# A Fully Differential Input Voltage Amplifier

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## INTRODUCTION

The instrumentation amplifier is useful for amplifying small differential signals which may be riding on high common mode voltage levels. These amplifiers are particularly useful in amplifying signals in the milli-volt range which are supplied from a high impedance source ($> 2\ k\Omega$).

This brief will demonstrate how a low cost, high performance instrumentation amplifier can be built using the newly introduced LM3900 quad amplifier. It is also indicated how a compact transducer bridge amplifier system can be developed to take advantage of the versatility of the LM3900.

## BASIC AMPLIFIER OPERATION

*Figure 1* shows the basic operation of the amplifier. The bias of the LM3900 is set by the resistors $R_2$ and $R_3$ (neglecting for now, the transistors $Q_1$ and $Q_2$). Current which enters the non-inverting input of the LM3900 will be "mirrored" about $V^-$ and then will be drawn into the inverting input terminal. This causes the current to flow through the feedback resistor, $R_3$, which establishes the output voltage level. If $R_2 = R_3$ and further, if $R_2$ is connected to ground (0V), then the output voltage biasing level will also be exactly zero volts. It should be noticed that an *OUTPUT OFFSET CONTROL* can be implemented by supplying a reference voltage, $E_R$, between $R_2$ and ground.

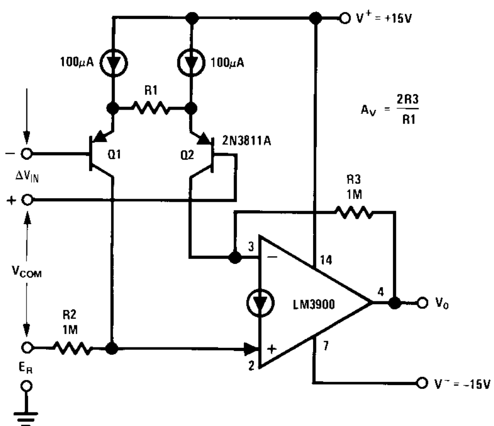


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**FIGURE 1. Basic Instrumentation Amplifier**

Adding transistors $Q_1$ and $Q_2$, as shown in *Figure 1* will not disturb this biasing if the two collector currents of the transistors are well matched for a 0V differential input signal. The current sources which bias $Q_1$ and $Q_2$, are chosen to be 100 $\mu$A each to guarantee high $\beta$ and low offset voltage in $Q_1$ and $Q_2$.

The gain of the amplifier is calculated as follows:

Any differential input voltage, $\Delta V_{IN}$, appears across $R_1$, and produces a current change $\Delta I$, which is given by:

$$\Delta I = \frac{\Delta V_{IN}}{R_1} \qquad (1)$$

This current change will show up in the collectors of $Q_1$ and $Q_2$ with opposite polarity. The input mirror of the LM3900 returns $\Delta I_{Q1}$ to the inverting input terminal where it is added (with sign) to $\Delta I_{Q2}$ yielding a total current change of $2\Delta I$. This current flows through the feedback resistor, $R_3$, which causes an output voltage change, $\Delta Vo$, which is given by:

$$\Delta Vo = 2\Delta I \times R_3 = 2 \times \frac{\Delta V_{IN}}{R_1} \times R_3 \qquad (2)$$

to yield a gain,

$$A_v = 2\frac{R_3}{R_1} \qquad (3)$$

At this point it is convenient to evaluate the result obtained. The gain can be established by one resistor ($R_1$) according to equation (3). Conventional instrumentation amplifiers usually have a gain given by:

$$A_v = 1 + \frac{\text{Constant}}{R} \qquad (4)$$

This means that the minimum gain of unity is obtained if R is left out ($R = \infty$). Note that this is different from the result indicated in equation (3) where unity gain is obtained for

$$R_1 = 2R_3 \qquad (5)$$

and minimum gain (or maximum attenuation) is obtained if $R_1$ is left out ($R_1 = \infty$). This suggests that the amplifier can be turned OFF without disturbing the output voltage dc bias.

The two current sources for $Q_1$ and $Q_2$ are implemented with a dual transistor ($Q_3$ and $Q_4$) in conjunction with an additional amplifier of the LM3900 as shown in *Figure 2*. The operation can be easily understood if $R_4$ and $R_5$ are incorporated within the amplifier, which then takes the form of a conventional opamp closed loop regulator which maintains a reference voltage (the drop across $R_6$) at the emitter of $Q_4$.

