Evaluation of commercial surge suppressors

François Martzloff
General Electric Company
Schenectady NY

Reprint, with permission, of declassified *GE Report 67-C-06*

Significance
Part 7 – Protection Techniques

While all the “commercial surge suppressors” evaluated in the original 1963 report have most likely disappeared from the market, this report provides some historical perspective on the intense quest for effective “suppression” of the transient overvoltages occurring in AC power circuits, transients that were belatedly identified as the cause of the in-field failures of the novel solid-state devices that were being introduced at that time.

Nine available candidate commercial surge suppressors had been secured and subjected to breakdown or turn-on tests in order to compare their performance. Gap types exhibited the expected volt-time lag characteristics with or without self-clearing, while semiconductor types offered fast turn-on, but no self-clearing.

Quote from the report: *“There is a definite need to develop and promote a less expensive surge suppressor, which could receive more acceptance than the devices covered in this report.”*

Historical Notes:

1. This report was formerly issued as GE ATL TIS Report.64GL174 (work performed in 1963).
2. Some devices were priced over $8.00 (1963 dollars), severely restricting their application.
3. Some other early sixties GE reports on related subjects are cited in this report, which are no longer available but certainly represent obsolete information. The present report is sufficient for the purpose of giving a historical perspective on the quest for a solution to the problerms of translents-related field failures.
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GENERAL ELECTRIC

RESEARCH AND DEVELOPMENT CENTER

SCHENECTADY, NEW YORK

TECHNICAL INFORMATION SERIES

AUTHOR	SUBJECT	NO.
Martzloff, FD	surge suppressors	67-C-067
		DATE March 1967
TITLE Evaluation of Commercial Surge Suppressors		G.E. CLASS 2
		GOVT. CLASS -
ADDITIONAL COPIES AVAILABLE AT Distribution Unit, Bldg. 5, Room 345, Research and Development Center, P.O. Box 8, Schenectady, New York 12301		NO. PAGES 39

SUMMARY

Nine commercial surge suppressors have been secured and subjected to breakdown or turn-on tests in order to compare their performance.

Gap types exhibit the expected volt-time lag characteristics with or without self-clearing, while semiconductor types offer fast turn-on, but no self-clearing.

Most devices are priced above $8, which severely restricts their application.

There is a definite need to develop and promote a less expensive surge suppressor, which could receive more acceptance than the devices covered in this report.

This report was formerly issued as Advanced Technology Laboratories Rept. No. 64GL174.

KEY WORDS

overvoltages, transients, surges, gaps, arresters, suppressors

INFORMATION PREPARED FOR:

Electronic Physics Laboratory

Table of Contents

Introduction

A number of surge suppressors which were advertised in the trade magazines were purchased for a limited evaluation of their performance. In the course of attempting to order several of these, it was found that some of the companies advertising these devices had either dropped the line or gone out of business altogether.

Furthermore, in the course of discussing device performance or availability with representatives from companies still offering devices for sale, a distinct impression was gathered that these devices did not meet the acceptance which their makers had expected. This is not too surprizing in view of the prices which were quoted, even for volume purchasing.

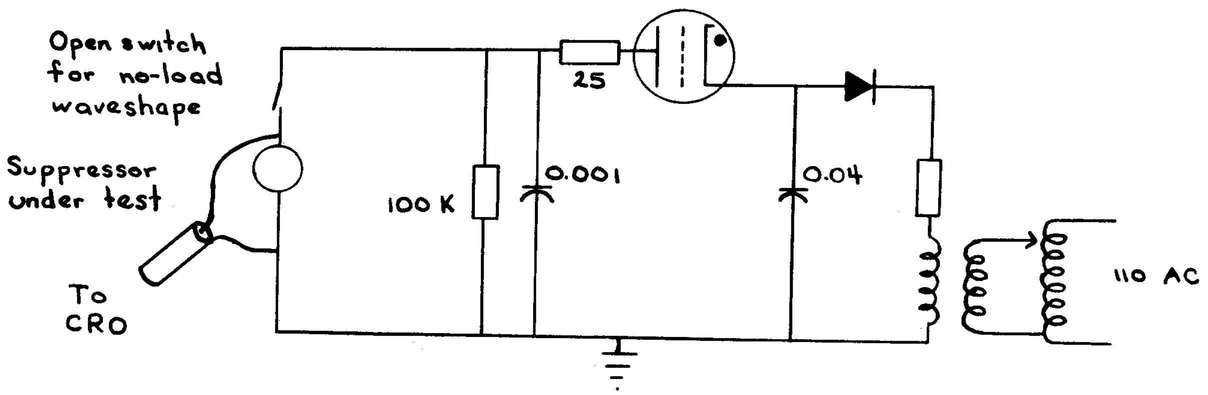
In some cases, rather fundamental questions such as the existence of a volt-time characteristic for the breakdown seemed rather startling to the company representative who answered the telephone inquiry, although he allegedly was a technical representative. Others, on the other hand, gave the impression of being quite sophisticated in this technology.

Those devices which could be purchased were subjected to a consistent test for volt-time characteristic, which was the most conspicuously absent data from manufacturers' specifications. Other characteristics are generally well defined in the manufacturers specification sheets, which are reproduced in this report when available.

The test circuit, consisting of a capacitor discharge circuit, is shown on the following page.

All the devices which were tested are covered in separate sections of this report, grouping manufacturers specifications if any, general description, typical performance oscillograms and a brief discussion of the device capabilities.

References are also made to other devices which were previously tested and reviewed in this program.


Open switch
for no-load
waveshape
Suppressor
under test
To
CRO
100 K
0.001
25
0.04
110 AC

Test Results and Discussion

The detailed performance results will be found in separate sections which follow. For the purpose of presenting a general comparison, the most significant characteristics are tabulated below, including the Thyrector and Westinghouse device which were investigated in earlier reports.

Manufacturer and Type	Type of Device	Ratio of 0.1 μs breakdown to min. breakdown	Permissible Dissipation	Self Clearing	Typical Price $
GE 730B Gap	Gap	160%	4 to 5 ωsec.	No	8 to 16
Cerberus UA1	Gap	250%	2000 amp.	No	2
EG&G Fenotron	Gap	Not defined	3000 amp.	No	5
Dale LA9	Gap	600%	300 amp.	Yes	15
Bell	Gap	140%	?	No	Not av.
Westinghouse AP*	Gap & Varistor	over 400%	1500 amp (?)	Yes	2 to 3
Mark I SCP	Solid State	Turn on in 40 ns	150	No	12
TI Klixon	Solid State & Breaker	Turn on in 60 ns	?	Yes	18
Dressen-Barnes	Solid State	Turn on in 90 ns	100 amp.	No	14
Hunt SSS	Solid State	Turn on in 50 ns	100 amp. (?)	No	2
Thyrector*	nonlinear Solid State	No time lag	5 to 100 amp.	Yes	.75 to 5

The gaps are characterized by their volt time performance; some are quite successful in producing a "flat" curve, i.e., the breakdown voltage at short times (0.1 μs) is not a large multiple of the breakdown voltage at DC. The Dale device has combined an interesting arc-interrupting feature, which has not been

*See TIS 64GL118 and references

investigated, however. On the other hand, this Dale gap has the worst volt-time characteristic. The General Electric series 730B gaps exhibit a relatively flat characteristic which make them quite attractive. The Westinghouse device, although self-clearing, was found to have questionable reliability, and also has a poor volt-time characteristic.*

Semiconductor devices are generally characterized by a fast turn-on time, which appears to be practically independent of the surge voltage. With increasing steepness of the applied surge, this means that an increasing voltage peak will be allowed to exist for a short time, while for surges with rise times longer than 0.1 μs, the clipping effect of the device will be near perfect. On the other hand, all these devices are latching. The Klixon is combined with a circuit breaker which will interrupt the power follow current (as well as overloads), with the corresponding added cost. The Dressen-Barnes and Mark I packages do not seem to offer for $14 any more features than the $2 Hunt device with the exception of a wide range of turn-on voltages. On the other hand, the Hunt device is not polarized and it is conceivable that it could be obtained, by selective grading, in a wide range of turn on-voltages.

