Rejustor™ Control for a Precision, Adjustable Voltage Regulator

1 Introduction

The ***Rejustor*** from Microbridge Technologies represents a transformation in analog circuit design. This application note describes a precision voltage regulator based on a linear adjustable voltage regulator integrated circuit with the output voltage precisely controlled by a ***Rejustor*** divider. The same approach can be used to compensate an adjustable switching regulator to reduce power dissipation.

As cell-phones, battery-powered and portable electronics become more complex, power supply capabilities need to scale accordingly. Power management for portable systems offer new challenges in energy conservation, stability and control. In addition, shrinking design cycles coupled with the need to minimize inventory give rise to requirements for a single, high-precision design that can be trimmed to fulfill the need for a range of supply voltages.

This application note describes an innovative approach to tackle the need for disparate voltage supplies with increased precision while minimizing inventory and improving manufacturing processes. Offered here is a high-precision voltage regulator solution using ***Rejustors*** from Microbridge Technologies. The design example includes ***Rejustor*** trimming procedures using the MBK-408 in-circuit calibration capability.

The combination of ***Rejustors*** with adjustable voltage regulators allows manufacturers the freedom to design, manufacture and stock a single regulator circuit for a range of voltage requirements. The Regulator can be adjusted during manufacturing to meet specific needs; reducing design costs, inventory costs and simplifying production.

The ***Rejustor*** is clearly the best method for active-trimming a voltage regulator. The ***Rejustor*** is a passive device. Once adjusted, the ***Rejustor*** holds its target resistance with negligible drift and most importantly for this application the ***Rejustor*** does not require a boot-up process (unlike using an active component for adjustment).

2 Overview

The ***Rejustor*** based solution uses the LM317[1] "***3-Terminal Adjustable Regulator"*** from National Semiconductor Corporation, a work-horse for low-voltage high-current supplies. The LM317 with precise, adjustable control with ***Rejustors***[2] provides an output voltage range from 2.2V to 3.2V from a 10V supply. This application describes an implementation where the specific output voltage range is controlled by the Microbridge ***Rejustor*** divider connected to the ADJ pin. The LM317 family of regulators provides additional features which are beyond the scope of this document.

™ *Rejustor* is a trademark of Microbridge Technologies
[1] LM317 is a product of National Semiconductor Inc.
[2] *Rejust-it* in-circuit trimming software required for target voltage trimming

In this application, the ***Rejustor*** Divider provides an adjustable range from 2.2V to 3.2V, a sufficient range for most on-board linear and digital devices. While it is possible to achieve lower output voltages with a different ***Rejustor*** configuration, it's not advisable due to the loss in efficiency in a linear regulator. Figure 1 shows a simplified schematic representation of the ***Rejustor*** based circuit.

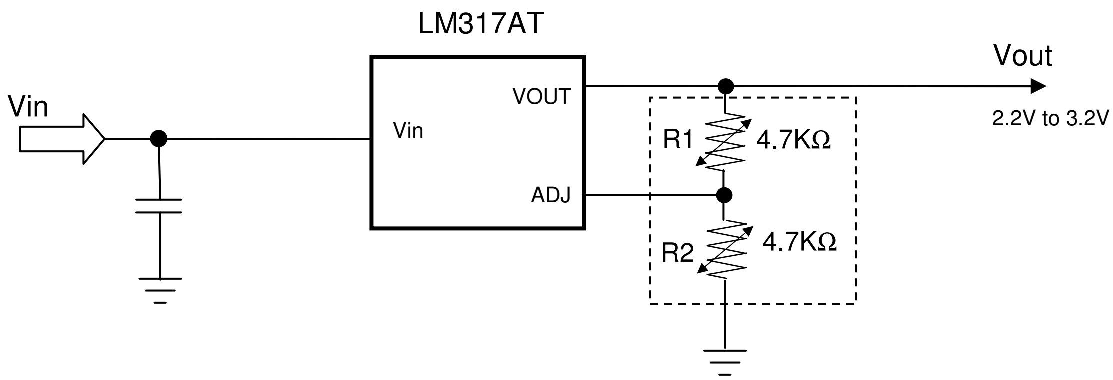

Figure 1: Adjustable Output Voltage Regulator

The ***Rejustor*** divider combination is chosen to provide sufficient adjustment range across the output voltage range from 2.2V to 3.2V. The output voltage is set by the ***Rejustor*** divider, which is adjusted to a final (target) value during final assembly.

