Resistive Products

Pulse Load on SMD Resistors: At the Limit

By Joachim von der Ohe

The resistors used in electronic applications with low power consumption are getting ever smaller. However, the conditions for the pulse load capability need to be considered already in the design phase. And there are different effects of continuous pulse trains or of single pulses. This application note deals with the selection of the right type of resistor, aimed at optimized pulse load capability.

The nominal power dissipation is an essential parameter of a resistor and thus stated in the datasheet. It mainly depends on the permissible temperature of the resistive film and the thermal resistance of the component on a standardized circuit board.

Resistors are selected for their power dissipation as stated in the specification. The requirements towards smaller components increase with the shrinking of designs, rendering the thermal management of a circuit board ever more critical. There is not only the requirement not to exceed the permissible film temperature as a result of the true power dissipation and thermal resistance of the actual circuit board. Above that, there is a limitation for the component's solder joint not to exceed 110 °C in continuous operation.

But designing according to temperature limits is just one layout criterion. Another aspect is the circuit's reliability when subjected to various overload conditions. Here the decreasing component size is likely to cause a critical sensitivity to overload.

CAUSES FOR OVERLOAD

Failures of film resistors are mainly caused by pulse voltage overload or by excess current. There are many possible causes for pulse loads to occur in electronic circuits:

- Devices have to withstand voltage spikes carried forward on telephone or mains lines. Typical test pulses are defined in IEC 60115-1, clause 4.27.
- The switching of capacitors C or inductors L (e.g. relay coils) may introduce pulses at other passive components in a circuit. Shape and energy of the pulse depend on the time constant and on the energy stored in the components C or L.
- The voltage on the automotive supply system is known to be distorted. One of the most severe overload conditions is the "load dump" pulse, caused by disconnecting the battery with the engine and the generator still running.

CALCULATION OF PULSE LOADS

The pulse load capability of resistors is much lower towards pulse trains than it is towards single pulses. Therefore single pulses and continuous pulses are considered separately.

CONTINUOUS PULSE LOADS

The estimation of the expected pulse load depends on the pulse shape. In most cases it can be approximated by a rectangular or by an exponential pulse (Figure 2).

The list of significant parameters includes:

- The duration t_i of a rectangular pulse
- The time constant τ_e of an exponential falling pulse
- The period t_p of continuous pulse sequences
- The pulse peak voltage U_i

The resistor's datasheet specifies the nominal power dissipation at an ambient temperature of 70 °C as P_{70}.

For pulses whose duration t_i is not small compared to the component's time constant for warming up, the pulse voltage must not exceed:

$$\hat{U}_i = \sqrt{P_{70} \times R} \quad (1)$$

For shorter pulse durations a higher peak voltage may be permitted as long as the following three conditions are met.

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CONDITION A

The issue of condition A is that the average power dissipation $\bar{P}$ of the pulse sequence must not exceed the nominal dissipation P_{70}. The calculation of the average power dissipation $\bar{P}$ is shown below.

$$\bar{P} = \left(\frac{1}{t_p \times R} \times \int_{t_a}^{t_e} U_i^2 \right)(t)dt \qquad (2)$$

The equation looks much simpler for rectangular pulses:

$$\bar{P} = \frac{U_i^2}{R} \times \frac{t_i}{t_p} \qquad (3)$$

and for exponential pulses, too:

$$\bar{P} = \frac{U_i^2}{R} \times \frac{\tau_e}{2 \times t_p} \qquad (4)$$

P_{70} is in the range of 50 mW through 1 W for all popular surface-mount resistor types.

CONDITION B

The pulse peak voltage may exceed the limit as calculated with equation [1] for ever shorter pulse durations t_i. Still the permissible pulse power depends on the pulse duration. Related diagrams are published in the CECC detail specifications, and also in the data books of some resistor manufacturers.

For any given pulse load capability it is important however to consider the criterion used to decide on the actual capability:
While CECC specifications define the permissible influence on the component in comparison to the influence of operational ageing (drift) after 8000 h, this issue is left completely indistinct in a great number of data books. Here the circuit developer urgently requires the advise whether a specified pulse will result in 0.5 % through 4 % change of resistance at maximum, or will lead to the component's failure.

CONDITION C

Also the maximum voltage along the resistor needs to be considered for pulse loads. For example, the MINI-MELF surface-mount resistor is specified with 200 V as the highest permissible operation voltage, while the peak voltage of short time pulses may be significantly higher. Again, related diagrams are published in the CECC detail specifications, and also in the data books of some resistor manufacturers.
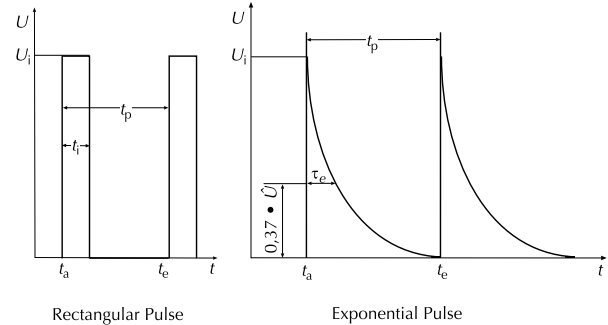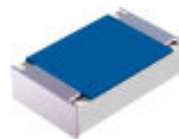

Fig. 2 - Typical pulse shapes

STANDARDS ON RESISTORS

Standards make a lot of sense as they provide a common base for the relationship between a customer and a supplier. They achieve this by defining minimum requirements for products. The quality standard of any manufacturer is shown in his appreciation of existing standards and his interest to have his products, or even his development and manufacturing processes regularly audited through an independent certification body.
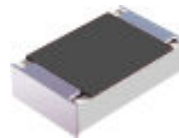
Resistors are standardized in the following CECC specifications ...

