

# LB-21

## *LB-21 Instrumentational Amplifiers*



Literature Number: SNOA727

# Instrumentational Amplifiers

National Semiconductor  
Linear Brief 21  
June 1973



## INTRODUCTION

One of the most useful analog subsystems is the true instrumentation amplifier. It can faithfully amplify low level signals in the presence of high common mode noise. This aspect of its performance makes it especially useful as the input amplifier of a signal processing system. Other features of the instrumentation amplifier are high input impedance, low input current, and good linearity.

It has never been easy to design a high performance instrumentation amplifier; however, the availability of high performance IC's considerably simplifies the problem. IC op amps are available today that can give very low drifts as well as low bias currents; however, most of the circuits have some drawbacks.

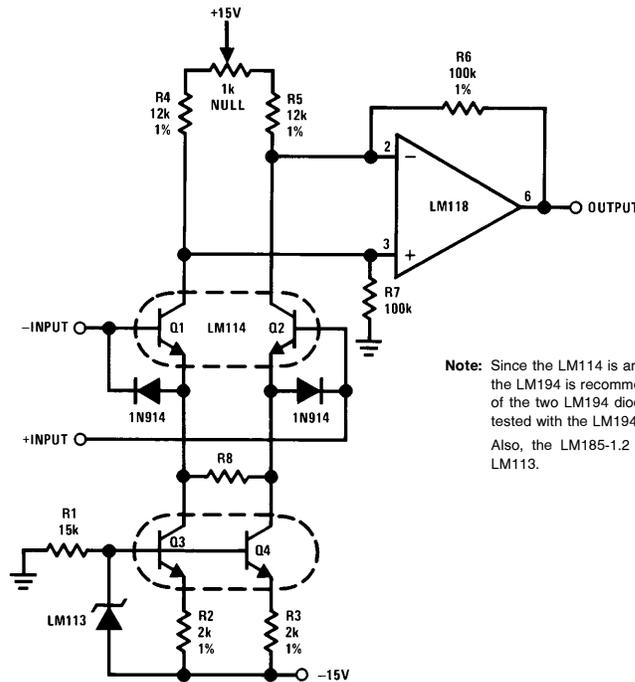
The most commonly used instrumentation amplifier designs utilize either 2 or 3 op amps and several precision resistors. These are capable of excellent performance; however, for high performance they require very precisely matched resistors. The common mode rejection of these designs depends on resistor matching and overall gain. Since op amps are now available with exceedingly high CMRR, this is no longer a problem. The CMRR of the instrumentation amplifier is approximately equal to half resistor mismatch plus the gain. For a 1% resistor mismatch the CMRR is limited to 46 dB plus the gain—referred to the input.

Referred to the output, the common mode error is independent of gain and fixed by the resistor mismatch. For 1% match the error is 0.5%, and for 0.1% match the error is 0.05%. These errors are not trivial in high precision systems.

An instrumentation amplifier is shown here that compares favorably with multiple op amp designs, yet does not require precisely matched resistors. Further, the design allows a single resistor to adjust the gain. In comparing this instrumentation amp to multiple op amp types there are of course some drawbacks. The gain linearity and accuracy are not as good as the multiple op amp circuits.

The errors appearing in multiple op amp circuits are independent of the output signal level. For example, a common mode error at the output of 0.5% of full scale is a 33% error if the desired output signal is only 1.5% of full scale. With the new circuit maximum errors at full scale output and the percentage of output error decreases at lower output levels.

Figure 1 shows a general purpose instrumentation amplifier optimized for wide bandwidth. It can provide gains from under 1 to over 1000 with a single resistor adjustment. Gain linearity is worst for unity-gain at 0.4%, and gain stability is better than 1.5% from  $-55^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$ . Typically over a  $0^{\circ}\text{C}$  to  $+70^{\circ}\text{C}$  range gain stability is 0.2%. Common mode rejection ratio is about 100 dB— independent of gain.



**Note:** Since the LM114 is an obsolete part, substitution of the LM194 is recommended, along with the removal of the two LM194 diodes. This circuit has not been tested with the LM194 included.  
Also, the LM185-1.2 could be substituted for the LM113.

FIGURE 1. Instrumentation Amplifier

TL/H/8727-1

Transistor pair, Q1 and Q2, are operated open-loop as the input stage to give a floating, fully differential input. Current sources, Q3 and Q4, set the operating current of the input pair. To obtain good linearity the output current of Q3 and Q4 are set at about twice the current in R8 at full differential voltage. The temperature sensitivity of the transconductance of Q1 and Q2 is compensated by making their operating current directly proportional to absolute temperature. It has been shown that by biasing the base of transistor current sources at 1.22V, the output current varies as absolute temperature. The LM113 diode provides a constant 1.22V to the current sources. Both the compensated gm of Q1 and Q2 and the large degeneration from R8 give the amplifier stable gain over a wide temperature range.

In operation, transistors Q1 and Q2 convert a differential input voltage to a differential output current at their collectors. This is fed into a standard differential amplifier to obtain a single ended output voltage. Since the diff amp does not see the common mode input voltage, 1% resistors are adequate. Gain is set by the ratio of R8 (plus the  $r_e$  of Q1 and Q2) to the sum of R6 and R7.

