

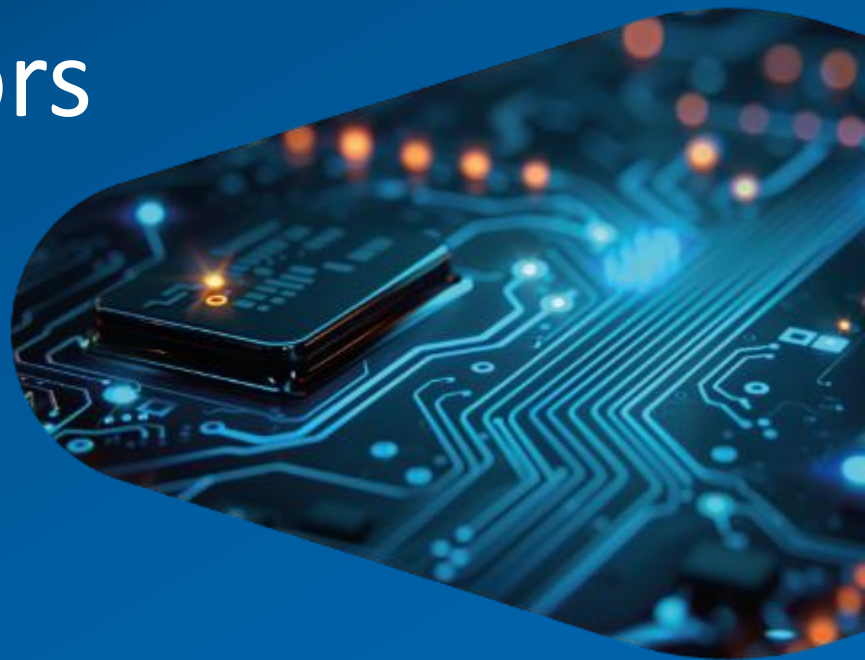


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Workshop on resistors

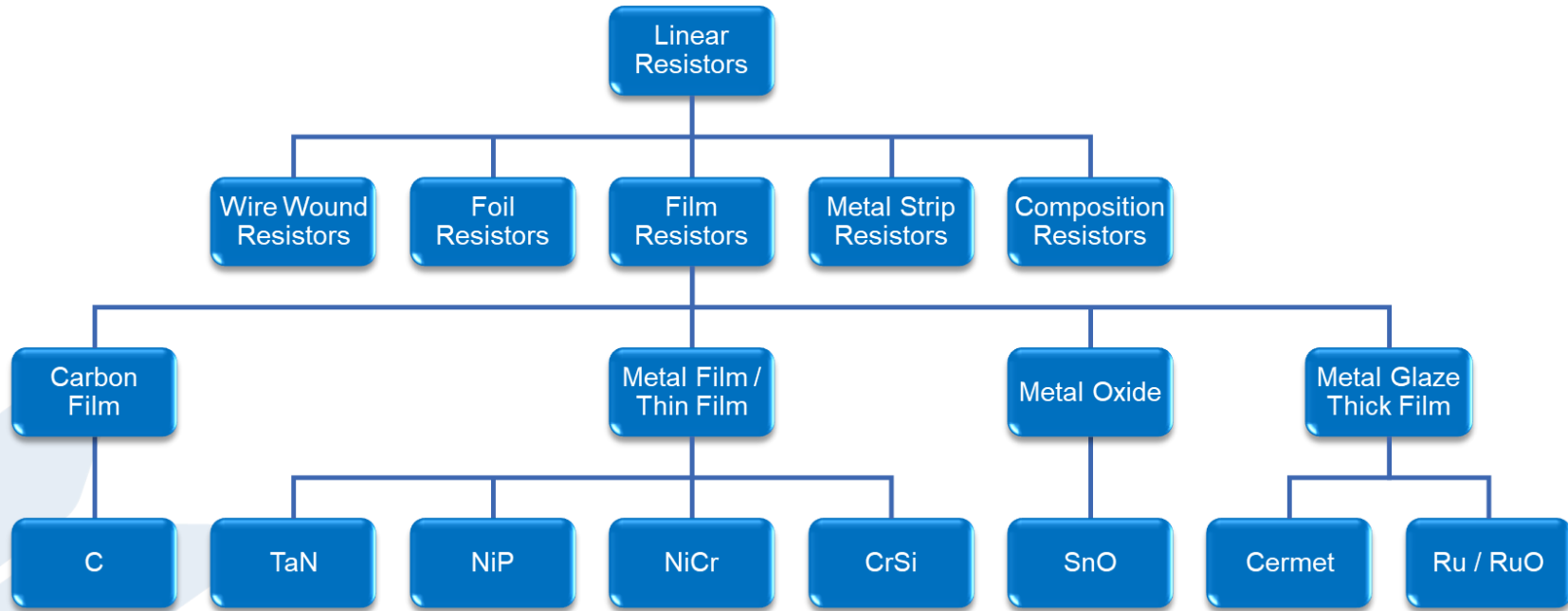
2026, May 15th



AGENDA

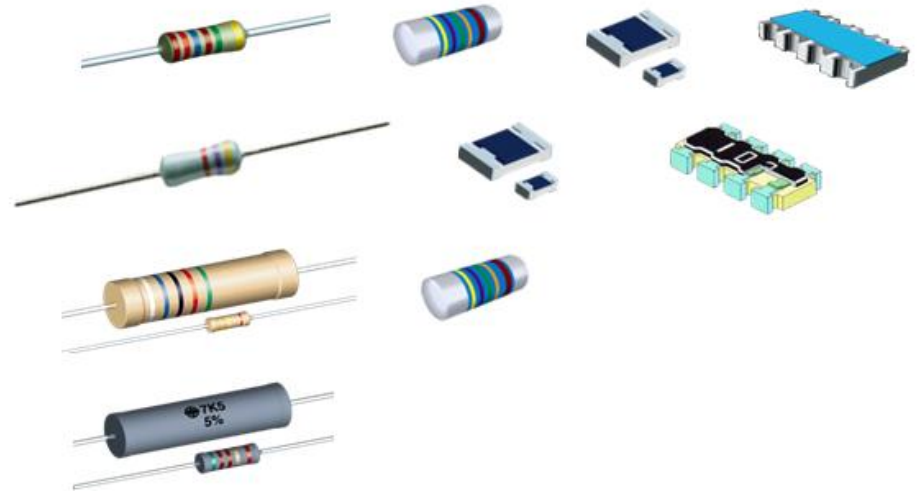
- 1 - Resistors Technologies**
- 2 - Basic parameters: tolerance & TCR
- 3 - Thermal management and resistance drift
- 4 - Rated power dissipation & Pulse Load Capability
- 5 - Thin Film Vs. Thick Film
- 6 - Applications examples
- 7 - Conclusions

Resistor Technologies and basic materials



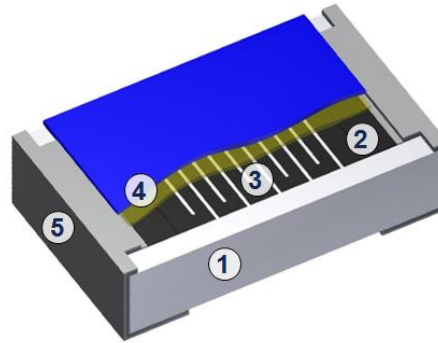
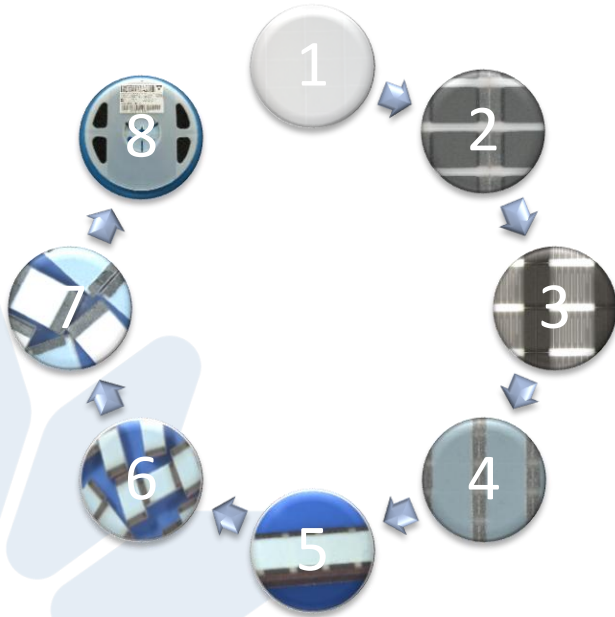
Resistor Packages & assembly types

- SMD (surface-mount device)
 - single chip resistor (0201, 0402, 0603...2512)
 - melf (0102, 0204, 0207)
 - resistors array
- THT (through-hole technology)
 - various sizes & dimensions types



Chip Resistor Design and Production

Manufacturing Steps



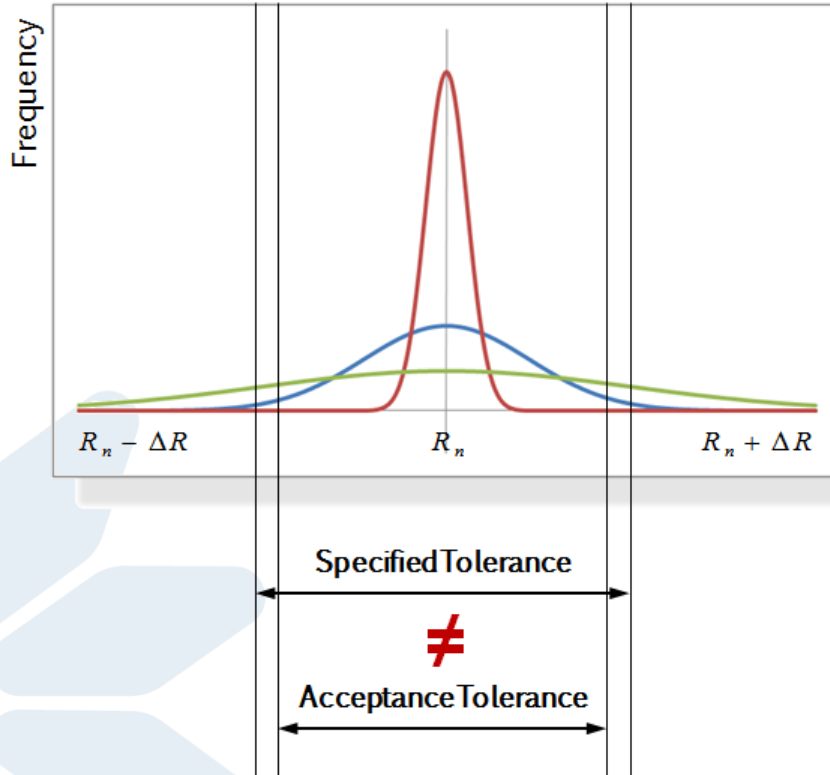
1. Ceramic Substrate
2. Resistive Layer
3. Trimming
4. Protective Lacquer
5. Side Contacts
6. Singulation
7. Plating
8. Testing, Tape & Reel

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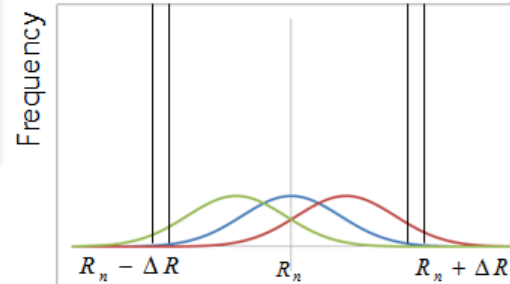
Resistor Characteristic: Tolerance

Gaussian Distribution (approx.)