The same design process can be used to compensate a switching regulator such as the LM2614 from National Semiconductor. Switching regulators are more efficient in applications where the input voltage is significantly higher than the required output voltage.

3 Output Voltage Adjustment Range

The Regulator application (Figure 1) is designed such that the nominal output is about one-third of the way between Vin and ground. Adjusting ***Rejustor*** R1 increases the output voltage, and adjusting R2 decreases the voltage. In this case R1 and R2 act in conjunction to generate any value within the adjustable range. The MBD-472-AS, which can be used for this application, contains two ***Rejustors*** in a SOIC8 package with 4.7KΩ nominal (as-manufactured) resistance.

In order to regulate the output voltage, a minimum current must be drawn from the regulator into the load. Low-resistance ***Rejustors*** were chosen to draw current from the regulator to enhance load regulation capability. The 4700Ω ***Rejustors*** draw a minimum of ½ mW. In practice, sufficient load should be placed on the output of the regulator during adjustment to ensure the load is being regulated and the regulator is operating normally.

Output voltage calculation for the LM317 is approximately:

Equation 1: Output Voltage Selection

$$Vout = Vref \times \left(1 + \frac{R2}{R1}\right) + \left(Iadj \times R2\right)$$

Where Vref = 1.25V and Iadj = 50µA

This equation describes the output voltage of the regulator in terms of the ratio between R1 and R2. As such, the absolute value of the ***Rejustor*** is less important than the ratio between them. There is an additive effect caused by the output current through ADJ dropped across R2. This element is inconsequential since in-circuit calibration adjusts the ***Rejustors*** to provide the required voltage; compensating all factors that affect the output of the regulator at the sample point.

Rejustor dividers are manufactured with high-precision Temperature Coefficient of Resistance (TCR) matching which means that the divider pair maintains their voltage ratio over a -40 to 125°C range.

Microbridge Technology's family of Low-TCR standard ***Rejustors*** provide at least 30% resistance adjustment range (down from the as-manufactured value). The output voltage range is calculated using Equation 1 knowing the relative changes in ***Rejustor*** resistance, as shown below:

$$Vref \times \left(1 + \frac{R2}{0.7R1}\right) + (Iadj \times R2) < Vout < Vref \times \left(1 + \frac{0.7R2}{R1}\right) + (Iadj \times 0.7R2)$$

$$(1.25 \times 2.4) + 0.235 < Vout < (1.25 \times 1.7) + 0.165$$

$$3.2 < Vout < 2.2$$

From the equation above, the output voltage can be varied from less than 2.2V up above 3.2V. Multiple instantiations of the same circuit on a single PCB assembly can be tuned to support most system power requirements. The adjustment range can be moved up or down with the addition of a series resistor at R2 or R1 respectively.

For integrated solutions, the regulator can be adjusted to provide a fixed voltage at the load instead of at the source. This is accomplished by connecting the ***Rejustor*** Calibration Tool to the supply rail at the load. In this way, the resistors are adjusted to create the desired voltage at the load irrespective of the voltage at the source (regulator). Doing so compensates for voltage droop in the system without increasing inductive coupling on the ADJ signal (since the resistors are still co-located with the regulator).

4 *Rejustor* Calibration – Hardware Connections

Rejustor Calibration Tools from Microbridge Technologies provides all the I/O requirements to adjust the ***Rejustors*** in this application. Target voltage trimming mode using a single-ended input on the MBK-408A can provide adjustments to a precision of 3mV (1 ADC bit).

The Voltage regulator requires five connections to the MBK-408A as depicted in Figure 2. These connections are: Vout, TP_{RJ1}, TP_{RJ2} in addition to HGND and the reference ground for the A-to-D. In this application HGND and reference ground can be connected, eliminating a wire from the interconnect.

There are several methods to physically connect the Calibration Tool to the design including using flying probes or installing a custom connector. This example assumes flying probes are used to connect the MBK-408A to the circuit. Testpad landing areas must be added on the layout as targets for the flying probes. The output from the regulator can be monitored at the source or at the load.

