

# OPA835 Ultra Low-Power Op Amp Applications

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High Speed Amplifiers

## ABSTRACT

The following circuits show application information for the OPA835 and OPA2835. For simplicity, power supply decoupling capacitors are not shown in these diagrams.

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## 1 Non-Inverting Amplifier

The OPA835 and OPA2835 can be used as non-inverting amplifiers with signal input to the non-inverting input,  $V_{IN+}$ . A basic block diagram of the circuit is shown in [Figure 1](#).

If we set  $V_{IN} = V_{REF} + V_{SIG}$ , then

$$V_{OUT} = V_{SIG} \left( 1 + \frac{R_F}{R_G} \right) + V_{REF} \quad (1)$$

$$G = 1 + \frac{R_F}{R_G}$$

The signal gain of the circuit is set by:  $\frac{R_F}{R_G}$ , and  $V_{REF}$  provides a reference around which the input and output signals swing. Output signals are in-phase with the input signals.

The OPA835 and OPA2835 are designed for the nominal value of  $R_F$  to be  $2k\Omega$  in gains other than +1. This gives excellent distortion performance, maximum bandwidth, best flatness, and best pulse response.  $R_F = 2k\Omega$  should be used as a default unless other design goals require changing to other values. All test circuits used to collect data for this data sheet had  $R_F = 2k\Omega$  for all gains other than +1. Gain of +1 is a special case where  $R_F$  is shorted and  $R_G$  is left open.

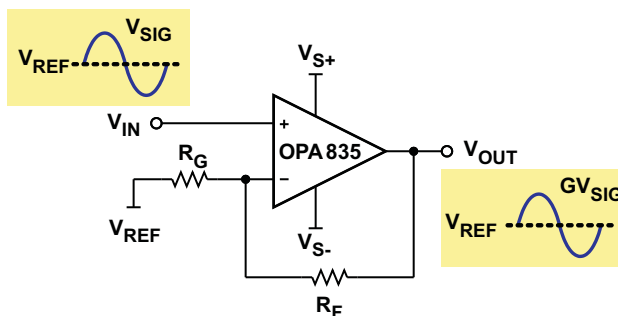


Figure 1. Non-Inverting Amplifier

## 2 Inverting Amplifier

The OPA835 and OPA2835 can be used as inverting amplifiers with signal input to the inverting input,  $V_{IN-}$ , through the gain setting resistor  $R_G$ . A basic block diagram of the circuit is shown in [Figure 2](#).

If we set  $V_{IN} = V_{REF} + V_{SIG}$ , then

$$V_{OUT} = V_{SIG} \left( \frac{-R_F}{R_G} \right) + V_{REF} \quad (2)$$

$$G = \frac{-R_F}{R_G}$$

The signal gain of the circuit is set by:  $\frac{-R_F}{R_G}$  and  $V_{REF}$  provides a reference point around which the input and output signals swing. Output signals are  $180^\circ$  out-of-phase with the input signals. The nominal value of  $R_F$  should be  $2k\Omega$  for inverting gains.

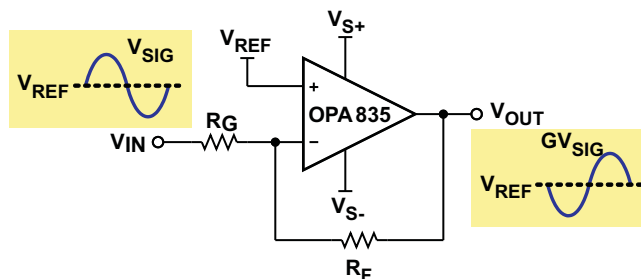


Figure 2. Inverting Amplifier

### 3 Attenuators

The non-inverting circuit of Figure 1 has minimum gain of 1. To implement attenuation, a resistor divider can be placed in series with the positive input, and the amplifier set for gain of 1 by shorting  $V_{OUT}$  to  $V_{IN-}$  and removing  $R_G$ . Since the op amp input is high impedance, the attenuation is set by the resistor divider.

The inverting circuit of Figure 2 can be used as an attenuator by making  $R_G$  larger than  $R_F$ . The attenuation is simply the resistor ratio. For example a 10:1 attenuator can be implemented with  $R_F = 2\text{ k}\Omega$  and  $R_G = 20\text{ k}\Omega$ .

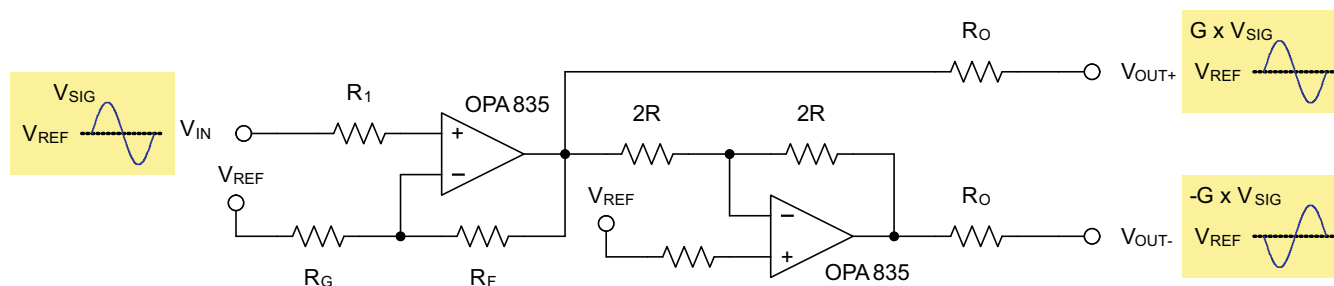
### 4 Single Ended to Differential Amplifier

Figure 3 shows an amplifier circuit that is used to convert single-ended signals to differential, and provides gain and level shifting. This circuit can be used for converting signals to differential in applications like line drivers for CAT 5 cabling or driving differential input SAR and  $\Delta\Sigma$  ADCs.

By setting  $V_{IN} = V_{REF} + V_{SIG}$ , then

$$V_{OUT+} = G \times V_{IN} + V_{REF} \quad \text{and} \quad V_{OUT-} = -G \times V_{IN} + V_{REF} \quad \text{Where: } G = 1 + \frac{R_F}{R_G} \quad (3)$$

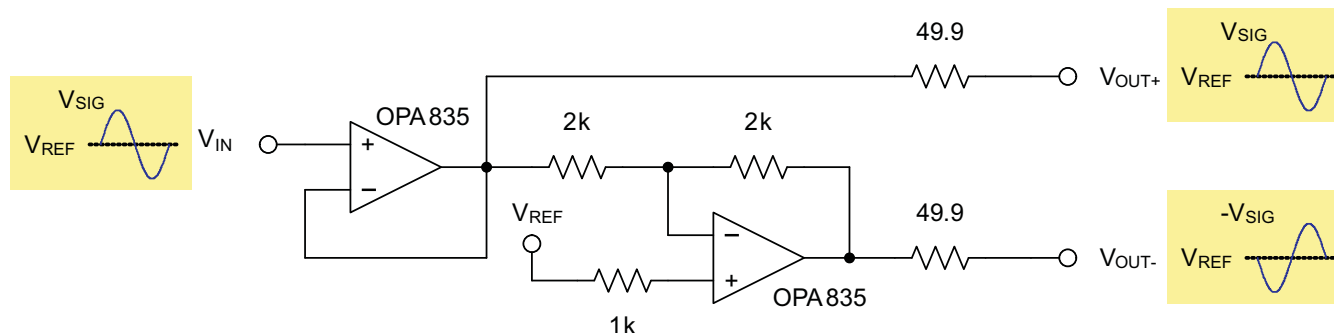
The differential signal gain of the circuit is  $2 \times G$ , and  $V_{REF}$  provides a reference around which the output signal swings. The differential output signal is in-phase with the single ended input signal.



