GE-MOV® Varistor – The Super Alpha Varistor

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General Electric Company

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Significance
Part 7 – Mitigation techniques

A public-domain (unclassified) General Electric report aimed at the engineering community to provide technical information in support of the trade announcement published in Electronics (see MOV Announce in Part 6.

Note – 2005 perspective:
With hindsight, this report reflecting the enthusiasm at General Electric for the answer to the quest for an effective and economical transient suppressor in consumer products (see Evaluate 1963 SPDs in Part 7), is probably at the source of the unfortunate selection of device ratings that made the electronics-oriented "GE-MOV®" select a disc thickness for its 130-V rating according to what became a perception of "lower is better" for surge protection (200 V at 1 mA DC, see Figure 12 in the report). That position was abetted by some now-forgotten trade publications emphasizing the need to limit transient overvoltages to less than 100 V above peak line voltage, hence the citing of a low level 330 V for the "clamping voltage" of 130-V TVSSs in the fist edition of UL Std 1449.

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SUMMARY

Today there is considerable interest and development activity in a new class of metal oxide varistor which exhibits a high degree of non-linearity as compared with previous devices. Because of the metal oxide, the device has been named a metal oxide varistor and has been trademarked MOV.* This quest for "super" or higher performance is seemingly a continuous one -- which, for example, in the case of transistors has seen the emergence of the Darlington and super beta transistor.

The voltage across a varistor and the current through it are related by a power law $I = k V^n$. The exponent n will typically have values 25 to 50 or more, leading to a characteristic very similar to that of a Zener diode. Over a wide current range, the voltage remains within a very narrow band for a specific device, and can be referred to as the "varistor voltage" for that device. The nonlinear electrical characteristic makes the device useful in voltage regulation applications, and in particular for limiting surges and transient voltages that may appear on power lines.

Polycrystalline devices using zinc oxide have been the subject of much research over the past dozen or so years. Recent work on the zinc oxide-bismuth oxide system has shown many improvements in properties compared to other devices based on silicon carbide, selenium, etc.

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KEY WORDS varistor, nonlinear varistor, metal oxide varistor, MOV, GE-MOV

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GE-MOV* VARISTOR--The Super Alpha Varistor

J. D. Harnden, Jr., F. D. Martzloff, W. G. Morris† and F. B. Golden‡

INTRODUCTION

Varistors are perhaps among the oldest of the electrical and electronic devices. Yet today there is considerable interest and development activity in a new class of metal oxide varistor which exhibits a high degree of nonlinearity as compared with previous devices. Because of the metal oxide, the device has been named a metal oxide varistor and has been trademarked MOV*. This quest for "super" or higher performance is seemingly a continuous one -- which, for example, in the case of transistors has seen the emergence of the Darlington and super beta transistor.

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Polycrystalline devices using zinc oxide have been the subject of much research over the past dozen or so years.(1) Recent work on the zinc oxide-bismuth oxide system has shown many improvements in properties compared to other devices based on silicon carbide, selenium, etc.(2-4)

STRUCTURE AND PROCESSING

A preferred type of metal oxide varistor consists of a polycrystalline ceramic body, with metal contacts and wire leads applied, and suitably encapsulated (Fig. 1). Zinc oxide and bismuth oxide, desirable ingredients for a high exponent varistor, are mixed with other (proprietary) additives in powder form, pressed into disks and sintered above 1200°C. The bismuth oxide is molten above 825°C, assisting the formation of a dense polycrystalline ceramic through liquid-phase sintering. During cooling, the liquid phase forms a rigid, amorphous coating around each ZnO grain, giving a microstructure of ZnO grains isolated from one another by a thin, continuous intergranular phase. This complex, two-phase microstructure is responsible for the nonlinear characteristic.

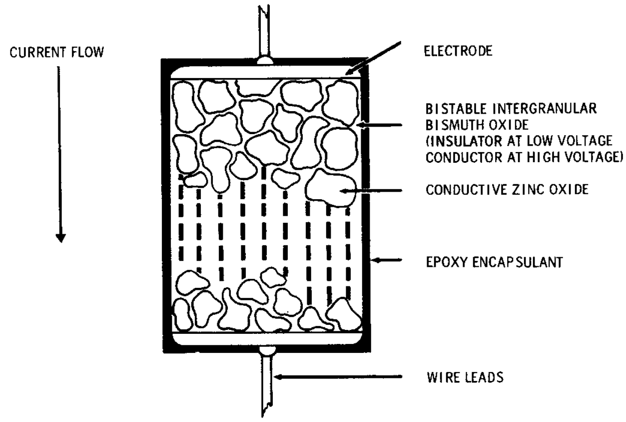

Fig. 1 Structure of metal oxide varistor.

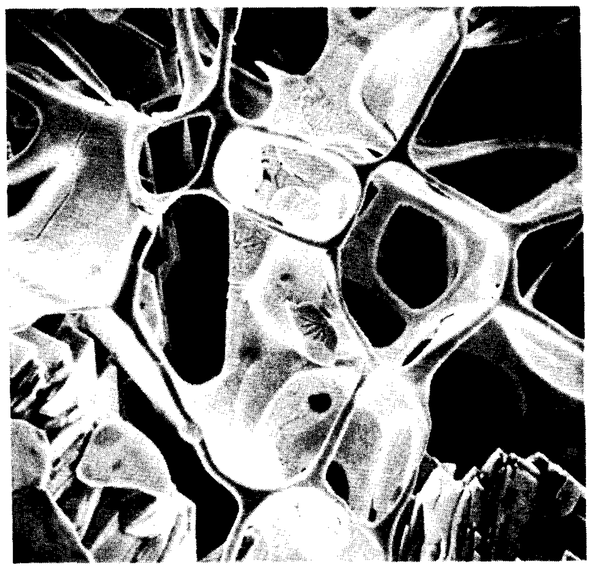

Fig. 2 Scanning electron micrograph (860X).

MICROSTRUCTURE AND INTERGRANULAR PHASE

The nature of the continuous intergranular phase can be seen in Fig. 2. This is a scanning electron micrograph at 2000X of a sintered ceramic, containing zinc oxide and bismuth oxide in a ratio of 50:1. The zinc oxide grains have been dissolved in an ammonium chloride solution, revealing the amorphous phase. The most prominent feature is the triangular rods which appear at the intersection of three grain edges, although there are several regions where the very thin membrane (less than 1000Å) which separated grain faces remains intact. To understand the

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electrical properties of the MOV varistor, one must consider not only the doping of ZnO crystals by bismuth ions, but also the doping of the bismuth oxide intergranular phase by zinc ions, and the geometrical effects of the two-phase structure.

