microbridge APPLICATION NOTE

eTC Rejustor™ Primer

Advanced Solutions for Temperature Compensation

1 Introduction

When Microbridge introduced the Low-TCR ***Rejustor*** it revolutionized the way analog designers performed resistance-based calibration. The Low-TCR ***Rejustor*** allows true in-circuit calibration to facilitate production, improve yield and reduce rework expense.

The ***eTC Rejustor*** provides the next-generation solution for passive calibration and temperature compensation. ***eTC Rejustors*** are passive resistive devices with adjustable resistance and TCR (temperature coefficient of resistance). These devices are used not only to correct for variation in offset, but also for variation in temperature sensitivity and drift. ***eTC Rejustors*** allow unprecedented flexibility for control of temperature related circuit problems in an all-passive, all-analog solution.

eTC Rejustors are typically used in circuit applications where high precision and temperature stability is required and the exact value of the desired resistance and temperature correction factor depends on variation in other circuit components – for example, batch-to-batch or unit-to-unit manufacturing variations, or where packaging-induced stresses cause significant changes in electrical output

Both resistance and TCR of the ***eTC Rejustor*** can be adjusted many times (as needed) using analog signals. Once adjusted these parameters hold their final value indefinitely, unless they are re-adjusted. Microbridge provides ***Rejust-it*** software to facilitate adjusting. Adjusting can be performed in the factory or in the field. Factory adjusting can be performed during final assembly, during ATE testing, or at probe for wafers and die.

eTC Rejustors can be adjusted, in-circuit, to generate a resistance ratio and temperature profile to compensate temperature and offset sensitive devices. The resistance of each ***eTC Rejustor*** is adjusted to correct for manufacturing variance in the uncompensated circuit. In addition, the ***Rejustor's*** temperature response is adjusted to counteract the temperature-related drift of the uncompensated circuit. In other words the ***Rejustor*** is adjusted in-circuit to compensate for offset and cumulative temperature sensitivities of all the components within the circuit.

The Microbridge Technologies ***eTC Rejustor*** family of electrically adjustable micro-resistors can be matched to specific values for precision control of sensors, voltage regulators, amplifiers and other analog circuit applications.

2 *eTC Rejustor* Basics

The innovation behind the ***eTC Rejustor*** uses the inherent material-characteristics of typical poly-silicon resistor materials at very-high temperatures (several hundred degrees Celsius) to enable this adjustability. The adjustment temperature is far above normal operating temperatures and ***eTC Rejustors*** have proven to be stable beyond +150°C. By thermally isolating portions of the resistor and by providing a highly localized and electrically-controlled heat source, resistance elements are raised by many hundred of degrees Celsius, to temperatures approaching or even greater than film

™ ***eTC*** and ***Rejustor*** are trademarks of Microbridge Technologies deposition temperatures, Here the material properties, such as room-temperature resistance and TCR can be deliberately manipulated by careful design of the heating and cooling algorithms.

Microbridge uses microstructures which provide sufficient thermal isolation from the main silicon substrate to allow localized heating of the resistance element without affecting the rest of the surrounding chip. The thermal mass being heated is small enough that rapid heating and cooling is possible allowing a software-controlled feedback-based adjustment algorithm. A sequence[1] of electrical heating pulses, governed by Microbridge's proprietary algorithms, is enough to fine-tune the material properties of the ***eTC Rejustor***.

The schematic symbol for the ***eTC Rejustor*** is shown in Figure 1. Based on the symbol for a potentiometer, the ***eTC Rejustor*** uses double-headed arrows for differentiation and to imply bi-directional adjustment. Two arrows are used to differentiate the ***eTC Rejustor*** from the resistance-only ***Rejustor***. The ***eTC Rejustor*** can be visualized as a potentiometer with two wipers, where one wiper controls resistance and the other controls TCR, although wiper adjustment is performed electrically and independently.

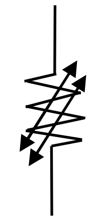

Figure 1: Rejustor Schematic Symbol

The standard-product ***eTC Rejustor*** comprises two independently adjustable resistors in a divider configuration. (See Figure 2) Each ***eTC Rejustor*** within the divider comprises a Compound ***Rejustor***. The two resistive portions of a compound ***Rejustor*** are doped differently during manufacture in order to have a known, predicable, but different R vs. TCR dependency. The target value of R and TCR for the ***Rejustor*** is achieved by the combined contribution of the two portions' R and TCR in a predictable manner, as they are adjusted. The individual adjustments to the two portions are governed by Microbridge's adjustment software.

