

## Operational Amplifiers

### How to Bias Op-Amps Correctly

#### Abstract

The inputs of an operational amplifier (op-amp) must be DC-biased to ensure proper device operation. A basic requirement that many textbooks neglect to discuss in detail. Consequently, engineers new to op-amps might overlook this important requirement, which can lead to malfunctioning circuits.

This application note tries to rectify this shortcoming by explaining the need for input biasing and suggesting practical solutions that ensure proper circuit operation.

#### Contents

1.	<b>The Need for Input Biasing</b> . . . . .	2
2.	<b>AC-Coupled Amplifiers with Dual Supplies</b> . . . . .	2
3.	<b>AC-Coupled Amplifiers with Single Supply</b> . . . . .	4
3.1	Design Example . . . . .	6
4.	<b>Appendix</b> . . . . .	8
4.1	Deriving the -3dB Frequency, $f_{CT}$ , of the Overall Circuit Gain, $G_T$ . . . . .	8
5.	<b>Revision History</b> . . . . .	10

#### List of Figures

Figure 1.	Input Biasing Principle . . . . .	2
Figure 2.	DC-Coupled Buffer and Amplifier . . . . .	2
Figure 3.	A Malfunctional AC-Coupled Amplifier with Missing DC Bias Path. . . . .	3
Figure 4.	Correctly AC-Coupled Amplifier for Dual-Supply Operation . . . . .	3
Figure 5.	Examples of Non-Functional AC-Coupled Instrumentation Amplifiers . . . . .	3
Figure 6.	Correctly Biased INA Inputs use High-Value Input Resistors Between Each Input and Ground . . . . .	3
Figure 7.	Input Biasing with Voltage Reference for Highest PSRR . . . . .	4
Figure 8.	Input Biasing with Buffered Voltage Divider to Maintain High PSRR . . . . .	4
Figure 9.	Transfer Function and Frequency Response of the Supply-Noise Gain of the Voltage Divider . . . . .	4
Figure 10.	Transfer Function and Frequency Response of the AC-Coupled Input Stage . . . . .	5
Figure 11.	Transfer Function and Frequency Response of the Closed-Loop Gain of the Op-Amp, $A_{CL}$ . . . . .	5
Figure 12.	Frequency Responses of the Various R-C Units of the Circuit in <a href="#">Figure 7 on page 4</a> . . . . .	6
Figure 13.	AC-Coupled Noninverting Amplifier with ISL28134 . . . . .	7
Figure 14.	AC-Coupled Inverting Amplifier . . . . .	7
Figure 15.	AC-Coupled Inverting Amplifier with ISL28134 . . . . .	8
Figure 16.	AC-Signal Equivalent Circuit of <a href="#">Figure 8</a> and its Frequency Responses . . . . .	8
Figure 17.	$F_{CT}/F_{pG}$ Ratio vs Passband Gain. . . . .	9

## 1. The Need for Input Biasing

[Figure 1](#) shows the differential input stage of an op-amp. The base terminals of transistors  $Q_1$  and  $Q_2$  form the non-inverting and inverting op-amp inputs,  $IN+$  and  $IN-$ , respectively. For the op-amp to operate correctly, these inputs must be DC biased. That is, the DC bias currents ( $I_{B+}$  and  $I_{B-}$ ), must be able to flow into or out of the input terminals. The direction of the bias currents depends on the type of transistors. For NPN transistors and N-channel enhancement MOSFETs, the currents flow into the inputs, for PNPs and P-channel enhancement MOSFETs, the currents flow out of the inputs.

DC biasing is achieved by connecting the inputs via resistors to a reference potential,  $V_{mid}$ , which is the mid potential of the positive and negative supply voltages ( $V_{S+}$  and  $V_{S-}$ ) ([Figure 1](#)).

The biasing resistors ( $R_{B+}$  and  $R_{B-}$ ), represent equivalent resistances, because they can consist of one or more resistors as depicted in the DC-coupled amplifier circuits of [Figure 2](#).

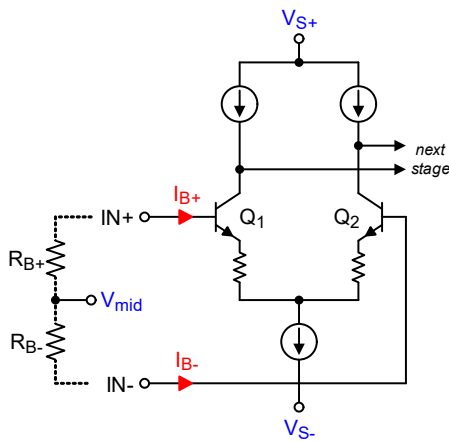


Figure 1. Input Biasing Principle

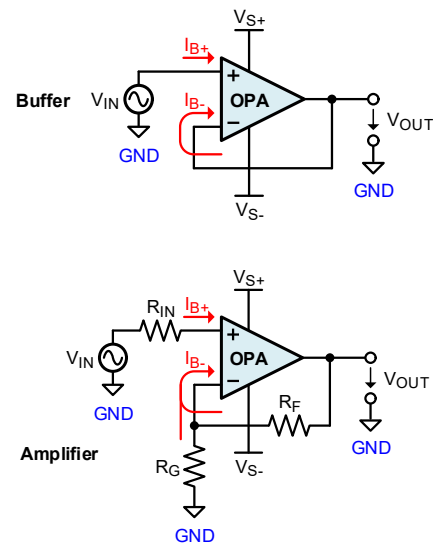


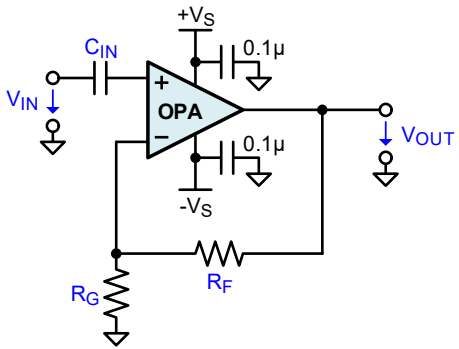
Figure 2. DC-Coupled Buffer and Amplifier

In the DC-coupled buffer of [Figure 2](#),  $I_{B+}$  flows through the signal source and its low source impedance into the noninverting input, while  $I_{B-}$  flows from the output of the op-amp into the inverting input.