PROPERTIES OF ZINC OXIDE GRAINS

The rather low resistivity, about 1 ohm-cm at 25°C, of semiconducting zinc oxide is attributed to conduction electrons from ionized zinc interstitial atoms. The addition of monovalent ions, such as Na^{+}, introduces traps, and the resistivity increases. Conversely, trivalent ions such as Cr^{+3} contribute additional electrons with a further reduction in resistivity. Bismuth doping of the zinc oxide grains is less than 100 ppm as determined by electron microprobe analysis. Trivalent bismuth ions would be expected to decrease the resistivity of zinc oxide, but in this concentration they probably have a negligible effect. It is sufficiently accurate to describe the zinc oxide grains in the MOV varistor as being n-type, 1 ohm-cm semiconductor.

PROPERTIES OF THE Bi_2O_3 INTERGRANULAR PHASE

Unlike the abundance of material available on zinc oxide, very little is known about the electrical behavior of Bi_2O_3. It has a much higher resistivity, about 10^{11} ohm-cm at 25°C, but virtually nothing is known about the nature of the carriers and the defect structure. The melting point is 825°C with the liquid dissolving an appreciable amount of ZnO. According to a limited phase diagram, it forms a $6Bi_2O_3 \cdot ZnO$ cubic compound below 800°C. Accurate analysis of the intergranular phase in the ZnO-Bi_2O_3 ceramic is difficult, but most evidence points towards an amorphous structure, containing up to perhaps 20 percent zinc, with a resistivity much greater than the zinc oxide grains.

RELATING PROPERTIES TO MICROSTRUCTURE

Many properties of the MOV varistor can be directly related to the microstructure, and the properties of the two phases. At low applied voltages, the resulting electrical characteristics is primarily that attributable to the leakage current through the intergranular phase. The behavior is approximately that of an insulator at the low ranges of applied voltage, and the applied voltage thus results in a very high field across the intergranular phase and a low field in the grains. In the varistor range, the intergranular phase becomes nonlinear and current through it increases very rapidly as the voltage is slowly increased. The conduction mechanism which results in the nonlinear characteristic is a source of intense investigation and is probably space charge limited currents or tunneling. In the very high current range, the resistance of the intergranular layer becomes less than the ZnO grains, causing the V-I characteristic to once again tend towards linearity. Capacitance-frequency and capacitance-voltage curves for the ceramic body indicate conduction limited by hopping or tunneling in the thin layers, with relatively easy conduction through the n-type ZnO grains.

EVAPORATED THIN-FILM EXPERIMENT

Experiments on evaporated films of Bi_2O_3 on ZnO show that the intergranular layer is capable of nonlinear characteristic alone. Figure 3 illustrates the fact that a ZnO single crystal is linear, whereas the same crystal with an evaporated Bi_2O_3 film shows nonlinearity similar to the metal oxide varistor. This, together with the microstructure shown in Fig. 2, emphasizes the importance of the intergranular phase in order to achieve good varistor properties.

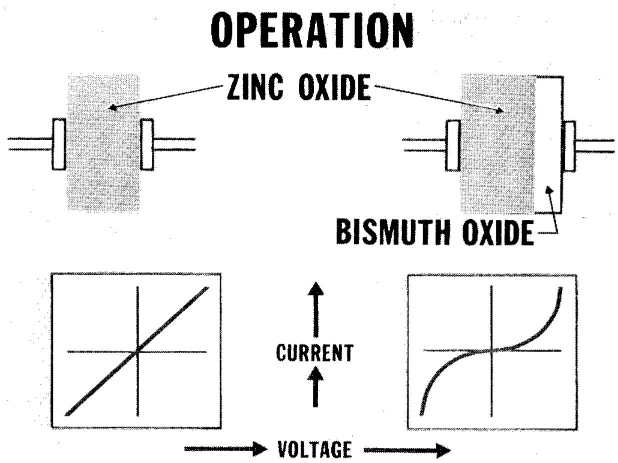


Fig. 3 V-I characteristic of zinc oxide and ZnO-Bi_2O_3.

PROPOSED MECHANISM -- HOPPING

By comparing all the electrical properties measured in this work, it is proposed that the mechanism is a combination of electron hopping and tunneling in the amorphous thin layers. The specific areas of agreement with the hopping model are (1) a very slight decrease in polarizability with frequency, (2) a decrease in AC resistivity with frequency, approaching $1/f^2$ near 10^5 Hz, and (3) a low activation energy value of less than 0.01 ev is calculated.

PROPOSED MECHANISM -- HOPPING AND TUNNELING

Linear conduction is one feature of the hopping model which does not agree with the measured characteristics. Electron tunneling is a nonlinear conduction mechanism usually associated with a small temperature coefficient which may be considered as a series step in the conduction process. The estimated thickness of approximately 600Å for the intergranular phase is, however, rather large for tunneling through it to take place; but if the process is assumed to consist of a series of tunneling and hopping steps, the highly nonlinear conduction feature of tunneling can be introduced. The fields calculated in the intergranular phase are approximately 10^5 V/cm so that one might expect local field concentrations sufficient to initiate tunneling.

COMPARISON OF THIN-FILM PROPERTIES WITH SINTERED PROPERTIES

In the evaporated thin-film experiment, it is required that the ZnO single crystal substrate temperature be above 200°C, or that a subsequent annealing be done, in order to get an insulating layer. Thus, it is likely that diffusion of Zn into the film will result in a doping level comparable to the intergranular phase. The inherent surface roughness even on a polished surface results in thin regions which are more susceptible to electric breakdown. The thin-film samples show similar V-I characteristics to the sintered ceramics in the low current region, but generally fail as high localized current densities develop. These types of defects are less likely to occur in the liquid-phase sintered bodies. An important feature of liquid-phase sintering is the increased solubility in the liquid phase of regions of small radius of curvature on the surface of the grains, and the transport of this material to regions of negative curvature or preferred low energy faces. Thus the interfaces are naturally smooth and flat and more uniform conduction is possible. Liquid-phase sintering is a rather unsophisticated technique by modern semiconductor processing standards. It tends to automatically develop the atomically smooth interfaces and uniform intergranular phase required for nonlinear conduction. This, together with the redundancy of a large three-dimensional, series-parallel network, results in the MOV varistor being a device which has outstanding nonlinear properties and remarkable stability.

VOLTAGE RANGE, VOLTS PER MIL CONCEPT, AND LOWER VOLTAGE LIMIT

Devices of various varistor voltages are feasible from approximately 30 volts to many kilovolts. For a given composition and processing, it is convenient to talk about volts per mil; the varistor voltage is proportional to the thickness of the material between the contacts. Indeed, it is possible to mechanically slice the varistor material into small pieces, and calculate the voltage from the thickness. There is, of course, a minimum divisibility which is practical in terms of preservation of the high exponent characteristic. This limitation begins to show itself when there are insufficient grain boundaries within the statistical electrical path remaining for the thin cross section.

