# Fully Differential Amplifiers - 2

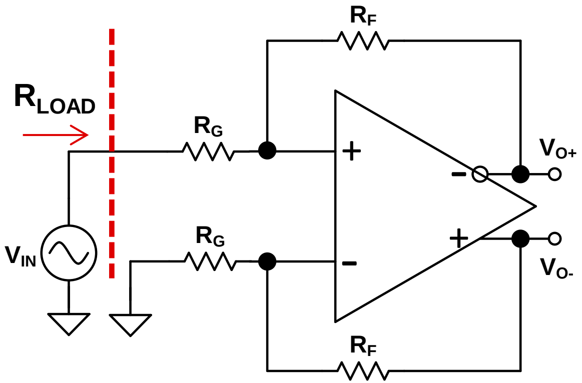
## Exercises

## TI Precision Labs: Op Amps

# Questions

1. How would you AC couple a single-ended input source to an FDA?

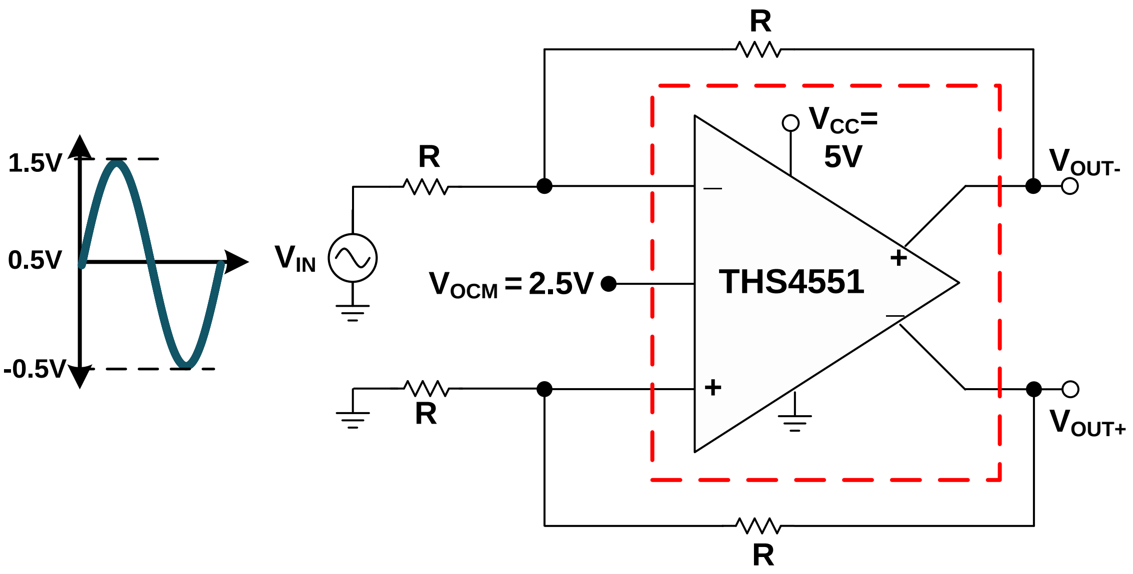
2. What is the load seen by the single-ended input source? (HINT: It is not $R_G$). Assume that both the VOCM = 0V and the input signal common-mode is 0V.



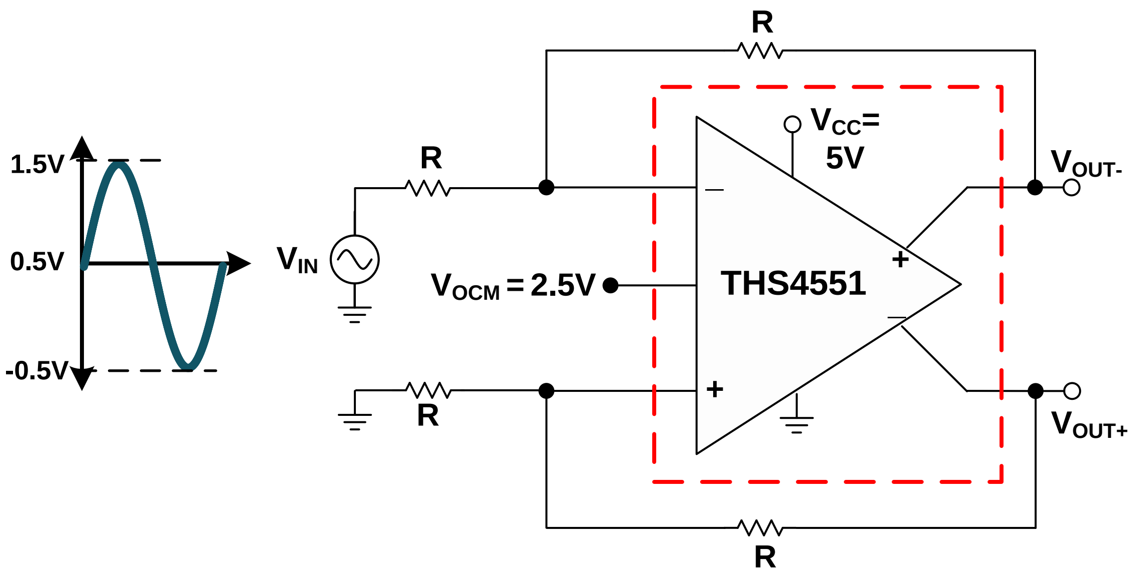
3. For the circuit shown below what is the,

