APPLICATION NOTE

Rejustor™ Primer

Introducing the *Rejustor* – High-Precision Adjustable Resistor

1 Introduction

The ***Rejustor*** from Microbridge Technologies represents a major technological improvement for analog resistive adjustment and compensation. ***Rejustors*** are typically used in circuit resistance-trimming applications where high precision and/or temperature stability is required and the exact value of the desired resistance depends on variations 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. The ***Rejustor's*** resistance can be adjusted typically to 0.1% precision in about a second, within a range of at-least 30% down from the initial value.

The ***Rejustor*** is an analog adjustable resistor. These units can be adjusted dozens of times and always maintain the last adjusted state, even if they are placed in storage for extended periods. After adjustment, these passive devices require no power to hold their final value. Adjusting is performed by applying short duration analog voltage pulses to the auxiliary pin(s). Microbridge provides ***Rejust-it*** software to facilitate adjusting. Adjusting can be performed in the factory or in the field. Factory adjusting includes adjustment during final assembly, during ATE testing, or at probe for wafers and die.

Rejustors offer the lowest noise and the widest bandwidth of any adjustable resistor technology. The resistance provides continuous value adjustment (not discrete steps which are offered with digital pots). As an electrically adjustable device, the resistance can be set after the circuit is fully assembled, including potting and encapsulation prior to adjustment. In this way, all parasitic effects are considered when calibrating the assembly. Low-TCR Rejustors are designed with low initial TCR, and provide minimal TCR variation across the adjustment range. These devices are specified for operation from 0℃ to 70℃, but are suitable for use from below -40℃ to above +125℃.

This application note provides an introduction to ***Rejustors*** including physical characteristics, typical performance and applications. An overview of ***Rejust-it*** software is also provided.

2 *Rejustor* Basics

A ***Rejustor*** contains two basic elements – the resistor and adjustment element. The schematic symbol for the basic ***Rejustor*** is shown in Figure 1.

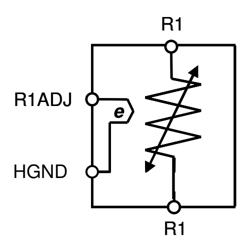

Figure 1: *Rejustor* Schematic Symbol

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The resistive element in the ***Rejustor*** is a simple passive, bi-directional resistor made of poly-silicon material with behaviour similar to a thin-film resistor. Precision adjustment of the resistance of each ***Rejustor*** is accomplished during calibration by means of a proprietary process which adjusts the resistive poly-silicon element by applying analog pulses to the adjustment pins in a closed-loop system under control of ***Rejustor*** Calibration tools and Rejust-it software. After adjustment, the calibrated ***Rejustor*** is stable from -40°C to +125°C. The adjustment elements are only required during adjustment of the device.

The advantage of the ***Rejustor*** is that it provides reliable, consistent behavior over temperature, a requirement in the automotive industry. The ***Rejustor*** has no moving parts, unlike a potentiometer, and cannot be adjusted in the field unless the operator is using factory-approved adjusting equipment. The ***Rejustor*** is the only analog resistor than can be adjusted in-circuit with simple, electrical signals. The adjustment pins are electrically isolated from the resistive element to facilitate in-circuit adjustment.

In some applications it may be desirable that the ***Rejustor*** not be adjustable after final assembly. In this case, the adjustment pins need not be made available after wafer probe or ATE, although it is recommended to connect HGND to analog ground. Denying access to the adjust pins provides a lock-out to prevent accidental adjustment of the ***Rejustor***.

Like resistors, ***Rejustors*** operate across the frequency spectrum from low frequency, such as sensors, to high frequency such as RF circuitry in wireless base stations. High-frequency response of the ***Rejustor*** is limited by the package. The ***Rejustor*** element itself maintains its resistive characteristics into the hundreds of megahertz. ***Rejustors*** also offer the lowest noise of any adjustable resistive technology.

