Multilayer Varistor Filters

Truly Multi-functional Passive Components

It is forecast that component densities for hand held wireless products will increase from today's figure of 14/cm^2 to about 54/cm^2 within a five year time span. Passive components form 80% of the total present on a typical circuit board, occupy about 50% of the board area and require 25% of the solder joints.

Some of that increase in density will be achieved by down-sizing discrete components.

On the other hand, Integrated Passive Components (IPCs), where more than one passive element are incorporated within a component package, are becoming more popular and, within the specified period, they are forecast to comprise some 23% of the total component count.

Another approach towards increases in circuit compression is that of multi-functionality. Varistors were single function products - their only purpose was to suppress transient voltages. Now, available in a multilayer construction, enhanced properties have enabled them to be used as viable alternatives to Capacitors in EMI Filter applications. Such components both attenuate continuous noise and suppress voltage spikes - an additional protection capability. These are truly multi-functional. They are available in all Filter formats from simple Capacitor style outlines, through Feed Thru' chips to the sophisticated Planar Array for use in EMI Filter Connectors where as many as 200 or more dual function components may be incorporated into a single device.

1 Electronic Pollution

1.1 Electromagnetic Interference

Electromagnetic Interference is a degradation in performance of an electronic system caused by an electromagnetic disturbance. At best, it passes by unnoticed, at worst it can cause loss of human life. Whilst EMI does encompass interruptions to power supplies, frequency variations and waveform distortions, for the purposes of this work, EMI is unwanted voltage variation, electronic noise - another form of pollution.

The means of noise transmission between equipment are...

Conduction
& Radiation

Noise may be conducted down any lead entering or leaving the equipment. Radiation may be emitted directly from the equipment itself or be radiated by the aforementioned leads. Reception of radiation may occur in the same manner.

Direct Conduction is mainly restricted to low frequencies whilst radiation is generally limited to high frequencies. Some specifications recognise 30 MHZ as the cut-off point between low and high frequencies.

For any form of interference to occur, it requires....

a A source of energy

b A receptor that is adversely affected by that energy

and c A coupling path between source and receptor.

All three must be present at the same time for interference to happen - omission of any one eliminates the EMI problem.

EMC is the ability of equipment to function satisfactorily in an electromagnetic environment without contributing intolerable electromagnetic disturbances to that environment.

1.2 Electronic Noise

Noise is of two types, Continuous or Transient. The terms have been 'standardised' - anything occurring in less than 16.6 mSecs (one cycle of 60 Hz) is considered to be transient.

1.2.1 Continuous Noise

Common low frequency noise sources are electric motor brushes, fluorescent lights and switch-mode power supplies.

High frequency noise is sometimes known as Radio Frequency Interference (RFI). It can emanate from a wide variety of sources ranging from high power radio transmitters to computer clocks.

Continuous noise is a relatively low voltage phenomenon and is best countermeasured with EMI Filters and shielding, as appropriate.

1.2.2 Transient Noise

A transient is any brief over-voltage that a circuit may be subjected to - it is an unwanted voltage spike.

As the level of integration of IC's increases, so does their vulnerability - in some instances, IC's may be affected by an over-voltage of a few tens of volts. The result may be damage or disfunction (in digital applications, transients may cause signal corruption leading to equipment malfunction).

Transients are either...

Repeatable

or... Random

1.2.2.1 Repeatable Transients

A sudden change in the electrical condition of any circuit will cause a transient voltage to be generated from the energy stored in the circuit,

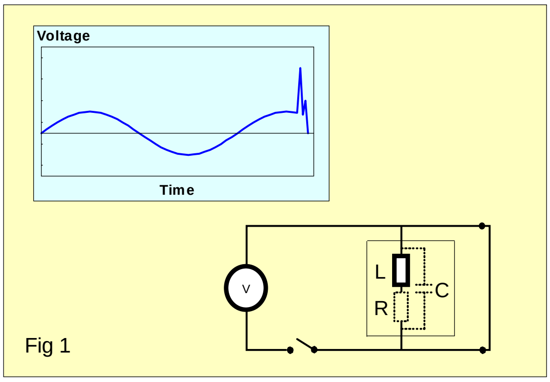


Fig 1

An example of this is the discharge of an Inductor. Figure 1. Change of current (di/dt) in an Inductor (L) will generate a voltage equal to -Ldi/dt. The energy stored in the Inductor is ½Li^2. If the intrinsic Capacitance of the Inductor is C, the energy stored is also equal to ½CV^2.

$$\tfrac{1}{2} Li^2 = \tfrac{1}{2} CV^2$$

$$V_{peak} = i_{peak}\sqrt{(L/C)}$$

and inserting some component values...

$I = 1\text{ A}$
$L = 1\text{ mH}$
$C = 250\text{ pF}$

$V_{peak} = 2{,}000\text{ volts}$

Another type of repeatable transient is the Electrically Fast Transients (EFT) - it results from arcing somewhere within the circuit.

Repeatable transients are internally generated, are measurable and therefore are predictable. This enables relatively easy selection of over-voltage protection devices.

1.2.2.2 Random Transients

Random Transients are unpredictable. They are difficult to define in terms of amplitude, duration and energy. Examples of random transients are...

ESD	Electrostatic Discharge
LEMP	Lightning (Electromagnetic Pulse)
NEMP	Nuclear (Electromagnetic Pulse)

etc.

Predictions of random transients are made upon the basis of statistical data - when available. For example, Figure 2 illustrates the frequency of lightning strikes to US domestic electrical systems (in this instance, exposure categorisation is largely done on the basis of geographic location).

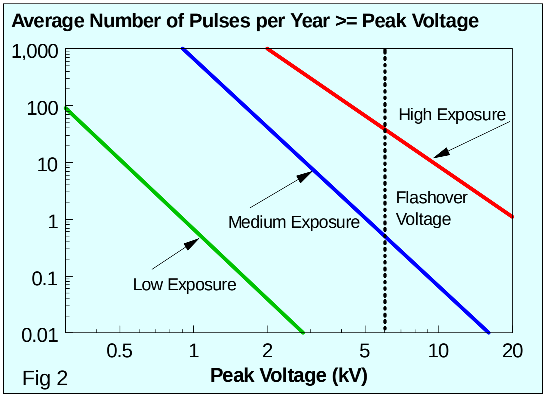


Fig 2

Based on such data, choices are made weighing cost of protection against random transients relative to the probability and the consequences of their occurrence.

1.2.2.3 Attenuation or Suppression

With the exception of ESD, EMP and surges due to lightning strikes, most transients are low voltage events and can be attenuated enough by conventional Filters. Such Filters may need to be rated up to a few kV dc to handle occasional large transients..

Seriously high voltage events will demand the use of Transient Voltage Suppressors (TVSs) such as Varistors.

1.2.3 Transient Waveforms

Less is known about the wave shapes of transients than is known about their amplitudes or frequencies of occurrence but, for the purposes of specification and test, standard waveforms are assumed.

1.2.3.1 Repeatable Transient Waveforms

Repeatable transients are usually generated from within the affected circuit and are, for the most part, exponentially decreasing oscillations.

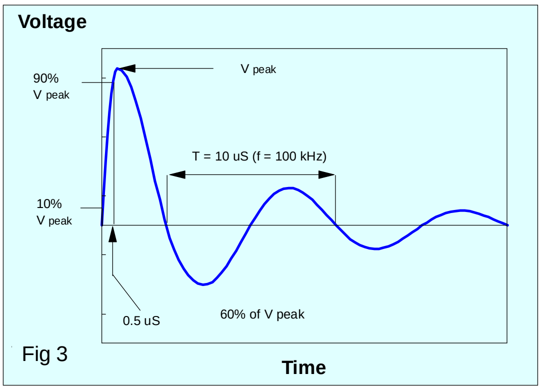


Fig 3

The wave form of Figure 3 is generally accepted to be representative of surge voltages in low voltage AC systems. This is known as a "0.5 µS - 100 kHz Ringwave" - the wave rises to peak voltage in 0.5 µ seconds then decays whilst oscillating at 100 kHz, the peak value of each peak being 60% of that of the prior peak.

1.2.3.2 Random Transient Waveforms

Random Transients are generally assumed to be unidirectional pulses.

a) Electrostatic Discharge

The wave shape of a typical ESD surge resembles that of Figure 4 . ESD is a very fast pulse. Its rise time is less than 1 nanosecond.

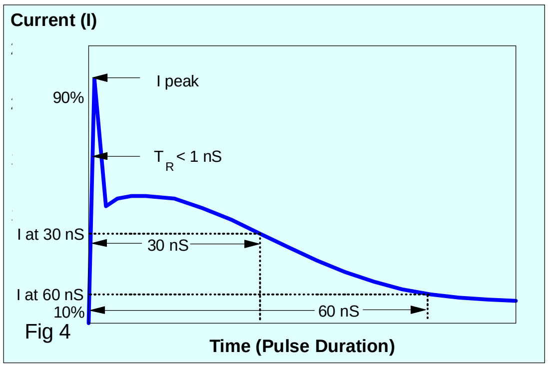


Fig 4

b) Lightning Surge

The wave shape of a typical lightning surge is similar to that of Figure 5 . The voltage surge is defined as a 1.2/50 µS wave whilst the current surge is an 8/20 µS wave. Compared with ESD, it is a very slow pulse.

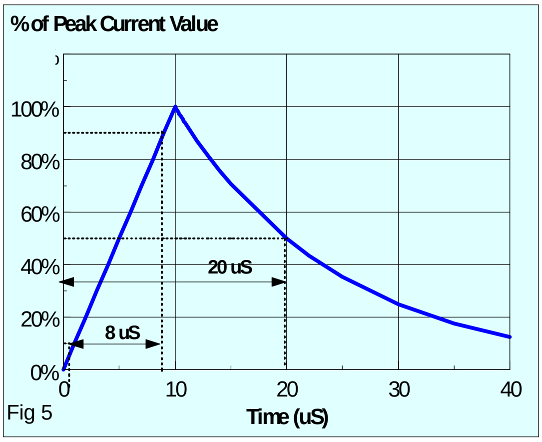


Fig 5

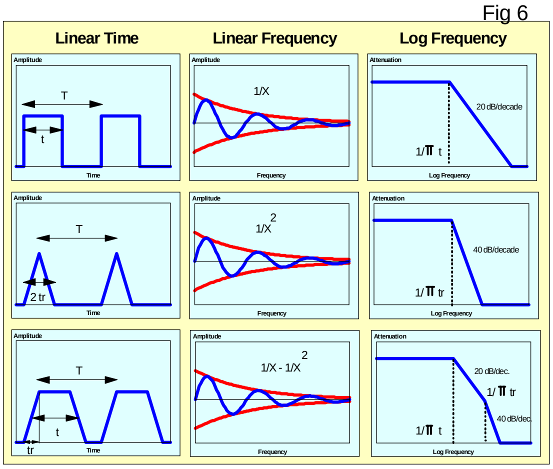
1.2.4 Frequency Spectrum

Wave shapes may be considered to be composed of a series of harmonically related Sine waves. Figure 6 illustrates the frequency components of a square wave and a triangular wave. It suggests that a trapezoidal wave shape may be considered as a composite of the two.