The following diagram shows how to connect the Voltage Regulator design to the MBK-408A ***Rejustor*** Calibration Tool. Rj1 is adjusted with DAC0, and Rj2 is adjusted with DAC1. Some details have been omitted for clarity.

The LM317 Linear Voltage Regulator needs a load that will draw at least 2mA in order to operate correctly. If no load is present in the circuit-under-test, a 600Ω resistor (R_L) should be installed in the probe assembly to draw sufficient current during the calibration process.

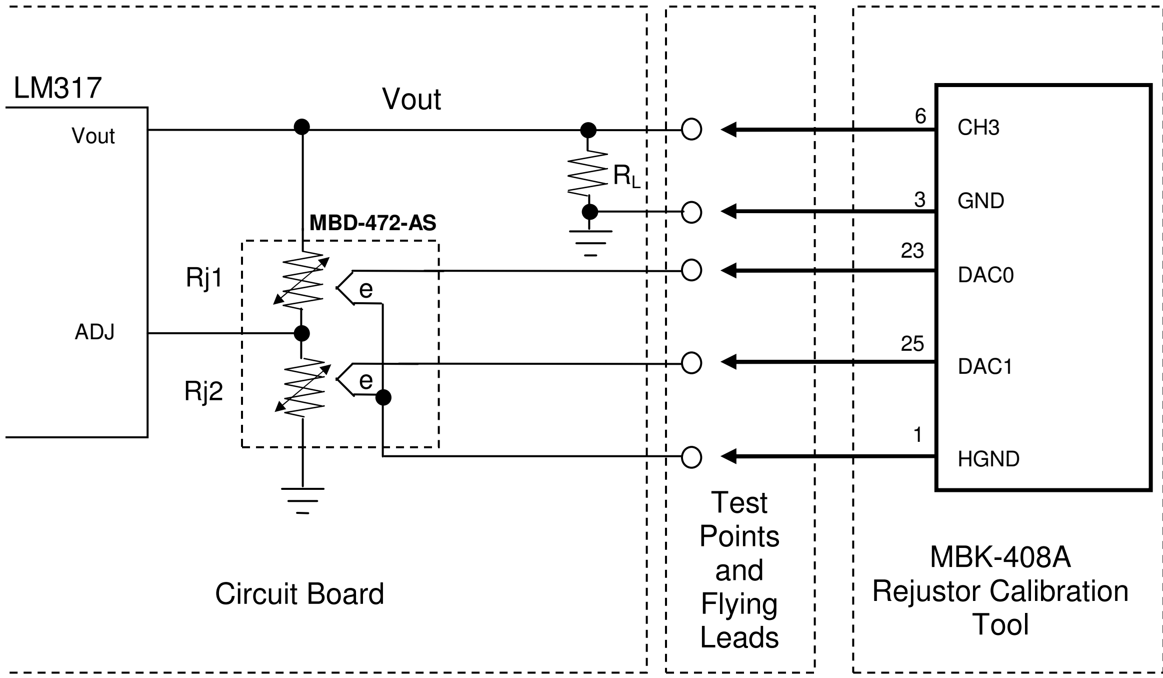

Figure 2: Calibrating the Circuit - Hardware Connection

The circuit connects Vout to analog input #3 in the MBK-408A. Notice that the sensing point is at the load instead of at the source to compensate for line loss.

5 Creating Rejustor Calibration Parameters

Rejust-it software from Microbridge Technologies Inc. is provided as royalty-free executable based on LabVIEW[3] software. The *Rejust-it* user interface creates the (soft) connections between the MBK-408A hardware, the circuit under test and the ***Rejustor*** algorithms.

The relationship between the output from the unit-under-test (or input to the MBK-408A ***Rejustor*** Calibration Tool) and the ***Rejustors*** adjustment pins (or output from the MBK-408A) must be defined in *Rejust-it*. This relationship maps the percentage decrease in the resistance of the ***Rejustor*** to a corresponding change in the output voltage of the regulator circuit. These parameters provide a rough-order-of-magnitude comparison between input and output.

