 2\,V/V$$

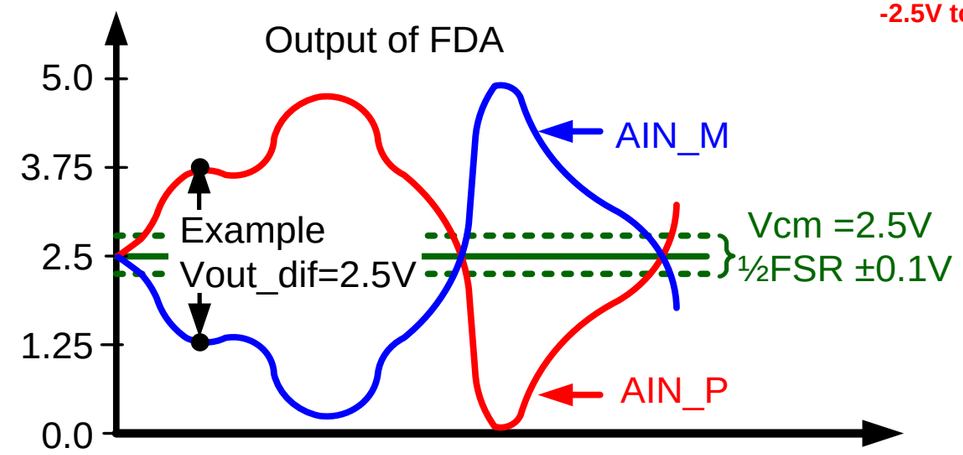
$$V_{OutP} = \left(\frac{2}{2}\right) \cdot (3.75V - 2.5V) + 2.5V = 3.75V$$

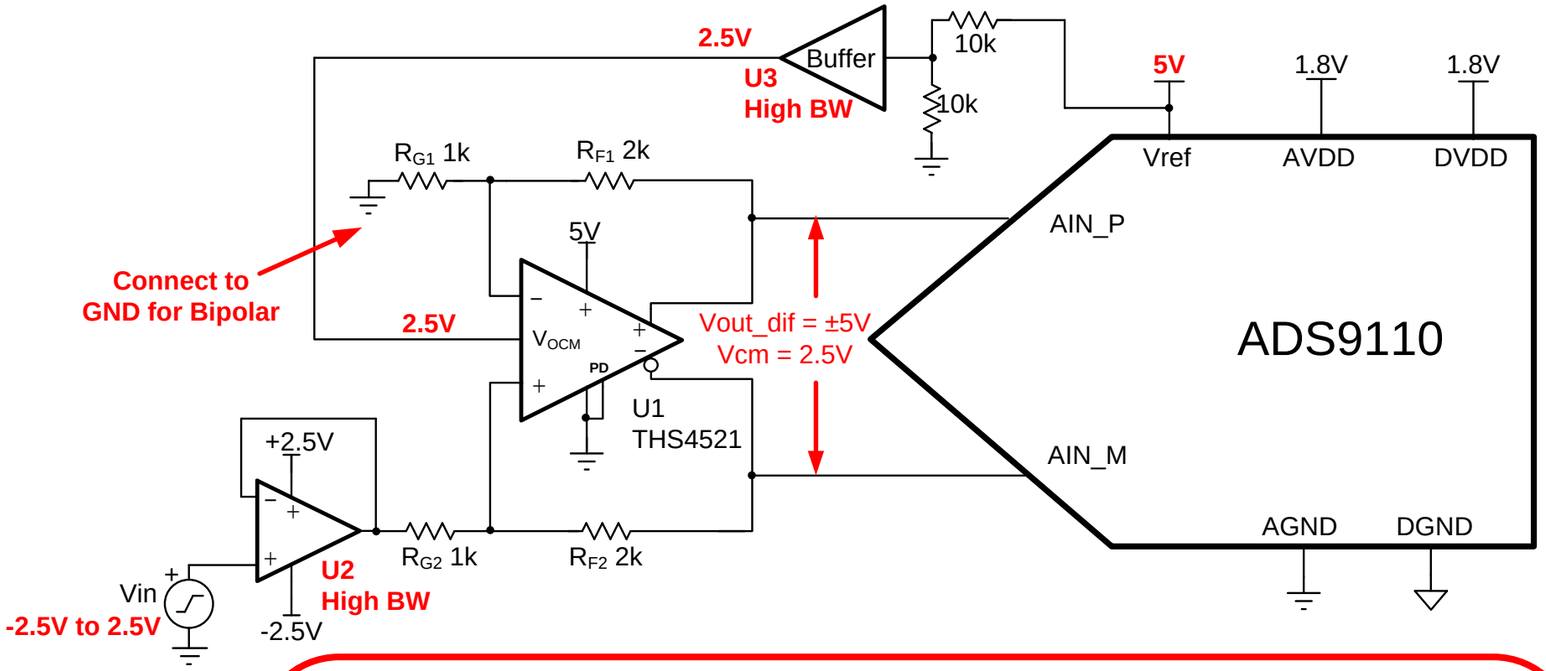
$$V_{OutN} = -\left(\frac{2}{2}\right) \cdot (3.75V - 2.5V) + 2.5V = 1.25V$$