## PERFORMANCE

The performance of the complete instrumentation amplifier of *Figure 2* is outlined below (Table I and *Figure 3*).

**TABLE I. Typical Performance Characteristics**

| | |
|---|---|
| **GAIN** | |
| Range of gain | $-34$ dB ($R_1 = \infty$) to 72 dB ($R_1 = 0$) |
| Gain is set according to: | $A_v = \frac{2R_3}{R_1}$ |
| **INPUT** | |
| Voltage offset referred to input is adjustable to zero. | Pos supply less 2.4V |
| Common-mode and differential input voltage | Neg supply less 300 mV |
| Common-mode rejection ratio at 10 Hz | 115dB (gain of 1000) |
| Bias current (either input) | 200 nA |
| **OUTPUT** | |
| Output offset is adjustable to zero. | 12 $mV_{rms}$ (open loop) |
| Output noise | 3 $mV_{rms}$ ($A_{CL} = 66$ dB) |
| **FREQUENCY RESPONSE** | |
| Small signal frequency response ($-3$ dB) | 1 MHz (gain of 1000)<br>3 MHz (gain of 1) |



 

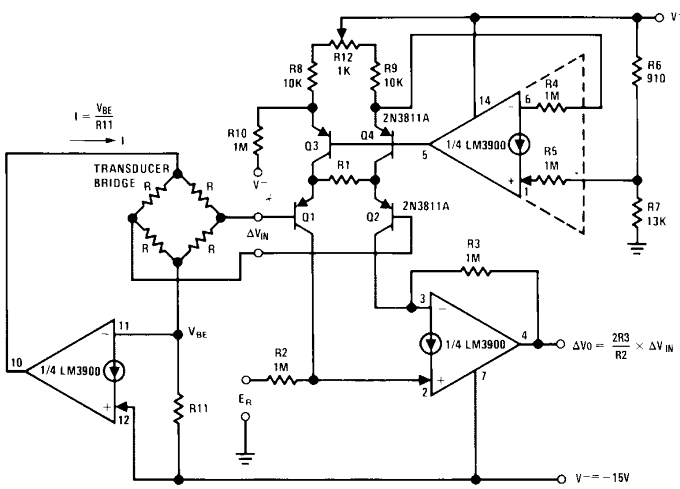


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**FIGURE 2. Bridge Amplifier**

Since quantitative discussion of the sources of offset voltage is beyond the scope of this brief, only the procedure for nulling the amplifier will be included.

Letting $R_1$ go to zero causes the amplifier to operate in the open-loop mode. The main offset voltage source is now the $V_{BE}$ mismatch of $Q_1$ and $Q_2$. The output can be nulled by the *OUTPUT OFFSET CONTROL* (the reference voltage for $R_2$) or by adjusting the value of $R_2$. With $R_1 = \infty$, the main offset voltage source is the mismatch in the collector currents of $Q_3$ and $Q_4$. This is easily adjusted via $R_{12}$. These first and second adjustments interact, however, after repeating the procedure a couple of times a good result is obtained.

**TRANSDUCER BIAS SOURCE**

Having in mind that the LM3900 consists of four independent amplifiers makes it relatively easy to bias a transducer bridge with a constant current source using only one more of the amplifiers and one resistor. The technique is self-explanatory and is also shown in *Figure 2*.

**CONCLUSION**

A brief review of a new concept for an instrumentation amplifier has been presented. Many applications can be derived from this basic connection which require amplifying the low level differential signals which are obtained from sensors such as strain gages, pressure transducers, and thermocouples. The performance of this instrumentation amplifier is adequate for many system applications. (See National Semiconductor Application Note 72, "The LM3900 — A New Current-Differencing Quad of ± Input Amplifiers" for further information.)

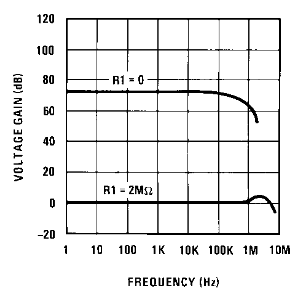


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**FIGURE 3. Frequency Response**



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