2.1 MEMS Technology

Rejustors are fabricated in a standard CMOS process using MEMS techniques applied after the main IC process is finished. They are available packaged, in die form, or may be licensed as IP (intellectual Property) for incorporation with other semiconductor devices. Micro-Electro-Mechanical Systems (MEMS) are the integration of mechanical elements and electronics on a common silicon substrate through micro-fabrication techniques.

The semiconductor processes required to manufacture ***Rejustors*** can be integrated on the same die with standard CMOS devices, and have been developed for standard-CMOS manufacturers.

2.2 Adjustment Range

Rejustors are specified at a nominal as-manufactured resistance. The adjustable range is at-least 30% down from the as-manufactured resistance. For example, a 10KΩ ***Rejustor*** can be adjusted down to 7KΩ. ***Rejustors*** are adjustable bi-directionally; however physics in the ***Rejustor*** structure and material limits the ability to adjust the ***Rejustor*** back to its nominal value.

The up adjustment range is constrained to 1.5% to 5% of the absolute adjustment range. For example a 10KΩ ***Rejustor*** adjusted down 10% (to 9KΩ) could be adjusted as high as 2% up (to 9.2KΩ). The same ***Rejustor*** adjusted down 30% (to 7KΩ) could be adjusted up about 5% (to 7.4KΩ).

2.3 Stability

Adjusting a ***Rejustor*** changes the physical properties of the resistive element. The material properties of the resistive element are altered to cause a change in the electrical performance of the device. Once adjusted, the ***Rejustor*** maintains these physical properties across operating temperature and storage temperature. The material properties of the ***Rejustor*** do not change further unless the device is re-adjusted or exposed to temperatures beyond the specified maximum ratings. ***Rejustor*** annealing algorithms built into *Rejust-it* software automatically perform a post-process anneal to improve stability. This special sequence of pulses can improve long term stability by a factor of 2 to 5 times. Annealing also improves relative drift (between multiple ***Rejustors*** on the same die) by a factor of 5.

Rejustor drift is always positive (from the final adjusted value) and is typically 0.5[1]% or better.

2.4 Accuracy and Precision

The ***Rejustor*** has the same behavior as any passive resistor with the exception that it is adjustable. In principle, infinitely-high precision and accuracy are possible. In practice, the precision and accuracy of adjusting is determined by the measurement equipment, hardware resolution, noise and application circuit in which the ***Rejustor*** is embedded.

2.5 Repeatability

Rejustors can be adjusted dozens of times, where an adjust cycle may have multiple adjusting steps as shown in Figure 4. Adjusting is generally bi-directional, except within a few percent of the as-manufactured value.

2.6 Noise

Relative ***Rejustor*** noise has been analyzed by comparing the ***Rejustors*** to other precision and adjustable resistors. ***Rejustor*** noise is similar to that observed for thick-film resistors. ***Rejustor*** noise is significantly less than potentiometers and digital-pots. Observed noise for the Low-TCR Rejustor is 1.7μV/√Hz. ***Rejustors*** offer the lowest noise adjustable resistance technology.

2.7 Bandwidth

Operation of the ***Rejustor*** die has been confirmed well beyond 100MHz. High-frequency performance of a packaged Rejustor is limited by the capacitance and inductance of the package (refer to datasheets).

2.8 Rejustor TCR

The ***Rejustor*** was designed with TCR in mind. Low-TCR ***Rejustors*** are designed to maintain their nominal TCR across operating temperature and the 30% adjusting range. Low-TCR ***Rejustors*** are designed with an as-manufactured TCR of 0 ±100ppm/K.

Low-TCR ***Rejustor*** dividers and duals are designed to deliver matching TCR, just like the resistors they replace. This means that an integrated system designed with ***Rejustors*** not only offers the ability to optimize resistance, but also provides excellent temperature stability.

Figure 2, below, provides a graphical representation of ***Rejustor*** TCR precision on the left. Low-TCR ***Rejustors*** are specified as zero TCR with a worst-case (unadjusted) tolerance ±100ppm/K.