- Output signal (differential and common-mode), and
- Input signal (differential and common-mode)

(HINT: The signal input common-mode is 0.5V while the non-driven input is at GND.)



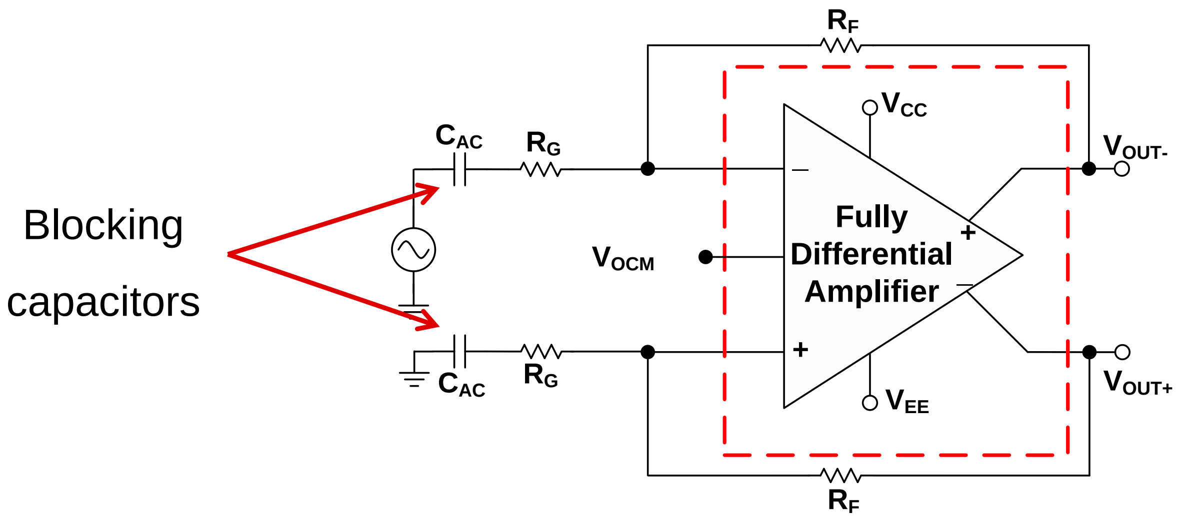
4. In the previous question how would you solve the problem of each output having a different common-mode (2.75V and 2.25V)



# Answers

1. How would you AC couple a single-ended input source to an FDA?

***Answer:*** This circuit configuration is useful when the DC and low-frequency signal content can be ignored. If the single-ended input common-mode is not GND, then using this circuit configuration precludes the need for a 2nd opamp on the un-driven FDA side, to match the common-mode of the input signal.



2. What is the load seen by the single-ended input source? (HINT: It is not $R_G$). Assume that both the VOCM = 0V and the input signal common-mode is 0V.

***Answer:*** The load is not $R_G$ because the amplifiers input common-mode is not fixed but is a function of the signal input and the feedback network.

$$V_{CM} = V_{O-}\left(\frac{R_G}{R_G + R_F}\right) \rightarrow \text{(1) Using KCL on the bottom half of FDA}$$