The Thyrector and other non-linear semiconductors (Zener diodes or selenium plates) offer interesting characteristics which were discussed earlier.*

RC networks are also effective surge suppressors, but their performance is intimately tied to the circuit parameters of the system in which they are applied. Under some circumstances, they can produce system oscillations so thatcaution is required in their use, while the other devices discussed here generally can be added to the system without unexpected interaction.

*See TIS 64GL118 and references

Conclusions

The devices now offered for sale fall within two categories: gaps, with or without associated arc-extinguishing features, and semiconductor devices.

Gaps exhibit their typical time-lag characteristic. Some designs appear more successful than others in reducing this undesirable limitation.

Semiconductor suppressors have fast turn-on characteristics, often with no volt-time effect but rather with a constant time to turn-on. Their price is generally higher and not within attractive ranges for consumer type appliances.

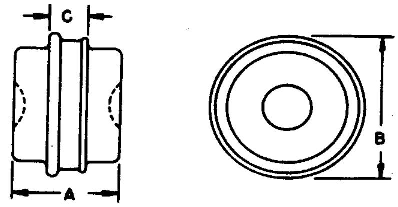
A number of firms which at one time advertised a line of suppressors have either dropped the line or gone out of business. indicating the difficulty of marketing suppressor components at the present prices. This indicates that there is a need to develop a low price suppressor.

References

Other devices than those reported here have been discussed in earlier reports written for this Program. These devices include:

	Reference
Bendix Gap Cat TG98	TIS 62GL191
W Lightning Arrester Cat 632A189A01	"
GE Signal Arrester Cat 9LA4C4	"
GE Secondary Arrester Cat 9L15CCB001	"
Ledex Transient Control A-46800-001	"
Amperex Gap Cat 4369	"
Hunt SSS 5 Layer Switch	63GL97, 64GL118
GE DIAC	63GL197
W Appliance Lightning Protector	64GL118
GE Thyrectors	63GL97, 63GL144, 64GL118 Also, see RCD application note 200.5; section 180, RCD spec. sheets.

SERIES 730B SPARK GAPS
WITH STAINLESS STEEL OR TUNGSTEN ELECTRODES



For A, B and C Dimensions—See Reverse Side

Rating:	60 Cycle Peak Breakdown Voltage from 250 Volts to 6000 Volts—to Customer Specification. (See Reverse Side)
Underwriters' and C.S.A. Listings:	Suitability of Application Applies.

FEATURES

Small in size the sealed breakdown gaps protect costly electronic equipment over a large range of voltage conditions.

The gaps are hermetically sealed—unaffected by humidity, atmospheric conditions, or foreign particles.

Stainless steel electrodes are for normal applications. Tungsten electrodes available for heavy duty applications.

Device acts as an open circuit switch, until the rated voltage is exceeded, at which time the gap breaks down, providing an energy dissipating path to an appropriate source. It thus prevents excess voltage from building up on electrical equipment connected to the circuit following the gap.

Arc is broken in arc suppressing gas.

Application: Where any transient voltage protection is required for the electrical safety of units such as costly condensers, transformers, tubes and other electrical equipment.

By use of such a protective device, other components may be utilized at maximum ratings at their smallest size.

Stainless steel electrode gaps can tolerate continuous discharge of 4 watt seconds of energy. A similar figure for Tungsten gaps is 25 watts.

ALL DATA SUBJECT TO CHANGE WITHOUT NOTICE.

GENERAL ELECTRIC

SERIES 730B—SPARK GAPS—DETAILED DATA

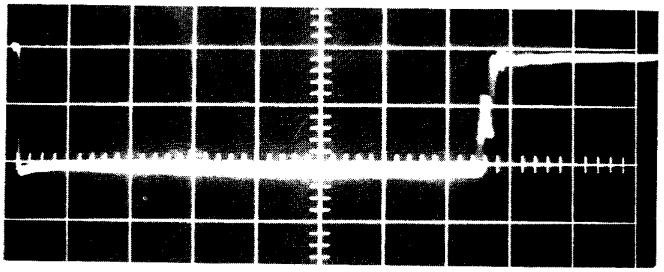
CATALOG NO.	VOLTAGE	DIMENSIONS A (Max.)	B (Max.)	C (Approx)
	STAINLESS STEEL ELECTRODE			
95X713	250 ~ 600	.515	57/64	1/8
95X712	325 ± 175	.515	57/64	1/8
95X932	450 ± 100	.515	57/64	1/8
95X612	500 ± 100	.515	57/64	1/8
503X42	600 ± 100	.515	57/64	1/8
503X43	700 ± 100	.515	57/64	1/8
95X446	1200 ± 120	.515	57/64	1/8
503X93	1500 ± 150	.515	57/64	1/8
503X73	1960 ± 460	.620	1"	1/4
95X606	2200 ± 220	.620	1"	1/4
95X711	2500 ± 500	.650	1"	1/4
504X66	2600 ± 400	.650	1"	1/4
95X714	3000 + 500 − 100	.650	1"	1/4
503X47	3250 ± 165	.687	1"	1/4
504X67	3400 ± 200	.650	1"	1/4
503X48	4000 ± 400	.687	1"	1/4
AG4300-01	4300 ± 430	.687	1"	1/4
503X49	4500 ± 450	.687	1"	1/4
503X50	5000 ± 500	.687	1"	1/4
95X981	6000 ± 1200	.687	1"	1/4
	TUNGSTEN ELECTRODE			
503X66	500 ± 100	.515	57/64	1/8
AG600-02	600 ± 60	.515	57/64	1/8
AG700-02	700 ± 100	.515	57/64	1/8
AG750-02	750 ± 75	.515	57/64	1/8
503X64	1200 ± 120	.515	57/64	1/8
503X86	1300 ± 100	.515	57/64	1/8
504X2	1400 ± 100	.515	57/64	1/8
AG1500-02	1500 ± 150	.520	57/64	1/8
503X65	2200 ± 220	.620	1"	1/4
AG2278-02	2278 ± 228	.620	1"	1/4
505X48	2450 ± 245	.620	1"	1/4
AG3000-02	3000 + 500 − 100	.650	1"	1/4
AG4300-02	4300 ± 430	.687	1"	1/4
AG6000-02	6000 ± 1200	.687	1"	1/4

ALL DATA SUBJECT TO CHANGE WITHOUT NOTICE.

