Technical Note 11241 Effective January 2021 Multilayer varistor (MLV) application note

Multilayer varistors (MLVs) for overvoltage protection

Suppressing surge voltages and transient events

Multilayer Varistors (MLVs) are voltage variable resistors that protect sensitive electronic circuits from overvoltage without changing the behavior of the circuit during normal operation. When installed in parallel with a circuit under normal conditions, an MLV appears as a high impedance and is essentially "invisible" to the circuit. During surge voltage, however, an MLV undergoes a reduction in impedance within a few nanoseconds. This reduced impedance offers a shunt current path for the surge to ground and clamps the voltage between the MLV's terminals to a specified value. This helps to ensure that the downstream circuit components are not exposed to either the prospective surge voltage or subsequent shunt current, effectively mitigating the impact of a transient high-energy pulse.

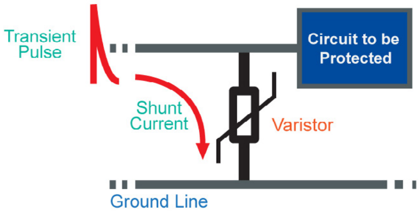

Figure 1. MLVs act as a shunt resistor to ground during transient surges that exceed the varistor's turn-on voltage.

MLVs are ideal for suppressing electrostatic discharge (ESD) events from damaging small portable electronics and sensitive electronic modules. MLVs are often used for protecting electronics in low-frequency, high-frequency, and signal-line applications, including the protection of portable electronic devices (laptop computers, tablets, smartphones, wearables, external storage, etc).

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Overvoltage overview

A surge event occurs when a near-instantaneous and transient pulse/surge is presented at the terminals of an electronic device that exceeds the normal operating voltage of the device. The term "surge" generally applies to violent, high-voltage and/or large currents applied to a circuit over a very short time (nanoseconds). This can occur during lightning storms, from switching events, brown-outs/black-outs, if an electromagnetic pulse (EMP) device is deployed, or when static is discharged from contact with a user or object (ESD). A surge may also be caused by the failure of internal components or interconnect, such as switching failure or interconnect failure.

	Voltage	Current	Rise time	Duration
Lightning	25 kV	20 kA	10 ns	1 ms
Switching	600 V	500 A	50 ns	500 ms
EMP	1000 V	10 A	20 ns	1 ms
ESD	15 kV	30 A	< 1 ns	100 ns

Figure 2. Surge characteristics of common overvoltage events.

Lightning is an unpredictable, yet ubiquitous, threat to electronics. Lightning can cause surge events either from direct strike, inter-cloud flashing, and cloud-to-ground flash. Although a direct lightning strike can generate enormous electromagnetic (EM) field energies that induce surge overvoltages in adjacent cables, inter-cloud flashing and cloud-to-ground flashing can also induce surge voltages in cables miles away from the flash. Other concerns include EMP events, even from a great distance away.

MLV construction and theory of operation

MLVs are constructed of fine grain ceramic layers stacked with alternating connections between two electrodes. Adjacent grains form diode junctions arranged to perform like opposing diodes in series and are inherently bi-directional. MLVs made using Metal Oxide Varistor (MOV) technology use oxide zinc grains with other metal oxides between the two electrode plates. When a large voltage is applied across the exterior terminals, the grain boundaries break down via electron tunneling and become conductive. The conductivity of this boundary is voltage dependent, with high peak voltages causing the otherwise high-impedance MLV to behave as a low resistance shunt.

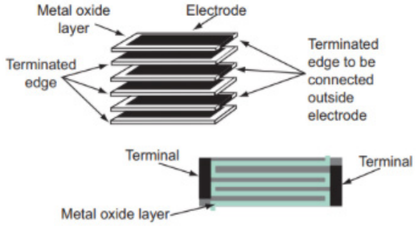

Figure 3. Multilayer varistor construction.

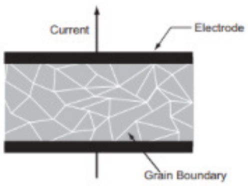

Figure 4. Metal Oxide Varistor construction.