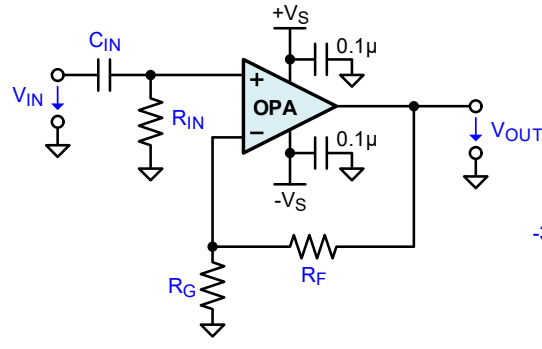
In the DC-coupled amplifier,  $I_{B-}$  flows through  $R_F$  and  $R_G$ ; therefore changing the DC voltage at the inverting input by  $I_{B-} \cdot (R_F || R_G)$ . This introduces a DC offset voltage between the inputs. To minimize this offset, the DC potential at the non-inverting input must be adjusted by about the same amount. This is achieved by inserting a resistor ( $R_{IN}$ ), in series whose value matches the parallel combination of  $R_F$  and  $R_G$ ,  $R_{IN} = R_F || R_G$ .

## 2. AC-Coupled Amplifiers with Dual Supplies

While DC-coupled op-amp circuits receive their biasing through the signal source impedance, AC-coupled circuits have this bias path blocked by the input coupling capacitor ( $C_{IN}$ ). [Figure 3](#) shows an AC-coupled amplifier without a path for the DC bias current to flow. In this case,  $I_{B+}$  charges the coupling capacitor until the common-mode voltage rating of the input circuit is exceeded, or its output is driven into saturation. Depending on the polarity of the bias current, the capacitor charges towards the positive or negative supply rail, with the resulting bias voltage being amplified by the closed-loop DC gain of the amplifier,  $1 + R_F/R_G$ .



**Figure 3. A Malfunctional AC-Coupled Amplifier with Missing DC Bias Path**



**Figure 4. Correctly AC-Coupled Amplifier for Dual-Supply Operation**

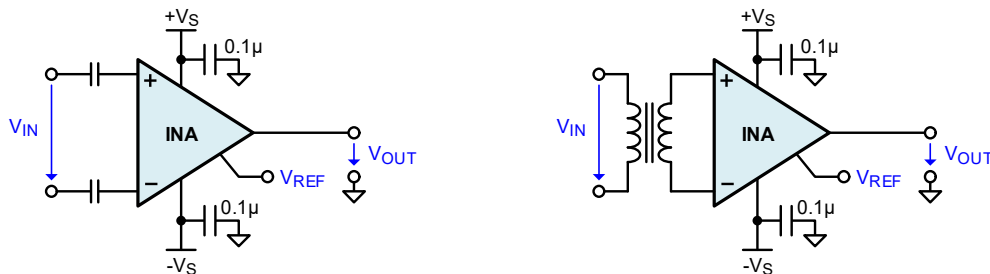
-3dB Input Bandwidth  
 $f_{C-in} = \frac{1}{2\pi C_{IN} R_{IN}}$   
 with  $R_{IN} = R_F || R_G$

For a small bias current, such as 1pA, this process can take hours. Therefore, a casual lab test with an AC-coupled scope is more than likely to miss this problem, and the circuit does not fail until much later. Obviously, this problem must be avoided.

Figure 4 shows a simple solution by connecting the noninverting input through  $R_{IN}$  to ground. This forms a new DC path for the bias current. Like in the DC-coupled case before, minimizing the offset due to bias currents requires  $R_{IN} = R_F || R_G$ .

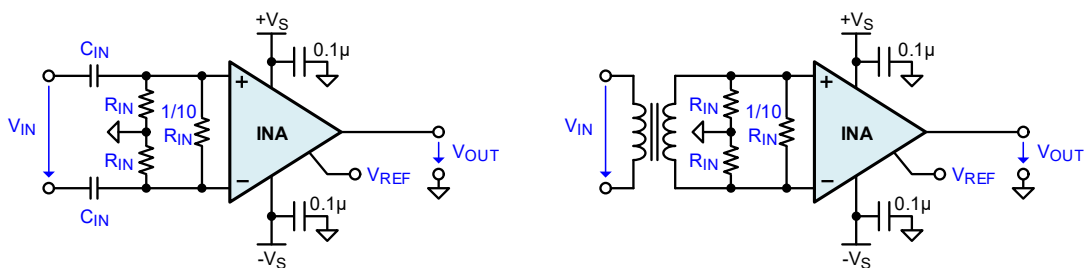
**Note:** AC-coupling forms a high-pass filter with a cutoff at  $f_C = 1/(2\pi C_{IN} R_{IN})$ , which sets the minimum input bandwidth of the amplifier. With the circuit gain being defined by the application,  $R_F$  and  $R_G$  can be determined. Their parallel value defines  $R_{IN}$ , which then allows the calculation of the input capacitor:  $C_{IN} = 1/(2\pi f_C R_{IN})$ .

Similar input biasing methods must be applied to the differential input stages of three-amp Instrumentation Amplifiers (INAs). Figure 5 shows INA circuits that are AC-coupled using either two capacitors or a transformer, without providing a DC bias path.



**Figure 5. Examples of Non-Functional AC-Coupled Instrumentation Amplifiers**

Correct biasing solutions for these circuits are shown in Figure 6, where a high-value resistor ( $R_{IN}$ ) is added between each input and ground.



