



Using Laser Trimmable Resistors

By Thomas Bluhm

PURPOSE AND APPROACH

Recently, trimmable resistors have been in high demand due to their properties. Many manufacturers of electronic equipment see the benefits of using these components in theory; however, the results can be quite different in practice without knowledge of laser trimming technology. To fully realize the benefits of these devices, it is necessary to carefully set up and control the trimming process, which will also greatly influence the component's achievable performance. This paper will explore trimmable resistors and the trimming process.

MAIN APPLICATIONS

Trimmable resistors are intended to be used in all applications requiring an initial calibration, such as operational amplifiers, sensors, voltage dividers, and oscillators. This technique enables parametric values of the circuitry to be realized by trimming the resistance value. They can be used as substitutions for trimming potentiometers or manually selected precision fixed resistors to calibrate an electronic device. The main advantages are the possible functional adjustment (e.g. trimming of the output frequency of an oscillator instead of the resistance value), the higher reliability of a component without movable parts, and the pick-and-place capability of a high-volume passive component. Other benefits include cost reductions, PCB space savings, and the full automatic in-line trimming process with reduced tuning time.

TYPICAL CONSTRUCTION

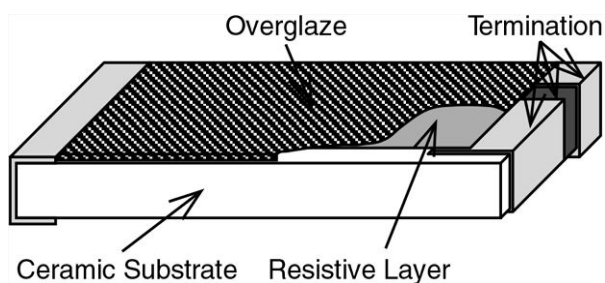


Fig. 1 - Typical construction of a trimmable resistor

Figure 1 shows the typical construction of a trimmable resistor, which is similar to an untrimmed thick film chip resistor. A resistive layer is printed, followed by an overglaze, on a ceramic substrate. The construction of the terminations usually contains different layers, a pre-contact and a nickel barrier covered by a pure tin finish. The resistance increases as a trimming kerf is cut in the resistive layer. The material is vaporized with a controlled laser beam. The ratio of the trimmed to the untrimmed value (= trim factor) depends on the trimming geometry.

The material used and the thickness of the resistive layer, as well as the detailed construction of the terminations, vary from manufacturer to manufacturer. This leads to different properties in terms of temperature coefficient and long-term stability.

ACTIVE OR PASSIVE TRIM?

A passive trim is used if a determined resistance value is needed. The advantage is that only a resistance bridge for the measurement is required.

Many more opportunities are given to the user with an active or functional trim. The circuitry is set to a specific parameter, such as a DC or AC voltage, the output frequency of an oscillator, or the trigger of a proximity switch. The actual resistance value is then unimportant. The trimming system is often capable of being integrated into an existing measurement system.

For the active trim, a continuous trim or a step-by-step trim can be used. If measuring the nominal value leads to a comparator signal, this signal can control the laser directly. If the data transfer speed is high enough, a continuous trim is also possible. Otherwise the adjustment will be done step-by-step. After the first measurement of the required parameter, the length of the cut is calculated depending on the deviation from the final value. After trimming this length, the parameter is measured again. This loop runs as long as there is a difference between the desired and measured values.

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DATA BOOK INFORMATION

For all fixed film resistors, performance mainly depends on the resistive layer, the terminations, and the trimming. The objective is to get a high-reliability component with long-term stability and well-determined, reproducible characteristics.

Data book information gives a first overview about available products. The table below shows a summary of the data on trimmable resistors according to data books of different manufacturers.

ELECTRICAL DATA OF LASER TRIMMABLE RESISTORS (UNTRIMMED) ACCORDING TO DATA BOOKS	
PARAMETER	VALUE
Component size	0603, 0805, 1206
Resistance range	1 Ω to 10 M Ω
Tolerance	$\pm 5\%$ / $\pm 10\%$ / $\pm 20\%$ / $\pm 30\%$ 0 % to - 10 % / - 20 % / - 30 %
Rated power P_{70}	63 mW to 250 mW
Maximum operating voltage	50 V to 200 V
Temperature coefficient	50 ppm/K to 250 ppm/K
Endurance (1000 h at P_{70})	1 % to 2 %
Damp heat, steady state	0.5 % to 2 %

As shown, there is a wide variety of products with different electrical properties. This is mainly caused by the materials used and the detailed construction of the component. Also noticeable is that most of the manufacturers only give basic electrical values, such as resistance value, tolerance, and temperature coefficient. This is due to the fact that other performance parameters such as overload and long-term stability depend on the trimming. As a result, data book information can only be used to pre-select the component.