Low Pass Filters will attenuate the high frequency components of both continuous and transient noise.

Figure 7 illustrates the frequency components of surges due to Lightning and NEMP.

Fig 6



Lightning is a slow event with a significant proportion of its energy in the low frequencies (< 50 MHZ). It is heard on the radio on AM but not on FM. These low frequencies will not be effectively attenuated by Low Pass Filters (the majority of EMI Filters) so a suppression device is required.

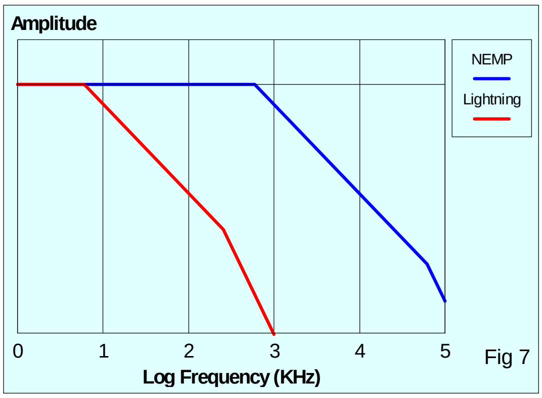


Fig 7

1.2.5 Electrostatic Discharge

It has been determined that, under the appropriate circumstances, humans can become electrostatically charged to voltages as high as 25 KV. Typical voltages, however, are in the region 8 to 15 KV.

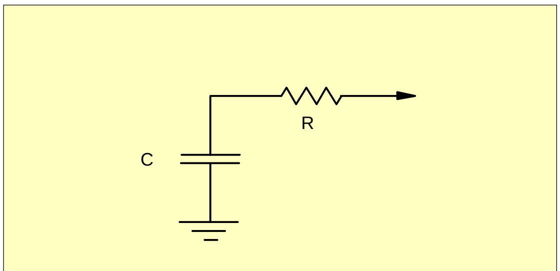


Fig 8

Discharges of less than 3.5 KV will not be felt by the person involved but, at 25 KV, they can be painful.

An electrical model of the human body is very simple (Figure 8), it consists of a Capacitor and a Resistor only. Dependent upon Standards Authority, Capacitor values are typically 100 to 150 pF whilst Resistor values are 150 to 500 Ω.

The energy in an ESD discharge may be calculated from...

$$E = \tfrac{1}{2}CV^2$$

where...

E = Energy (J)
C = Human body capacitance (F)
V = Charging voltage (V)

The stored energy of an ESD discharge is low. If C = 150 pF and V = 15 kV then E = 0.017 J.

Notwithstanding the very low energy content of the discharge I/C's are vulnerable to ESD.

Discharge on contact may cause damage.

Handling circuits or components in circumstances where ESD is generated can cause damage and manufacturers of solid state devices are well versed in the appropriate grounding procedures.

Induced charge can result in voltages appearing across battery powered equipment with a floating ground - it can lead to the destruction of semiconductors. Figure 9.

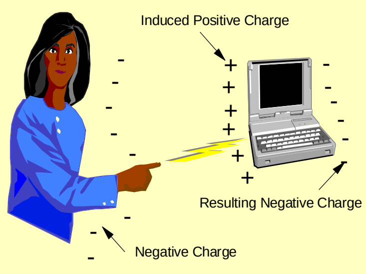


Fig 9

1.2.6 Lightning Surge

1.2.6.1 Domestic and Commercial Power Supplies.

The return stroke of a cloud-to-ground lightning flash produces a peak current which is typically of the order 20,000 A but may range from a few thousands amps to 200,000 A.

When power networks are affected by lightning, it is usually as a result of strikes to the primary transmission system but voltages may be induced in secondary lines as a result of mutual inductive or capacitive coupling. Such strikes will trigger Surge Arrestors.

Flashover will occur at points of minimum clearance and it is this that will voltage limit the surge. Outdoor flashover voltages will typically be around 10 KV but voltages up to 20 KV may occur. The indoor wiring of 120 v and 230/240 v systems will flashover at around 6 KV.

Such factors will determine the maximum ratings required of devices which are required to act as secondary or lower orders of circuit protection.

1.2.6.2 Aircraft

Lightning strikes to aircraft generally are within cloud (intracloud) phenomena, the currents associated with which (1,000 to 4,000 amps) are generally much lower than those of a cloud-to-ground strike.

The Faraday Effect of an all Aluminium fuselage limits the need to protect airborne electrical systems from lightning strikes but the increased used of composite materials in major structural components of modern airframes has precipitated a demand for effective, low volume, light weight protection systems for their avionics.

1.2.7 Nuclear Electromagnetic Pulse

A one megaton ground burst generates 10^{11} J of energy. Unprotected electrical systems will be damaged by a small fraction of a joule and equipment malfunctions within a radius of 10 to 20 kilometres of the blast may be expected.

However, Gamma rays, hitting the Earth’s atmosphere after a nuclear detonation in space would generate a Nuclear Electromagnetic Pulse that would damage or destroy electrical or electronic systems, which had not been 'hardened', across a wide area of the Earth's surface.

1.2.8 Specifications for Transient Testing

A plethora of specifications exists for the description of transients, relevant test methods and test criteria. These include...

MIL-STD-461
RTCA DO 160-C
IEC 801
EIAJ IC121
ANSI/IEEE C62.41-1980
IEC 1000-4

The latter, IEC 1000-4 became a compulsory requirement for all commercial electrical and electronic devices sold in Europe from 1996 on. It subdivides into a series of specifications which classify the performance of electronic components and equipment when subjected to transients and incident Radio Frequency Interference. This specification includes...

IEC-1000-4-2 An ESD test which may be applied as a contact or an air discharge test at 4 levels of voltage.

IEC-1000-4-3 A test for susceptibility to Electromagnetic Interference (EMI). Devices under test are subject to RF at frequencies of 27 to 500 MHZ. The test may be applied at any one of 3 field strengths.

IEC-1000-4-4 Electrically Fast Transients (EFT) are applied at four voltage levels.

1.3 Capacitor Suppressors

EMI Filters will attenuate the high frequency components of transients and alone may reduce their interference to acceptable levels. Fast impulses such as ESD and EFT will have significant proportions of their high frequency components removed but longer surges such the lightning pulse, with a significant proportion of its energy content in the low frequencies, may not be significantly attenuated.

If the attenuation achieved by Filtering alone is insufficient, due attention should be given to achieving the required level by the use of additional Transient Voltage Suppression.

2 Varistors

2.1 Definition

Varistors are Variable Resistors. At low values of applied voltage a Varistor acts as a conventional high value Resistor obeying Ohms Law but, above a threshold voltage, the device becomes highly conductive presenting a low impedance to high voltages.

When the Varistor becomes conductive, it clamps the applied voltage to a specified maximum that the protected system can withstand. Figure 10.

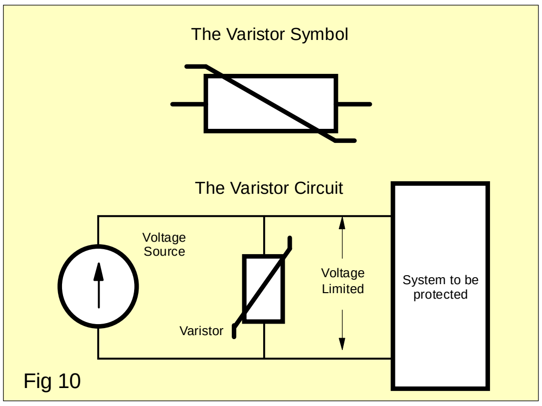


Fig 10

With these properties, Varistors are employed in electrical applications to protect circuitry from momentary or transient over-voltages. When used for protection purposes, Varistors are mounted in parallel with the system to be protected, between signal line and ground.

At low voltages, Varistor behaviour resembles that of a ceramic Capacitor and thus mounted, such a device acts as an electrical Filter.

2.2 Varistor Materials

Varistors are made from ceramic materials. The predominant Varistor type has a main component which is Zinc Oxide (Zn0). To this are added small amounts of other oxides such as Bismuth, Cobalt, Manganese and others. Accordingly, Varistors are sometime known as Metal Oxide Varistors or MOVs.

A given Varistor specification may be satisfied by a variety of material formulations.

2.3 Varistor Formats

Varistors are available in many electronic component formats.

Until recently, the most common were the Radial Lead types, which might be rated up to several thousand volts dc. The Varistor element of this type of part is a single layer of ceramic (a disk or plate). This configuration is sometimes referred to a Single Layer Varistor (SLV's). Figure 11.

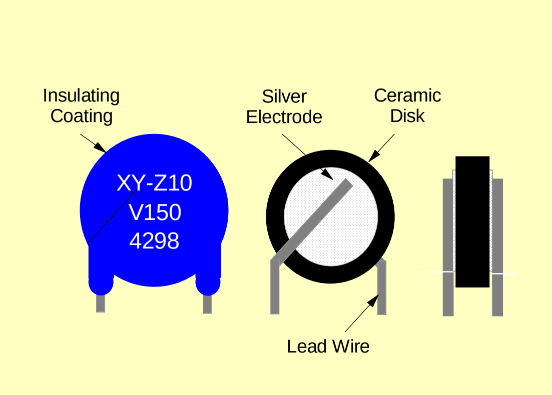


Fig 11

Surface Mount (SM) Varistor products predominate, today. They are produced in Multilayer Chip (MLC) format. Industry standard sizes are the same as those for Capacitors and Resistors, These range from 0603 (length 1.5 mm x width 0.75 mm) through 2220 (5.5 mm x 5.0 mm). Operating voltages are from 3.5 to 120 volts dc. Figure 12.

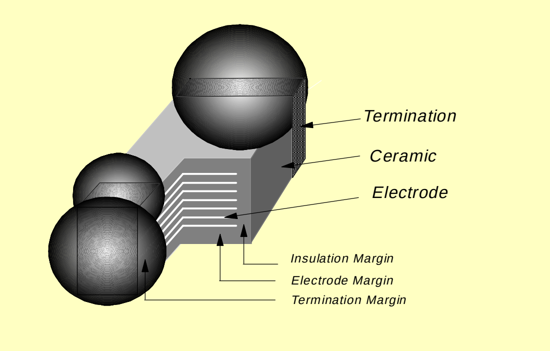


Fig 12

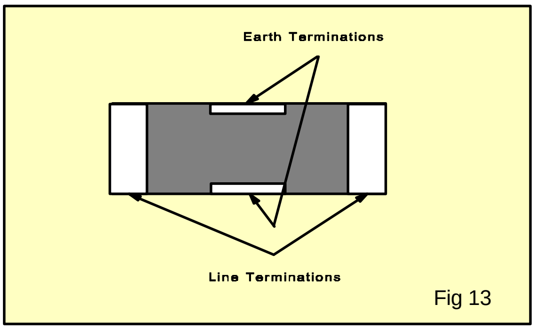


Fig 13

Recently, Multilayer Varistors (MLV's) have become available, from Syfer Technology Ltd., in more 'exotic' outlines, such as the 3 Terminal Chip (Figure 13), the Discoidal (Figure 14) and the Multilayer Array (Figure 15), which are configured especially to suit applications involving attenuation of Electro-Magnetic Interference (EMI). Ratings for these parts generally are similar to those of MLV chips.