**Figure 6. Correctly Biased INA Inputs use High-Value Input Resistors Between Each Input and Ground**

There is a small offset-voltage error due to mismatches between the input resistors and the input bias currents. To minimize this error, a third resistor, about 1/10th their value (yet still large compared to the differential source resistance), can be connected between the two in-amp inputs, therefore bridging both resistors.

### 3. AC-Coupled Amplifiers with Single Supply

The DC biasing of AC-coupled single-supply amplifiers also requires an input resistor connecting the noninverting input to the reference potential,  $V_{mid}$ . In single supply circuits however,  $V_{mid}$  is derived from  $V_S$  as  $V_S/2$  to ensure a symmetrical, maximum dynamic range for both, input and output signals. This can make  $V_S/2$  susceptible to supply noise.

The ideal design approach is to use an integrated voltage-reference chip (VREF) with high power-supply rejection ratio (PSRR). A VREF also provides low output impedance, allowing to provide  $V_S/2$  potential to multiple reference locations within a larger circuit design (Figure 7).

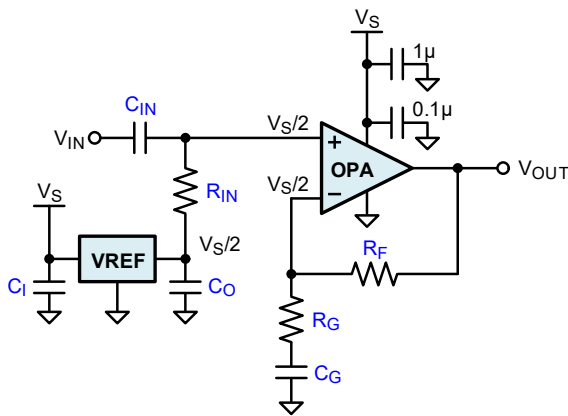


Figure 7. Input Biasing with Voltage Reference for Highest PSRR

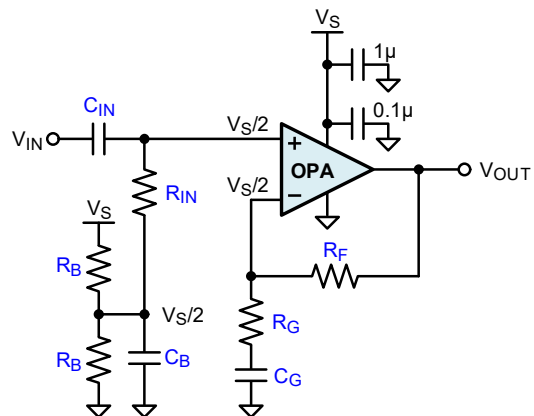


Figure 8. Input Biasing with Buffered Voltage Divider to Maintain High PSRR

For biasing a single-supply op-amp, a more convenient low-cost method exists in form of a voltage divider, whose output must be buffered with a large capacitor ( $C_B$ ), to make  $V_S/2$  less sensitive to supply noise, thus maintaining a high PSRR (Figure 8).

AC-coupled single-supply amplifiers also require the capacitive decoupling of the feedback path to ensure 0dB gain at DC. This prevents the  $V_S/2$  potential at the noninverting input from being amplified by the passband gain, therefore saturating the output.

To calculate the component values, it is important to understand the interactions of the various time constants:  $R_B-C_B$ ,  $R_{IN}-C_{IN}$ , and  $R_G-C_G$ . For clarity, their frequency responses are depicted in Figure 9, Figure 10, and Figure 11.

To the  $V_S$  supply, the biasing voltage divider presents a low-pass filter whose frequency response is:

$$G_{SN} = \frac{\Delta V_{CC}/2}{\Delta V_{CC}} = \frac{1}{2} \cdot \frac{1}{1 + j\omega C_B R_B/2}, \text{ with a cutoff frequency of } f_{CB} = \frac{1}{2\pi C_B R_B/2}. \text{ Here, } G_{SN} \text{ denotes the supply-noise gain.}$$

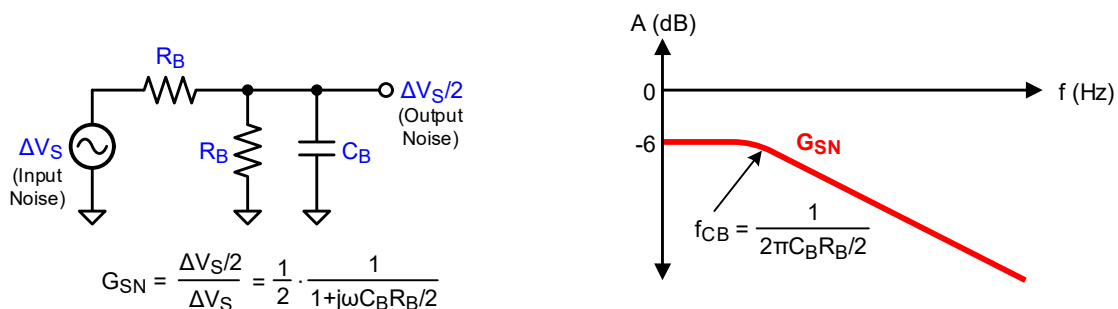


Figure 9. Transfer Function and Frequency Response of the Supply-Noise Gain of the Voltage Divider

The  $R_{IN}$ - $C_{IN}$  circuit has a high-pass response  $G_{IN} = \frac{j\omega C_{IN} R_{IN}}{1 + j\omega C_{IN} R_{IN}}$  with pole at  $f_{CI} = \frac{1}{2\pi C_{IN} R_{IN}}$ . This pole and the pole of the closed-loop gain,  $f_{pG}$ , determine the minimum input bandwidth of the amplifier circuit,  $f_{CT}$ .