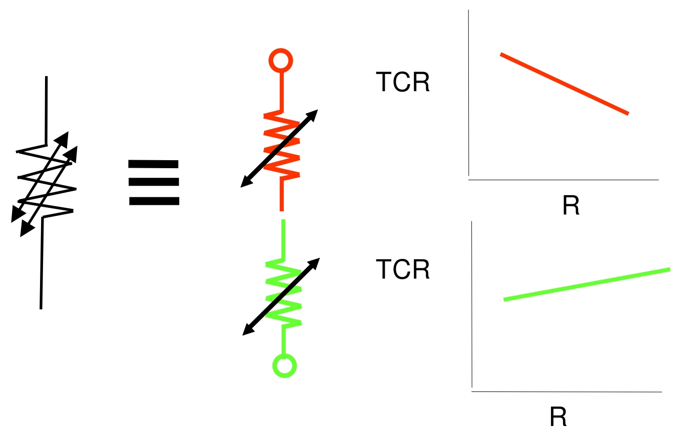

Figure 2: Analogous Model of eTC Compound Rejustor. The graphs depict variation of the overall TCR of the Compound Rejustor as a function of variation in overall resistance, as each of the two resistive portions is trimmed.

The result is a simple passive resistor, an "***eTC-Rejustor***", with adjustable material properties. No extra temperature sensor is needed. As a passive TC-controlled component, it *is* its own temperature sensor, as well as being the adjustment device. The ***eTC Rejustor*** element features very fast temperature response. The response time of the ***eTC Rejustor*** is limited by the thermal properties of the package and is approximately 100msec per degree Celsius.

[1] Using Microbridge's scalable production-calibration hardware (based on the NI-DAQ platform from National Instruments) and ***Rejust-it*** software, multiple units can be calibrated simultaneously during roughly the same amount of time required for a single device

eTC Rejustors offer two principal advantages over conventional precision resistors. First, they can be adjusted within a defined range while maintaining high precision. Secondly the temperature response of the resistor can be adjusted – like an adjustable temperature sensing resistor. ***eTC Rejustors*** are the first TCR compensation devices which offer adjustability and high precision. In addition, ***Rejustors*** offer a significant advantage over laser-trimmed resistors, particularly for dynamic adjustment, since they can be adjusted bi-directionally. ***eTC Rejustors*** offer both the widest bandwidth and the lowest noise of any adjustable resistor technology and the only analog device to provide adjustable TCR.

The adjustment elements (and circuit connections to the Calibration tool) are only required during device calibration. After the resistance and TCR have been set the adjustment pins can be left open or grounded with no affect. The ***Rejustor*** has no moving parts, unlike a potentiometer. The ***Rejustor*** is the only analog resistor than can be adjusted in-circuit with simple, isolated electrical signals.

3 *eTC Rejustor* Dividers

The ***eTC Rejustor*** divider consists of a pair of resistors connected in series. Access is provided to both ends of the divider and to the center-tap. The ohmic value and TCR of each resistor in the divider can be adjusted independently. As a result, applying a voltage across the adjusted divider generates a stable reference voltage (Offset) with a fixed temperature response (TC-Offset).

Microbridge ***eTC Rejustor***-dividers provide in-circuit adjustability for both output voltage and the temperature drift of that output voltage. This is done using a pair of R- and TCR-adjustable ***Rejustors***, and adjusting the resistance and TCR of each ***Rejustor***.

By adjusting the resistance ratio of the two ***Rejustors***, one can fine-calibrate the output voltage (e.g. for a 1:1-ratio divider Vin/2, or Vin/2 + delta-V, where delta-V is the amount one ***Rejustor*** is changed). By adjusting the relative TCR's of the two ***Rejustors***, one can establish a particular temperature-coefficient of that output voltage (e.g. +25ppm/K, -70ppm/K, 0ppm/K, etc.) The adjustment of output voltage and its TC are independent within certain ranges.

An ***eTC*** divider allows adjustment of the divider output voltage away from its initial ratio ("Offset" in mV per Volt applied to the top of the divider), and at the same time allows independent adjustment of the temperature coefficient of the output voltage (TC-Offset in µV per degree Kelvin per volt applied to the top of the divider). In this way, a temperature-conditioned voltage divider is obtained. One way to think of the technology is to consider the basic equation of a straight-line:

$$y = mx + b$$

Where: y is the output voltage response from the ***eTC Rejustor***
x is temperature
m is the slope of the temperature response – TCR
b is the initial offset – resistance

For example, the top (orange) line in Figure 4, has the form Vout = (-100µV/V/K)T+ 90mV (where T is measured in Kelvin).