It can be observed from the voltage-current (V-I) characteristic curve of a zinc oxide (ZnO) varistor that at low voltages the current drops off asymptotically. Hence, at low voltages the resistance of a MLV is extremely high. Starting at the clamping voltage level, the V-I curve rises and plateaus with a relatively flat V-I curve, which indicates that as the voltage increases the current stays relatively the same. In this "normal operating region" the resistance of the MLV decreases with rising voltage to a peak current level. Exceeding this peak current on the V-I curve can result in damage to the MLV device.

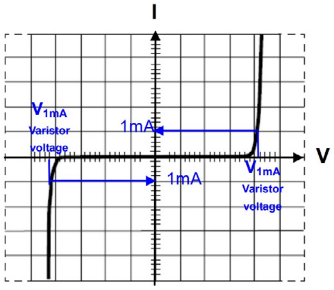

Figure 5. Varistor voltage defined at 1 mA.

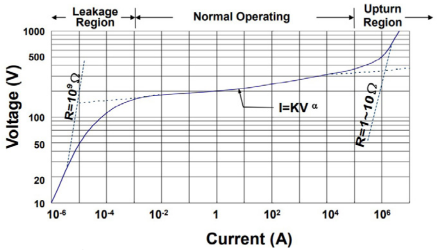

Figure 6. Varistor V-I curve.

Key terms and definitions

Working voltage (V_{RMS} & Vdc): Maximum alternating current (AC) voltage (Vac) and direct current voltage (Vdc) the device can maintain while not exceeding a defined leakage current (typically 10 µs).

Varistor voltage (V): Voltage across the device measured at 1 milliampere (mA); voltage at which the device begins to conduct; similar to breakdown voltage in a TVS diode.

Clamping voltage (V_C): Maximum peak voltage across the device with a 8/20 microsecond (µs) surge waveform and a specified current (often 1A).

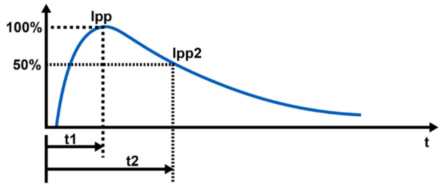

Figure 7. 8/20 µs waveform.

Peak current (I_{PP}): The rated maximum pulse current of a specified amplitude and waveform that can be applied without damage. Usually 8/20 µs current waveform.

Transient energy (J): Maximum power (W) which may be dissipated under a specified waveform (often 10/1000 µs) waveform without device failure.

Capacitance: The characteristics of the circuit element allow it to store charge. For MLVs, capacitance is usually measured at 1 MHz with a zero volt bias.

Leakage current (I_L): Varistor current measured at rated voltage V_{RMS} or Vdc; also called standby current.

MLV selection considerations

For optimal performance, an MLV device should be as close to the signal input as is feasible for the design. The MLV should be directly connected to the signal input with the remaining circuit components following the MLV placement. A "0-stub" pad design is recommended due to the high currents associated with ESD events. A 0-stub pad design has the pad directly on the signal/data line and second pad directly on the common ground plane/trace.

High priority considerations:

- The clamping voltage rating of the MLV device for a given circuit should be below the maximum withstand voltage the circuit can experience without suffering damage. The MLV clamping voltage should be set low enough to ensure an acceptable margin below the maximum operating voltage of the weakest circuit component in the circuit.
- For signal line/data line applications, it is important to select a MLV device with a capacitance rating that is low enough to avoid degrading the signal integrity of the line. In general, the lower the capacitance rating of the MLV the less high-frequency signal degradation will occur. In other words, higher speed/higher frequency signal line/data lines require lower capacitance MLVs to operate as intended.
- The working voltage rating of the MLV should be higher than the normal operating voltage of the circuit and not exceed 10 uA leakage current.
- MLVs, like most semiconducting devices, experience derating at temperature extremes. It is therefore vital that an MLV device is selected with desired electrical parameters at the operating temperatures of the application. Specifically, MLVs exhibit a reduction in the energy they can handle at high temperature extremes, and the capacitance value of an MLV is directly related to the operating temperature of the device.

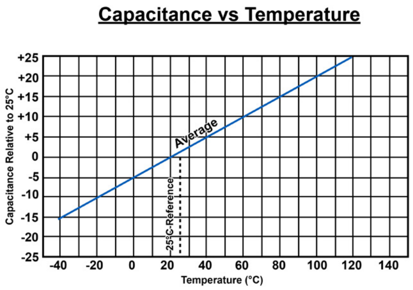
Capacitance vs Temperature

Figure 8. Typical capacitance vs temperature derating curve.