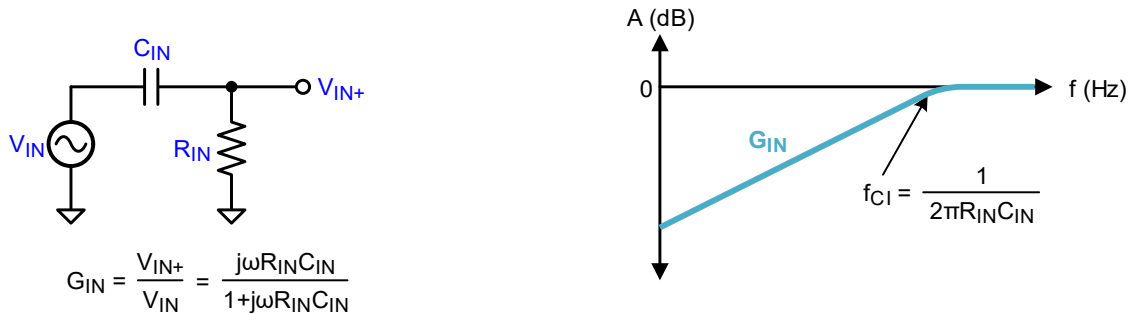


Figure 10. Transfer Function and Frequency Response of the AC-Coupled Input Stage

The closed-loop gain of the op-amp is given with  $A_{CL} = \frac{1 + j\omega C_G (R_G + R_F)}{1 + j\omega C_G R_G}$ . It has a pole and a zero-location due to the decoupling effect of  $C_G$ . The zero frequency,  $f_{zG} = \frac{1}{2\pi C_G (R_G + R_F)}$ , is the +3dB corner frequency above unity gain. This zero ensures that DC voltages at the noninverting input, such as  $V_S/2$  and any offset errors, are amplified at a gain of 1V/V (0dB). The pole frequency,  $f_{pG} = \frac{1}{2\pi C_G R_G}$ , defines the -3dB cutoff of  $A_{CL}$ . This pole and the pole of the input stage,  $f_{CI}$ , determine the minimum input bandwidth of the amplifier circuit,  $f_{CT}$ .

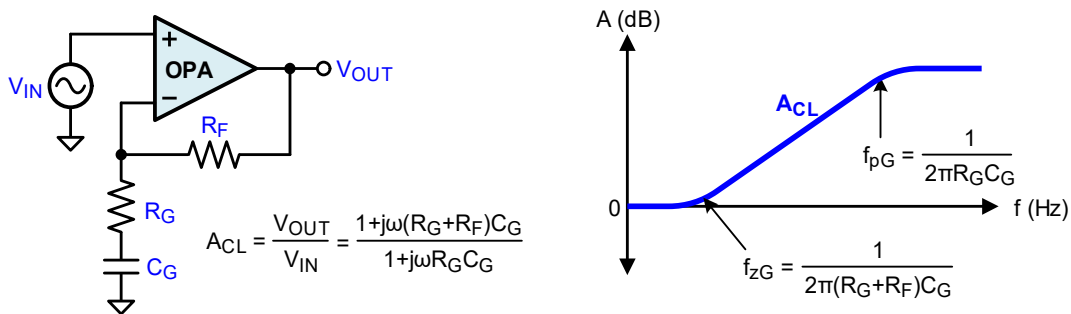


Figure 11. Transfer Function and Frequency Response of the Closed-Loop Gain of the Op-Amp,  $A_{CL}$

Depicting all discussed frequency responses, [Figure 12](#) shows how  $G_{IN}$  and  $A_{CL}$  define the total gain ( $G_T$ ), of the AC-coupled amplifier using  $G_T = G_{IN} \cdot A_{CL}$ , therefore moving the new -3dB cutoff,  $f_{CT}$ , to a higher frequency.

To ensure enough supply-noise suppression at this new cut-off frequency, practical experience suggests that the corner frequency of the voltage divider should be at least 1/10<sup>th</sup> of  $f_{CT}$ :  $f_{CB} = 0.1 \cdot f_{CT}$ .

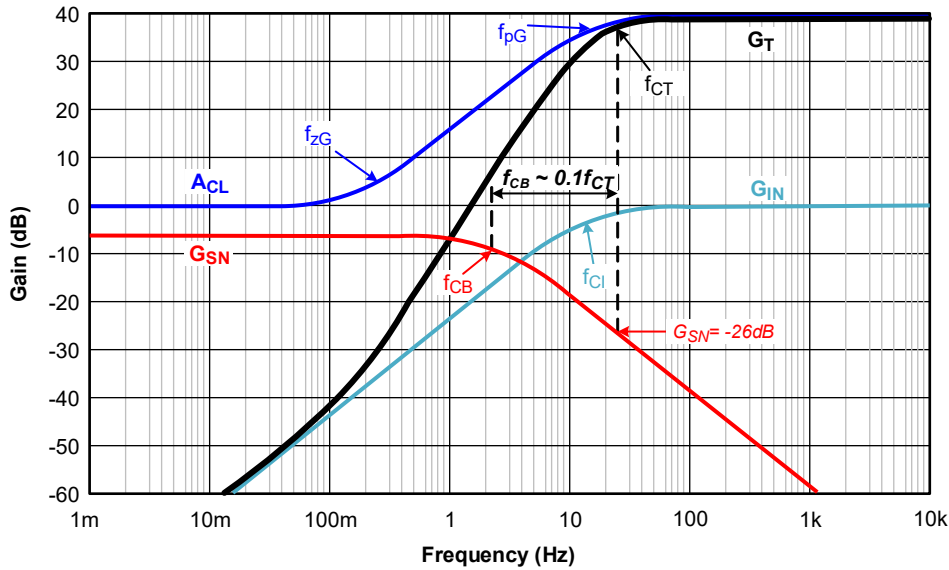


Figure 12. Frequency Responses of the Various R-C Units of the Circuit in [Figure 7 on page 4](#)

### 3.1 Design Example

This section discusses the practical design of an actual amplifier circuit. As previously mentioned, with regard to component selection there are always compromises to be made between power consumption, resistor noise contribution, and supply noise rejection.