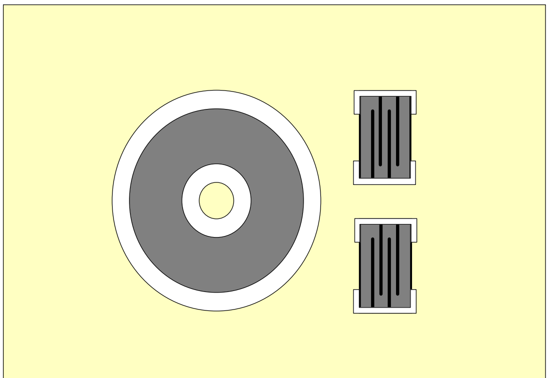


Fig 14

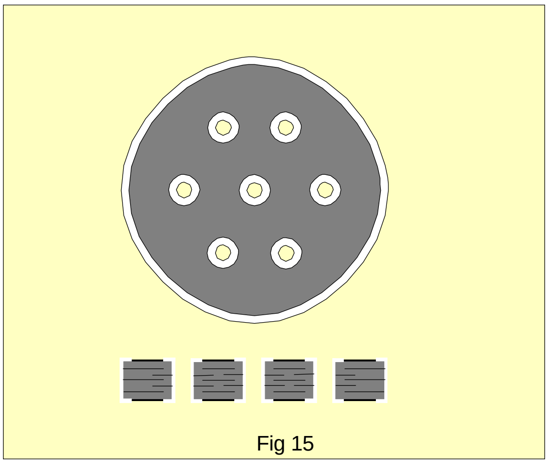


Fig 15

2.4 Varistor Manufacture

Varistors are ceramic components. During manufacture, original ceramic powders are mixed and shaped then fired. Metallization is applied to afford an electrical connection. Leads and encapsulation may be added, as necessary.

Disk Varistors are pressed from the powder whilst tubular Varistors are extruded. Individual layers of Multilayer Varistors are either cast or printed.

All formats must be fired at high temperature (1,000 to 1,400^{o}C) to realise the appropriate electrical properties.

On firing, a multicrystaline structure is formed. Figure 16. The mean grain size is determined by the original powder formulation and the firing temperature.

The bulk of the individual grain is formed from Zinc Oxide. It is highly conductive - its basic Resistivity is around 0.3 Ω-cm.

During firing, the metal oxide additives move to the boundaries of the grains where they form semiconducting layers, P-N junctions.

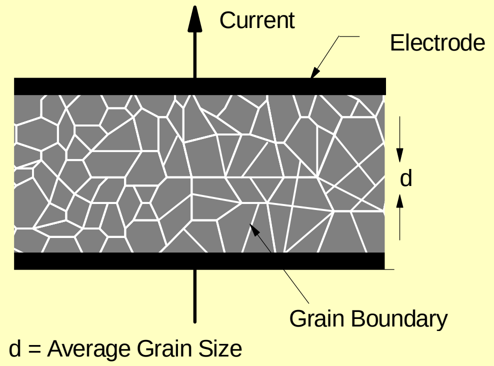


Fig 16

2.5 Varistor Grain Size

Below an applied voltage stress of around 3.6 volts per grain boundary, the junctions are highly resistive. Above that threshold, the junctions switch and become highly conductive.

The voltage at which the Varistor, itself, switches is determined by the average number of grains between the electrodes of the part...

$$V_{T\,dc} = S_T n$$

where...

$V_{T\,dc}$ = Threshold Voltage

n = Avg. no. of grains between electrodes

S_T = Threshold Stress (~ 3.6 v)

so... $V_{T\,dc} \sim 3.6\,n \sim 4\,n$

Now... $D = (n + 1)d$

where...

D = Ceramic Thickness between electrodes

d = Average grain size

and to a first approximation...

$$D = nd$$

so... $D \sim V_{T\,dc}\,d / 4$

For the purposes of characterisation, the threshold voltage at which the Varistor switches is defined as the voltage across the Varistor when it draws a specified current, i.e. 1 mA.

Designing a Varistor for a given threshold voltage is simply a matter of knowing the average grain size of a given Varistor composition and determining the ceramic thickness between the electrodes appropriate to accommodate the requisite number of grains.

ZnO grain sizes are in the region 10 to 100 µ dependent upon Varistor format and specification. Ceramic thicknesses run from several millimetres or so on some Single Layer Varistors down to 30 u per layer for some 'low voltage' Multilayer types.

3 Varistor Characterisation

3.1 The V-I Curve

The crystal structure of a Varistor has no directionality therefore Varistors are bi-polar devices. With symmetrical, sharp voltage breakdown characteristics, they exhibit an electrical behaviour similar to back-to-back Zener Diodes. Figure 17.

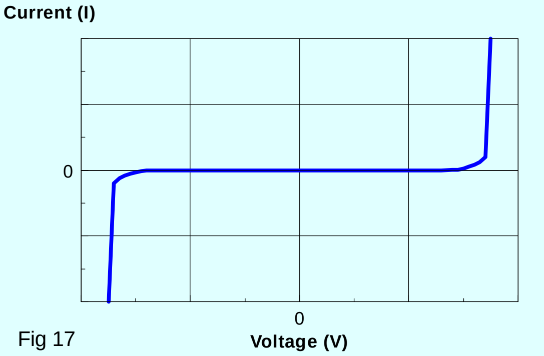


Fig 17

Varistor electrical characteristics are conventionally displayed using the log-log format of Figure 18. This type of display is known as the 'V-I Curve' or 'Characteristic Curve'.

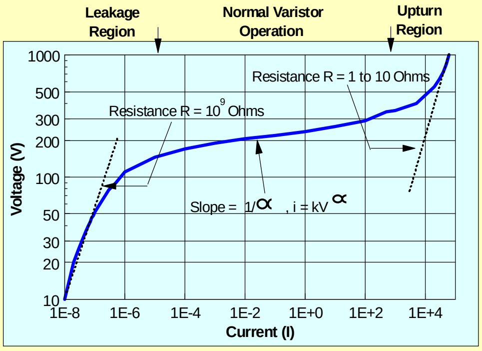


Fig 18

The V-I Curve has three distinct regions...

3.1.1 The Leakage Region

At low current levels (< ~ 10^{-5} A), the V-I Curve approaches a linear (Ohmic) relationship. The Varistor exhibits a resistance greater than some 10^7 Ω.

This parameter shows a significant temperature dependence. The relationship between Leakage Current (I) and Temperature (T) is...

$$I = I_O\,\varepsilon^{-V_B/kT}$$

where...

I_O = constant

K = Boltzmann's Constant

V_B = 0.9 eV

Room temperature resistance levels may reduce by a couple of orders at 125°C.

8.1.2 Region of Normal Varistor Operation

It is in this region that the semiconducting grain boundaries become conductive. They dissipate the energy contained in transient voltage pulses as heat. Figure 19.

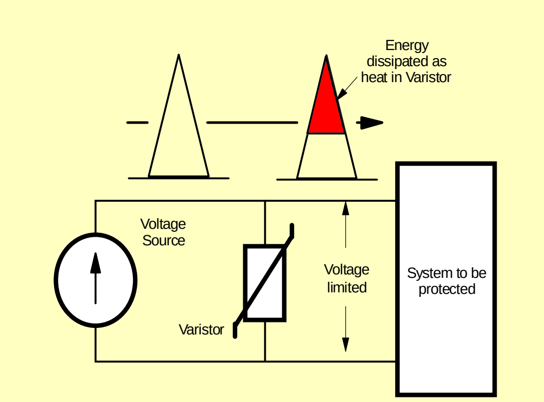


Fig 19

The highly conductive ZnO grains act as heat sinks ensuring a rapid and even distribution of the thermal energy throughout the device, minimising temperature rise.

Varistors, however, can only dissipate a relatively small amount of average power and are unsuited to applications which demand continuous power dissipation.

In the Region of Normal Varistor Operation, the V-I Curve follows the equation $I = KV^{\alpha}$ where k is a constant and the Nonlinear Exponent α defines the degree of non-linearity. Alpha is a figure of merit which can be determined from the slope of the V-I Curve.

3.1.3 The Upturn Region

At high currents, approaching its maximum rating, the Varistor approximates to a short circuit (R in the region of 1 to 10 Ω). The V-I Curve returns to near linearity reflecting the bulk resistance of the ZnO grain structure.

3.2 Varistor Voltages

Three relatively arbitrary points from the V-I Curve are used in the specification of individual types of Varistor. Figure 20.

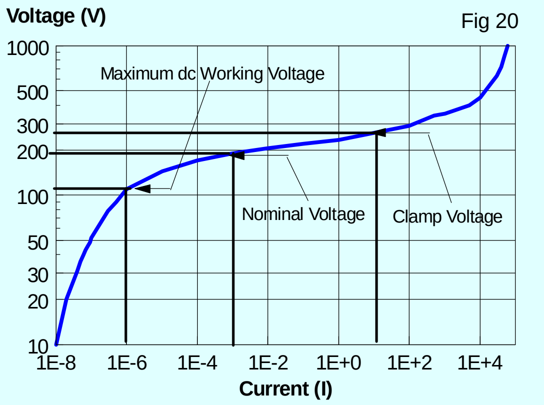


Fig 20

3.2.1 The Maximum Continuous DC Working Voltage ($V_{M(DC)}$)

This is the maximum continuous dc working voltage which may be applied up to the maximum operating temperature of the Varistor.

This voltage is used as the reference voltage for measurement of Leakage Current (I_L).

It is usually the maximum leakage current tolerable in a given application that will determine the maximum continuous working voltage - typically specified maximum leakage currents for MLV's range from 5 to 50 µA.

The Maximum Continuous AC RMS Working Voltage ($V_{M(AC)}$) is the maximum permissible continuous sinusoidal RMS voltage that may be applied under the same circumstances. Typically, this will be about 80% of the maximum dc voltage for most MLV's.

3.2.2 The Nominal Voltage ($V_{N(DC)}$)

This is the voltage across the Varistor when drawing a dc current of 1 mA. It is this point that is notionally the start of the Region of Normal Varistor Operation.

A tolerance is applied the Nominal Voltage (V nom) when specifying individual Varistor types.

This parameter may also be referred to as the 'Breakdown Voltage' of the Varistor.

3.2.3 The Maximum Clamping Voltage (V_C)

As a Varistor is designed for handling Transient Voltages, all tests requiring currents in excess of 1 mA are conducted as pulse tests.

The Clamping Voltage of a Varistor is the peak voltage appearing across the device when measured under the conditions of a specified pulse current and a specified waveform.