The equation provided in the datasheet for the LM317 output voltage is used to create a table of values that describe the output as each ***Rejustor*** is adjusted. The table below (developed in Excel[4]) relates a percentage change in the resistance of each ***Rejustor*** to the absolute value of the output voltage. For example, the first entry in the table assumes R1=R2 at the as-manufactured value of 4700Ω. The second line indicates Vout decreasing to 2.587V when R2 is adjusted down 10%. The table is populated using percentage change in R2 followed by R1 (each assuming the other resistor is held constant at the as-manufactured value).

[3] LabVIEW is a registered trademark of National Instruments
[4] Excel is a registered trademark of Microsoft Corp.

Table 1: Vout as a function of R1 and R2

R1(Ω)	R2 (Ω)	Vout = $1.25x(1+{}^{R2}/_{R1})+(IadjxR2)$
4700	4700	2.735
4700	4230	2.587
4700	3760	2.438
4700	3290	2.290
4230	4700	2.874
3760	4700	3.048
3290	4700	3.270

Alternatively, the relationship could be determined experimentally by placing parallel resistors across R1 and R2 to reduce the effective resistance by 10%, 20%, 30%, etc. while recording the value of Vout. Figure 3 depicts the approximately linear relationship from the resistance of R1 and R2 to Vout.

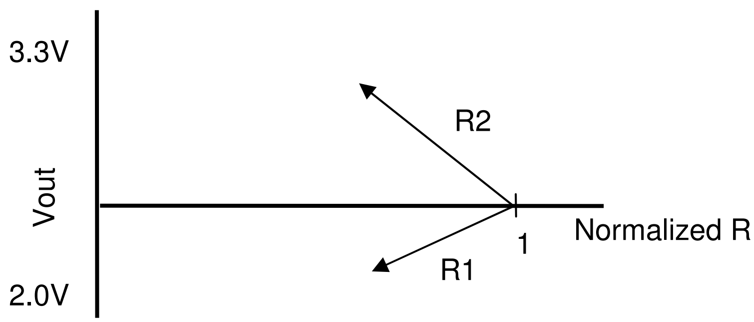

Figure 3: Vout - Rejustor Relationship

6 Develop *Rejust-it* Configuration File

The configuration file defines the connections between the circuit-under-test (the voltage regulator) and the MBK-408A hardware. The process is similar to developing Spice files for simulation, although made easier through the use of the **Circuit Configuration** Editor GUI. The connection nodes indicate the configuration of inputs and outputs, and the parameter file is the table of values shown in Table 1. The partially completed GUI is shown in Figure 4. For more information on the Circuit Configuration Editor, please refer to the MBK-408A ***Rejustor*** Calibration Tool User Manual.