The design goal is to build an AC-coupled noninverting amplifier, operating from a single 5V supply, with an overall passband gain of 100V/V (40dB) and a minimum bandwidth of  $f_{CT} = 16\text{Hz}$ .

This requires the corner frequency of the voltage divider to be  $f_{CB} \leq 1/10^{\text{th}} f_{CT} = 1.6\text{Hz}$ . To preserve the power in the voltage divider, a DC quiescent current of  $50\mu\text{A}$  is allowed. This makes the value of  $R_B$ .

$$\text{(EQ. 1)} \quad R_B = \frac{V_S}{2I_q} = \frac{5\text{V}}{2 \cdot 50\mu\text{A}} = 50\text{k}\Omega$$

The buffer capacitor,  $C_B$ , can therefore be calculated with:

$$\text{(EQ. 2)} \quad C_B = \frac{1}{2\pi f_{CB} R_B/2} = \frac{1}{2\pi \cdot 1.6\text{Hz} \cdot 25\text{k}\Omega} = 4\mu\text{F}$$

To ensure an earlier rather than later supply-noise roll-off, chose the next higher standard value with  $C_B = 4.7\mu\text{F}$ .

Aiming for equal corner frequencies for the input  $R_{IN}$ - $C_{IN}$  stage and the closed-loop gain of the op-amp ( $A_{CL}$ ), demands that  $f_{CI} \sim f_{pG}$ . These frequencies are derived from  $f_{CT}$  using:

$$\text{(EQ. 3)} \quad f_{CI} = f_{pG} = \frac{f_{CT}}{\sqrt{1+\sqrt{2}}} = \frac{16\text{Hz}}{1.554} = 10.3\text{Hz} \approx 10\text{Hz}$$

To see the detailed derivation of [Equation 3](#), see "[Appendix](#)" on page 8.

For the noninverting amplifier, a passband gain of 100V/V requires the ratio  $R_F/R_G = 99$ . Here, the compromise between the feedback path loading, noise contribution from  $R_F$ , and the capacitor size of  $C_G$  lead to resistor values of  $R_F = 100\text{k}\Omega$  and  $R_G = 1.01\text{k}\Omega$ .

The capacitance ( $C_G$ ), required to place the  $A_{CL}$  pole at 10.3Hz can now be calculated with:

$$\text{(EQ. 4)} \quad C_G = \frac{1}{2\pi f_{pG} R_G} = \frac{1}{2\pi \cdot 10.3\text{Hz} \cdot 1.01\text{k}\Omega} = 15\mu\text{F}$$

To calculate  $R_{IN}$ , the offset due to bias current flow must be considered. While  $I_{B-}$  flows through  $R_F$  only, as the DC path through  $R_G$  is blocked by  $C_G$ ,  $I_{B+}$  flows through  $R_{IN}$  and the parallel circuit of the two  $R_B$  resistors. To minimize this offset, the sum of  $R_{IN}$  and  $R_B/2$  must equal  $R_F$ .  $R_{IN}$  is the difference between  $R_F$  and  $R_B/2$ :

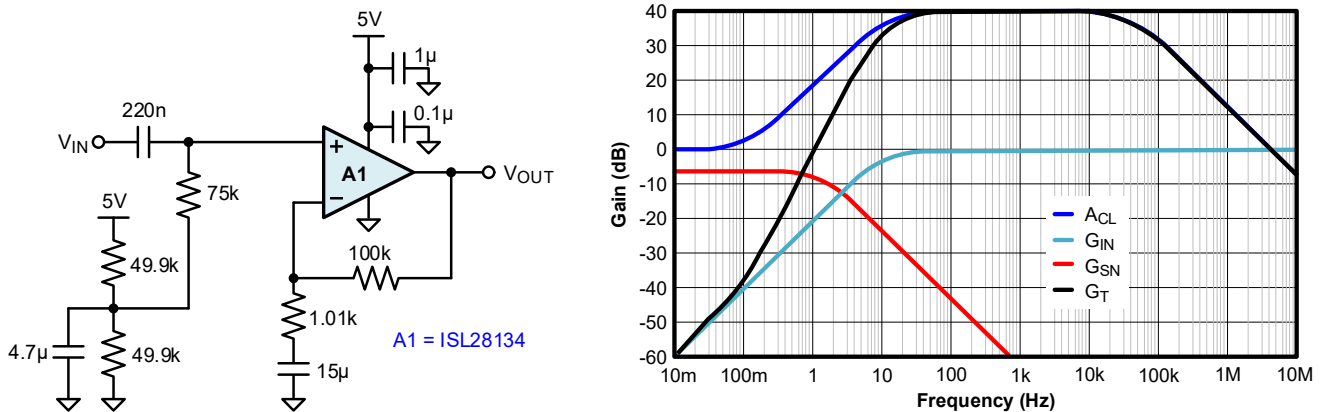
$$(EQ. 5) \quad R_{IN} = R_F - R_B/2 = 100k\Omega - 25k\Omega = 75k\Omega$$

Then, the input capacitance that produces the corner frequency derived in [Equation 3 on page 6](#) is calculated with:

$$(EQ. 6) \quad C_{IN} = \frac{1}{2\pi f_{CI} R_{IN}} = \frac{1}{2\pi \cdot 10.3Hz \cdot 75k\Omega} = 206nF$$

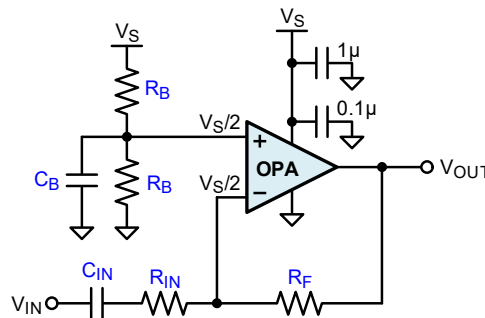
Again, to make the roll-off occur slightly earlier, chose the next higher standard value with  $C_{IN} = 220nF$ .