Definition:

Resistance tolerance specifies the maximum permissible deviation (in percentage) of a resistor's actual resistance from its nominal resistance value, under specified conditions (and 25 °C)



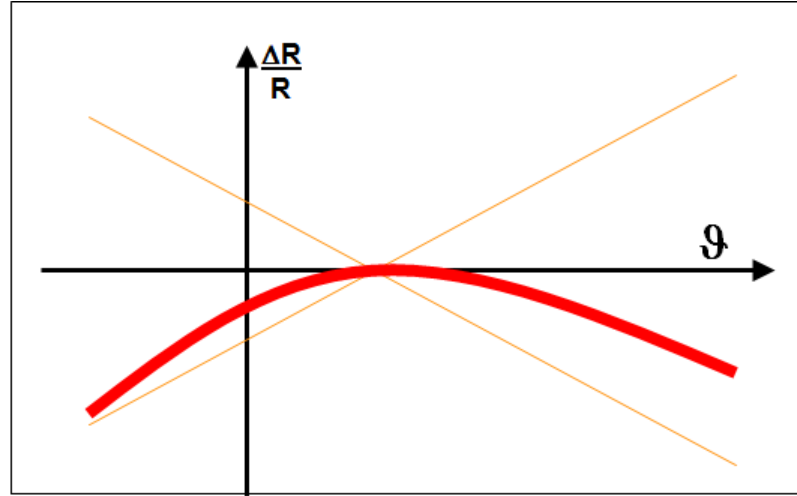
Resistor Characteristic: Temperature Coefficient of Resistance (TCR)

Formula of TCR:

$$\alpha_R = \frac{R - R_n}{R_n * \Delta \vartheta}$$

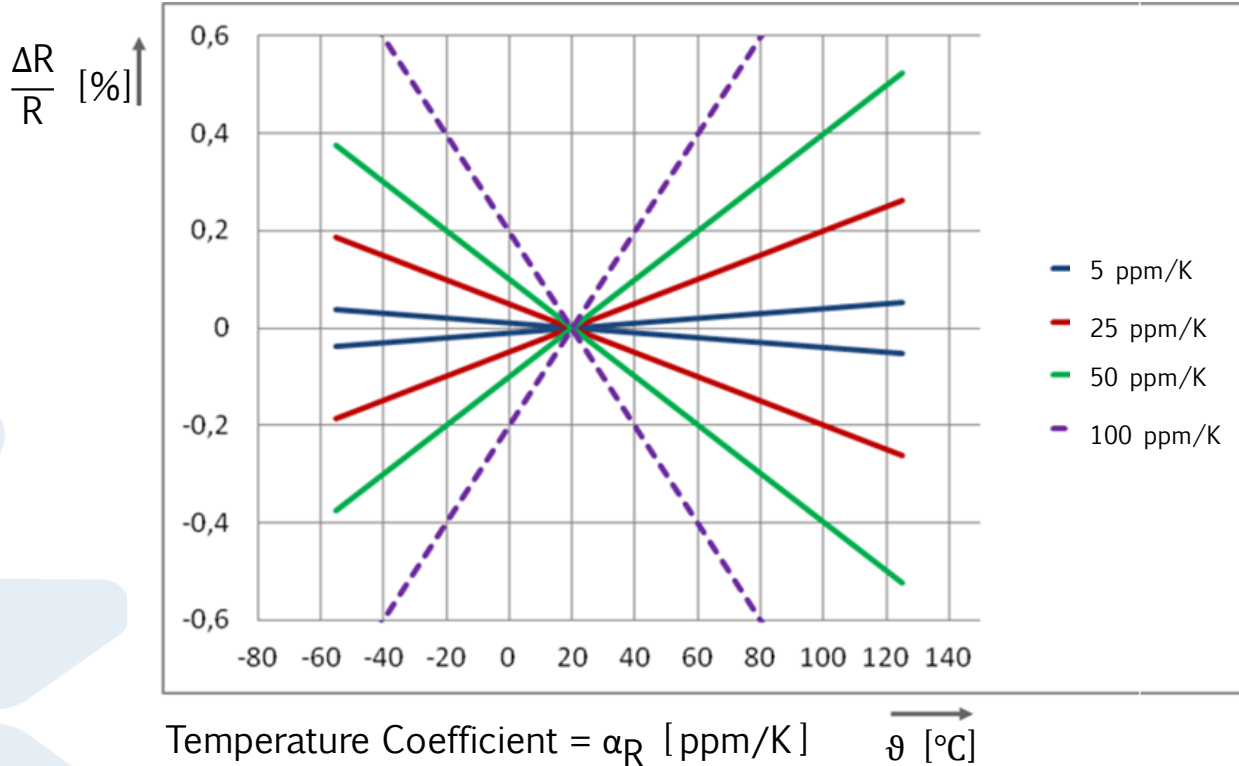
Definition:

The Temperature Coefficient of Resistance (TCR) is the relative change in resistance per degree of temperature change, referenced to a specified temperature (25 °C). **The TCR is specified in ppm / K**



Resistor Characteristic: Temperature Coefficient of Resistance (TCR)

Temperature Impact



Worked example of tolerance and TCR calculation

Nominal resistor value: $R_{nom} = 10 \text{ k}\Omega$

1. Initial Tolerance ($\pm 1\%$)

- Tolerance variation: $\pm 1\% \times 10 \text{ k}\Omega = \pm 100 \Omega$
- Resistance range at 25°C: **9.9 k Ω \rightarrow 10.1 k Ω**

2. Temperature Effect (TCR = 50 ppm/°C)

- Assume temperature variation: $\Delta T = 50^\circ\text{C}$
- change due to TCR: $\Delta R = 10 \text{ k}\Omega \times 50 \text{ ppm}/^\circ\text{C} \times 50^\circ\text{C} = 10 \text{ k}\Omega \times 0.0025 = \pm 25 \Omega$

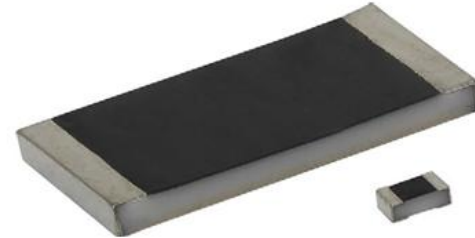
3. Total Worst-Case Variation

- Tolerance: $\pm 100 \Omega$
- Temperature drift: $\pm 25 \Omega$

Total worst-case deviation:
 $\pm 125 \Omega$ ($\pm 1.25\%$)

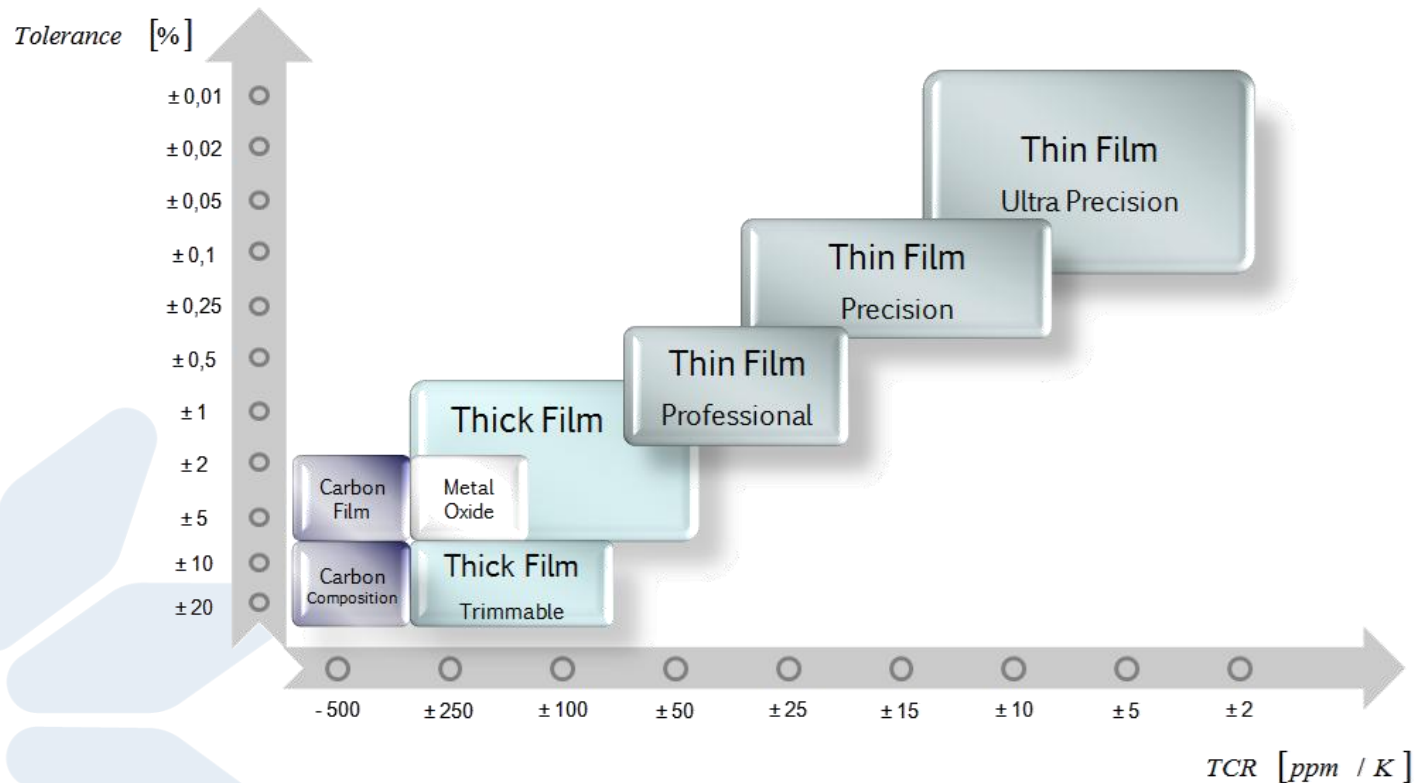
4. Final Resistance Range: **9.875 k Ω \rightarrow 10.125 k Ω**

Even with a tight **$\pm 1\%$ tolerance**, temperature drift can significantly impact accuracy
TCR becomes critical in precision circuits, especially over wide temperature ranges



Potential of Film Resistor Technologies

TCR & Tolerance Combination



AGENDA

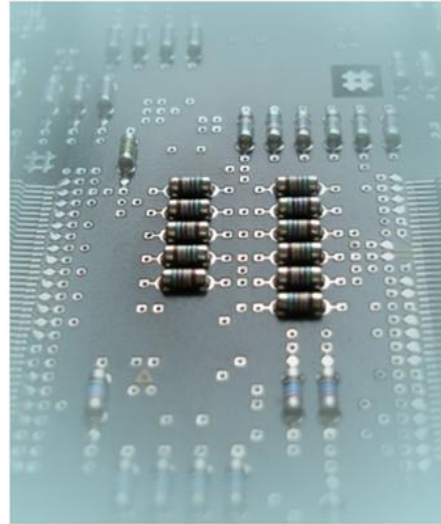
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Thermal Resistance

The **thermal resistance** R_{th} is interfering the heat dissipation from the resistive layer ambience.

$$\vartheta_S = \vartheta_{amb} + R_{th} * P$$

- ϑ_S : film temperature
- ϑ_{amb} : ambient temperature
- P : electrical power
- R_{th} : thermal resistance