3.1 1:1 eTC Rejustor Divider

The **MBT-303-A** is a 30KΩ, as-manufactured ***eTC Rejustor*** divider with a 1-to-1 ratio, that is, both ***Rejustors*** have the same initial resistance and TCR. The resulting divider output adjustment range is from +100mV/V to -100mV/V, with a temperature coefficient of output range from +150µV/V/K to -150µV/V/K (refer to Figure 3). Applying a voltage across the adjusted divider generates a stable reference voltage (Offset) with a fixed temperature response (TC_Offset).

3.1.1 Active Adjustment Range

The active adjustment range is shown as the area within the 2-dimensional plots below. Offset is defined as the deviation of the output voltage from the nominal output voltage for unadjusted ***Rejustors***. For a 1:1 divider, the nominal output voltage is Vin/2. Microbridge's ***eTC*** adjustment software allows one to pick target values for Offset and TC-Offset as any point within the roughly-parallelogram-shaped region shown in Figure 3.

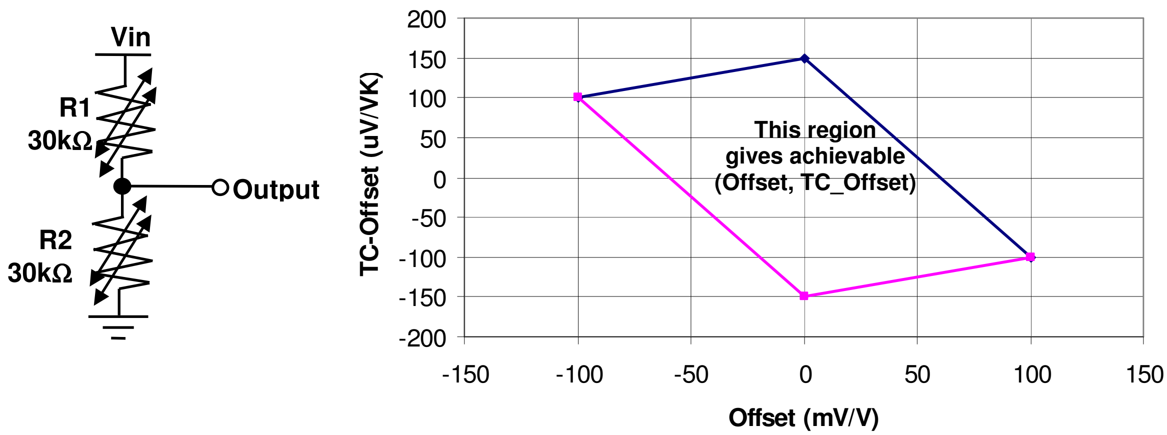

Figure 3: *eTC* Divider: Region of achievable values (Offset and TC_Offset)

3.1.2 Adjusted *eTC Rejustor Examples*

The chart in Figure 4 provides several examples of the output offset and temperature response that can be achieved with the ***eTC Rejustor***. Output offset voltage is shown as a function of temperature where the initial offset is specified at 10℃. Of course the actual number of examples is unlimited; this chart offers the viewer a visualization of several combinations.