The industry recommended waveform for measurement of Clamp Voltage is an 8/20 µS pulse. *(8 µS is the time taken for the current pulse to rise from 10% of its peak value to 90% of its peak value. 20 µS is the time taken to decay to 50% of its peak value - this is measured from the time of pulse initiation. Figure 21.)*

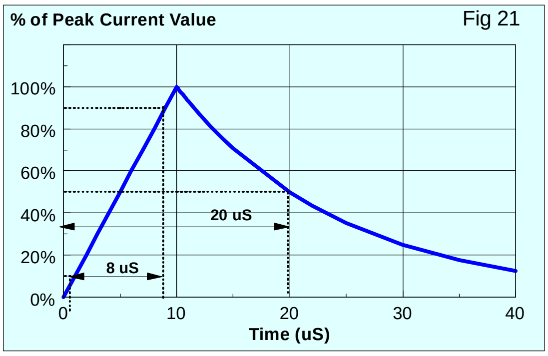


Fig 21

For most MLV's, the current level, at which the Clamp Voltage is measured, lies in the region 2 to 10 A.

V_{NOM} and Clamp Voltage are mathematically related. A change to one will result in a similar change to the other.

(Note - V-I Curves for individual Varistor types are often displayed in manufacturer's catalogues. All include a transition in voltage at a current level of 1 mA. This results from a change in methodology - at currents <= 1 mA, all measurements are made under direct current conditions. Above 1 mA, measurements are made using 8/20 µS current pulses. Figure 22.)

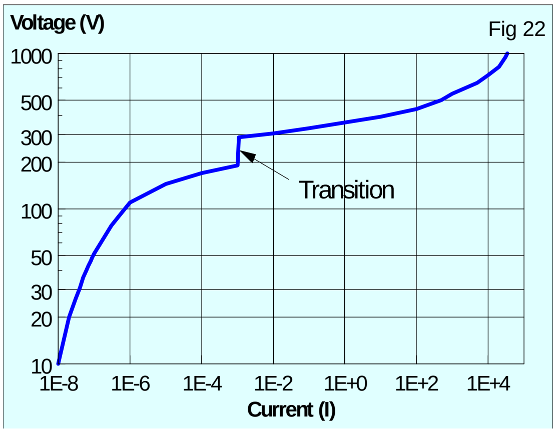


Fig 22

Whilst operating in the Leakage Region, some Varistor parameters exhibit a temperature dependence. Figure 23.

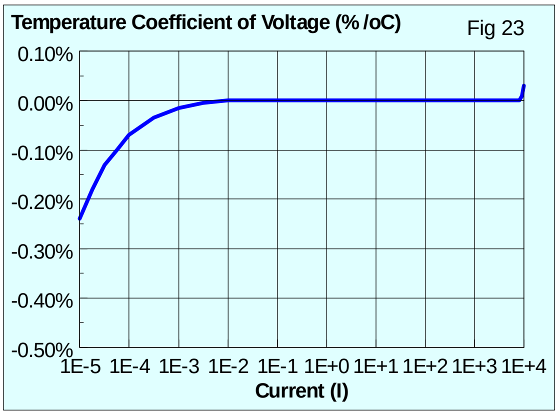


Fig 23

This temperature dependence disappears in the Region of Normal Varistor Operation, e.g the Clamp Voltage of a Varistor at 125°C is the same its Clamp Voltage at 25°C.

3.3 Current and Energy Ratings

3.3.1 Peak Current Capability

The Maximum Non-Repetitive Surge Current (I_{TM}) is the maximum peak current that may be applied to a Varistor, as an 8/20 µS pulse, without causing device failure.

In this instance, device failure is defined as a shift in the Nominal Voltage of >= 10% of its initial value.

Generally, minor over-stressing of a Varistor will result in a decrease in both V_{NOM} and Clamp Voltage. The device will still function, continuing to afford a measure of protection to the circuit.

Gross over-stressing will result in catastrophic failure of the Varistor. The failure mode will generally be short circuit but devices may explode, as a result of a high energy input, which may lead to an open circuit condition.

3.3.2 Maximum Energy Capability

The Maximum Non-Repetitive Surge Energy (W_{TM}) is the maximum peak energy that may be absorbed by a Varistor, as a pulse, without causing device failure.

Pulses used to measure this parameter are defined in manufacturers' catalogues and include 10/1000 µS, 10/700 µS and 2 mS current wave shapes.

The same failure criterion, that outlined above in 3.3.1, applies.

The Energy Rating of a Varistor is expressed in Joules (Watt-Seconds). The energy absorbed by a Varistor from a pulse may be calculated as follows...

Energy (E) = Clamp Voltage (V_C) x Mean Current (I_{MEAN}) x Pulse Duration (τ)

Simple formulae exist for the calculation of the energy content of various wave shapes. These are based on solutions to the equation...

$$E = \int_0^{\tau} V_C(t)\, I_{PK}(t)\, \Delta t$$

$$= K V_C\, I_{PK} \tau$$

where I_{PK} is the peak current applied and K is a constant. Some examples of such formulae are provided later.

3.3.3 Pulse Ratings

3.3.3.1 Pulse Duration

As the energy content of a given pulse in dependent upon its duration, I_{PK}, the peak current, must be factored downwards as pulse duration increases.

In establishing a revised I_{PK}, due account must be taken of the wave shape.

8.3.3.2 Number of Pulses

Traditionally, Single Layer Varistors suffered a degradation of electrical performance as a result of repeated pulsing at high current levels (notably a decrease in Nominal Voltage and an increase in Leakage Current).

Most SLV specifications and some of the early Multilayer Specifications were very definite that the pulse ratings provided meant that the Varistor could survive but one pulse of the indicated magnitude - with the implication that application of a second pulse of the same magnitude might result in device failure.

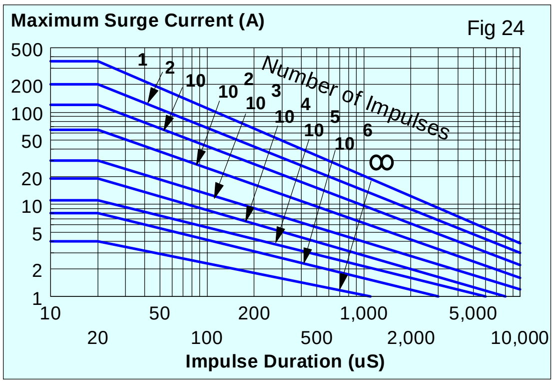
8.3.3.3 Pulse Deratings

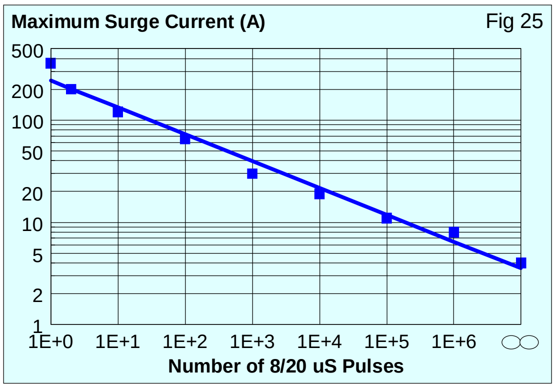
Most SLV data sheets incorporate a Pulse Rating Curve which enables a user to establish the 'lifetime' derating, that the Varistor manufacturer is prepared to 'underwrite', i.e. the number of pulses of a given magnitude and duration that the Varistor should survive. Figure 24 illustrates just such a curve for a low voltage Varistor.

In Figure 25 the predicted number of survivable pulses taken from Figure 24, for a single wave duration, an 8/20 µS pulse, is separated out.

8.3.3.4 Pulse Derating - Single Layer Varistors

The manufacture of some SLV's demanded the use of large grain size ceramic formulations. Large grain sizes resulted in fewer grain boundaries per unit area of electrode and longer current paths, via the grain boundaries, between electrodes. Series Resistance per unit area of electrode was relatively high resulting in a commensurately low peak current capability.





8.3.3.5 Multilayer Varistors - No Pulse Derating

The need to produce a genuine Surface Mountable Varistor configuration that would operate at low voltage demanded the development of fine grain ceramic formulations that would be capable of successful fabrication in Multilayer Chip format.

This done, these small and uniform grain size materials, coupled with the high electrode area relative to the component planform provided by the Multilayer format, resulted in massive increases in peak current capability per unit of component volume.

Current and Energy Ratings for MLV's are very conservative compared with those for SLV's and manufacturers publish curves which demonstrate that **MLVs survive multiple pulses, as many as 10,000 strikes, at full rated peak current**.

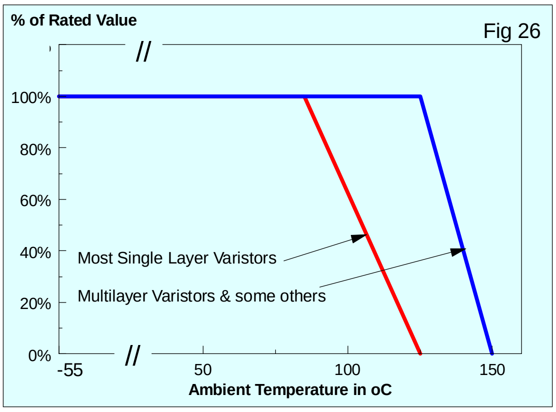
Manufacturers of MLV's are nevertheless still reluctant to specify maximum peak current and energy ratings as capabilities of surviving any other than a single pulse.

8.3.3.6 Temperature Derating

The Operating Ambient Temperature Range (that range over which parts may be operated to the full extremes of voltage and current specifications) for most SLV's is -55°C to +85°C Parts may be operated at temperatures up to 125°C but must be de-rated linearly from 100% of specified voltage at 85°C to 0% of that voltage at 125°C.

Some more modern SLV products may be rated to 125°C derating to zero at 150°C.

The Operating Ambient Temperature Range for most Multilayers is -55°C to +125°C derating to zero at 150°C. Figure 26.



3.4 Power Dissipation

A Varistor is optimised to absorb large amounts of power in a very short time. Electrical energy is transformed into heat which is distributed rapidly throughout the device, however, heat is generated too quickly to be dissipated during the pulse interval.

Power dissipation may be of concern if transients occur in rapid succession. Under these circumstances, the average power dissipation is simply the energy per pulse (J, watt-seconds) multiplied by the number of pulses per second.

Maximum power ratings are set by manufacturers for individual Varistor products.

Varistors can only dissipate relatively small amounts of average power. Typical, power ratings for MLV's lie in the region 0.05 W to 0.15 W.

3.5 Capacitance

In the Leakage Region of Operation, Varistors behave like Capacitors. Grain Boundaries are insulators and have dielectric properties.

Capacitance C α NAK / t

where... N = Number of Layers (SLV = 1, MLV = [No of electrodes-1])

A = Overlap area of a pair of electrodes

K = Effective Dielectric Constant

t = Thickness of ceramic between electrodes

When the above formula is used to derive a measure of the Dielectric Constant of a device, values of around 800 may be expected, i.e. about one quarter to one third of the value of a typical X7R Multilayer Capacitor dielectric. Capacitance values available from Varistors are commensurately lower than may be obtained from conventional Capacitors. MLV chip values typically run from around 50 to 6,000 pF.

Conventionally, and contrary to Capacitor Industry practise, the capacitance of Varistors is measured at a frequency of 1 MHZ. Reference voltages are 0.5 or 1.0 volts rms.