TRIMMING

The optimal trimming geometry depends on the detailed requirements:

- High trim speed
 - High accuracy of trimming
 - Long-term stability and high reliability
 - Wide range of trim factors to minimize positions in stock
- Often a compromise has to be made. For example, a high trim speed usually works against a high accuracy of trimming.

To meet the given requirements, resistors may be trimmed in a number of ways. Figure 2 shows the most commonly used ones.

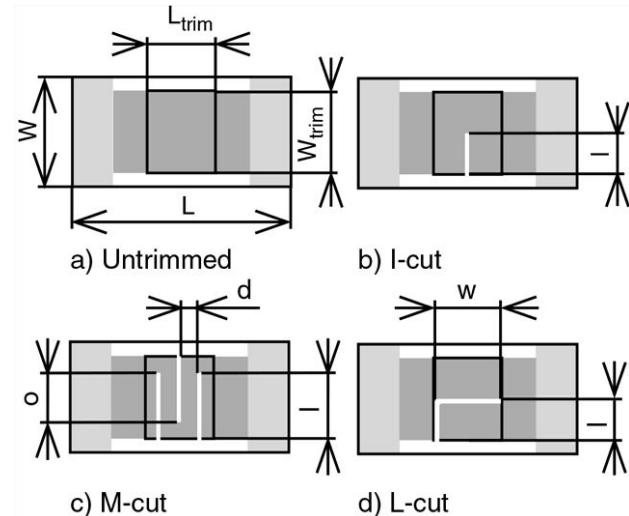


Fig. 2 - Commonly used trimming geometries

All of the requirements mentioned above are influenced by the trimming geometry. The table below shows the relationships in general.

PROS AND CONS OF DIFFERENT TRIMMING GEOMETRIES			
PARAMETER	I-CUT	L-CUT	M-CUT
Trim speed ⁽¹⁾	+++	++	+
Accuracy	+	+++	++
Long term stability	+	++	+
Trim factor	+	+	+++

Note

⁽¹⁾ In contrast to the below mentioned trim speed of the laser beam, these values refer to the speed of trimming the whole component.

The I-cut is the fastest and simplest cut. The disadvantage is a low accuracy compared to other trimming geometries. To achieve a higher trimming accuracy without extending the trimming time by much, the trim speed can often be reduced when the final value is nearly reached. The trim cut should be placed in the middle of the resistor length. The achievable trim factor is lower than 2.

The L-cut is an alternative cut to improve the trimming accuracy. The part perpendicular to the resistor length (dimension l) roughly sets a resistance value below the desired value. The final trim is then done by cutting a second part parallel to the resistor length (dimension w). The first part should start at one of the sides of the given trimming window and should be as short as possible (10 % to 30 % of the length of the whole cut), whereas the other part should be as long as possible (90 % to 70 %). Again, the maximum trim factor is about 2.

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The functional trim in particular often requires a high change in resistance, making the M-(meander) cut the first choice. Due to the wide variation of the parameter number of cuts, length of cuts, and distance between cuts, a wide range of trim factors can be obtained. To achieve a good performance of the M-trimmed resistor, the material for the resistive layer has to be selected very carefully by the component's manufacturer. It has to be very tolerant against the trimming process. For that reason, this cut is probably not applicable to some of the offered components. The maximum trim factor can exceed 20.

Below table gives achievable trim factors, depending on the dimensions of the cut, for two examined trimmable resistors: TCT 0603 and TCU 0805.

TRIM FACTOR VS. CUT DIMENSIONS in mm							
PARAMETER		TCT 0603			TCU 0805		
		l	w/d	TF	l	w/d	TF
I	20 %	0.14	-	1.2	0.25	-	1.1
	50 %	0.25	-	1.4	0,40	-	1.4
	80%	0.40	-	2	0,60	-	2.1
L		0.25	0.13	1.8	0.40	0.40	1.9
M3	Wide	0.40	0.25	5.3	0.60	0.30	4.8
	Narrow	0.40	0.12	9.3	-	-	-
M4		0.40	0.25	10	-	-	-
M5		-	-	-	0.60	0.15	16

Notes

- For the definitions of dimensions refer to "Trimming"
- TF - Trim Factor
- M_ - M-cut, 3/4/5 meander

The trim factors are nearly the same for both TCU 0805 and TCT 0603 using the same geometry, due to the comparable length-to-width ratio of the resistive layer. The difference is that the TCU 0805 can be trimmed with up to five meander cuts compared to the TCT 0603, which has a maximum of four cuts.

TRIMMING EQUIPMENT

The trimming is done by using a pulse-mode-driven Nd-YAG (Neodymium-Yttrium Aluminium Garnet) laser with the following parameters.