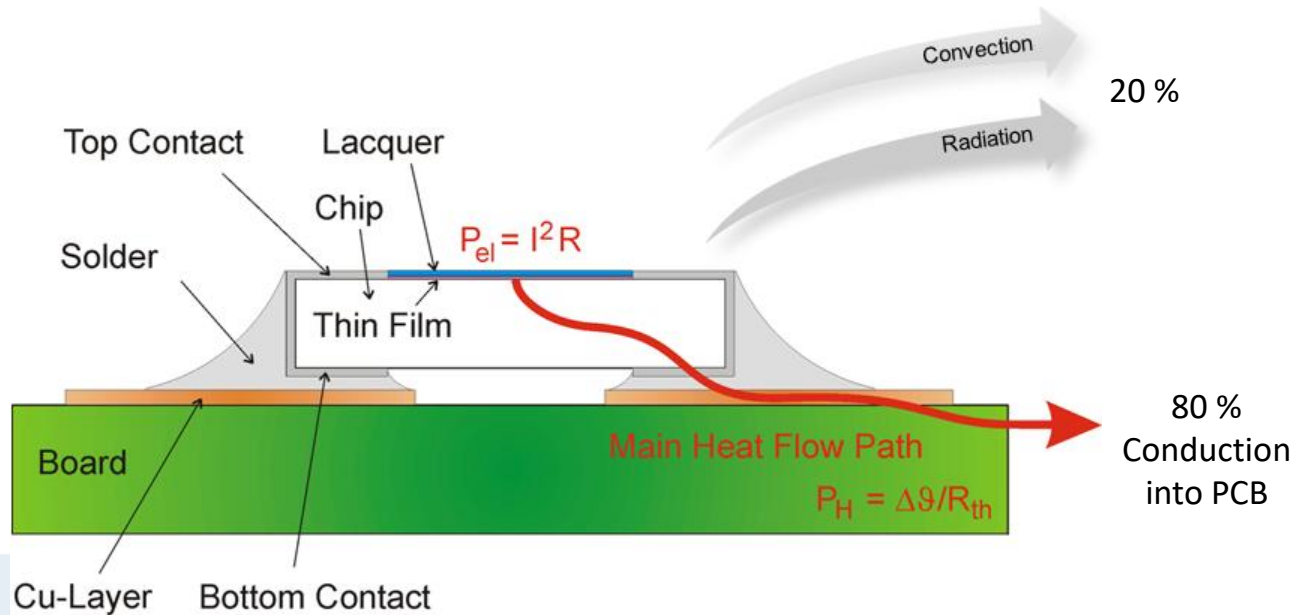
Definition:

Thermal resistance of a resistor is the measure of how effectively heat is transferred from the resistive element to the ambient environment. It is defined as the temperature rise of the resistor per unit of dissipated power.

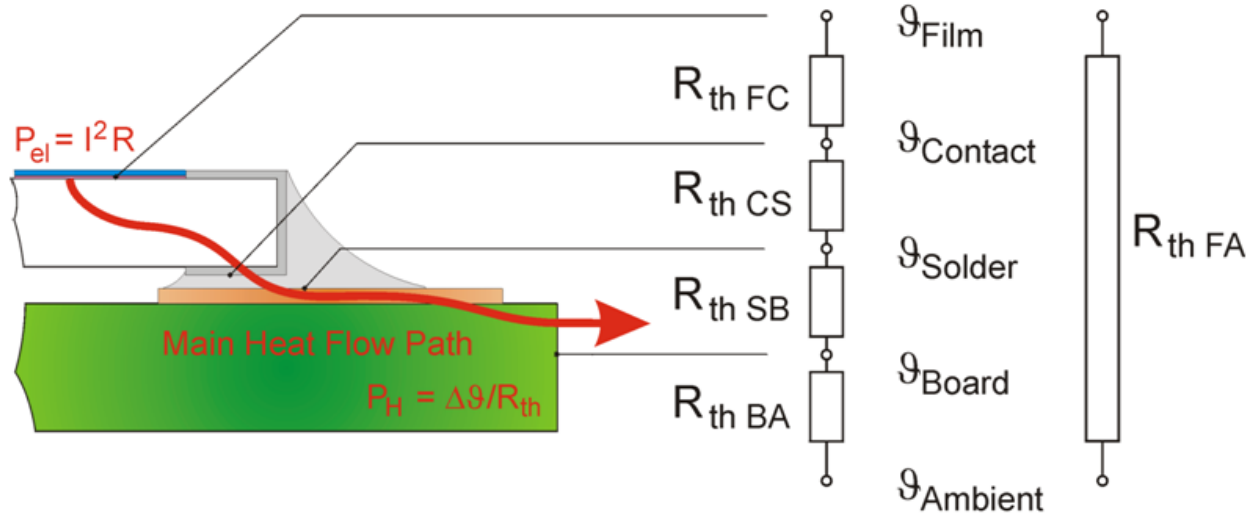
At zero power dissipation, the resistor temperature equals the ambient temperature.
Any applied power causes a temperature rise proportional to the thermal resistance.

Thermal Management

Convection, Radiation and Conduction



Thermal Resistance – Conductive Portion



$$R_{th} = \frac{\vartheta_s - \vartheta_{amb}}{P} = R_{th FC} + R_{th CS} + R_{th SB} + R_{th BA}$$

- ϑ_s : film temperature
- ϑ_{amb} : ambient temperature

MELF 0207 Operated Under Different Conditions

Power
Dissipation
Calculated Results

Standard Operation	Power Operation	Special Application
0.4 W	1.0 W	1.5 W

Thermal
Resistance
Film Temperature

140 K/W	140 K/W	85 K/W	52 K/W
126°C	210°C	155°C	148°C
116°C	184°C	129°C	109°C

b)
Solder Joint
Temp.

Circuit Board

Material

FR 4 ^{c)}	FR 4	flexible
1.5 mm ^{c)}	1.5 mm	0.2 mm ^{d)}
≈ 10 mm ² ^{c)}	≈ 320 mm ²	≈ 5 mm ²

Thickness

Pad Size

a) $\vartheta_{amb} = 70^\circ\text{C}$

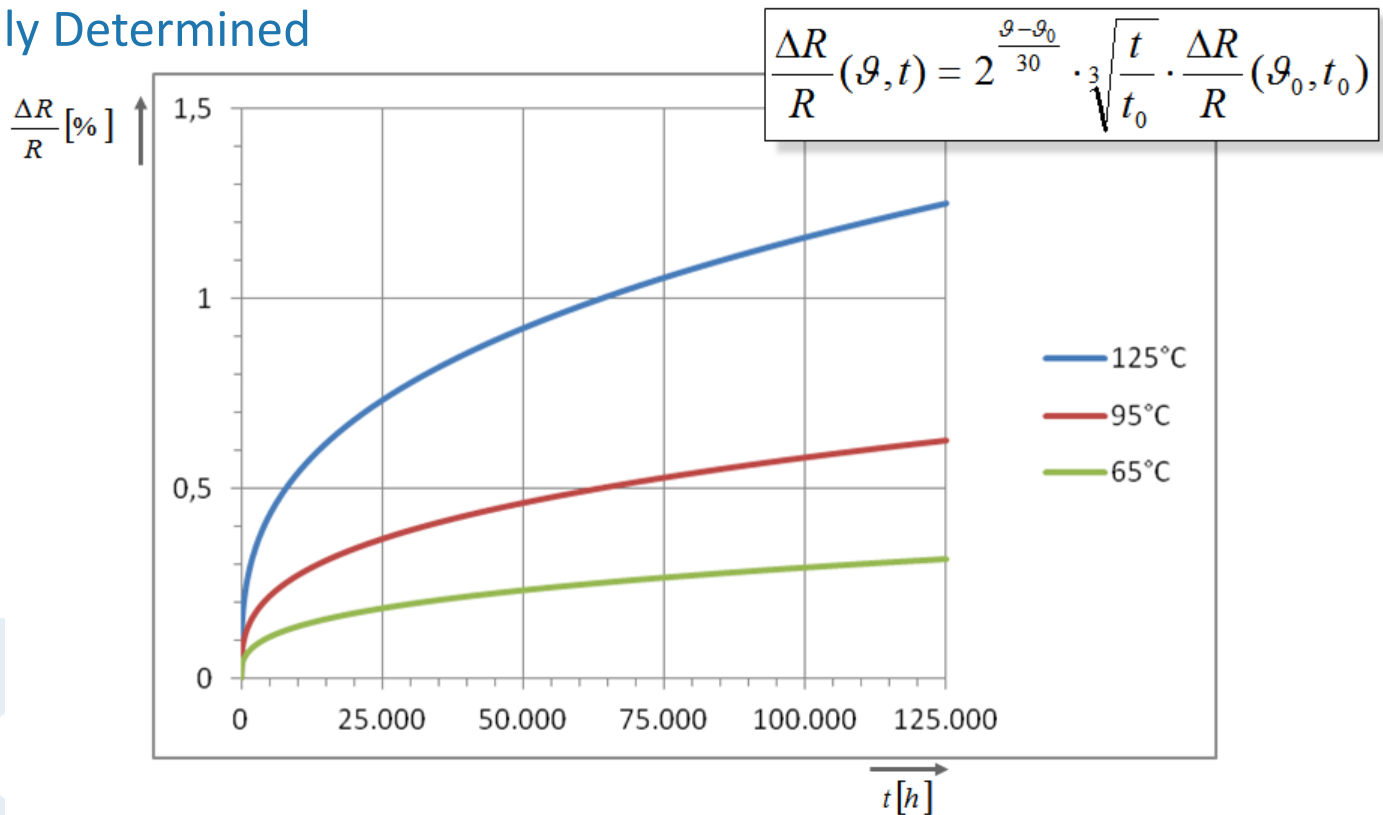
b) $R_{th\ int.} \approx 26\ \text{K/W}$

c) as specified in EN 60115-8

d) laminated on 1.2 mm aluminum sheet

Resistance Drift of Thin Film Resistors over lifetime and temperature

Empirically Determined



Resistance Drift of Thin Film Resistors

Drift Estimation for Application Temperatures and Lifetimes

MAXIMUM RESISTANCE CHANGE AT RATED DISSIPATION			
OPERATION MODE		STANDARD	POWER
Rated dissipation, P_{70}	MCS 0402	0.063 W	0.100 W
	MCT 0603	0.100 W	0.125 W
	MCU 0805	0.125 W	0.200 W
	MCA 1206	0.250 W	0.400 W
Operating temperature range		-55 °C to 125 °C	-55 °C to 155 °C
Permissible film temperature, $\vartheta_{F \max}$		125 °C	155 °C
Max. resistance change at P_{70} for resistance range, $ \Delta R/R $ after:	MCS 0402	10 Ω to 4.99 M Ω	10 Ω to 4.99 M Ω
	MCT 0603	1 Ω to 10 M Ω	1 Ω to 10 M Ω
	MCU 0805	1 Ω to 10 M Ω	1 Ω to 10 M Ω
	MCA 1206	1 Ω to 2 M Ω	1 Ω to 2 M Ω
	1000 h	$\leq 0.25 \%$	$\leq 0.5 \%$
	8000 h	$\leq 0.5 \%$	$\leq 1.0 \%$
	25 000 h	$\leq 1.5 \%$	-

$$\frac{\Delta R}{R}(t; \vartheta_j) = \sqrt[3]{\frac{t}{t_0}} * 2^{\frac{\vartheta_j - \vartheta_0}{30K}} * \frac{\Delta R}{R}(t_0; \vartheta_0)$$

Resistance Drift of Thin Film Resistors

Example:

$$t_0 = 1000 \text{ h}$$

$$\vartheta_0 = 125 \text{ }^\circ\text{C}$$

$$\frac{\Delta R}{R}(t_0; \vartheta_0) = 0,15 \%$$

Example parameters (other operating hours and other film temperature):

$$t = 65700 \text{ h}$$

$$\vartheta_j = 85 \text{ }^\circ\text{C}$$

$$\frac{\Delta R}{R}(65700 \text{ h}; 85 \text{ }^\circ\text{C}) = \sqrt[3]{\frac{65700 \text{ h}}{1000 \text{ h}}} \times 2^{\frac{85 \text{ }^\circ\text{C} - 125 \text{ }^\circ\text{C}}{30\text{K}}} \times 0,15 \% \approx \mathbf{0,24 \%}$$