[Figure 13](#) shows the final amplifier circuit and its corresponding frequency responses.



**Figure 13. AC-Coupled Noninverting Amplifier with ISL28134**

In the case of the inverting amplifier in [Figure 14](#), the biasing voltage divider remains the same as in the noninverting case. The  $V_S/2$  potential at the noninverting input also appears at the inverting input due to feedback action.



**Figure 14. AC-Coupled Inverting Amplifier**

**Note:** The gain setting resistor ( $R_G$ ), also represents the input resistance ( $R_{IN}$ ). With that, the closed-loop gain of the amplifier becomes the overall circuit gain. Its pole frequency is the cutoff frequency of the input stage and therefore, the minimum input bandwidth of the circuit. This simplifies the calculation of component value enormously.

The main difference is,  $I_{B+}$  only flows through the parallel circuit of the two bias resistors. Therefore, reducing the offset due to bias current forces  $R_F$  to drop in value to match  $R_B/2$ . For high gain applications with low input bandwidth, this necessitates a much smaller  $R_G$  value, which in turn requires the increase of  $C_{IN}$ .

The simple design procedure would be to:

- Make  $R_F = R_B/2$  for offset reduction,
- Then deriving the gain resistor with  $R_G = R_F/G$
- And finally, calculating the input capacitor with  $C_{IN} = 1/(2\pi f_{IN} R_G)$

Applying the above equations to an AC-coupled inverting amplifier with passband gain of  $G = 100V/V$  and minimum input bandwidth of  $f_{IN} = 16\text{Hz}$ , while maintaining  $R_B = 49.9\text{k}\Omega$ , results in  $R_F = 24.9\text{k}\Omega$ ,  $R_G = 249\Omega$ , and  $C_{IN} = 47\mu\text{F}$ .

Setting the supply-noise roll-off of the voltage divider to  $1/10^{\text{th}}$  of  $f_{IN}$  makes  $f_{CB} = 1.6\text{Hz}$ , which yields a capacitor value of  $C_B = 1/(2\pi f_{CB} R_B/2) = 4\mu\text{F}$ . Again, chose the next higher standard value of  $4.7\mu\text{F}$ .

Figure 15 shows the actual circuit with its corresponding frequency responses.

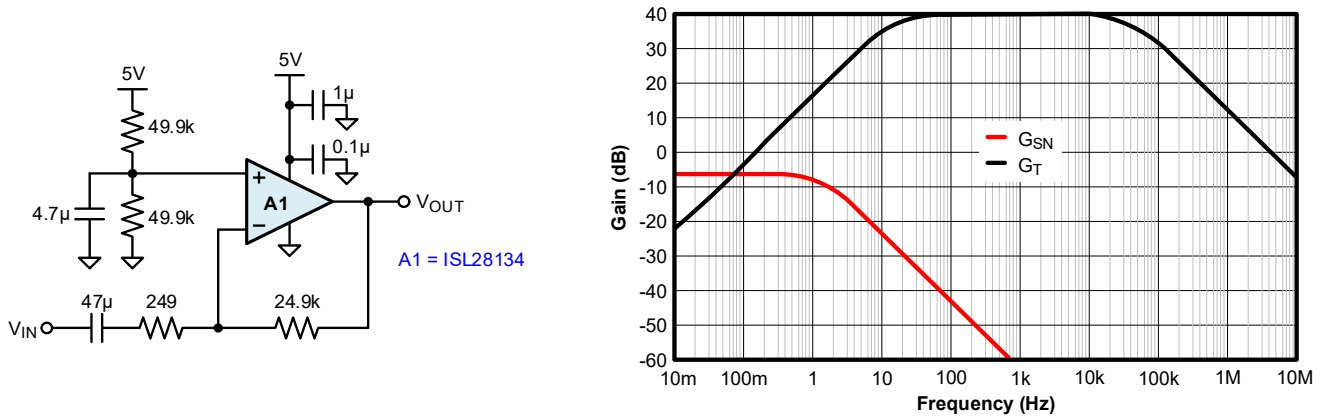


Figure 15. AC-Coupled Inverting Amplifier with ISL28134

## 4. Appendix

### 4.1 Deriving the -3dB Frequency ( $f_{CT}$ ), of the Overall Circuit Gain ( $G_T$ )

Figure 16 shows the AC-signal equivalent schematic of the noninverting amplifier in Figure 8 on page 4 and its individual and overall gain responses.

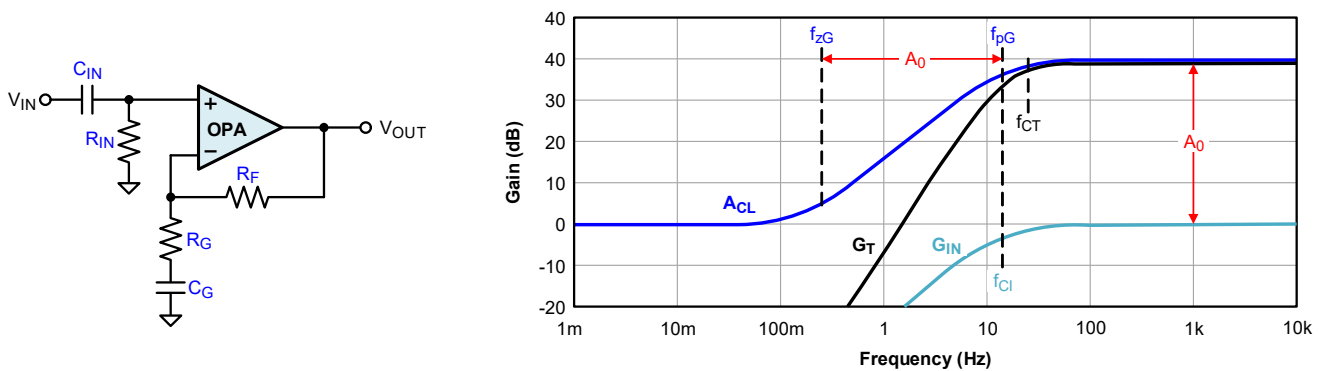


Figure 16. AC-Signal Equivalent Circuit of Figure 8 and its Frequency Responses

The gain responses for  $G_{IN}$  and  $A_{CL}$  are:

