Ceramic transient voltage suppressors, CTVS

Selection procedures

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1 Selection procedures

The selection procedure for ceramic transient voltage suppressors consists of the following main steps:

1. Defining the requirements of the application circuit
2. Determining the expected transient surge
3. Selecting of a suitable CTVS

The maximum possible loading of a CTVS is determined by both the electrical specifications of the intended application and its own physical capabilities. Note that we will differentiate between these two in this chapter. We will mark the maximum possible loading of the CTVS determined by the electrical specifications of the intended circuit with the superscript $\ll *\gg$.

1.1 Defining the requirements of the application circuit

- Operating voltage V_{op} of the circuit to be protected
- Minimum protection level (clamping voltage) needed for the circuit

1.2 Determining the expected transient surge

Determining the transient load on the CTVS when limiting overvoltage means that you have to know the surge current that is to be handled. For proper selection we need the following parameters of the transient load:

- Surge current $I_{surge,max}*$
- Pulse duration t_r*
- Estimated number of surge repetitions N

1.2.1 Surge current $I_{surge,max}*$ and surge voltage $V_{surge,max}*$

The surge current in a given application is either specified or can be calculated from the application's voltage. Either way, it has to be converted into a rectangular waveform and then derated to calculate the load the CTVS has to handle.

Case A: predefined surge current $I_{surge,max}*$

Often the surge current is predefined in specifications. After transformation into an equivalent rectangular wave, a suitable CTVS type can be selected with the aid of the derating curves.

Case B: predefined surge voltage $V_{surge,max}*$

If the surge voltage is predefined, the surge current in a specific network can be determined in one of the following ways:

■ Simulation

The most convenient method to determine the surge load is by using the PSpice simulation models of the EPCOS ceramic transient voltage suppressors. Thus, the surge current, the waveform and the energy content can be calculated. In these models, the maximum surge current is deduced for the lower limit of the tolerance band, i. e. setting TOL = –10.

■ Test circuit

The amplitude and waveform of the surge current can be determined with the aid of a test circuit (predefined network). The dynamic processes for overvoltages require adapted measuring procedures.

■ Graphical method

The overvoltage can be drawn into the V/I characteristic curve fields as a load line (with end points: open circuit voltage, short-circuit current). At the intersection of this load line with the CTVS curve selected to suit the operating voltage, the maximum protection level and the corresponding surge current can be read off. The waveform and thus the energy content cannot be determined by this method. Since the V/I characteristic curves are drawn in a log-log representation, the load line is distorted to a curve.

■ Mathematic approximation

The surge current is determined solely from the source impedance of the surge voltage (V_{surge}). By subtracting the voltage drop across the CTVS (from the V/I curve) you can approximate the maximum surge current as follows: $I_{surge,max}* = (V_{surge} - V_{CTVS}) / Z_{source}$. For reference refer to chapter "Design notes," section 1.1.

1.2.2   Preparation of surge current figures for CTVS selection

Once the surge current in the application is known ($I_{surge,max}*$), the data must be prepared for the actual selection of a CTVS.

For appropriate comparison of the obtained surge current figures with the maximum ratings of the CTVS devices, we need to first convert the surge current waveform into an equivalent rectangular wave by keeping the maximum surge current value. This is done using the rectangular wave method.

1.2.3   The rectangular wave method

The rectangular wave method is illustrated in figure 1. Keeping the maximum surge current value $I_{surge,max}*$, you can change the surge current wave into a rectangular wave of the same area. t_r* is then the duration of the equivalent rectangular wave and is identical to the "pulse width" in the derating curves.

The time period $T*$ is needed to calculate the average power dissipation $P_{diss,max}*$ resulting from periodic application of energy.
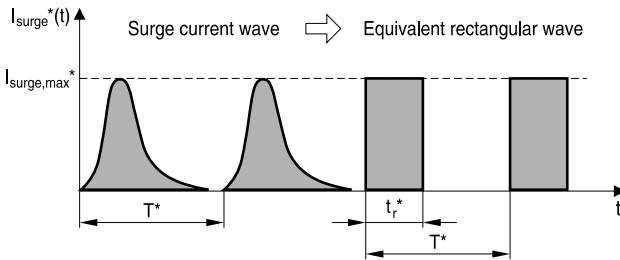
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Figure 1
Rectangular wave
method

MLV0121-O-E

If the pulse load

$$\int I_{surge}{}^*(t)\, dt$$

is known, then $t_r{}^*$ can be calculated using the following equation:

$$t_r{}^* = \frac{\int I_{surge}{}^*(t)\, dt}{I_{surge,max}{}^*} \qquad \text{(equ. 1)}$$