IDEALIZED V-I CHARACTERISTICS

Figure 4 shows the idealized voltage versus current characteristic. The wide range of current covering approximately 10 orders of magnitude is a highly

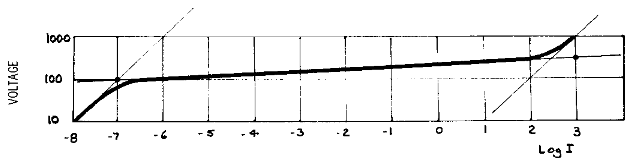


Fig. 4 Idealized V-I characteristic.

useful characteristic of the new metal oxide varistors. The low current level resistance is due basically to the resistivity of the intergranular phase. The capacitance is due to very thin dielectric of the inner granular phase and is a fairly significant factor in the dynamic characteristic of the material. The high current characteristic is due to the basic resistivity of the zinc oxide grains and represents the limiting resistance of the device.

ELECTRICAL CHARACTERIZATION

The following treatment serves as an introduction rather than exhaustive treatment of the electrical properties. For more details see Refs. 5 and 6.

Figure 5 provides an interesting composite view of the voltage-current relationship for silicon carbide varistors and MOV varistors and parametrically with linear resistances. The presence of linear resistor curves helps to highlight the great range of varistor operation. As pointed out earlier, the zinc oxide material by itself is essentially a linear resistor highly conducting.

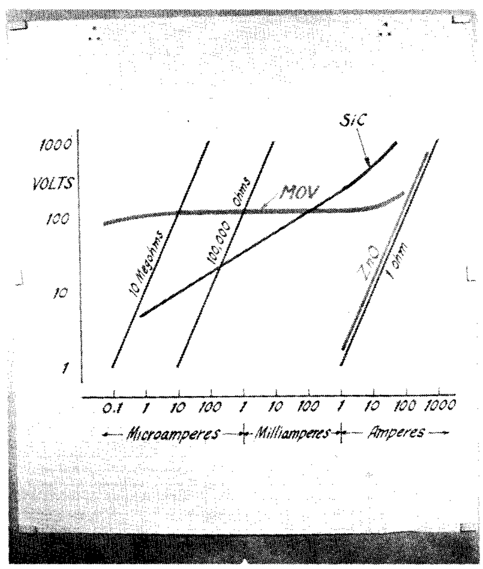


Fig. 5 Varistor and resistor log-log comparison.

The important electrical significance of the alpha or exponent upon clamping ratio is shown in Fig. 6. Thus it will be seen, for example, with a typical alpha of 30 that the current can vary over a range of 10,000 to one with a voltage change in the order of approximately 1.36.

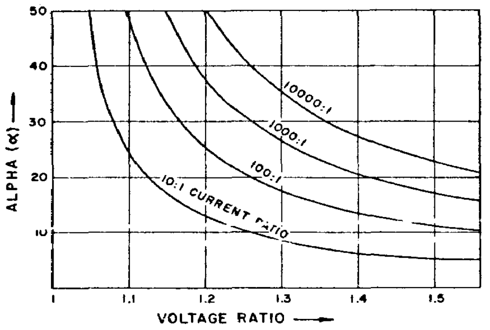


Fig. 6 Clamping ratios for different current ratios as a function of alpha (α).

As in the case with any new electronic device, questions regarding effects of temperature aging under storage and stress, plus overload conditions, and high-frequency properties all need to be examined and characterized in detail.

Figure 7 shows the temperature effect for the typical VP series of MOV varistors. The material exhibits a slight negative voltage temperature coefficient in the order of 0.05% to 0.1% per °C. This

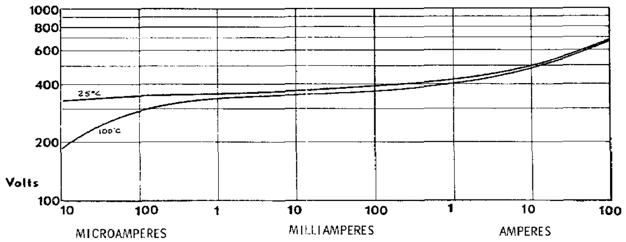


Fig. 7 Typical VP series temperature effect.

coefficient may change with composition. At very low current levels the coefficient is substantially larger, but this does not affect the normal operating range of the device. Storage at temperatures of 125°C has shown no degradation (the process involves sintering above 1200°C and tempering at several hundred degrees). There is a relationship between maximum steady state dissipation and ambient temperature. Typical values indicate 1 watt for a disk with 3 cm square total surface area and a 70°C free convection ambient.

Long-term stability tests under DC and AC conditions have well exceeded 10,000 hours under various stress levels with encouraging results. Several important stability areas being investigated include long term with DC bias at moderate power dissipation and stability with repetitive short-duration, high-energy pulses. The DC stability under moderate power dissipation (1 watt for 14 mm disk) has been established with a trend to a polarization-like mechanism whereby a small shift in the device voltage occurs with time. Under a condition of constant current in the device, the voltage across the device increases by a few percent and tends toward the stable asymptote. Under a condition of constant voltage applied to the device, the current drawn by the device decreases with time. Because of the high exponent characteristic the constant voltage test with decreasing current results in substantial decrease in the power dissipation in the device. Hence, even less current and greater stability.

RATINGS

Repetitive pulses of high energy (up to 60 joules in a 20 mm disk) have also been applied, producing a detectable shift in the V-I characteristic with asymptotic trends. Most of the changes take place in the first 1 to 10 pulses, while 90 additional pulses produce the shift to decreasing amplitude. The low power ratings reflect a package thermal transfer limitation rather than a basic limitation on the part of the varistor.

Peak current ratings in the case of the larger diameter sizes have been arbitrarily limited due to lack of rating equipment capability. The larger diameter devices have twice the active area of their smaller counterparts. Linearly extrapolating the current rating would yield a figure of 2000 amp in place of the 1250 amp value of the data sheet. Although localized areas of nonuniformity may prevent the use of a linear ratio it appears the 1250 amp value is ultraconservative and will be upgraded in the near future. Likewise, the 7 μsec pulse base width is an arbitrary value limited by the first generation of rating test equipment. There are strong indications that the device may be capable of sustaining rated peak currents for base widths in the 50 to 100 μsec range. The equivalent circuit for the MOV varistor is approximately indicated in Fig. 8. The typical value of capacitance is broken out and characterized in Fig. 9. In addition, the high-frequency properties are of interest and are shown for two production devices in Fig. 10, where resonance with the inductance of the leads becomes apparent. As a point of comparison a fixed point 0.005 μF capacitor is included.

SWITCHING SPEED

Tests have been performed with current pulses of 0.5 nsec rise time, 2 to 250 nsec pulse widths up to 65 amp on devices with 1.4 cm diameter. To perform this test, a disk of MOV material was placed in a low inductance test circuit and a current pulse was applied. Current in the device and voltage across

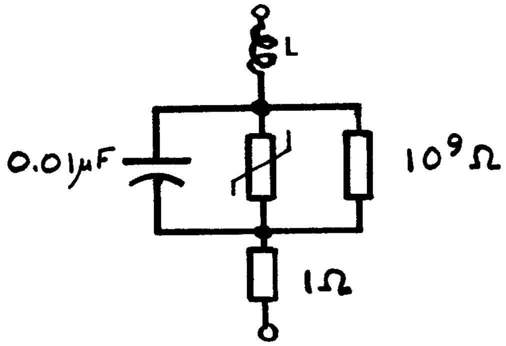


Fig. 8 MOV varistor elementary equivalent circuit.