$$V_{OutDif} = 2 \cdot (3.75V - 2.5V) = 2.5V$$

FDA – Single Ended Bipolar to Differential







Equations for this Configuration

$$A_{vdif} = \frac{R_F}{R_G}$$

$$V_{OutP} = \left(\frac{A_{vdif}}{2}\right) \cdot (V_{in}) + V_{OCM}$$

$$V_{OutN} = -\left(\frac{A_{vdif}}{2}\right) \cdot (V_{in}) + V_{OCM}$$

$$V_{OutDif} = A_{vdif} \cdot (V_{in})$$

Example Calculation: $V_{in} = 3.75V$

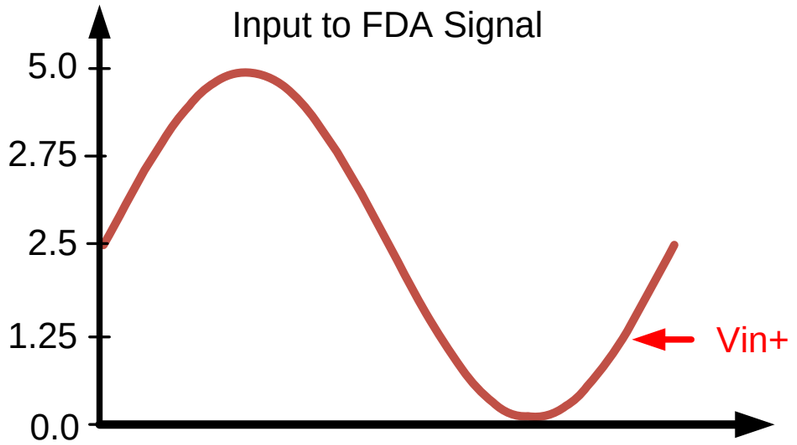
$$A_{vdif} = \frac{R_F}{R_G} = \frac{2k\Omega}{1k\Omega} = 2\,V/V$$

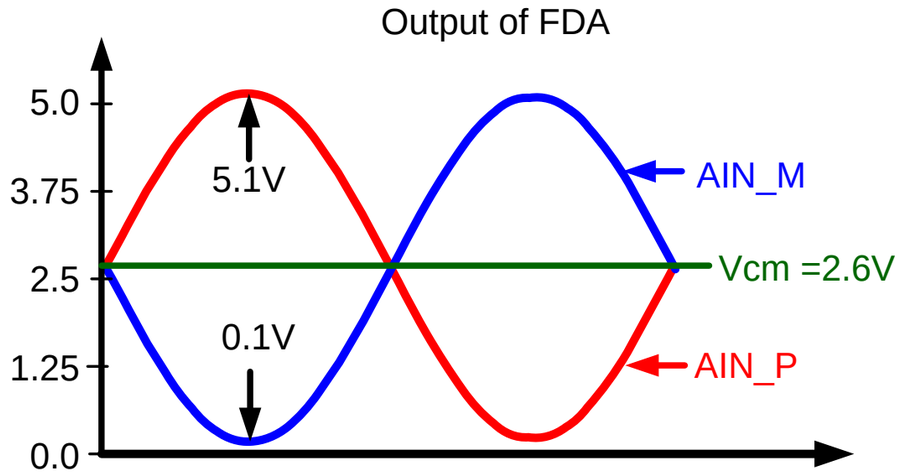
$$V_{OutP} = \left(\frac{2}{2}\right) \cdot (1.25V) + 2.5V = 3.75V$$

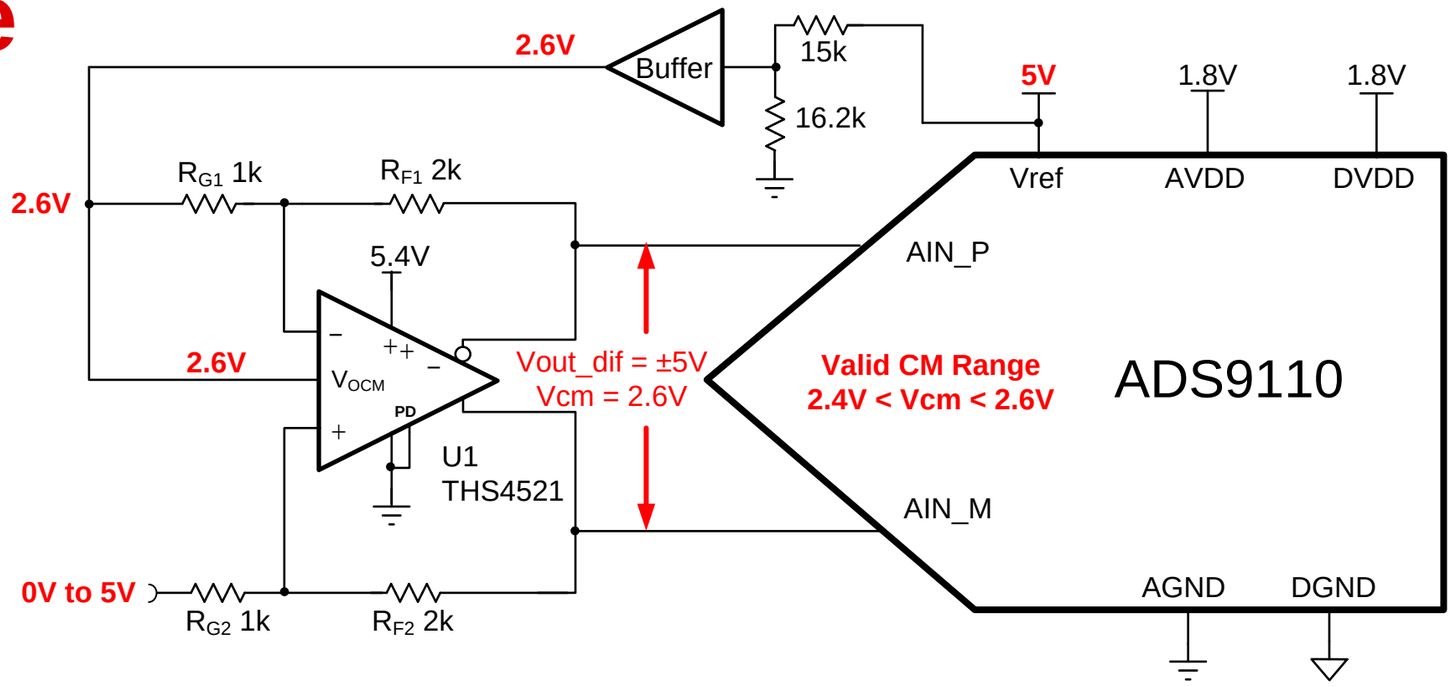
$$V_{OutN} = -\left(\frac{2}{2}\right) \cdot (1.25V) + 2.5V = 1.25V$$