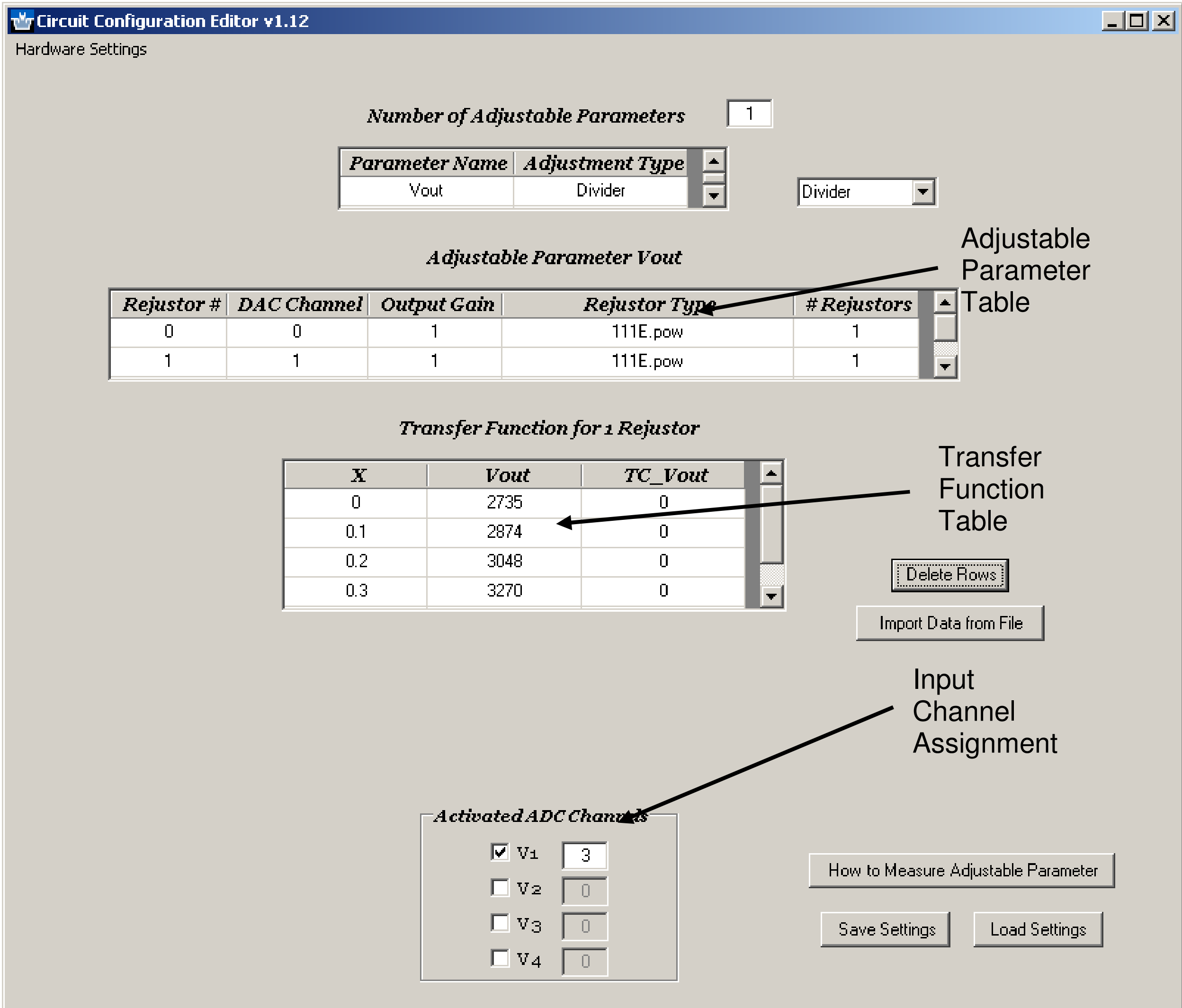

Figure 4: Configuration Editor showing *Rejustor* Rj1

Notice in Figure 4, the **Transfer Function** table in the center of the screen shows the parameters for ***Rejustor*** Rj1 (the bottom rows from Table 1). The transfer function for Rj2 is created by first clicking on ***Rejustor***# 2 in the **Adjustable Parameter Vout** table then entering the normalized change in resistance and corresponding voltage Vout using the top 4 rows of Table 1.

The **Circuit Configuration Editor** uses **Coefficients** to define the relationship between the input to the ADC from the circuit-under-test and the type of measurement being performed. The **Coefficients** can be used, for example, to create differential measurements or convert the input to an equivalent ohmic vale for each ***Rejustor***. The **Coefficients** are entered by pressing the **How To Measure Adjustable Parameter** button in the **Circuit Configuration Editor**.

The output voltage from the Voltage Regulator is the signal that is being calibrated, as defined in this Application Note. Vout from the Regulator is assigned to the V1 **Input Channel** in the configuration file. In other words,

$$Vout = V1$$

Where V1 is assigned to input channel 3 on the MBK-408A

Looking at the general form of the equation, A1 and B0 must be defined as ‘1’ with all other parameters set to zero to complete the equation. The complete **Coefficient** table is shown in Figure 5.

