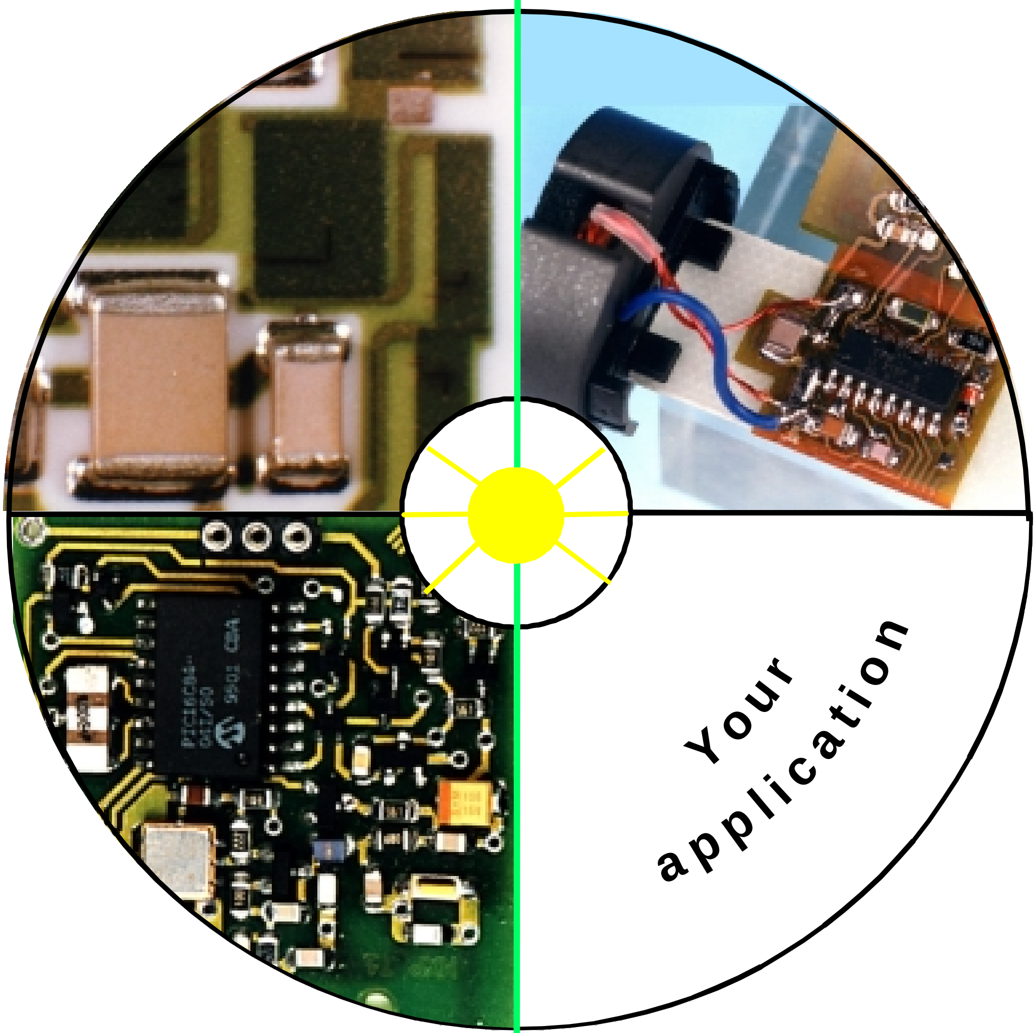
LASER-TRIMMING fast and reliable

Optimise your electronic application



LS

Laser Systems GmbH

Laser trimming
fast and reliable

Optimierse your electronic application

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CONTENT

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fast and relaible

Optimise your electronic application

1. Laser trim - how and why

1.1 Who uses laser trim systems?

Laser trim systems are since many years available on the market. Especially for **thick-** and **thin-film applications** they are always necessary for the production process. Passive trims on hybrid circuits will be done there in large volumes.

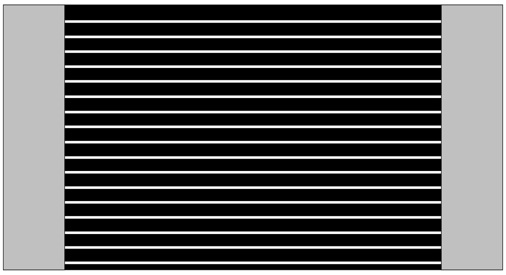
Also in the production process of **chip resistors** in SMD technology laser trim systems are the only possibility to get the given nominal value of the chip resistors fast and reliable. High throughput systems, which are build up for highest production speeds, will be used for these application. They can reach up to 400.000 trims per hour with an accuracy of 1%.

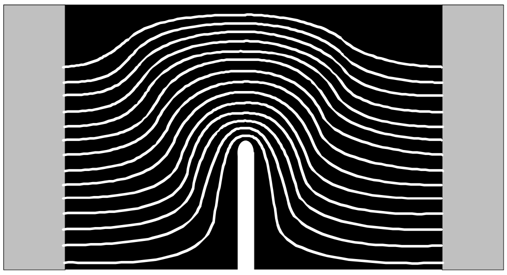
Laser systems for the active trim will be used in the hybrid technology as well as in the **SMD-technology** and for **sensors**. In this area we find a growing field of system integrations. This technology allows the customers of SMD-circuits to replace the extensive selection and resoldering of pre-trimmed chip resistors or the replace of potentiometers. He get a higher reliability and a higher throughput at lower personnel cost.