The figure on the right shows the relative difference between unadjusted ***Rejustors*** in a matched-pair (divider and discrete) will be ±50ppm/K within the absolute range of ±100ppm/K. (The figure shows an absolute offset of approximately -30ppm/K.)

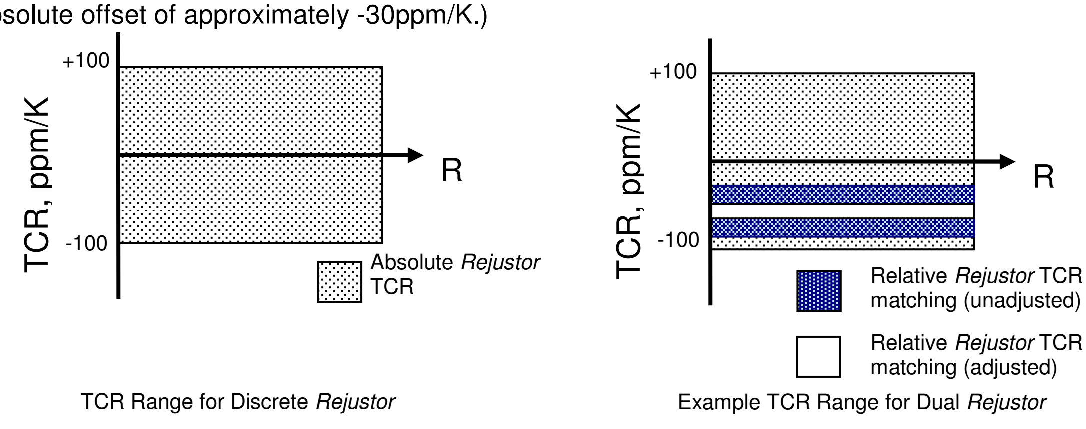

Figure 2: *Rejustor* TCR Precision

[1] Drift specifications refer to resistance drift in the positive direction. Best performance is achieved at adjustments larger than 10% down from the as-manufactured resistance.

It is important to consider that both ***Rejustors*** in a divider or dual must be adjusted at least 5% in order to improve resistance stability. Low-TCR duals and dividers follow the same drift profile, improving the relative drift by an order of magnitude to 0.1% lifetime drift.

Additionally, ***Rejustors*** in a matched pair maintain relative TCR within ±10ppm/K or better. This means that pairs of Low-TCR ***Rejustors*** are virtually immune to temperature changes. This is important in applications such as voltage regulator adjustment (see Figure 6) where the relative difference between two ***Rejustors*** will not deviate as a function of temperature or lifetime drift.

Low-TCR ***Rejustors*** maintain absolute TCR at 0±100ppm/K across the normal operating and adjustment ranges. Pairs of ***Rejustors*** (adjusted and unadjusted) within the same package maintain a relative TCR in the range of ±50ppm/K. These TCR specifications are based on linear (first-order) temperature coefficients (commonly referred to as TC1). Within the 0 to 70°C operating range, TC1 is a sufficient approximation of the temperature behavior, (the 2^{nd}-order coefficient is +1ppm/K^2 or less). Over the -40°C to +125°C range, the full second-order behavior of resistance vs. temperature (R vs. T) should be considered.

3 Rejustor Adjustment with Rejust-it Software

Rejustors are adjusted by applying controlled analog voltages between the ADJ and HGND pins. The voltage is in the range of 2.0 to 11V with a typical power of 40mW. The adjustment voltage is applied as a stream of pulses with varying amplitude and pulse width. Typical pulse duration ranges from 5 to 200msec. The proprietary ***Rejust-it*** software application from Microbridge makes it quick and easy to adjust ***Rejustors*** and can be easily incorporated into standard production test equipment.

Rejustor Calibration Tools are available that consists of ***Rejust-it*** hardware and software. The LabVIEW™ compatible ***Rejust-it*** software provided as royalty-free executable, loads onto a PC and will operate under Windows® on an IBM-compatible PC. ***Rejustor*** Calibration Tools include a power-supply, a USB cable, to interface to the host computer and ***Rejustor*** samples. The calibration tools interface to the circuit containing the ***Rejustors*** through a cable. Microbridge provides the mating connector to facilitate this operation. For more information on ***Rejust-it***, refer to the Calibration Tool user manual (MBK-408-User_Manual).