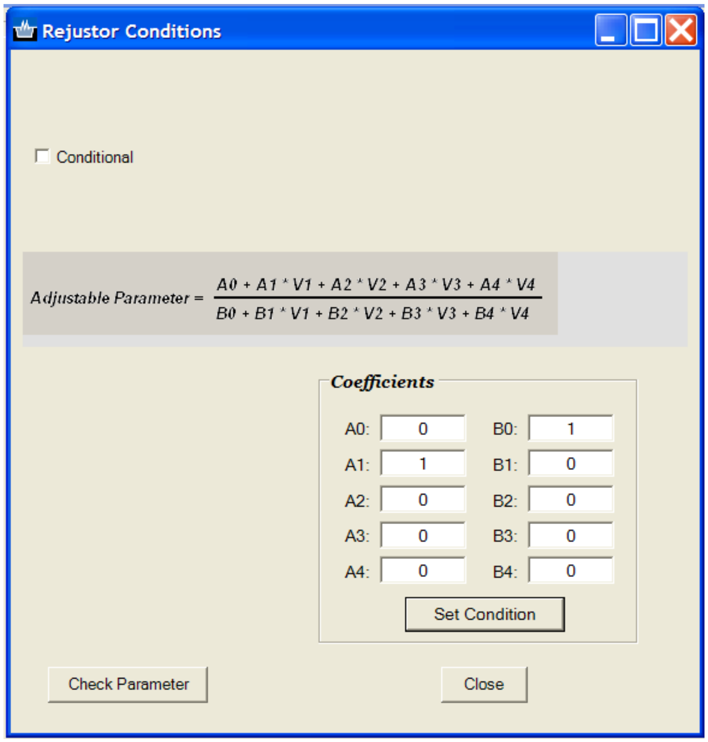

Figure 5: Coefficients for Vout

Click **Set Condition** and **Close** to close this window, when complete.

Save the configuration file using the **Save Settings** button on the bottom of the **Circuit Configuration Editor** GUI. The file can be saved as LM317.set, for example.

The settings file is created once for the circuit. Rejust-it uses the output of the Circuit Configuration Editor to calibrate the circuit.

7 *Rejust-it* Calibration Software

The *Rejust-it* software tool adjusts the resistance of the ***Rejustors*** to create the target output voltage Vout. The ***Rejustors*** can be adjusted to provide any voltage from the regulator within the linear range of adjustment. Precision is expected in the range of ±5mV or better, depending on the noise in the system.

Figure 6, below, shows the Rejust-it window. The tool is launched by double-clicking the Rejust-it icon from the installed directory. After loading the settings file (created with the Circuit Configuration Editor, above), it is possible to measure the output of the circuit and adjust the ***Rejustors*** to a target value. In the example below, the target value is set to 3100mV. Note that, by default, Rejust-it represents the output voltage in millivolts.