$$V_{OutDif} = 2 \cdot (3.75V - 1.25V) = 2.5V$$

Improve Linear Range







PARAMETER THS4521		MIN	TYP	MAX	UNIT
Output voltage low			(V-) + 0.1	(V-) + 0.15	V
Output voltage high		(V+) – 0.3	(V+) – 0.25		V

PARAMETER ADS9110		MIN	TYP	MAX	UNIT
Full-scale input voltage span		-Vref		Vref	V
Absolute Input voltage range	AIN to GND	-0.1		AVDD+0.1	V
Common-mode voltage range		(Vref/2)-0.1	Vref/2	(Vref/2)+0.1	V

Thanks for your time!
Please try the quiz.

Quiz: Driving a SAR ADC with a Fully Differential Amplifier

TIPL 4103

TI Precision Labs – ADCs

Created by Art Kay

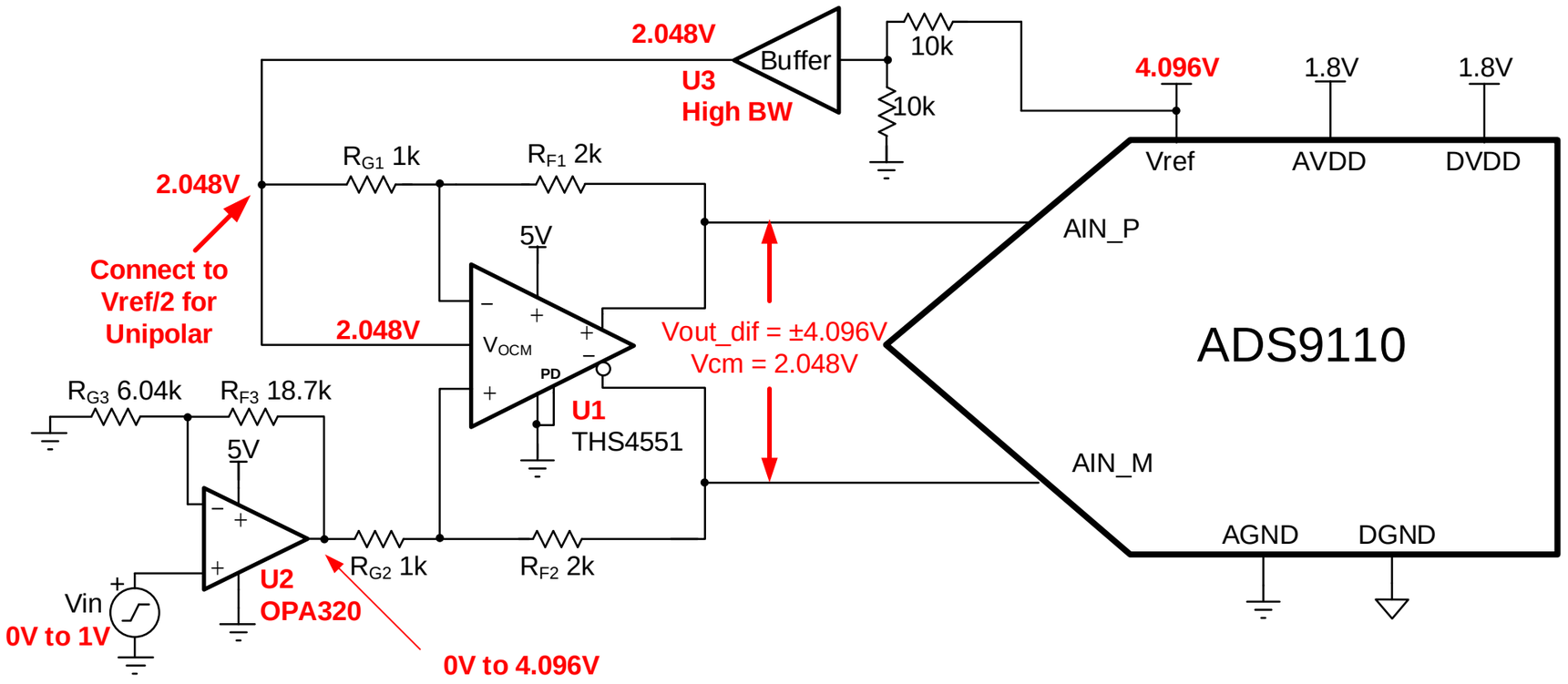
Quiz: Linear Range ADC + FDA

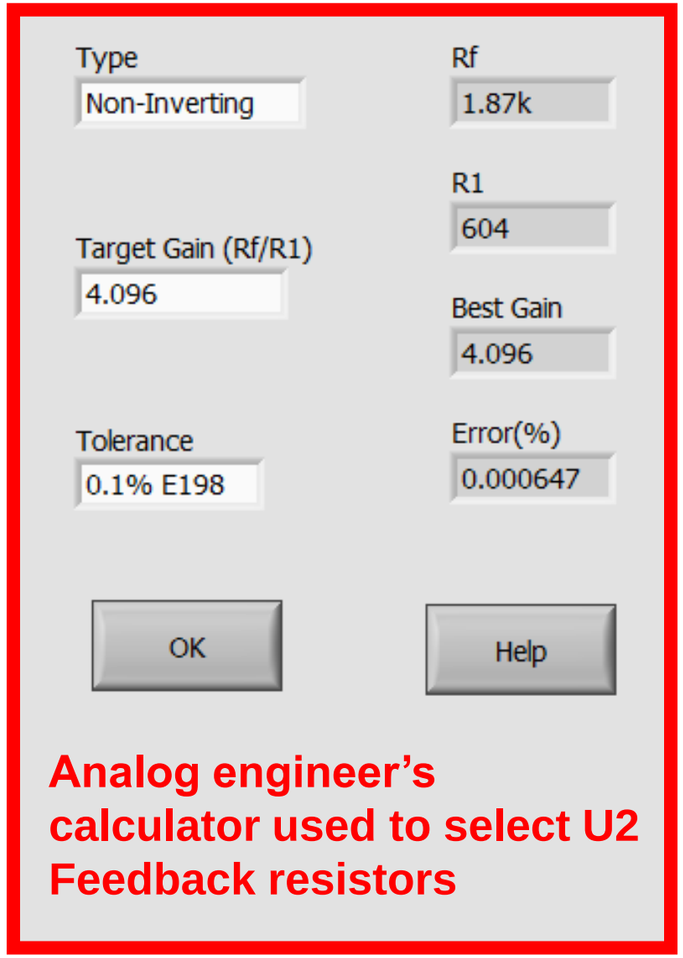
1. Design a FDA circuit topology to translate a single ended 0V to 1V, to 0V to 4V. Use THS4551, OPA320, and ADS9110 with a 4.096V reference. Will the output be linear over the full 0V to 1V signal range?
2. Design a FDA circuit topology to translate a single ended -0.1V to +0.1V, to 0V to 2.5V. Use THS4551, OPA320, and ADS9110 with a 2.5V reference. Will the output be linear over the full 0V to 1V signal range?
