Fully Differential Amplifiers – 4

TIPL 2024

TI Precision Labs: Op Amps

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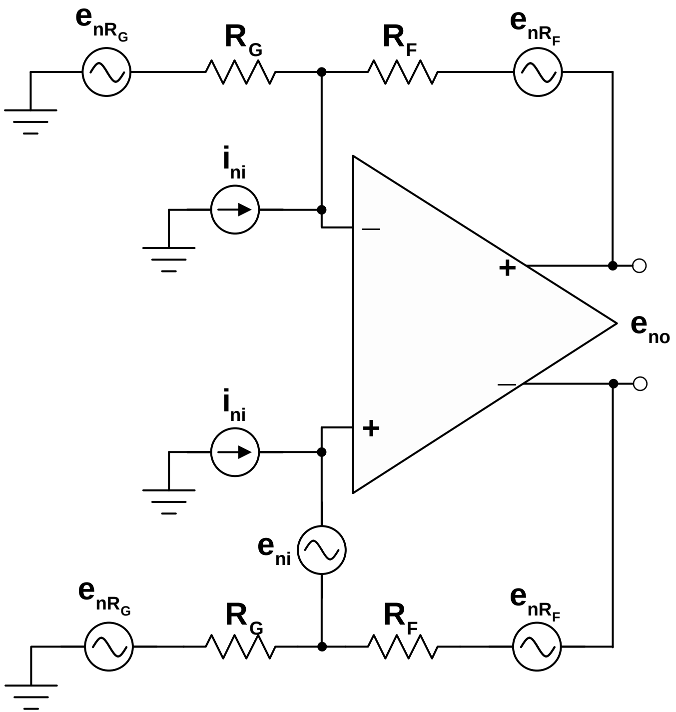
Noise Analysis



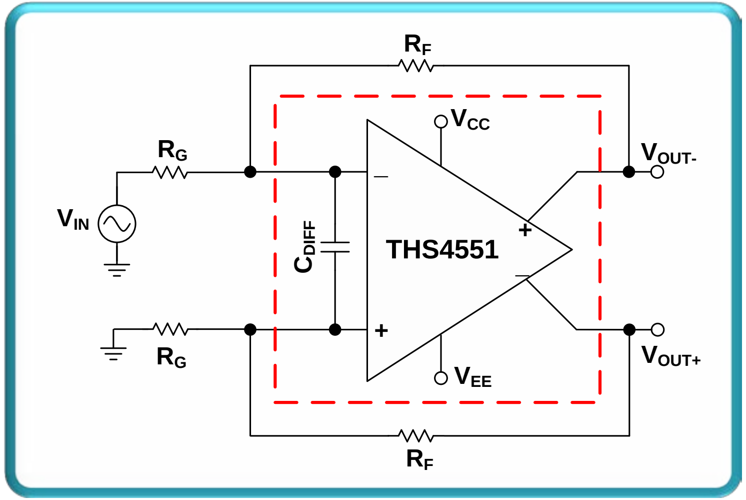
$$e_{no} = \sqrt{(e_{ni} \cdot NG)^2 + 2(i_{ni} \cdot R_F)^2 + 2(4kTR_F) + 2(4kTR_G \cdot (\frac{R_F}{R_G})^2)}$$

$$e_{no} = \sqrt{(e_{ni} \cdot NG)^2 + 2(i_{ni} \cdot R_F)^2 + 2(4kTR_F \cdot NG)}$$

