A Programmable Instrumentation Amplifier for 12-Bit Resolution Systems

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Abstract—This paper describes the design of and experimental results obtained from a monolithic gain-programmable instrumentation amplifier that attains performance compatible with 12-bit or higher resolution data acquisition systems. Nonlinearity is held to a 0.01 percent worst-case level over the −25 to 85°C temperature range for gains of 1-1000, independent of process variations. Input and output voltage noise and offset drift are also reduced to low levels. A novel input overvoltage protection scheme is also described. The amplifier is fabricated on a standard-beta junction isolated bipolar process that has in addition process-compatible ion implanted JFET's and silicon-chromium thin-film resistors.

Introduction

PREVIOUS monolithic instrument amplifiers (true differential to single-ended voltage amplifiers) reported in the literature have been limited to 8-10-bit levels of accuracy by their nonlinearity, voltage noise, or offset voltage drift. Much of this limitation is attributable to reliance on some form of controlled active current source either as a feedback element [1], [2], or as an open-loop current transfer element [3]. The current sources have two major shortcomings. First, it has proven difficult to integrate a linear active current source. Worst-case nonlinearity limits of 0.03-0.2 percent typify the performance of most designs. Second, the current sources typically have a linear signal range of 100 μA, so a 100 kΩ transresistance is required to obtain a 10 V full-scale output voltage. This relatively high resistance value transforms the output current noise and offset current drift to referred to output (RTO) noise levels of 500-1000 nV/$\sqrt{\text{Hz}}$ or 0.5-1 mV rms in 1 MHz bandwidth and offset drifts of 1 mV/°C.

Nelson [2] has reported on an improved current feedback amp that does achieve 0.01 percent nonlinearity. His particularly compact design employs a thin-film resistor feedback and level-shift network to drive a controlled current source. Attenuation in the feedback path limits the amplifier's minimum gain to 10 and also increases RTO errors to levels similar to earlier designs, e.g., 600 nV/$\sqrt{\text{Hz}}$ of noise.

With the advent of low-cost 12-bit data acquisition systems, the need to extend the performance of instrumentation amplifiers to this level is evident. This paper describes a self-contained systems-level instrumentation amplifier with pin-programmable gains designed to address this need. Nonlinearity is held to a worst-case level of 0.01 percent of full scale for gains of 1-1000 and for temperatures between −25 and +85°C. This is accomplished in part by employing low-temperature-coefficient silicon-chromium thin-film resistors as the primary signal transfer and feedback elements in a symmetrical circuit architecture and chip layout. The input and output components of voltage noise and offset drift are also consistent with 12-bit or higher resolution. In addition, the initial errors of offset voltage and scale factors are minimized by automatic laser trimming of on-chip thin-film resistors during wafer probe.

Manuscript received June 1, 1982; revised July 15, 1982.
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Description of the Circuit

Fig. 1 is a simplified representation of the circuit of the instrumentation amplifier. Amplifiers A_1 and A_2 provide feedback through R_{57} and R_{56} which keeps the collector currents of Q_1, Q_2, Q_3, and Q_4 constant; as a result, the input voltage is impressed across R_G. Since the unity-gain subtractor (A_3, and R_{52}-R_{54}) amplifies the difference between the outputs of A_1 and A_2, V_0 is just the differential portion of the input voltage times the programmed gain. R_{52}, R_{53}, R_{54}, and R_{55} are laser-trimmed to ratio match within ±0.01 percent; this ensures over 80 dB attenuation of common-mode signals and unity-gain error of ±0.02 percent.

Three pin-selectable R_G's are provided for gains of 10, 100, and 1000, trimmed to achieve gain errors of 0.1 percent at gains of 10 and 100. The very low value, 40 Ω, of the gain-of-1000 resistor limits the gain error to 0.5 percent due to variations in probe resistance during trimming.

A particular advantage of on-chip gain resistors is that the gain TC now depends only on the ratio of similar homogeneous film resistors. Scale factor TC's of under 10 ppm/°C are obtained for gains to 100. At a gain of 1000, the TC increases to 25 ppm/°C due to the more significant effect of metal intraconnect and bond-wire resistance in series with the 40 Ω gain resistor.

The R_G terminals are brought out to enable the user to set any gain between 1 and 1000 with an appropriate resistor value. However, the amplifier's gain TC will now depend on the tracking of the external R_G's TC with the approximately −50 ppm/°C of the on-chip resistors.

As R_G is reduced to increase closed-loop (programmed) gain, the transconductance of the input preamp increases asymptotically to the transconductance of the input transistors (≃2000

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TABLE I
TABLE OF KEY PERFORMANCE SPECIFICATIONS

	Gain of 1	Gain of 1000
OFFSET VOLTAGE	250μV	25μV
OFFSET VOLTAGE DRIFT	10μV/°C	0.2μV/°C
NOISE	$90nV/\sqrt{Hz}$	$7nV/\sqrt{Hz}$
CMRR	>80dB	>120dB
NONLINEARITY OF GAIN	<0.005%	<0.01%
BIAS CURRENT	<±10nA	<±10nA
SETTLING TIME TO 0.01%	15μs	75μs
BANDWIDTH	1MHz	25kHz
SUPPLY CURRENT	3.5mA	3.5mA

cent over a wide range of gains and temperatures, as well as input noise levels of less than 7 $nV/\sqrt{Hz}$ and excellent ac performance.

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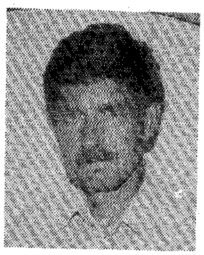

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