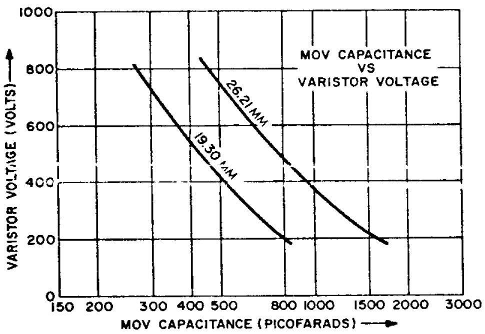


Fig. 9 Typical capacitance.

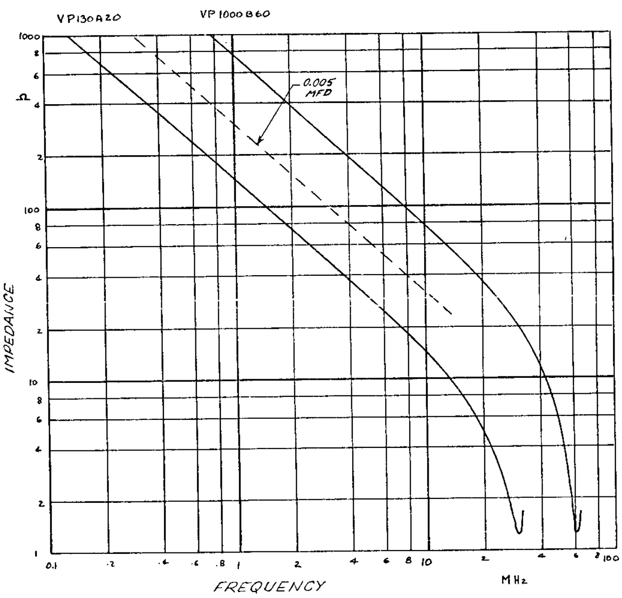


Fig. 10 Typical VP series capacitance.

it were recorded with a high-speed oscilloscope. There does not appear to be a "switching time" nor a dv/dt effect involved. When a fast front voltage surge is applied to the device, its capacitance will immediately make it appear as low impedance and, when the capacitance is fully charged, the device will merely operate at the point corresponding to its V-I characteristic. This is to be compared with some other suppression devices such as spark gaps which possess considerable variation in their protection level depending upon the rate at which the voltage is applied to them.

APPLICATION TO DISTRIBUTION SYSTEM PROBLEMS

Transient surges originate from a variety of sources. Regardless of whether they are operating on AC or DC voltages, the electrical circuits are often plagued by voltage transients that are either generated within the individual circuit or transmitted into the circuit through external sources. With increasing sensitivity of electronic equipment and its widespread application, it is important to understand the nature of such disturbances, their source and effective methods of coping with them in order to achieve satisfactory levels of reliability consistent with the inherent properties of solid-state components. The most common source of transients in a distribution system is the L(di/dt) transient that results from transformer magnetizing currents as they are switched, either within the feeder utility system or within an industrial plant's own distribution system. Another source of concern is due to residual lightning surges. These residual surges can be thought of as the overflow on the main lightning arresters that most consumer, commercial, and industrial distribution systems are protected with at the interface between the utility and the user's distribution systems. Still other sources will be found in homes themselves resulting from equipment that is connected to the utility system. Field exposure over many years and millions of device operating hours produced the following typical data for small synchronous line cord clocks. Refer to Fig. 11. With the development of high-speed continuously monitoring oscilloscopes, pictures of some of this electrical pollution sheds further light on the energy content and duration of such surges. Figure 12(a) shows the results on a log photo of an

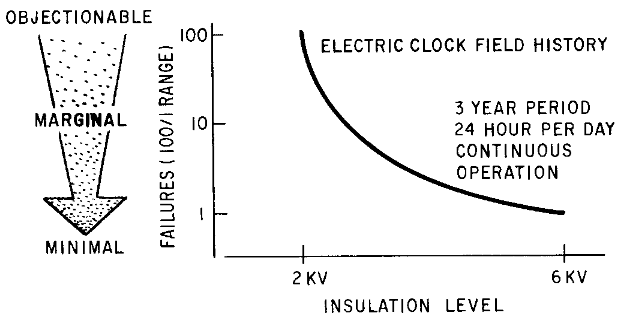


Fig. 11 Electric clock (line operated) field history.