**Figure 3. Single Ended to Differential Amplifier**

Line termination on the output can be accomplished with resistors  $R_O$ . The impedance seen differential from the line will be  $2 \times R_O$ . For example if  $100\text{ }\Omega$  CAT 5 cable is used with double termination, the amplifier is typically set for a differential gain of  $2\text{ V/V}$  (6 dB) with  $R_F = 0\text{ }\Omega$  (short)  $R_G = \infty\text{ }\Omega$  (open),  $2R = 2\text{ k}\Omega$ ,  $R1 = 0\text{ }\Omega$ ,  $R = 1\text{ k}\Omega$  to balance the input bias currents, and  $R_O = 49.9\text{ }\Omega$  for output line termination. This configuration is shown in Figure 4.

For driving a differential input ADC the situation is similar, but the output resistors,  $R_O$ , are typically chosen along with a capacitor across the ADC input for optimum filtering and settling time performance.



**Figure 4. CAT 5 Line Driver with Gain = 2 V/V (6 dB)**

## 5 Differential to Signal Ended Amplifier

Figure 5 shows a differential amplifier that is used to convert differential signals to single-ended and provides gain (or attenuation) and level shifting. This circuit can be used in applications like a line receiver for converting a differential signal from a CAT 5 cable to single-ended.

If we set  $V_{IN+} = V_{CM} + V_{SIG+}$  and  $V_{IN-} = V_{CM} + V_{SIG-}$ , then

$$V_{OUT} = (V_{IN+} - V_{IN-}) \times \left( \frac{R_F}{R_G} \right) + V_{REF} \quad (4)$$

$$G = \frac{R_F}{R_G}$$

The signal gain of the circuit is set by:  $\frac{R_F}{R_G}$ ,  $V_{CM}$  is rejected, and  $V_{REF}$  provides a level shift around which the output signal swings. The single ended output signal is in-phase with the differential input signal.

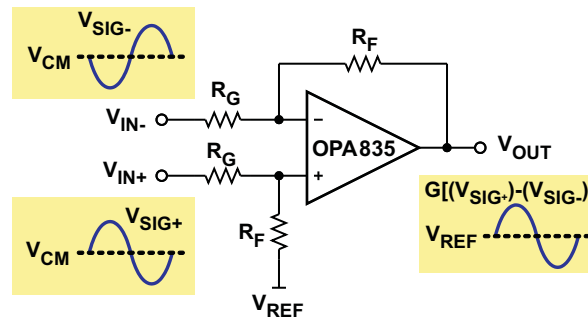


Figure 5. Differential to Single Ended Amplifier

Line termination can be accomplished with a resistor shunt across the input. The impedance seen differential from the line will be the resistor value in parallel with the amplifier circuit. For low gain and low line impedance the resistor value to add is approximately the impedance of the line. For example, if 100  $\Omega$  CAT5 cable is used with a gain of 1 amplifier and  $R_F = R_G = 2 \text{ k}\Omega$ , adding a 100  $\Omega$  shunt across the input will give a differential impedance of 99  $\Omega$ ; this should be adequate for most applications.

For best CMRR performance, resistors must be matched. Assuming  $\text{CMRR} \approx$  the resistor tolerance; so 0.1% tolerance will provide about 60 dB CMRR.

## 6 Differential to Differential Amplifier

Figure 6 shows a differential amplifier that is used to amplify differential signals. This circuit has high input impedance and is often used in differential line driver applications where the signal source is a high impedance driver like a differential DAC that needs to drive a line.

If we set  $V_{IN\pm} = V_{CM} + V_{SIG\pm}$  then

$$V_{OUT\pm} = V_{IN\pm} \times \left( 1 + \frac{2R_F}{R_G} \right) + V_{CM} \quad (5)$$

The signal gain of the circuit is set by:  $G = 1 + \frac{2R_F}{R_G}$ , and  $V_{CM}$  passes with unity gain. The amplifier in essence combines two non-inverting amplifiers into one differential amplifier with the  $R_G$  resistor shared, which makes  $R_G$  effectively  $\frac{1}{2}$  its value when calculating the gain. The output signals are in-phase with the input signals.

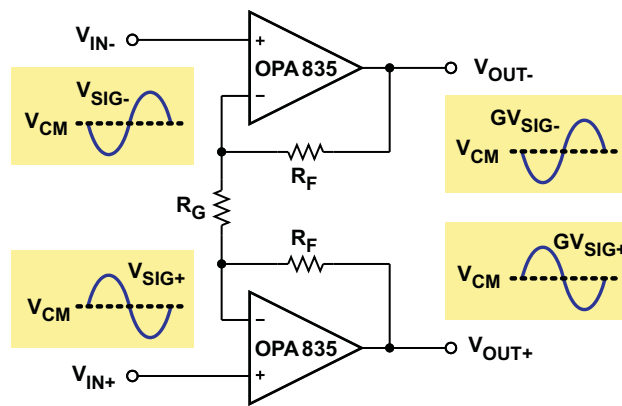


Figure 6. Differential to Differential Amplifier

## 7 Instrumentation Amplifier

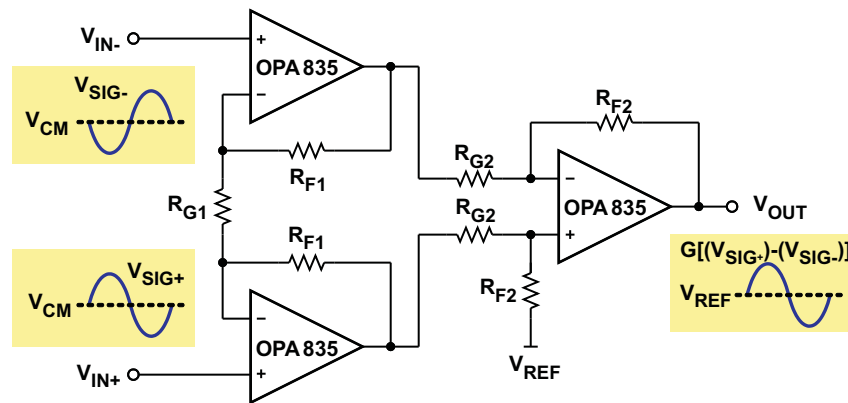
Figure 7 is an instrumentation amplifier that combines the high input impedance of the differential to differential amplifier circuit and the common-mode rejection of the differential to single-ended amplifier circuit. This circuit is often used in applications where high input impedance is required like taps from a differential line or in cases where the signal source is a high impedance.

