

Rejutor[™] Based Amplifier Compensation

1 Introduction

Many applications require amplification of small signals where there is variation in the input signal level. A variable gain amplifier is calibrated to produce uniform output signals independent from the sensitivity of the input signal. Signal compensation corrects for input variance, providing consistent output levels in the analog domain.

Rejutors have demonstrated their ability to passively compensate resistance-based sensors. This application note provides several examples of analog compensation for analog problems using an amplifier under *Rejutor* gain control to compensate for input signal level variation.

The two most common amplifier configurations are single-ended and differential. A single-ended amplifier increases the input signal relative to ground (or a common signal). These amplifiers are easy to implement and require very little circuit real-estate. Signal-ended amplifiers are ideal for single-ended input signals; such as simple diode-based sensors and optical devices.

Differential (or instrumentation) amplifiers are one of the most useful configurations for amplifying very low signal levels in the presence of high common mode noise. They are typically constructed with several op amps to provide very high input impedance and high gain. These amplifiers are well suited for active sensor compensation since they don't significantly load the sensor yet are capable of achieving extremely high gain.

2 Overview

Rejutors are electrically-adjustable MEMS-based micro-resistors. The resistance of *Rejutors* can be adjusted down at-least 30% from the as-manufactured value to very high-precision. The adjustment process reversibly alters the material properties of the device and the resistance is "stored" in the material indefinitely with no external power required. The resistance can be adjusted bi-directionally many times using low-power analog signals under control of Microbridge *Rejutor* Calibration Tools.

There are many different *Rejutor* based gain and offset control configurations depending upon how the *Rejutors* are configured in the user circuit. This document highlights just a few possibilities. Custom *Rejutor* networks can be developed that include all fixed resistors and *Rejutors* in a single, integrated network.

Rejutor-based implementations of high-precision single-ended and differential adjustable gain amplifiers can be configured to control gain, offset or both. Operational amplifier gain is controlled by the ratio of feedback resistor (R_f) to input resistor (R_{in}). The ability to adjust these resistors to a precise value using *Rejutors* dramatically increases the flexibility and control of the amplifier as an active compensation element.

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Five configurations are presented here representing a range from simple, single-**Rejistor** implementations to complex five-**Rejistor** differential instrumentation grade amplifiers.

Rejistors are simple but powerful circuit compensation components. They are pure resistive elements that require no-power to maintain their resistance. These resistors can be used in implementations from low-frequency sensors to high-frequency RF amplifiers. Our objective is to demonstrate the flexibility afforded by **Rejistors** in circuit design. Go ahead, adjust your design!

3 Single-Ended Amplifiers

Single-ended amplifiers use a minimum number of components to increase and buffer small-signal inputs. The single op-amp configuration can be implemented using little circuit board real estate.

3.1 Single Rejistor, Single-Ended Amplifier

The single **Rejistor** configuration simply adjusts amplifier gain to meet the output signal requirement.

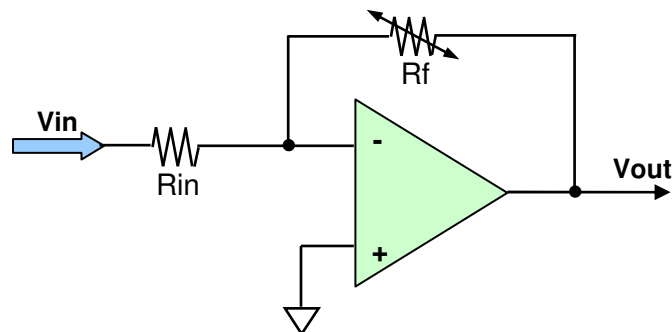


Figure 1: Single-Ended Gain Adjustment

The basic configuration is shown in Figure 1. Note this configuration is an inverting amplifier. The **Rejistor** is shown in the feedback path, but it could also be placed on the input (in the position of R_{in}). **Rejistors** are adjustable to at least 30% below their as-manufactured resistance. In this configuration with the **Rejistor** in the feedback path, the gain can only be decreased from the initial gain.

For example, if the amplifier shown in Figure 1 was designed to compensate an input signal and the maximum required gain is 10, the ratio of R_f to R_{in} would also be 10. R_f could be adjusted to provide a minimum gain of 7 for higher input signal levels.