1.2 What is laser trimming

Laser trimming is the controlled alteration of the attributes of a capacitor or a resistor by a laser beam. Selecting one or more components on the circuit and adjusting them by the laser achieve this. The trim changes the resistor or capacitor value until the nominal value has been reached.

The resistance value of a film resistor is defined by his geometrical dimensions (length, width, height) and the resistor material. A lateral cut in the resistor material by laser narrows the current flow and increases the resistance value. It is unimportant, whether the laser change a thick- or a thin-film resistor on a ceramic substrate or a SMD-resistor on a SMD circuit. The SMD-resistor is produced with the same technology and normally is laser trimmed as well.





Trimmable chip capacitors are build up as multilayer plate capacitors. Vaporising the top layer by a laser decreases the capacitance by reducing the area of the top electrode.

Passive trim is the adjustment of a resistor to a given value. If the trim adjusts the whole circuit output (e.g. output voltage, frequency, switching threshold ...), this is called **active trim**. During the trim process the corresponding parameter is measured continuously and compared to the programmed nominal value. The laser stops automatically when the value reaches the nominal value.

The laser is a flexible tool for trimming and has the following advantages:

- high trim speed
- high trim accuracy
- good long time stability of the resistors
- variable cuts
- simple possibility for active trims

The different possibilities for the laser cuts depend on the resistor size, the resistor material, the passivation, the length/width ratio, the thermal management and the required resistor change.

A laser trim system exists on the following components:

- the laser source
- the beam positioning system
- the circuit handling
- the prober unit
- a measurement system for active/passive trim

1.3 How does an actice trim work?

Especially circuits in SMD technology has to be trimmed to a function. Often customers use potentiometers, which will be adjusted during the end test until the function of the circuit has been reached. In many applications the end user of the products does not allow potentiometers. Therefore manufacturers determine the needed resistance or capacitance values by measurement and calculation methods and afterwards solder the suitable component into the pcb. This procedure is personnel-intensive and has a high error rate.

It is simpler to substitute the **potentiometer** or the **adjust element** by a trimable **chip resistor** or **chip capacitor** and the **screwdriver** by the **laser** and trim active. The achieved accuracy is higher, the procedure could simplier automated and the long time stability is better than at potentiometers or at least in the same region like replace and resolder chip components. Often the laser for the active trim could be integrated in existing measurement places at the customer factories. This means no new programming for the measurement instruments and lower investment cost for the trim system.

For the active trim a continuos trim cut or a step **-** by **-** step trim could be used. When the stop signal of the circuit (reaching the nominal value) could be referred to a comparator signal, this signal could be used to control a continuous trim cut directly. A fast data transfer via the IEEE bus allows also continuous trimming. A simple example is the trim to a nominal voltage or a nominal frequency. Application examples are the adjustment of approximate switches or oscillators. In this applications areas the laser trimming of SMD circuits is much scattered.

A step-by-step trim has to be used, when the trim function could not run via a comparator or signal delay times or measurement times do not allow a continuous trim cut. In this case the current output signal is compared to the given limit and this decides whether a trim cut of a given length should be done. Different limits could change the cut geometry as well as the cut length and guarantee a good accuracy.

A method to reduce the longer trim times at the step-by-step trim is the precalculation of the required trim cut length. Therefore the userhas to know or must determine how the function of the circuit depends on the trim cut length.

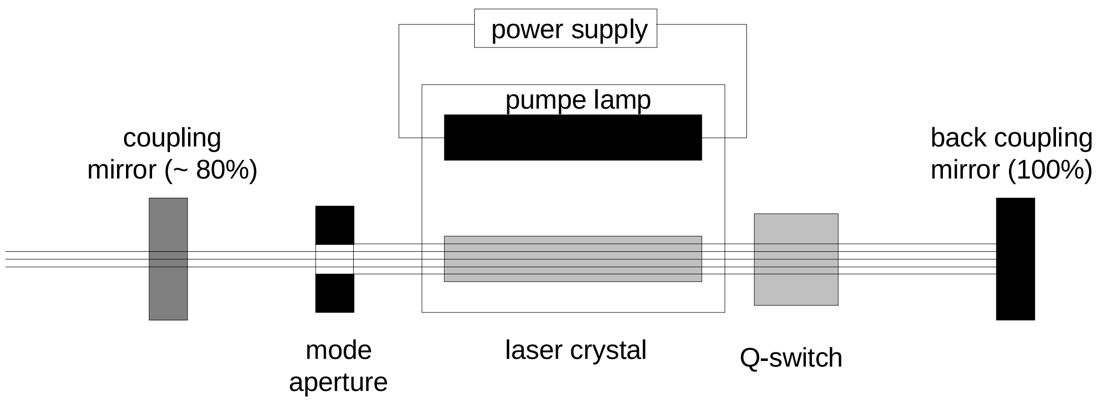
2. The laser, the main part of a trim system

Laser (**L**ight **A**mplification by **S**timulated **E**mission of **R**adiation) is the term for a lot of transmitters and sources of electro-magnetic radiation, which work depending on the same physical principle. The different lasers differ as well in the power (lower one milli watt up to tera watt) as for the radiated wavelength (from the far UV about 0,2 µm up to the far IR to 200µm).