TRANSIENT VOLTAGES IN HOMES

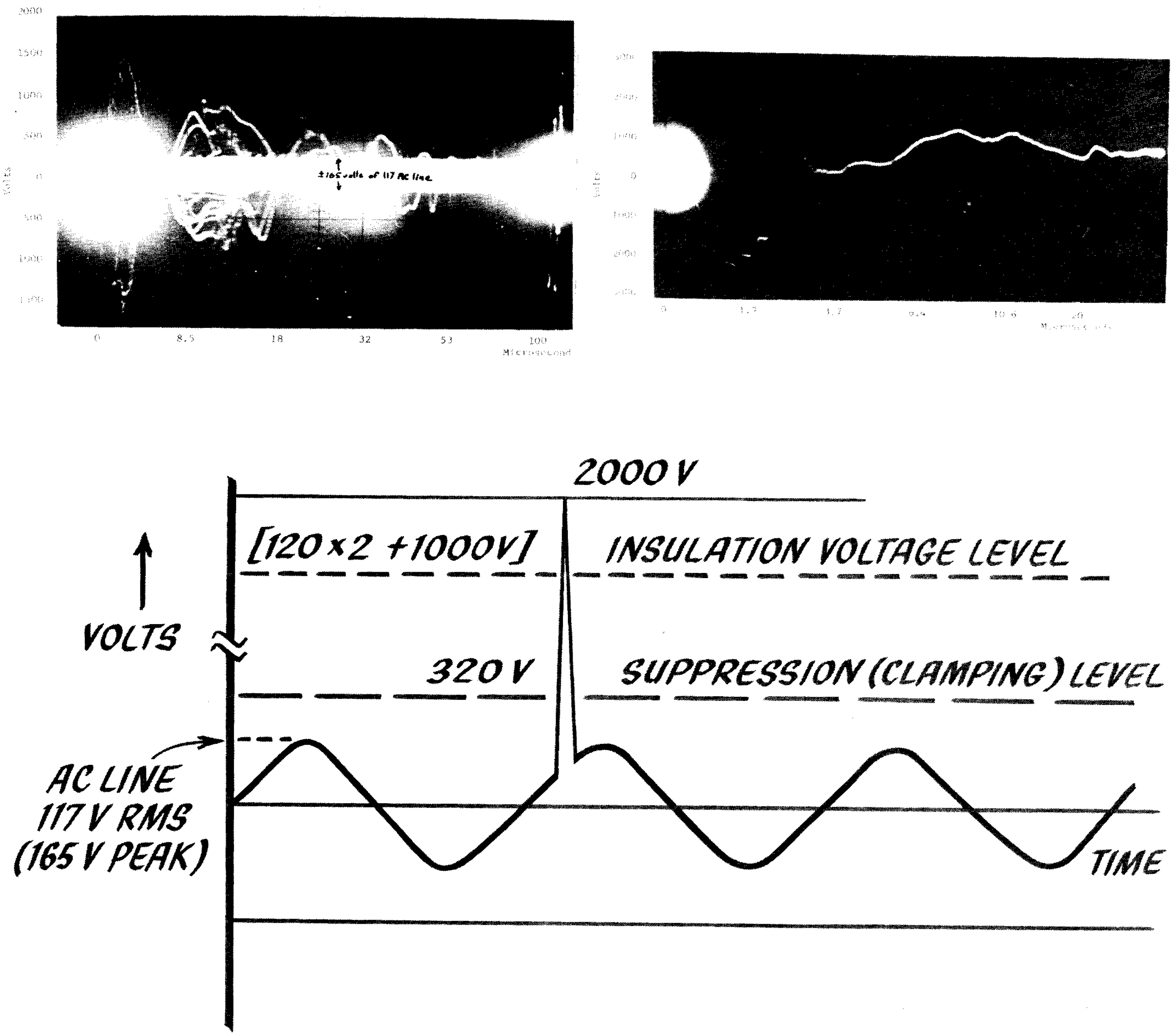
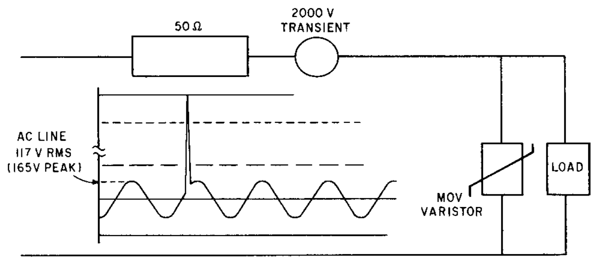


Fig. 12 Transient voltages in homes.

automatic recording camera in a home installation. Notice that there are a number of surges within the time span of this recording, i.e., 24 hours. The bright stripe is the 117 volts which are present at all times, while the transients are a composite of all transients photographed during a 24-hour period. In (b) a single transient is isolated in order to give a clearer view of the oscillatory nature and length of such a disturbance. In (c), reference is made to several levels of electrical voltage level stress. The dotted line indicates the typical practice of insulation design in which twice rated voltage is added to a thousand. It will be noticed that this is really insufficient in view of the oscillograms and data presented previously in Fig. 11 if adequate long-term stability is to be achieved. By incorporating a MOV device, it might be possible to successfully operate at a suppression or clamping level as exhibited by the dashed characteristic. Thus, rather than increasing the over-all insulation requirements to a higher level it would be possible through a coordinated systems design to achieve an improved product.

The surges presented in Fig. 12 are not at all atypical. Indeed, with more automatic switching functions and complex electrical equipment in the home they will be found rather frequently. In fact, the better and newer the wiring and installation, the less protection is inherently provided by spillover occurring in poorly wired outlets, switches, etc., so that there will be an increase in the resulting impressed level on connected equipment. As more and more automatic controls begin to make their way into home applications with the upgrading of heating systems, cooking equipment, air conditioning--not to name the sophisticated electronic entertainment equipment to be found in a typical home. This gives rise to concern on the part of the manufacturer to adequately insure for the user the longevity and satisfaction that he is entitled to.

Thus, the challenge of how to protect and improve "environment" certainly must include the electrical spectrum. The following Fig. 13 very graphically illustrates the importance of the high alpha in order to provide varying degrees of protection. Again, as a matter of convenience, the dotted and dashed bands are superimposed upon the 60 Hz wave with its impressed transient. In case 1 the assumption is made that the varistor shunted across the load in the presence of the 2000-volt transient with a surge impedance of 50 ohms will be protecting at 400-volt level. This will require a steady-state power dissipation in the varistor since it is connected continuously to the 117 volt rms line. For the silicon carbide varistor with a typical alpha of 3, this would result in 600 watts of steady-state dissipation. In many applications, this, of course, would be an unacceptable limitation and penalty on the total equipment. Notice that in the case of the metal oxide varistor with an exponent of ≈30, the dissipation is many orders of magnitude lower and completely satisfactory for such applications. The lower the exponent, the higher will be the power dissipation under steady-state conditions; and conversely the higher the exponent, the lower will become the standby losses. In case 2, each example is shown for steady-state power dissipation of 1 watt in the varistor bodies and the resulting clamping peak voltages.



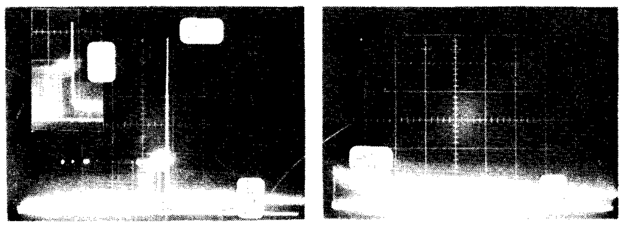
	CASE 1 OBJECTIVE: CLAMP AT 400V	CASE 2 OBJECTIVE: DISSIPATE 1 WATT MAX AT 117 V RMS
	RESULT: STEADY STATE LOSSES AT 117 V RMS-WATTS	RESULT: CLAMPED VOLTS
SiC VARISTOR (α = 3)	600	1950
GE-MOV VARISTOR (α = 20-30)	0.001	320

Fig. 13 Varistor steady state losses.

APPLICATION TO EQUIPMENT PROBLEMS

Arcless Switching

Arcless or black switching commutation can be approached by placing the varistor directly across switch contacts. Where explosive environments may be encountered such as in the oil refinery industry, considerable savings can be achieved by eliminating the threat of an arc-induced explosion. Applications requiring high reliability and long life will want to use the varistor across mechanical contacts for purposes of reducing contact erosion inherent with arcing contacts. This problem is especially acute when operating on DC. The oscillograms in Fig. 14 show recordings of the voltage generated by a snap-acting contact operating from a 90 volt DC supply interrupting an inductive load. With a MOV varistor attached externally to the contact structure, the voltage is virtually that of the varistor, and restriking is greatly reduced, as is of course the magnitude, since it is limited in a very effective manner. This is in direct contrast to the normal situation in which the energy appears as heating of contacts and blades.



