

FEATURES

- High CMRR: typ. 90dB at 60Hz
- Excellent audio performance
 - Wide bandwidth: typ. >24 MHz
 - High slew rate: typ. 12 V/ μ s
 - Low distortion: typ. 0.0006 % THD
 - Low noise: typ. -103 dBu (re: input)
- Low current: typ. 2 mA
- Several gains: 0 dB, ± 3 dB, & ± 6 dB
- Industry-standard pinout

APPLICATIONS

- Balanced Audio Line Receivers
- Instrumentation Amplifiers
- Differential Amplifiers
- Precision Summers
- Current Shunt Monitors

Description

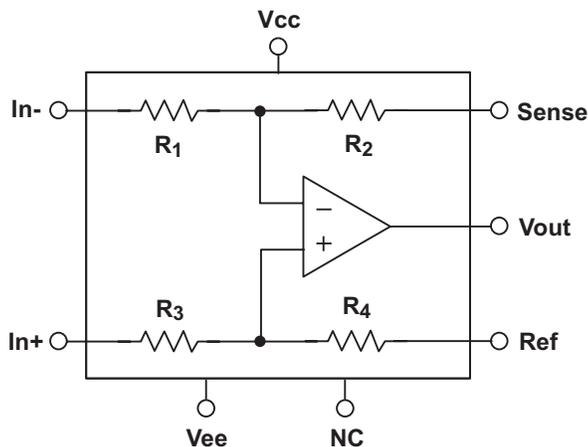
The THAT 1240-series of precision differential amplifiers was designed primarily for use as balanced line receivers for audio applications. Gains of 0 dB, ± 3 dB, and ± 6 dB are available to suit various applications requirements.

These devices are laser trimmed in wafer form to obtain the precision resistor matching needed for high CMR performance and precise gain. Manufactured in THAT Corporation's proprietary complementary dielectric isolation (DI) process, the THAT 1240-series provides the sonic benefits of discrete designs with the simplicity, reliability,

matching, and small size of a fully integrated solution.

All three versions of the part typically exhibit 90dB of common-mode rejection. With 12 V/ μ s slew rate, >24MHz bandwidth, and 0.0006% THD, these devices are sonically transparent. Moreover, current consumption is typically a low 2 mA. Both surface-mount and DIP packages are available.

The THAT 1246 is pin-compatible with the TI INA137 and Analog Devices SSM2143, while the THAT 1240 is pin-compatible with the SSM2141.



Part no.	Gain	R_1, R_3	R_2, R_4
THAT1240	0 dB	9 k Ω	9 k Ω
THAT1243	-3 dB	10.5 k Ω	7.5 k Ω
THAT1246	-6 dB	12 k Ω	6 k Ω

Figure 1. THAT1240-series equivalent circuit diagram

Pin Name	DIP Pin	SO Pin
Ref	1	1
In-	2	2
In+	3	3
Vee	4	4
Sense	5	5
Vout	6	6
Vcc	7	7
NC	8	8

Table 1. 1240 Series pin assignments

Gain	Plastic DIP	Plastic SO
0 dB	1240P	1240S
-3 dB	1243P	1243S
-6 dB	1246P	1246S

Table 2. Ordering information

SPECIFICATIONS¹

Absolute Maximum Ratings			
Positive Supply Voltage (V_{CC})	+20 V	Power Dissipation (P_D) ($T_A = 85^\circ\text{C}$)	400 mW (DIP)
Negative Supply Voltage (V_{EE})	-20 V	Power Dissipation (P_D) ($T_A = 85^\circ\text{C}$)	260 mW (SO)
Storage Temperature Range (T_{ST})	-40 to +125°C	Operating Temperature Range (T_{OP})	0 to 85°C
Output Short-Circuit Duration (t_{SH})	Continuous	Junction Temperature (T_J)	125°C
Input Voltages ($In+$, $In-$)	± 50 V	Lead Temperature (Soldering 10 seconds)	300 °C