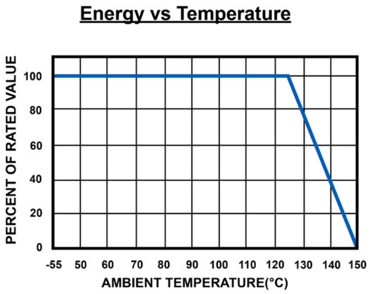
Energy vs Temperature

Figure 9. Typical energy vs temperature derating curve.

Recommended MLV selection steps

Eaton's surface mount MLVs provide ESD, load switching and up to induced lightning protection. MLV devices are commonly available in footprints from 0402 to 1206 with working voltages and peak surge current ratings up to 68 Vdc and 35 A. Eaton's MLV portfolio offers footprints down to 0201 but also up to 4032, with working voltages up to 200 Vdc and 1200 A peak surge current rating. MLVs are inherently bi-directional in nature.

Eaton MLV selection steps

1. Identify the nominal and worst case operating voltage of the circuit, and if the circuit voltage is AC or DC.

   a.) Select a device with Working Voltage that is greater than the operating voltage of the circuit given maximum parameters.

   b.) It is often advisable to add ~10% buffer to the device Working Voltage to ensure a minimal leakage current.

   c.) For circuit voltages above 70 Vdc, the high energy MLVCs, TVS Diodes or MOVs would be ideally suited.

2. Determine the maximum allowable downstream circuit voltage before damage. It is important to note that the dynamic behavior may change the "load" of the circuit, and it is advisable to consider the worst case loaded scenario for maximum downstream circuit voltage.

   a.) Select a device with a Clamping Voltage (V_C) that is less than the maximum allowable voltage for the circuit.

3. Determine Peak current and/or energy withstand protection requirements for the downstream circuit.

   a.) Select a device with a Peak Current (I_{PP}) that is greater than the anticipated transient threat current (A).

   b.) Select a device with a Transient Energy (J) rating that is greater than the anticipated transient threat.

4. Of the available options, choose a device with a capacitance rating that minimizes the high frequency impact to the downstream circuit.

   a.) ESD for high speed data lines will require lower capacitance (MLVB, PolySurg, or TVS Diode).

   b.) V_{bus} and power lines are generally not sensitive to capacitance.

Resources

Eaton parametric search tool

Eaton overvoltage electronic components

Eaton MLV products

Multilayer varistors (MLV) selection guide

MLVA - Compact

Package size	Working voltage (Vdc)	Clamping voltage (V)	Max peak current (8/20 µs)	Capacitance (pF) range
0201	5.5	26 to 30	-	33 to 64
0402	5.5 to 18	28 to 54	20	85 to 270
0603	5.5 to 26	31 to 70	30	100 to 270

MLVB - Low capacitance

Package size	Working voltage (Vdc)	Clamping voltage (V)	Max peak current (8/20 µs)	Capacitance (pF) range
0402	9 to 18	35 to 250	-	0.5 to 5
0603	9 to 18	35 to 250	-	0.5 to 5

MLVC - Standard

Package size	Working voltage (Vdc)	Clamping voltage (V)	Max peak current (8/20 µs)	Capacitance (pF) range
0402	12 to 18	34 to 44	20	90 to 150
0603	12 to 33	34 to 79	30	80 to 210
0805	12 to 48	34 to 110	35	80 to 220
1206	12 to 68	34 to 151	35	90 to 450

MLVC - High energy

Package size	Working voltage (Vdc)	Clamping voltage (V)	Max peak current (8/20 µs)	Capacitance (pF) range
0805	12 to 33	34 to 79	120	230 to 420
1206	12 to 60	34 to 134	150	180 to 850
1210	11 to 65	33 to 144	300	400 to 1800
1812	11 to 60	33 to 134	500	650 to 2400
2220	18 to 68	44 to 151	600	700 to 4000
3225	18 to 200	44 to 425	400	250 to 3500
4032	14 to 200	35 to 422	1200	700 to 5000

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Printed in USA
Publication No. 11241 BU-MC20220
January 2021

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