

Differential input to differential output circuit using a fully-differential amplifier

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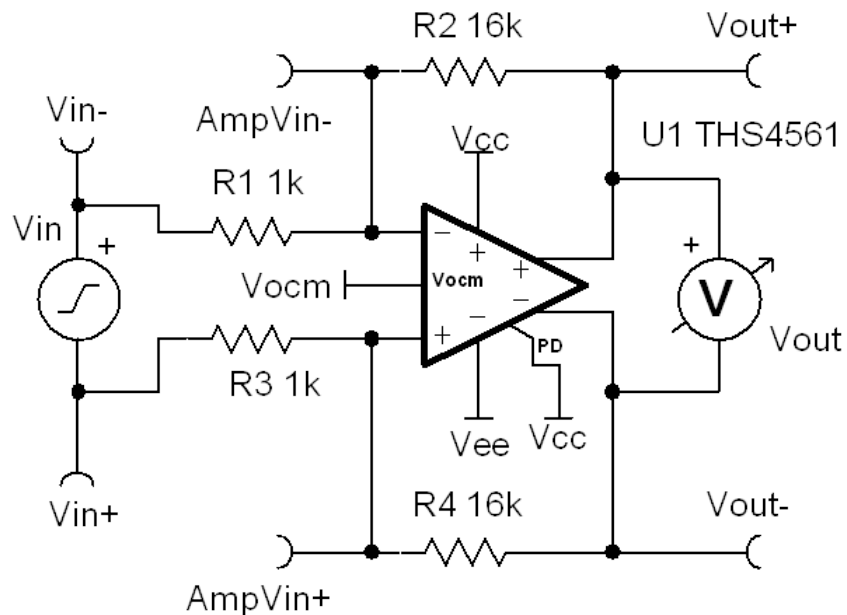
Design Goals

| Input | Output | Supply | |
|--------------|--------------|----------|----------|
| Differential | Differential | V_{cc} | V_{ee} |
| 1Vpp | 16Vpp | 10V | 0V |

| Output Common-Mode | 3dB Bandwidth | AC Gain (G_{ac}) |
|--------------------|---------------|----------------------|
| 5V | 3MHz | 16V/V |

Design Description

This design uses a fully differential amplifier (FDA) as a differential input to differential output amplifier.



Design Notes

1. The ratio $R2/R1$, equal to $R4/R3$, sets the gain of the amplifier.
2. For a given supply, the output swing for an FDA is twice that of a single ended amplifier. This is because a fully differential amplifier swings both terminals of the output, instead of swinging one and fixing the other to either ground or a V_{ref} . The minimum voltage of an FDA is therefore achieved when V_{out+} is held at the negative rail and V_{out-} is held at the positive rail, and the maximum is achieved when V_{out+} is held at the positive rail and V_{out-} is held at the negative rail.
3. FDAs are useful for noise sensitive signals, since noise coupling equally into both inputs will not be amplified, as is the case in a single ended signal referenced to ground.
4. The output voltages will be centered about the output common-mode voltage set by V_{ocm} .
5. Both feedback paths should be kept symmetrical in layout.

Design Steps

- Set the ratio R_2/R_1 to select the AC voltage gain. To keep the feedback paths balanced,
 $R_1 = R_3 = 1k\Omega$ (Standard Value)
 $R_2 = R_4 = R_1 \cdot (G_{AC}) = 1k\Omega \cdot \left(16 \frac{V}{V}\right) = 16k\Omega$ (Standard Value)
- Given the output rails of 9.8V and 0.2V for $V_s = 10V$, verify that 16Vpp falls within the output range available for $V_{ocm} = 5V$.

In normal operation:

$$\text{Amp}V_{IN+} = \text{Amp}V_{IN-}$$

$$V_{OUT+} - V_{ocm} = V_{ocm} - V_{OUT-}$$

$$V_{OUT} = V_{OUT+} - V_{OUT-}$$

- Rearrange to solve for each output voltage in edge conditions

$$V_{OUT-} = 2V_{ocm} - V_{OUT+}$$

$$V_{OUT-} = V_{OUT+} - V_{OUT}$$

$$2V_{OUT+} = 2V_{ocm} + V_{OUT}$$

$$V_{OUT+} = V_{ocm} + \frac{V_{OUT}}{2}$$

$$V_{OUT-} = V_{ocm} - \frac{V_{OUT}}{2}$$

- Verifying for $V_{out} = +8V$ and $V_{ocm} = +5V$,

$$V_{OUT+} = 5 + \frac{8}{2} = 9V < 9.8V$$

$$V_{OUT-} = 5 - \frac{8}{2} = 1V > 0.2V$$

- Verifying for $V_{out} = -8V$ and $V_{ocm} = +5V$,

$$V_{OUT+} = 5 + \frac{-8}{2} = 1V > 0.2V$$

$$V_{OUT-} = 5 - \frac{-8}{2} = 9V > 9.8V$$

Note that the maximum swing possible is:

$$(9.8\text{V} - 0.2\text{V}) - (0.2\text{V} - 9.8\text{V}) = 18.4\text{V}_{\text{pp}}, \text{ or } \pm 9.4\text{V}$$

- Use the input common mode voltage range of the amplifier and the feedback resistor divider to find the signal input range when the output range is 1V to 9V. Due to symmetry, calculation of one side is sufficient.