Electrical Characteristics²							
Parameter	Symbol	Conditions	Min	Typ	Max	Units	
Supply Current	I_{CC}	No signal	—	2.0	2.8	mA	
Supply Voltage	V_{CC}		+3		+18	V	
	V_{EE}		-3		-18	V	
Input Voltage Range	$V_{IN-DIFF}$	Differential (equal and opposite swing)					
		THAT 1240 (0 dB gain)	—	21.5	—	dBu ³	
		THAT 1243 (-3 dB gain)	—	24.4	—	dBu	
	V_{IN-CM}	Common mode					
		THAT 1240 (0 dB gain)	—	27.5	—	dBu	
		THAT 1243 (-3 dB gain)	—	29.1	—	dBu	
Input Impedance ⁴	Z_{IN-CM}	Common mode (all versions)	—	9	—	k Ω	
		Differential					
	$Z_{IN-DIFF}$	THAT 1240 (0 dB gain)	—	18	—	k Ω	
		THAT 1243 (-3 dB gain)	—	21	—	k Ω	
		THAT 1246 (-6 dB gain)	—	24	—	k Ω	
Common Mode Rejection Ratio	CMRR	Matched source impedances; $V_{CM} = \pm 10$ V					
		DC	70	90	—	dB	
		60 Hz	70	90	—	dB	
		20 kHz	70	85	—	dB	
Power Supply Rejection Ratio ⁵	PSR	at 60 Hz, with $V_{CC} = -V_{EE}$					
		THAT 1240 (0 dB gain)	—	90	—	dB	
		THAT 1243 (-3 dB gain)	—	90	—	dB	
		THAT 1246 (-6 dB gain)	—	90	—	dB	
Total Harmonic Distortion	THD	$V_{IN-DIFF} = 10\text{V}$; BW = 20 kHz; $f = 1$ kHz, $R_L = 2$ k Ω	—	0.0006	—	%	
Small Signal Bandwidth	BW_{-3dB}	$R_L = 2$ k Ω ; $C_L = 10$ pf					
		THAT 1240 (0 dB gain)	—	24	—	MHz	
		THAT 1243 (-3 dB gain)	—	33	—	MHz	
		THAT 1246 (-6 dB gain)	—	44	—	MHz	
		$R_L = 2$ k Ω ; $C_L = 300$ pf					
		THAT 1240 (0 dB gain)	—	17	—	MHz	
		THAT 1243 (-3 dB gain)	—	18	—	MHz	
THAT 1246 (-6 dB gain)	—	20	—	MHz			

Output Noise	$e_{(OUT)}$	22 Hz to 22 kHz bandwidth	—	-103	—	dBu
		THAT 1240 (0 dB gain)	—	-105	—	dBu
		THAT 1243 (-3 dB gain)	—	-106	—	dBu
Slew Rate	SR	$R_L = 2 \text{ k}\Omega$; $C_L = 300 \text{ pf}$	7	12	—	V/ μs
Output Gain Error	$G_{ER(OUT)}$	$f = 1 \text{ kHz}$	-0.05	0	+0.05	dB
Output Voltage Swing	V_{O+}	$R_L = 2 \text{ k}\Omega$	$V_{CC} - 2.5$	$V_{CC} - 2$	—	V
	V_{O-}	$R_L = 2 \text{ k}\Omega$	—	$V_{EE} + 2$	$V_{EE} + 2.5$	V
Output Offset Voltage	V_{OFF}	No signal	-7	—	+7	mV
Output Short Circuit Current	I _{SC}	$R_L = 0 \Omega$	—	± 25	—	mA
Resistive Load	R_L		2	—	—	k Ω
Capacitive Load	C_L		—	—	300	pF

Package Characteristics						
Parameter	Symbol	Conditions	Min	Typ	Max	Units
Through-hole Package						
Type		See Figure 14, Page 10 for dimensions		8-Pin PDIP		
Thermal Resistance	θ_{JA}	DIP package soldered to board	-	100	-	$^{\circ}\text{C}/\text{W}$
Surface Mount Package						
Type		See Figure 15, Page 10 for dimensions		8-Pin SOP		
Thermal Resistance	θ_{JA}	SO package soldered to board	-	150	-	$^{\circ}\text{C}/\text{W}$
Soldering Reflow Profile				JEDEC JESD22-A113-B (220 $^{\circ}\text{C}$)		

¹ All specifications are subject to change without notice.

² Unless otherwise noted, $T_A = 25^{\circ}\text{C}$, $V_{CC} = +15\text{V}$, $V_{EE} = -15\text{V}$, Test circuit is as shown in Figure 2.

³ 0 dBu = 0.775V_{rms}.

⁴ While specific resistor ratios are very closely trimmed, absolute resistance values can vary $\pm 25\%$ from the typical values shown. Input impedance is monitored by lot sampling.

⁵ Defined with respect to differential gain.