Measurement of capacitance at 1 KHz may be specified in particular instances, e.g. where Varistors are to be used in EMI Filter applications as this frequency is the reference frequency for measurement of Filter capacitance.

Capacitance values measured at 1 KHz will be approximately 15% to 30% higher than 1 MHZ values.

Generally manufacturers do not specify a tolerance on capacitance value - most catalogues quote the parameter as typical. When pressed, the tightest tolerance usually offered is ± 30%.

3.6 Varistor Testing

3.6.1 100% End-of Line Testing

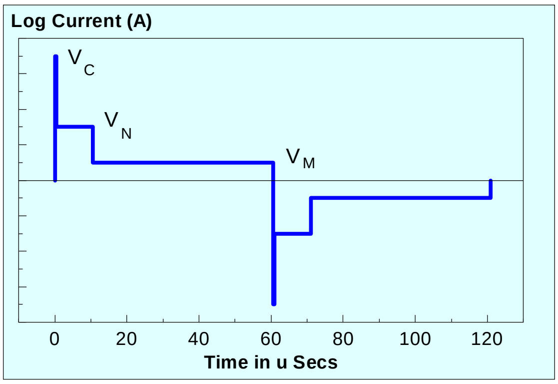
Nominal Voltage and Leakage Current are generally specified as parameters requiring 100% Test.

100% measurement of Clamp Voltage is optional but it is generally undertaken, if it can be done, as part of the test sequence for Nominal Voltage and Leakage Current

Testing is undertaken by submitting parts to dc pulses which are square waves. Pulse durations are relatively short - a typical test sequence might be...

$+V_C$	0.5 µS
$+V_N$	10 µS
$+I_L$	50 µS
$-V_C$	0.5 µS
$-V_N$	10 µS
$-I_L$	50 µS

Figure 27.



Clamp and Nominal Voltages are checked using current pulses. Leakage Current is determined either using a voltage pulse or a current pulse at the stipulated I_L verifying that V exceeds V_M.

3.6.2 Final Inspection

Maximum Surge Current and Maximum Surge Energy are checked on a sample basis, only, lot-by-lot. Manufacturers are generally circumspect as to sample size and number of pulses.

Generally, Capacitance is checked on a sample basis, only.

4 Multilayer Varistors

4.1 Some History

The voltage rating of a Capacitor is directly related to the thickness of the ceramic layer between its electrodes - likewise, the Varistor.

The invention of the transistor presented Capacitor makers with a dilemma. Its associated circuitry demanded both higher values of capacitance and would permit lower operating voltages than valve technology.

Making the ceramic element thin rendered the single layer Capacitor fragile. Requiring high values of capacitance rendered that same Capacitor large and therefore even more fragile.

A solution proved to be the adoption of 'multilayering' as a technique. Otherwise large but thin Capacitors could be subdivided into a number of layers which were stacked in an interdigitated, parallel plate system. Figure 3. The problem of fragility was all but eliminated as the device thickness now became the sum of the thicknesses of all the layers.

Such devices were substantially smaller and more light weight than single layer types. Adopting principles already established by the manufacturers of Thick Film Circuits, it was demonstrated that these components could be mounted to Printed Circuit Board making the MLC the ideal Capacitor for the coming Surface Mount revolution.

Varistor manufacturers were slow to adapt to this change but MLV's made in exactly the same way as MLC's are now available from several sources.

4.2 Ceramic Layer Thickness

Structurally MLV's are indistinguishable from MLC's - the giveaway is, however, colour - whilst most MLC dielectrics are either shades of brown or grey, the ZnO of MLV's is black.

Internally, dc voltage for dc voltage, the ceramic layer thickness of an MLV is much larger than an MLC. Typically MLV's are rated at around 0.15 v dc per µ of fired ceramic layer thickness, whilst an MLC rating might be up to 4 v dc. per µ.

With the dc voltage ratings of MLV's typically ranging from 3 to 120 v, layer thicknesses lie in the range 20 to 800 µ.

4.3 Margins

The distances between electrodes and device perimeter are known as 'margins'.

In chips, the distances between electrodes and major surfaces are known as 'Insulation Margins', whilst between electrode edges and sides they are known as 'Edge Margins'. Between electrode edges and chip ends, they are known as 'Termination Margins'. Figure 28.

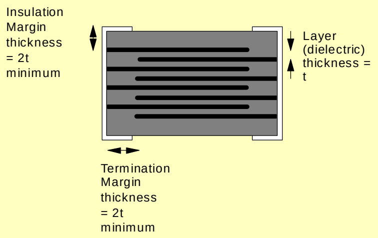


Fig 28

A Varistor action in these margins is unwanted so their dimensions must be significantly greater than the Varistor layer thickness.

At higher dc voltage ratings, margins can reduce the amount of electrode 'real estate' available for overlap. e.g...

Chip Size	**1210**	
Typical	Length Width Thickness	3.0 mm 2.5 mm 2.0 mm
Min. Margins	Min. of 0.25 mm or 2 x layer thickness	
Voltage Rating	**5 V**	**50 V**
Layer Thickness	0.03 mm	0.3 mm
Max. No. of Elect.	50 *	2
Electrode...		
Length Width Area Volume	2.5 mm 2.0 mm 5.0 sq.mm 7.5 cu.mm	1.8 mm 1.3 mm 2.3 sq. mm 1.4 cu. mm
Result	50 v part has 19% of available 5 v part volume)	

* in theory - see on.

4.4 Electrodes

As their ceramic layers are so much thicker, so there are fewer of them in an MLV than in an MLC of the same voltage rating. Standard MLV chips typically contain 6 to 10 electrodes although certain low capacitance products, may have fewer.

The material of the electrodes of an MLV also differs from that of an MLC.

Conventional MLC's employ electrode materials which are, substantially, mixtures of Silver [Ag] and Palladium [Pd] (Silver may form as much as 85% of the total metal content of the electrode).

MLV's which employ electrodes with a Palladium content tend to exhibit performance deficiencies so Platinum [Pt] is the electrode material of choice for MLV's.

Platinum is much more expensive than mixtures of Ag and Pd and, unlike Capacitor practice, there are few opportunities for economy of materials usage by making electrodes thinner - those electrodes are expected to carry heavy currents and any increase to their resistance would have a negative effect on device performance.

4.5 Varistor Capacitor Properties

In the Leakage Region of operation, a Varistor will function as a Capacitor with similar properties to an X7R MLC of the same capacitance value.

4.5.1 Capacitance vs. Temperature

The change of capacitance over the temperature range -55°C to + 125°C that may be expected from a Varistor material is of the order -15 to +25% from its value at 20°C when the measurement frequency is 1 MHZ.

Measured at 1 kHz, the rate of capacitance change with temperature increases to around -20 to +60%.

Figure 29. Note - the specification for an X7R MLC would be ± 15% over the same temperature range.

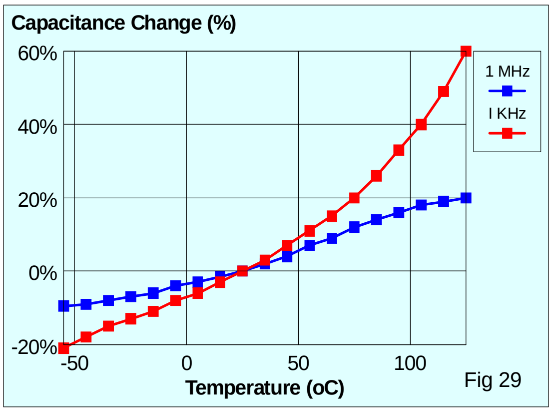


Fig 29

4.5.2 Capacitance vs. Frequency

The change of capacitance that occurs between the frequencies of 1 KHz and 1 MHZ is of the order - 20%. Figure 30. Note - the capacitance of an X7R MLC would be expected to change by -5% over the same frequency range.

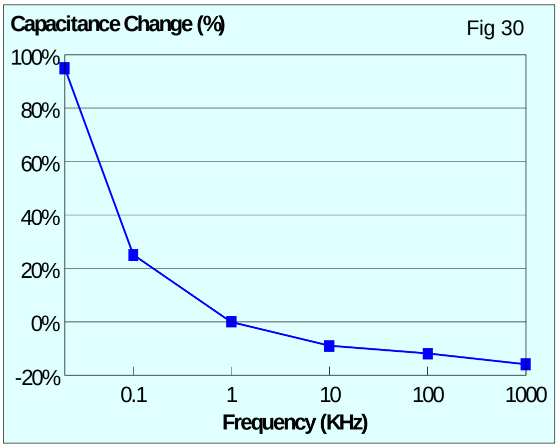


Fig 30

4.5.3 Capacitance vs dc Voltage

As dc voltage is applied, the capacitance of a Varistor decreases almost linearly to around -15% when the Varistor nears its Nominal Voltage at which points the capacitance abruptly increases. Figure 31 illustrates the change for a 38 v dc working device.

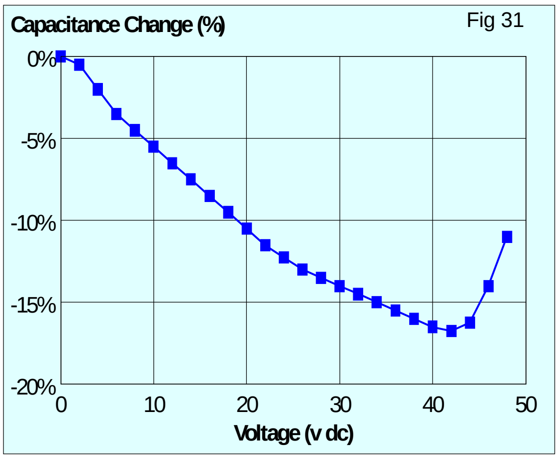


Fig 31

4.6 Currents, Energy and Capacitance

Multilayer types exaggerate some of the design principles of Varistor devices...

4.6.1 Leakage Current

When operating in the Leakage Region, the magnitude of Leakage Current that a Varistor exhibits at a specified voltage is determined by the resistivity of the grain boundaries (under the prevailing conditions) and the dimensions of the part.

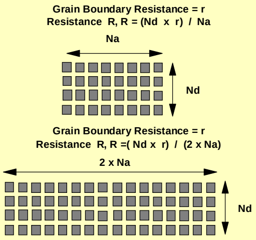


Fig 32

When the electrode area is doubled, the number of grain boundary current paths between the electrodes is doubled, halving resistance and doubling current. Figure 32.

$V_{LR} = I_{LR} R_{LR}$

and $R_{LR} = R_{ZnO} + R_{GB}$

where R_{ZnO} = Resistance of Zinc Oxide grains

R_{GB} = Resistance of grain boundaries

and as $R_{GB} >> R_{ZnO}$

$I_{LR} = V_{LR} / R_{GB}$
$= V_{LR} G_{GB}$

where... G_{GB} = Conductance of grain boundaries

now.. $G_{GB} = (NA K_{GB}) / t$

where A = Area of a single Varistor electrode

N = Number of active ceramic layers in the Varistor (Number of electrodes less one)

and... K_{GB} = Resistivity of the grain Boundaries

so... $I_{LR} = V_{LR} (NA K_{GB}) / t$

and for the specified conditions...