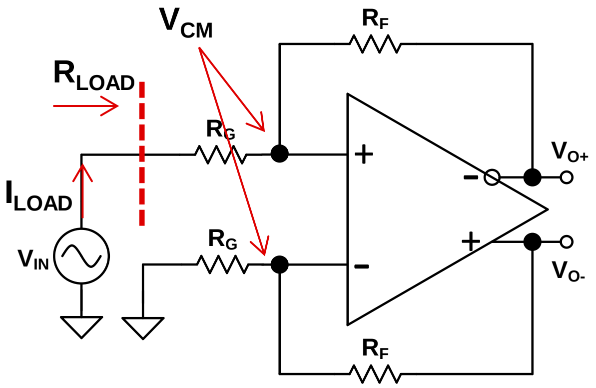
$$\frac{V_{O-}}{V_{IN}} = \frac{1}{2}(\text{SignalGain}) = \frac{1}{2}\left(\frac{R_F}{R_G}\right) \rightarrow \text{By definition}$$

$$\Rightarrow V_{O-} = \frac{1}{2}\left(\frac{R_F}{R_G}\right)V_{IN} \rightarrow (2)$$

$$I_{LOAD} = \frac{V_{IN} - V_{CM}}{R_G} = \frac{V_{IN} - \frac{1}{2}\left(\frac{R_F}{R_G}\right)V_{IN}\left(\frac{R_G}{R_G + R_F}\right)}{R_G}$$

$$R_{LOAD} = \frac{V_{IN}}{I_{LOAD}} = \frac{R_G}{\left(1 - \frac{1}{2}\left(\frac{R_F}{R_G + R_F}\right)\right)}$$

*__Divide $R_G$ by this factor to find the load seen by the signal source__*



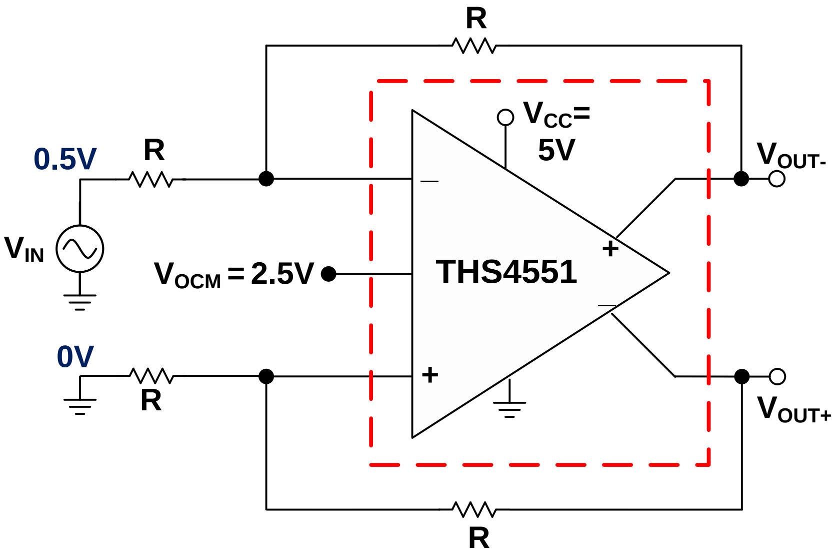
3. For the circuit shown below what is the,

- Output signal (differential and common-mode), and
- Input signal (differential and common-mode)

***Intuitive derivation of input and output common-mode***

***Answer:*** **First lets start with the common-mode analysis**

- The input common-mode is 0.5V and 0V respectively.
- The difference in common-mode is amplified by the signal gain and manifests itself as a differential signal centered on the output common-mode of 2.5V.
- The common-mode for $V_{OUT-}$ is therefore equal to 2.25V and $V_{OUT+}$ = 2.75V
- Also the input common-mode, $V_{CM}$ = ½ $V_{OUT+}$ = 1.375V
- The mathematical derivation for this is shown on the next slide.



$$V_{CM} = \frac{1}{2}(V_{OUT+}) \rightarrow$$ Simple resistive divider on un-driven side (1)

$$V_{OCM} = 2.5V = \left(\frac{V_{OUT+} + V_{OUT-}}{2}\right) \rightarrow$$ By definition $\Rightarrow V_{OUT-} = (2V_{OCM} - V_{OUT+})$ (2)

$$\frac{0.5 - V_{CM}}{R} = \frac{V_{CM} - V_{OUT-}}{R} \rightarrow$$ Using KCL on the driven side

$$\Rightarrow \frac{0.5V - \frac{1}{2}(V_{OUT+})}{R} = \frac{\frac{1}{2}(V_{OUT+}) - (2V_{OCM} - V_{OUT+})}{R}$$

$$\Rightarrow \left(\frac{1}{2}\right)V_{OUT+} + \left(\frac{1}{2}\right)V_{OUT+} + V_{OUT+} = 0.5V + 5V$$

