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THE MAIDA DEVELOPMENT COMPANY

For over 52 years the Maida Development Company has been a leading manufacturer and supplier of high quality components for the electronic industry. Maida currently has three full product lines, consisting of zinc-oxide varistors, ceramic disk capacitors, and PTC and NTC thermistors. From its founding in 1947 by Francis X. Maida, the corporate offices and manufacturing facilities for Maida are located in Hampton, Virginia, where today it encompasses over 100,000 square feet of space.

Maida products are distributed worldwide to OEMs and end-users who require exceptional service and delivery. Distribution is achieved with an international team of trained, experienced sales representatives and distributors strategically located worldwide. Maida products are shipped to customers in North America, Central and South America, Europe, and Asian countries including Korea, Taiwan, China, Malaysia, and Singapore.

Component products manufactured by Maida cover a wide range of uses and industries. Maida's zinc-oxide varistors are used in many applications that require protection against transients induced by lightning struck power lines. They also provide protection for suppression of transients caused by switching inductive loads from transformers, relays and coils. Common applications include ground fault interrupters, specialty high-voltage power supplies, telecommunication equipment, computer and computer-related products, motor control systems, cable TV systems, and AC smoke detectors, plus many special applications.

The Maida manufactured products include a complete line of radial-leaded ceramic zinc-oxide varistors along with a line of surface mount varistors. Maida also manufactures a complete line of high voltage ceramic disc capacitors, complemented by a full selection of safety capacitors. NTC ceramic thermistors used for in-rush current limiting and temperature sensing applications as well as PTC thermistors for over-current protection are also parts of the product line-up at Maida. Custom design and fabrication of components for specific customer requirements are also available from Maida.

Maida products are component-recognized in the United States as well as internationally by organizations such as UL, CSA, VDE, SEMKO, NEMKO, DEMKO, FIMKO, and SEV.

Maida products have a long heritage of proven high quality performance and reliability. They even worked their way to the moon and back during the Apollo Space Program. The Maida success story in part has resulted from a continuous dynamic program of research and development for improving both products and manufacturing processes to meet customer needs. Dedicated employees, management with a customer service attitude, sound competitive marketing, and state-of–the art products sum up the Maida story.

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INTRODUCTION TO VARISTORS

Maida Development Company, domestically owned and operated for over fifty years, has served the electronics industry with a wide variety of ceramic components. Our line of Zinc Oxide Varistors (ZOV) is designed for transient voltage suppression and surge energy absorption. Most are component-recognized by Underwriters Laboratories, Canadian Standards Association, VDE, and SEV.

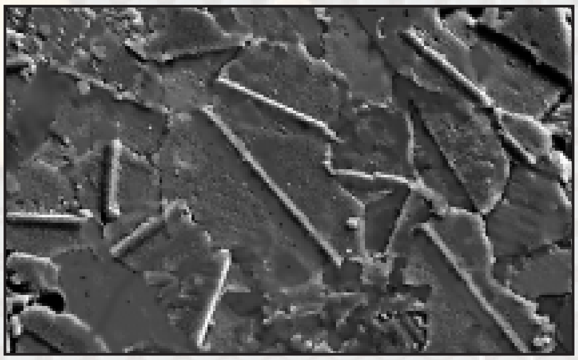

figure 1

The terms zinc oxide varistor (ZOV) and metal oxide varistor (MOV) are synonymous. Other metal oxides are added to zinc oxide to produce a multi-grain ceramic semiconductor made up of randomly oriented, highly conductive zinc oxide crystals separated by insulating barrier layers (refer to figure 1). The resistivity of the grains is in the range of 1 - 10 ohm-cm. That of the barrier junction is near 10^{12} ohm-cm. Two adjacent grains in direct contact constitute an n-p-n junction which is non-polar (like back-to-back diodes). The barrier energy that must be exceeded to produce conduction through the grain boundary is approximately 3 V per grain boundary. Voltage, current, and energy ratings are determined by the oxide composition and by the physical dimensions of the part. For a given ceramic composition, voltage ratings increase with ceramic thickness, current increases with area (diameter), and energy increases with the mass of the unit.