3. (T/F) Assume the input signal applied to an FDA has both even and odd order harmonics. The the FDA will cancel the even order harmonics.
4. (T/F) The Vocm pin can be directly connected to a voltage divider to set it's output common mode.

Solutions

Quiz: Linear Range ADC + FDA

1. Design a FDA circuit topology to translate a single ended 0V to 1V, to 0V to 4V. Use THS4551, OPA320, and ADS9110 with a 4.096V reference. Will the output be linear over the full 0V to 1V signal range?





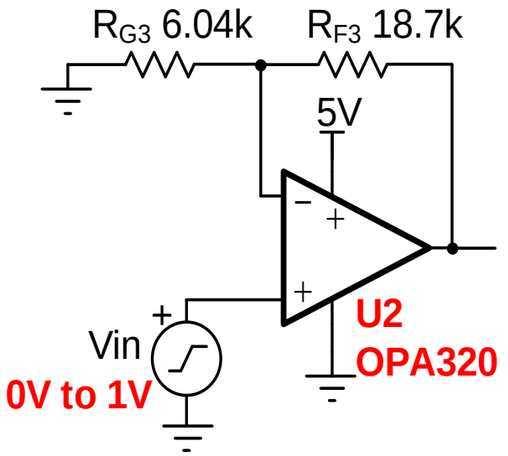
Analog engineer's calculator used to select U2 Feedback resistors

Quiz: Linear Range ADC + FDA

Problem 1: continued.

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	$-0.1V < V_{cm} < 5.1V$
Amplifier output range	$0.02 < V_O < 4.98V$
Amplifier Linear Range	$0.1 < V_O < 4.9V$
Worst Case Range	**$0.1 < V_O < 4.9V$**



Target:0V to 4.096V
Linear range: 0.1V to 4.096V

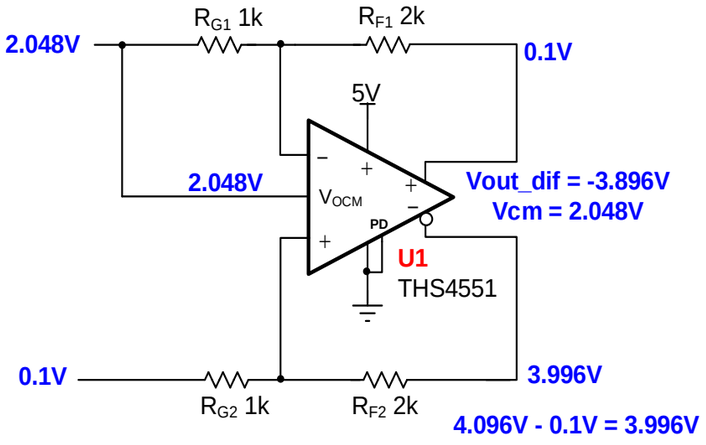
Quiz: Linear Range ADC + FDA

Problem 1: continued.