Each laser exists from an optical resonator for the light wave amplification. He includes two mirrors, the active medium and the excitation source, which pumps the electrons and ions to a higher energy level in the active medium. The active medium could be gases (e.g. CO_2), liquids or solid states. For the excitation electrical energy (high voltage) or optical pumping by light waves with a suitable wavelength is used depending to the laser type. The excitation could be impulse formed (impulse laser) or continuously (cw-laser).

For the laser source only lamp-pumped or diode-pumped Nd:YAG lasers are used. The advantage of these lasers is the low absorption of the radiation by the ceramic substrate where the resistors are printed on. This avoids uncontrolled cracks in the resistor structure as much as possible. The main parts of a continuous pumped Nd:YAG laser are:

- the resonator, existing of laser mirrors and laser crystal
- the pump lamp or the laser diodes
- the mode aperture
- the quality switch (Q-Switch)

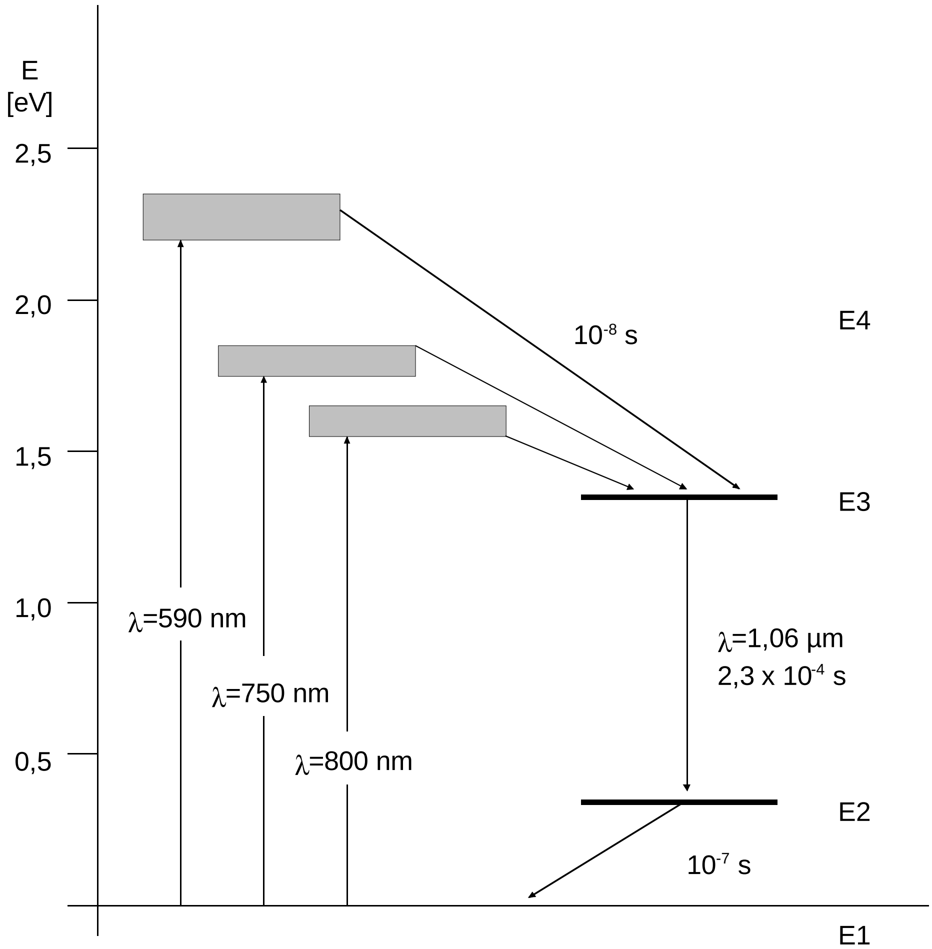


schematic representation of a Nd:YAG laser

The optical resonator, which is required for the use of a laser oscillator, exists of two opposite positioned mirrors. The surface of the coupling mirror is flat. He is semitransparent for the wavelength of the laser beam. The second mirror is flat concave and has a high reflecting dielectric layer, that the wavelength of 1064 nm is nearly reflected to 100%.

2.1 The Nd:YAG laser

Like at the most solid-state lasers, the laser medium of the Nd:YAG laser exists of a crystal that includes the laser active ion. The crystal is the Yttrium-Aluminium-Granat (YAG) that is dotted with Nd^{3+} ions. To get a laser beam out of the Nd:YAG crystal, the atoms must be stimulated in a suitable energy level scheme. The energy scheme of the Nd^{3+} ions is a four level system.



At the ground level E1 nearly all electrons are in the thermal balance (Boltzmann). By absorping energy the Nd^{3+} ion is put up from the ground level E1 to the stimulated level E4. To get back to the ground level E1 the electron moves mostly over the E3 and E2 level. The output of the energy difference between the E4 and E3 and the E2 and E1 level is without any radiation. During the transition from the metastabile E3 level to the E2 level happens spontaneous emission of light. This transition is called laser transition. The energy difference compares to the wavelength of 1064 nm. Depending on the short relaxation time of 10^{-7} s in a four level system a population inversion could easily be produced. This means the number of electrons in the upper laser level (E3) is bigger than in the lower laser level (E2).