If we set  $V_{IN+} = V_{CM} + V_{SIG+}$  and  $V_{IN-} = V_{CM} + V_{SIG-}$ , then

$$V_{OUT} = (V_{IN+} - V_{IN-}) \times \left(1 + \frac{2R_{F1}}{R_{G1}}\right) \left(\frac{R_{F2}}{R_{G2}}\right) + V_{REF} \quad (6)$$

The signal gain of the circuit is set by:

$G = \left(1 + \frac{2R_{F1}}{R_{G1}}\right) \left(\frac{R_{F2}}{R_{G2}}\right)$ ,  $V_{CM}$  is rejected, and  $V_{REF}$  provides a level shift around which the output signal swings. The single ended output signal is in-phase with the differential input signal.



**Figure 7. Instrumentation Amplifier**

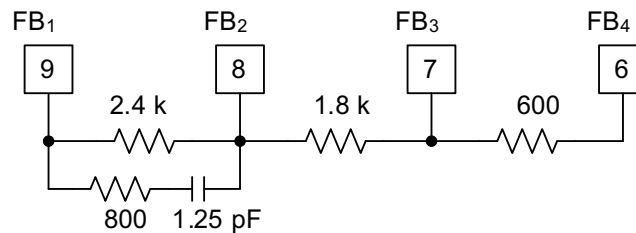
Integrated solutions are available, but the OPA835 provides a much lower power high frequency solution. For best CMRR performance, resistors must be matched. A rule of thumb is CMRR  $\approx$  the resistor tolerance; so 0.1% tolerance will provide about 60 dB CMRR.

## 8 Gain Setting with OPA835 RUN Integrated Resistors

The OPA835 RUN package option includes integrated gain setting resistors for smallest possible footprint on a printed circuit board ( $\approx 2\text{mm} \times 2\text{mm}$ ). By adding circuit traces on the PCB, gains of +1, -1, -1.33, +2, +2.33, -3, +4, -4, +5, -5.33, +6.33, -7, +8 and inverting attenuations of -0.1429, -0.1875, -0.25, -0.33, -0.75 can be achieved.

Figure 8 shows a simplified view of how the OPA835IRUN integrated gain setting network is implemented. Table 1 shows the required pin connections for various non-inverting and inverting gains (reference Figure 1 and Figure 2). Table 2 shows the required pin connections for various attenuations using the inverting amplifier architecture (reference Figure 2). Due to ESD protection devices being used on all pins, the absolute maximum and minimum input voltage range,  $V_{S-} - 0.7\text{V}$  to  $V_{S+} + 0.7\text{V}$ , applies to the gain setting resistors, and so attenuation of large input voltages will require external resistors to implement.

The gain setting resistors are laser trimmed to 1% tolerance with nominal values of 2.4 k $\Omega$ , 1.8 k $\Omega$ , and 600  $\Omega$ . They have excellent temperature coefficient and gain tracking is superior to using external gain setting resistors. The 800  $\Omega$  and 1.25 pF capacitor in parallel with the 2.4 k $\Omega$  gain setting resistor provide compensation for best stability and pulse response.



**Figure 8. OPA835IRUN Gain Setting Network**

**Table 1. Gains Setting**

Non-inverting Gain ( Figure 1 )	Inverting Gain ( Figure 2 )	Short Pins	Short Pins	Short Pins	Short Pins
1 V/V (0 dB)	-	1 to 9			-
2 V/V (6.02 dB)	-1 V/V (0 dB)	1 to 9	2 to 8	6 to GND	-
2.33 V/V (7.36 dB)	-1.33 V/V (2.5 dB)	1 to 9	2 to 8	7 to GND	-
4 V/V (12.04 dB)	-3 V/V (9.54 dB)	1 to 8	2 to 7	6 to GND	-
5 V/V (13.98 dB)	-4 V/V (12.04 dB)	1 to 9	2 to 7 or 8	7 to 8	6 to GND
6.33 V/V (16.03 dB)	-5.33 V/V (14.54 dB)	1 to 9	2 to 6 or 8	6 to 8	7 to GND
8 V/V (18.06 dB)	-7 V/V (16.90 dB)	1 to 9	2 to 7	6 to GND	-

**Table 2. Attenuator Settings**

Inverting Gain ( Figure 2 )	Short Pins	Short Pins	Short Pins	Short Pins
-0.75 V/V (-2.5 dB)	1 to 7	2 to 8	9 to GND	-
-0.333 V/V (-9.54 dB)	1 to 6	2 to 7	8 to GND	-
-0.25 V/V (-12.04 dB)	1 to 6	2 to 7 or 8	7 to 8	9 to GND
-0.1875 V/V (-14.54 dB)	1 to 7	2 to 6 or 8	6 to 8	9 to GND
-0.1429 V/V (-16.90 dB)	1 to 6	2 to 7	9 to GND	-



## 9 Input Common-Mode Voltage Range

When the primary design goal is a linear amplifier, with high CMRR, it is important to not violate the input common-mode voltage range ( $V_{ICR}$ ) of an op amp.

Common-mode input range low and high specifications in the table data use CMRR to set the limit. The limits are chosen to ensure CMRR will not degrade more than 3 dB below its limit if the input voltage is kept within the specified range. The limits cover all process variations and most parts will be better than specified. The typical specifications are from 0.2 V below the negative rail to 1.1 V below the positive rail.

Assuming the op amp is in linear operation the voltage difference between the input pins is small (ideally 0 V) and input common-mode voltage can be analyzed at either input pin and the other input pin is assumed to be at the same potential. The voltage at  $V_{IN+}$  is easy to evaluate. In non-inverting configuration, [Figure 1](#), the input signal,  $V_{IN}$ , must not violate the  $V_{ICR}$ . In inverting configuration, [Figure 2](#), the reference voltage,  $V_{REF}$ , needs to be within the  $V_{ICR}$ .

The input voltage limits have fixed headroom to the power rails and track the power supply voltages. For with single 5 V supply, the linear input voltage range is  $-0.2$  V to 3.9 V and with 2.7 V supply it is  $-0.2$  V to 1.6 V. The delta from each power supply rail is the same in either case;  $-0.2$  V and 1.1 V.

## 10 Output Voltage Range

The OPA835 and OPA2835 are rail-to-rail output (RRO) op amps. Rail-to-rail output typically means the output voltage can swing to within a couple hundred milli-volts of the supply rails. There are different ways to specify this; one is with the output still in linear operation and another is with the output saturated. Saturated output voltages are closer to the power supply rails than linear outputs, but the signal is not a linear representation of the input. Linear output is a better representation of how well a device performs when used as a linear amplifier. Both saturation and linear operation limits are affected by the current in the output, where higher currents lead to more loss in the output transistors.

Data in the ([SLOS713](#) data sheet) ELECTRICAL SPECIFICATIONS tables list both linear and saturated output voltage specifications with 2k $\Omega$  load. [Figure 9](#) and [Figure 10](#) show saturated voltage swing limits versus output load resistance and [Figure 11](#) and [Figure 12](#) show the output saturation voltage versus load current. Given a light load, the output voltage limits have nearly constant headroom to the power rails and track the power supply voltages. For example with 2 k $\Omega$  load and single 5 V supply the linear output voltage range is 0.15 V to 4.8 V and with 2.7 V supply it is 0.15 V to 2.5 V. The delta from each power supply rail is the same in either case; 0.15 V and 0.2 V.