(a) (b)

Fig. 14 Snap action contact voltage-time oscillograms (a) no varistor (b) with varistor.

This application will also serve to introduce a new concept of integrated design. Unlike other suppressor components, this new varistor can also serve in a structural mode. Thus, by removing a typical spacer from the switch contacts, it is possible to provide both functions as shown in Fig. 15.

Fig. 15 Integral use of MOV varistor in contact assembly.

Start-up Transients

Because of interwinding capacitance, step-down transformers when switched on can impress severe transients on any connected secondary as shown in Fig. 16. Another sometimes overlooked source of

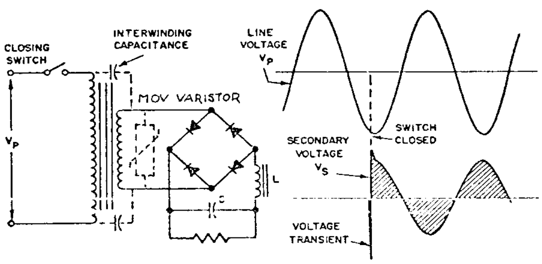


Fig. 16 Voltage transient due to energizing step-down transformers.

component failure can occur in the transistor series pass regulation as shown in Fig. 17. Upon turn-on, the capacitor appears as a short and the transistor is exposed to the full unregulated bus voltage. By placing the MOV varistor across the transistor, it

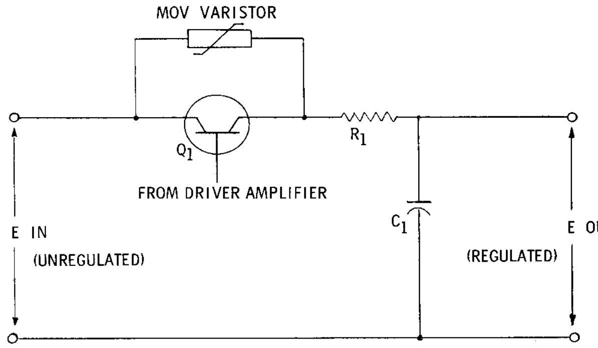


Fig. 17 Start up transient voltage surge protection.

enables the circuit designer to program a soft current rise through the series regulator while avoiding the accompanying voltage surge that would be present during slow charging of C_1 without the varistor. Another example of semiconductor voltage protection shows us the simplification of component count resulting from the improved electrical properties of the metal oxide varistor. The small 117 volt line-operated radio chassis (Fig. 18) requires the use of resistors and capacitors and high-voltage transistors in the output stage in order to successfully stand the voltage spikes which result from distortion under overloading conditions. The oscillogram for the transistor stress with normal resistor and capacitor suppression should be compared with the simplified version and its resulting oscillogram when the MOV alone is used for suppression. Note that the resulting voltage stress on the transistor is reduced to a significantly low value allowing a re-optimization of the transistor and its circuit components. Resulting current through the metal oxide varistor is also indicated.

Protection from Color TV Kinescope Interelement Arcing

Metal oxide varistors can be made rather thick and thus readily applied to high-voltage circuits. Kilovolt (per device) applications should become common in the near future. Such a possible application might be in television sets. At the present time, sparkgaps together with diode clamp circuits are often used for video driver transistor protection. These, however, suffer from sensitivity to moisture and dust and limited life. It is believed that by replacing the gap with a metal oxide varistor improved reliability will result. This is shown schematically in Fig. 19.

Other potential high-voltage applications which can be achieved with increased power handling metal oxide varistor packages include high-voltage stabilization circuits, television vertical and horizontal output limiting and driver protection, microwave oven magnetron protection and x-ray generation control, and high-voltage AC clamping.

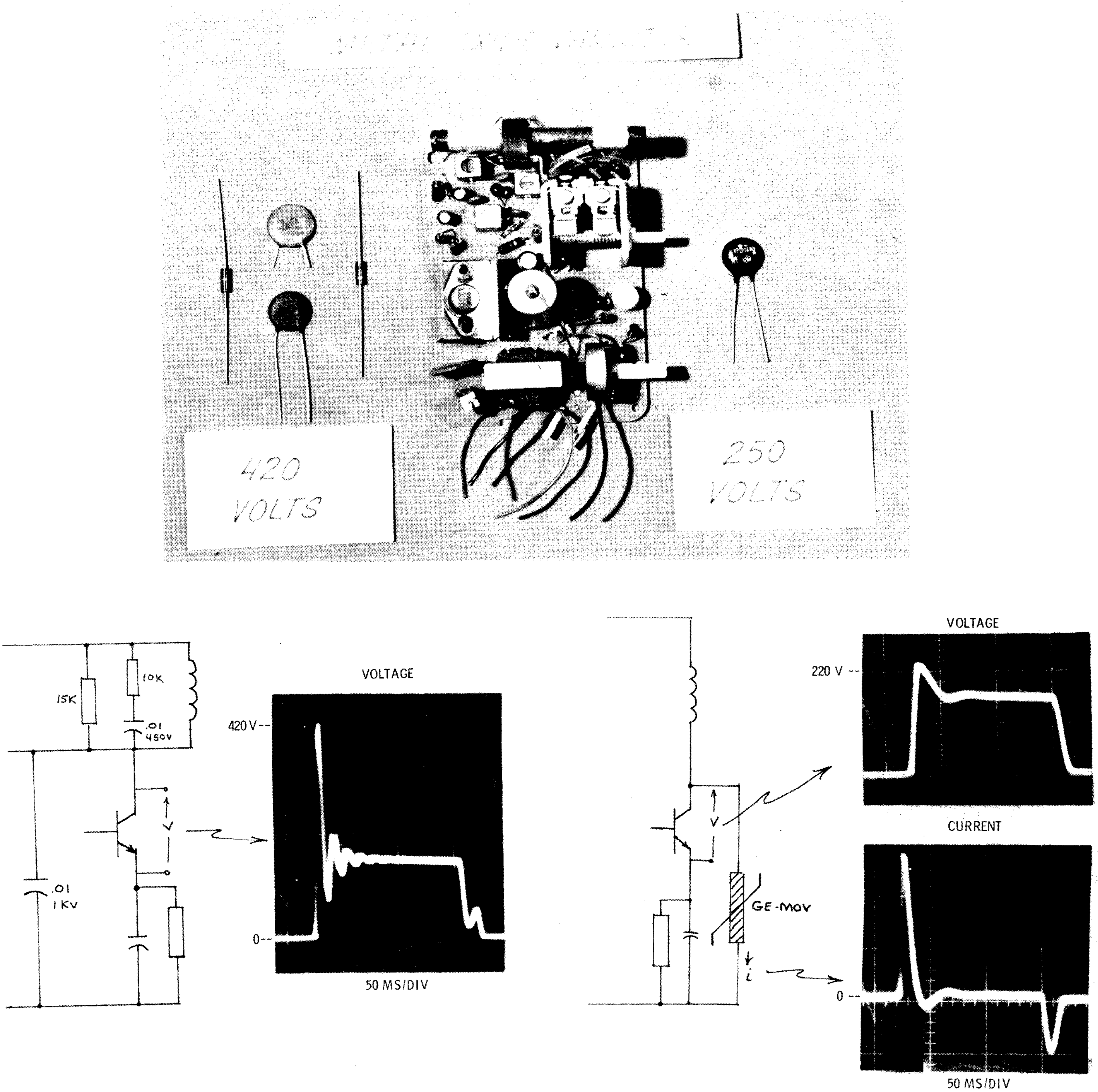


Fig. 18. Application of varistors in A-M receiver.