As mentioned previously this circuit is optimized for wide bandwidth: however, it is easily modified for other applications. If low bias current is needed, all resistors can be increased by a factor of 100 and an LM108 substituted for the LM318. Other possible improvements are cascaded current sources and a modified Darlington input stage.

**LIFE SUPPORT POLICY**

NATIONAL'S PRODUCTS ARE NOT AUTHORIZED FOR USE AS CRITICAL COMPONENTS IN LIFE SUPPORT DEVICES OR SYSTEMS WITHOUT THE EXPRESS WRITTEN APPROVAL OF THE PRESIDENT OF NATIONAL SEMICONDUCTOR CORPORATION. As used herein:

1. Life support devices or systems are devices or systems which, (a) are intended for surgical implant into the body, or (b) support or sustain life, and whose failure to perform, when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in a significant injury to the user.
2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.



**National Semiconductor Corporation**  
 1111 West Bardin Road  
 Arlington, TX 76017  
 Tel: 1(800) 272-9959  
 Fax: 1(800) 737-7018

**National Semiconductor Europe**  
 Fax: (+49) 0-180-530 85 86  
 Email: cnjwge@tevm2.nsc.com  
 Deutsch Tel: (+49) 0-180-530 85 85  
 English Tel: (+49) 0-180-532 78 32  
 Français Tel: (+49) 0-180-532 93 58  
 Italiano Tel: (+49) 0-180-534 16 80

**National Semiconductor Hong Kong Ltd.**  
 19th Floor, Straight Block,  
 Ocean Centre, 5 Canton Rd.  
 Tsimshatsui, Kowloon  
 Hong Kong  
 Tel: (852) 2737-1600  
 Fax: (852) 2736-9960

**National Semiconductor Japan Ltd.**  
 Tel: 81-043-299-2309  
 Fax: 81-043-299-2408

National does not assume any responsibility for use of any circuitry described, no circuit patent licenses are implied and National reserves the right at any time without notice to change said circuitry and specifications.

## IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

TI products are not authorized for use in safety-critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, unless officers of the parties have executed an agreement specifically governing such use. Buyers represent that they have all necessary expertise in the safety and regulatory ramifications of their applications, and acknowledge and agree that they are solely responsible for all legal, regulatory and safety-related requirements concerning their products and any use of TI products in such safety-critical applications, notwithstanding any applications-related information or support that may be provided by TI. Further, Buyers must fully indemnify TI and its representatives against any damages arising out of the use of TI products in such safety-critical applications.

TI products are neither designed nor intended for use in military/aerospace applications or environments unless the TI products are specifically designated by TI as military-grade or "enhanced plastic." Only products designated by TI as military-grade meet military specifications. Buyers acknowledge and agree that any such use of TI products which TI has not designated as military-grade is solely at the Buyer's risk, and that they are solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI products are neither designed nor intended for use in automotive applications or environments unless the specific TI products are designated by TI as compliant with ISO/TS 16949 requirements. Buyers acknowledge and agree that, if they use any non-designated products in automotive applications, TI will not be responsible for any failure to meet such requirements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

### Products

Audio	<a href="http://www.ti.com/audio">www.ti.com/audio</a>
Amplifiers	<a href="http://amplifier.ti.com">amplifier.ti.com</a>
Data Converters	<a href="http://dataconverter.ti.com">dataconverter.ti.com</a>
DLP® Products	<a href="http://www.dlp.com">www.dlp.com</a>
DSP	<a href="http://dsp.ti.com">dsp.ti.com</a>
Clocks and Timers	<a href="http://www.ti.com/clocks">www.ti.com/clocks</a>
Interface	<a href="http://interface.ti.com">interface.ti.com</a>
Logic	<a href="http://logic.ti.com">logic.ti.com</a>
Power Mgmt	<a href="http://power.ti.com">power.ti.com</a>
Microcontrollers	<a href="http://microcontroller.ti.com">microcontroller.ti.com</a>
RFID	<a href="http://www.ti-rfid.com">www.ti-rfid.com</a>
OMAP Mobile Processors	<a href="http://www.ti.com/omap">www.ti.com/omap</a>
Wireless Connectivity	<a href="http://www.ti.com/wirelessconnectivity">www.ti.com/wirelessconnectivity</a>

### Applications

Communications and Telecom	<a href="http://www.ti.com/communications">www.ti.com/communications</a>
Computers and Peripherals	<a href="http://www.ti.com/computers">www.ti.com/computers</a>
Consumer Electronics	<a href="http://www.ti.com/consumer-apps">www.ti.com/consumer-apps</a>
Energy and Lighting	<a href="http://www.ti.com/energy">www.ti.com/energy</a>
Industrial	<a href="http://www.ti.com/industrial">www.ti.com/industrial</a>
Medical	<a href="http://www.ti.com/medical">www.ti.com/medical</a>
Security	<a href="http://www.ti.com/security">www.ti.com/security</a>
Space, Avionics and Defense	<a href="http://www.ti.com/space-avionics-defense">www.ti.com/space-avionics-defense</a>
Transportation and Automotive	<a href="http://www.ti.com/automotive">www.ti.com/automotive</a>
Video and Imaging	<a href="http://www.ti.com/video">www.ti.com/video</a>

TI E2E Community Home Page

[e2e.ti.com](http://e2e.ti.com)

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265  
Copyright © 2011, Texas Instruments Incorporated