Analog Engineer's Circuit

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

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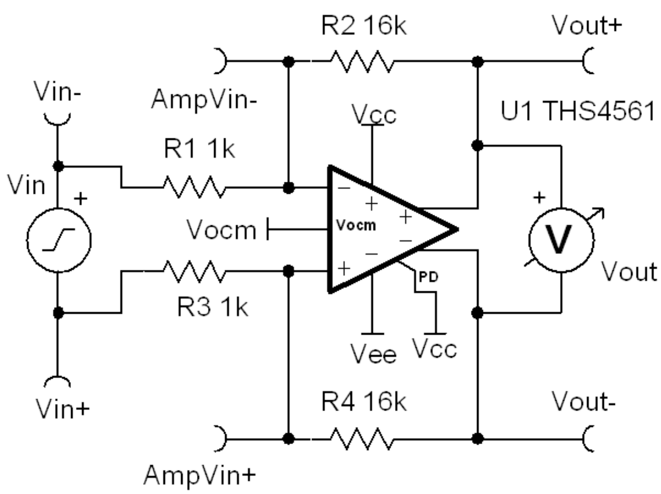
Design Goals

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 and 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 Vref. The minimum voltage of an FDA is therefore achieved when Vout+ is held at the negative rail and Vout- is held at the positive rail, and the maximum is achieved when Vout+ is held at the positive rail and Vout- 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 Vocm.
5. Both feedback paths should be kept symmetrical in layout.

Design Steps

- Set the ratio R2/ R1 to select the AC voltage gain. To keep the feedback paths balanced,

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

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

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

  In normal operation:

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

- 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 Vout = +8 V and V_{ocm} = +5 V,

$$V_{OUT+} = 5 + \frac{8}{2} = 9V < 9.8V$$
$$V_{OUT-} = 5 - \frac{8}{2} = 1V > 0.2V$$

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

$$V_{OUT+} = 5 + \frac{-8}{2} = 1V > 0.2V$$
$$V_{OUT-} = 5 - \frac{-8}{2} = 9V > 9.8V$$

  Note that the maximum swing possible is:

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

- 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.

$$\text{Min}(\text{AmpV}_{IN+}) = \text{Min}(\text{AmpV}_{IN-}) = \text{Vee} - 0.1\text{V} = -0.1\text{V}$$

$$\text{Max}(\text{AmpV}_{IN+}) = \text{Max}(\text{AmpV}_{IN-}) = \text{Vcc} - 1.1\text{V} = 8.9\text{V}$$

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

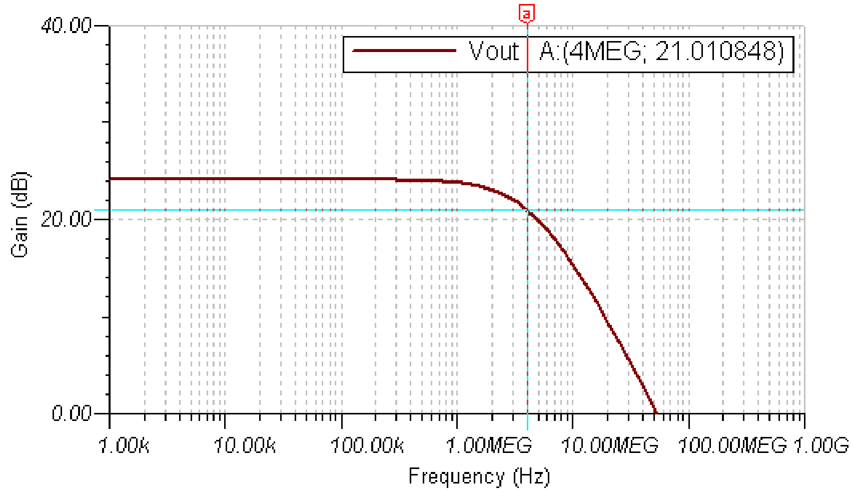
$$V_{IN-} = \text{AmpV}_{IN-} - \frac{V_{OUT+} - \text{AmpV}_{IN-}}{\frac{R_2}{R_1}}$$

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

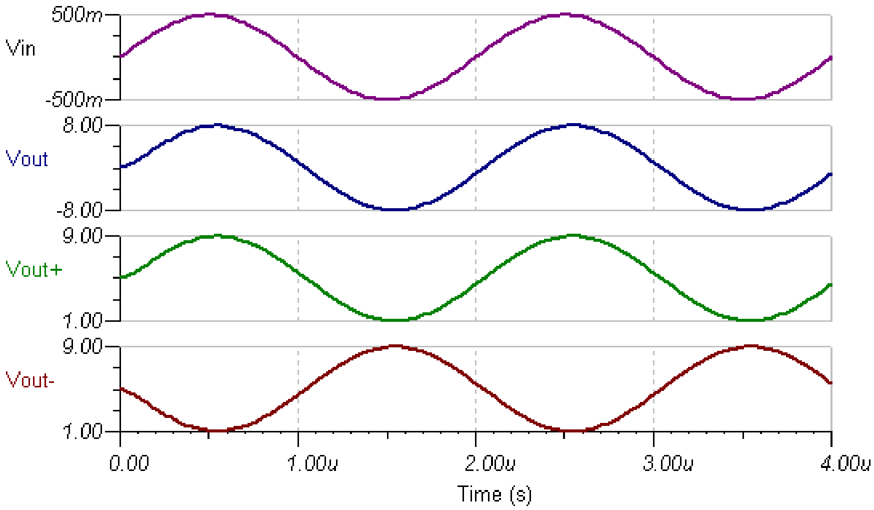
$$\text{Max}(V_{IN-}) = 8.9\text{V} + \frac{8.9\text{V} - 1\text{V}}{16\frac{\text{V}}{\text{V}}} = 9.4\text{V}$$

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/µs
#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 µA
UGBW	80 MHz
SR	52 V/µs
#Channels	1
THS4131	