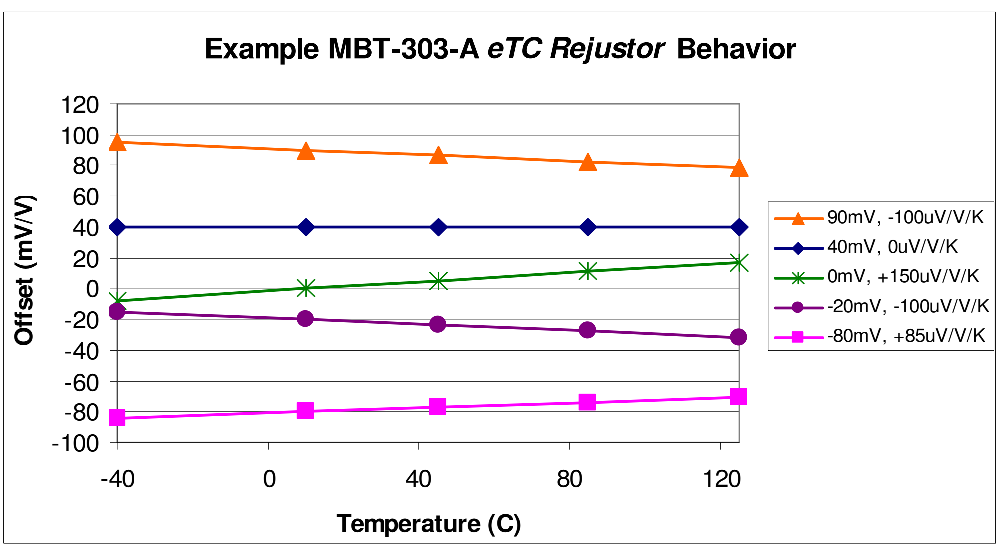

Figure 4: Example *eTC Rejustor* Response

4 ***eTC Rejustor*** Adjustment

The resistance and TCR of the ***Rejustor*** are changed by heating the poly-silicon in a controlled manner. ***Rejustor*** Calibration tools, like the MBK-408A, provide the electrical connection to physically perform the adjustment under control of ***Rejust-it*** Software.

The ***Rejustor*** calibration tool must be connected to the ***Rejustor***-based circuit during the calibration process. The tool has an analog input to measure the output of the circuit being adjusted. The analog outputs from the ***Rejustor*** Calibration tool drive power into the auxiliary pins on the ***Rejustor***. Refer to Figure 5. The power from the Calibration tool generates heat in the ***Rejustor***, which changes the resistance of the ***Rejustor***. It's important to note that the adjustment power is electrically isolated from the ***Rejustor*** in the circuit. The resistance and TCR of the ***Rejustor*** are stable when the heat is removed (i.e. at normal operating temperatures).

The electrical connection between the auxiliary pins on the ***Rejustor*** and a suitable ***Rejustor*** calibration tool are required only during adjustment. NO POWER SUPPLY OR QUIESCENT CURRENT IS NECESSARY TO MAINTAIN THE PRECISION ADJUSTED RESISTANCE.

Rejust-it is based on LabVIEW software and provided as executable for standard Windows-based computers. ***Rejust-it*** communicates with the ***Rejustor*** calibration tool through the computer's USB port. ***Rejust-it*** implements patented algorithms which control the heating and cooling process in the ***Rejustor*** in order to meet the system requirements for offset and drift.