With devices like the OPA835 and OPA2835, where the input range is lower than the output range, it is typical that the input will limit the available signal swing only in non-inverting gain of 1. Signal swing in non-inverting configurations in gains  $> +1$  and inverting configurations in any gain is generally limited by the output voltage limits of the op amp.

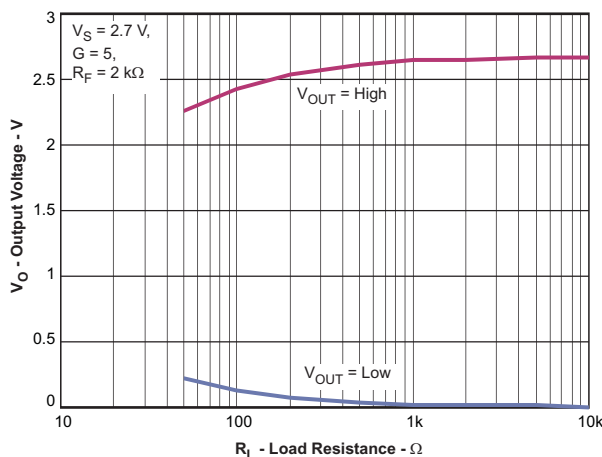


Figure 9. Output Voltage Swing vs Load Resistance

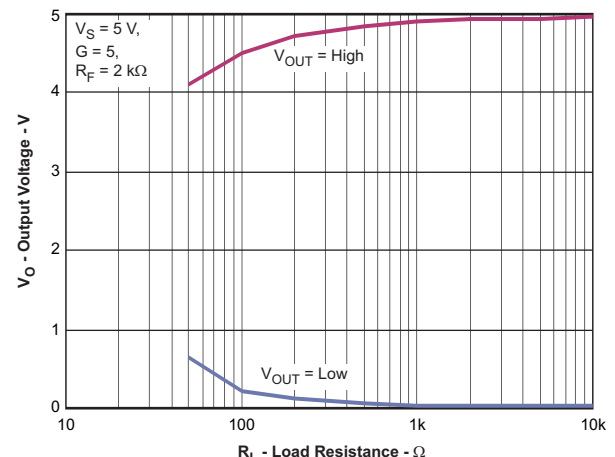


Figure 10. Output Voltage Swing vs Load Resistance

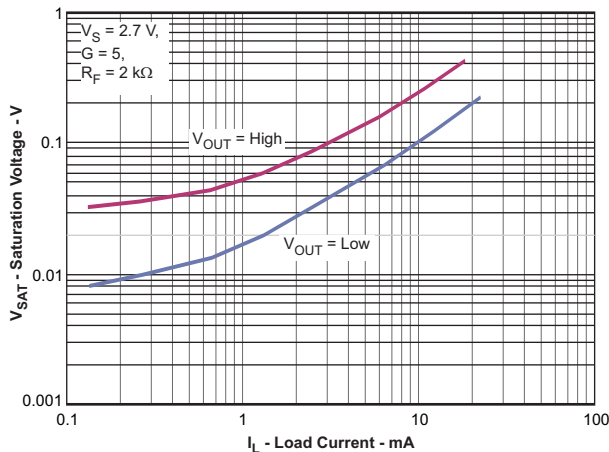


Figure 11. Output Saturation Voltage vs Load Current

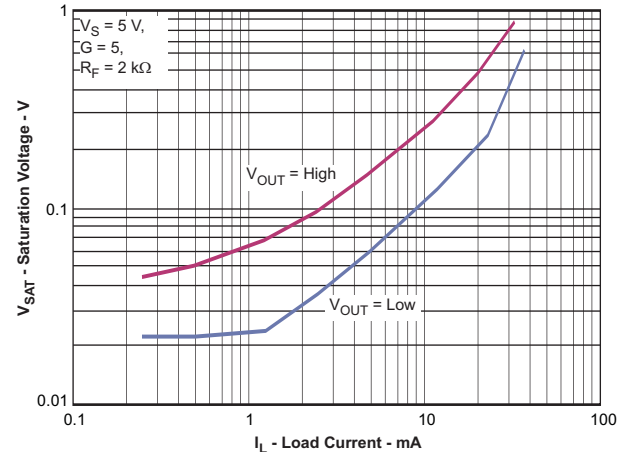


Figure 12. Output Saturation Voltage vs Load Current

## 11 Split-Supply Operation ( $\pm 1.25\text{V}$ to $\pm 2.75\text{V}$ )

To facilitate testing with common lab equipment, the OPA835 EVM [SLOU314](#) is built to allow for split-supply operation. This configuration eases lab testing because the mid-point between the power rails is ground, and most signal generators, network analyzers, oscilloscopes, spectrum analyzers and other lab equipment reference their inputs and outputs to ground.

Figure 13 shows a simple non-inverting configuration analogous to Figure 1 with  $\pm 2.5\text{V}$  supply and  $V_{\text{REF}}$  equal to ground. The input and output will swing symmetrically around ground. Due to its ease of use, split supply operation is preferred in systems where signals swing around ground, but it requires generation of two supply rails.

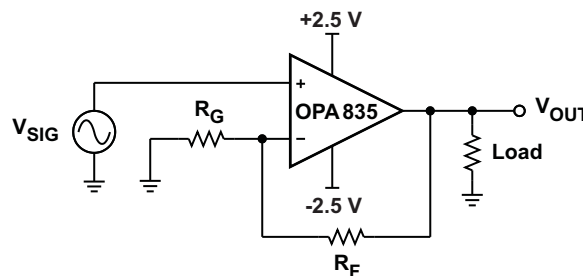
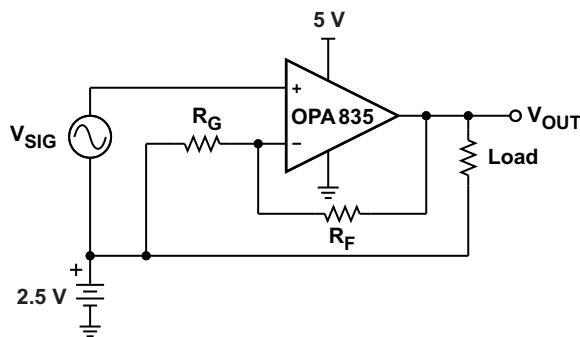


Figure 13. Split Supply Operation

## 12 Single-Supply Operation (2.5V to 5.5V)

Many newer systems use single power supply to improve efficiency and reduce the cost of the power supply. OPA835 and OPA2835 are designed for use with single-supply power operation and can be used with single-supply power with no change in performance from split supply as long as the input and output are biased within the linear operation of the device.

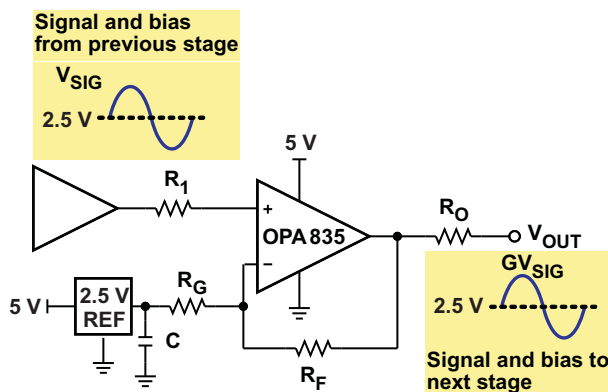
To change the circuit from split supply to single supply, level shift of all voltages by  $\frac{1}{2}$  the difference between the power supply rails. For example, changing from  $\pm 2.5\text{V}$  split supply to  $5\text{V}$  single supply is shown conceptually in Figure 14.