TYPICAL LASER PARAMETER	
PARAMETER	VALUE
Average power	1 W to 10 W
Wavelength	1064 nm
Q-rate	1 kHz to 20 kHz
Trim speed	1 mm/s to 300 mm/s
Spot size	25 µm to 50 µm

The advantage of this laser is the low absorption of the beam on the ceramic substrate (alumina). Several lamp-pumped and diode-pumped lasers are available from different vendors. Laser power is controlled by setting the lamp current. CO₂ lasers should be avoided, because the wavelength of the beam is more suitable to cutting alumina than resistive material.

A beam positioning system is used to focus the laser beam and to move it to the working area. A special optic guarantees that the laser beam is always focused. In addition to the laser, the trimming station contains a vision system that looks for the actual position of the component to be trimmed.

Circuit handling is performed by a step-and-repeat table, a manual one-position handler, or by integration into a measurement system.

The required measurement device depends on the value to be set, such as resistance, current, voltage, frequency, S-parameter, etc. It may be a resistance bridge, frequency counter, voltmeter, network analyzer, or a number of other devices. Often the measurement system is controlled using an IEEE 488-system.

The equipment may also be used for trimming capacitors or cutting conductors.

SETTING UP LASER PARAMETERS

The laser has to be set up to achieve a smooth kerf without leaving any resistive material and without damaging the ceramic body. It has to be taken into consideration that the thickness of the resistive layer and the overglaze differ from manufacturer to manufacturer. The critical parameters are laser power, energy density, Q-rate, and trim speed or bite size.

$$\text{Bite Size} = \frac{\text{Trim Speed}}{\text{Q-Rate}} \quad [\mu\text{m}]$$

$$\text{Overlap} = \frac{\text{Spot Size} - \text{Bite Size}}{\text{Spot Size}} \times 100 \%$$

$$\text{Energy per Pulse} = \frac{\text{Power}}{\text{Q-Rate}} \quad [\text{mJ}]$$

$$\begin{aligned} \text{Energy Density} &= \frac{\text{Power}}{\text{Trim Speed} \times \text{Bite Size}} \\ &= \frac{\text{Power} \times \text{Q-Rate}}{(\text{Trim Speed})^2} \quad [\text{J}/\text{mm}^2] \end{aligned}$$

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Starting with the given parameters for trim speed and Q-rate of the trimming equipment, a bite size has to be found. The overlap should be at least 40 %. As shown in Figure 3 below, the bite size influences the smoothness of the kerf. An overlap of 40 % means 10 % roughness on each side related to the spot size. A rough cut leads to poor performance, mainly in terms of non-linearity and pulse load stability. As an extreme, Figure 3c shows a trim cut with an overlap of only 10 % and the resulting very rough trimming kerf. 60 % overlap is a good compromise for a smooth trim and sufficient trimming speed. The roughness related to the spot size is then less than 5 % on each side. For an overlap percentage of more than 90 %, the laser beam is likely to damage the ceramic body due to heat penetration.

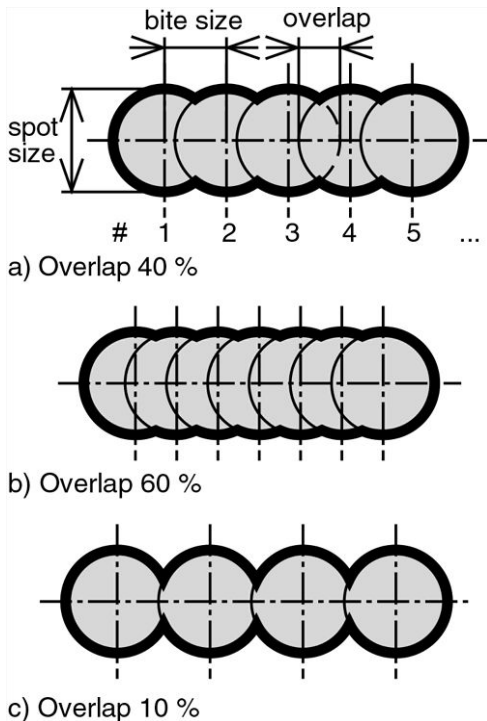


Fig. 3 - Relationship between bite size, overlap and spot size

Next, the laser power has to be set. Only sufficient peak power leads to a complete vaporization of the resistive material. Otherwise, the resulting “dirty” kerf leads to poor resistor performance. The given laser power varies depending on the Q-rate. The higher the Q-rate, the lower the peak power and the higher the average power. In production, the trimming process can be sped up using a high trim speed. A sufficient overlap requires a high Q-rate linked with a high average power. This may heat up the ceramic body and induce micro cracks. Considering this, a compromise between high peak power and high trim speed has to be found.