NG is the Noise Gain

Resistor Noise Power = 4kTR

Using large resistors with high-speed amplifiers



Recommended R_F = 402 Ω

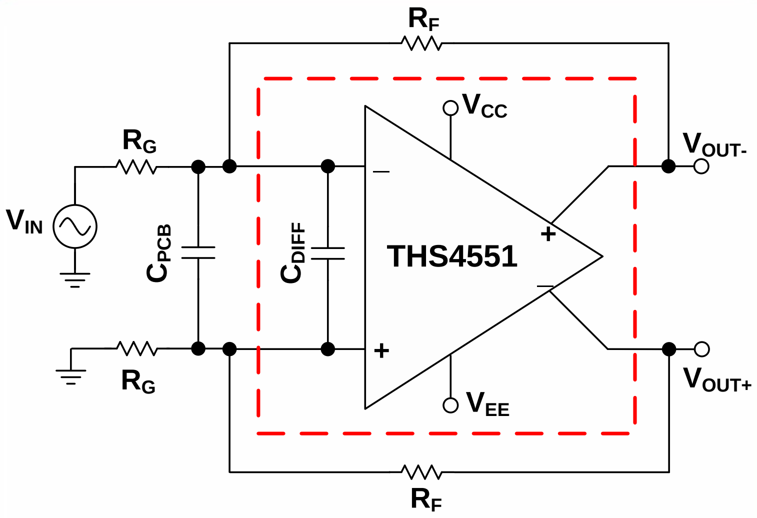
Voltage noise, E_N = 2.2 nV/√Hz

Current noise, I_{BN} = 1.9 pA/√Hz

Input offset current, I_{BOS} = 150 nA

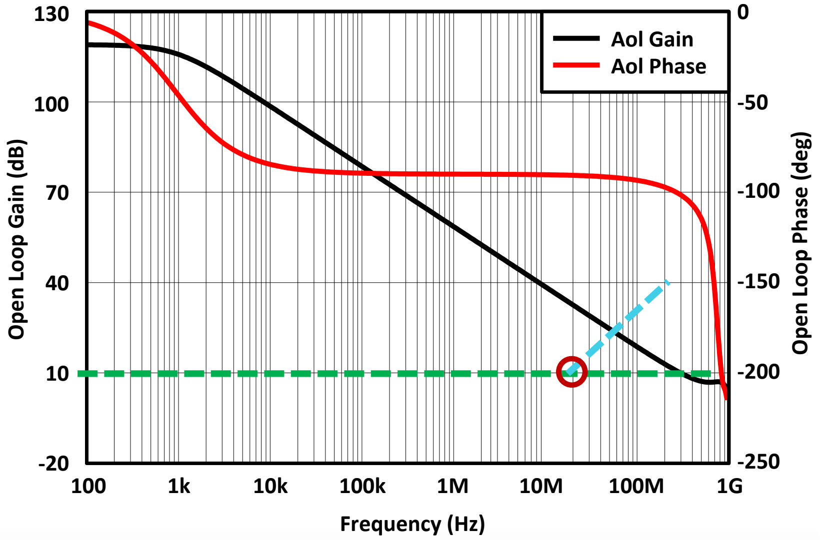
- Increasing R_F and R_G will result in larger noise contributions from the resistors compared to the amplifier.
- The current noise will be multiplied by R_F and will increase the overall system noise.
- Increased output offset voltage due to I_{BOS}.
- C_{DIFF} will introduce a noise gain zero which will reduce the phase margin and could cause oscillation. Large resistors lower the frequency of the zero within the amplifiers bandwidth

Effect of the noise gain zero



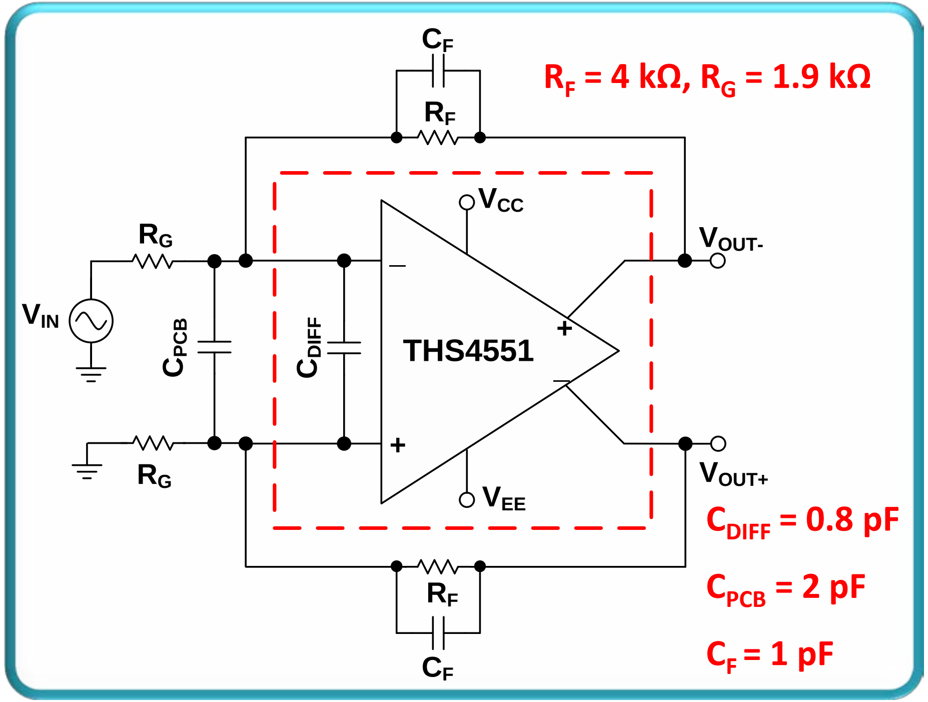
Case 1: R_F = 402 Ω, R_G = 187 Ω C_{DIFF} = 0.8 pF