**Figure 14. Single Supply Concept**

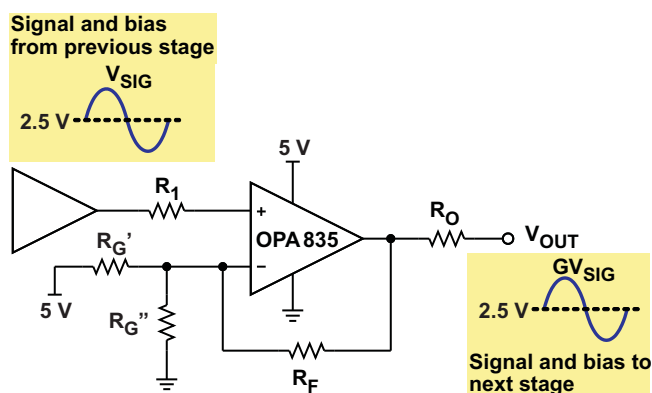
A more practical circuit will have an amplifier or other circuit before to provide the bias voltage for the input and the output provides the bias for the next stage.

Figure 15 shows a typical non-inverting amplifier situation. With 5V single supply, a mid supply reference generator is needed to bias the negative side via  $R_G$ . To cancel the voltage offset that would otherwise be caused by the input bias currents,  $R_1$  is chosen to be equal to  $R_F$  in parallel with  $R_G$ . For example if gain of 2 is required and  $R_F = 2\text{ k}\Omega$ , select  $R_G = 2\text{ k}\Omega$  to set the gain and  $R_1 = 1\text{ k}\Omega$  for bias current cancellation. The value for C is dependent on the reference, but at least  $0.1\mu\text{F}$  is recommended to limit noise.



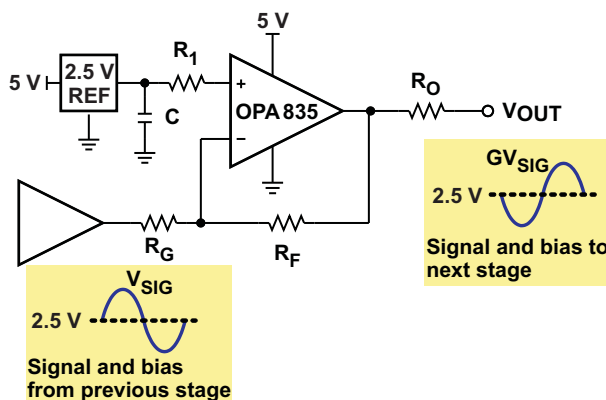
**Figure 15. Non-Inverting Single Supply with Reference**

Figure 16 shows a similar non-inverting single supply scenario with the reference generator replaced by the Thevenin equivalent using resistors and the positive supply.  $R_G'$  and  $R_G''$  form a resistor divider from the 5V supply and are used to bias the negative side with their parallel sum equal to the equivalent  $R_G$  to set the gain. To cancel the voltage offset that would otherwise be caused by the input bias currents,  $R_1$  is chosen to be equal to  $R_F$  in parallel with  $R_G'$  in parallel with  $R_G''$  ( $R_1 = R_F || R_G' || R_G''$ ). For example if gain of 2 is required and  $R_F = 2\text{ k}\Omega$ , selecting  $R_G' = R_G'' = 4\text{ k}\Omega$  gives equivalent parallel sum of  $2\text{ k}\Omega$ , sets the gain to 2, and references the input to mid supply (2.5 V).  $R_1$  is then set to  $1\text{ k}\Omega$  for bias current cancellation. This can be lower cost, but note the extra current draw required in the resistor divider.



**Figure 16. Non-Inverting Single Supply with Resistors**

Figure 17 shows a typical inverting amplifier situation. With 5V single supply, a mid supply reference generator is needed to bias the positive side via  $R_1$ . To cancel the voltage offset that would otherwise be caused by the input bias currents,  $R_1$  is chosen to be equal to  $R_F$  in parallel with  $R_G$ . For example if gain of -2 is required and  $R_F = 2\text{ k}\Omega$ , select  $R_G = 1\text{ k}\Omega$  to set the gain and  $R_1 = 665\text{ }\Omega$  for bias current cancellation. The value for C is dependent on the reference, but at least  $0.1\text{ }\mu\text{F}$  is recommended to limit noise into the op amp.



**Figure 17. Inverting Single Supply with Reference**

Figure 18 shows a similar inverting single supply scenario with the reference generator replaced by the Thevenin equivalent using resistors and the positive supply.  $R_1$  and  $R_2$  form a resistor divider from the 5V supply and are used to bias the positive side. To cancel the voltage offset that would otherwise be caused by the input bias currents, set the parallel sum of  $R_1$  and  $R_2$  equal to the parallel sum of  $R_F$  and  $R_G$ . C should be added to limit coupling of noise into the positive input. For example if gain of -2 is required and  $R_F = 2\text{ k}\Omega$ , select  $R_G = 1\text{ k}\Omega$  to set the gain.  $R_1 = R_2 = 1.33\text{ k}\Omega$  for mid supply voltage bias and for op amp input bias current cancellation. A good value for C is  $0.1\text{ }\mu\text{F}$ . This can be lower cost, but note the extra current draw required in the resistor divider.

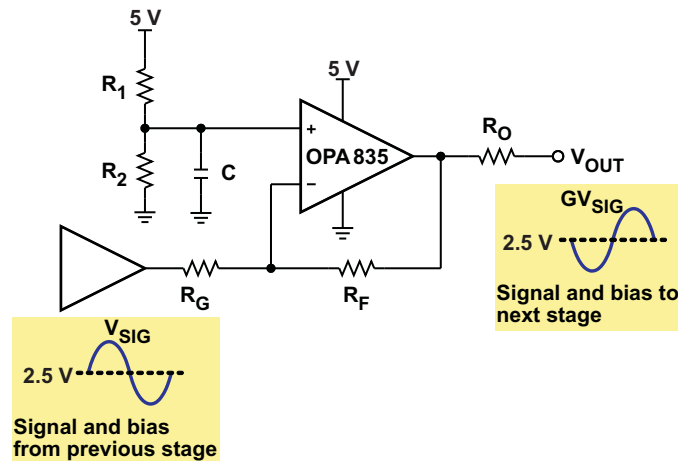


Figure 18. Inverting Single Supply with Resistors

### 13 Pulse Application with Single-Supply

For pulsed applications, where the signal is at ground and pulses to some positive or negative voltage, the circuit bias voltage considerations are different than with a signal that swings symmetrical about a reference point and the circuit configuration should be adjusted accordingly. Figure 19 shows a pulsed situation where the signal is at ground (0 V) and pulses to a positive value.