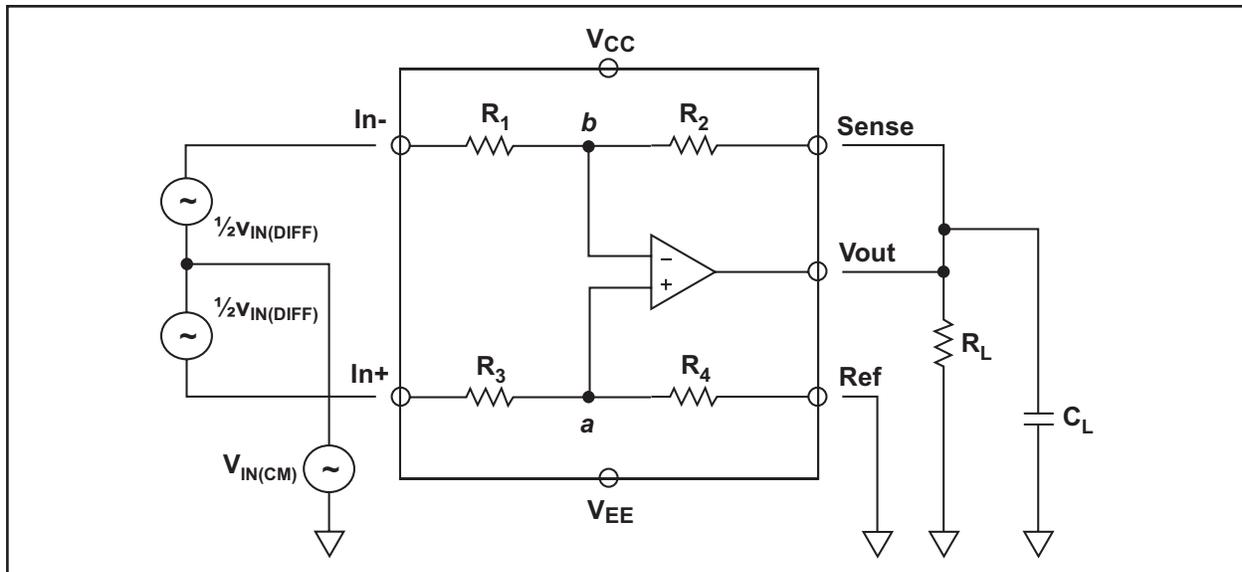


Figure 2. THAT1240 series test circuit

Theory of Operation

The THAT1240-series ICs consist of high performance opamps with integrated, laser-trimmed resistors. These designs take full advantage of THAT's fully complementary dielectric isolation (DI) process to deliver excellent performance with low current consumption. The devices are simple to apply in many applications.

Resistor Trimming, Values, and CMRR

The 1240-series devices rely upon proprietary, laser-trimmed, silicon-chromium (Si-Cr), thin-film, integrated resistors to deliver the precise matching required to achieve a 90dB common mode rejection ratio. Trimming is performed in two cycles, both using dc inputs. First, gain is set by trimming the R_1/R_2 pair. Then, CMRR is set by trimming the other pair (R_3/R_4). Generally, only one resistor of each pair is trimmed (whichever needs to increase to meet the required specification).

To achieve 90 dB CMRR, the R_3/R_4 ratio is trimmed to within $\pm 0.005\%$ of the R_1/R_2 ratio. Since the resistors themselves are on the order of 10 k Ω (see Figure 1 for actual values, which change with the specific part), an increase of as little as 0.6 Ω can reduce the CMRR from over 90 dB to only 84 dB. The better the starting CMRR, the more impact (in dB) a given added resistance will have.

Therefore, to achieve this high CMRR in practice, care should be taken to ensure that all source impedances remain balanced. To accomplish this, PCB traces carrying signal should be balanced in

length, connector resistance should be minimized, and any input capacitance (including strays) should be balanced between the + and - legs of the input circuitry. Note that the additional contact resistance of some sockets is sufficient to undo the effects of precision trimming. Therefore, socketing the parts is not recommended. THAT's 1200-series InGenius[®] input stages address many of these difficulties through a patented method of increasing common-mode input impedance.

A further consideration is that after trimming, the two resistor divider ratios are tightly controlled, but the actual value of any individual resistor is not. In fact, two of the four resistors are normally left without trimming. The initial tolerance of the resistors is quite wide, so it is possible for any given resistor to vary over a surprisingly wide range, Lot-to-lot variations of up to $\pm 25\%$ are to be expected.