An example connection between the ***Rejustor*** and the ***Rejustor*** Calibration Tool is shown in Figure 4. Note that these connections are only required during the calibration process. After adjustment, the auxiliary pins are not required and can be left open or grounded.

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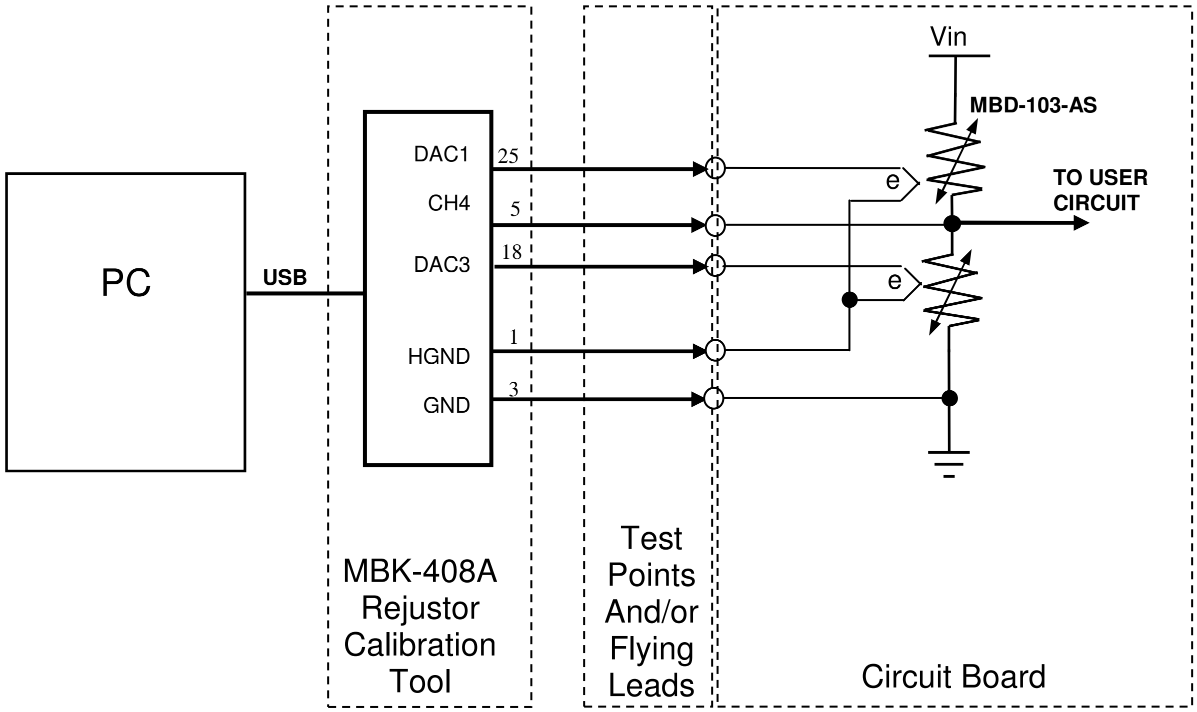

Figure 3: Rejustor Hardware Connection

Rejustor Calibration Tools contain Analog-to-Digital Converters (ADC) which are used to measure the output of the circuit being adjusted by the ***Rejustor***. They also incorporate Digital-to-Analog Converters (DAC) to provide the pulse stream to adjust the ***Rejustor***. Adjusting is performed through an iterative closed loop which measures the output of the circuit-under-test then adjusts the resistance until the desired precision is achieved as shown in Figure 4.