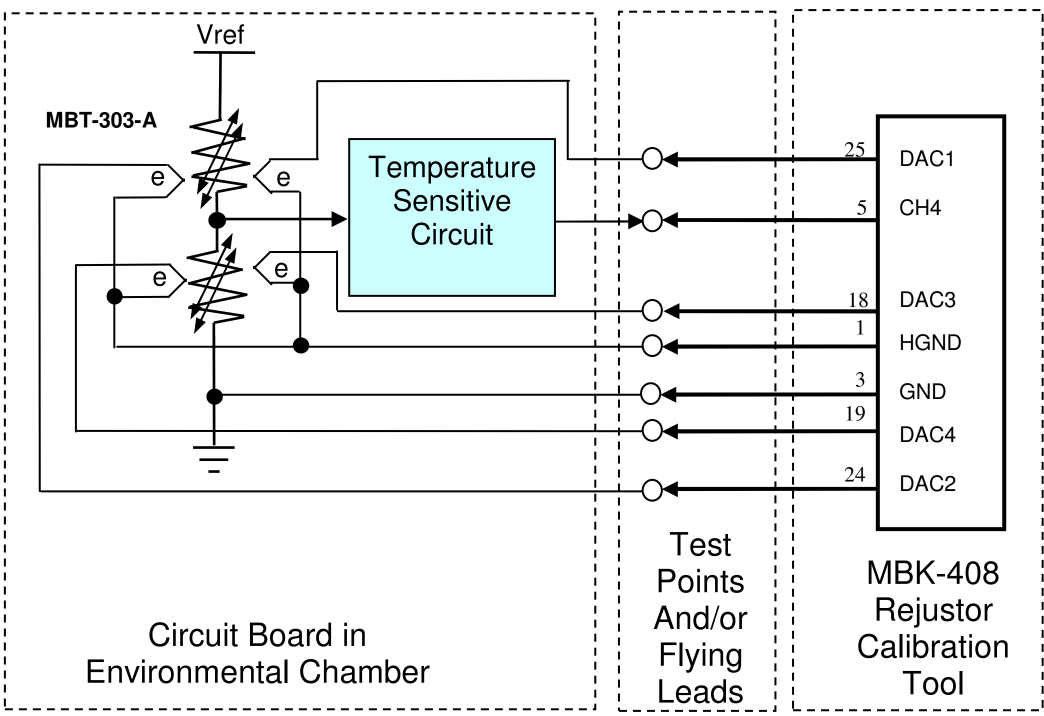

Figure 5: Rejustor Hardware Connection

Rejustors are an element in the overall system, where the system can be a voltage regulator, an amplifier, a sensor, etc. ***Rejust-it*** examines the output of the system and adjusts the resistance and TCR of the ***Rejustors*** to meet target values. Example target values may be an output voltage of 3.333V for a regulator or a gain of 1.5 for an amplifier or an offset of zero for a sensor. ***Rejust-it*** and the ***Rejustor*** Calibration tool adjust the resistance to achieve this target; however, it is not necessary to measure the final resistance of the ***Rejustor***. It is sufficient to know that what ever the value of the ***Rejustor***, it is adequate to meet the system target.

4.1 eTC Rejustor Adjustment Mechanics

TCR adjustment is more complex than resistance adjustment because there is no immediate feedback. With resistive adjustment, the calibration tool can measure the response of the circuit and iterate towards the target value. With TCR adjustment, ***Rejust-it*** uses proprietary knowledge of the relationship between TCR and resistance of the ***Rejustor*** to achieve the desired result.

Rejust-it software is configured with the Resistance versus TCR profile for the MBT-303-A ***eTC Rejustor***. Using this knowledge, ***Rejust-it*** is able to close the feedback loop to achieve the resistance and TCR targets.

4.1.1 *eTC Rejustor* Adjustment Example

Consider the ***eTC Rejustor*** configured as a divider with one volt applied to the top of the divider (as shown in Figure 3). The output voltage from the divider will be 0.5V, with no temperature drift. Assume it is necessary to adjust the output of the voltage divider to provide an additional +50mV offset (i.e. move Vout to 0.505V) with a temperature drift of -100µV/°C.

The ***Rejustor*** would be connected to the ***Rejustor*** Calibration tool as shown in Figure 5, with the output of the divider connected directly to Channel 4 of the MBK-408A. The offset target would be set to 0.505V, and the TC_Offset target set to -100µV/°C. After the TRIM button is pressed, ***Rejust-it*** would first adjust the negatively-doped element in R1, the top ***Rejustor***, to a target Vout of approximately 0.5025V, knowing the corresponding TC_Vout is approximately +20µV/°C. Next, the positively-doped element within R1 would be adjusted to the target final value of 0.5050V, knowing that this corresponds to TC_Vout of -100µV/°C. The adjustment steps are shown graphically in Figure 6.

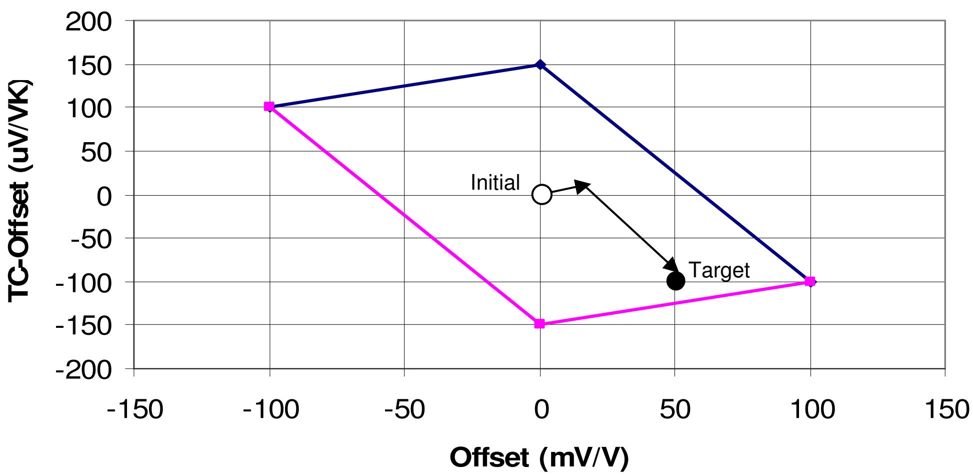

Figure 6: Example Adjustment Mechanics

4.2 Compensation Process

Typical temperature-compensation of an analog circuit or sensor requires a soak period at two temperatures (e.g. room temperature and one elevated temperature) in order to determine the slope of the temperature-induced drift. A typical calibration sequence for an in-circuit ***eTC***-divider is:

1. Measure circuit Vout at room temp
2. Raise to elevated temperature
3. Measure circuit Vout at elevated temperature
4. Calculate ***eTC***-divider adjustment targets (automatically)
5. In-circuit adjust ***eTC***-divider, while using Vout for feedback
6. Return to room-temperature

7. Measure adjusted circuit Vout at room temperature
8. Calculate ***eTC***-divider adjustment targets (automatically)
9. Optionally fine-adjust ***eTC***-divider, while using Vout for feedback.