When the **Rejistor** is installed as the input resistor, the gain can only be increased. If the circuit was designed to have a minimum gain of 10, ratio of R_f to R_{in} would also be 10. R_{in} could be adjusted to provide a maximum gain greater than 14, to amplify weaker input signals.

3.2 Dual Rejistor, Single-Ended Amplifier

The dual **Rejistor** single-ended amplifier configuration provides the ability to adjust gain bi-directionally. This increases the overall amplification range and increases the flexibility of the design. The inverting amplifier configuration is shown in Figure 2.

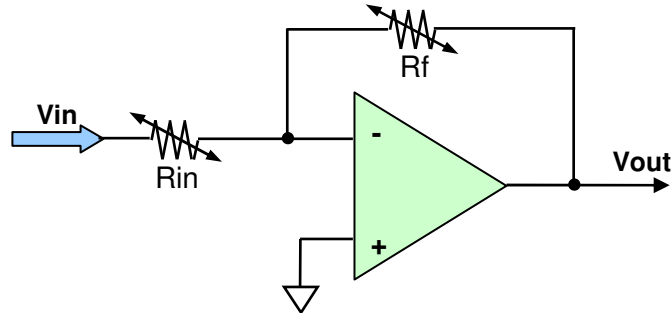


Figure 2: Bi-directionally Adjustable Single-Ended Amplifier

Consider the example where the nominal gain (both **Rejutors** at their as-manufactured value) is 10. The amplification spans from 7 to 14, a range of 3dB. This application example could be used where input signals have a wide range of responsivity (based on manufacturing variants). The gain could be adjusted to provide consistent Vout voltage levels independently from the variation of input signals.

3.3 Dual Rejutor, Single Ended Amplifier with Offset Adjust

The ability to adjust offset in addition to gain is provided in the non-inverting amplifier configuration shown in Figure 3. The dual **Rejutor** single-ended amplifier configuration provides the ability to adjust gain bi-directionally.

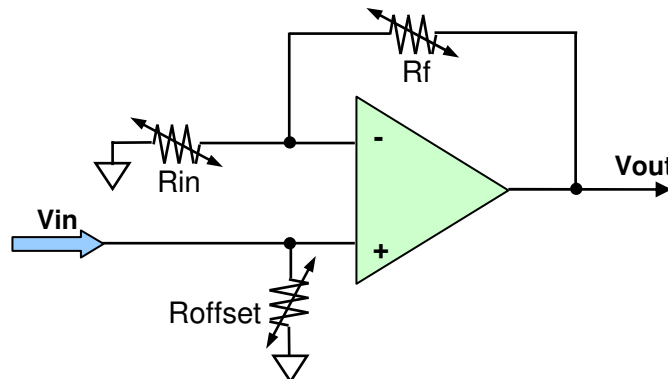


Figure 3: Bi-directionally Adjustable Single-Ended Amplifier with Offset Adjust

The input signal in Figure 3 is dropped across the offset **Rejutor**. Decreasing the offset **Rejutor** (R_{offset}) decreases the voltage at the non-inverting input to the op amp which in turn decreases the DC-bias on Vout. Resistors R_f and R_{in} adjust the gain as described in Section 3.2.

Obviously the single-ended amplifier with offset adjust can be implemented using the gain adjustment discussed in section 3.1. One **Rejutor** is used to adjust offset and the other to control sensitivity (or gain) up or down depending placement. This maintains the design with a single Op amp and a dual **Rejutor**.

4 Differential Amplifiers

A differential instrumentation amplifier with **Rejutor** gain control is shown in Figure 4. The **Rejutors** are integral to the feedback path in the first stage of the amplifier. R_{in} in conjunction with the **Rejutors** sets the gain for the input stage. **Rejutors** R_{j1a} and R_{j1b} can be adjusted independently to improve the gain-matching of the input stage. The result is superior common mode

rejection ratio (CMRR). Resistors labeled R2 should be assigned the same value. The value of R4 and R3 set the gain for the output stage.

Common mode noise rejection also depends upon tight matching of the R2 resistors. The remaining resistors (non-R2) could be replaced with **Rejutors** to provide maximum flexibility in gain control. In addition, offset control can be implemented using a buffered **Rejutor** voltage divider. Replacing Rin with a **Rejutor** will decrease the gain of the first stage. Replacing R4 with a **Rejutor** will increase gain as described in Section 3.1.