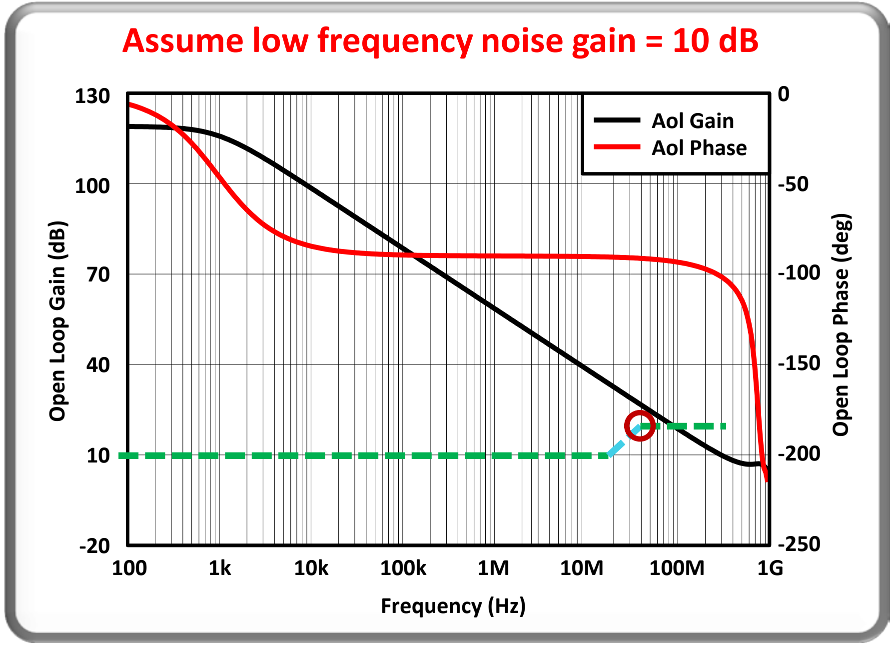
Case 2: R_F = 4 kΩ, R_G = 1.9 kΩ C_{PCB} = 2 pF



- The noise gain zero will occur at: $$\frac{1}{2\pi(R_F \,||\, R_G)(2C_{DIFF\_IN} + C_{CM\_IN})}$$

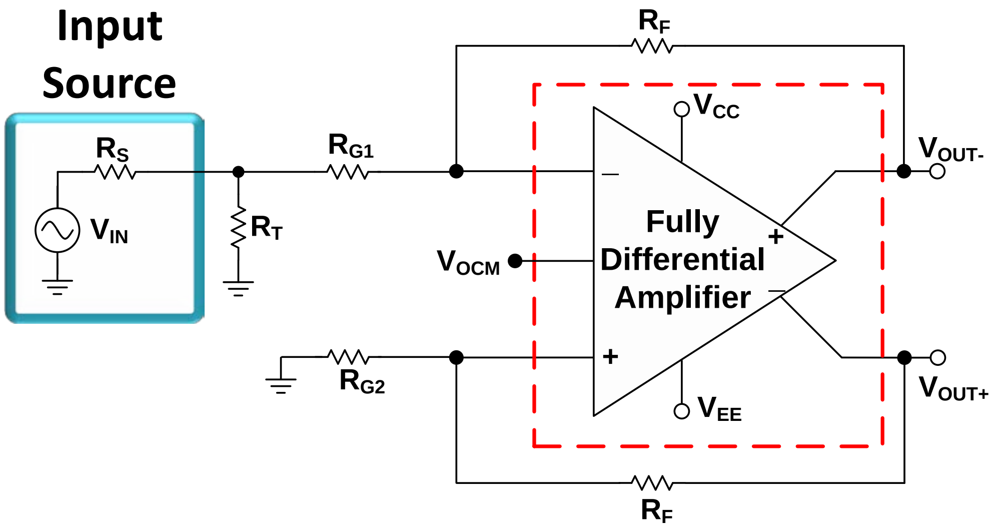
Feedback compensation





- Adding C_F introduces a pole in the noise-gain response which compensates for the zero. Pole is at: $\frac{1}{2\pi R_F C_F}$
- The high frequency noise gain is: $1+\frac{\left(2C_{DIFF\_IN}+C_{CM\_IN}\right)}{C_F}$