2.2 The pump lamp

To stimulate the Neodym ions energy must be given to the laser medium. For the Nd:YAG laser, like at all solid state lasers, optical pumping is used. This means the pump energy is given by radiation with a suitable light. For the radiation either one or more laser diodes with a suitable wavelength (see four level scheme) or a Krypton lamp could be used.
For continuously operated laser (cw) the pump lamp works in the direct current mode. To start the gas burst inside the lamp an ignition voltage of several kV is required. The laser power corresponds then to the programmed current flow. The lamp produces a continuously spectrum, that reaches from far UV to near IR and additional a group of intensive lines in the area from 750 nm to 900 nm wavelength. The optical pumping of the Nd:YAG laser uses mainly theses spectral lines. Fot this reason the laser needs a cooling section.

2.3 The mode selection

Without mode apertures the laser works in a multi mode. In this case not all stationary waves are aligned exactly to the optical axes. This transversal part of the waves increases the divergence of the laser beam. Therefore the laser has a worser focal diameter. But in the multi mode the laser has the highest laser power. With the help of the mode apertures you can set up the mode selection and the divergence. When all waves ar aligned exactly the laser runs in the so called mono mode. The mono mode has a energy distribution, that corresponds to a Gaussian bell-shaped curve, and the divergence is the lowest one. But the average power is about 1/8 to 1/6 of the power in the multi mode. The mono mode is the only suitable mode for the trim of electronic circuits.

2.4 The quality switch (Q-Switch)

To run the laser in a pulse mode inside of the resonator an acousto-optical Q-switch is used. Therefore the laser can produce in a short time considerable higher energy pulses. The quartz oscillator generates a stabile high frequency of 27 MHz that will be boost to 50 watts at 50 ohms. This frequency produces an acoustical wave in the crystal of the q-switch by using a pieco electrical transformer. This wave deflects the continuous laser beam. The deflection is low, but high enough to reduce the quality of the laser resonator and avoids the laser oscillation. The Q-switch allows a very short turn off time for the laser. The modulation of the high frequency with an external frequency produces the pulse frequency (0.1 to about 50 kHz). This is the main assumption for high accuracy resistor trimming.

3. Parts of a laser trim system

To focus and move the laser beam over the working area. it will be deflected by a beam psoitioning system. For laser trim systems 2-axes mirror galvanometer are a standard. Inside such a deflection unit two mirrors will be moved by the principle of a glavanometer. Therefore only low masses has to be moved. This is important for position and deflection speed. Th egalvanometer prinziple is described in the following part.

To get high power densities and fast speeds, the laser beam must be focussed well after the deflection. When the focal length is fixed, the possible focal diameter depends only of the beam diameter. A suitable beam expansion has therefore influence to the spot size:

(1)	$w_A = w * A$	w_A	= beam diameter after the expansion
		w	= beam diameter before the expansion
		A	= expansion factor
(2)	$w_f = SF_x * f/w_A = SF_x * f/(w*A)$	w_f	= beam diameter at the focus
		SF_x	= beam parameter product
		f	= focal length o fthe lens

This means a expansion about the factor A reduces the spot diameter by 1/A. You have to take care, that the followed components like deflection unit and mirrors do not limit the expanded beam!

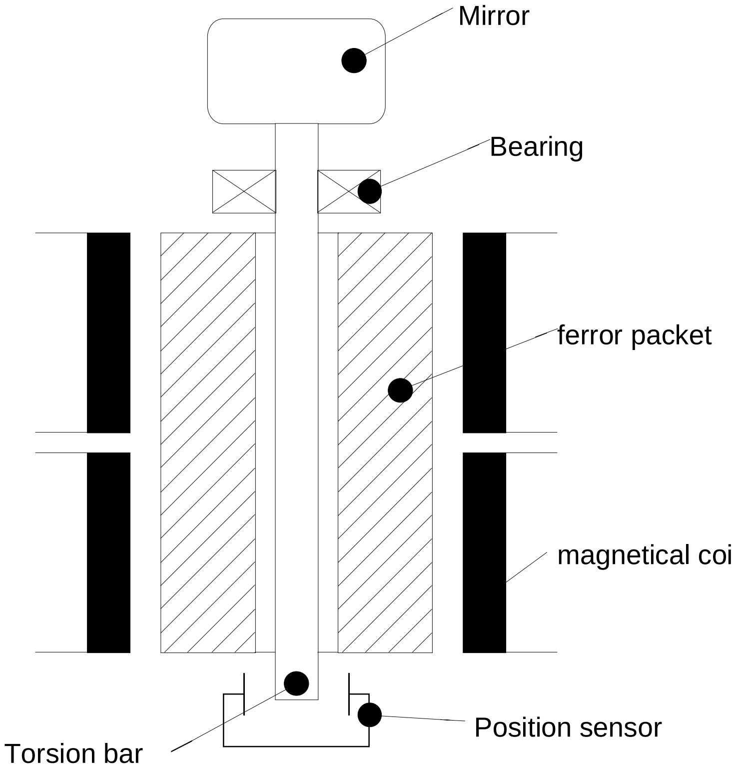
Another important parameter beside the focal diameter is the focal depth. It is defined as the deviation from the ideal focal point, at which the beam intensity is 90% of the maximum value. As higher the focal depth is as mor uncritical is the focal distance and unflatness of the work piece:

(3)	$Z_f = (w_f)^2/SF_x = SF_0*f^2/(w_0*A)^2$	Z_f	= focal depth at the focus

You see the formula (3) is undependend of the beam quality (mode) and only depends on the focal length and the expansion.

3.1 The galvano unit

The galvo unit represents beam deflection. These scanners are electro-magnetic drives with fixed mirrors. A trim system incorporates normally two mirrors to deflect the beam in x- and y-direction. The prinziple of a glavo unit is very simular to a moving-iron instrument.