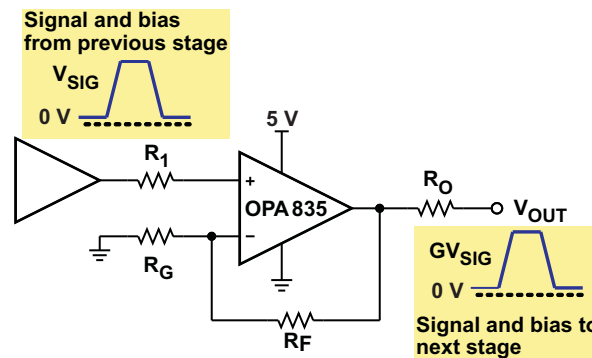


Figure 19. Non-Inverting Single Supply with Pulse

If the input signal pulses negative from ground, an inverting amplifier is more appropriate as shown in Figure 20. A key consideration in both non-inverting and inverting cases is that the input and output voltages are kept within the limits of the amplifier, and since the V<sub>ICR</sub> of the OPA835 includes the negative supply rail, the op amp lends itself to this application.

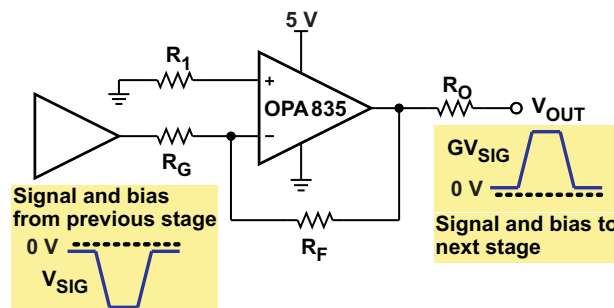


Figure 20. Inverting Single Supply with Pulse

## 14 Power-Down Operation

The OPA835 and OPA2835 include a power-down mode. Under logic control, the amplifiers can be switched from normal operation to a standby current of  $<1.5\ \mu\text{A}$ . When the  $\overline{\text{PD}}$  pin is connected high, the amplifier is active. Connecting  $\overline{\text{PD}}$  pin low disables the amplifier, and places the output in a high impedance state. Note: the op amp's output in gain of +1 is high impedance similar to a 3-state high impedance gate, but in other gains the feedback network is a parallel load.

The  $\overline{\text{PD}}$  pin must be actively driven high or low and should not be left floating. If the power-down mode is not used,  $\overline{\text{PD}}$  should be tied to the positive supply rail.

$\overline{\text{PD}}$  logic states are TTL with reference to the negative supply rail,  $V_{\text{S-}}$ . When the op amp is powered from single supply and ground, driving from logic devices with similar  $V_{\text{DD}}$  voltages to the op amp should not require any special consideration. When the op amp is powered from split supply,  $V_{\text{S-}}$  is below ground and an open collector type of interface with pull-up resistor is more appropriate. Pull-up resistor values should be lower than 100k and the drive logic should be negated due to the inverting action of an open collector gate.

## 15 Low Power Applications and the Effects of Resistor Values on Bandwidth

The OPA835 and OPA2835 are designed for the nominal value of  $R_F$  to be 2 k $\Omega$  in gains other than +1. This gives excellent distortion performance, maximum bandwidth, best flatness, and best pulse response. It also loads the amplifier. For example; in gain of 2 with  $R_F = R_G = 2$  k $\Omega$ ,  $R_G$  to ground, and  $V_{OUT} = 4$  V, 1mA of current will flow through the feedback path to ground. In gain of +1,  $R_G$  is open and no current will flow to ground. In low power applications, it is desirable to reduce this current by increasing the gain setting resistors values. Using larger value gain resistors has two primary side effects (other than lower power) due to their interaction with parasitic circuit capacitance.

1. Lowers the bandwidth.
2. Lowers the phase margin
  - (a) This will cause peaking in the frequency response.
  - (b) And will cause over shoot and ringing in the pulse response.

Figure 21 shows the small signal frequency response on OPA835EVM for non-inverting gain of 2 with  $R_F$  and  $R_G$  equal to 2 k $\Omega$ , 10 k $\Omega$ , and 100 k $\Omega$ . The test was done with  $R_L = 2$  k $\Omega$ . Due to loading effects of  $R_L$ , lower values may reduce the peaking, but higher values will not have a significant effect.

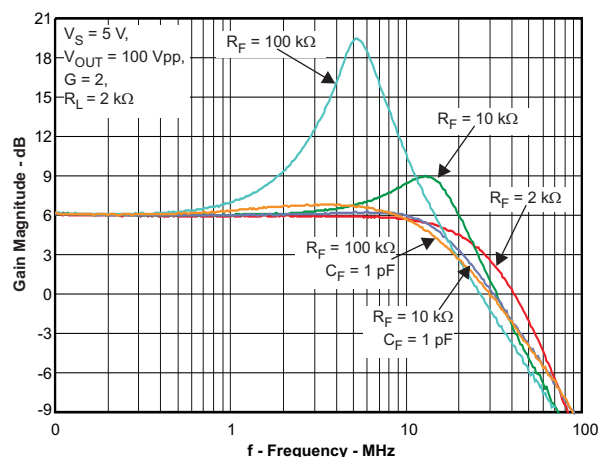


Figure 21. Frequency Response with Various Gain Setting Resistor Values

As expected, larger value gain resistors cause lower bandwidth and peaking in the response (peaking in frequency response is synonymous with overshoot and ringing in pulse response). Adding 1 pF capacitors in parallel with  $R_F$  helps compensate the phase margin and restores flat frequency response. Figure 22 shows the test circuit used.

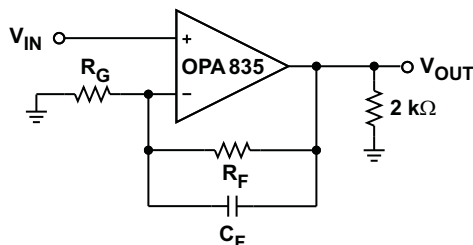


Figure 22. G=2 Test Circuit for Various Gain Setting Resistor Values

## 16 Driving Capacitive Loads

The OPA835 and OPA2835 can drive up to a nominal capacitive load of 10pF on the output with no special consideration. When driving capacitive loads greater than this, it is recommended to use a small resistor ( $R_O$ ) in series with the output as close to the device as possible. Without  $R_O$ , capacitance on the output will interact with the output impedance of the amplifier causing phase shift in the loop gain of the amplifier that will reduce the phase margin. This will cause peaking in the frequency response and overshoot and ringing in the pulses response. Interaction with other parasitic elements may lead to instability or oscillation. Inserting  $R_O$  will isolate the phase shift from the loop gain path and restore the phase margin; however, it will also limit the bandwidth.

Figure 23 shows the test circuit and Figure 24 shows the recommended values of  $R_O$  versus capacitive loads,  $C_L$ . See Figure 25 for frequency response with various values.