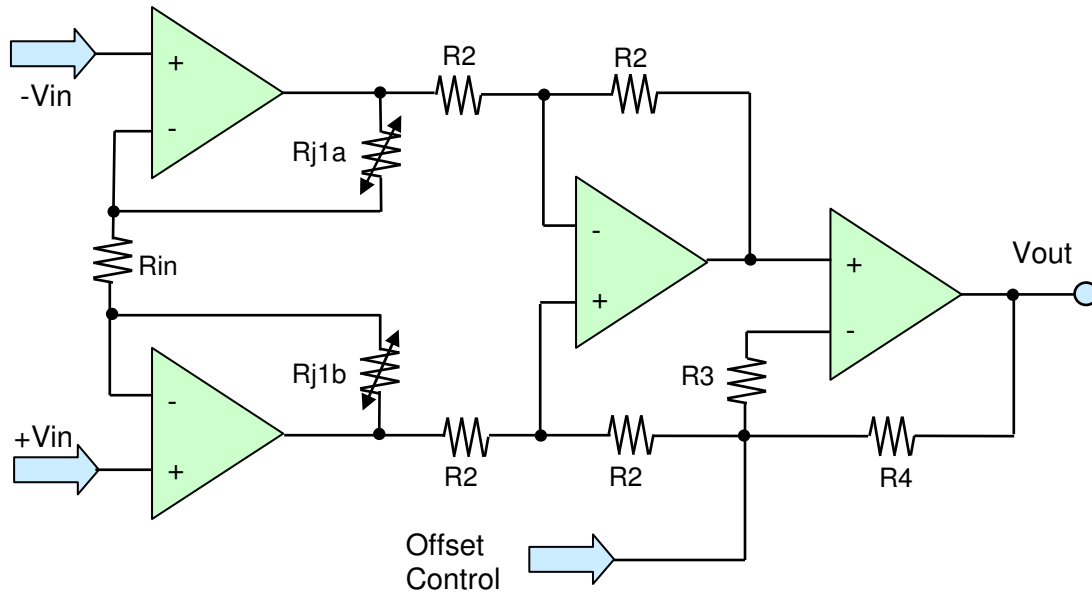


Figure 4: Differential Instrumentation Amplifier

The overall system gain is given by:

$$G = \left(1 + \frac{Rj1 + Rj2}{Rin}\right) \times \left(\frac{R3 + R4}{R3}\right)$$

The input signal in this amplifier is mirrored across Rin, through the high input impedance of an op amp. The current flow across Rin is sourced by the op amps, generating a voltage drop across the **Rejutors**. The middle amplification stage is simply a buffer to match impedance across the differential amplifiers, contributing to high CMRR. The output op amp provides final gain and offset control.

The differential instrumentation amplifier is another example of active signal condition using **Rejutors**. These amplifiers are ideal for recovering very weak signals in a high noise environment.

5 Summary

The active compensation schemes presented here demonstrate that **Rejutors** are an excellent compensation choice. Already proven in the area of passive compensation, these micro-resistors provide a flexible, convenient solution for small-signal compensation and amplification. The set and forget technology allows rapid adjustment and requires no bias current to maintain its value. These devices demonstrate high-stability in storage or operational life.

Single-ended amplifier configurations are ideal when circuit board space is scarce. They are also ideal for single-ended signals, such as the voltage drop across a diode which is proportional to a change in the external environment. Compensation can be performed with a dual SOIC-8 device, or

16-pin QFN. Microbridge also supplies **Rejustor** IP for integration with the amplifier for a single-chip solution.

Differential amplifiers designed with **Rejustors** provide considerable flexibility in the control of gain and offset without a CMRR penalty. Using Low-TCR **Rejustors**, these amplifiers are stable across a broad operating range and capable of operating as high-frequency RF amplifiers.

Being able to perform analog electronic adjustment without the need for digital solutions will change the game. **Rejustors** can automate the process of manually selecting and assembling resistors, or laser-trimming using in-circuit calibration^{*} to control offset and gain. Not only do they increase precision, they are also the lowest noise adjustable resistor technology and provide the widest bandwidth. **Rejustors** are a great solution for set-on-test amplifier calibration.

^{*} *Rejust-it* in-circuit calibration software required for target voltage adjustment