$$G_{IN} = \frac{j\omega C_{IN} R_{IN}}{1 + j\omega C_{IN} R_{IN}} \text{ with pole frequency } f_{CI} = \frac{1}{2\pi C_{IN} R_{IN}}.$$

$$A_{CL} = \frac{1 + j\omega C_G (R_G + R_F)}{1 + j\omega C_G R_G} \text{ with pole frequency } f_{PG} = \frac{1}{2\pi C_G R_G}, \text{ zero frequency } f_{ZG} = \frac{1}{2\pi C_G (R_G + R_F)}, \text{ and}$$

$$\text{passband gain } A_0 = \frac{R_G + R_F}{R_G}.$$

Because the ratio of pole to zero frequency is:  $\frac{f_{PG}}{f_{ZG}} = \frac{R_G + R_F}{R_G} = A_0$ , it follows that  $f_{PG} = \frac{f_{ZG}}{A_0}$ .



Expressing the transfer functions in their generic forms gives:

$$G_{IN} = \frac{j\omega/\omega_{Cl}}{1+j\omega/\omega_{Cl}} = \frac{jf/f_{Cl}}{1+jf/f_{Cl}} \text{ and } A_{CL} = \frac{1+j\omega/\omega_{zG}}{1+j\omega/\omega_{pG}} = \frac{1+jf/f_{zG}}{1+jf/f_{pG}}$$

This makes the overall gain:  $G_T = G_{IN} \cdot A_{CL} = \frac{jf/f_{Cl}}{1+jf/f_{Cl}} \cdot \frac{1+jf/f_{zG}}{1+jf/f_{pG}}$

And its magnitude function:  $|G_T| = \sqrt{\frac{(f/f_{Cl})^2}{1+(f/f_{Cl})^2} \cdot \frac{1+(f/f_{zG})^2}{1+(f/f_{pG})^2}}$

By making  $f_{Cl} = f_{pG}$  and replacing  $f_{zG}$  with  $f_{pG}/A_0$  the magnitude function becomes:

$$|G_T| = \sqrt{\frac{(f/f_{pG})^2}{1+(f/f_{pG})^2} \cdot \frac{1+(f \cdot A_0/f_{pG})^2}{1+(f/f_{pG})^2}}$$

To find  $f_{CT}$ ,  $|G_T|$  is set  $A_0/\sqrt{2}$  (the -3dB magnitude of  $A_0$ ) and the generic frequency,  $f$ , is replaced with  $f_{CT}$ :

$$\frac{A_0}{\sqrt{2}} = \frac{\left[ \frac{(f_{CT})^2}{f_{pG}^2} \cdot \left[ 1 + \left( \frac{f_{CT} \cdot A_0}{f_{pG}} \right)^2 \right] \right]}{\sqrt{\left[ 1 + \left( \frac{f_{CT}}{f_{pG}} \right)^2 \right] \cdot \left[ 1 + \left( \frac{f_{CT}}{f_{pG}} \right)^2 \right]}} \Rightarrow \frac{A_0^2}{2} = \frac{\frac{f_{CT}^2}{f_{pG}^2} \cdot \left( 1 + \frac{f_{CT}^2 A_0^2}{f_{pG}^2} \right)}{1 + 2 \frac{f_{CT}^2}{f_{pG}^2} + \frac{f_{CT}^4}{f_{pG}^4}}$$

Then, solving for  $f_{CT}$  results in:

$$f_{CT} = f_{pG} \sqrt{1 - 1/A_0^2 + \sqrt{1 + (1 - 1/A_0^2)^2}} \text{ Therefore, for } A_0 > 10, f_{CT} = f_{pG} \cdot \sqrt{1 + \sqrt{2}} = 1.55 f_{pG}.$$

Using 1.55 for  $A_0 \geq 2V/V$ , yields less than 9% deviation from the theoretical  $f_{CT}$  value.

Plotting the factor of  $f_{pG}$  over  $A_0$ , one might simply use an average factor of 1.5.