A at the end fixed torion bar of magnetic material is surrounded from four electrical coils, which mostly are switched parallel. Input of a control current produces a resulting magnetical field, that deflects the torsion bar from its home position, This defliction moves as well the mirror.

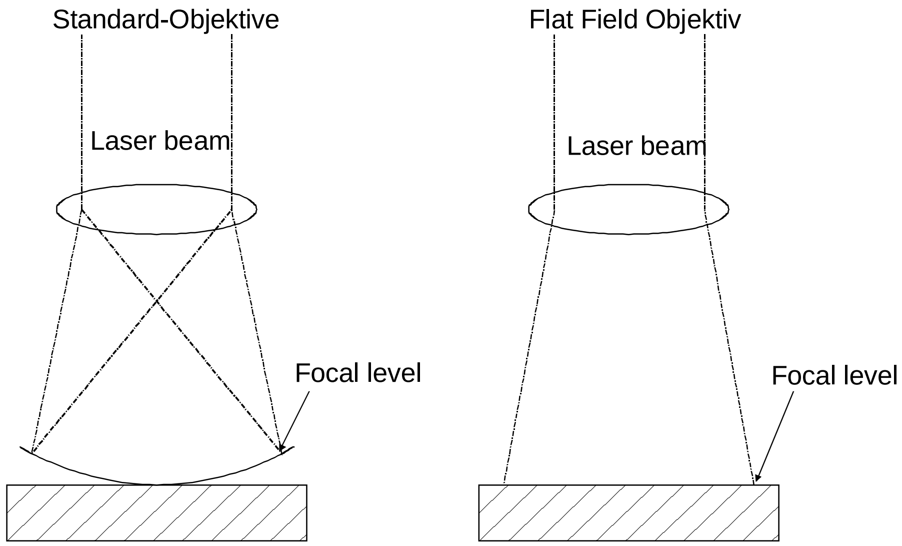
The current could have negativ or positiv values and therefore allows deflections in both directions arround the home position. An integerated position sensor at the end of the torsion bar guaraties a reliable positioning. The deflection of the bar changes the capacitance of a capacitor. This change chamges the amplitude of the ac-volateg at the capacitor. Thes change of the amplitude is used for the position control.

To avoide mechanical drifts caused by temperature changes, the galvo units are temperature stabilised. This allows position accuracies and resolutions in the micro meter range.

Beside the mechanical parts the galvo unit includes as well a control electronic. This control electronic amplifies the voltages (analogue) or signals (digital) from the control units to move the mirrors. Parallel the electronic takes care on the position signal and combindes this signal in a control circuit to the power amplifier. Addition the electronic controls and monitors the temperature stabilisation.

3.2 The flat field objective

After the positioning of the laser beam with the galvo unit the beam will be focussed by the flat field objective. The flat field objectives are optival systems, which have several lenses. This systems control the focus undepending of the deflection in a fixed level.



The important data of the objective are:

- focal length f
- working distance a
- maximum field size F
- minimal Focal diameter d

Depending on the application and the material the corresponding suitable objective has to be choosen. The most suitable falt field objective has a focal length of about 160 mm. For other focal length several parameters must be changed in the user software, because the same deflection causes another position. The following schedule showes some parameters of different objectives.

focal length f/mm	working distance a/mm	field size F/mm²	min. focal diameter w/mm
80 telezent.		50 x 50	< 0,020
100	100	75 x 75	~ 0,025
160	205	110 x 100	~ 0,050
250	340	160 x 160	~ 0,120
300	400	190 x 190	~ 0,170

3.3 The circuit handling

The circuit handling depends usually on the use of the system. For the passive trim of hybrid circuits mostly handler with a step & repeat table, sometimes in connection with an automatical loader is used. For the active trim, especially at SMD circuits, there are lot of possibilities for the handling systems. Handling systems with step & repeat table, manual one position handler and the integration of the laser system into an given measurement system or In-line integration are some of the possibilities. To connect the circuit probes or pins, will be integrated into adapters or probe cards. This contacts are connected to a scanner, which switches the contacts to the measurement system.

3.4 The measurement system

The measurement system for the passive trim is usually a high accuracy measurement bridge. Sometimes for active trims it is possible to measure voltages by the measurement bridge as well as resistance. Complex trim instructions for an active trim need mostly external instruments, which will be controlled by IEEE bus. The exact dimensions of the measurment system is customised and depends on the given application. Important is a stabil mess signal with short measuring times. Only this allows a fast trim.

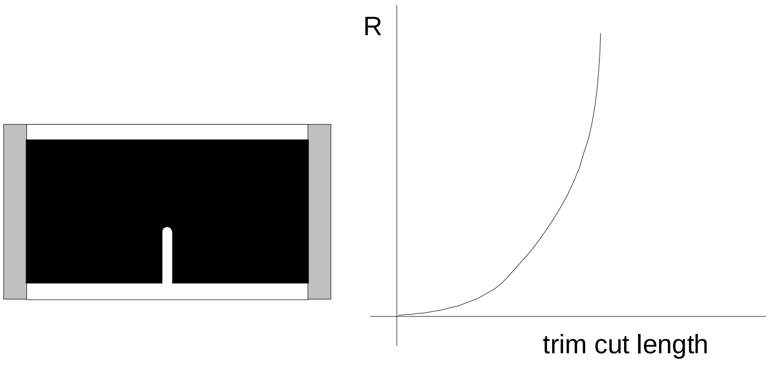
4. Which trim cuts are available?