PARAMETER THS4551	MIN	TYP	MAX	UNIT
Output voltage low		(V-) + 0.2	**(V-) + 0.23**	V
Output voltage high	**(V+) – 0.23**	(V+) – 0.2		V
Common mode input voltage low		(V-) + 0.2	**(V-) – 0.1**	V
Common mode input voltage high	**(V+) – 1.2**	(V+) – 1.1		V

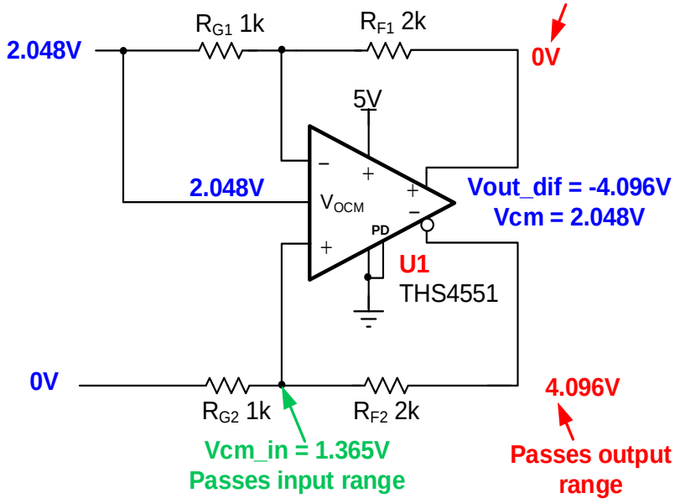
input range	$-0.1V < V_{cm} < 3.8V$
output range	$0.23 < V_O < 4.77V$