MAXIMUM RESISTANCE CHANGE AT RATED DISSIPATION			
OPERATION MODE		STANDARD	POWER
Rated dissipation, P_{10}	MMU 0102	0.2 W	0.3 W
	MMA 0204	0.25 W	0.4 W
	MMB 0207	0.4 W	1.0 W
Operating temperature range		-55 °C to 125 °C	-55 °C to 155 °C
Permissible film temperature, ϑ_f max.		125 °C	155 °C
Max. resistance change at P_{10} for resistance range, $ \Delta R/R $ after:	MMU 0102	0.22 Ω to 221 k Ω	0.22 Ω to 221 k Ω
	MMA 0204	0.22 Ω to 332 k Ω	0.22 Ω to 332 k Ω
	MMB 0207	0.1 Ω to 1 M Ω	0.1 Ω to 1 M Ω
	1000 h	$\leq 0.15 \%$	$\leq 0.25 \%$
8000 h	$\leq 0.3 \%$	$\leq 0.5 \%$	
225 000 h	$\leq 1.0 \%$	-	

$$\frac{\Delta R}{R}(t; \vartheta_j) = \sqrt[3]{\frac{t}{t_0}} * 2^{\frac{\vartheta_j - \vartheta_0}{30\text{K}}} * \frac{\Delta R}{R}(t_0; \vartheta_0)$$

Resistance Drift of Thin Film Resistors

In this example, following should be considered:

- Initial tolerance: $\pm 0,5 \%$
- Drift as calculated above: $\pm 0,24 \%$ (65700 h)
- Resistance change due to soldering $\pm 0,02 \%$

Algebraic sum (worst case, not reality)

$$\Delta R = \text{Initial tolerance} + \text{Drift} + \text{Soldering}$$

$$= \pm 0.5 \% + \pm 0,24 \% \pm 0,02 \%$$

$$= \pm \mathbf{0.76 \%}$$

Square Root Sum (realistic)

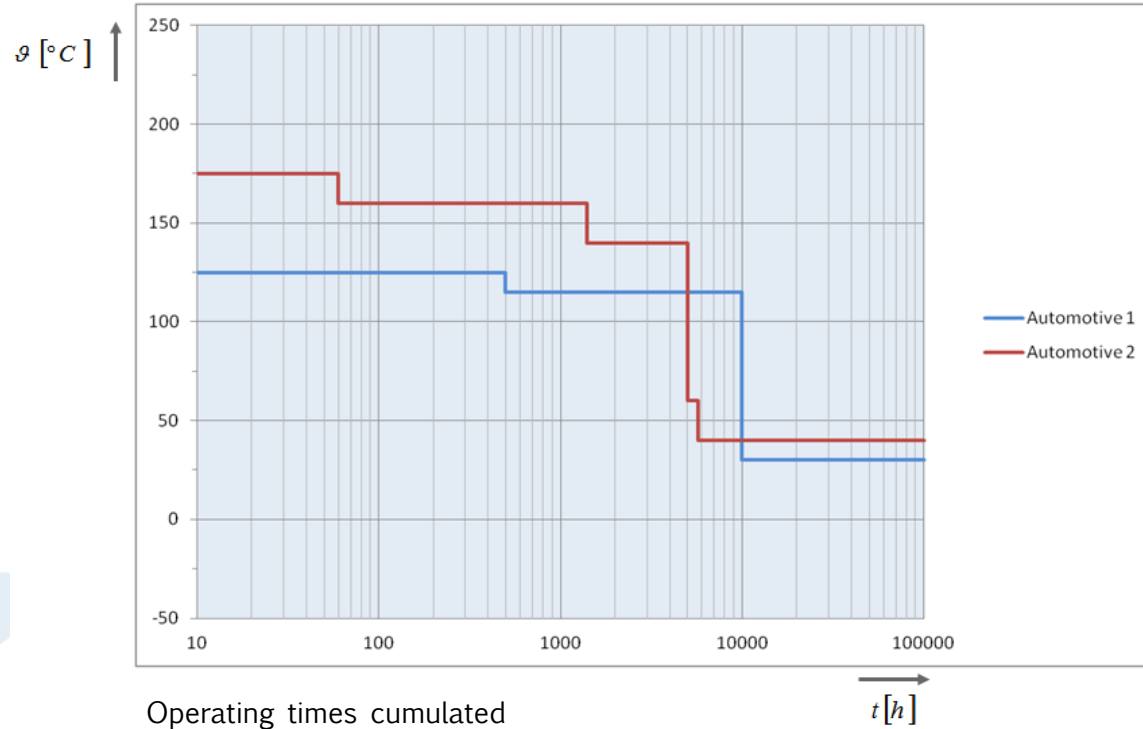
$$\Delta R = \sqrt{\text{Initial tolerance}^2 + \text{Drift}^2 + \text{Soldering}^2}$$

$$= \sqrt{0,5 \%^2 + 0,24 \%^2 + 0,02 \%^2} \approx \pm \mathbf{0,56 \%}$$

TEST PROCEDURES AND REQUIREMENTS					
EN 60115-1 CLAUSE	IEC 60068-2 (1) TEST METHOD	TEST	PROCEDURE	REQUIREMENTS PERMISSIBLE CHANGE (1/R)	
			Stability for product types:	STABILITY CLASS 0.25 OR BETTER	STABILITY CLASS 0.5 OR BETTER
			MMU 0102	10 Ω to 221 kΩ	< 1 Ω
			MMA 0204	10 Ω to 332 kΩ	< 1 Ω
			MMB 0207	10 Ω to 1 MΩ	< 1 Ω
4.39	-	Periodic electric overload: Standard operation mode Periodic electric overload: Power operation mode	$U = \sqrt{15 \times P_{avg} \times R}$ or $U = 2 \times U_{max}$ whichever is the less severe: 0.1 s on; 2.5 s off; 1000 cycles	$\pm (0.5 \% R + 5 \text{ m}\Omega)$ $\pm (1 \% R + 5 \text{ m}\Omega)$	
4.22	6 (Fc)	Vibration	Endurance by sweeping: 10 Hz to 2000 Hz no resonance amplitude $\leq 1.5 \text{ mm}$ or $\leq 200 \text{ m/s}^2$; 7.5 h	$\pm (0.1 \% R + 5 \text{ m}\Omega)$	$\pm (0.1 \% R + 5 \text{ m}\Omega)$
4.38	-	Electrostatic discharge (Human Body Model)	IEC 61340-3-1 (1); 3 non- $\pm 3 \text{ kV}$ discharges MMA 0204: 2 kV MMB 0207: 4 kV	$\pm (0.5 \% R + 0.05 \text{ m}\Omega)$	
4.17	58 (Td)	Solderability	Solder bath method: SnPb40; non-activated flux; (2 ± 0.3) °C; (5 ± 0.3) s Solder bath method: SnAg3Cu0.5 or SnAg3.5; non-activated flux; (235 ± 3) °C; (2 ± 0.2) s	Good timing ($\geq 95 \%$ covered); no visible damage	
4.18	58 (Td)	Resistance to soldering heat	Solder bath method: (260 ± 5) °C; (10 ± 1) s Reflow method 2 (IR/forced gas convection): (260 ± 5) °C; (10 ± 1) s	$\pm (0.05 \% R + 10 \text{ m}\Omega)$	$\pm (0.1 \% R + 10 \text{ m}\Omega)$ $\pm (0.25 \% R + 10 \text{ m}\Omega)$ $\pm (0.05 \% R + 10 \text{ m}\Omega)$ $\pm (0.1 \% R + 10 \text{ m}\Omega)$
4.29	45 (XA)	Component solvent resistance	Isopropyl alcohol; 50 °C; method 2	No visible damage	
4.30	45 (XA)	Solvent resistance of marking	Isopropyl alcohol; 50 °C; method 1, toothbrush	Marking legible; no visible damage	
4.32	21 (Jc)	Shear (adhesion)	45 N	No visible damage	
4.33	21 (Jc)	Substrate bending	Depth 2 mm, 3 times	No visible damage, no open circuit in bent position $\pm (0.05 \% R + 5 \text{ m}\Omega)$ (2)	
4.7	-	Voltage proof	$U_{app} = U_{nom} + 60 \text{ V}$ IEC 60068-11-5 (1);	No flashover or breakdown	
4.35	-	Flammability	needs flame test; 10 s	No burning after 30 s	

„Mission Profiles“

Example: Automotive



Operating times cumulated

t [h]

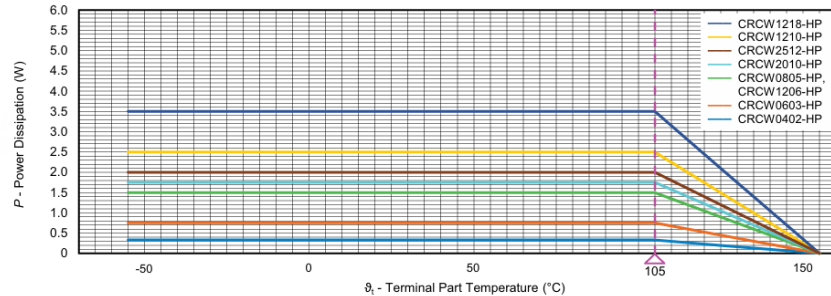
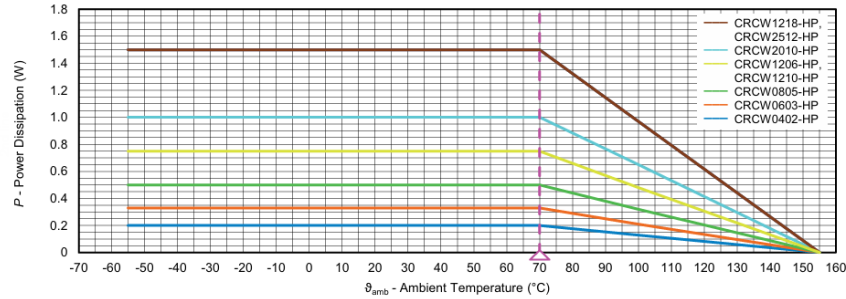
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Rated power dissipation

Ambient and terminal part Temperature

Derating



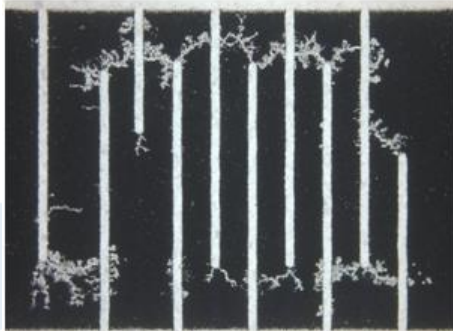
Definition:

Rated power dissipation is the maximum continuous power (**specified in W**) a resistor can dissipate under specified conditions without exceeding its maximum allowable temperature or causing unacceptable change in resistance

Pulse Load Capability

Definition

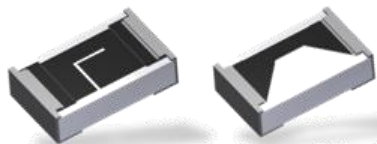
- The permissible pulse load is determined by the same level of resistance change as defined in the datasheet for 8000 h continuous operation (or 0.5 % maximum for Thin Film / 4% for Thick Film).
- Excessive pulse load will burn the conductive band on the resistor and thus open the circuit (fail-to-open).