$I_{LR} = C_{LR} NA$

where... C_{LR} = constant

A factor in determining the Leakage Current of a Varistor is the total electrode area of the device.

4.6.2 Surge Current

The level of Surge Current that a Varistor can handle is determined by the electrode area of the part. When the electrode area is doubled, the number of current paths between the electrodes is doubled, halving resistance and doubling the potential surge current.

Following the same logic as that used in 4.6.1...

$I_{SC} = C_{SC} NA$

A factor in determining the Maximum Surge Current of a Varistor is the total electrode area of the device.

4.6.3 Surge Energy

It is the Zinc Oxide grains which dissipate an energy surge. Increasing the number of grains between electrodes increases the amount of energy that the part can dissipate. Figure 33. So the Maximum Surge Energy (W_{TM}) that the Varistor can handle is related to the volume of ceramic between the electrodes...

$W_{TM} \alpha NAt$

where t = Ceramic Layer Thickness

so.. $W_{TM} = C_{SE} NA$

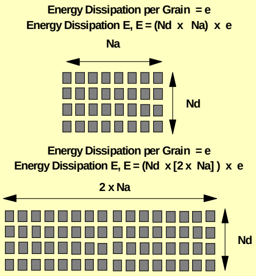


Fig 33

A factor in determining the Maximum Surge Energy of a Varistor is the total electrode area of the device.

4.6.4 Capacitance

In the Leakage Region of operation, Varistors behave like Capacitors. Capacitance © is derived from the formula....

$C \alpha NAK / t$

or $C = C_C NA$

A factor in determining the Capacitance of a Varistor is the total electrode area of the device.

4.6.5 Electrode Area

It is the total overlapping electrode area (NA) of a Varistor which determine the following Varistor parameters...

Leakage Current
Maximum Surge Current
Maximum Surge Energy
Capacitance Value

...for a given Varistor material composition.

All four parameters are inextricably linked.

Increases in Maximum Surge Current and Surge Energy ratings can only be gained at the expense of increases in both Capacitance and Leakage Current values.

4.6.6 Parameter Adjustment

All of the aforementioned parameters are effected by ceramic sintering as all depend upon grain size which is a function of firing. Figure 34.

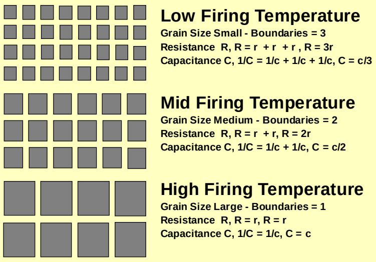


Fig 34

As firing temperature or firing time is increased so the Varistor grain size increases - the number of grains per layer decreases causing...

A decrease in resistance

An increase in capacitance.

Change of firing temperature may be used to adjust Varistor parameters after an initial sample firing or two.

5 Varistor Selection

5.1 Varistor Equivalent Circuit

The equivalent circuit of a Varistor is shown in Figure 67. Its formats across the three regions of Varistor operation are shown in Figure 35.

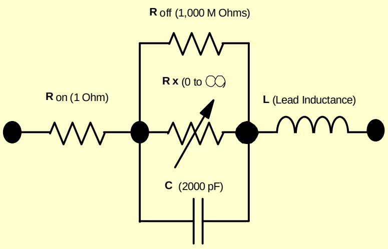


Fig 35

The over-voltage should drop almost entirely across the source impedance. The principle of the division is shown in Figure 36.

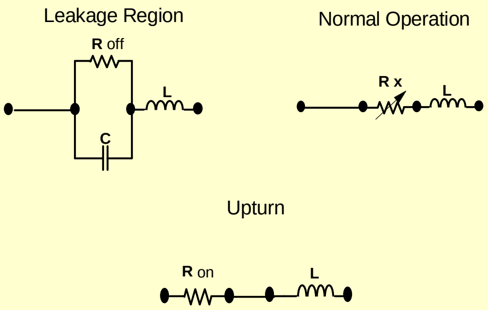


Fig 36

5.1.1 Leakage Region

The Varistor is in a high resistance mode - R_{off} is so much less than R_X and so much greater than R_{ON} that both can be ignored from any calculations.

R_{off} is frequency sensitive - R_{off} ~ (1/f) - however the parallel combination of R_{off} and C is predominantly capacitive as the capacitive reactance also varies linearly with 1/f.

5.1.2 Normal Operation Region

The Varistor becomes conductive and R_X predominates C. R_X is much less than R_{OFF} but remains much larger than R_{ON}.

5.1.3 Upturn Region

The upturn occurs as the value of R_X approaches that of R_{ON} after which the low value of R_{ON} (1 to 10 Ω) predominates.

5.2 Source and Line Impedance

The circuit configuration of a Varistor placed across a signal line is that of a voltage divider. Figure 37.

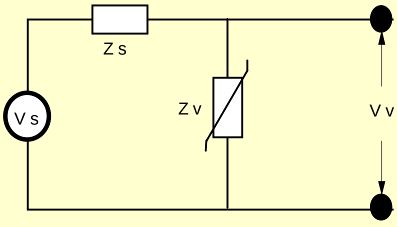


Fig 37

Voltages are divided between the Varistor and the Source Impedance dependent upon their resistances at the prevailing currents...

$$V_V = V\left(Z_V / (Z_S + Z_V)\right)$$

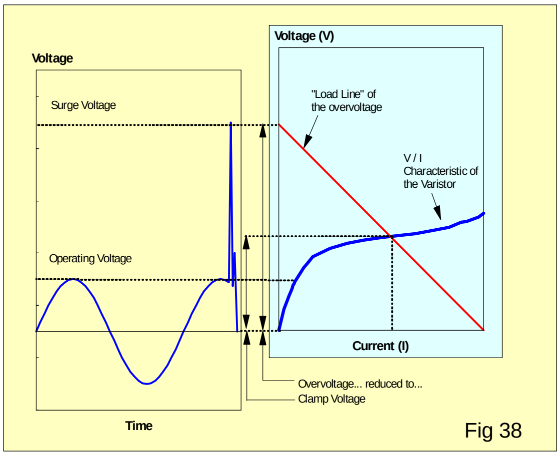


Fig 38

For selection of the appropriate Varistor, the Surge Current Waveform associated with the worst transient that the Varistor is supposed to provide protection against should be known.

Some assumptions must be made about Source Impedance - in many applications it is safe to assume a value of 50 Ω - Surge Suppression Test Equipment is designed around this number.

Calculation of the Source Impedance at the line frequency may yield very low values leading to over estimation of current amplitudes. Typical transients contain significant proportions of high frequencies (in the KHz and MHZ regions) and it is the high characteristic impedance of cables at such frequencies that will dominate the Source Impedance. Figure 39.

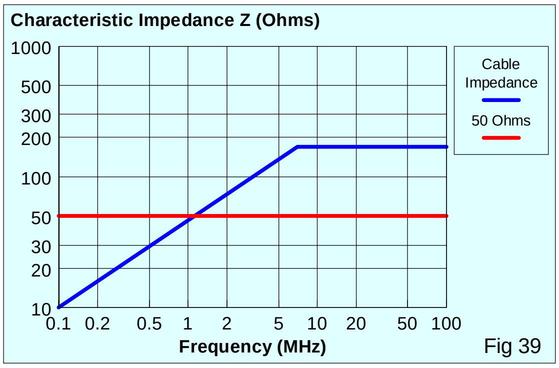


Fig 39

5.3 Energy

The energy absorbed by a Varistor is...

Energy (E) = Clamp Voltage (V_C) x Mean Current (I_{MEAN}) x Pulse Duration (τ)

For complex wave shapes, E may be calculated using the equation...

$$E = \int_0^{\tau} V_C(t)\, I_{PK}(t)\, \Delta t$$

$$= K V_C I_{PK} \tau$$

where I_{PK} is the peak current applied and K is a constant. Formulae for calculating the energy content of some simple wave shapes are shown in Figures 40 thru' 44.

These formulae can be used for complex wave shapes by dividing the shape into segments that can be treated separately. Consider the example of a Varistor, subject to the exponential 5/50 µS waveform of Figure 45, which at 100 A clamps to 500 volts...

Section 1 E $= K V_C I_{PK} \tau$

$= 0.5 \times 500 \times 100 \times 5 \times 10^{-6}$

$= 0.13J$

Section 2 E $= K V_C I_{PK} \tau$

$= 1.4 \times 500 \times 100 \times (50-5) \times 10^{-6}$

$= 3.15J$

Total E $= 0.13 + 3.15$

$= 3.28$ J

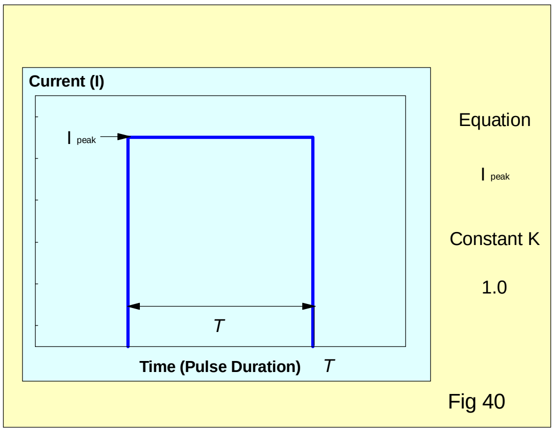


Fig 40

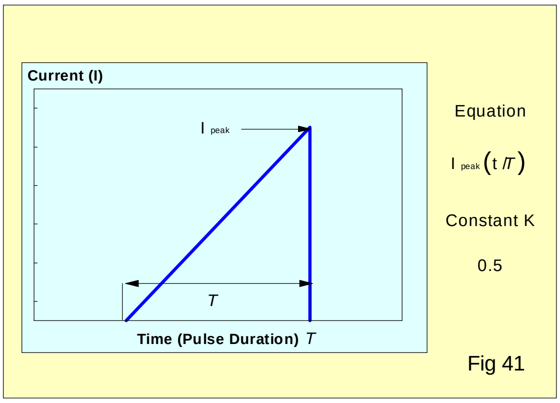


Fig 41

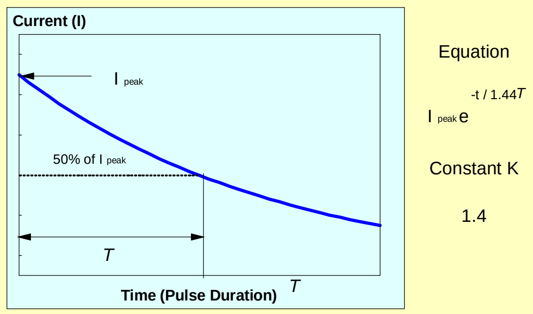


Fig 42

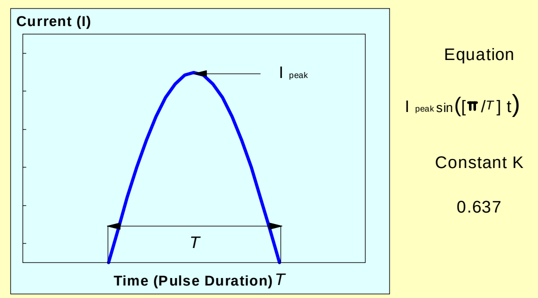


Fig 43

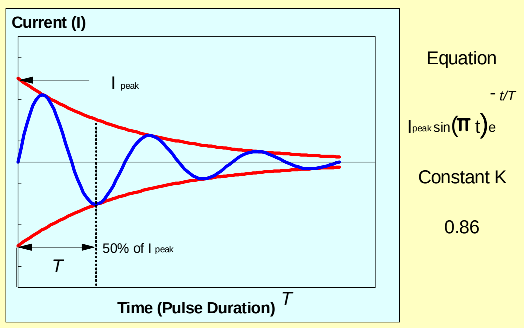


Fig 44

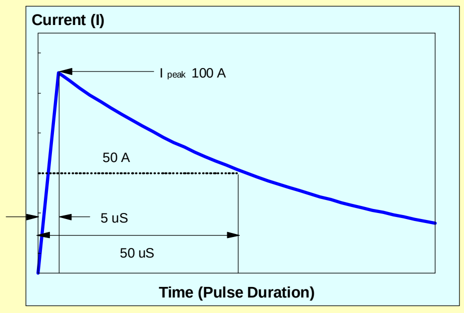


Fig 45

5.4 Speed

As the manufacturers of components of various transient protection technologies seek to press their case for adoption of their preferred products, speed of response, or lack thereof, is often raised as an issue in their literature. In particular, this is true of suppliers of Zener Diodes and Varistors.