Minimum output swing from OpAmp

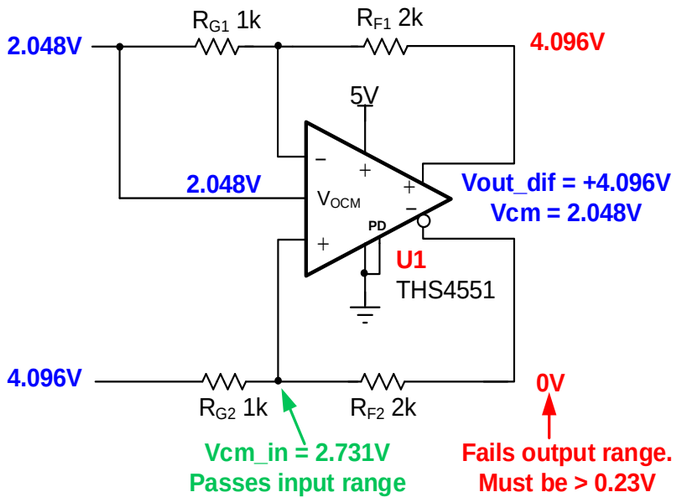


Ideal minimum output swing

Fails output range.
Must be > 0.23V



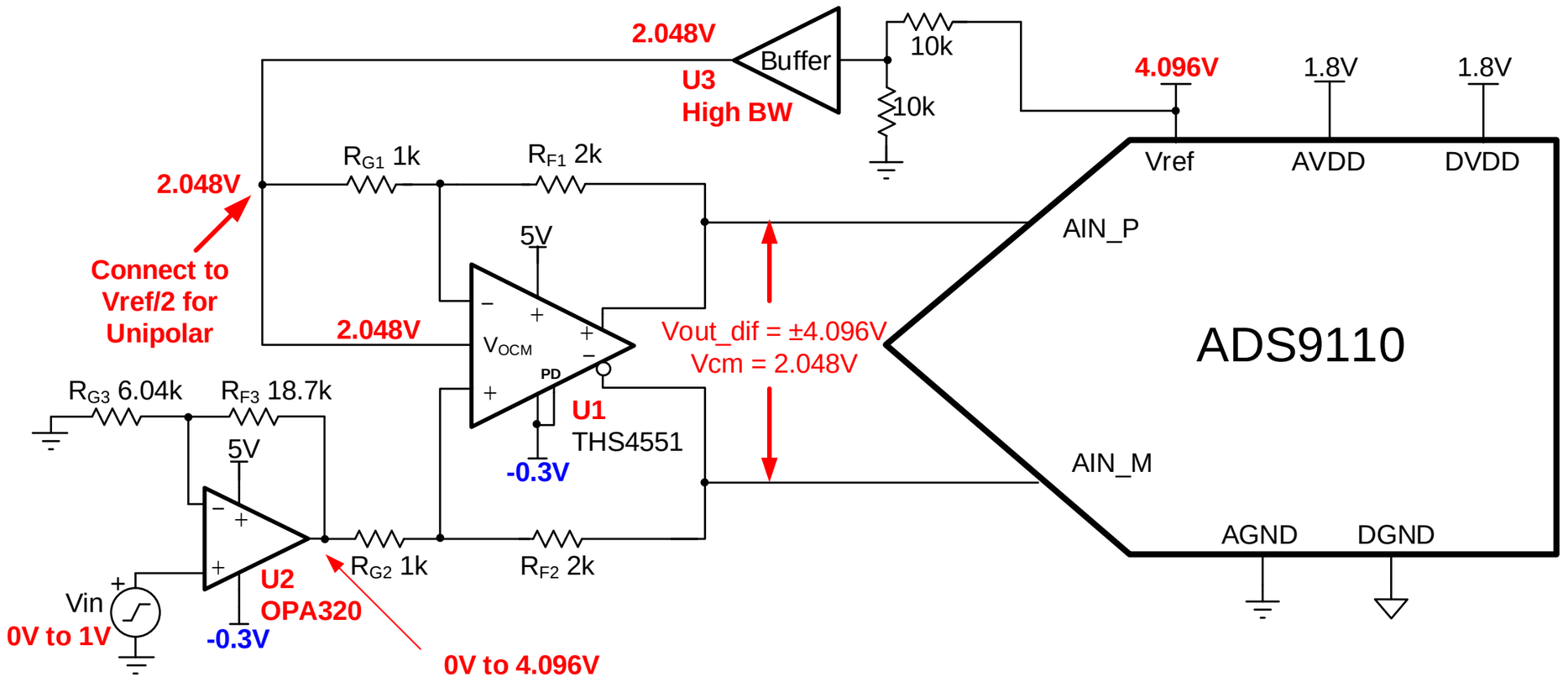
Maximum output swing



Note: The output swing low on the THS limits the range.

Quiz: Linear Range ADC + FDA

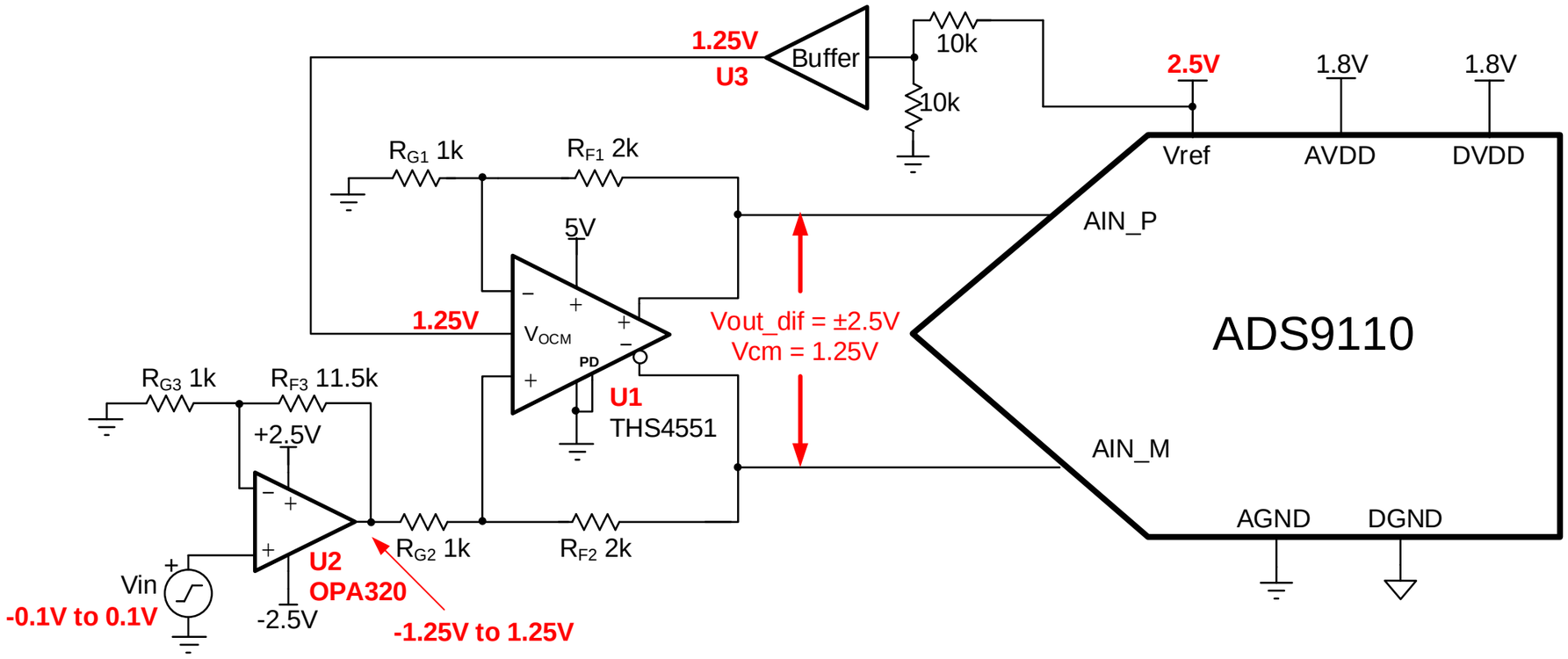
Problem 1: continued.