Pulse Load Capability

Area of Resistive Layer

Thick Film Chip Resistor



Thin Film Chip Resistor



Pulse load capability depends on:

- Resistive area
- Volume / mass
- Geometry (chip vs. cylindrical)
- Distribution of the resistive path



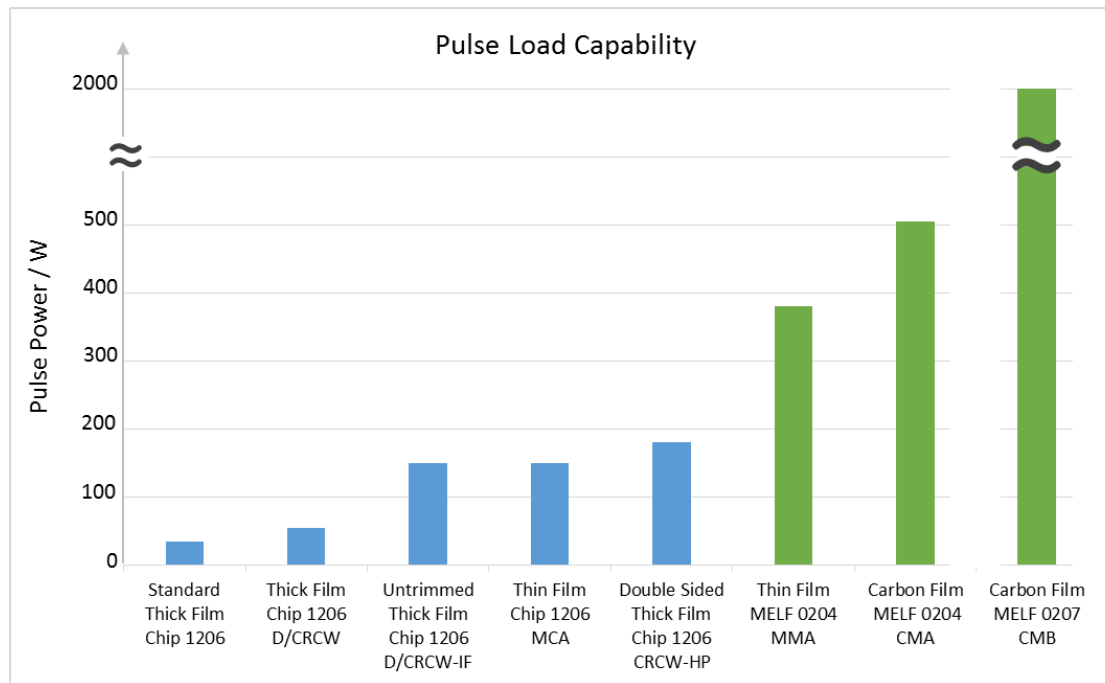
standard MICRO-MELF



high quality thin Film MICRO-MELF Resistor



Technology Comparison

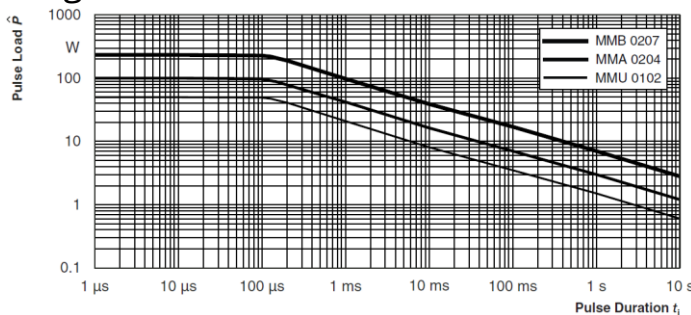


*) on Pad Size 1206, 1k Ω Resistors, rectangular pulse 3ms

Examples from resistor Datasheet

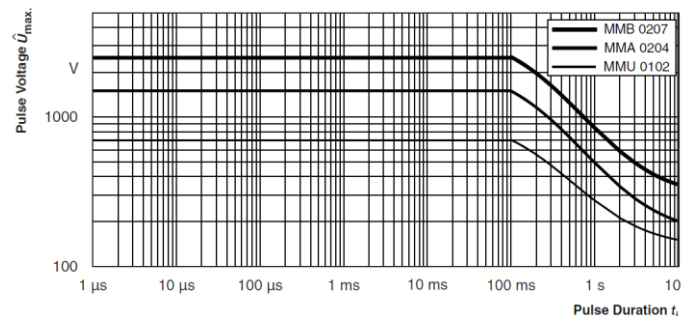
Single Pulse

$$\bar{P} \rightarrow 0$$



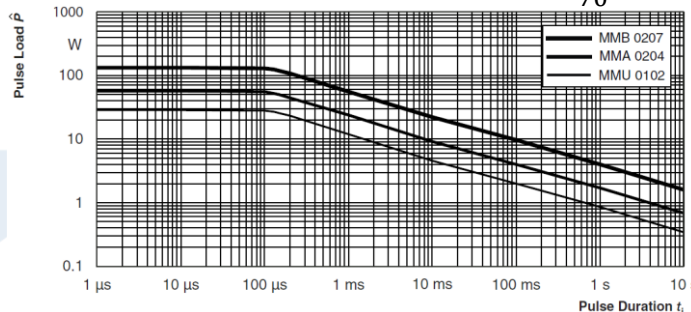
Rated values reflect common ground for whole resistance value range.

Pulse Voltage



Continuous Pulse

$$\bar{P} \rightarrow P_{70}$$



Pulse Load Conditions:

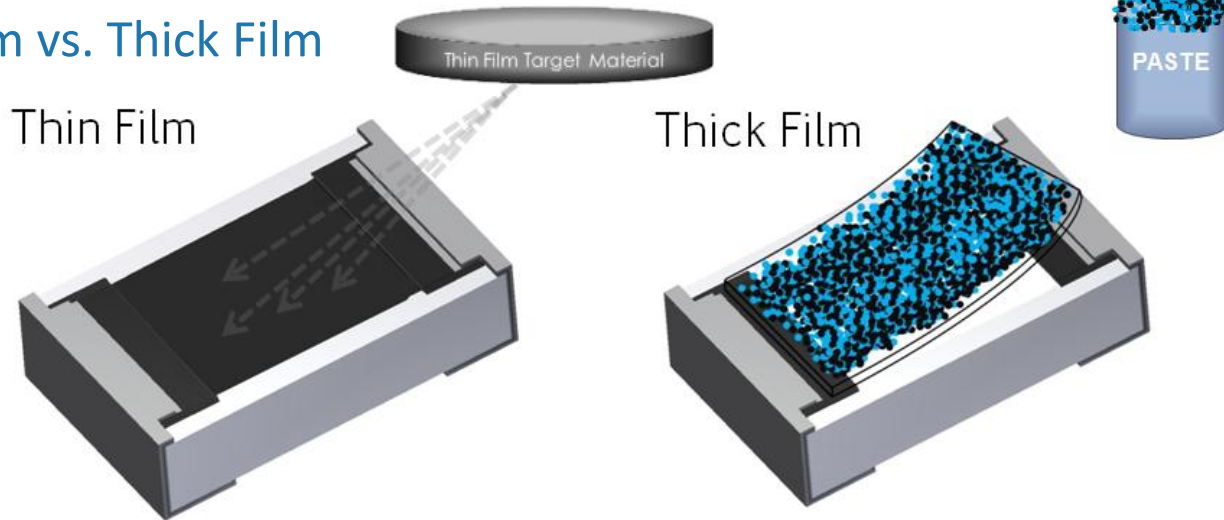
- 1) $\bar{P} \leq P_{70}$
- 2) $\hat{P} \leq \hat{P}_{permissible}$
- 3) $\hat{U} \leq \hat{U}_{permissible}$

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Resistive Layers

Thin Film vs. Thick Film



100 % Metal film

- Thickness 50 nm ... 0,5 μm
- Homogeneous coverage
 - Low current noise
 - Excellent stability

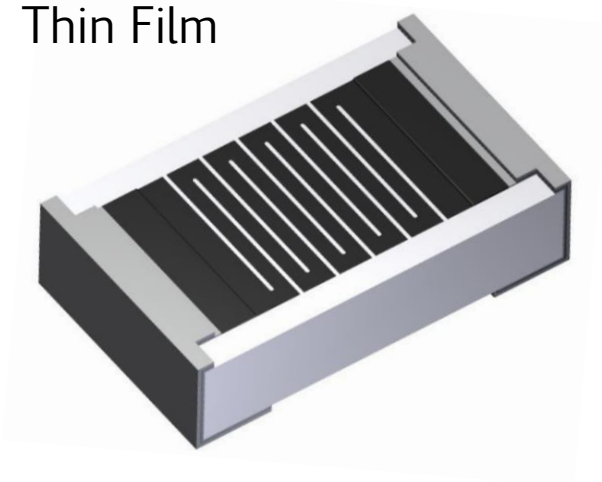
Mixed metal / metal oxide / glass

- Thickness up to 10 μm
- Inhomogeneous layer
 - Limited long-term stability
 - Poor pulse load stability

Trimming Patterns

Thin Film vs. Thick Film

Thin Film

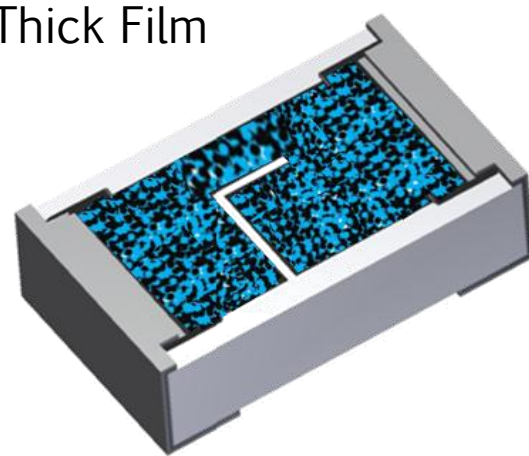


Pulsed Laser

More expensive, but:

- Clean kerf, smooth edges
- No damage to substrate
- Low current noise

Thick Film



CO₂ Laser

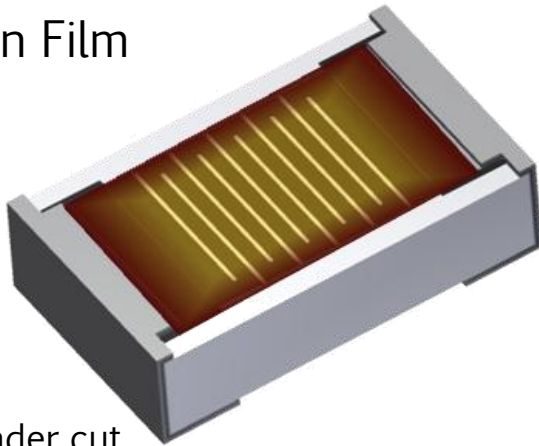
Fast & cheap, but:

- Rough cut, damaging substrate
- Scorched edges
- Thermally stressing R-layer

Trimming Patterns: Temperature Distribution

Thin Film vs. Thick Film

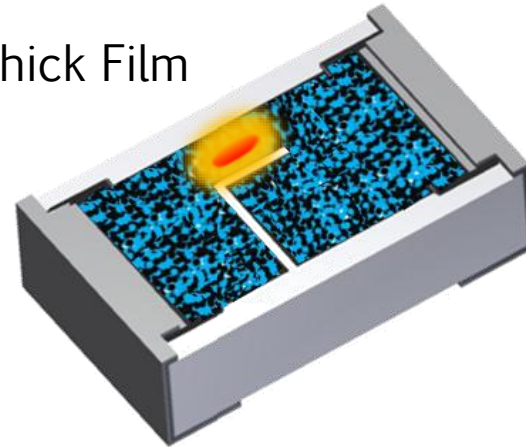
Thin Film



Meander cut

- Spreads dissipation equally over active surface
- Facilitates low load life drift
- Enables high pulse load capability