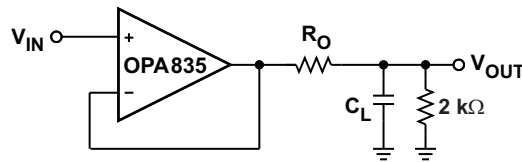


Figure 23.  $R_O$  versus  $C_L$  Test Circuit

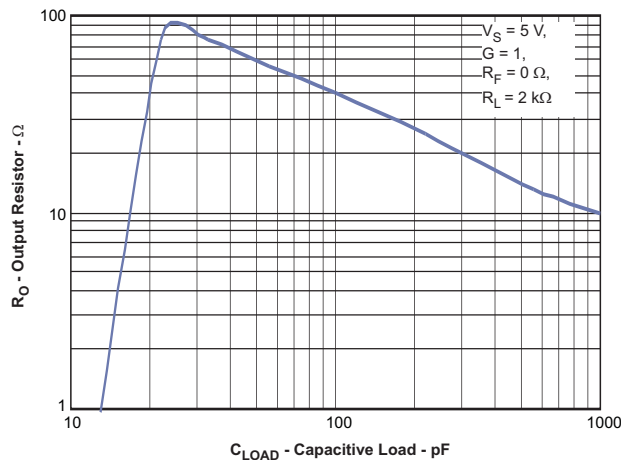


Figure 24. Series Output Resistor vs Capacitive Load

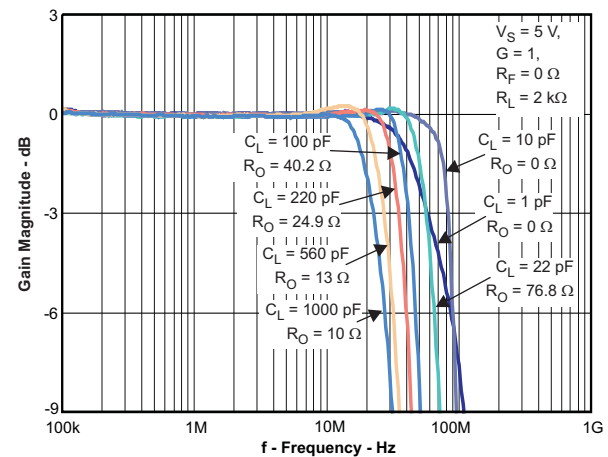


Figure 25. Frequency Response with Capacitive Load

## 17 Active Filters

The OPA835 and OPA2835 can be used to design active filters. Figure 27 and Figure 26 show MFB and Sallen-Key circuits designed using FilterPro™ <http://focus.ti.com/docs/toolsw/folders/print/filterpro.html> to implement 2<sup>nd</sup> order low-pass butterworth filter circuits. Figure 28 shows the frequency response.

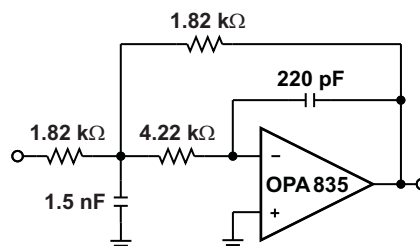
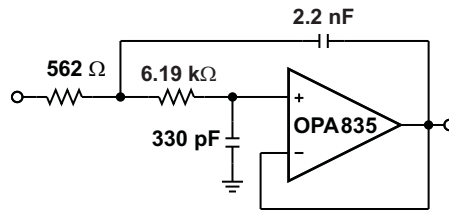
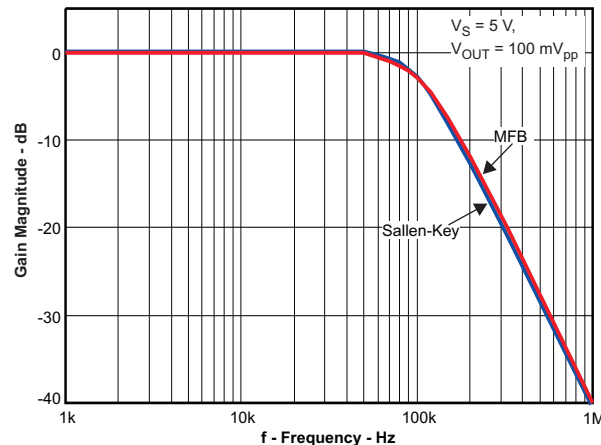


Figure 26. MFB 100kHz 2<sup>nd</sup> Order Low-Pass Butterworth Filter Circuit





**Figure 27. Sallen-Key 100kHz 2nd Order Low-Pass Butterworth Filter Circuit**



**Figure 28. MFB and Sallen-Key 2<sup>nd</sup> Order Low-Pass Butterworth Filter Response**

MFB and Sallen-Key filter circuits offer similar performance. The main difference is the MFB is an inverting amplifier in the pass band and the Sallen-Key is non-inverting. The primary pro for each is the Sallen-Key in unity gain has no resistor gain error term, and thus no sensitivity to gain error, while the MFB has inherently better attenuation properties beyond the bandwidth of the op amp.

## 18 Audio Frequency Performance

The OPA835 and OPA2835 provide excellent audio performance with very low quiescent power. To show performance in the audio band, a 2700 series Audio Analyzer from Audio Precision was used to test THD+N and FFT at 1 V<sub>RMS</sub> output voltage. Figure 29 is the test circuit used. Note the 100 pF capacitor to ground on the input helped to decouple noise pick up in the lab and improved noise performance.

Figure 30 shows the THD+N performance with 100 kΩ and 300 Ω loads, and with no weighting and A-weighting. With no weighting the THD+N performance is dominated by the noise for both loads. A-weighting provides filtering that improves the noise so a larger difference can be seen between the loads due to more distortion with R<sub>L</sub> = 300 Ω.

Figure 31 and Figure 32 show FFT output with a 1 kHz tone and 100kΩ and 300Ω loads. To show relative performance of the device versus the test set, one channel has the OPA835 in line between generator output and analyzer input and the other channel is in “Gen Mon” loopback mode, which internally connects the signal generator to the analyzer input. With 100 kΩ load, Figure 31, the curves are basically indistinguishable from each other except for noise, which means the OPA835 cannot be directly measured. With 300Ω load, Figure 32, the main difference between the curves is OPA835 shows higher even order harmonics, but odd order is masked by the test set performance.

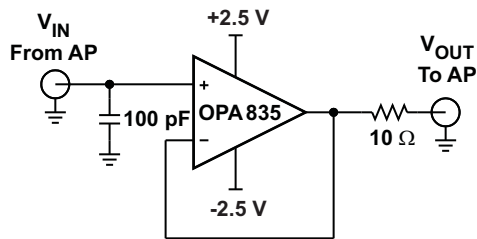


Figure 29. OPA835 AP Analyzer Test Circuit

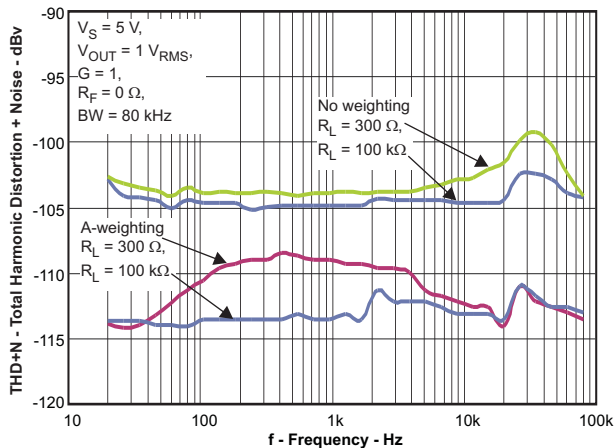


Figure 30. OPA835 1 Vrms 20 Hz to 80 kHz THD+N

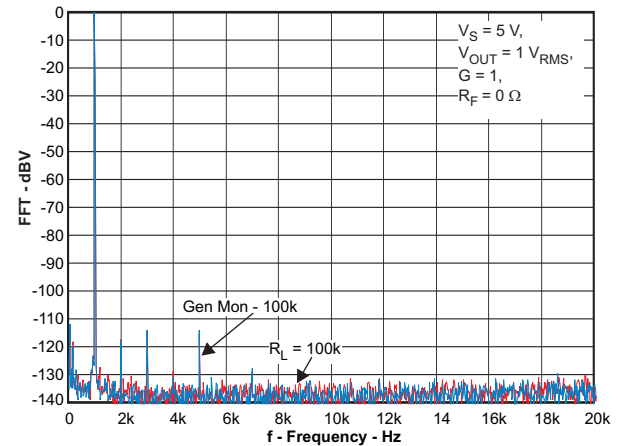


Figure 31. OPA835 and AP Gen Mon 1kHz FFT Plot;  
 $V_{OUT} = 1 V_{RMS}$ ,  $R_L = 100k\Omega$