Transient over-voltages are a major cause for malfunction or total failure of electronic circuitry and equipment. These transients occur whenever there are sudden changes in a power distribution system whether resulting from lightning disturbances on incoming power lines or from energy demand changes of equipment from within the circuit. With such changes, voltage spikes are created by the energy stored in reactive components of inductance and capacitance. These voltage impulses can (1) destroy semiconductor devices through high avalanche currents and thermal runaway, (2) diminish dielectric strength of insulations, (3) impair electromechanical contacts, and (4) cause malfunctions of logic circuitry by stray signals. Transient voltage rise times can be extremely fast and any effective transient suppression device must be capable of "clamping" the voltage during the early portion of this rise, i.e., in the nano-second range.

The most distinguishing feature of zinc oxide varistors is their highly exponential variation of current over a narrow range of applied voltage. Within the useful varistor voltage range, the voltage-current relationship is empirically approximated by the expression:

$$I = AV^{\alpha} \quad [1]$$

where I = current in amperes
V = voltage
A = a material constant
α = an exponent defining the degree of non-linearity

The value of alpha (α) is an index or figure of merit indicating the effectiveness of a varistor (refer to figure 2). For an ideal resistor α would be unity; for silicon carbide varistors α is 2-6; and for zener diodes, 5-100. Maida's ZOV varistors have alpha values ranging from 15 to 50 but are typically 25-40.

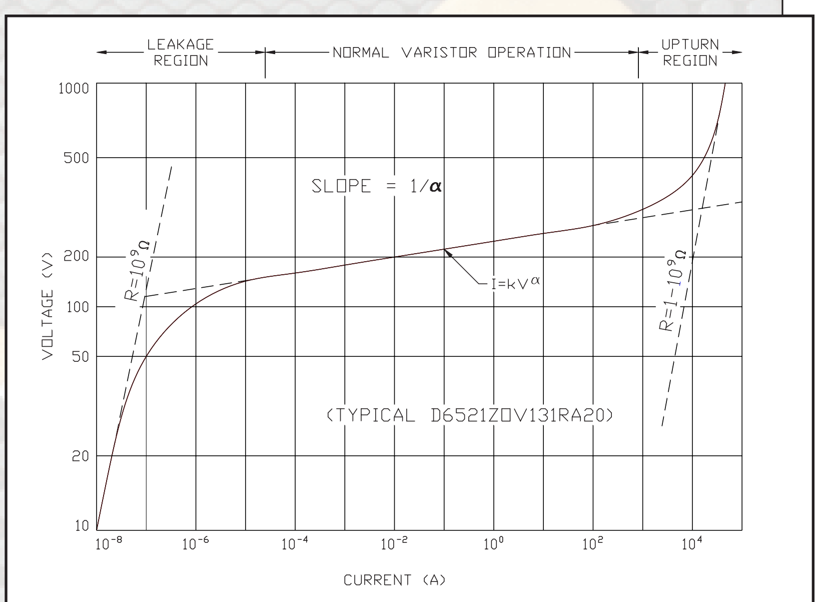

figure 2

A ZOV exposed to voltage transients above the active varistor voltage range changes from an insulating state with very low leakage current to a highly conductive state having a current level several orders of magnitude above the “stand-by” level. The conduction mechanism is a semiconductor process so rapid (<1ns) that effective measurement of response time is difficult. For a ZOV with radial leads, the time required for voltage “clamping” to occur is determined more by lead inductance effects than by varistor action itself. Current pulses associated with transient voltage spikes have inherently slower rise times than the voltage wave, often in the microsecond range and quite long compared to ZOV response time. The result is that transient voltages are clamped at a safe level and the associated pulse energy is absorbed by the ceramic varistor.

Maida’s ZOVs perform very reliably and experience low failure rates. However, catastrophic failure may occur if a ZOV is subjected to transient surges beyond its rated values of energy and peak current. Voltage breakdown, or “puncture”, of the ceramic discs results in a short-circuit. Also, open-circuit failures are possible if a ZOV is operated at steady state conditions above its voltage rating so that the exponential increase in current causes overheating and eventual separation of the wire lead and disc at the solder junction. Proper fusing and shielding from other circuit components are recommended.