GENERAL ELECTRIC

GENERAL ELECTRIC SERIES 730B SPARK GAP

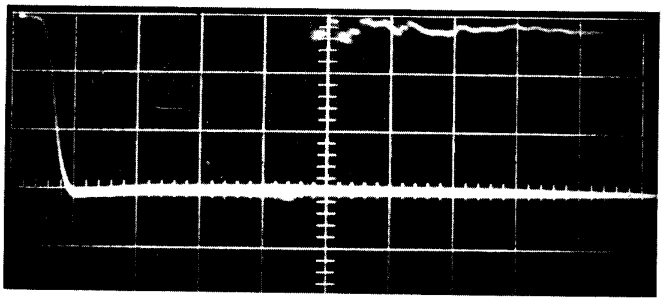
Manufacturer:	Accessory Equipment & Wiring Device Departments
Specifications:	See AE-7305 sheets reproduced on opposite page
Device principle:	Hydrogen-filled gap, stainless steel or tungsten electrodes
Available voltage ratings:	250 to 6000 volts
Permissible surge current:	Not specified--Total permissible energy per discharge is 4 watts-sec. for stainless steel and 25 watts-sec. for tungsten
Will interrupt power follow current:	No
December 1964 price:	Stainless steel \$8 to \$9 depending on quantities Tungsten \$16 to \$17 depending on quantities



1100 volts applied surge

Breakdown in 7 μs

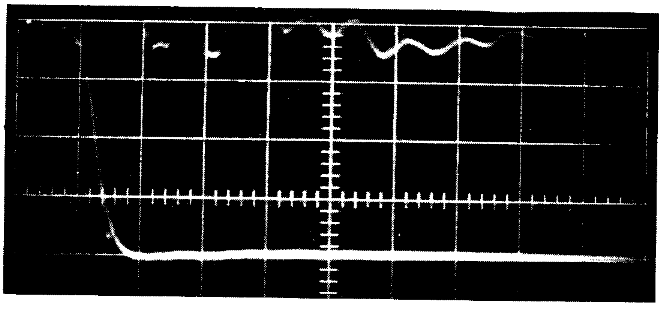
500 volts/div.
1.0 μs/div.



1500 volts applied surge

Breakdown in 800 ns

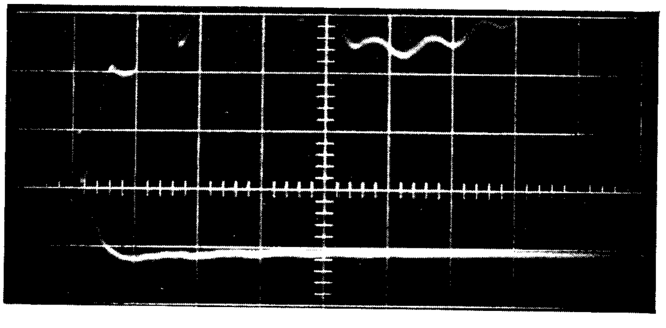
500 volts/div.
0.2 μs/div.



2000 volts applied surge

Breakdown in 80 ns
with 1800 volts peak

500 volts/div.
0.1 μs/div.



4000 volts applied surge

Breakdown in 30 ns
with 2900 volts peak

1000 volts/div.
0.1 μs div.

Performance of 500 volts GE Gap

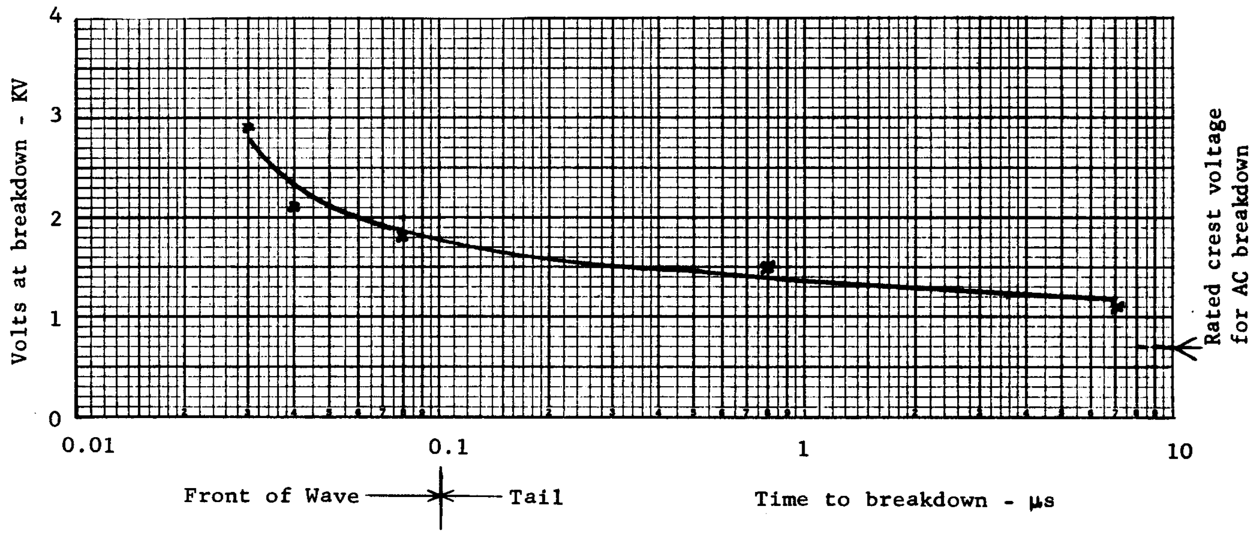
Oscillograms showing applied surge with and without gap

Performance of the GE Gap

The volt-time characteristic of a 500 volt gap is plotted below; typical oscillograms shown on the opposite page were recorded during tests for plotting this characteristic.

The discharge capacity is stated as "continuous" 4 watt-seconds or 25 watt-seconds, which is somewhat ambiguous as a watt-second rating would rather imply a discrete total energy than a continuous rating. Actually, what is meant is that a number of single discharges at these energy levels may be applied without changing the breakdown characteristics.

In spite of the statement "arc is broken in arc suppressing gas", the device is not self cleaning.



No breakdown could be produced with a single shot impulse below 1100 volts, however the breakdown voltage at 60 cps is 500 volts (crest).

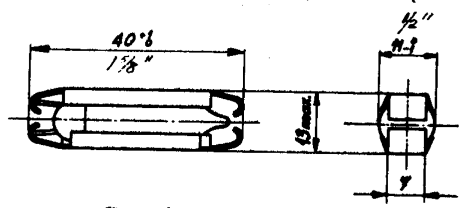
The 0.1 μs breakdown is 160% of the minimum breakdown voltage.

AMARK CORPORATION

129-11 18th AVENUE • COLLEGE POINT, N. Y. 11356
TELEPHONE 212-762-1400
CABLE: AMARKCORP NEW YORK

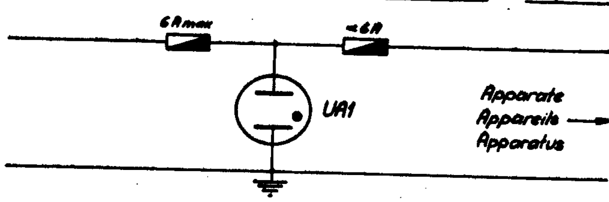
CERBERUS	UEBERSPANNUNGSABLEITER UA 1 TUBE PARA - SURTENSION UA 1 SURGE ARRESTER UA 1	Type UA 1 Nr. 2.16.12 DFE Ed. 1.66 Fol.