Refer to Figure 7 for an equivalent flow-chart.

In applications where high-precision is required, it is recommended that both coarse and fine adjustments be made on each assembly. These measurements can be combined within the same cold-to-hot-to-cold temperature cycle.

Alternatively, if the target TC is known (e.g. batch characterization determines that they all have temperature non-ideality roughly 75µV/VK), then it may not be necessary to temp-cycle the devices – the software can roughly hit the TC target needing only output voltage feedback, as long as the transfer function between ***Rejustors*** and circuit output is well-enough known. The precision of adjustment (for both offset and TC-offset) using this method will depend on how well-known is this transfer function.

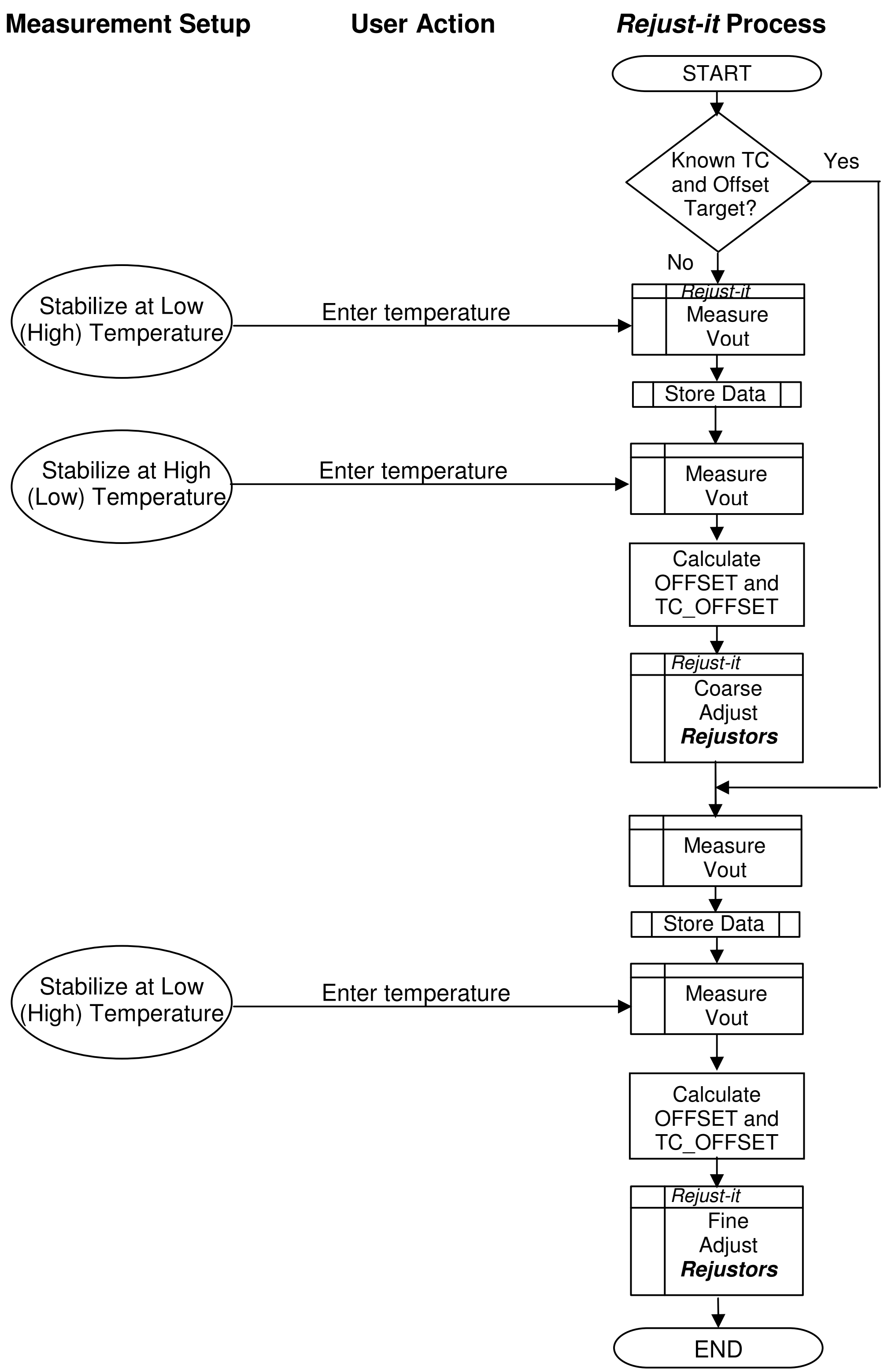

Figure 7: Adjustment Process Flow Diagram

Adjustment Process Flow Diagram for Rejust-it Software. During operation, it is only necessary to change the temperature. Rejust-it automates the calculation and adjustment process.