Thick Film

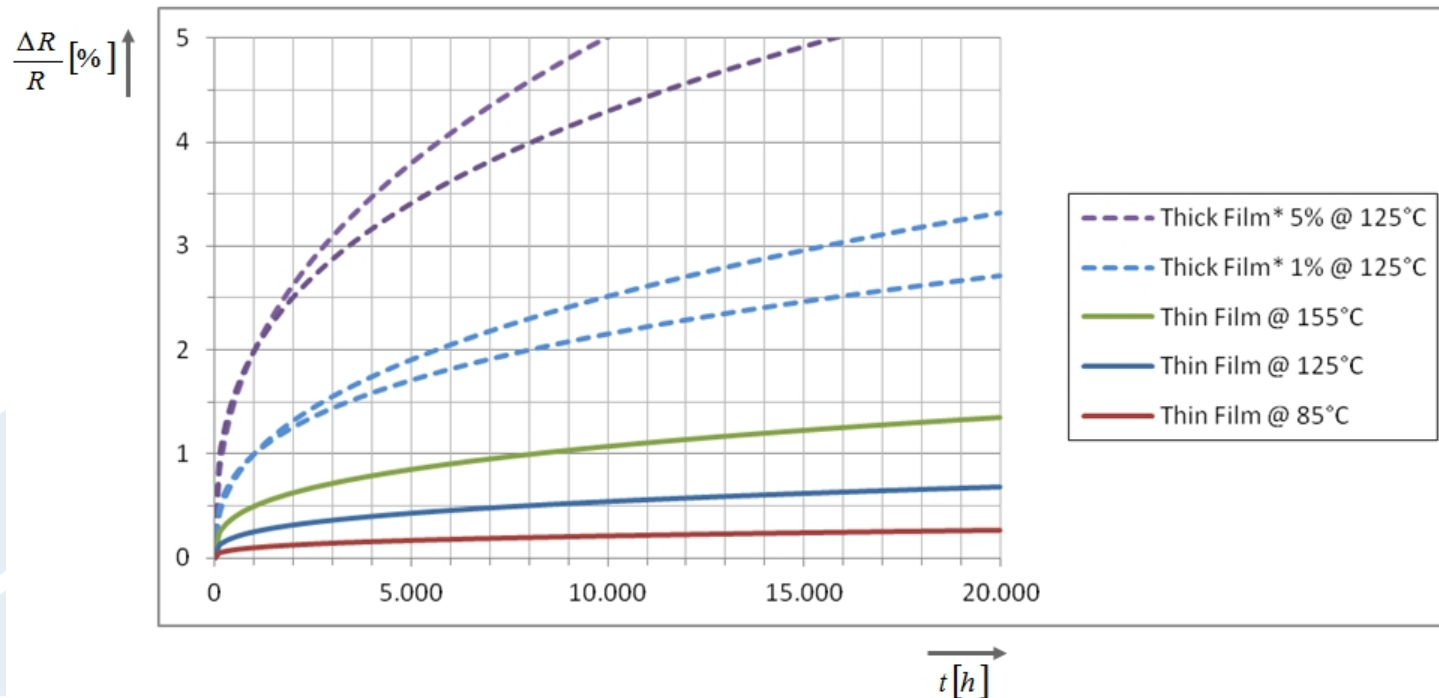


L-cut

- Focuses dissipation in small fraction of active surface
- Builds hot spot
- Adversely affects load life stability
- Limits pulse load capability

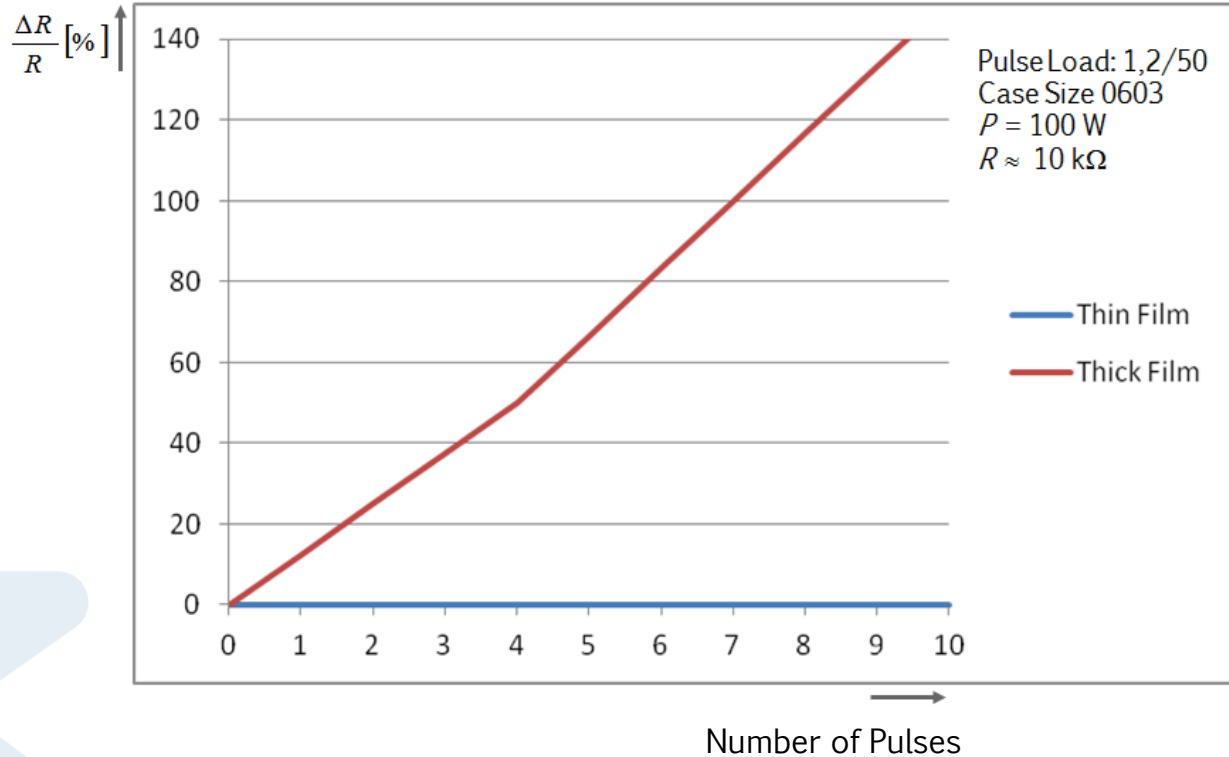
Resistor Characteristic: Resistance Drift

Thin Film vs. Thick Film



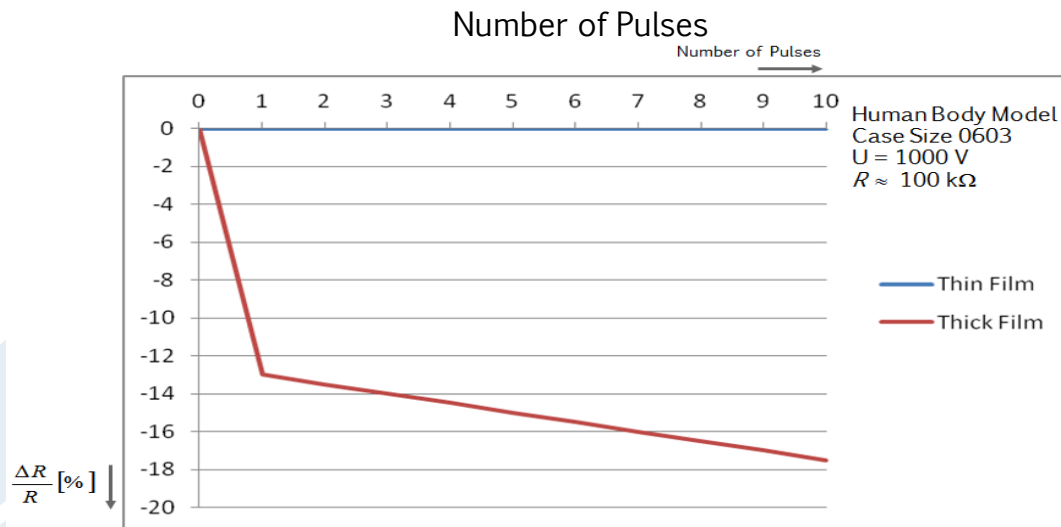
Resistor Characteristic: Pulse Load Capability

Thin Film vs. Thick Film



Resistor Characteristic: Electrostatic Discharge (ESD) Capability

Thin Film vs. Thick Film



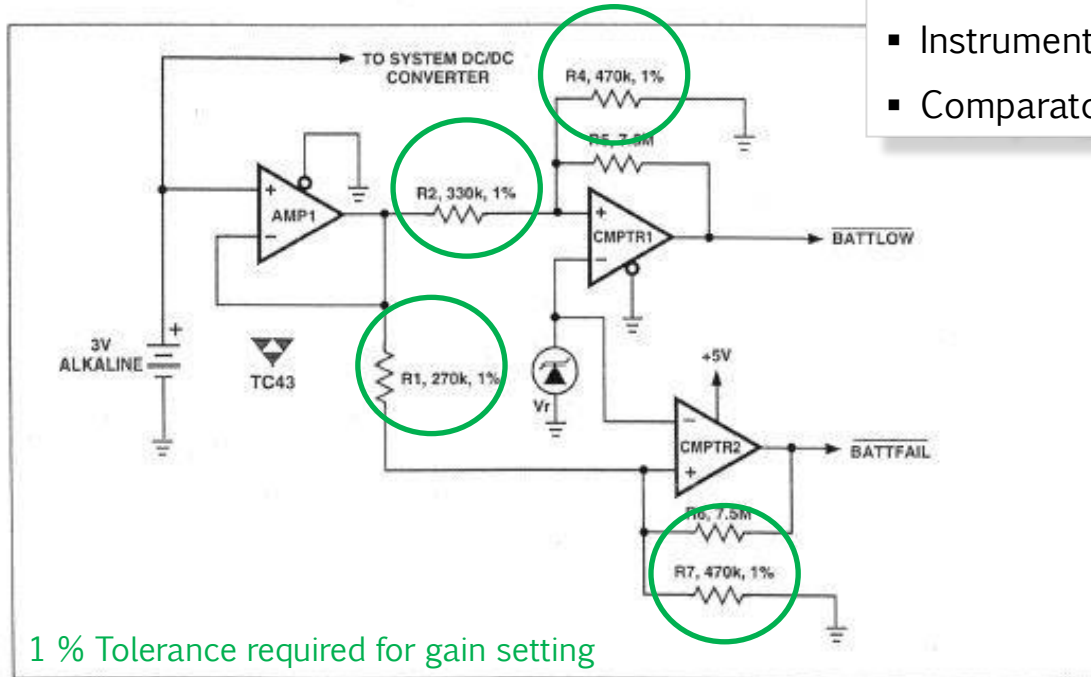
Definition:

ESD is a rapid transfer of electrostatic charge between objects at different electrical potentials.

ESD can generate high voltage and fast transient currents that may damage electronic components.