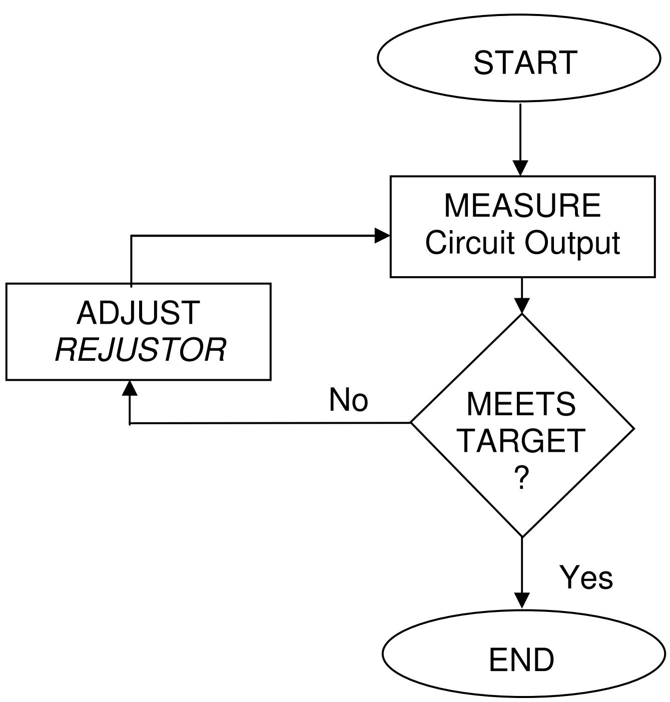

Figure 4: *Rejust-it* Flow Diagram

Adjusting time varies directly with the desired precision and stability. Typical adjustment time is one second. Absolute accuracy of the ***Rejustor*** is limited by the accuracy of the measuring equipment.

4 *Rejustor* Product Families

Rejustor devices are available in package or die form, or may be licensed for incorporation with existing semiconductor products.

Microbridge currently offers two families of packaged ***Rejustors***. The MBD-xxx-xS standard family of discrete ***Rejustors*** is nominal 1mW per device. The MBD-xxx-xL family of low-power devices nominally dissipates 1mW between both devices. Standard power products are available in 8-pin SOIC and 16-pin QFN. The Low-power devices are only available in space-saving 16-pin QFN packages. Both families are offered in a variety of resistance values and ratios (the difference in value between two ***Rejustors*** in a package). Refer to individual datasheets for more information.

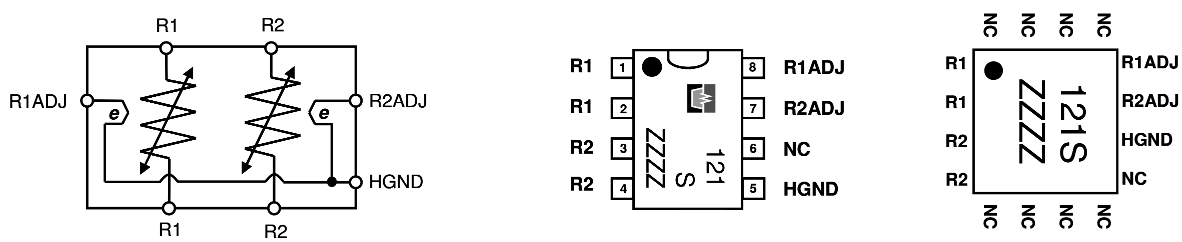

Figure 5: Discrete Resistor Schematic and Package

5 Typical Applications

Rejustors are typically used in sensitive applications to optimize efficiency of the design. For example, the ***Rejustor*** can be used to reduce zero-offset and increase range for a temperature sensor, or the ***Rejustor*** can be used to fine-tune a voltage regulator for high-stability voltage references.

5.1 Voltage Regulator Application

The LM317[2] voltage regulator application in Figure 6 uses a dual 4.7KΩ ***Rejustor*** (MBD-472-AS) as a precision divider to fine tune the output voltage. The output voltage range can be adjusted from 2.5V to 3.3V from a 5V supply.