Edelgasgefüllter Ueberspannungsableiter mit kleiner Stoss-Ansprechspannung.
Tube para-surtension à basse tension d'amorçage.
Rare gas filled surge arrester with especially low response time.



Technische Daten	Données techniques	Technical data
Zündspannung (stat. Ansprechspannung) Tension d'amorçage statique Static Breakdown voltage		220 - 270 V=
Stoss-Ansprechspannung (Spannungsstoss mit 2 kV µs Anstieg) Tension d'amorçage au choc (Front du choc : 2 kV / µs) Dynamic breakdown voltage (Voltage rising with 2 kV / µs)		650 V
Belastbarkeit Charge admisible Load		2 kA (50 µs) 10 A (1 s)
Isolation bei 60 V= Isolation à 60 V= Insulation at 60 V=		min. 1000 MΩ

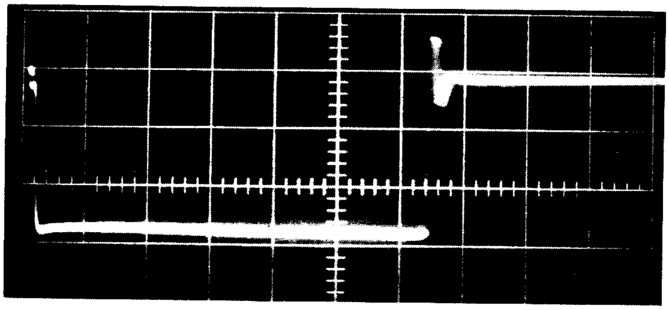
Typisches Anwendungsbeispiel: Application typique: Typical application:



Montage: Montage: Mounting:	In jeder Lage en tout position any position
Anwendungsgebiet:	Schutz von Schwachstromanlagen und -Kabeln gegen Ueberspannungen (Blitzschlag, atmosphärische Aufladungen, Kontakt mit Hochspannungsleitungen etc.)
Applications:	Protection d'installations à courant faible et de câbles contre les surtensions (foudre, surtensions atmosphériques, contact avec des lignes de haute tension.)
Applications:	Protection of low-current installations and cables against overvoltages lightning, atmospheric,overvoltages, etc.)

CERBERUS UA1 SURGE ARRESTER

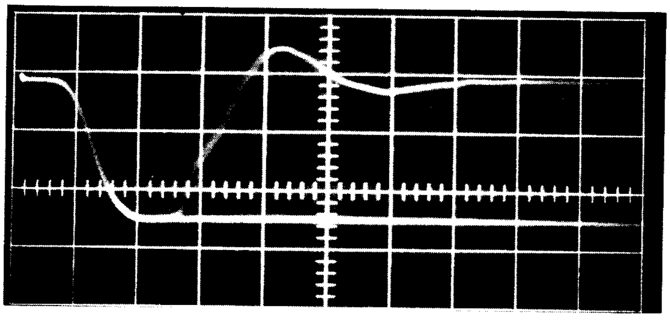
Manufacturer's Distributor:	AMARK Corporation
Specifications:	See manufacturer's data sheet opposite page
Device principle:	Rare gas filled gap
Available voltage rating:	One rating, 220 - 270 V DC
Permissible surge current:	2000A (50 μs) 10A (1 sec)
Will interrupt power follow current:	No
December 1964 price:	\$2.44 each 25-49 \$1.95 each 100-up



280 volts applied surge

Breakdown in 6 μs

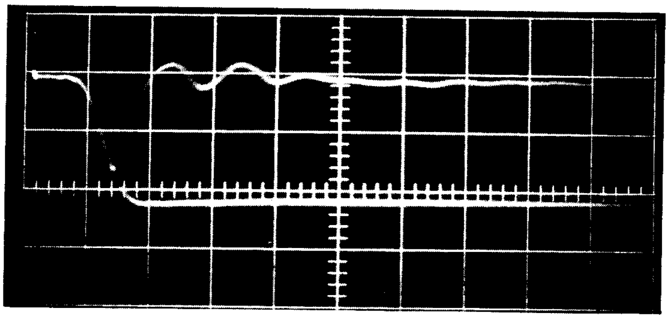
100 volts/div.
1.0 μs/div.



500 volts applied surge

Breakdown in 150 ns

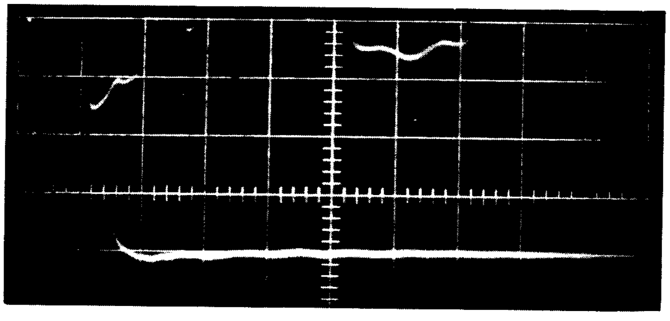
200 volts/div.
0.1 μs/div.



1100 volts applied surge

Breakdown in 50 ns at 800 volts

500 volts/div.
0.1 μs/div.



4000 volts applied surge

Breakdown in 30 ns at 1500 volts

1000 volts/div.
0.1 μs/div.

Performance of CERBERUS Gap

Oscillograms showing applied surge with and without gap

Performance of UA1 Arrester

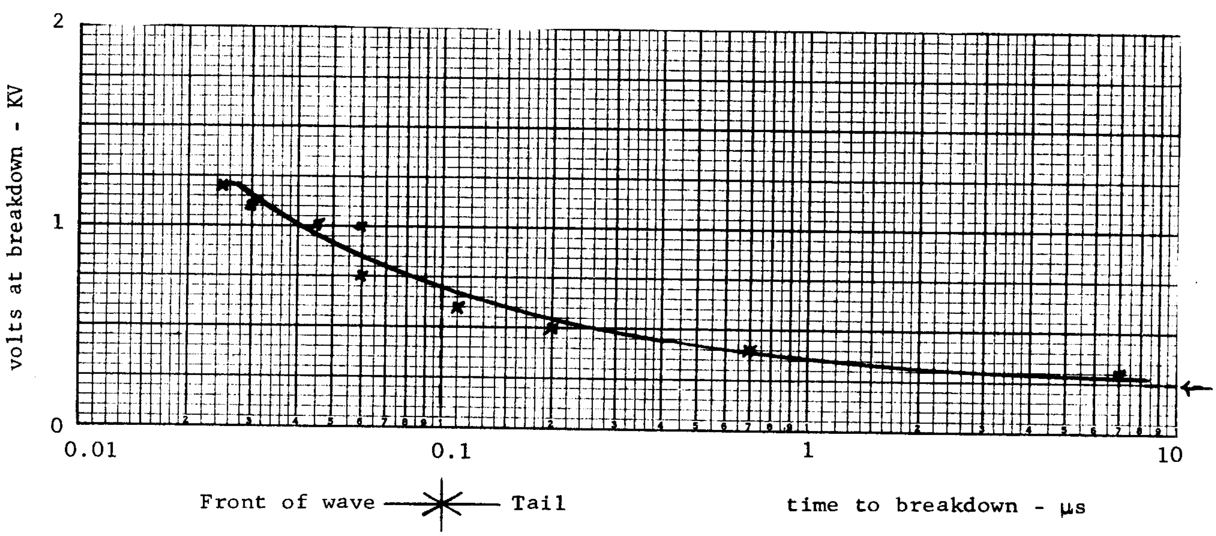
The device exhibits the typical gap breakdown characteristic, i.e., rising breakdown voltages at short times.