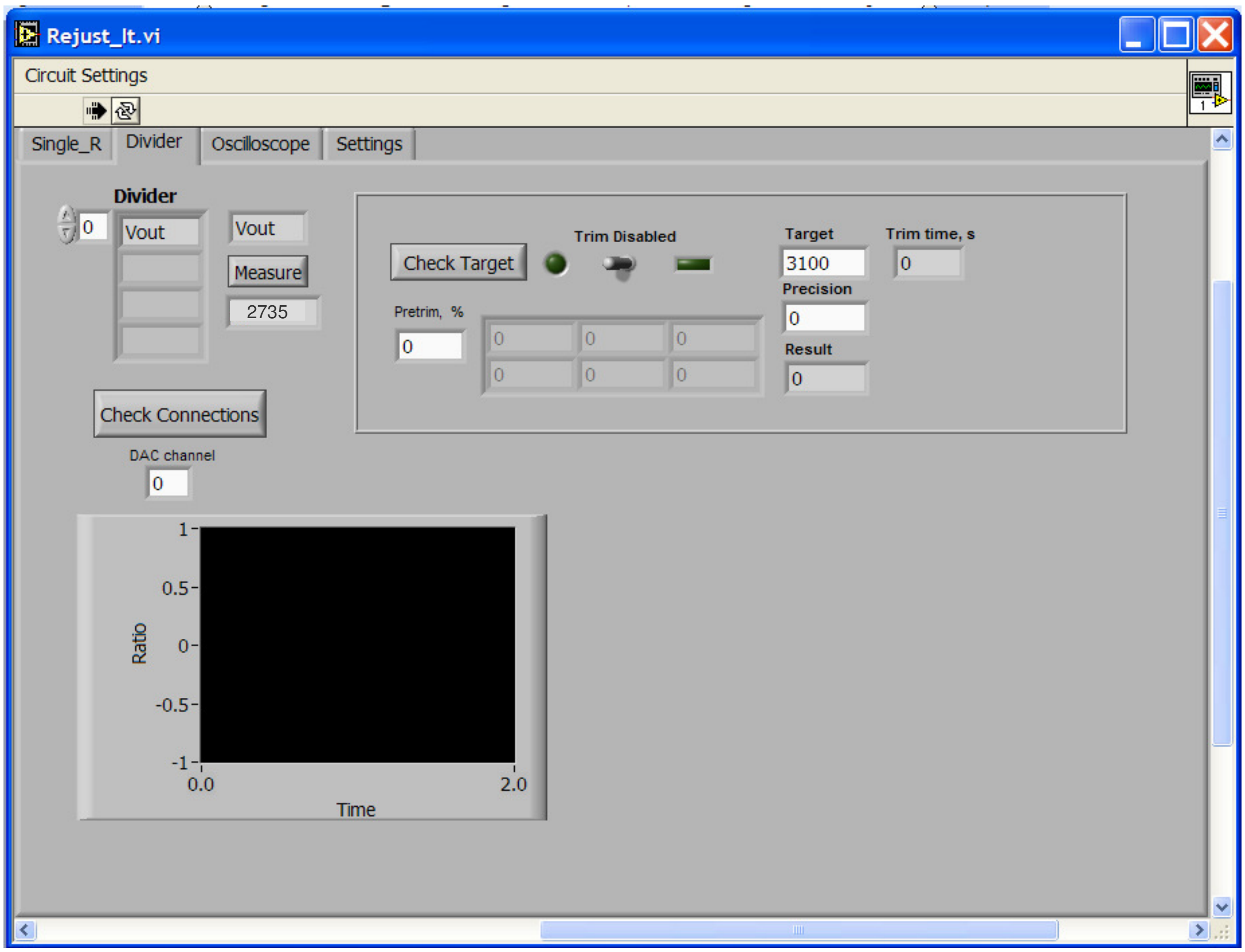

Figure 6: *Rejust-it* Graphical User Interface

8 Summary

This application note describes a practical circuit that provides a regulated voltage using a linear adjustable regulator adjusted to a precise voltage with ***Rejustors*** from Microbridge Technologies. The combination of flexibility and precision make this an excellent replacement for fixed voltage regulators in addition to a wide variety of other applications.

The same process can be used with switching regulators. The output of most adjustable switching regulator designs is generally governed by the same equation used for the linear regulator, with some variation in Vref. The resistance of the ***Rejustors*** for the switching regulator should be as high as possible to present a high-impedance to the adjustment pin. ***Rejustor*** dividers are available at a nominal 10KΩ in ratios of 1:1, 1:2 and 1:5. These ***Rejustors*** provide the capability to define several different output voltage ranges.

A precision switching regulator calibrated with ***Rejustors*** is ideal for low-power portable designs such as cell-phones with the input voltage generated from a Li-ION cell. These regulators are typically used to bias RF power amplifiers. ***Rejustors*** remain pure resistors across frequency up beyond 100MHz. Therefore they are immune to any switching frequency parasitics.

Rejustor controlled adjustable regulators can be used for any power supply requirements in a system allowing a very high degree of design reuse while lowering inventory of precision fixed regulators. Target voltage is set by the ***Rejustors*** during final-assembly.

As an added benefit, the ***Rejustors*** can be placed near the regulator to reduce inductive noise at the ADJ pin of the regulator while the calibration process is performed at the load point. This process compensates for line loss without increasing inductive coupling in the adjustment path.

Using ***Rejustors*** for this application reduces design cycle-time since a generic unit is produced and configured to meet each specific application. Raw material and finished goods inventory are reduced as a result of the flexibility of the design.

As a passive device, the ***Rejustor*** is ideally suited for this application since no boot-up sequence is required. Using non-adjusted ***Rejustors*** doesn't harm the voltage regulator since the ***Rejustor*** is always a resistor. Once calibrated, this regulator design will hold its target voltage with no noticeable drift over time. In addition, the regulator can be readjusted at any time using the ***Rejustor*** calibration Tool. No power is required by the ***Rejustors*** to maintain their target value, which is held indefinitely.

These designs meet the output voltage requirements over a wide range of input voltages. In addition to being highly configurable, the design is both power and real-estate efficient.

This application note provides another example of how Microbridge Technologies is enabling step-ahead analog compensation and signal conditioning. For more information, contact Microbridge Technologies Inc, at www.***Rejustor***.com