When to Use Thin Film or Thick Film

Application Example

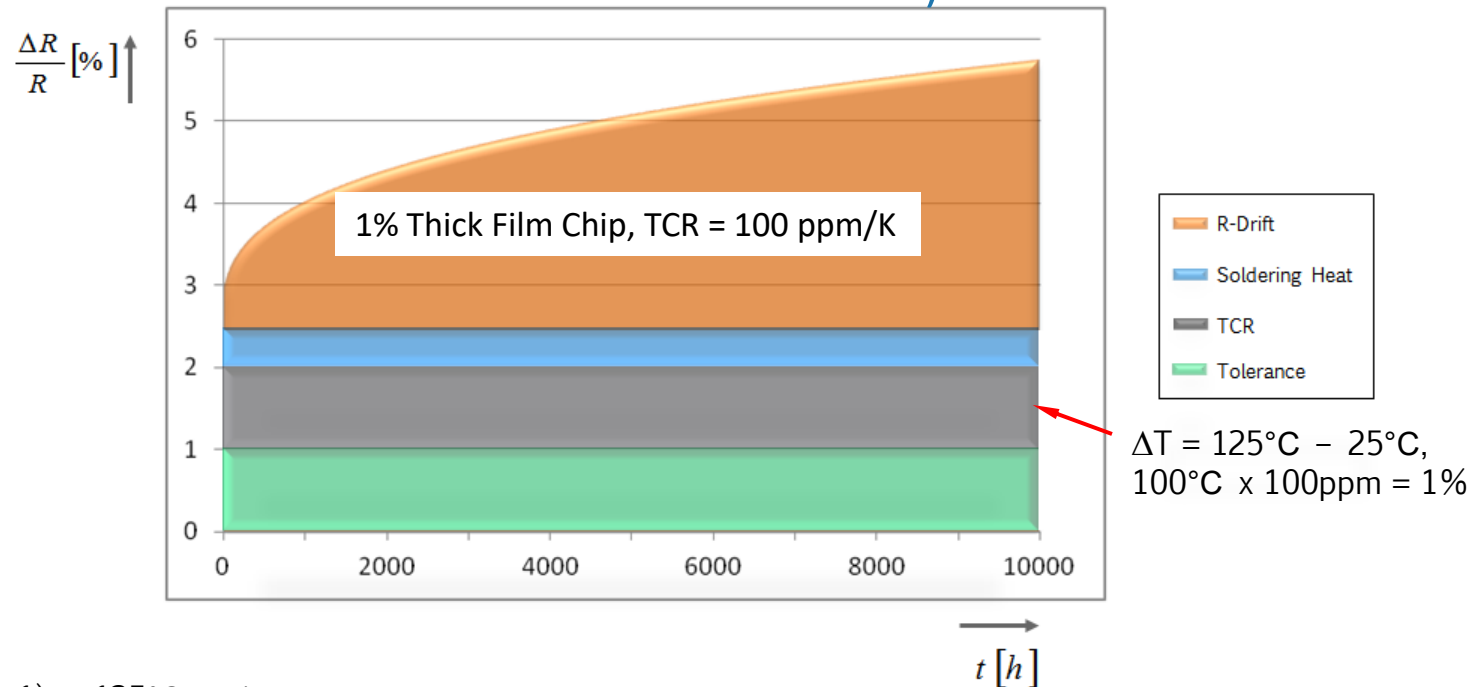


- Amplifier
- Instrumentation Amplifier
- Comparator

- Optimum choice:
- 1 % Thick film chip?
 - 1 % Thin film chip?

When to Use Thin Film or Thick Film

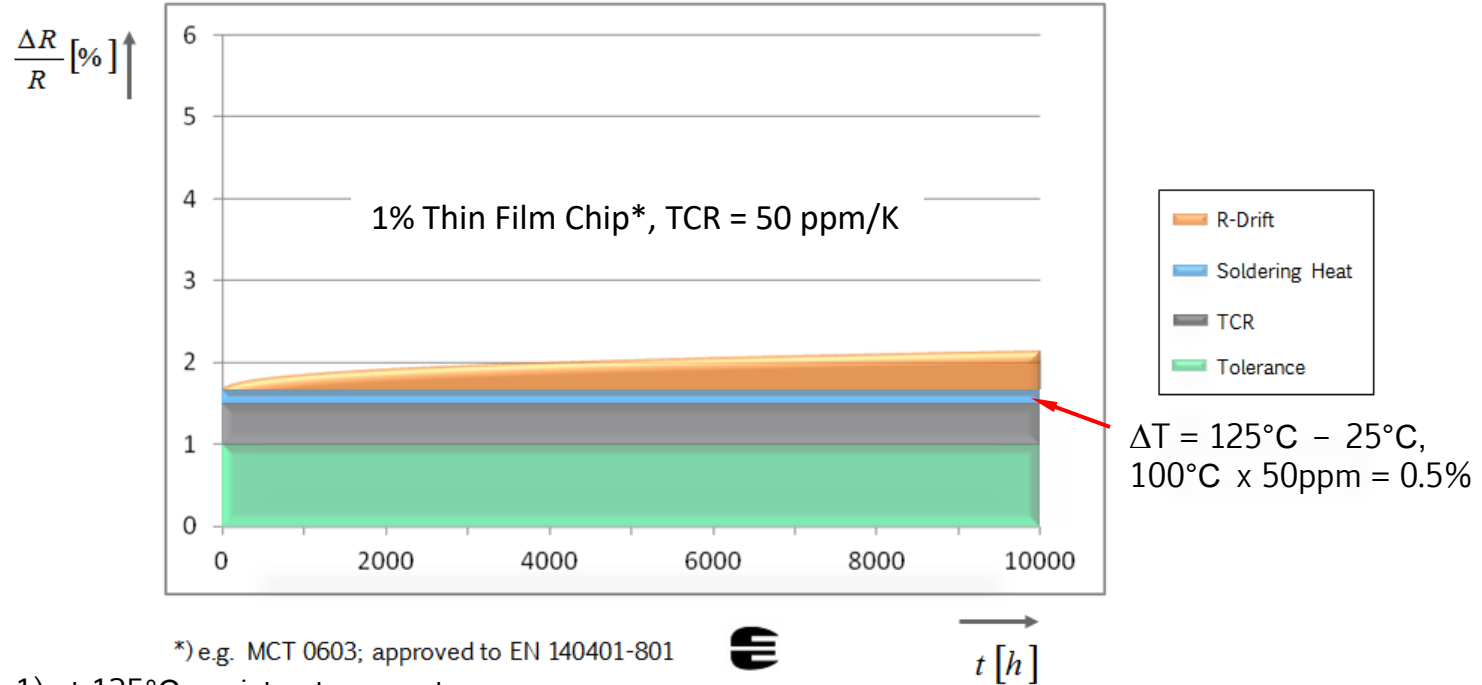
Worst Case Calculation for a Thick Film Resistor 1)



1) at 125°C resistor temperature

When to Use Thin Film or Thick Film

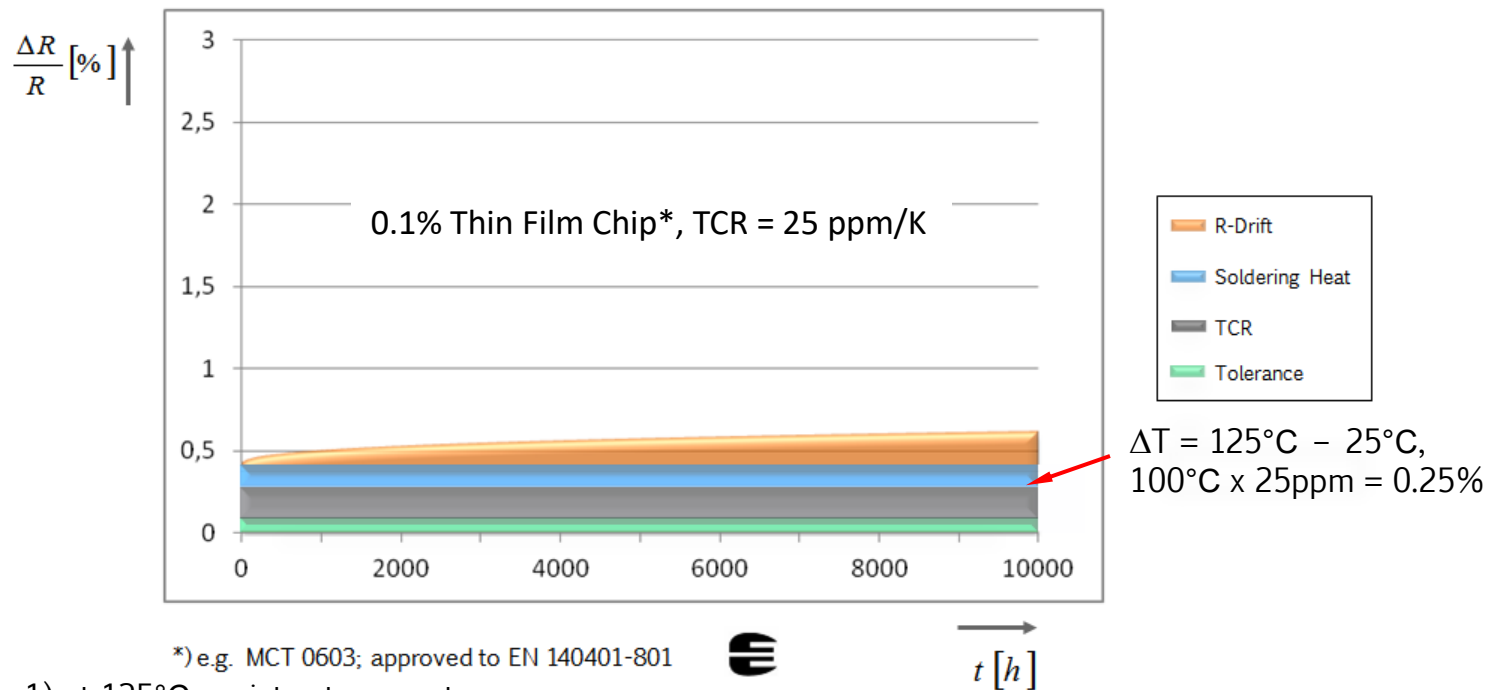
Worst Case Calculation for a Thin Film Resistor 1)



1) at 125°C resistor temperature

When to Use Thin Film or Thick Film

Worst Case Calculation for a Precision Thin Film Resistor 1)