5 Typical *eTC Rejustor* Applications

Applications for ***eTC Rejustors*** are plentiful, existing in any analog circuit or system which requires calibration and temperature compensation. Following are some examples.

5.1 Temperature Compensated Current Source for Hall Effect Sensors

Hall Effect Devices have been used for positional and rotational measurements for many years. The ***eTC Rejustor*** is a complimentary device for reducing temperature dependence in Hall sensors.

The problem with Hall Sensors is that the resistance of the sensor is dependant upon temperature. Applying a constant voltage to the sensor amplifies the temperature-induced drift of the sensor. Constant current is generally recommended for operating Hall Sensor since it reduces the magnitude of the temperature-induced drift, but doesn't eliminate it.

The solution is to utilize an ***eTC Rejustor*** divider to temperature compensate the current source, as shown in Figure 8. An ***eTC Rejustor*** controlled constant current source compensates for both changing resistance and output drift as a function of temperature. The ***Rejustors*** are compensated in-circuit to offset the specific offset and temperature drift of each sensor.

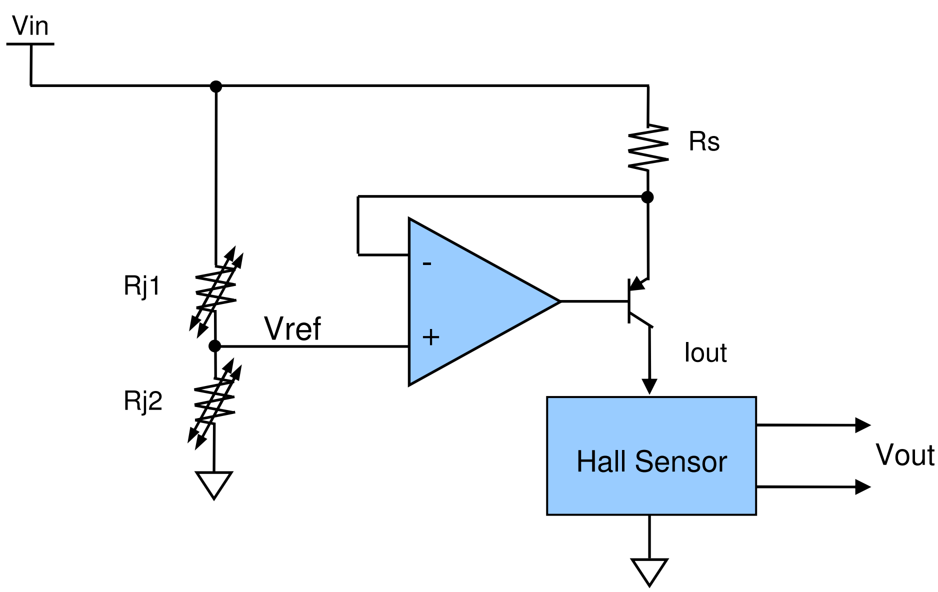

Figure 8: Hall Sensor Application Circuit

5.2 Voltage Reference adjustment and compensation

eTC Rejustor dividers can be configured with a buffer as shown in Figure 9. This circuit is useful for adjusting offset, or a reference, in circuits that require offset and TC of offset correction. The output voltage and temperature response of the reference can be adjusted independently. Applying a voltage across the divider generates a stable reference voltage with a fixed temperature response. Once adjusted, the response parameters remain fixed. No external power is required to maintain the adjusted value of the ***Rejustors***. The voltage and/ or temperature response can be re-adjusted many times.

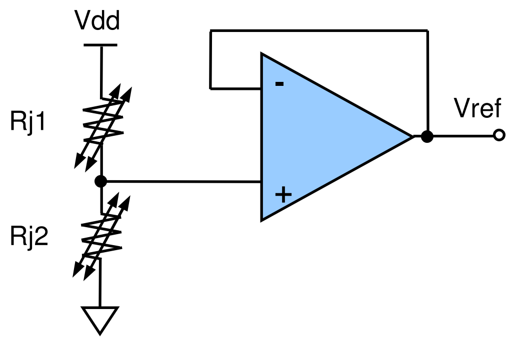

Figure 9: Temperature Compensated Reference

This circuit provides a stable reference voltage with a fixed temperature response. Both the voltage level and temperature response are adjustable in the analog domain. That is, a finite range of non-discrete values can be obtained. The ***eTC Rejustors*** are buffered with an op amp for isolation under moderate loads.