Input Considerations

The 1240-series devices are internally protected against input overload via an unusual arrangement of diodes connecting the + and - Input pins to the power supply pins. The circuit of Figure 3 shows the arrangement used for the R_3/R_4 side; a similar one applies to the other side. The zener diodes prevent the protection network from conducting until an input pin is raised at least 50 V above V_{CC} or below V_{EE} . Thus, the protection networks protect the devices without constraining the allowable signal swing at the input pins. The reference (and sense) pins are

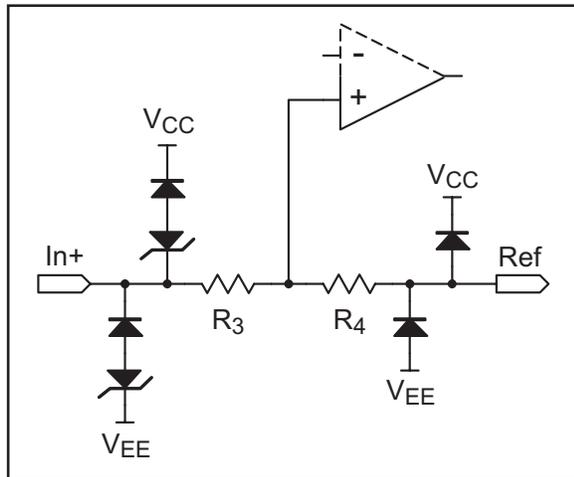


Figure 3. Representative Input Protection Circuit

protected via more conventional reverse-biased diodes which will conduct if these pins are raised above V_{CC} or below V_{EE} .

Because the 1240-series devices are input stages, their input pins are of necessity connected to the outside world. This is likely to expose the parts to ESD when cables are connected and disconnected. Our testing indicates that the 1240-series devices will typically withstand application of up to 1,000 volts under the human body ESD model.

To reduce risk of damage from ESD, and to prevent RF from reaching the devices, THAT recommends the circuit of Figure 4. C_3 through C_5 should be located close to the point where the input signal comes into the chassis, preferably directly on the connector. The unusual circuit design is intended to minimize the unbalancing impact of differences in the values of C_4 and C_5 by forcing the capacitance from each input to chassis ground to depend primarily on the value of C_3 . The circuit shown is approximately ten times less sensitive to mismatches between C_4 and C_5 than the more conventional approach, in which the junction of C_4 and C_5 is grounded directly. An excellent discussion of input stage grounding can be found in the June 1995 issue of the *Journal of the Audio Engineering Society*, Vol. 43, No. 6, in articles by Stephen Macatee, Bill Whitlock, and others.

Note that, because of the tight matching of the internal resistor ratios, coupled with the uncertainty in absolute value of any individual resistor, RF bypassing through the addition of R-C networks at the inputs (series resistor followed by a capacitor to ground at each input) is *not* recommended. The

added resistors can interact with the internal ones in unexpected ways. If some impedance for the RF-bypass capacitor to work against is deemed necessary, THAT recommends the use of a ferrite bead or balun instead.

If it is necessary to ac-couple the inputs of the 1240-series parts, the coupling capacitors should be sized to present negligible impedance at any frequencies of interest for common mode rejection. Regardless of the type of coupling capacitor chosen, variations in the values of the two capacitors, working against the 1240-series input impedance (itself subject to potential imbalances in absolute value, even when trimmed for perfect ratio match), can unbalance common mode input signals, converting them to balanced signals which will not be rejected by the CMRR of the devices. For this reason, THAT recommends dc-coupling the inputs of the 1240-series devices.

Input Voltage Limitations

When configured, respectively, for -3 dB and -6 dB gain, the 1243 and 1246 devices are capable of accepting input signals above the power supply rails. This is because the internal opamp's inputs connect to the outside world only through the on-chip resistors R_1 through R_4 at nodes a and b as shown in Figure 2. Consider the following analysis.

Differential Input Signals

For differential signals ($V_{IN(DIFF)}$), the limitation to signal handling will be output clipping. The outputs of all the devices typically clip at within 2V of the supply rails. Therefore, maximum differential input signal levels are directly related to the gain and supply rails.

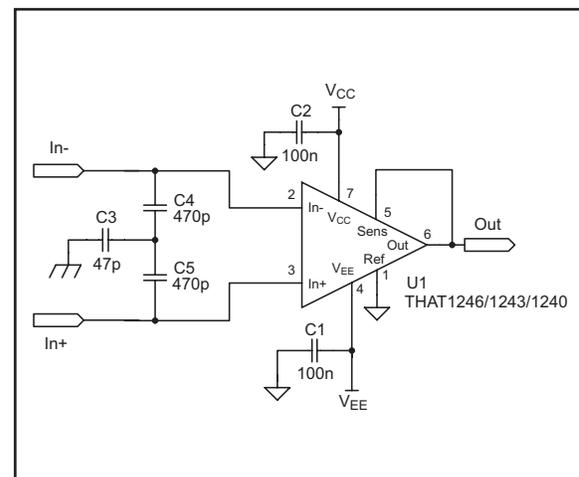


Figure 4. RFI and Supply Bypassing

Common Mode Input Signals

For common-mode input signals, there is no output signal. The limitation on common-mode handling is the point at which the inputs are overloaded. So, we must consider the inputs of the opamp.

