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| **TOC** | **Title** |
| Fully-Differential Amplifier Circuits | Differential Input to Differential Output using a Fully Differential Amplifier |

**Design Goals**

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| **Input** | **Output** | **Supply** |
| Differential | Differential | Vcc | Vee |
| 1Vpp | 16Vpp | 10V | 0V |

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| **Output Common-Mode** | **3dB Bandwidth** | **AC Gain (Gac)** |
| 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. The effective 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**

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

$$R\_{1}=R\_{3}=1 kΩ (Standard Value)$$

$$R\_{2}=R\_{4}=R\_{1}×\left(G\_{ac}\right)=1 kΩ×\left(16\frac{V}{V}\right)=16kΩ (Standard Value)$$

1. Given the output rails of 9.8V and 0.2V for Vs= 10V, verify that 16Vpp falls within the output range available for Vocm=5V.
	1. In normal operation,

$$AmpVin\_{+}=AmpVin\_{-}$$

$$Vout\_{+}-Vocm=Vocm-Vout\_{-}$$

$$Vout=Vout\_{+}- Vout\_{-}$$

* 1. Rearrange to solve for each output voltage in edge conditions

$$Vout\_{-}=2Vocm-Vout\_{+}$$

$$Vout\_{-}=Vout\_{+}-Vout$$

$$2Vout\_{+}=2Vocm+Vout$$

$$Vout\_{+}=Vocm+\frac{Vout}{2}$$

$$Vout\_{-}=Vocm-\frac{Vout}{2}$$

* 1. Verifying for Vout=+8V and Vocm=+5V,

$$Vout\_{+}=5+\frac{8}{2}=9V<9.8V$$

$$Vout\_{-}=5-\frac{8}{2}=1V>0.2V$$

* 1. Verifying for Vout=-8V and Vocm=+5V,

$$Vout\_{+}=5+\frac{-8}{2}=1V>0.2V $$

$$Vout\_{-}=5-\frac{-8}{2}=9V<9.8V $$

* 1. Note that the maximum swing possible is

$$\left(9.8V-0.2V\right)-\left(0.2V-9.8V\right)=18.4Vpp, or\pm 9.4V$$

1. Use the amplifier’s input common mode voltage range 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.

$$Min\left(AmpVin\_{+}\right)=Min\left(AmpVin\_{-}\right)=Vee-0.1V=-0.1V$$

$$Max\left(AmpVin\_{+}\right)=Max\left(AmpVin\_{-}\right)=Vcc-1.1V= 8.9V$$

$$\frac{AmpVin\_{-}-Vin\_{-}}{R\_{1}}=\frac{Vout\_{+}-AmpVin\_{-}}{R\_{2}}$$

$$Vin\_{-}=AmpVin\_{-}-\frac{Vout\_{+}-AmpVin\_{-}}{R\_{2}/R\_{1}}$$

$$Min(Vin\_{-})=-0.1V-\frac{9V--0.1V}{16V/V}=-0.65V$$

$$Max(Vin\_{-})=8.9V+\frac{8.9V-1V}{16}=9.4V$$

**Design Simulations**

**AC Simulation Results**

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**Transient Simulation Results**

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**Design References**

See TIPD185, [www.ti.com/tool/tipd185](http://www.ti.com/tool/tipd185).

**Design Featured Op Amp:**

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| **THS4561** |
| **Vss** | 3V to 13.5V |
| **VinCM** | Vee-0.1V to Vcc-1.1V |
| **Vout** | Vee+0.2V to Vcc-0.2 |
| **Vos** | TBD |
| **Iq** | TBD |
| **Ib** | TBD |
| **UGBW** | 70MHz |
| **SR** | 4.4V/µs |
| **#Channels** | 1 |
| [**http://www.ti.com/product/THS4561**](http://www.ti.com/product/THS4561) |

**Design Alternate Op Amp:**

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| **THS4131** |
| **Vss** | 5V to 33V |
| **VinCM** | Vee+1.3V to Vcc-0.1V |
| **Vout** | Varies |
| **Vos** | 2mV |
| **Iq** | 14mA |
| **Ib** | 2uA |
| **UGBW** | 80MHz |
| **SR** | 52V/µs |
| **#Channels** | 1 |
| [**www.ti.com/product/THS4131**](http://www.ti.com/product/THS4131) |