1.3   Selecting a suitable CTVS for overvoltage protection

After determining the operating conditions necessary for the applications, the next step is to find a CTVS that can withstand the requirements

Select a CTVS that is suitable in terms of the following maximum ratings:

1. Maximum operating voltage: $V_{RMS,max}$, $V_{DC,max}$ in V
2. Maximum surge current: $I_{surge,max}$ in A
3. Maximum energy absorption: W_{max} in J
4. Maximum power dissipation: $P_{diss,max}$ in W
5. Maximum protection level: $V_{clamp,max}$ in V

Determine the maximum possible voltage rise on the selected CTVS in case of overvoltage and compare this value to the electric strength of the component or circuit that is to be protected.

Maximum operating temperature: $T_{op,max}$

Note:
For operating the CTVS above the specified maximum operating temperature $T_{op,max}$, you must consider the derating of the specified maximum figures according to the temperature derating curves stated for each CTVS (see chapter "General technical information", section 2.7.2).

1.3.1 Selecting a CTVS in terms of the maximum ratings

The electrical behavior of the CTVS results from the number of microvaristors connected in series or in parallel.

This implies that the electrical properties are controlled by the physical dimensions of the CTVS (refer to chapter "General technical information", sections 2.1.1 and 2.3).

- Twice the ceramic layer thickness produces twice the protection level because then twice as many microvaristors are arranged in series.
- Twice the overlapping area produces twice the current handling capability because then twice the number of current paths are arranged in parallel.
- Twice the active volume produces almost twice the energy absorption capability because then there are twice as many absorbers in the form of zinc oxide grains.

Keep this in mind when selecting a CTVS.

1.3.2 Maximum operating voltage $V_{RMS,max}$ and $V_{DC,max}$

Step 1:
Maximum permissible AC and DC operating voltages are stated in the product tables for all CTVS components. The operating voltage must not exceed these maximum ratings.

To obtain as low a protection level (clamping voltage) as possible, a CTVS should be selected so that the maximum permissible operating voltage $V_{DC,max}$ is close to the operating voltage of the application V_{op}.

Of course, you may also select a CTVS with a higher permissible operating voltage $V_{DC,max}$. This procedure is used, for example, when it is more important to have an extremely small leakage current than the lowest possible protection level (clamping voltage). In addition, the life time of the varistor is also increased by a higher security margin between V_{op} and $V_{DC,max}$.

Note:

- CTVS are transient voltage suppression devices and therefore not designed for voltage regulation. It is important to ensure that the intended operating voltage does not exceed the specified maximum permissible operating voltage.
- In the case of power line applications, you must take into account the tolerance of the line operating voltage (e.g. European supply systems to IEC 60038: 230 V +10% = 253 V).

1.3.3 Maximum surge current $I_{surge,max}$

Step 2:
The definition of the maximum possible operating voltage in the previous step will have narrowed down the choice of an optimum CTVS to the types of a defined voltage class (maximum permissible AC operating voltage). Then you check, with reference to the conditions of the application, what kind of load the CTVS can be subjected to. From the derating curves you can obtain maximum figures for rectangular surge current waves. For correct comparison with these maximum permissible values, the real surge current wave (any shape) has to be converted into an equiva-

lent rectangular wave. This is best done graphically by the rectangular method illustrated above.

The maximum permissible surge current of the CTVS ($I_{surge,max}$) depends on the duration of current flow t_r* and the required number of surge repetitions N in the application. Taking these two parameters, the maximum surge current $I_{surge,max}$ can be read from the derating curves (see figure 2) .
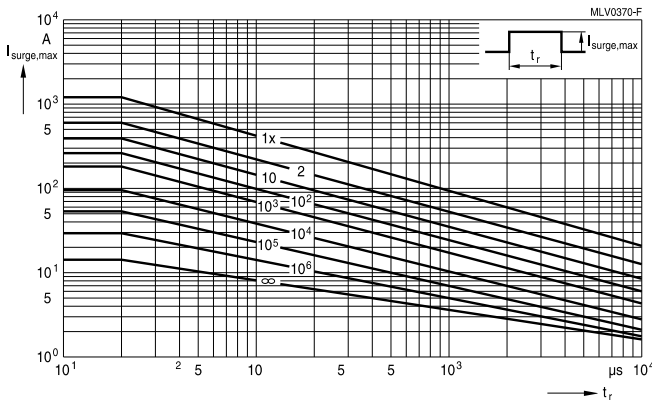

Figure 2
Example: pulse derating diagram

This figure is compared to the maximum possible surge currents in the intended electrical environment of the CTVS.