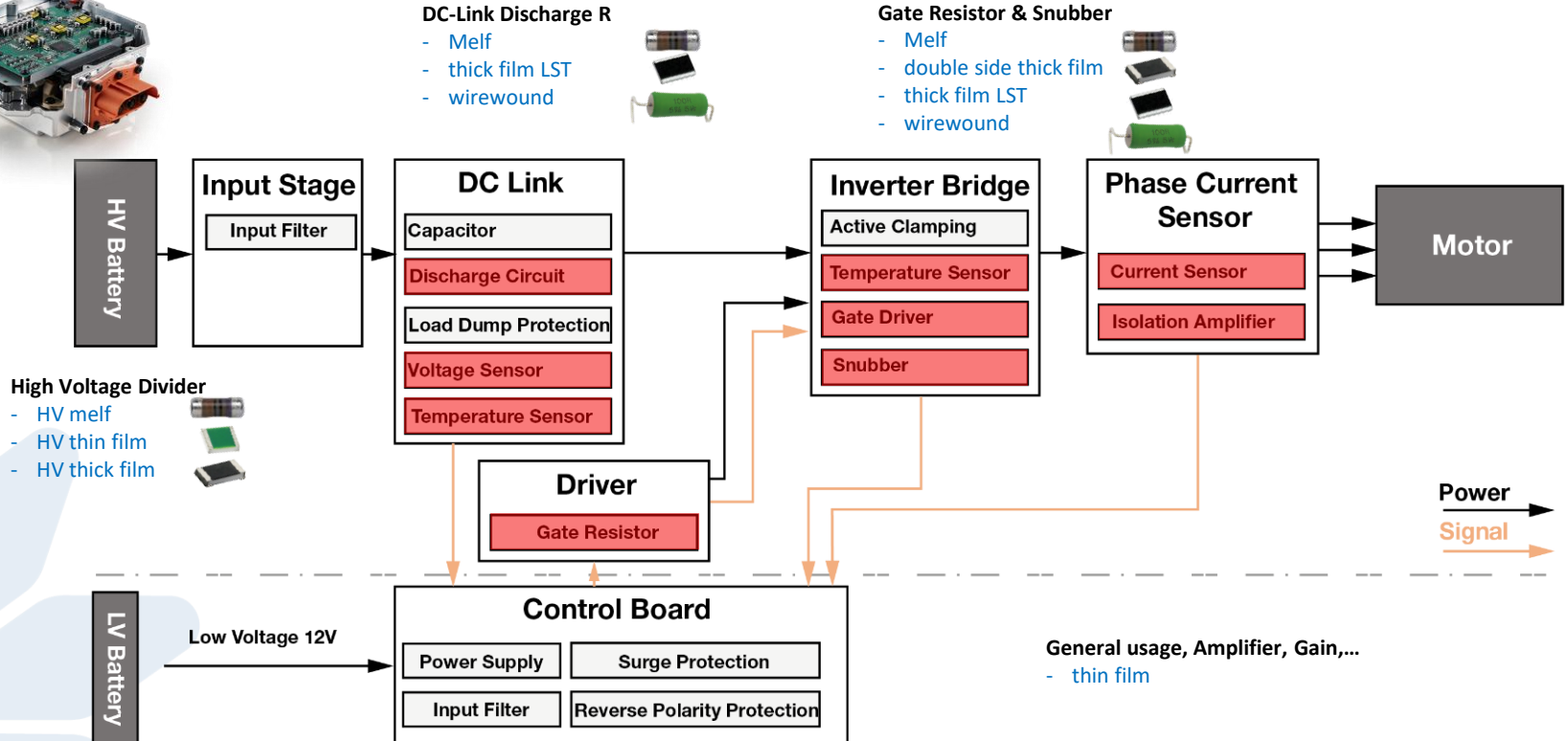


1) at 125°C resistor temperature

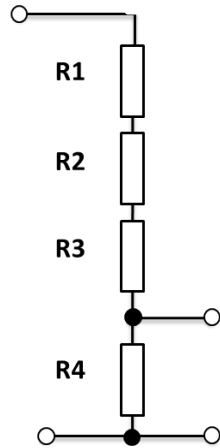
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- 7 - Conclusions

Where to Find These Resistors in an Inverter



High Voltage Divider



Application

- Battery management systems
 - Battery junction box, battery disconnect unit, power distribution unit
 - DC/DC converter
 - On-board and wall charger
 - Inverters
 - e-compressor / e-supercharger
 - Server and AI power supplies
 - Uninterruptible power supplies
- } Combo

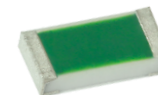


Benefits

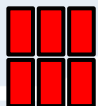
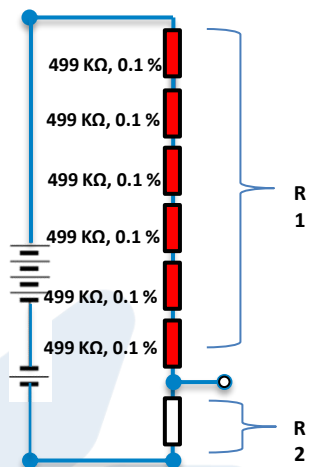
- Reduce component counts
- Reduce board space requirements
- Reduce assembly costs
- Reduce failure rate of entire circuit
- Reduce drift behavior over lifetime (thin film)

High Voltage Thin Film

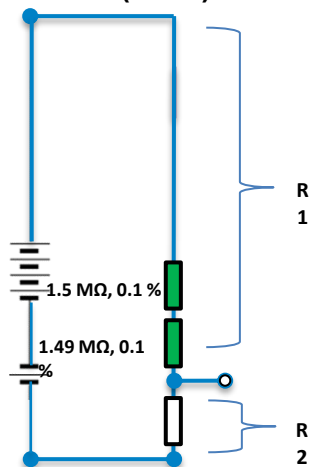
... how to Save Space and Money







Standard Thin Film (1206)



High voltage / High ohmic value Thin Film (1206)



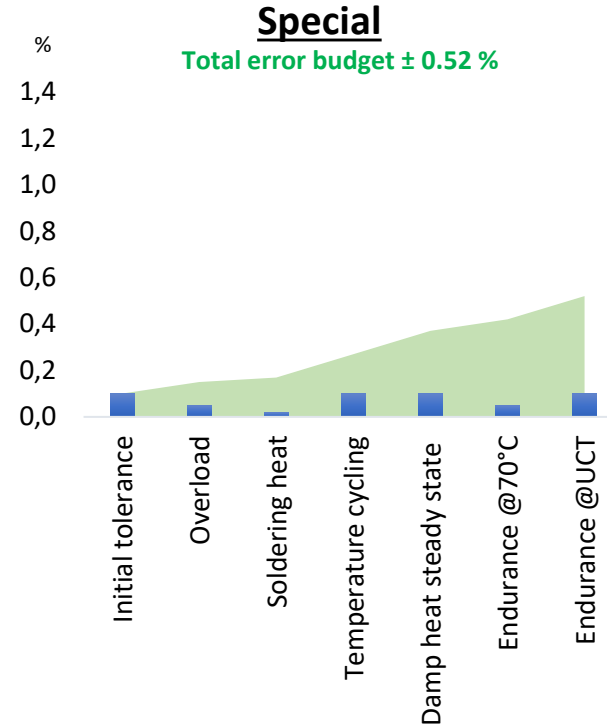
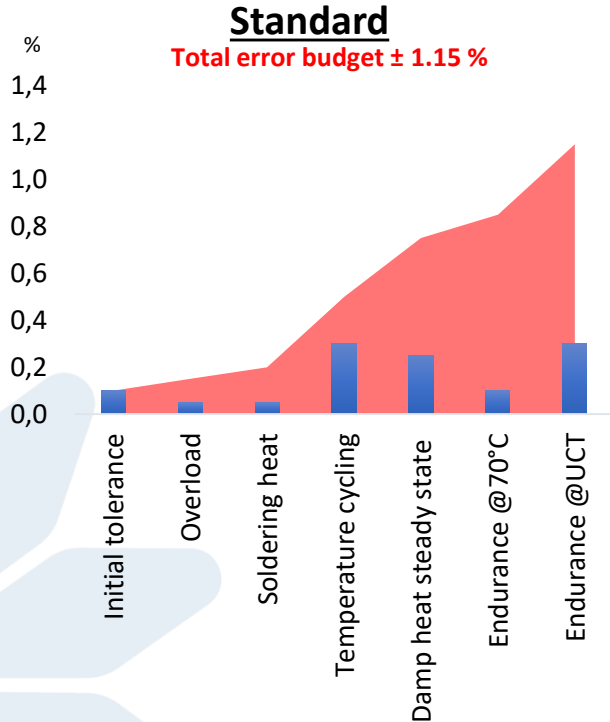
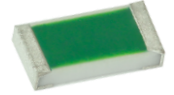
3.0x smaller

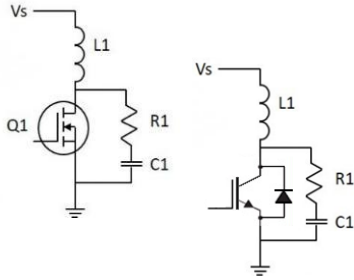
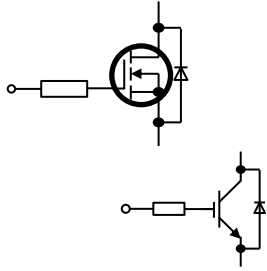
	Standard	Special HV
Products	499 KΩ 6pcs	1.5 MΩ 1pcs 1.49 MΩ 1pcs
R1 (Total)	2.994 MΩ	2.99 MΩ
Voltage (Umax)	1200 V	1400V
Tolerance	0.1 %	0.1 %
TCR	25 ppm/°C	25 ppm/°C
Size (inch)	1206	1206
Total Q'ty	6	2
Price (pcs)		
Price (total)		

Cost savings up to 55 %

High Voltage Thin Film – comparison

2 x Lower Error Budget





Gate & Snubber Circuits



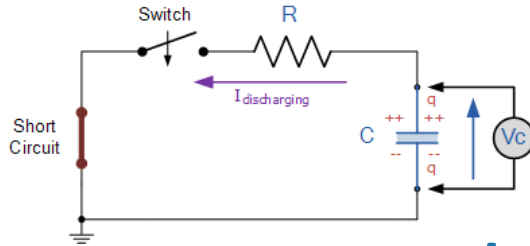
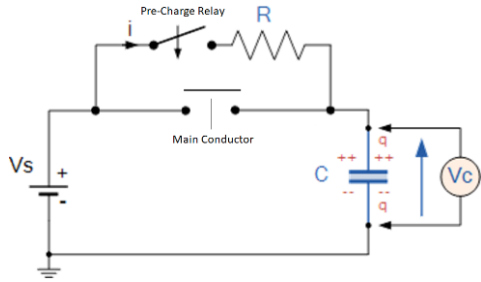
Applications

- DC/DC converters
- On-board and wall chargers
- Inverters
- eFuses / circuit breakers
- e-compressor / e-supercharger
- Server / AI power supplies
- Uninterruptible power supplies



Benefits

- Reduce component counts
- Reduce board space requirements
- Reduce assembly costs
- Reduce failure rate of entire circuit



Pre- and Discharge Circuits



Applications

- Battery management systems
- Battery junction boxes, battery disconnect units, power distribution units
- DC/DC converters
- On-board and wall chargers
- Inverters
- e-compressors / e-superchargers



Benefits

- Reduce component counts
- Reduce board space requirements
- Reduce assembly costs
- Reduce failure rate of entire circuit
- Reduce drift behavior over lifetime (thin film)

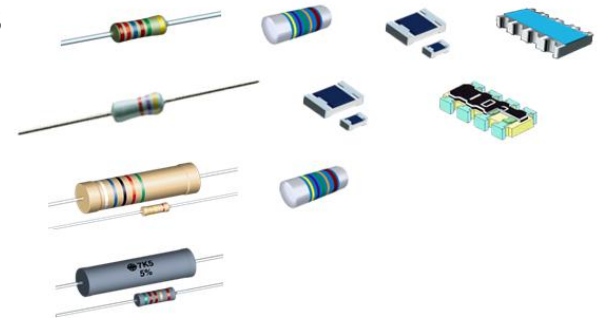
AGENDA

- 1 - Resistors Technologies
- 2 - Basic parameters: tolerance & TCR
- 3 - Thermal management and resistance drift
- 4 - Rated power dissipation & Pulse Load Capability
- 5 - Thin Film Vs. Thick Film
- 6 - Applications examples
- 7 - Conclusions**

Conclusions

Choosing the Right Resistor: What Really Matters

- **Tolerance** defines the initial accuracy
- **TCR** defines variation with temperature
- **Drift** defines long-term stability
- **Power dissipation** defines self-heating and thermal limits
(allowable power continuous dissipation)
- **Pulse load** defines robustness under transient stress



System-Level Considerations

- **Thermal management** influences all error contributions
- **Mission profile** determines how long each condition applies

Key Takeaway

Real resistor accuracy is the result of all these factors combined — over temperature and over time

“Don’t select resistors by tolerance alone – design for lifetime accuracy.”

Thank you very much for your attention!