The form of the trim cut determines the trim speed, the reachable trim accuracy and the electrical attributes of the trimmed resistors, like long time stability, current noise and temperature coefficient. General is valid, the higher the resistor variation by trimming, the worse the electrical attributes will be. To get highest accuracy (± 0,1%) for a long time, the resistors should be pre-trimmed to about 1% and then temperature stored (500h at 150 °C) and at least fine-trimmed. In the following schedule you see the different trim cuts and their attributes. To measure the long time stability the resistors has been stored for 1000h at 85°C and 85% relative humidity. The given value are evidences, which can vary depending on the resistor material, the resistor variation and the laser parameters.

Cut form	L/B	Trim time	Trim accuracy	Long time stability
I-Cut	< 1,5	fast	±0,50%	0,20%
L-Cut	> 1,5	medium	±0,30%	0,30%
D-Cut	< 2,5	medium	±0,20%	0,20%
M-Cut	> 2,0	medium	±0,30%	0,50%
U-Cut	> 1,5	medium	±1,00%	0,30%
Shave-Cut	> 0,2	long	±0,15%	0,30%

4.1 The I-Cut

The I – cut is the simplest and fastest trim cut. The disadvantage of this trim cut is the exponential growth of the resistance during the trim. This gives you a lower trim accuracy. The trim cut should be placed in the middle of the resistor length, to get the maximum variation of the resistance.



Advantage

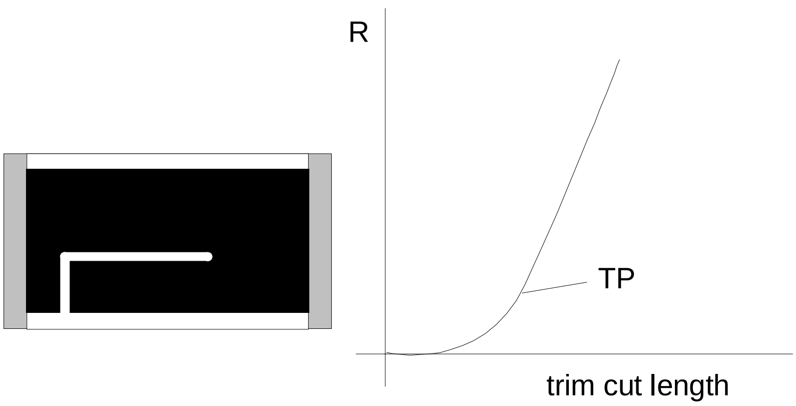
- simple cut
- very fast

Disadvantage

- lower accuracy (about ± 0,50 %)

4.2 The L-Cut

To avoid the exponential growth of the resistance by using the I-cut, you can choose for the trim geometrie a L shape The so called L-cut cuts until a defined resistance, the **turn point**, vertical to the current flow and afterwards parallel to the current flow until the nominal value (**stop point, pre stop**) is reached. Behind the turn point this trim cut shows an almost linear variation of the resistor value with a constant trim sensibility. In the most cases the turn point (TP) is calculated by the percentage deviation of the untrimmed resistance to the nominal value dR/Rnom. A calculated turn point (TPcal) will then be programmed. Typical values for the **calculated turn point** of a L-cut are between **0,1** to **0,4** which corresponds to **10%** to **40%** of resistance deviation for the first cut. The I part of the L-cut should start a minimum distance of 250mm from the connection metallization.



Advantage

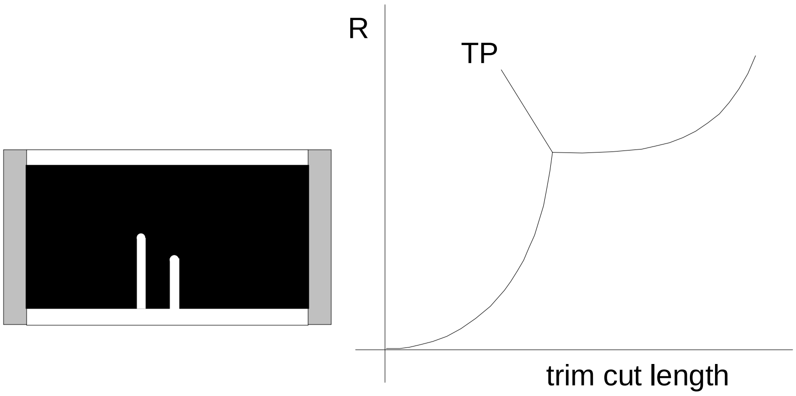
- relative exact (about ± 0,30 %)
- fast

Disadvantage

- lower long time stability

4.3 The D-Cut

An other possibility, to avoid the exponential change with the I-cut is the double cut (D-cut). First the resistor will be trimmed like the I-cut until the programmed turn point has reached. Then the fine-trim of the resistor will be done in the shadow of the current flow of the first cut. Typical values for the **calculated turn point** of a D-cut are between **70%** to **90%** of the resistance deviation for the first cut. You have to take care that the second cut is shorter than the first cut, otherwise the effect of the fine-trim will be lost.