The base materials of both technologies have response times of much less than 500 Pico-seconds.

What contributes to slower response times on the part of finished components is the parasitic inductance of the package.

With 25 to 50 mm of lead used in the construction and an inductance of 0.6 nH per mm length of lead wire, high levels of inductance were a feature of Radial Lead Ceramic components, both Varistors and Capacitors.

Multilayer constructions and Surface Mount Technology have eliminated lead wire and now the typical inductance of a 1206 MLV chip would be of the order 1,200 pH.

Conventional MLV's have response times of less than 1 nS. Parts designed for ESD applications exhibit response times of between 0.2 and 0.7 nS whilst Silicon based Transient Voltage Suppressors recommended for the same application exhibit response times ranging from 1.2 to 5 nS.

Other component configurations, pioneered as Capacitor structures, which exhibit very low ESLs are now becoming available as Varistors - these afford the opportunity for response times down to one fortieth of those of conventional MLVs, i.e. response times of a few tens of picoseconds.

Varistors are characterised with dc or relatively slow 8/20 µS pulses. Published V-I Curves are therefore low frequency impulse response curves. Varistor response to fast surges differs from that of a typical V-I Curve. Figure 46 illustrates some typical clamp voltage responses to E.S.D. surges tested as per IEC 1000-4-2.

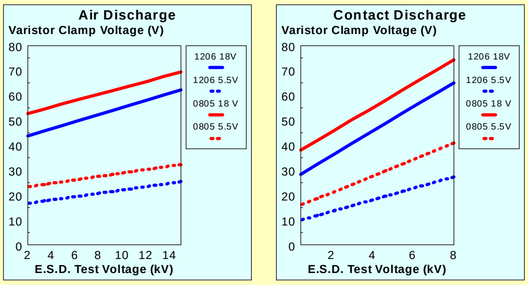


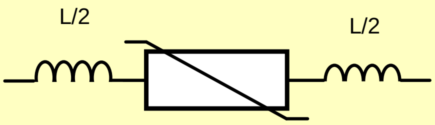
Fig 46

5.5 Voltage Overshoot

Another issue created by the inductance inherent in the construction of SLV's was Voltage Overshoot. Across the Varistor would appear the sum of the clamp voltage plus a voltage induced in the lead wires.

Figure 47 illustrates the Equivalent Circuit of a Varistor and Figure 48 shows the voltage induced in the inductive components by a 10 A pulse with rise times varying from 1 µS to 1 fS, both for a Radial Lead Varistor (L = 15 nH) and a Multilayer Chip Varistor (L = 1,200 pH).

Whilst from a pulse with a rise time of 1 nS, an over-voltage of around 200 v might be expected of a Radial device, that resulting from an MLV chip would be around 10 v only.



$$V_L = (dI/dt)\,L$$

Fig 47

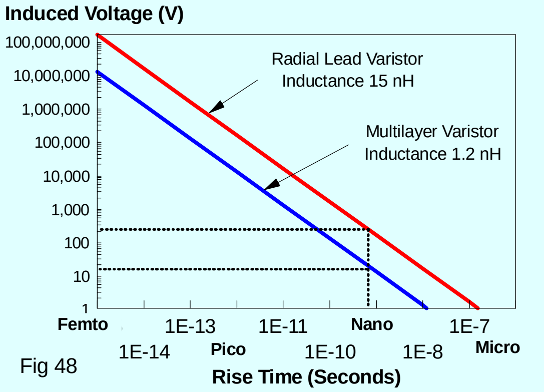


Fig 48

5.6 Response to Radiation

Varistors are substantially unaffected by imposed radiation. Figure 49 includes a table which lists radiation levels to which Varistors have be tested without any substantial deterioration of electrical properties.

Type of Radiation	Unaffected by Dosage Level
Electron	10^{8} Rads
Neutron	10^{15} N/cm^{2}
Gamma	10^{6} Rads

Fig 49

6 The Varistor Selection Sequence

Selection is a step-by-step process. It requires information on the intended application.

6.1 Working Voltage

Determine the working voltage (steady state voltage) of the system to be protected. This will determine the working voltage of the Varistor.

Manufacturers provide dc and sinusoidal ac ratings for their products. If a non-sinusoidal waveform is applied, the sinusoidal rating sought should be the peak voltage of the waveform divided by √2.

6.2 Clamp Voltage

Determine the maximum tolerable transient voltage that the system to be protected can withstand. This will determine the Varistor Maximum Clamp Voltage.

6.3 Wave Form Evaluation

Establish the Wave shape, amplitude and duration of the maximum transient that the Varistor is expected to handle.

6.4 Energy

Estimate the maximum energy to be absorbed by the Varistor.

6.5 Peak Current

When transients are repeatable, the peak current rating can be established from measurement data.

Otherwise, the technique shown in Figure 38 may be used to estimate peak current - if the transient voltage and source impedance are known, a 'Load Line' may be constructed overlaying the V-I characteristics of potential Varistors, which will yield an estimate of peak current

6.6 Power Dissipation

Estimate the Maximum Continuous Power Dissipation.

6.7 Packaging

Chose the appropriate component format to suit the application**.**

6.8 Selection

Finally select the Varistor part number.

7 Varistor Filters

7.1 Dual Function Components

Whilst capacitance values of up to 20 nF could be obtained in an SLV format, many factors, amongst them size, cost and a supposedly limited life, inhibited any argument that they might be a useful alternative to conventional ceramic Capacitors, affording an extra function, that of protection against transients.

The ability to build small, low cost and reliable MLVs has overcome many of those reservations.

The MLV chip reflects all of the advantages of the similar Capacitor technology, including cost, size, performance, reliability and convenience of handling.

Varistor chips are readily available in standardised sizes ranging from 0603 to 2220. Working voltages are from 3.3 v dc to around 120 v dc. Surge current ratings of up to 500 A and energy ratings of up to 2.5 J are normal and capacitances run from a low of 65 pF to a high of around 6,000 pF.

A natural train of thought, as equipment manufacturers were expected to provided increased protection against transient voltages, was to substitute all or part of the Capacitor element of an EMI Filter with a Varistor of similar capacitance value.

It transpired that the performance of a Varistor Filter was virtually indistinguishable from that of an X7R dielectric Capacitor Filter. Impedance was similar across all frequencies and with all voltage biases up to the dc working voltage.

The use of low ESL Filter component configurations now provides the user with a faster responding TVS device than anything else available on the market. A dual function Filter!

Advantages are fewer components (and therefore higher reliability), reduced board space and weight and reduced component cost. These are true multi-functional components.

Syfer Technology Ltd. is a leading manufacturer of EMI Filters and Filter Components. Combining its expertise in the manufacture of Multilayer structures with a mature Varistor materials technology has enabled Syfer to be able to offer the most advanced of Varistor based Filters and Filter components.

Available in a number of product formats which included Feed Thru' chips, Balanced Line chips, Discoidal Capacitors and Planar Arrays, these devices may be incorporated into more sophisticated Filter assemblies.

7.2 Feed Thru' Chip Varistor

A result of its external configuration, this component is also known as a 3 Terminal Chip Varistor.

Internally, two sets of electrodes cross at right angles within the chip - these permit signals to flow through the device whilst Filtering noise to ground. Figure 50.

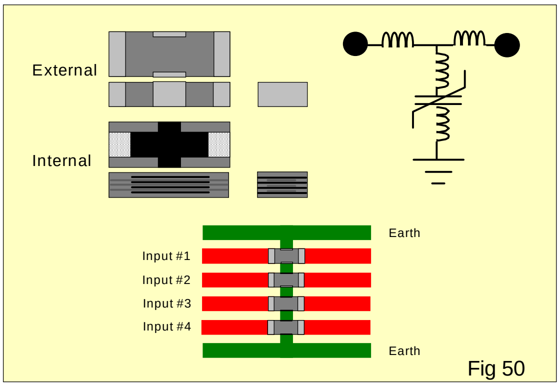


Fig 50

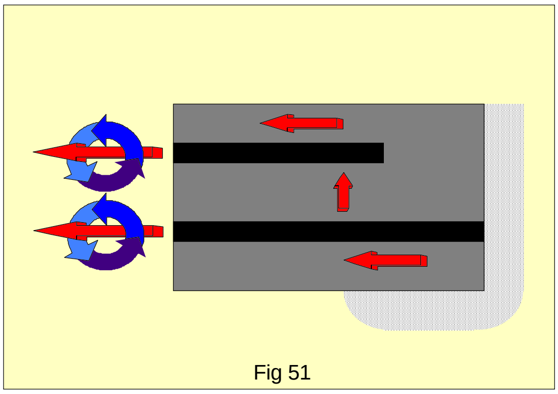


Fig 51

A significant reduction in ESL is achieved by utilising the self inductance properties of this electrode configuration. Current flowing in a linear conductor generates Magnetic Flux.

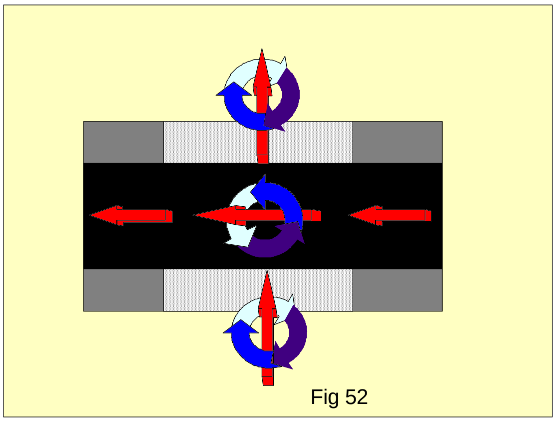


Fig 52

That flux circles the conductor. Current flowing in the same direction in a second linear conductor placed parallel to and in close proximity to the first generates a similar flux field. As the two flux fields flow in the same circular direction, the total inductance of the system is increased over that of the sum of the individual parts. Reverse the direction of current flow in the second conductor, the circular direction of its flux field reverses and the total inductance of the system decreases.