Typical oscillograms recorded during tests performed for plotting this volt-time characteristics are shown on the opposite page.

The current discharge capacity for relatively long pulse duration (50 µs) is substantial, but only one breakdown voltage rating is offered, so that the device is not very flexible.

Furthermore, the device is not self-clearing, so that power follow current will have to be interrupted by other means such as fuses or circuit breakers.

The volt time curve of the device is plotted below.



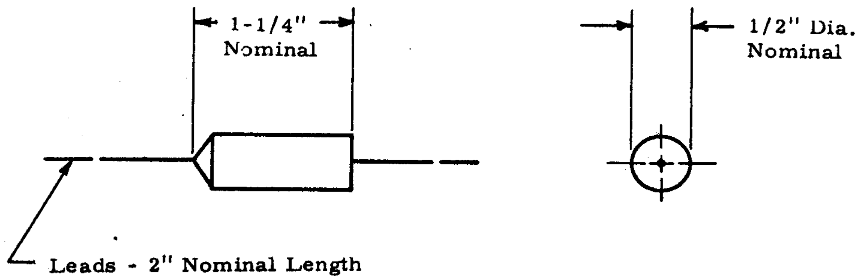
There is good agreement between the test point and the manufacturer's specified breakdown levels. The 0.1 µs breakdown voltage is 250% of the minimum breakdown voltage.

Data Sheet #011
Tentative

FENOTRON*

High Voltage Spark Gap for Protecting

Silicon Diode Stacks from Over-Voltage



The Fenotron is an encapsulated, miniature, high voltage protective spark gap. The Fenotron's dependability and long-life make it especially suited for use in protecting silicon stacks from over-voltage. The device is a reliable, fast switching (40 nanoseconds) spark gap requiring no keep-alive voltage or trigger voltage. It operates at 800 V minimum with a voltage pulse rise time of 100 kv/usec with 3000 amperes maximum peak current switching capability.

A typical application for Fenotrons is to protect silicon diode stacks used in clamping a trigger input voltage for Traveling Wave Tubes. Life of thousands of operations has already been realized.

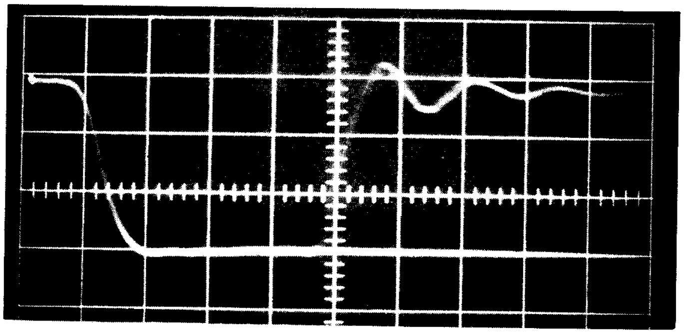
*EG&G Trade Mark

EDGERTON, GERMESHAUSEN & GRIER, INC.
160 Brookline Avenue Boston 15, Mass.
COpley 7-9700

3-13-63

EG&G FENOTRON

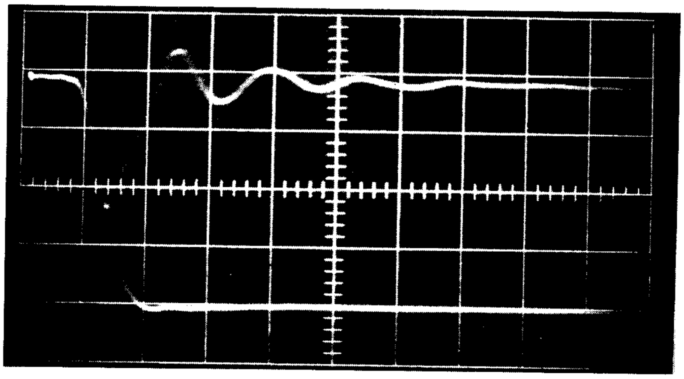
Manufacturer	Edgerton, Germeshausen and Grier, Inc.
Specifications	See tentative data sheet on next page.
Device principle	Sealed gap, flat brass electrodes with ceramic spacer.
Available voltage rating	One rating, not specified in terms of steady-state
Permissible surge current	3000 ampere crest
Will interrupt power follow current	No
December 1964 prices	$25 for samples - no large orders accepted at this time. Manufacturer estimated $5 for quantities if production were to start



1500 volts applied surge

Breakdown in 400 ns

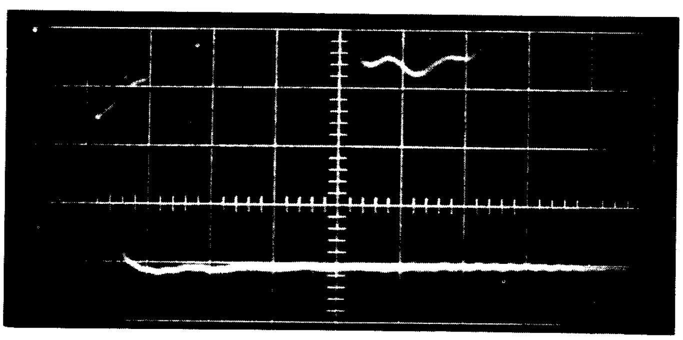
500 volts/div.
0.1 μs/div.



2000 volts applied surge

Breakdown in 50 ns at 1100 volts

500 volts/div.
0.1 μs/div.



4000 volts applied surge

Breakdown in 30 ns at 1500 volts

1000 volts/div.
0.1 μs/div.

Performance of EGG Fenotron Suppressor

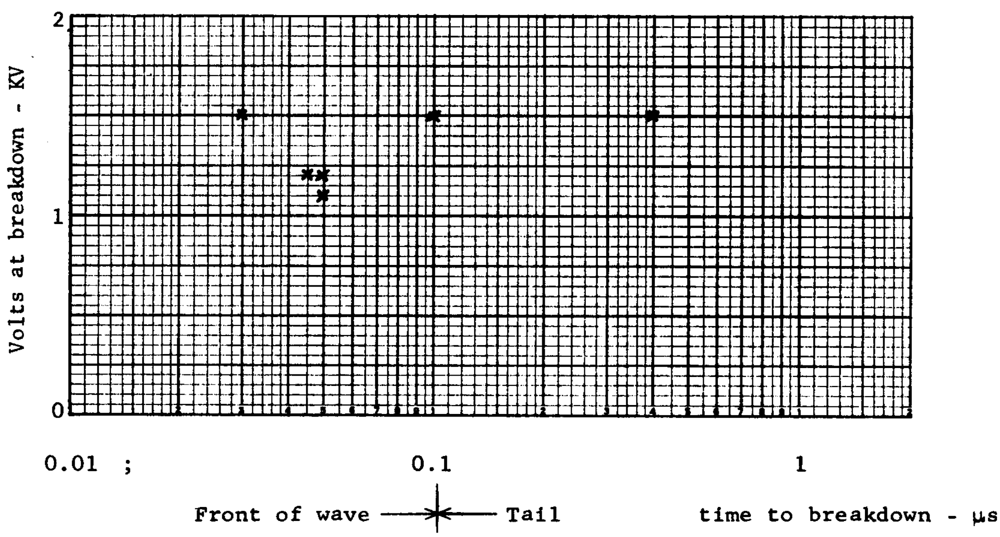
Oscillograms showing applied surge with and without suppressor

Performance of Fenotron Gap

No breakdown could be produced below 1500 volts applied surge; however, as the crest of the surge was raised, so that the front of the wave was steeper, breakdown occurred as low as 1100 volts. This particular point was obtained with a 20 KV/μs rise time (second oscillogram). With 40 KV/μs (third oscillogram), a step closer to the 100 KV/μs quoted on the data sheet as producing a "800 volt minimum" breakdown, the actual voltage at breakdown was 1500 volts.