For common mode signals ($v_{in(CM)}$), the common mode input current splits to flow through both R_1/R_2 and through R_3/R_4 . Because v_b is constrained to follow v_a , we will consider only the voltage at node a.

The voltage at a can be calculated as:

$$v_a = v_{IN(CM)} \left[\frac{R_4}{R_3 + R_4} \right]$$

Again, solving for $V_{IN(CM)}$,

$$v_{IN(CM)} = v_a \left[\frac{R_3 + R_4}{R_4} \right]$$

For the 1240, $(R_3 + R_4) / R_4 = 2$. For the 1243, $(R_3 + R_4) / R_4 = 2.4$. For the 1246, $(R_3 + R_4) / R_4 = 3$. Furthermore, the same constraints apply to v_a as in the differential analysis.

Following the same reasoning as above, the maximum common mode input signal for the 1240 is $(2V_{CC} - 4)$ V, and the minimum is $(2V_{EE} + 4)$ V. For the 1243, these figures are $(2.4V_{CC} - 4.8)$ V, and $(2.4V_{EE} + 4.8)$ V. For the 1246, these figures are $(3V_{CC} - 6)$ V, and $(3V_{EE} + 6)$ V.

Therefore, for common-mode signals and ± 15 V rails, the 1240 will accept up to ~ 26 V in either direction. As an ac signal, this is 52 V peak-peak, 18.4 V rms, or +27.5 dBu. With the same supply rails, the 1243 will accept up to ~ 31 V in either direction. As an ac signal, this is 62 V peak-peak, 21.9 V rms, or +29 dBu. With the same supply rails, the 1246 will accept up to ~ 39 V in either direction. As an ac signal, this is 78 V peak-peak, 27.6 V rms, or +31 dBu.

Of course, in the real world, differential and common-mode signals combine. The maximum signal that can be accommodated will depend on the superposition of both differential and common-mode limitations.

Output Considerations

The 1240-series devices are typically capable of supplying 25 mA into a short circuit. While they will survive a short, power dissipation will rise dramatically if the output is shorted. Junction temperature must be kept under 125 °C to maintain the devices' specifications.

These devices are stable with up to 300 pf of load capacitance.

Power Supply Considerations

The 1240-series parts are not particularly sensitive to the power supply, but they *do* contain wide bandwidth opamps. Accordingly, small local bypass capacitors should be located within a few inches of the supply pins on these parts, as shown in Figure 4.

Selecting a Gain Variation

The three different parts offer different gain structures to suit different applications. The 1246 is customarily configured for -6 dB gain, but by reversing the resistor connections, can also be configured for +6 dB. The 1243 is most often configured for -3 dB gain, but can also be configured for +3 dB. The choice of input gain is determined by the input voltage range to be accommodated, and the power supply voltages used within the circuit.

To minimize noise and maximize signal-to-noise ratio, the input stage should be selected and configured for the highest possible gain that will ensure that maximum-level input signals will not clip the input stage or succeeding stages. For example, with ± 18 V supply rails, the 1240-series parts have a maximum output signal swing of +23 dBu. In order to accommodate +24 dBu input signals, the maximum gain for the stage is -1 dB. With ± 15 V supply rails, the maximum output signal swing is $\sim +21.1$ dBu; here, -3 dB is the maximum gain. In each case, a 1243 configured for -3 dB gain is the ideal choice. The 1240 (0dB gain only) will not provide enough headroom at its output to support a +24 dBu input signal. The 1246 (configured for -6 dB gain) will increase noise, thus reducing dy-