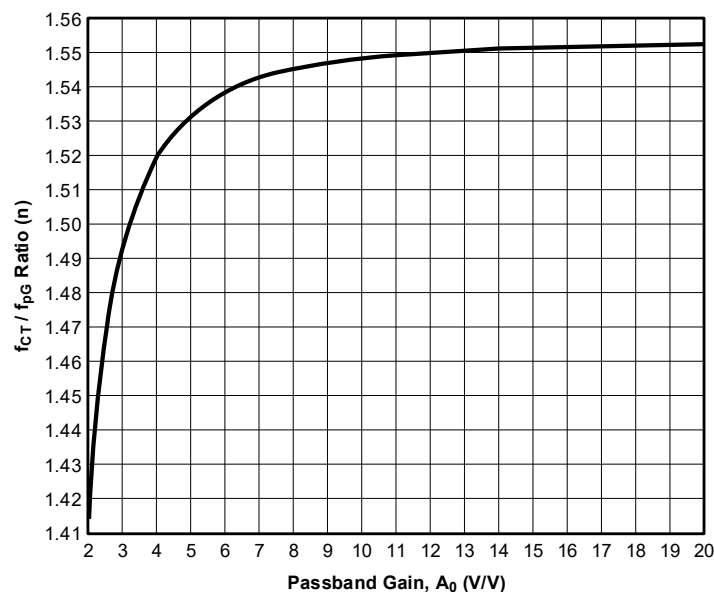


Figure 17.  $f_{CT}/f_{pG}$  Ratio vs Passband Gain

---

## 5. Revision History

Rev.	Date	Description
0.00	Dec.13.19	Initial release

## Notice

1. Descriptions of circuits, software and other related information in this document are provided only to illustrate the operation of semiconductor products and application examples. You are fully responsible for the incorporation or any other use of the circuits, software, and information in the design of your product or system. Renesas Electronics disclaims any and all liability for any losses and damages incurred by you or third parties arising from the use of these circuits, software, or information.
2. Renesas Electronics hereby expressly disclaims any warranties against and liability for infringement or any other claims involving patents, copyrights, or other intellectual property rights of third parties, by or arising from the use of Renesas Electronics products or technical information described in this document, including but not limited to, the product data, drawings, charts, programs, algorithms, and application examples.
3. No license, express, implied or otherwise, is granted hereby under any patents, copyrights or other intellectual property rights of Renesas Electronics or others.
4. You shall not alter, modify, copy, or reverse engineer any Renesas Electronics product, whether in whole or in part. Renesas Electronics disclaims any and all liability for any losses or damages incurred by you or third parties arising from such alteration, modification, copying or reverse engineering.
5. Renesas Electronics products are classified according to the following two quality grades: "Standard" and "High Quality". The intended applications for each Renesas Electronics product depends on the product's quality grade, as indicated below.
  - "Standard": Computers; office equipment; communications equipment; test and measurement equipment; audio and visual equipment; home electronic appliances; machine tools; personal electronic equipment; industrial robots; etc.
  - "High Quality": Transportation equipment (automobiles, trains, ships, etc.); traffic control (traffic lights); large-scale communication equipment; key financial terminal systems; safety control equipment; etc.Unless expressly designated as a high reliability product or a product for harsh environments in a Renesas Electronics data sheet or other Renesas Electronics document, Renesas Electronics products are not intended or authorized for use in products or systems that may pose a direct threat to human life or bodily injury (artificial life support devices or systems; surgical implantations; etc.), or may cause serious property damage (space system; undersea repeaters; nuclear power control systems; aircraft control systems; key plant systems; military equipment; etc.). Renesas Electronics disclaims any and all liability for any damages or losses incurred by you or any third parties arising from the use of any Renesas Electronics product that is inconsistent with any Renesas Electronics data sheet, user's manual or other Renesas Electronics document.
6. When using Renesas Electronics products, refer to the latest product information (data sheets, user's manuals, application notes, "General Notes for Handling and Using Semiconductor Devices" in the reliability handbook, etc.), and ensure that usage conditions are within the ranges specified by Renesas Electronics with respect to maximum ratings, operating power supply voltage range, heat dissipation characteristics, installation, etc. Renesas Electronics disclaims any and all liability for any malfunctions, failure or accident arising out of the use of Renesas Electronics products outside of such specified ranges.
7. Although Renesas Electronics endeavors to improve the quality and reliability of Renesas Electronics products, semiconductor products have specific characteristics, such as the occurrence of failure at a certain rate and malfunctions under certain use conditions. Unless designated as a high reliability product or a product for harsh environments in a Renesas Electronics data sheet or other Renesas Electronics document, Renesas Electronics products are not subject to radiation resistance design. You are responsible for implementing safety measures to guard against the possibility of bodily injury, injury or damage caused by fire, and/or danger to the public in the event of a failure or malfunction of Renesas Electronics products, such as safety design for hardware and software, including but not limited to redundancy, fire control and malfunction prevention, appropriate treatment for aging degradation or any other appropriate measures. Because the evaluation of microcomputer software alone is very difficult and impractical, you are responsible for evaluating the safety of the final products or systems manufactured by you.
8. Please contact a Renesas Electronics sales office for details as to environmental matters such as the environmental compatibility of each Renesas Electronics product. You are responsible for carefully and sufficiently investigating applicable laws and regulations that regulate the inclusion or use of controlled substances, including without limitation, the EU RoHS Directive, and using Renesas Electronics products in compliance with all these applicable laws and regulations. Renesas Electronics disclaims any and all liability for damages or losses occurring as a result of your noncompliance with applicable laws and regulations.
9. Renesas Electronics products and technologies shall not be used for or incorporated into any products or systems whose manufacture, use, or sale is prohibited under any applicable domestic or foreign laws or regulations. You shall comply with any applicable export control laws and regulations promulgated and administered by the governments of any countries asserting jurisdiction over the parties or transactions.
10. It is the responsibility of the buyer or distributor of Renesas Electronics products, or any other party who distributes, disposes of, or otherwise sells or transfers the product to a third party, to notify such third party in advance of the contents and conditions set forth in this document.
11. This document shall not be reprinted, reproduced or duplicated in any form, in whole or in part, without prior written consent of Renesas Electronics.
12. Please contact a Renesas Electronics sales office if you have any questions regarding the information contained in this document or Renesas Electronics products.

(Note1) "Renesas Electronics" as used in this document means Renesas Electronics Corporation and also includes its directly or indirectly controlled subsidiaries.

(Note2) "Renesas Electronics product(s)" means any product developed or manufactured by or for Renesas Electronics.

(Rev.4.0-1 November 2017)

## Corporate Headquarters

TOYOSU FORESIA, 3-2-24 Toyosu,  
Koto-ku, Tokyo 135-0061, Japan  
[www.renesas.com](http://www.renesas.com)

## Contact Information

For further information on a product, technology, the most up-to-date version of a document, or your nearest sales office, please visit:  
[www.renesas.com/contact/](http://www.renesas.com/contact/)

## Trademarks

Renesas and the Renesas logo are trademarks of Renesas Electronics Corporation. All trademarks and registered trademarks are the property of their respective owners.