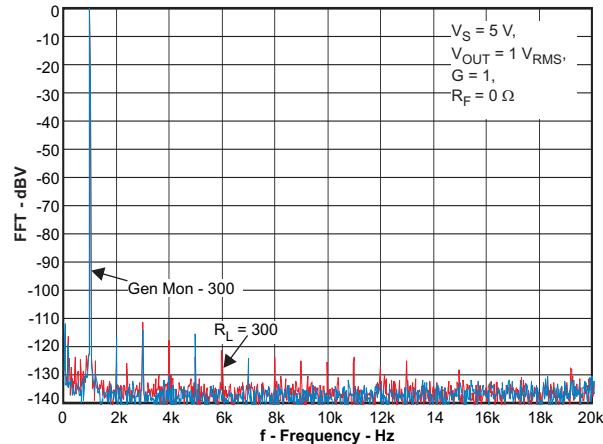


Figure 32. OPA835 and AP Gen Mon 1kHz FFT Plot;  
 $V_{OUT} = 1 V_{RMS}$ ,  $R_L = 300\Omega$

## 19 ADC Driver Performance

The OPA835 provides excellent performance when driving high performance delta-sigma ( $\Delta\Sigma$ ) and successive approximation register (SAR) ADCs in low power audio and industrial applications.

## 20 OPA835 and ADS8326 Combined Performance

To show achievable performance, the OPA835 is tested as the drive amplifier for the ADS8326. The ADS8326 is a 16-bit, micro power, SAR ADC with pseudo-differential inputs and sample rates up to 250kSPS. It offers excellent noise and distortion performance in a small 8-pin SOIC or VSSOP (MSOP) package. Low power and small size make the ADS8326 and OPA835 an ideal solution for portable and battery-operated systems, for remote data-acquisition modules, simultaneous multichannel systems, and isolated data acquisition.

The circuit shown in Figure 33 is used to test the performance, Figure 34 is the FFT plot with 10kHz input frequency showing the spectral performance, and the tabulated AC analysis results are in Table 3.

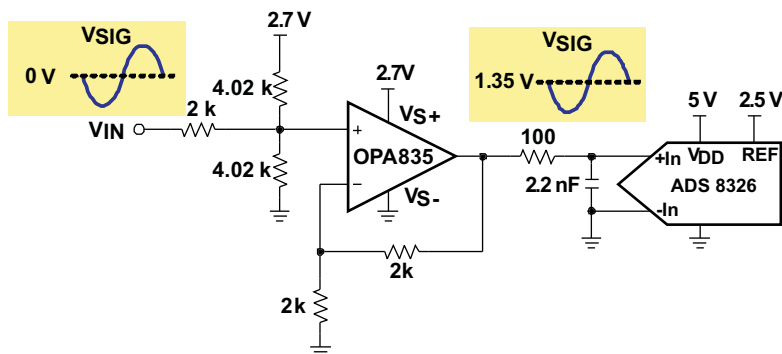


Figure 33. OPA835 and ADS8326 Test Circuit

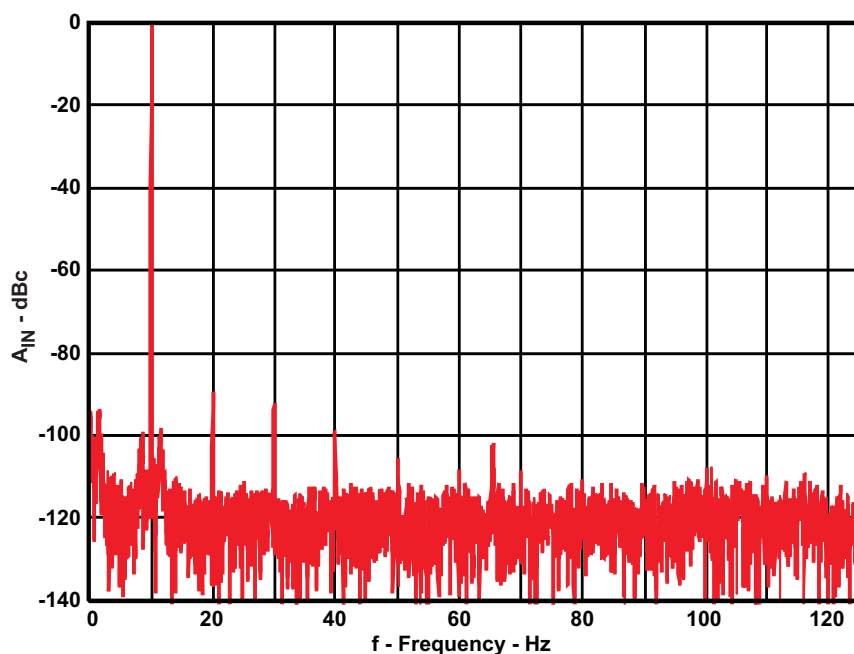


Figure 34. ADS8326 and OPA835 10kHz FFT

Table 3. AC Analysis

Tone (Hz)	Signal (dBFS)	SNR (dBc)	THD (dBc)	SINAD (dBc)	SFDR (dBc)
10k	-0.85	81.9	-87.5	80.8	89.9

## 21 Layout Recommendations

OPA835 EVM ([SLOU314](#)) should be used as a reference when designing the circuit board. It is recommended to follow the EVM layout of the external components near to the amplifier, ground plane construction, and power routing as closely as possible. General guidelines are:

1. Signal routing should be direct and as short as possible into an out of the op amp.
2. The feedback path should be short and direct avoiding vias if possible especially with  $G = +1$ .
3. Ground or power planes should be removed from directly under the amplifier's negative input and output pins.
4. A series output resistor is recommended to be placed as near to the output pin as possible. See "Series Output Resistor vs. Capacitive Load" ([Figure 24](#)) for recommended values given expected capacitive load of design.
5. A 2.2  $\mu\text{F}$  power supply decoupling capacitor should be placed within 2 inches of the device and can be shared with other op amps. For split supply, a capacitor is required for both supplies.
6. A 0.1  $\mu\text{F}$  power supply decoupling capacitor should be placed as near to the power supply pins as possible. Preferably within 0.1 inch. For split supply, a capacitor is required for both supplies.
7. The  $\overline{\text{PD}}$  pin uses TTL logic levels. If not used it should tied to the positive supply to enable the amplifier. If used, it must be actively driven. A bypass capacitor is not necessary, but can be used for robustness in noisy environments.

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