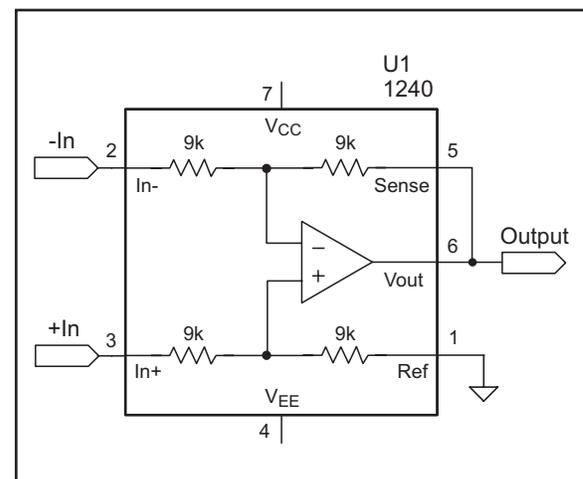


Figure 5. Zero dB line receiver

dynamic range, by attenuating the input signal more than necessary to support a +24 dBu input,

In fact, for most professional audio applications,

Applications

The THAT 1240, 1243, and 1246 are usually thought of as precision differential amplifiers with gains of zero, -3 and -6 dB respectively. These devices are primarily intended as balanced line receivers for audio applications. However, their topology lends itself to other applications as well.

Basic Balanced Receiver Applications

Figures 5, 6, and 7, respectively, show the THAT 1240, 1246, and 1243 configured as zero, -6 dB, and -3 dB line receivers. Figures 8 and 9, respectively, show the 1243 and 1246 configured as +3 dB and +6 dB line receivers. The higher gains are achieved by swapping the positions of the resistors within each pair in regard to signal input vs. output.

Figure 10 shows a THAT 1240 configured as a precision summing amplifier. This circuit uses both the In+ and Ref pins as inputs. Because of the excellent matching between the laser-trimmed resistor pairs, the output voltage is precisely equal to the sum of the two input voltages.

More Complex Applications

Figure 11 shows a 1240 configured as an instrumentation amplifier. The two opamps preceding the 1240 provide gain equal to $1 + (9.998 \text{ k}\Omega / R_g)$. The 1240 rejects common mode signals while accepting balanced ones.

THAT recommends the -3 dB input configuration possible only with the 1243 in order to preserve dynamic range within a reasonable range of power supply voltages and external headroom limits.

Figure 12 shows a convenient method of driving a typical audio ADC with balanced inputs. This circuit accepts +24 dBu in. By using a pair of THAT 1246 ICs connected in anti-phase, the signal level between their respective outputs is +24 dBu. An attenuator network brings this signal down by 24 dB while attenuating the noise of the line receivers as well.

The output noise of a THAT 1246 is -106 dBu, and since there are two of them, the total noise level going into the resistive pad will be -103 dBu. The pad reduces the noise level to -127 dBu at the input to the ADC. The noise density resulting from the line receivers will therefore be

$$e_{n \text{ line receiver}} = \frac{10^{\frac{-127 \text{ dBu}}{20}} \times 0.775}{\sqrt{20 \text{ kHz}}} = 245 \frac{\text{nV}}{\sqrt{\text{Hz}}}$$

The thermal noise of the 249Ω resistor is 2.05 nV/√Hz. We can assume that the noise contribution of R₈ and R₁₉ will be negligible, and therefore, the total noise density going into the input of the ADC will be

$$e_{n \text{ total}} = \sqrt{\left(245 \frac{\text{nV}}{\sqrt{\text{Hz}}}\right)^2 + \left(2.06 \frac{\text{nV}}{\sqrt{\text{Hz}}}\right)^2} = 3.2 \frac{\text{nV}}{\sqrt{\text{Hz}}}$$

The noise floor can then be calculated to be

$$\text{Noise}_{(\text{dBu})} = 20 \log \left[\frac{3.2 \frac{\text{nV}}{\sqrt{\text{Hz}}} \times \sqrt{20 \text{ kHz}}}{0.775} \right] = -124.7 \text{ dBu}$$