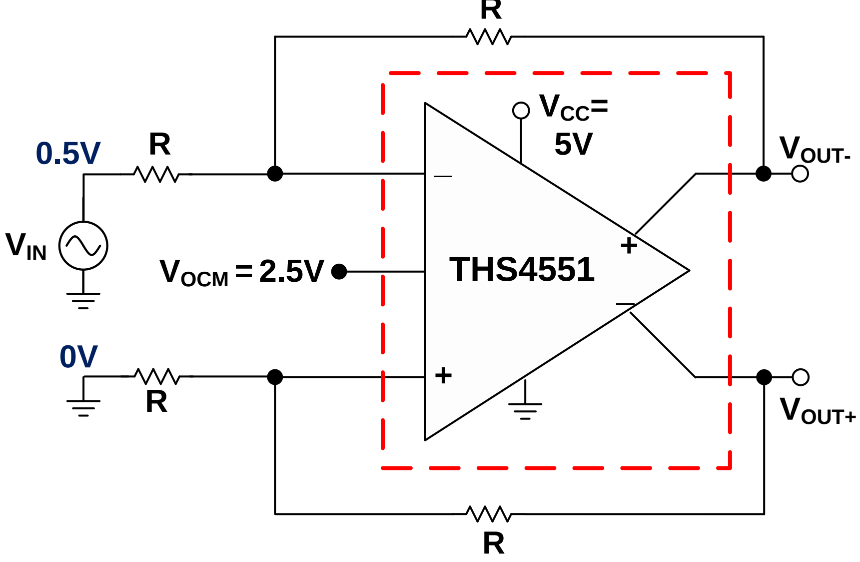
$$\Rightarrow 2V_{OUT+} = 5.5V \Rightarrow V_{OUT+} = 2.75V$$

*From (2) and (1) respectively -*

$$V_{OUT-} = (2V_{OCM} - V_{OUT+}) = (5V - 2.75V) = 2.25V$$

$$V_{CM} = \frac{1}{2}(V_{OUT+}) = \frac{1}{2}(2.75) = 1.375V$$

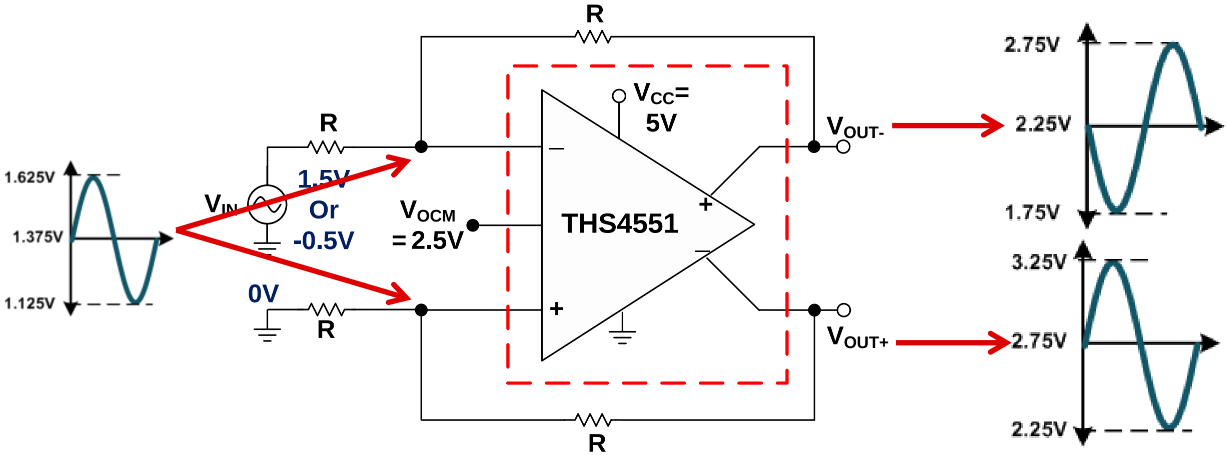
***Mathematical derivation of input and output common-mode***



**_Answer:_ Now on to differential analysis**

- Input sine-wave is $2V_{PP}$. FDA gain is 1V/V. So each output will swing $1V_{PP}$ on each outputs common-mode of 2.75V and 2.25V.
- The input common-mode will swing $0.5V_{PP}$ on the common-mode of 1.375V.
- The results are shown below. Mathematical derivation is left as an exercise. Use similar concepts as shown for the common-mode.

***Intuitive derivation of input and output differential-mode***



4. In the previous question how would you solve the problem of each output having a different common-mode (2.75V and 2.25V)

***Answer:*** Use a 2nd single-ended opamp to drive 0.5V into the un-driven side. It is important to use a wideband amplifier that has a bandwidth on par with the FDA used. (Try the OPA836)