Advantage

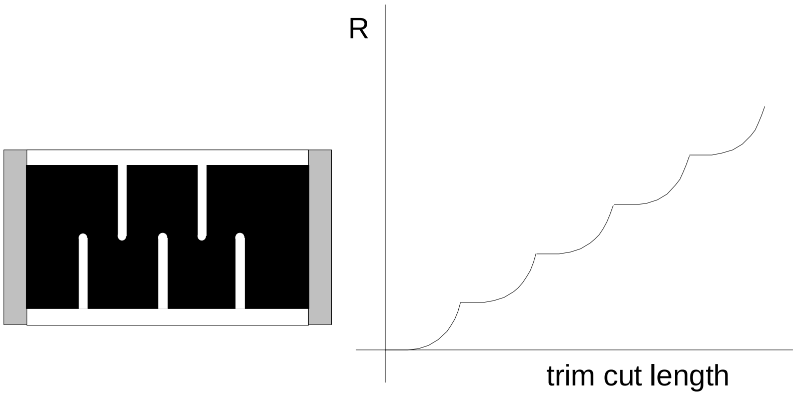
- relative exact (about ± 0,20 %)
- fast
- suitable for short resistors
- better long time stability than L-cut

Disadvantage

- Slower than I-cut
- unsuitable for long resistors

4.4 The M-Cut

Especially for the functional trim often a high resistor change must be done with one trimable resistor. To reach such a high change of the resistance the resistor could be meandered by the M-cut. This cut trims the resistor alternately from both sides. The first and the last cut should have a distance of about 250 µm from the connection metallization. With such a cut the resistor change could reach about 8 to 20 times of the start value. The long time stability will be worse. But you can reach moderate trim accuracy.



Advantage

- high change of resistance (about 20-times

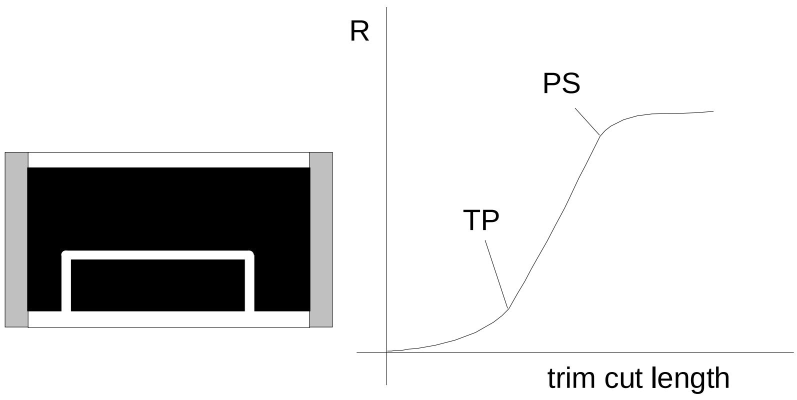
Disadvantage

- unsuitable for very short resistors
- lower long time stability

4.5 The U-Cut

The U-cut is simular to the L-cut. The particularity of the cut is that at the end of the L part the trim cuts completely outside of the resistor. Therefore the whole resistor area below the trim cut is electrical isolated. This avoids problems for applications with high voltages. The current flow of such a trimmed resistor is very homogeneous. However, the trim accuracy is low, because the change of the resistance for the last part of the cut could not be calculated exactly enough.

Der U-Cut verhält sich ähnlich wie der L-Cut. Als Besonderheit wird am Ende der L-Anteils der Trimmschnitt wieder ganz aus dem Widerstand herausgeführt. Dadurch wird die gesamte Widerstandsfläche unterhalb des Trimmschnitts elektrisch isoliert und somit ein Stromüberschlag bei Hochspannungsanwendungen vermieden. Der Stromlinienverlauf im Widerstand ist bei diesem Schnitt sehr homogen. Allerdings ist die Trimmgenauigkeit klein, da die Änderung des Widerstandswerts für den letzten Schnittanteil nicht exakt zu bestimmen ist.



Advantage

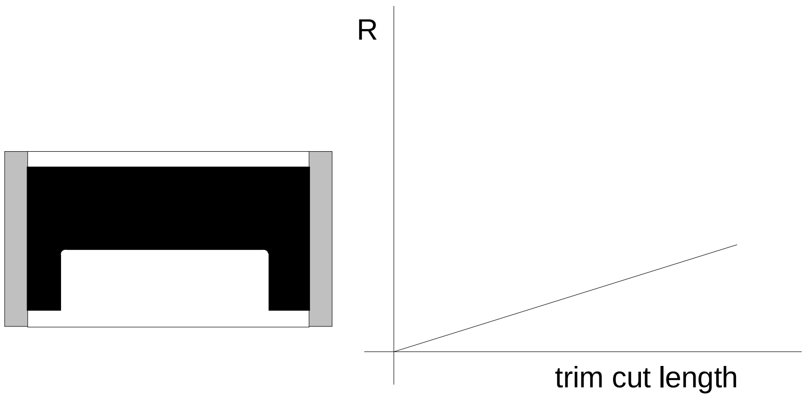
- suitable for applications with high voltage

Disadvantage

- lower trim accuracy (about ± 1,0%)
- lower long time stability

4.6 The Shave-Cut

If a high accuracy and a very good long time stability is required for the trim, the shave-cut is used. The shave-cut removes the resistor material at the whole length. The low resistance change per trim cut length causes a high accuracy. This cut is for the electrical parameters better than the other cuts. However, the trim speed is very low and depends a lot on the resistor length and needed change of resistor value. The shave-cut is the only possibility to adjust trimable chip capacitors. Like the U-cut this cut is also suitable for high voltage applications.