... for Thin Film Flat Chip resistors:

CECC 40 401-801, detail specification: "Fixed low power non-wirewound surface mounting (SMD) resistors, thin film resistors, rectangular, stability classes 0.1; 0.5; 1"

... for Thick Film (Metal Glaze) Flat Chip resistors:

CECC 40 401-802, detail specification: "Fixed low power non-wirewound surface mounting (SMD) resistors, thick film resistors, rectangular, stability classes 1; 2"

... for Thin Film MELF resistors:

CECC 40 401-803, detail specification: "Fixed low power non-wirewound surface mounting (SMD) resistors, thick film resistors, cylindrical, stability classes 0.25; 0.5; 1; 2"

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SINGLE PULSE LOADS

The permissible voltage depends on the shape and duration of the applied pulse. However, tests according to IEC 60115-1 clause 4.27 are useful for the comparison of different resistor products and provide a guideline for the circuit development. The specification describes two networks for the generation of pulses with defined shape and duration, suitable for the qualification of resistors: 1.2 µs/50 µs and 10 µs/700 µs.

The first number describes the front time of the pulse shape in µs, while the second identifies the time to half-value on the falling edge and gives the decay time down to 50 % of the peak value. The tests are conducted with 5 pulses 1.2 µs/50 µs at 12 s minimum intervals, or with 10 pulses 10 µs/700 µs at a period of 1 min or more.

The change of resistance resulting from this test should not exceed the same limiting margins as defined for tests of long term operation. Figure 3 provides curves for permissible voltages that still guarantee the resistance change of thin film MELF resistors to remain below 0.5 %. The comparison of these single pulse load capabilities to the diagrams for continuous pulse load reveals a significant safety margin.
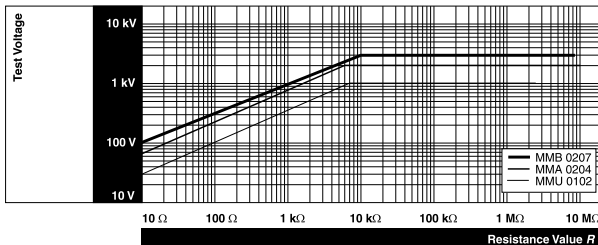

Fig. 3 - Pulse load capability for Thin Film MELF resistors, according to IEC 60115-1, clause 4.27.

TEST RESULTS

The components performance like described above is easily verified with a few simple tests. An inrush pulse typical for industrial electronics can be simulated with the discharge of a capacitor $C = 16$ µF into a resistor $R = 1$ kΩ; where the time constant is $\tau e = 16$ ms. The relationship of the resistance change to the applied pulse load can be observed by stepping up the pulse voltage for every new set of samples. Results of such tests are shown in Figure 4.

Most obvious in these graphs is the influence of the resistor's design and technology on the actual pulse load capability. It is even higher than the influence of the body size within a product family. In summary, thick film flat chip resistors fail at much lower pulse loads than thin film flat chips, and both types are outperformed by thin film MELF resistors.
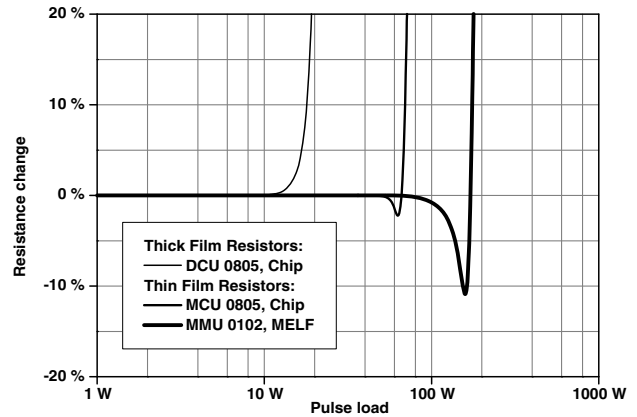

Fig. 4 - Pulse load test, resistance change for different 1 kΩ - resistor of comparable body size

CONCLUSIONS

The example of this load test reveals clearly the sensitivity of miniaturized components. And the advantage of thin film resistors over thick film resistors is as obvious as the advantage of the cylindrical MELF style over the flat chip style. These facts have of course been considered in the CECC component specifications. Now, what is the physical background for the observed differences?

- The polycristalline micro structure of the metal glaze (= thick film) renders the current flow through the resistor inhomogeneous.
- This disadvantage is further supported through the l-cut or L-cut laser trimming, popular for the manufacturing of thick film chip resistors. The pulse current is required to pass through the bottle neck at the edge of the trim pattern and causes a local hot spot there.
- The use of thin film technology together with meander trimming patterns avoids the generation of hot spots and rather ensures a uniform distribution of the dissipated heat on all of the product's surface.
- The helical trim pattern on the total available length of cylindrical thin film resistors likewise ensures a uniform heat distribution on the total surface. However, this surface is about three times as large as on a comparable flat chip.

Thin film resistors, particularly those in cylindrical style provide a significant safety margin for reliability. Therefore even today, next to a variety of flat chip resistors, there are always numerous reasons to design with MELF resistors.

THE AUTHOR

Dipl.- Ing. Joachim von der Ohe studied electrical engineering focussed on control and measurement systems at the Hannover University. In the course of his career he developed solid state image sensors in close cooperation with system developers, later he projected the back-end operations for a semiconductor prototyping fab. Since 1995 he is responsible at BCcomponents BEYSCHLAG for the technical customer support.

APPLICATION NOTE