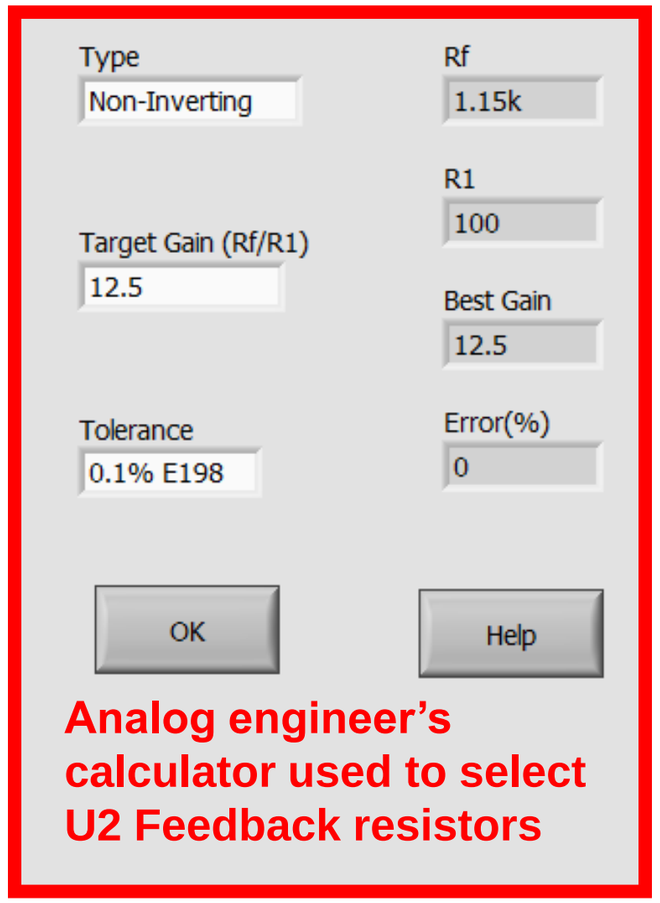


Note: One approach to avoiding the output swing limitation is a -0.3V negative supply.

Quiz: Linear Range ADC + FDA

2. Design a FDA circuit topology to translate a single ended -0.1V to +0.1V, to 0V to 2.5V. Use THS4551, OPA320, and ADS9110 with a 2.5V reference. Will the output be linear over the full 0V to 1V signal range?





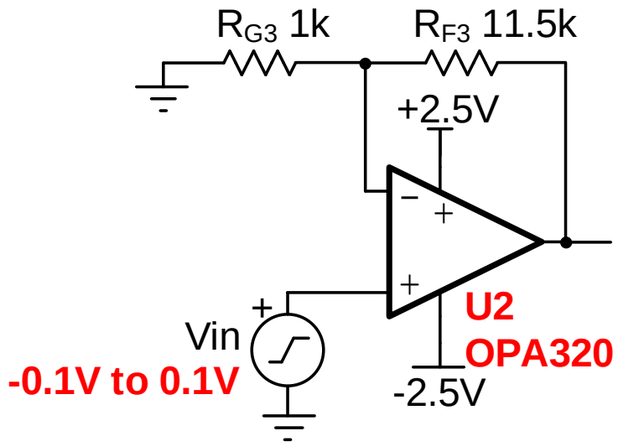
Analog engineer's calculator used to select U2 Feedback resistors

Quiz: Linear Range ADC + FDA

Problem 2: continued.

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	$-2.6V < V_{cm} < 2.6V$
Amplifier output range	$-2.48 < V_O < 2.48V$
Amplifier Linear Range	$-2.4 < V_O < 2.4V$
Worst Case Range	$\mathbf{-2.4 < V_O < 2.4V}$



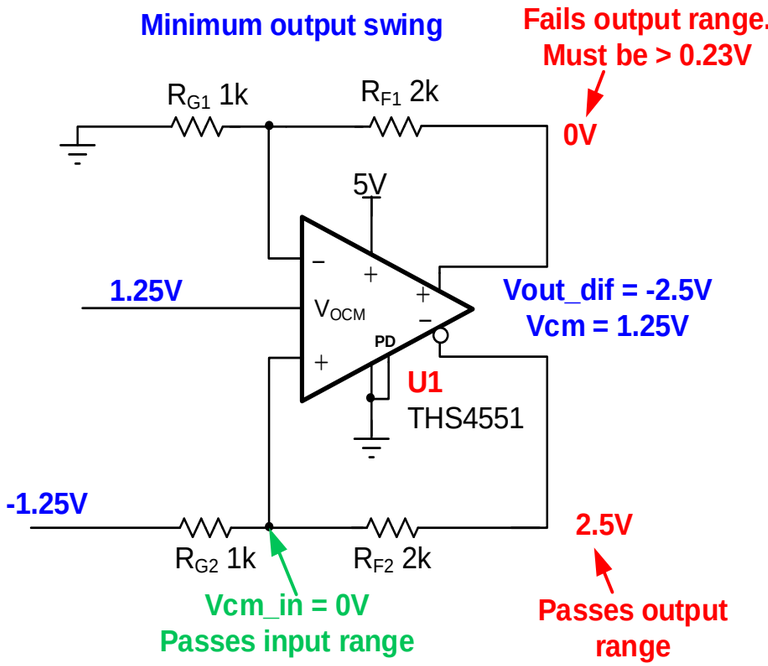
Target:-1.25V to +1.25V
Worst Case range: -2.4V to +2.4V
Not limited