It is convenient to use a log-log plot of equation [1] where α is the slope of the voltage versus current curve.

$$\alpha = \frac{\log (I_2/I_1)}{\log (V_2/V_1)} \qquad [2]$$

If voltage measurements are taken at current levels one decade apart ($I_2/I_1 = 10$), then for that decade:

$$\alpha = \frac{1}{\log (V_2/V_1)} \qquad [3]$$

The varistor voltage range is that portion of the V-I curve which falls between two regions of transition in resistivity: (1) at lower voltage, a linear/non-linear transition from a high resistance ohmic mode (10^8 - 10^9 ohms), and (2) at higher voltage , a non-linear/linear transition back to an ohmic mode with resistance of only a few ohms. Typically, within the varistor range, only a 6% change in applied voltage produces greater than a tenfold change in current (α>40).

Some specific areas of application of Maida’s ZOVs are:

- Protection against transients induced by lightning on incoming power lines
- Suppression of transients caused by switching inductive loads: transformers, relays, coils
- Ground fault interrupters
- Power supplies
- Communication equipment
- Microprocessor protection
- Motor control systems
- Cable TV systems
- AC operated smoke detectors
- Computers
- Medical equipment
- Street lighting
- Automotive
- Traffic facilities
- Railway distribution/vehicles
- Microwave devices

VARISTOR RATINGS AND CONCEPTS

- **AC voltage rating.** This is the maximum continuous sinusoidal RMS voltage which may be applied. In selecting a Maida ZOV, this value should include the nominal AC line voltage to be applied plus an allowance (~10%) for routine high-line fluctuations. As examples, select a 130 VAC ZOV for a 117 VAC, a 140 or 150 VAC for 125 VAC, and a 250 VAC ZOV for 220 VAC use.

- **DC voltage rating.** This is the maximum continuous DC voltage which may be applied across the ZOV and is determined by the DC idle power. This value is typically about 95% of the peak recurrent AC voltage. The peak recurrent AC voltage is √2 times the RMS value and coincides with the minimum varistor voltage at 1 mADC.

- **Nominal varistor voltage.** The nominal varistor voltage is defined as that point at which the linear/non-linear transition is complete and is arbitrarily specified as V@1 mADC. The usual tolerance on nominal varistor voltage is ± 10%. The varistor voltage rating is a function of: (1) the height of the energy barrier at the individual grain boundaries, (2) the average size of the ZnO grains within the ceramic, and (3) the thickness of the ceramic element.

- **DC leakage current.** With rated DC voltage applied the maximum leakage current value is 200µA. Typical values are less than 100µA.

- **Single impulse peak current rating.** This parameter characterizes the maximum current handling capability of a varistor for a non-recurring surge event. The 8/20 µs exponential current waveform defined in ANSI/IEEE C62.41 (1991), which simulates lightning induced surges, is the industry-accepted standard used to establish this parameter.

- **Single impulse energy rating.** This parameter characterizes the maximum energy handling capability of a varistor, expressed in joules, for a non-recurring surge event. The 10/1000µs exponential current waveform defined in ANSI/IEEE C62.41 (1991) is an industry-accepted standard used to establish this parameter. This is a relatively long waveform which simulates transient surges generated by the interruption of inductive loads or other major switching disturbances. See discussion on energy below.

- **Significance of energy specifications.** The single pulse energy rating of a varistor is often misunderstood and misused as a figure of merit for ZOV performance and effectiveness.

ANSI/IEEE C62.33 (1982) Standard for Surge Protective Devices states:

"Energy ratings can be misleading as an indicator of the comparative merit of different varistor designs. The energy deposited in a varistor by a transient current source depends on the varistor clamping voltage. Therefore, a lower energy rating does not necessarily mean a lower capability of survival in the transient environment."

"Instead, single and lifetime pulse current ratings are appropriate tests of varistor surge withstand capability. In the absence of special requirements, energy ratings are recommended for use only as supplements to the predominant current ratings, and for application problems which are more conveniently treated in terms of energy."

The energy absorbed by a device as a result of a surge, is defined by:

$$J = k \cdot E_{CLAMP} \cdot I_{PEAK} \cdot \tau \qquad [4]$$

where: J = energy absorbed in joules
k = form factor dependent upon shape of current impulse
k = 1 for a square wave pulse
k = 0.5 for a triangular pulse
k = 1.4 for an exponential waveform
E_{CLAMP} = measured clamping voltage in volts (assumed constant during current decay)
I_{PEAK} = maximum let-through current in amps (crest value of current impulse wave)
τ = effective impulse duration in seconds

For current waveforms commonly used in energy qualification testing, the waveshapes may be separated into a rise portion and a decay portion. The energy content of each portion, represented by the area under the curve, may be calculated separately and the two energies combined to yield the total energy.