From the size of the electrodes, the current discharge ability seems rather limited, therefore the quoted 3000 amperes must be of rather short duration.

Typical oscillograms are shown on the opposite page. Test points are plotted below; there is no apparent volt-time trend in these points and they do not correspond to the manufacturer's claims.



Better things in smaller packages

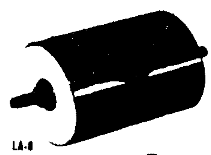
DALE

SURGE ARRESTERS

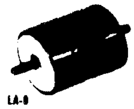
SURGE ARRESTERS DALE TYPES LA-8 and LA-9

SURGE ARRESTERS

This device has a very significant application in power supplies to protect silicon rectifiers. In addition, the same protection is afforded underground cables and other devices where transient voltages are a problem.



LA-8

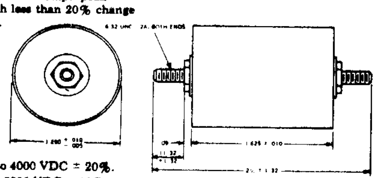


LA-9

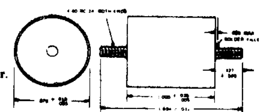
INSULATION RESISTANCE: In excess of 1000 megohms and will not drop below 10 megohms during or after rated number of current surges.

CURRENT SURGE BY-PASS CAPABILITY:
LA-8—Will by-pass 10 current surges consisting of a current rising to peak of 15,000 amps. in 5 microseconds and containing a total charge of 21 coulombs without damage to the arrester or equipment attached and with less than 20% change in the original DC breakdown voltage.
LA-9—Will by-pass 100 current surges of 300 amps. peak with 2 x 4 millisecond wave shape with less than 20% change in the original DC breakdown voltage.

SEAL:
LA-8—Enclosed and dustproof, but not hermetically sealed.
LA-9—Hermetically sealed with soft solder with a melting point in excess of 220° C.

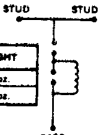


SPARK GAP ARC-OVER VOLTAGE:
LA-8—Factory adjustable from 1500 to 4000 VDC ± 20%.
LA-9—Factory adjustable from 500 to 5000 VDC ± 20%.
(Available with 10% tolerance at slight additional cost.)



MOUNTING:
LA-8—May be mounted in any position. Wires can be soldered directly to the case with 60/40 or 63/37 alloy solder.
LA-9—May be mounted in any position. Recommended mounting clip: Atlas E-E Clip #100-200-12A-13. Where very heavy by-pass current may be encountered, wires can be soldered directly to the case with 60/40 or 63/37 alloy solder.

Bulletin R-74T



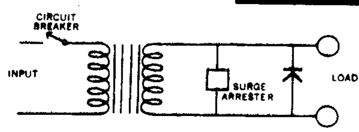
SPECIFICATIONS AND NOMINAL DIMENSIONS

	OUTSIDE LENGTH	BODY LENGTH	DIAMETER	SHUNT CAPACITY	WEIGHT
LA-8	2½"	1.625"	1¼"	7.5 MMFD	4 oz.
LA-9	1⅝"	1"	⅞"	3.5 MMFD	2 oz.

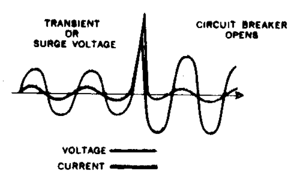
Specifications and prices subject to change without prior notice

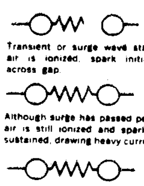
DALE ELECTRONICS INC.
Columbus, Nebraska

When a transient voltage of damaging magnitude (of system or natural origin) appears at the arrester terminals, the air within the arrester ionizes and arc is initiated between the top of (or large end) a spiral electrode and a surrounding cylindrical electrode. This energizes a coil and magnetically rotates the arc around and down the spiral electrode toward the small end and as it does it continually lengthens the gap until the arc is extinguished. In power supplies this automatic valve type action prevents a long sustaining current rise that would blow a fuse or open a circuit breaker.



HERE'S WHAT HAPPENS WHEN OLD FASHIONED SPARK GAP IS USED AS A SURGE ARRESTER . . .



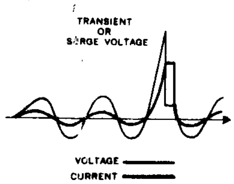


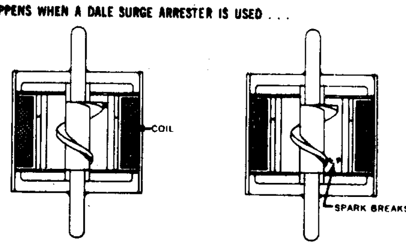
1. Transient or surge wave starts; air is ionized, spark initiates across gap.

2. Although surge has passed peak, air is still ionized and spark is sustained, drawing heavy current.

3. Spark does not extinguish until circuit breaker is opened. Long sustained arc burns electrodes and changes breakdown voltage.

HERE'S WHAT HAPPENS WHEN A DALE SURGE ARRESTER IS USED . . .





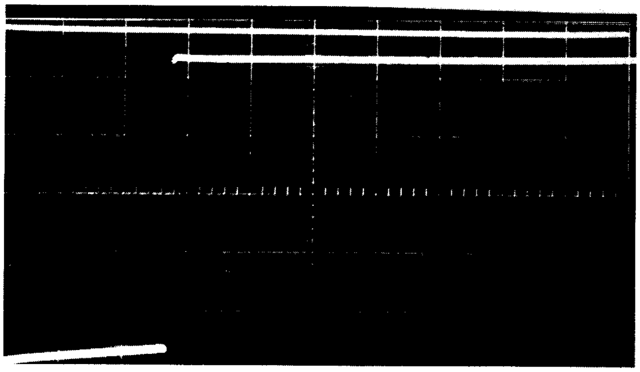
1. Surge ionizes air and arc is initiated between top of spiral electrode and cylindrical electrode. Coil is energized. Magnetic force of coil causes spark to rotate down spiral gap.