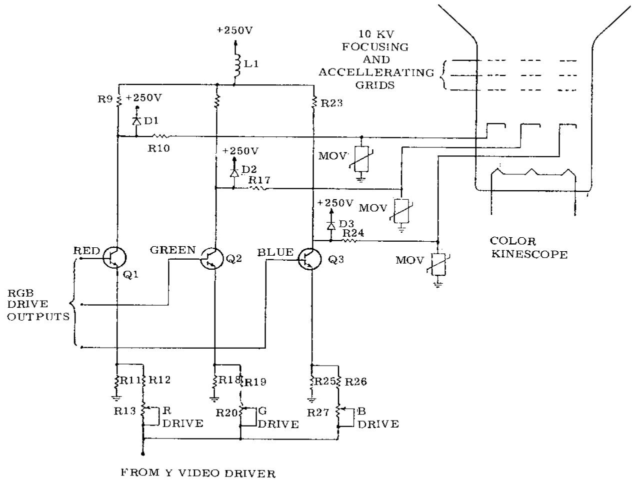


Fig. 19 Color RGB video driver protection from arcing kinescope.

Typical Steps in Selecting a Metal Oxide Varistor

At the present time, devices are available covering a range of voltage from 140 to 1400 and in continuous power ratings from 0. 5 to 1. 3 watts. The following guides will help to illustrate the major considerations in the proper device selection:

Step #1: Consider the normal high-line AC peak terminal voltage to be applied to the MOV varistor. Find the model with the closest higher peak recurrent voltage rating.

Step #2: Determine or estimate the energy level of the transient to be suppressed. This energy level is usually determined by $1/2\ LI^2$ where switching transients are involved. "I" is the peak of the magnetizing current flowing in the inductance "L, " the field of which stores the transient energy. In the case of transformers, "I" may be considered as the peak of the exciting current.

Step #3: Determine or estimate the current level of the transient to be suppressed. From step #2 the peak magnetizing current of feeder transformers, reflected to the secondary, is often used to estimate the peak transient current. From the specification sheet, determine the maximum clamping voltage that can be obtained. If this value is above the required clamping voltage, a special selection will be required.

Step #4: Select the model from the specification sheet that provides the required peak recurrent voltage, maximum clamping voltage, and energy rating. The larger varistors will be needed for the very high energy applications.

Step #5: Check steady-state power dissipation in the case of DC applications. Derate energy rating where power dissipation demands elevate the varistor case temperature beyond 85°C.

Step #6: Where repetitive transients may be encountered, calculate watt-seconds per pulse and multiply by repetition rate to determine added power device must dissipate. Add to steady state idling power of previous step #5.

Step #7: Review ambient environment factors such as operating and storage temperatures to insure compliance within specifications.

HOW DO METAL OXIDE VARISTORS COMPARE WITH OTHER DEVICES?

In Fig. 20 a comparison is presented for selenium and metal oxide varistors. Figure 21 indicates the peak current capability for selenium and metal oxide

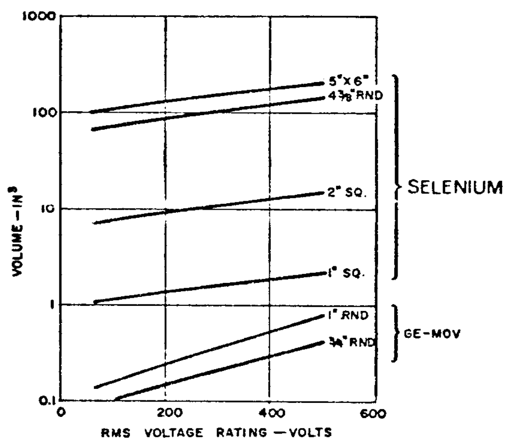


Fig. 20 Suppressor volume requirements.

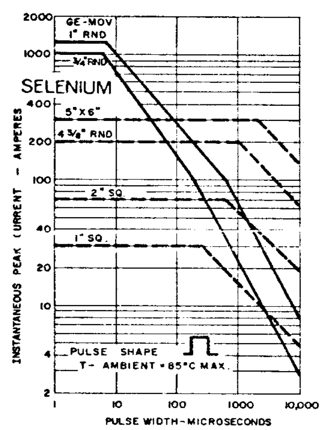


Fig. 21 Suppressor peak current capability.

varistors, while Fig. 22 indicates the surge energy dissipation capability. Figure 23 compares a number of varistor devices including silicon, selenium, silicon carbide, and metal oxide varistor, and as a point of reference a linear ohmic resistor. Figure 24 is a linear plot of some of the same characteristics. While the log plots are to be preferred in most applications, it does represent a somewhat new form of presentation for electronic component users who most

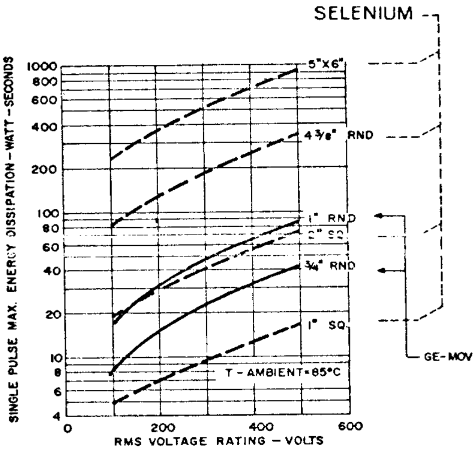


Fig. 22 Suppressor energy dissipation capability.

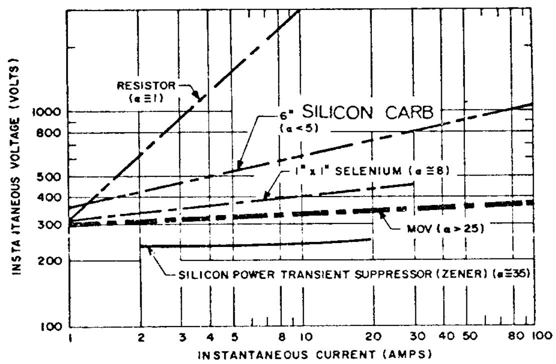


Fig. 23 Log-log volt/amperes characteristics of common voltage suppressors.

usually in the past have been accustomed to using linear scales.

