

Differential Input to Differential Output Circuit Using a Fully-Differential Amplifier



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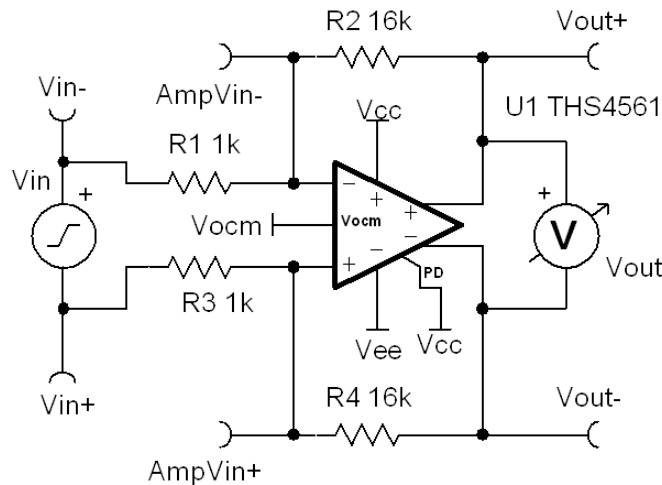
Design Goals

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

Output Common-Mode	3 dB Bandwidth	AC Gain (Gac)
5 V	3 MHz	16 V/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,

$$R_1 = R_3 = 1\text{k}\Omega \text{ (Standard Value)}$$

$$R_2 = R_4 = R_1 \cdot (G_{AC}) = 1\text{k}\Omega \cdot \left(16 \frac{\text{V}}{\text{V}}\right) = 16\text{k}\Omega \text{ (Standard Value)}$$

- Given the output rails of 9.8 V and 0.2 V for $V_s = 10$ V, verify that 16 V_{pp} falls within the output range available for $V_{ocm} = 5$ V.

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

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

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

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

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

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

Note that the maximum swing possible is:

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

- 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 1 V to 9 V. Due to symmetry, calculation of one side is sufficient.

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

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

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

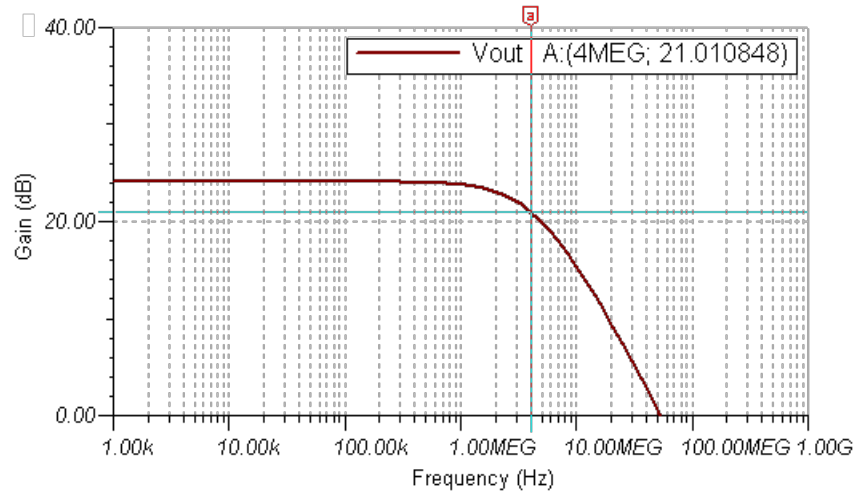
$$V_{\text{IN}-} = \text{Amp}V_{\text{IN}-} - \frac{V_{\text{OUT}+} - \text{Amp}V_{\text{IN}-}}{\frac{R_2}{R_1}}$$

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

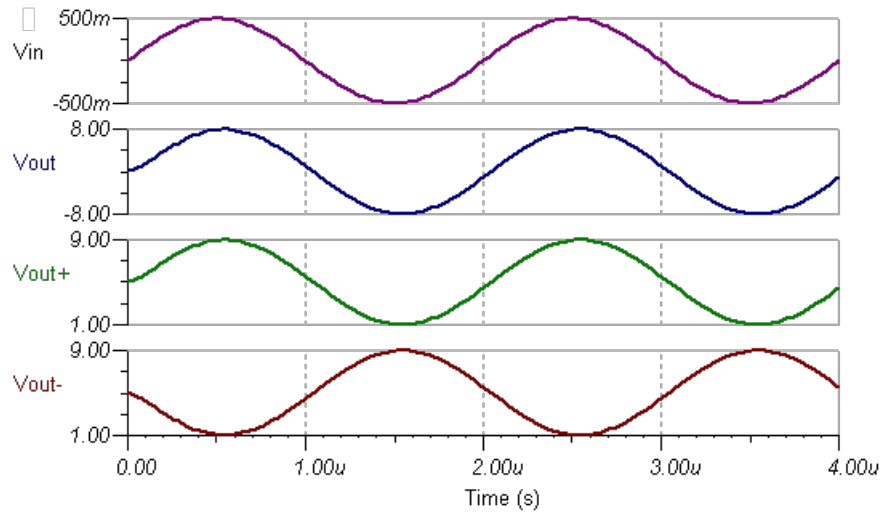
$$\text{Max}(V_{\text{IN}-}) = 8.9\text{V} + \frac{8.9\text{V} - 1\text{V}}{16 \frac{\text{V}}{\text{V}}} = 9.4\text{V}$$

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}	3 V to 13.5 V
V_{inCM}	$V_{ee}-0.1$ V to $V_{cc}-1.1$ V
V_{out}	$V_{ee}+0.2$ V to $V_{cc}-0.2$
V_{os}	TBD
I_q	TBD
I_b	TBD
UGBW	70 MHz
SR	4.4 V/ μ s
#Channels	1
THS4561	

Design Alternate Op Amp

THS4131	
V_{SS}	5 V to 33 V
V_{inCM}	$V_{ee}+1.3$ V to $V_{cc}-0.1$ V
V_{out}	Varies
V_{os}	2 mV
I_q	14 mA
I_b	2 μ A
UGBW	80 MHz
SR	52 V/ μ s
#Channels	1
THS4131	

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