5.3 Adjustable Lithium-Ion Battery Charge Controller

The LM3420 is a battery-charge controller designed for use with an external voltage regulator for charging and end-of-charge control of Lithium-Ion rechargeable batteries. An external compensation pin is provided to increase or decrease the regulation voltage.

As specified in the LM3420 datasheet, external voltage trimming up to ±10% of Vreg can be realized with only a small increase in the temperature coefficient. Figure 10 indicates that a 10% change includes about 3% drift across temperature (approximately 200ppm/K).

eTC Rejustors are ideal compensation devices for LM3420 Vreg adjustment because they can be automatically adjusted to set the regulated voltage and compensate for the inherent temperature drift in the device. An eTC Rejustor divider will cover a wide range of positive and negative voltage adjustments and positive and negative temperature compensation. No other analog resistor technology can achieve these objectives.

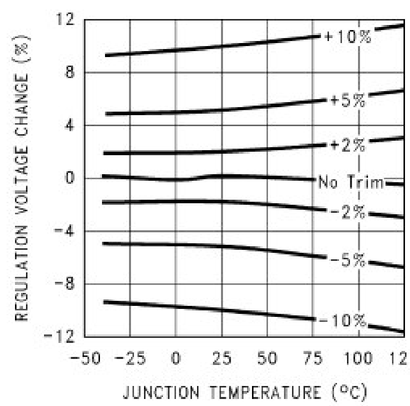

Figure 10: Normalized LM3420 Temperature Drift with Output Externally Trimmed

A sample circuit is shown in Figure 11. The advantages of the ***eTC Rejustor*** in this application are:

1) In-circuit Vreg calibration
2) Automated temperature-drift compensation
3) Electrical adjustment after assembly and packaging
4) No moving parts – not subject to vibration, dust or moisture damage
5) Significantly reduces the risk of over-charging or under-charging batteries across a wide temperature range
6) Easy, automated adjustment process suitable for volume production.

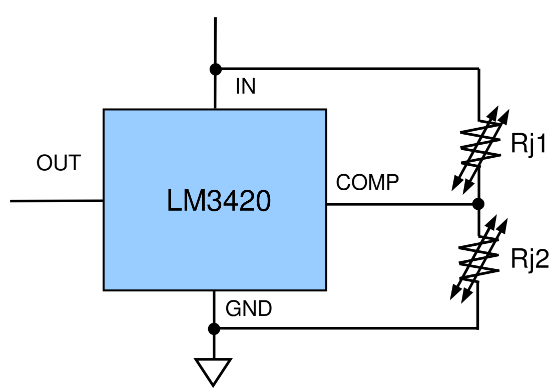

Figure 11: Adjustable LM3420 Battery Charge Controller

6 Summary

eTC Rejustors solve calibration and compensation problems. This revolutionary technology represents the future in passive compensation for resistive adjustment and temperature compensation. ***eTC Rejustors*** can be used to correct for manufacturing variance and compensate temperature induced changes in sensors, optical devices, voltage references and other active and passive circuits. ***Rejustors*** are changed using electrical signals generated from conventional manufacturing instruments. Once adjusted, ***Rejustors*** maintain these parameters indefinitely, unless they are re-adjusted.

eTC Rejustor pairs can be used in voltage divider configurations. The compound ***Rejustors*** within the pair can be adjusted to provide a specific output voltage and temperature coefficient of output within a two dimensional range.

Rejustors are adjusted by applying an electrical current through an element adjacent to the resistive element. The current temporarily heats the ***Rejustor*** to a high-temperature that anneals the element. When it returns to operating temperature, it has a different resistance and/ or TCR. The adjustment is made using a closed-loop system controlled by ***Rejust-it*** using conventional ADC and DAC hardware. The MBK-408 Calibration kit is available from Microbridge for evaluation.

The facility offered by the ***Rejustor*** to be adjusted after assembly or at the system level (active adjustment) allows the procurement of lower tolerance components, which are subsequently corrected with the ***Rejustor***, thereby adding significant indirect value.

Rejustors are high-quality precision devices that meet and exceed typical reliability and stability standards for integrated resistors. Once you've integrated a ***Rejustor*** into your application, you'll experience the flexibility and performance offered by Microbridge Technologies.