Figure 25 attempts to summarize in tabular form a variety of characteristics for some of the more competitive transient voltage suppressors. The voltage rating shown per device is the peak voltage, so that for rms operation the values are 1.41 lower. This portion of the table is not extirely consistent since many plates are used in a series connection for selenium and packaged as one to achieve higher than single plate voltages, whereas the other data are truely for single units. Series operation of MOV varistors is very practical.

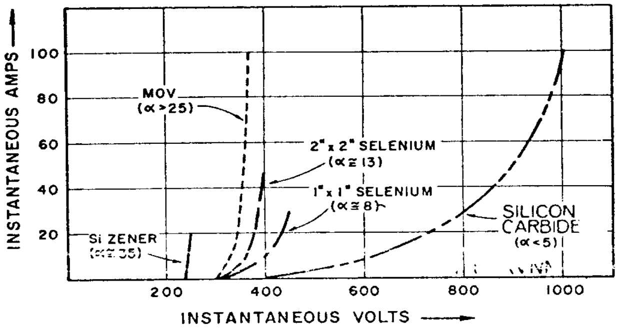


Fig. 24 Linear volt/ampere characteristics of common voltage suppressors.

Transient Suppressor	Peak Idle Current - ma -	Max Current - 1 ms - Amperes	Peak Power - 1 ms - kw	Peak Energy - 1 ms - Joules	Effective Clamping Ratio At 10 Amps	Weight Grams	Cubic Volume cm^3	Commercial Per Device Voltage Range
MOV Varistor (26.21 mm, O.D.)	1	65	18	18	2.0	5	4.4	140 - 1400**
Selenium (25.4 mm, Sq.)	12	30	9	9	2.3	35	20	35 - 700
Zener - Cluster* (38 mm, Sq.)	.05	20	7.7	7.7	1.50	30	24.5	14 - 165
Zener - Single (DO-13 Pkg.)	.005	5.7	1.65	1.65	1.65	1.5	.5	1.8 - 300
Spark Gap (8 mm, O.D.)	-	<100	50	50	2.55 (100 V/μs)	1.5	0.6	150 up

*6 Cells

** 30 - 10,000 In Development

Fig. 25 Comparison of transient voltage suppressors.

FUTURE DEVICE TRENDS

The flexibility of polycrystalline material should allow great versatility in meeting the great needs of the electronic and electrical industries. Mechanical adjustment of thickness by the manufacturer to provide exact voltage is an example. The ability to slice and dice from larger pieces should provide a flexibility in sample and prototype production while machining and shaping open up wide possibilities. A further development of a number of processes beyond the simple and conventional pill press process is very encouraging.

Figure 26 indicates a range of two leaded encapsulated devices covering a range of voltages up to 1400 some of which are typical of the VP series commercially available. Also included in this photograph are samples of higher power and voltage devices which can be achieved through simply increasing the volume of the material.

The next major developments will revolve around package changes for enhanced application versatility and improved heat transfer purposes. Packages will become available that will allow a variety of mounting methods for the equipment

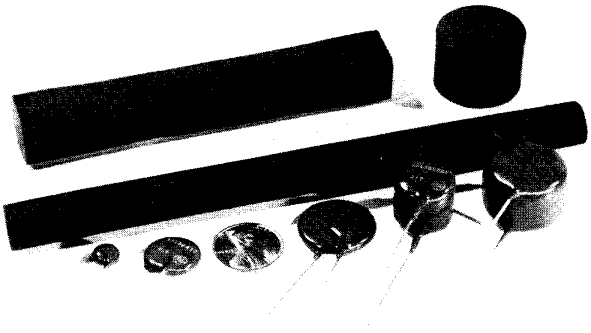


Fig. 26 Lead mounted MOV varistors and bulk varistor material.

designer. Bolt-down capability with and without heat transfer capability is envisioned. This will allow direct fastening to chassis, brackets, bus bars, and heat exchangers. Furthermore, low inductance pill-shaped packages that are compatible with pressure-mounted thyristor packaging are being investigated.

Finned design for direct air convection and forced cooling is very feasible. Initial prototypes a few being shown in Fig. 27 indicate 5 watt dissipation capability at 25° C ambient convection cooled using 1 1/2-inch-square plates and up to 50 watts for stud-mounted, water-cooled units (as with semiconductors electrical isolation can also be introduced into the package). The degree to which the application requires improved transient rating versus steady-state rating will, of course, influence the success of an individual approach.

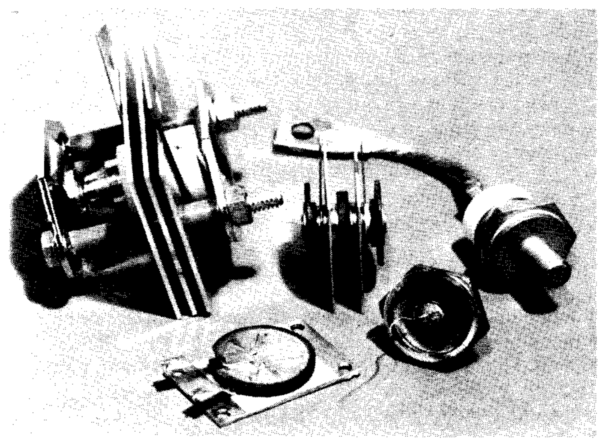


Fig. 27 Experimental higher power finned devices.

As mentioned earlier, increasing the heat dissipating capability of the metal oxide varistor substantially improve the effective electrical characteristics by changing the effective clamping ratio. This is accomplished by increasing the design maximum peak idle current. When the idle current is increased the clamping ratio is decreased. For a single device the exact value of the decrease in clamping ratio for a fixed level of peak suppression current can be determined by referring to Fig. 6. For example, assuming an alpha of 25 and a 1 ma peak idling current, the clamping ratio of 10 amp is 1.45. Changing the idling current by a decade to 10 ma results in a clamping ratio of 1.32 at the same peak current of 10 amp.

Beyond package improvements, the future holds promise of having varistors with alphas exceeding 35. Low-voltage processes (under 100 volts) should make them attractive for transportation and signal circuitry applications.

CONCLUSIONS

These developments coupled with the device's extraordinary speed should now allow the solution of many of the difficult problems of voltage control in the nanosecond and kilowatt area. A few applications have been cited by way of illustration, but knowingly to the exclusion of many others of interest such as semiconductor snubber networks, and storage recovery transients, industrial control circuits, instrumentation, and communications. The appended bibiography should be of keen interest in this regard.

It is becoming increasingly clear that the new metal oxide varistor is a valuable addition to the power conditioning design engineers tool kit. Its high-energy absorption capability coupled with tight clamping ratios make it a superior transient suppressor. High-voltage stabilization requirements may also be met, using the metal oxide varistor, as future packaging and higher alphas evolve. Commercially, it is expected that the market for these new polycrystalline semiconductors will amount to between $20 to $30 million within 5 years.

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