Selection criteria:

$I_{surge,max}$* $\leq I_{surge,max}$ (equ. 2)

1.3.4 Maximum energy absorption W_{max}

Step 3:
When a surge current flows across the CTVS, there will be absorption of energy. The amount of energy to be absorbed by the CTVS can generally be calculated by the following equation:

$$W = \int_{t_0}^{t_1} v(t) \cdot i(t)\ dt$$ (equ. 3)

Common ways to determine the surge energy:
- Calculation method
  Often the energy absorption can be read directly from a storage oscilloscope or can be calculated from the voltage/current curve using numerical methods.
- Simulation
  Determination of the energy absorption by PSpice simulation is even more convenient.

- Graphical method
  Otherwise the equation can be solved graphically with sufficient accuracy by using the rectangular wave method. The surge current wave I_{surge}* (t) is converted as explained in the above

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and *Cautions and warnings*.
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section into an equivalent rectangle and then multiplied by the highest voltage V_{max}* appearing on the CTVS.

$$W^* = V_{max}^* \cdot I_{surge}^* \cdot t_r^* \qquad \text{(equ. 4)}$$

V_{max}* can either be derived from the V/I characteristic as the value matching $I_{surge,max}$*, or likewise be determined with the aid of an oscilloscope as the maximum voltage drop across the CTVS

To check the selection requirement W* ≤ W_{max} (equation 6), you have to determine the maximum permissible energy absorption for the intended varistor. This can be calculated by equation 4 as a function of time the energy is applied (t_r*) and the number of repetitions N from the derating curves.

Selection criteria:

$$W_{max} = V_{max} \cdot I_{surge,max} \cdot t_r \qquad \text{(equ. 5)}$$

$$W^* \leq W_{max} \qquad \text{(equ. 6)}$$

1.3.5 Energy of an ESD pulse

IEC 61000-4-2 specifies 15 kV as the highest charging voltage (severity level 4, air discharge) for the 150 pF discharge capacitor according to figure 3.
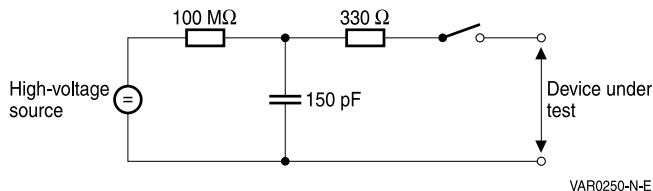

Figure 3
Typical ESD test circuit

This means that the stored energy is

$$W^* = 0.5 \cdot C \cdot V^2 = 0.5 \cdot 150 \cdot 10^{-12}\,F \cdot 15^2 \cdot 10^6\,V^2 < 0.02\,J \qquad \text{(equ. 7)}$$

The 330 Ω resistor limits the surge current to a maximum of

$$I^* = \frac{V^*}{R} = \frac{15000\,V}{330\,\Omega} = 45\,A \qquad \text{(equ. 8)}$$

If this surge current is to be handled by a multilayer varistor, then, according to equation 1 in chapter "Design notes", the effect of the varistor on this value of the current amplitude is negligible.

For CT0805M6G, for example, this means that

$$\overset{*}{I} = \frac{(V_{surge} - V_{VAR})}{Z_{surge}} = \frac{15000 \text{ V}}{330 \text{ }\Omega} = 45 \text{ A} \qquad \text{(equ. 9)}$$

By transforming the discharge current (figure 1) into an equivalent rectangular wave, we obtain $t_r^{*} \approx 40$ ns.

No value can be deduced from the derating curves for such an extremely short current flow time.

The energy absorption of multilayer varistors and CeraDiodes during ESD discharges lies in the region of μJ.

For the CT0805M6G, for example, according to equation this means that

$$W^{*} = V^{*} \cdot \overset{*}{I} \cdot t_r = 45 \text{ V} \cdot 45 \text{ A} \cdot 40 \cdot 10^{-9} \text{ s} = 80 \text{ }\mu\text{J} \qquad \text{(equ. 10)}$$

Thus the largest part of the energy content of the ESD pulse is absorbed by the 330 Ω discharge resistor.