$$\text{Min}(\text{Amp}V_{\text{IN}+}) = \text{Min}(\text{Amp}V_{\text{IN}-}) = V_{\text{ee}} - 0.1\text{V} = -0.1\text{V}$$

$$\text{Max}(\text{Amp}V_{\text{IN}+}) = \text{Max}(\text{Amp}V_{\text{IN}-}) = V_{\text{cc}} - 1.1\text{V} = 8.9\text{V}$$

$$\frac{\text{Amp}V_{\text{IN}-} - V_{\text{IN}-}}{R_1} = \frac{V_{\text{OUT}+} - \text{Amp}V_{\text{IN}-}}{R_2}$$

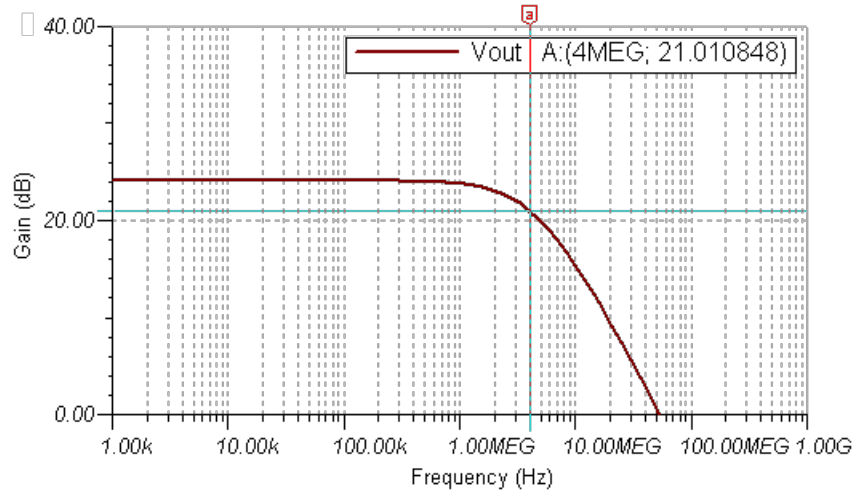
$$V_{\text{IN}-} = \text{Amp}V_{\text{IN}-} - \frac{V_{\text{OUT}+} - \text{Amp}V_{\text{IN}-}}{\frac{R_2}{R_1}}$$

$$\text{Min}(V_{\text{IN}-}) = -0.1\text{V} - \frac{9\text{V} - (-0.1\text{V})}{16 \frac{\text{V}}{\text{V}}} = -0.65\text{V}$$

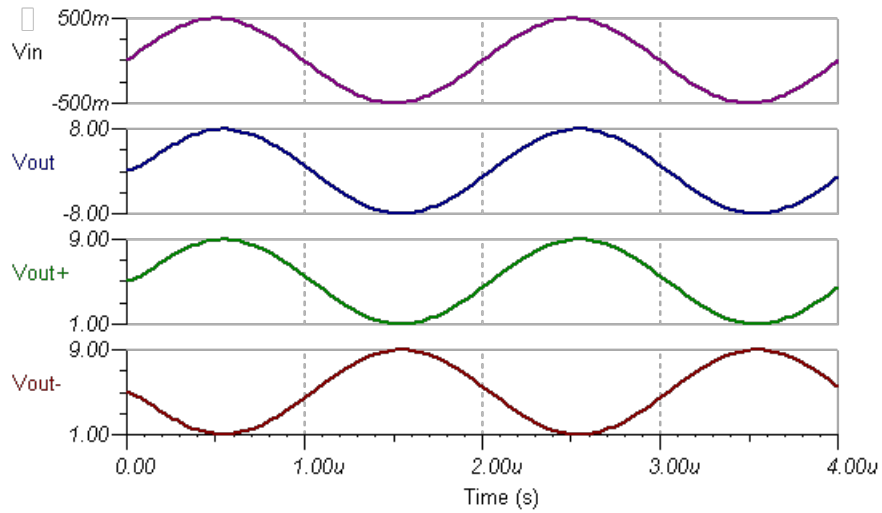
$$\text{Max}(V_{\text{IN}-}) = 8.9\text{V} + \frac{8.9\text{V} - 1\text{V}}{16 \frac{\text{V}}{\text{V}}} = 9.4\text{V}$$

Design Simulations

AC Simulation Results



Transient Simulation Results



Design References

See [Analog Engineer's Circuit Cookbooks](#) for TI's comprehensive circuit library.

See the [TIDA-01036](#) tool folder for more information.

Design Featured Op Amp

| THS4561 | |
|---|----------------------|
| V_{SS} | 3V to 13.5V |
| V_{inCM} | Vee-0.1V to Vcc-1.1V |
| V_{out} | Vee+0.2V to Vcc-0.2 |
| V_{OS} | TBD |
| I_q | TBD |
| I_b | TBD |
| UGBW | 70MHz |
| SR | 4.4V/ μ s |
| #Channels | 1 |
| http://www.ti.com/product/THS4561 | |

Design Alternate Op Amp

| THS4131 | |
|---|----------------------|
| V_{SS} | 5V to 33V |
| V_{inCM} | Vee+1.3V to Vcc-0.1V |
| V_{out} | Varies |
| V_{OS} | 2mV |
| I_q | 14mA |
| I_b | 2 μ A |
| UGBW | 80MHz |
| SR | 52V/ μ s |
| #Channels | 1 |
| http://www.ti.com/product/THS4131 | |

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