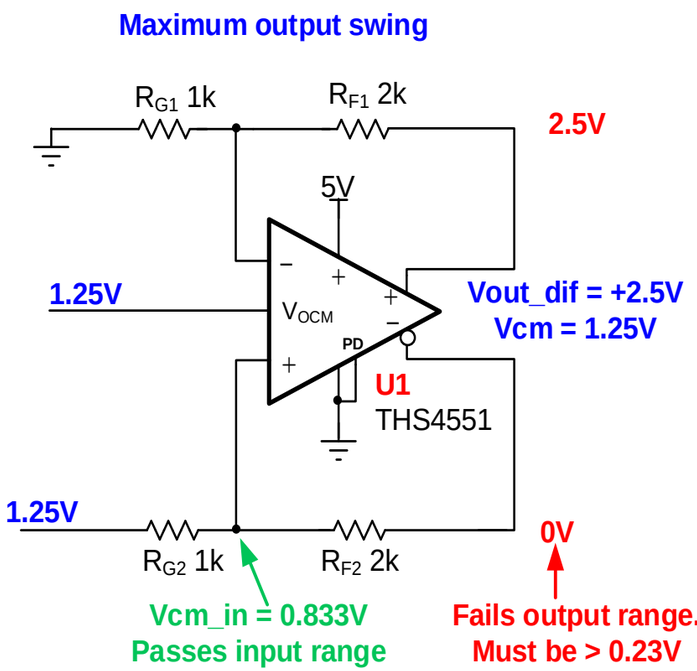
Quiz: Linear Range ADC + FDA

Problem 2: continued.

PARAMETER THS4551	MIN	TYP	MAX	UNIT
Output voltage low		(V-) + 0.2	**(V-) + 0.23**	V
Output voltage high	**(V+) – 0.23**	(V+) – 0.2		V
Common mode input voltage low		(V-) + 0.2	**(V-) – 0.1**	V
Common mode input voltage high	**(V+) – 1.2**	(V+) – 1.1		V

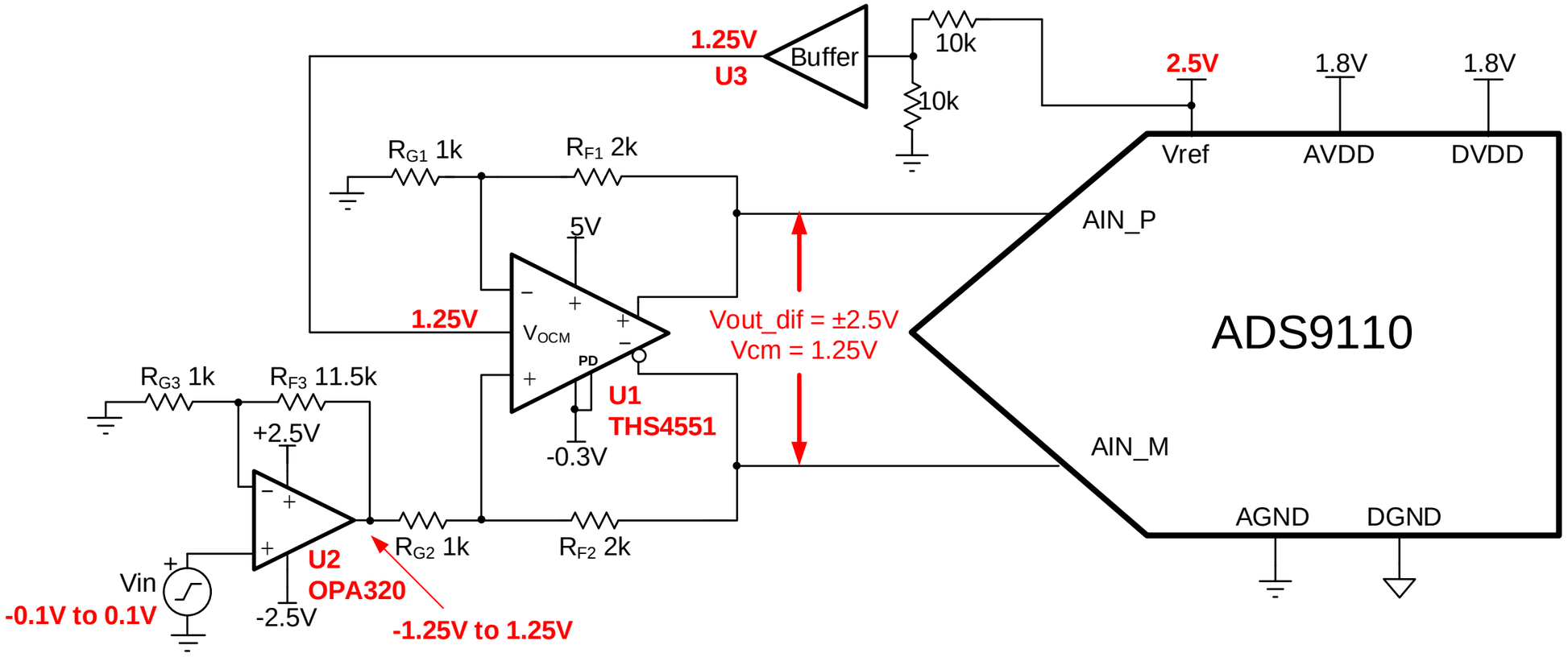
input range	$-0.1V < V_{cm} < 3.8V$
output range	$0.23 < V_O < 4.77V$





Quiz: Linear Range ADC + FDA

Problem 2: continued.



Note: One approach to avoiding the output swing limitation is a -0.3V negative supply.

Quiz: Linear Range ADC + FDA

3. (**False**) Assume the input signal applied to an FDA has both even and odd order harmonics. The the FDA will cancel the even order harmonics.
4. (**False**) The Vocm pin can be directly connected to a voltage divider to set it's output common mode.