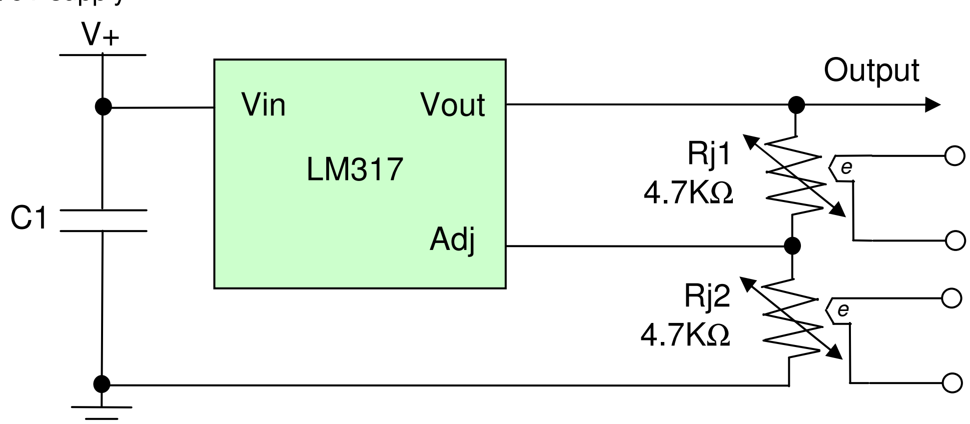

Figure 6: *Rejustor* in Voltage Regulator Application

Manufacturers use a variety of trimming methods to adjust the value of the output voltage at final assembly, including (simplest) manual potentiometers, digital trimming, and laser trimming on thick-film hybrid

[2] LM317 is a product of National Semiconductor Corp.

resistors. Superior precision coupled with ease of adjusting and non-volatile control of the ***Rejustor*** makes it a superior product for any application. Adjusting is easy to achieve in the factory or in the field. The mid-point output voltage can be adjusted up or down from its nominal value. Matched TCR between the ***Rejustor*** pair reduces temperature-induced offset variability. There are no mechanical parts to wear-out or spark. Unlike configurable resistor arrays, the ***Rejustor*** can be adjusted dozens of times without reducing precision.

5.2 Optical Transmitter Application

The example in Figure 7 demonstrates ***Rejustor*** control for all the adjustments available with the MAX3738[3], 155Mbps to 2.7Gbps SFF/SFP Laser Driver with Extinction Ratio Control. The ***Rejustor*** connected to APCSET sets the desired optical power or bias current for the laser. The modulation amplitude is controlled with the 15KΩ ***Rejustor*** on MODSET.

A 15KΩ ***Rejustor*** on APCSET configures the average optical power in conjunction with the laser's back-facet detector. The modulation range combined with average optical power sets the extinction ratio. Modulation range is adjusted with a 15KΩ ***Rejustor*** on MODSET. Therefore, the extinction ratio can be adjusted using a Dual ***Rejustor*** MBD-153-AS[4].

The ***Rejustors*** on PC_MON and BC_MON are adjusted to cause a logic threshold change when the current exceeds the maximum design specification. The MBD-103-AS Dual 10KΩ ***Rejustor*** was chosen to set the maximum photodetector current (PC_MON) at 300µA and maximum bias current (BC_MON) in the range of 30mA. These values are dependant on the relationships provided in the laser datasheet.