Input Terminations



- Matched termination is needed when the PCB trace > λ/8, where $\lambda = 300/f_{MHZ}$
- E.g., the wavelength of a 600-MHz signal is: $\lambda = 300/f_{MHz} = 300/600 = 0.5$ m= 19.7 in.

A cable or PCB trace is a transmission line if it's longer than 0.5/8 = 0.0625m or 2.5 in.

R_S is Source Resistance

R_T is Termination Resistance

$R_{G2} = R_{G1} + (R_S || R_T)$

$$R_T^2 - R_T * \frac{2R_S\left(2R_F + \frac{R_S}{2}A_V^2\right)}{2R_F(2+A_V) - R_S A_V(4+A_V)} - \frac{2R_F R_S^2 A_V}{2R_F(2+A_V) - R_S Av(4+A_V)} = 0$$

Excel calculator for single-ended to differential matched termination configuration

Solving for Rt and then Rg1 and Rg2 in the single to differential FDA configuration with input impedance matching.				
ENTER ONLY THE RED BOLD FIELDS				
MAIN RESULTS IN BLUE BOLD FIELDS				
Enter Source Rs	**50**	Ω	***This is single ended input to differential output design with Rf selected and other elements solved for.***	
Enter Feedback Rf	**402**	Ω		
Maximum gain	14.32502263	V/V		
Must enter a gain < this for valid solution				
Enter Target Gain	**5**	V/V	13.9794	dB

Now get standard 1% values			
Required Rt value	**79.65389444**	Ω	78.7
Closest 1% value	**80.6**	Ω	80.6
Required Rg1 value	**68.07085543**	Ω	66.5
Closest 1% value	**68.1**	Ω	68.1
Required Rg2 value	**98.78875048**	Ω	97.6
Closest 1% value	**97.6**	Ω	100
Snapping Rf to closest 1%	402	Ω	402
Closest 1%	**402**	Ω	412

Some example FDAs from Texas Instruments

Product Name	I_Q (mA)	GBP (MHz)	Slew-Rate (V/µs)	Voltage Noise (nV/√Hz)	Key Features
THS4531A	0.25	27	190	10	Low Power.
THS4551	1.35	135	220	3.3	Low Noise and High Precision.
THS4541	10.1	850	1500	2.2	Wide Bandwidth with Precision.
THS4509	37.7	3000	6600	1.9	
LMH5401	55	6200	17500	1.25	Ultra-wide bandwidth.
LMH3401	55	7000	18000	1.4	Fixed Gain with integrated resistors.
LMH6552	20.4	1500	3800	1.1	± 10V supplies. Current Feedback topology.
OPA1632	14	180	50	1.3	± 30V supplies and low-noise. Optimized for audio.

http://www.ti.com/lsds/ti/amplifiers/op-amps/fully-differential-amplifiers-overview.page

Digital Variable-Gain Amplifiers (DVGA)

- Wide gain range can be programmed through SPI or parallel-mode.
- Single-ended OR Differential Input to Differential Output.
- Input signals can be AC or DC coupled.
- Commonly used in Test & Measurement and Communications.

Product Name	I_Q (mA)	Gain Range	Noise Figure	Key Features
LMH6401	69	-6dB to 26dB	7.7 dB @ 100 Ω	4.5 GHz BW @ A_V= 26 dB
LMH6881	100	6dB to 26dB	9.7 dB @ 100 Ω	2.4 GHz BW @ A_V= 26 dB. SE or DIFF I/P
LMH6517	80	-9.5dB to 22dB	5.5 dB @ 100 Ω	1.2 GHz BW @ A_V= 22 dB
LMH6521	112.5	-5.5dB to 26dB	7.3 dB @ 200 Ω	1.2 GHz @ 0dB Gain. AC Coupled Only