Advantage

- suitable for applications with high voltage
- best trim accuracy (about ± 0,15%)
- trim of trimable chip capacitors

Disabdvantage

- lowest trim speed

4.7 Special cuts and combinations

Natural the standard cuts xould be combined and special trime cuts could be generated

For eample the L-cut could be transferres into a J.cut. This cut adds a short cut at the end of the L.cut. Therefore the trim end could be positioned outside of the sensible area of the current flow.

The L-cut, the J-cut and the U-cut could be done with rounded edges, this avoids „hot spots“ at the turn point.

The L-cut could be e.g combined with a fine cut. An additional I-cut in the current flow shadow increases the trim accuracy.

The U-cut could be combined with the shave-cut. First the U-cut is done with higher speed. The added shave-cut reaches a high accuracy with increased trim speed, because the main part is trimed by the U-cut.

Such combinations and special cuts could increase the electrical quality of the trimmed resistors, depending on the application.

5. Influences of the laser parameter

To achieve the required accuracy for the SMD and thick film technology, the laser parameters have to be adjusted exactly. The laser parameters are:

- Laser pulse power
- Laser pulse frequency
- Trim speed

These parameters are coupled directly. The parameter **bite size** is decisive for the trim accuracy. The bite size is the size that one laser pulse extends the trim kerf. It is defined as the the quotient of the trim speed and the pulse frequency. A high accuracy could be reached with a small bite size, but a high throughput could only be reached with high trim speeds. Therefore the laser must work with a high pulse frequency. The laser physics effects a reduction of the pulse power and an increase of the average power at higher frequencies (> 4 kHz). To vaporise the resistor material inside the trim kerf completely and to avoid simultaneous a high heat effect of the resistor, the power per pulse has to be high and the average power has to be as low as possible. These effects that for high trim speeds the bite size could not be as small as possible and therefore the trim accuracy is reduced. To compensate this effect in many laser trim systems a socalled **reduced point** could be defined. When the resistor value reaches this reduced point, the trim system reduces the trim speed and increases therefore the trim accuracy.

Typical values for the parameter laser pulse frequency, trim speed, bite size and reduced points are:

- Laser pulse frequency between 2,0 and 4,0 kHz
- Trim speed between 10 and 30 mm/s
- Bite size between 2,5 and 15,0 µm
- Reduced Point about 3 to 5 % before the nominal value

The radiation energy changes the ageing effects of laser trimmed resistors at the edge of the trim kerf the socalled heat-effected zone. In this area the laser do not varporise the resistor material but changes the material's attributes. this causes a changes of the resistor's attributes. When the laser beam is not focused well and the mode selection is unsuitable this zone has a strong influence for the complete resistor. Therefore the laser has to work in the base mode TEM_{00}. At the TEM_{00} the beam has a gaussian energy profile and this minimises the heat-effected zone when the laser is focused well.

6. Laser safety

Improper operation of the laser system can lead to damage of the eyes or burning of the skin. The safety class of a laser system characterise the danger potential, that is given by the accessible laser radiation. Generally the highest laser safety class 1 should always be aspired. In this case the laser system could be used in production surroundings without additional provisions (wearing of safety goggles, set up of safety walls or operation in side of closed rooms). Furthermore companies, that carry out service and adjustment work at a laser of safety class 3B or 4 with an open laser by their own personal, are obliged to have a laser safety commissioner. The producer of the laser system imparts the commissioner the important information for the safety in a two to four hours tutorial. This tutorial is enough for the prevention of the most countries.

Saftey class 1

The accessible laser radiation is harmless, respectively no laser radiation could retire from the operation area. If a producer sells a laser system including the handler unit with the promise, that the system corresponds to laser safety class 1, then the laser producer guaranties all safety aspects. Such systems could operate everywhere at the company without additional safety precautions. Pay attention, the safety class could be changed by service or adjustment work.

Safety class 2

The accessible laser radiation is in the visible spectral range (400 nm to 700 nm) only. The radiation is for a short ray exposure (up to 0,25 s) harmless for the eye.

Safety class 3A

The accessible laser radiation is dangerous for the eye, if the beam diameter will be reduced by optical instruments. In all other cases the laser radiation is in the visible spectral range for short ray-treatment (up to 0,25 s) and in the other spectral ranges for long time treatment harmless.

Safety class 3B

The accessible laser radiation is for the eye and in special cases for the skin dangerous.

Safety class 4

The accessible laser radiation is very dangerous for the eye and dangerous for the skin. Diffuse dispersed radiation could be dangerous also. The laser radiation could effect burn or explosion danger. The user is obliged to take care for all necessary safety precautions when he buys a laser system of the safety class 4. The most important precautions are:

- The beam outlet as well as the working area have to be screened tight for the radiation.
- All parts of the cover, that have access to the laser area and could be opened without any tool, have to have interlocks.
- Windows in the housing have to be equipped with safety glasses, which have to fit to the power and the wavelength of the laser (DIN EN 207).
- If these preventions are not enough to reach safety class 1, the area around the system has to be protected by setting up walls, light signs and notice labels, thus everyone can notice the danger by the laser radiation before he reaches this area.
- The user of a laser system safety class 4 has to wear always corresponding laser safety goggles during the operation.

Laser safety goggles

For identification the following parts have to be signed durable at the laser safety goggles or the goggles' body:

- Wave length or range in nm
- Safety class
- Identification sign of the producer
- Eventual approbation sign

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