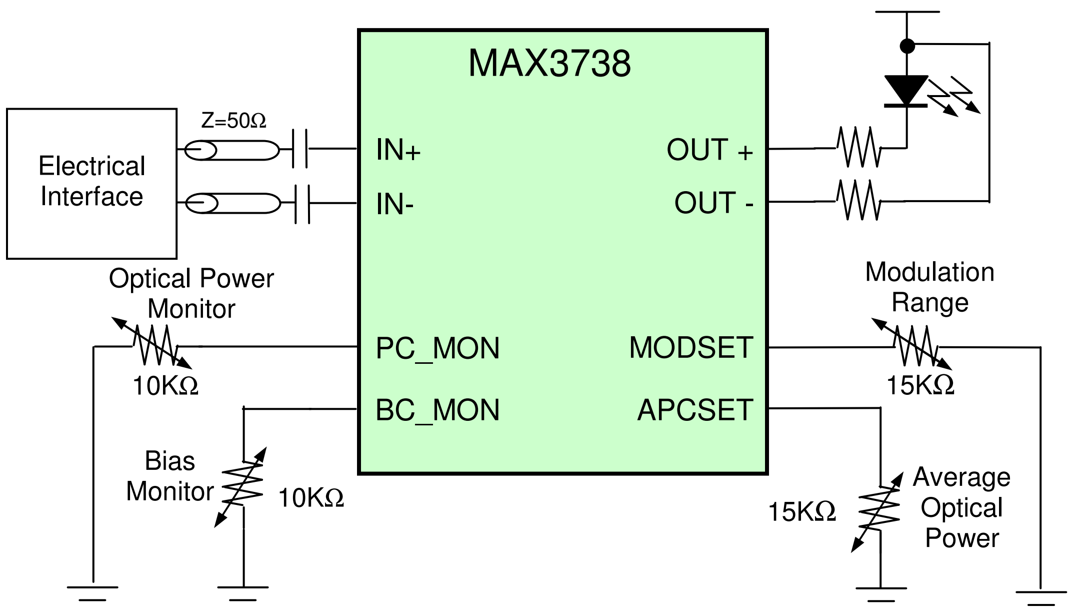

Figure 7: *Rejustor* Biased Laser Driver (details omitted for clarity)

The ***Rejustor*** based design provides a wide range of adjustment for laser bias current. Typically a given laser operates within a much narrower adjustment range. The 30% adjustment range of the ***Rejustor*** does not limit its use in this application. The re-adjustable bias current resistor can be re-calibrated as the laser ages. Custom tools could be deployed in the field to extend the life of older transmitters. Alternatively ***Rejustors*** become set-and-forget by removing or burying the auxiliary pins at final assembly.

In a production environment each laser and driver can be quickly calibrated and re-calibrated as required.

[3] MAX3738 is a product of Maxim Integrated Products, Inc.
[4] *Rejustor* value is dependant upon the characteristics of the laser. Consult product datasheets for more information

6 Availability

Rejustors are available now. Consult your local sales office, or contact Microbridge Technologies at 1-888-***Rejustor*** (1-888-735-8786) extension 1 or www.microbridgetech.com.

7 Summary

This application note introduced the Low-TCR ***Rejustor*** as a high-precision adjustable resistor. The ***Rejustor*** requires a new schematic symbol to include its auxiliary pin(s). After adjustment, the electrical behavior of the ***Rejustor*** is identical to that of a pure resistor across a broad frequency spectrum (DC to >100MHz).

The ***Rejustor*** is adjusted using LabVIEW-based ***Rejust-it*** software which consists of an adjusting box or circuit board and an intuitive software system that runs on Windows based platforms. ***Rejustor*** adjusting precision and stability is only limited by the time available to adjust the component, and by the circuit in which the ***Rejustor*** is embedded. Accuracy is limited by external test equipment.

The ***Rejustor*** is uniquely positioned within the adjustable resistor market because it allows for operation in the -40 to +125°C range and beyond, providing the application can tolerate relatively small increases in the overall resistance of the ***Rejustor*** away from the value to which it was adjusted in the 0 to 70°C range. Extended temperature operation facilitates ***Rejustor*** use in automotive markets and other harsh environments.

Rejustors provide continuous value resistance adjustment offering superior precision and reliability when compared to trim pots and digital pots. As an electrically adjustable device, the resistance can be adjusted after packaging or encapsulation, thereby incorporating any packaging parasitics in the calibrated value. No alignment or access points are required as is the case with laser-trimmed resistors. ***Rejustors*** also provide the widest bandwidth and the lowest noise of any adjustable resistor.

Microbridge Technologies are offering standard and low-power families of the Low-TCR ***Rejustor***. Standard products are available in 8-pin SOIC or 16-pin QFN packages and nominally dissipate 1mW per device. Low-power devices are offered in space-saving 16-pin QFN packages and nominally dissipate 1mW between both devices. ***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.