In a conventional MLV chip, current flows into one set of electrodes, across the dielectric and out through the second set of electrodes. Flux fields in both sets of electrodes are in the same direction. Figure 51.

In the Feed Thru' Chip, currents flow at 90° in the corresponding sets of electrodes thereby reducing their mutual inductance to well below that of the conventional chip structure. Figure 52.

Typically, Feed Thru' MLV Chips exhibit ESLs of the order 200 to 500 pH.

Temperature characteristics, capacitance values and working voltages are of the same order as those of conventional MLV Chips.

7.3 Balanced Line Varistor Filter

The Balanced Line EMI Chip Filter is also a 3 Terminal Chip, however, in this instance, only one set of electrodes span a pair of terminations. Distributed above and below those electrodes are two further sets of electrodes disposed in the same manner as those of a conventional MLV chip. Figure 53.

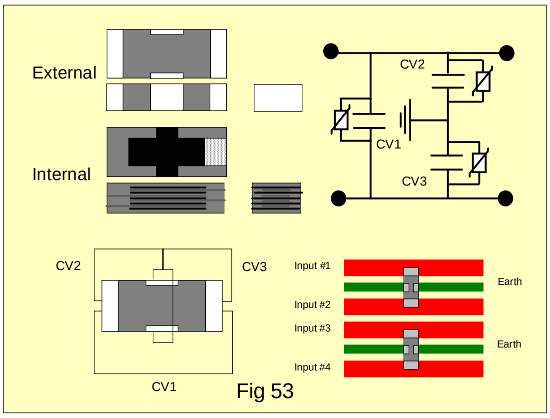


Fig 53

The interleaving sets of electrodes form a circuit of three Varistor Capacitors. It is precisely that Filter circuit recommended for balanced line applications and for joint elimination of differential and common mode noise. See the circuit so formed in Figure 53 where the Capacitance of CV1 is 50% of that of CV2 and that C2 is equal to that of CV3.

The Varistor voltages of CV2 and CV3 are equal. The Varistor voltage of CV1 is double that of CV2 nd CV3.

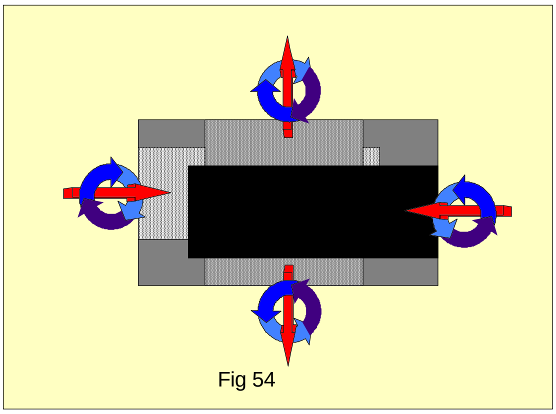


Fig 54

In common with a conventional 3 Terminal Varistor Chip, the electrode configuration continues to offer 90° orientation of common mode conduction paths but it now affords 180° orientation of differential mode conduction paths. Figure 54.

When measured in differential mode, examples of this type of device have exhibited ESLs down to 50 pH, about 4% of that of a conventional MLV, thus, it has a superb high frequency performance.

The Balanced Line Varistor Chip Filter is available in 0805 and 1206 chip sizes with voltages and capacitance values which are similar to those of conventional MLV chips.

This is a true Integrated Passive Component...

- three Capacitors and three Varistors in a single, surface mountable package.
- It is configured in the perfect circuit for the elimination of both common mode and differential mode interference.
- It offers both differential and common mode Filtering within a single device
- In differential mode, with an ESL of the order 50 pH, it is one of the fastest TVS components.
- It can eliminate the need for Ferrites in some Filter applications.
- It reduces the board area required for Filtering and Transient Suppression.
- It has a high current capability - mounted in by-pass mode, the signal current passes down the PCB traces only. Only continuous or transient noise passes through the chip.
- Line to ground capacitances and Varistor Voltages are equal and track across the entire temperature and voltage envelope throughout the life of the system in which it is used.
- It is an economic, high performance Filter and Transient Suppression solution.

The Balanced Line Varistor Filter is available with temperature characteristics, capacitance values and voltages which are close to those of conventional MLV chips of a similar size.

(Note - the electrode configuration of the Balanced Line EMI Chip Filter is the subject of patents owned by X2Y Inc.. Syfer Technology is a licensee of X2Y Inc..)

7.3 Discoidal Varistor Filters

The ESL of a rectangular chip is increased by a phenomenon called charge concentration. With terminations and electrodes of finite width, current density is greatest at the edges of electrodes. The terminations and electrodes of a circular part, such as a Discoidal MLV, are, effectively, of infinite width so a minimum of charge concentration is encountered. This coupled with short path lengths makes for components with the lowest values of ESR and ESL available today.

With an ESL of the order 30 pH, this configuration affords the fastest operating Varistor whilst offering the best of Filter performance.

The Varistor can be used instead of or as a supplement to a Capacitor in any of the conventional Filter configurations. Figure 55.

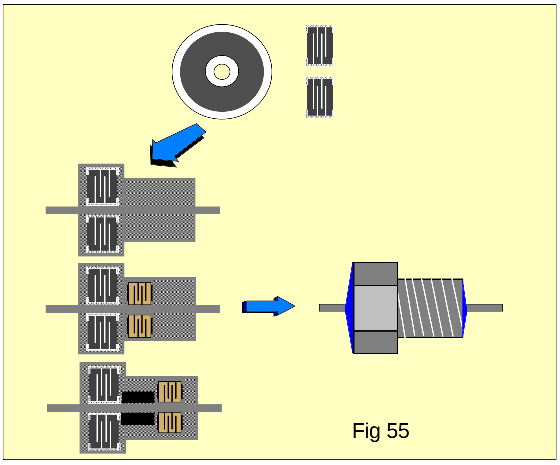


Fig 55

The only rule is that the Filter must be oriented so that the Varistor is in a position to intercept the transient before it reaches the Capacitor. Whilst bi-polarity of filtering of continuous noise remains, transient protection filters are polar.

7.4 Multilayer Varistor Planar Arrays.

The Multilayer Planar Varistor Array is an application specific component designed for use in protected EMI Filter connectors. It is a unitary block of ceramic, containing a multiplicity of Varistor / Capacitors. Figure 15.

Individual line connection is made, to each Varistor, through a via hole whilst ground connection is made to all at the device perimeter. Very low impedances are encountered as signals are presented with multi-directional paths to ground. Figure 34.

Protected EMI Filter Connectors and Filter Adaptors. Connectors can embody C, L, T or Pi Filters.

A Protected Filter Connector enables grouping of power and signal cables so that all enter the equipment shielding at a single point. It is bi directional - it keeps noise out of the equipment whilst preventing the equipment emitting noise.

Each cable is soldered to a contact in the Filter housing. Each contact is connected to a hole in the Array - 'hot electrodes' make connection with the hole perimeter whilst ground electrodes cover the entire Planar and make contact with the Connector shell through the Planar perimeter. Figure 56.

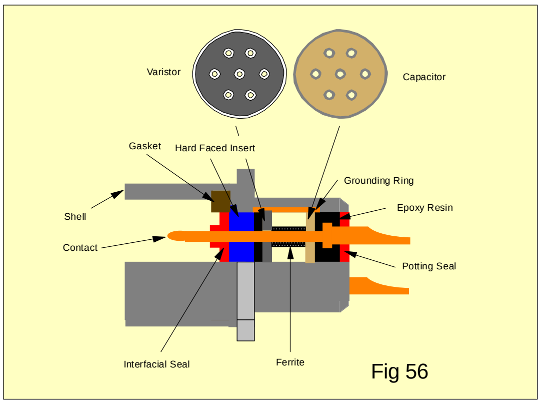


Fig 56

The Protected Filter Connector affords a reduction in overall system size and weight as it all but eliminates the need for board level Filter circuits. System reliability is improved as the number of solder joints is reduced.

A Multilayer Planar Varistor Array when used as the protection element in Protected Filter Connector may be substituted for a Capacitor planar, its own capacitance acting as part of the Filter element, or it may supplement it.

Filter Connectors which include additional transient protection are presently available using two other TVS technologies...

Tubular Varistors
and... Zener Diodes.

Compared with a planar based Filter Connector, both technologies demand a longer (and therefore heavier) Filter Connector shell.

Both make for less efficient use of Connector real estate as neither technology can compete with Planars in terms of Connector pin density.

Each of those other components must be handled individually during the Connector assembly process and neither affords a compensation for this added cost burden by way of a low piece part cost.

There are apocryphal tales of Connector prices - a simple $10 electrical connector becomes a $100 connector if filtering is needed - add a transient protection function and its cost soars to $1,000!. The advent of Planar solution now makes protected connectors affordable.

Varistor Planar based Transient Protected Filter Connectors are available in all MIL-STD Connector layouts including both circular and rectangular layouts.

Within the Planar Array, as many as 3 different voltage values may be distributed about the layout. Rated Voltages range from 5 to 70 volts dependent upon pin density.

Multiple capacitance values may be specified.

Individual holes can be grounded. Ground Plane Resistances will tend to be higher than those of similar Capacitor Arrays as the Resistivity of the electrode material (Pt) is higher and electrodes are generally fewer.

Where required, holes can be electrically isolated for use as feed thru's. It should be born in mind that a Varistor action will occur at a feed thru' hole if the filter pin is allowed to touch the hole bore so pins at feed thru' holes should be sleeved or otherwise electrically insulated from the planar.

Cross Talk Capacitance can be restricted to specified maxima.

Planar Arrays with the electrode configuration of the Balanced Line Chip (7.2) are also available from Syfer Technology Ltd..

The Transient Protected Filter Connector offers a reduction in overall system size and weight as it all but eliminates the need for board level Filter and Suppression circuits. System reliability is improved as the number of solder joints is reduced.

The sophistication of the Planar Array lies not in the complexity of electrical specifications that can be incorporated into a single component but in the mechanical precision with which such devices must be built.

Typically, pin positions in a Connector must be maintained to better than ± 0.002" (.05 mm) so Planar Arrays must be built to the same or better mechanical tolerances.

Planars must be formed (shaped and drilled) before ceramic firing, during which they shrink, typically by around 20%. Pin positions on an 1¼ inch fired diameter Planar will move more than 0.1" during firing relative to a central reference point - that is 50 x the magnitude of the permissible pin position tolerance!

The Varistor Planar Array is now the most sophisticated passive component. Affording transient protection at different voltages across different holes, multiple capacitance values per device, and other electrical function alternatives per hole, it is the ultimate Integrated Passive Component.

Not every manufacturer is capable of making such a device - only a handful of companies worldwide claim a capability. Syfer Technology Ltd. is acknowledged to be the World's leading manufacturer of Planar Arrays.

Syfer Technology Ltd. is the World's only manufacturer of Transient Protection Planar Arrays.

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