Figure 13 shows the recommended method for

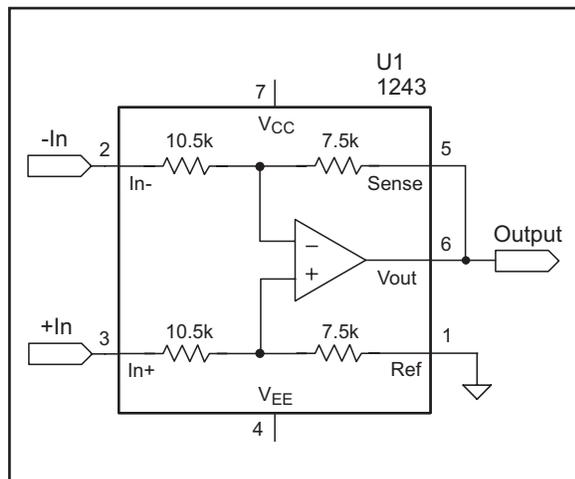


Figure 6. -3 dB line receiver

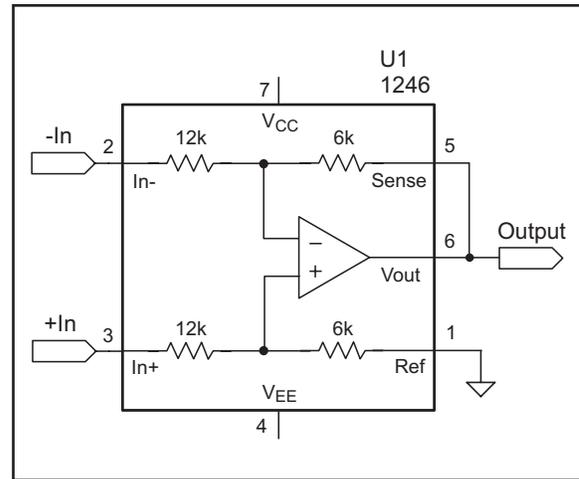


Figure 7. -6 dB line receiver

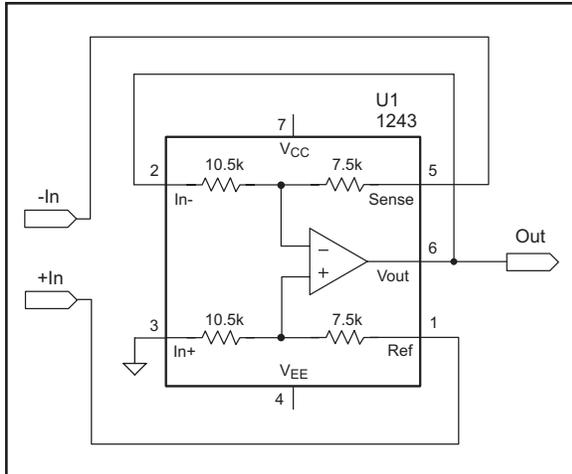


Figure 8. +3 dB line receiver

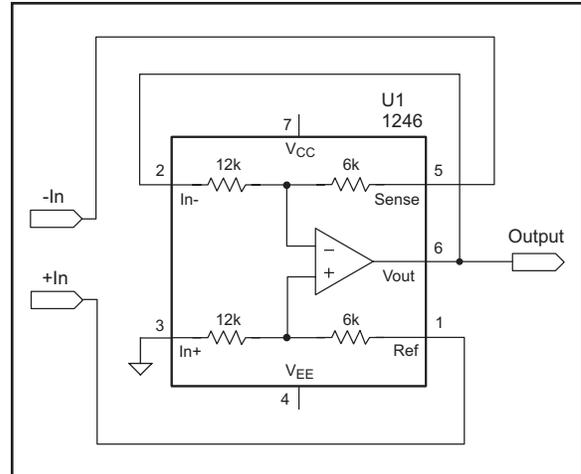


Figure 9. +6 dB line receiver

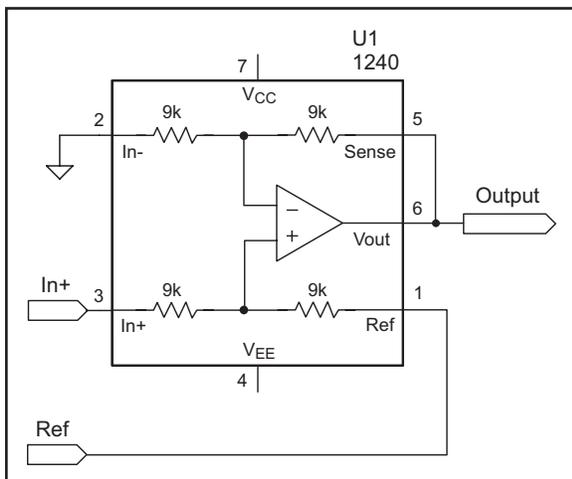


Figure 10. Precision two-input summing circuit

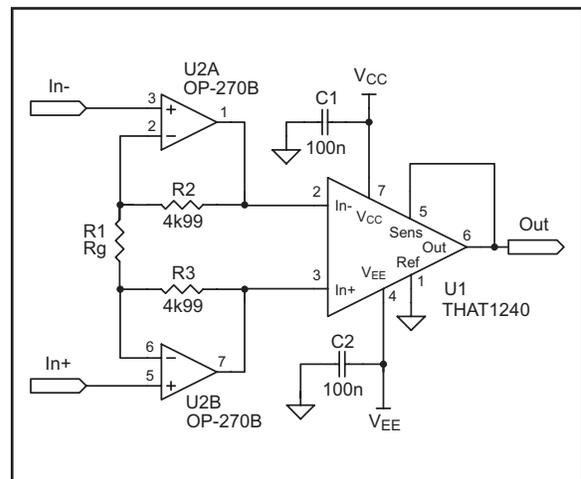


Figure 11. Instrumentation Amplifier

controlling gain in a balanced system. In such circuits, designers are often tempted to keep the signal balanced and use two Voltage Controlled Amplifiers (VCAs) to independently control the gain on each half of the balanced signal. Unfortunately, this can result in common-mode to differential mode conversion (degrading CMRR) when there are even slight differences in gain between the VCAs. A better approach is to convert the signal to single-ended, alter the gain, and then convert back to balanced.