The amount of energy density therefore provides a guideline for determining if calculated values are too low or too high. Again, low energy won't vaporize the resistive material, while high energy will probably damage the ceramic body. The permitted range of energy has to be found on a case-by-case basis, as it strongly depends on the laser equipment used and the component to be trimmed.

The calculated settings are intended to be used as a starting point, since the performance varies from station to station. A system of statistical process control (SPC) should be established to ensure the consistent output power of a laser over time and from station to station. Table 5 provides five examples of laser parameter sets.

EXAMPLES OF LASER PARAMETER SETS

PARAMETER	UNIT	#1	#2 ⁽¹⁾	#3	#4 ⁽¹⁾	#5 ⁽¹⁾
Power (avg.)	W	3	3	1.5	1.5	1
Q-rate	kHz	6	6	4	4	2
Trim speed	mm/s	48	24	24	48	8
Spot size	µm	30	30	30	30	30
Bite size	µm	8	4	6	12	4
Overlap	%	73	87	80	60	87
Energy per pulse	mJ	0.5	0.5	0.4	0.4	0.5
Energy density	J/mm ²	8	31!	10	2.6	31!

Note

⁽¹⁾ Not recommended, see text

Example 1 is calculated for a high trim speed, resulting in limited trimming accuracy. Reducing the speed by half will increase the accuracy, but the resulting energy density may be too high. With lower values for power and Q-rate (Example 3) and a reduced trim speed, the energy density may be sufficient. But now we find a value for the higher trim speed that is too low. Certainly, there is a solution with optimized parameters. These examples only provide an idea of which problems have to be considered.

Finally, Example 5 shows that with too low power and trim speed, the energy density may become too high.

Remarkably, all parameter sets have the required overlap of at least 60 %. The energy per pulse is nearly the same.

THE TRIMMING PROCESS

First, the component's position has to be found. Using a vision system allows at least the edges of the component in x- and y-directions to be determined. The system looks for the transition of the darker resistive layer to the lighter ceramic body or termination. Determining the rotation of the component, caused by the soldering process, requires further effort.



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Next the component is trimmed to the nominal resistance value (passive trim) or to a given parameter such as frequency or gain (active trim). The following factors have to be considered:

- The resistive layer has to be vaporized while minimizing the penetration into the underlying ceramic.
- The laser beam must be in focus. Otherwise the power density decreases rapidly, resulting in incomplete material removal and an odd shaped kerf.
- Avoid cutting into the termination. The silver contained in it will migrate and cause poor long-term stability.
- Avoid pinching of the current path. The length of the kerf for single-sided cuts (I and L) in particular should not exceed 50 % of the chip width. Otherwise a hot spot is generated, causing increased resistance drift.
- There has to be a significant overlap for M-cuts. Disregarding this point leads to poor long-term stability due to the current flow.
- There has to be a sufficiently wide current path left with M-cuts. The cut length and the distance between should be chosen so there is at least a conductive path of 0.12 mm.

Some manufacturers may have further constraints.

PERFORMANCE FOR UNTRIMMED AND TRIMMED RESISTORS

Tests were conducted on TCT 0603 trimmable resistors to investigate their long-term stability and reliability. The components were trimmed to a fixed geometry as given in table "Trim Factor vs. Cut Dimensions".

MEASURED CHANGE IN RESISTANCE $\Delta R/R$ VS. TRIMMING GEOMETRIES FOR TCT 0603		
PARAMETER		$\Delta R/R$
Endurance at 70 °C (0.1 W; 1000 h)	I, L M4 cuts	< ± 0.1 %
	M4	< ± 0.25 %
Damp heat, steady state, accelerated, with bias (85 °C, 85 % RH, 1000 h)	I, L, M4 cuts	< ± 0.1 %
	M3 narrow	< ± 0.5 %
	M3 wide	> ± 0.5 % ⁽¹⁾

Note

⁽¹⁾ For explanation see text

The endurance results prove that the components are perfectly suited to applications that need very good long-term stability, such as sensors, voltage references, and voltage dividers.

An additional coating may or may not be needed to protect the trimmed resistor against moisture. This is determined by the damp heat, steady state test, accelerated test (also

known as the load humidity or 85/85 test). A low change in resistance indicates that an additional coating is not required. However, what caused the strong resistance change in the wide M3 geometry? Further investigations lead to the result that the trimming was not done carefully enough. One of the meander kerfs was cut into the termination.

CONCLUSIONS

Laser trimmable resistors are good alternatives in all applications that need an initial calibration. They are simply constructed, cheap, and standardized components with high achievable performance and reliability. However, utilizing them is much more difficult than with standard fixed resistors or trimming potentiometers. Trimming equipment is required and experience has to be gained.

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APPLICATION NOTE