2. Spark is continually lengthened and breaks before excess current is drawn.

DALE

DALE SURGE ARRESTER

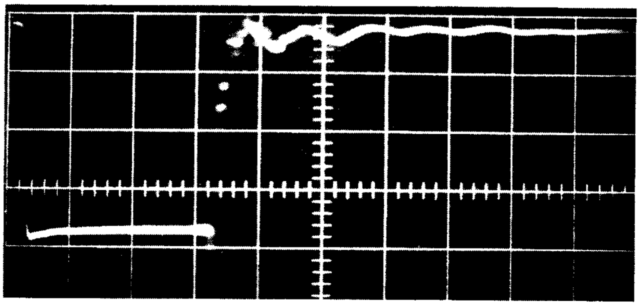
Manufacturer:	Dale Electronics, Inc. Columbus, Nebraska
Specifications:	See manufacturer's data sheet on opposite page
Device principle:	Air gap with magnetic arc blow-out for follow-current interruption
Available voltage ratings:	Factory adjustable 500 to 4000 volts DC (LA-8) or 1500 to 5000 volts DC (LA-9)
Permissible surge current:	15,000 amperes (LA-8) 300 amperes (LA-9)
Will interrupt power follow current:	Yes
December 1964 price:	LA-9, 500 volts ±10% $16.90 ea. in quantities of 25 $13.20 ea. in quantities of 200



1200 volts applied surge

Breakdown in 250 μs
100 volts arc voltage
(zero trace added for reference)

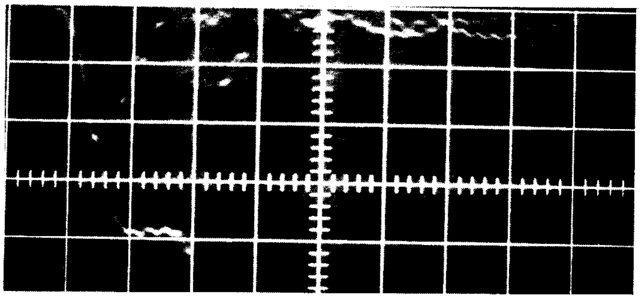
200 volts/div.
100 μs/div.



1800 volts applied surge

Breakdown in 1.5 μs

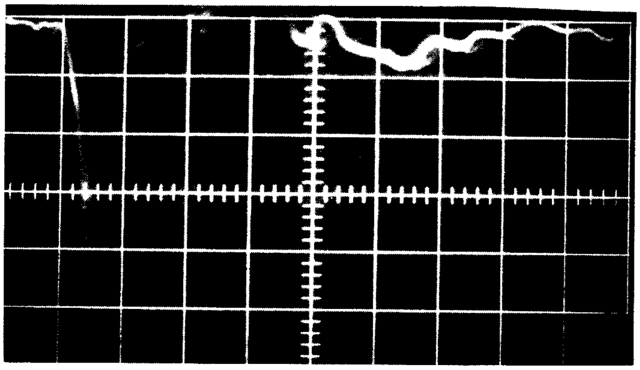
500 volts/div.
0.5 μs/div.



2000 volts applied surge
(2 shots)

Breakdowns in 200 ns at 2000 volts and 75 ns at 1500 volts

500 volts/div.
0.1 μs/div.



4000 volts applied surge
(4 shots)

Breakdowns in 40-60 ns at 3200 to 4200 volts
(highest breakdown trace higher than applied surge - see overshoots on 2000 and 1800 volt traces above)

1000 volts/div.
0.1 μs/div.

Performance of DALE Surge Arrester

Oscillograms showing applied surge with arrester in, single or multiple shot

Performance of DALE LA-9 Surge Arrester

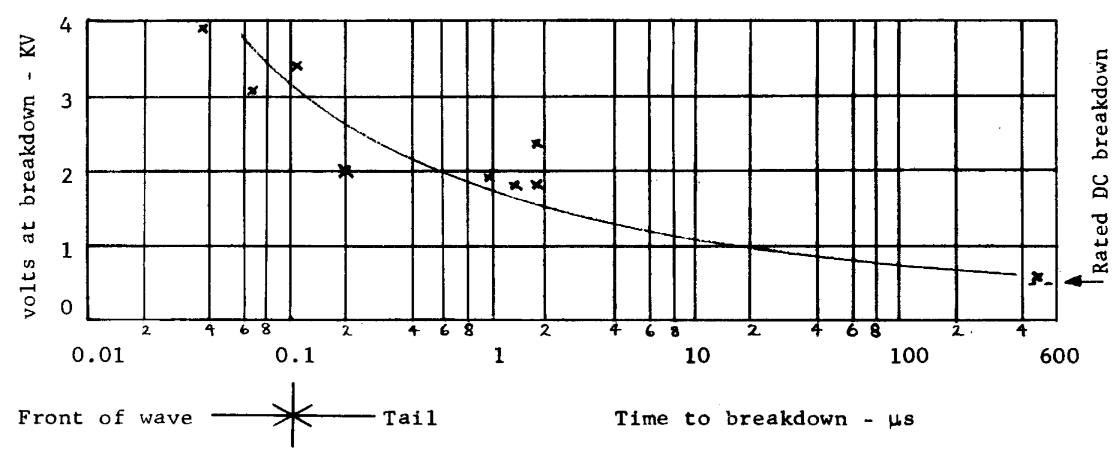
The device suffers from the inherent problem of all gaps, i.e., a substantial time-lag characteristic, as can be seen in the volt-time curve.

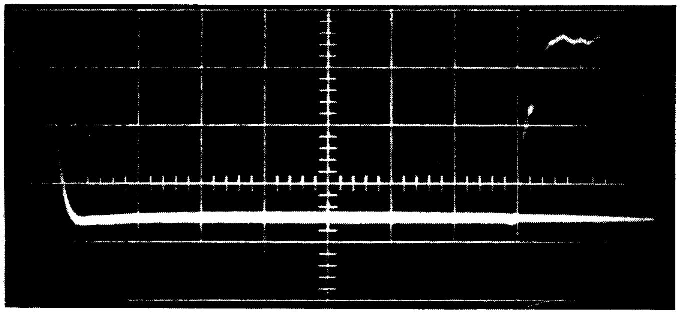
Typical oscillograms recorded during tests performed for plotting the volt time are shown on the opposite page.

On the other hand, the current discharge capacity of the LA-9 is substantial (300 amperes) and the device is self-clearing, in contrast to many of the suppressors covered in this report, which remain on after a surge-triggered turn-on.

A small detail on the specification sheet: The device has two threaded studs which might be construed as the two terminals; inspection of the drawings, however, shows that the case is one terminal while the two studs are connected together. The author found at least one case where the user started to complain of shorted devices, while using the two threaded studs as the two terminals of the device!

The volt-time curve of the device is plotted below. The 0.1 μs breakdown voltage is 600% of the minimum, with large variations between test points.