For the 10/1000 µs waveform, the rise portion may be considered triangular, and the decay portion exponential.

$$\begin{aligned} J_{TOTAL} &= J_{RISE} + J_{DECAY} \\ &= 0.5(E)(I)(10x10^{-6}) + 1.4(E)(I)(1000\text{-}10)(10^{-6}) \\ &= (E)(I)(10^{-6})(5 + 1386) \\ &= 1391(10^{-6})(E)(I) \qquad [5] \end{aligned}$$

In the same way, for the 8/20 µs impulse:

$$\begin{aligned} J_{TOTAL} &= J_{RISE} + J_{DECAY} \\ &= 0.5(E)(I)(8)(10^{-6}) + 1.4(E)(I)(20\text{-}8)(10^{-6}) \\ &= (E)(I)(10^{-6})(4 + 16.8) \\ &= 20.8(10^{-6})(E)(I) \qquad [6] \end{aligned}$$

In either case, the calculated energy is proportional to the product of the measured values of clamping voltage and let-through current. At any specified surge current level, lower clamping voltages are preferred for better surge protection, yet higher clamping voltages produce higher calculated energy values. This is misleading. Clearly the lower clamping voltage is more desirable because the varistor is required to absorb and dissipate less energy at the same current level. Only by increasing the peak current capability can real and unarguable increases in energy ratings be demonstrated.

- For both transient energy and transient peak current ratings, the values specified are the maximums that a ZOV can withstand without a disruptive failure or a change of varistor voltage (VDC@1 mA) that exceeds ± 10 percent of the pre-pulse value. Derating is required for multiple pulses of the same waveform as well as for pulses of longer duration.

- **Transient power dissipation.** This is the maximum power from a pulse or group of pulses that may be dissipated by the ZOV. The average pulse energy in joules, or watt-seconds, times the number of pulses per second indicates the total transient power in watts delivered to the ZOV. The transient power rating should not be exceeded.

- V - I curves, plotted between 1 µA and 10 kA or higher, reveal three distinct regions:
  - A leakage region below about 100 µA. Current is limited by the high resistivity of the boundary layers. Low leakage current is essential and depends upon the type, number, distribution, and mobility of charge carriers within the barrier layers. How these charge carriers respond to continuous application of voltage, and to variations of ambient temperature may greatly affect the life of a varistor.
  - The varistor range from 100 mA to about 1000 amps. In this range, barrier voltages are being exceeded. Slight voltage increases bring about multi-fold increases in let through current. Current flows nearly unrestricted through the barrier layers, and is limited only by the resistivity of the bulk ZnO grains.
  - A high current, or upturn, region. Survivability in this region depends upon the ability of the bulk ZnO grains to absorb energy and dissipate it as heat back to the environment.

- A ZOV, to operate without failure or degradation, must quickly dissipate absorbed energy and return to its pre-pulse standby operating temperature. It also must have thermally stable leakage characteristics. The leakage current is important because it determines the watts loss (I^2R heat) that will be generated at steady-state operating voltage.

- The life of a ZOV is usually defined as the time required to reach a thermal runaway condition. Empirically, the relationship between ambient temperature and the life of varistors subjected to continuous electrical stress can be expressed by the Arrhenius rate equation, which simply states that the rate of degradation varies exponentially with the reciprocal of temperature:

$$t = t_o \exp[E_a - f(V)]/RT \qquad [7]$$

where t = time to thermal runaway
t_o = constant
R = constant
E_a = activation energy
T = temperature in ºK
$f(V)$ = applied voltage

When voltage is applied for a very long time, micro currents flow within the ceramic. Physical and chemical changes occur within the boundary layers and the activation energy changes accordingly. After some certain period of time the joule heating increases rapidly and exceeds the ZOV's ability to dissipate the heat back to the environment. The thermal runaway condition has been reached and the varistor life ends.