All types of the MLV and CeraDiodes series are able to meet the (severest) ESD test level 4 to IEC 61000-4-2. Figure 4 demonstrates this for multiple pulses taking the low capacitance type CT0603L25HSG as an example.
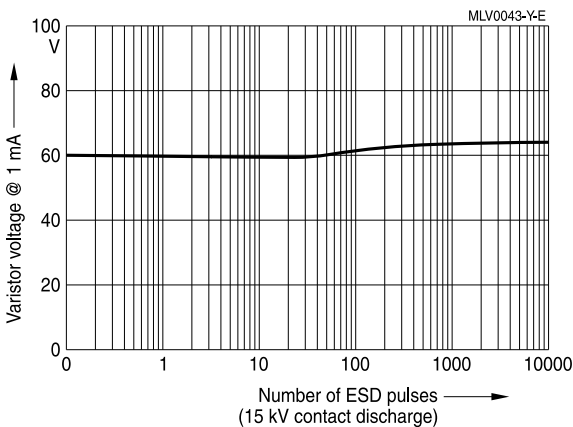

Figure 4
ESD stability of varistor voltage for type
CT0603L25HSG

Due to the steep edge of the ESD pulse, the inductance determined by mechanical construction of a device and of the layout of the test circuit is of great importance for the test result. The CTVS selection should therefore always be verified by an ESD test circuit.

1.3.6 Average power dissipation $P_{diss,max}$

Step 4:

The actual power dissipation of a CTVS is composed of the basic dissipation $P_0{}^*$ in steady-state conditions caused by the operating voltage and, possibly, the average of periodic energy absorption. If ceramic transient voltage suppressors are chosen from the product tables in agreement with the maximum permissible operating voltages, $P_0{}^*$ will be negligible within the specified ambient temperature range.

Periodic energy absorption produces an average power dissipation of

$$P_{diss}{}^* = \frac{W^*}{T^*} = \frac{\left(V_{surge,max}{}^* \cdot I_{surge,max}{}^* \cdot t_r{}^*\right)}{T^*} \qquad \text{(equ. 11)}$$

W^*	[J]	Energy absorption
T^*	[s]	Time period
$V_{surge,max}{}^*$	[V]	Maximum applied surge voltage
$I_{surge,max}{}^*$	[A]	Maximum applied surge current
$t_r{}^*$	[s]	Pulse duration

By solving this equation for T^* it is possible to calculate the minimum time t_{min} that must elapse before energy is applied again without exceeding the maximum permissible average power dissipation of the CTVS:

$$t_{min} = \frac{W^*}{P_{diss,max}} \qquad \text{(equ. 12)}$$

Note:

CTVS devices are not to be "operated" at $P_{diss,max}$. They are not suitable for "static" power dissipation, e.g. voltage stabilization. There are other kinds of components, like zener diodes, designed primarily for this kind of application, but with much lower surge current handling capability.

Selection criteria:

$$P_{diss}{}^* \leq P_{diss,max} \qquad \text{(equ. 13)}$$

1.3.7 Maximum protection level (clamping voltage) $V_{clamp,max}$

Step 5:

The maximum possible voltage rise in the event of a surge current is checked with the aid of the V/I curves or PSpice models. This figure can be read directly from the curve for a given surge current (for worst-case varistor tolerances). If the voltage value thus obtained is higher than acceptable, the following possibilities may assist in reducing the protection level.

- Choose a type with a larger case size. The protection level is lower for the same surge current because the current density is reduced.
- Choose a tighter tolerance band. A special type is introduced that only utilizes the bottom half of the standard tolerance band for example. This would mean a drop in the protection level by approx. 10%.
- Insert a series resistor. This reduces the amplitude of the surge current and thus the protection level of the CTVS.

Note:

If the protection level obtained from the V/I curve is lower than required, you can change to a varistor with a higher protection level (i.e. higher voltage class). This has a favorable effect on load handling capability and operating life. The leakage current is further reduced.

1.4 Remarks on automotive protection

1.4.1 Load dump

Under this condition peak voltages up to 200 V can occur, lasting for few hundred ms, yielding energy levels up to 100 J. In accordance with ISO 16750-2 (see chapter "Protection standards," section 1.3.2), the load dump pulse is specified by the parameters:

- Charge voltage (test level) V_S
- Internal resistance R_i
- Rise time t_r
- Duration t_d

The easiest way to determine the amount of energy dissipation by the varistor is to perform a software simulation (using e.g. PSpice) to determine which portion of the energy of this pulse the varistor absorbs. The value calculated by this method W^* must be lower than the value specified in the product tables W_{max}.

ISO 16750-2 requires that at least ten load dump absorptions must be tolerated for load dump test pulse A and five load dump absorptions for test pulse B. To comply with such regulations the automotive industry specifies load dump values for 10 repetitions for their applications.
The product tables in the data sheets show supplementary maximum energy values for load dump absorption W_{LD} (with $10 \cdot$ pulses).

If requested, EPCOS can perform load dump simulations according to the customer's specifications.

For such cases, we require information concerning the parameters listed above (charge voltage V_s, internal resistance R_i, rise time t_r, duration t_d) plus the number of repetitions desired.