In Figure 13 we use a THAT 1243 -3 dB line re-

ceiver to do the balanced-to-single-ended conversion. The VCA section also has a static gain of -3 dB due to the ratio of R_2 to R_3 . This circuit can accept +24 dBu, since the THAT 1243 output stage is capable of accepting 21 dBu without distortion. Reducing R_3 to 14 k Ω results in a 3 dB reduction in VCA output noise. This arrangement results in 3 dB greater dynamic range compared to the case where a -6 dB line receiver and a VCA with zero dB static gain are used. After the VCA, the signal is restored to 24 dBu by the THAT 1430.

Package Information

The THAT 1240 series is available in both plastic 8-pin Dual In-line (DIP) and 8-pin Surface Mount

(SOIC) packages. Package dimensions are shown in Figures 14 and 15; The pinouts are given in Table 1.

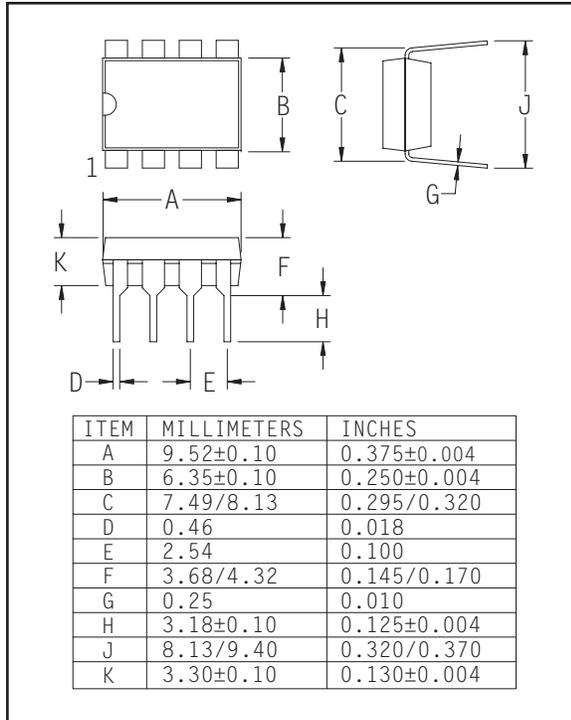


Figure 14. -P (DIP) version package outline drawing

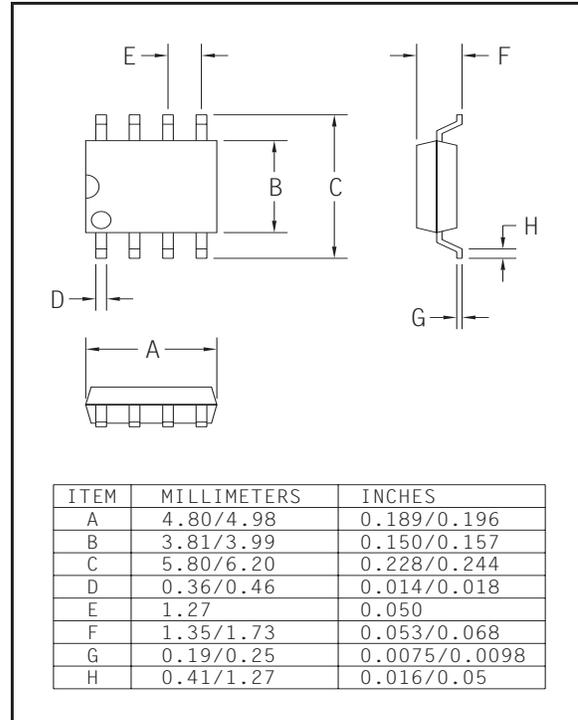


Figure 15. -S (SO) version package outline drawing

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