- Leakage current also empirically obeys the Arrhenius relationship as follows:

$$I_L = I_{Lo} \exp[- \{E_a - f(V)\}/kT \qquad [8]$$

where I_L = resistive leakage current causing joule heating
I_{Lo} = initial resistive current much smaller than 1 mA/cm2
E_a = activation energy
$f(V)$ = applied voltage
k = Boltzman's constant
T = absolute temperature

OTHER OVERVOLTAGE PROTECTION COMPONENTS

- Air breaks down at about 30,000 volts/inch, providing built-in overvoltage protection at about 6000 volts in most conventional and industrial wiring environments. This protection occurs by the uncontrolled breakdown that occurs in air between insulation terminals, i.e., at wall outlets.

- Gap-type carbon block arrestors have been widely used for years in the telecommunications industry. They function in air at atmospheric pressure. Arc-over voltages are established by very close air-gap dimensions. Replacement and maintenance costs are high.

- Gas tubes are a refinement of air-gap arrestors. Carefully shaped and separated electrodes are sealed in a hermetic envelope filled with a gas mixture. These "crowbar" devices are designed to fire in an arc discharge mode within a few microseconds, short-circuiting the high voltage surge to ground. They are rated to breakdown between 100 volts and several kilovolts and can sustain very large currents, up to 20,000 amps. During the discharge, the voltage across the gap drops to only a few volts. Once turned on, the gas tube may continue to conduct current after the transient has subsided, depending upon the power delivering capability of the circuit. This "follow" current can be catastrophic unless some specific means is provided to extinguish the arc. The actual breakdown voltage is a function of the rate of rise of the voltage spike and is statistical in nature. Discharge ranges as wide as 50 to 300 V may occur within a single manufactured lot. Because of sensitivity to rate of applied voltage, a gas tube which fires at 90 to 120 V with a voltage ramp of 100 V/sec, may not fire until 800 to 1000 V when a steep ramp of 10,000 V/sec is applied. Gas-tubes offer adequate protection against slow-rise surges, but may be inadequate for impulses with steeper fronts.

- Silicon avalanche diodes are available with clamping voltage ranges from 5 V to several hundred volts. These are large junction zener diodes specifically designed for surge suppression. They respond in a few nanoseconds and have precise clamping action. The major limitations are their inability to dissipate large amounts of energy and their cost.

Terminology & General Specifications

TECHNICAL TERM	DESCRIPTION	SPECIFICATION
Operating Temperature	Operating Temperature Range without Derating.	-40°C to +85°C
Storage Temperature	Storage Temperature Range without Voltage Applied.	-50°C to +125°C
Current / Energy Derating	Derating of Maximum Values when Operated above 85°C	-2.5%/°C
Varistor Voltage Temperature Coefficient	$\frac{V_v \text{ at } 85°C - V_v \text{ at } 25°C}{V_v \text{ at } 25°C} \times \frac{1}{60°C} \times 100$ Where Vv is varistor voltage at 1 mADC	-0.05%/°C
Insulation Resistance	Minimum resistance between shorted terminals and varistor surface.	10,000 MΩ minimum
HiPot Encapsulation	Minimum voltage applied for one minute between shorted terminals and varistor surface.	2,500 VDC
Impluse Reponse Time	Time lag between application of surge and varistor's "turn-on" conduction action.	<50 nanoseconds
DC Leakage Current	Maximum current with rated DC voltage applied.	200 μA maximum
Safety Agency Recognitions	UL1449 File E86730 - Transient Voltage Surge Suppression UL1414 File E38785 - Across The Line Applications CSA C22.2 File LR33458 VDE/CECC 42000/42201 & IEC 1051 UL497B - File E180012 SEV - 96.7 70250.01	See Specification tables
Applied Voltage - AC	Maximum continuous sinusoidal RMS voltage which may be applied.	See Specification tables
Applied Voltage - DC	Maximum continuous DC voltage which may be applied.	See Specification tables
Transient Energy (Joules)	The maximum energy absorbed with a varistor voltage change of less than +/- 10% when one impulse of a 10x1000 μsec. or 8x20 μsec. current waveform is applied.	See Specification tables
Transient Peak Current	The maximum current with a varistor voltage change of less than +/- 10% when one impulse of a 8x20 μsec. current waveform is applied.	See Specification tables
Varistor Voltage	Voltage across the varistor measured at 1 mADC.	See Specification tables
Maximum Clamping Voltage	Peak voltage across the varistor with a specified peak impulse current (8x20 μsec.).	See Specification tables
Capacitance	Typical value measured at 1Vrms and test frequency of 1KHz.	See Specification tables