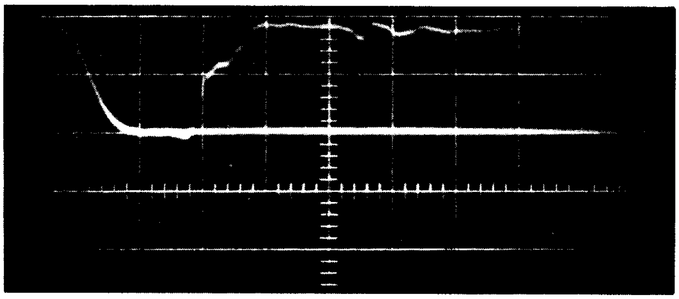




350 volts applied surge

Breakdown in 1.5 μs

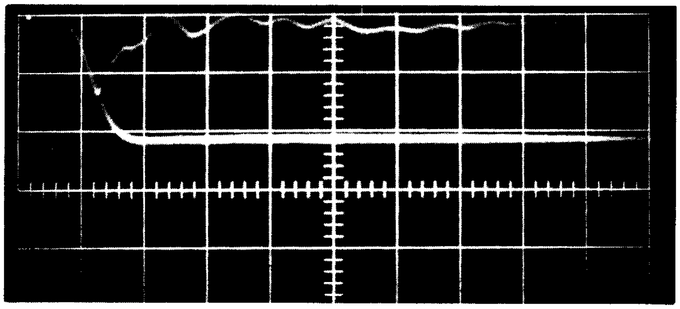
100 volts/div.
0.2 μs/div.



400 volts applied surge

Breakdown in 200 ns

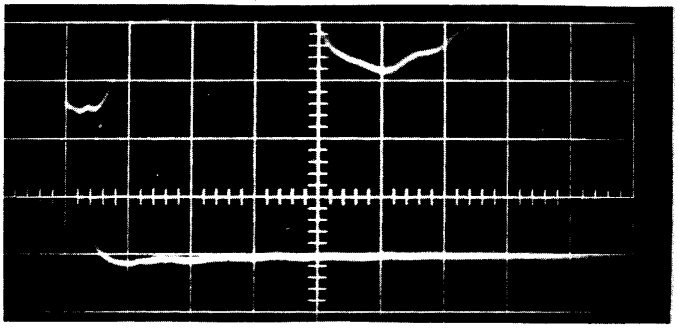
200 volts/div.
0.1 μs/div.



1100 volts applied surge

Breakdown in 40 ns at 700 volts

500 volts/div.
0.1 μs/div.



4000 volts applied surge

Breakdown in 20 ns with 1400 volts crest of 60 ns before chop.

1000 volts/div.
0.1 μs/div.

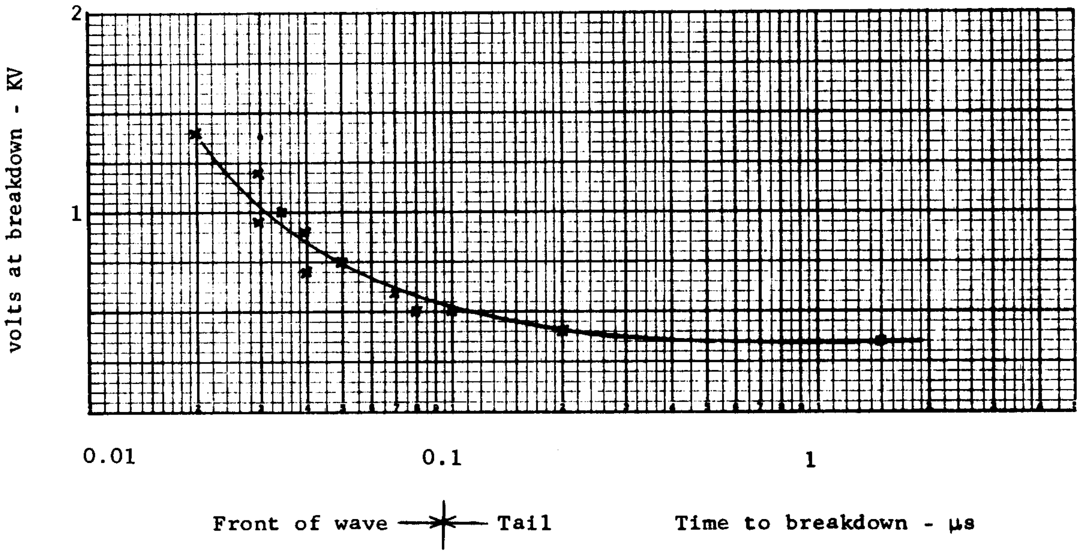
Performance of BELL Gap

Oscillograms showing applied surge with and without gap

BELL GAP

This gap was loaned by Mr. E. R. Uhlig of the High Voltage Laboratory, as a gap obtained from the Bell Laboratories. No specifications were available, but it was implied that this was a "fast" gap.

Typical oscillograms recorded during the tests made to plot the volt-time characteristic are shown on the opposite page; the characteristic is plotted below; the very small rise in breakdown voltage for times as short as 0.1 μs is remarkable, with the 0.1 μs voltage only 140% of the minimum breakdown voltage.



MARK 1 Engineering / 715 Sonora Avenue / Glendale 1, California / Phone (213) 245-0393

PRELIMINARY SPEC SHEET

S C P

(Semi-Conductor Protector)

The SCP is a high speed, high current, solid state switch. It is specifically designed to protect semi-conductor equipment and sensitive instrumentation against over-voltage line transients, that would normally damage or destroy semi-conductors.

With a time response of less than 1 micro-second, the SCP will handle voltage ratings, depending on model, 6 to 400 volts @ 0 to 150 amps., with a ± 5% firing voltage tolerance.

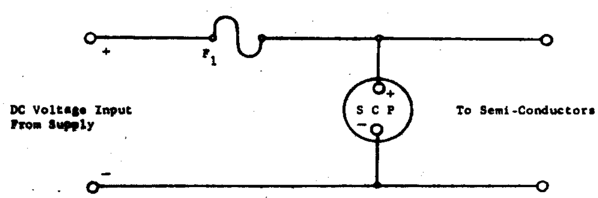
The SCP is extremely small in size and weight. It can be mounted in any position, and is completely unaffected by shock or vibration. It will operate in a temperature-range of -55°C to +100°C, with a life expectancy of greater than 1 million cycles. SCP modules can also be fired by a remote signal.

The SCP is normally used in conjunction with a standard fuse or a magnetic reset circuit breaker. There is no additional reset circuit necessary to reset the SCP. It automatically resets itself upon the replacement of the fuse, or the reactivation of the circuit breaker.

When used without a fuse or circuit breaker, power supply must be turned off momentarily to allow the SCP to reset.

Designed and priced for commercial use, the SCP is applicable to Mil Specs.

(BASIC CIRCUIT OF OPERATION)

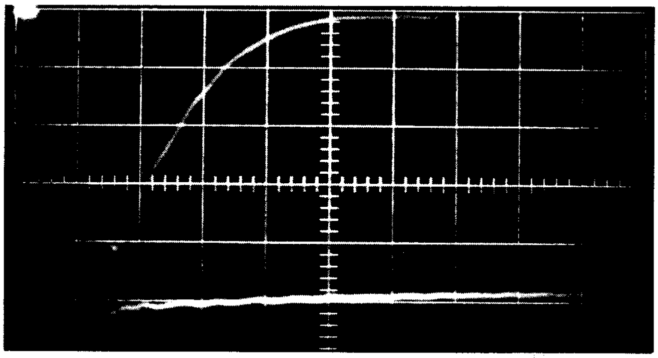


(F_1) Standard fuse or magnetic circuit breaker.

When an over-voltage condition exists, the SCP fires and shorts the output to the semi-conductor. Upon this activation, the voltage drops to approximately zero on the output, and allows the SCP to draw excessive current to blow the fuse or activate the circuit breaker (F_1).

MARK I ENGINEERING SEMICONDUCTOR PROTECTOR

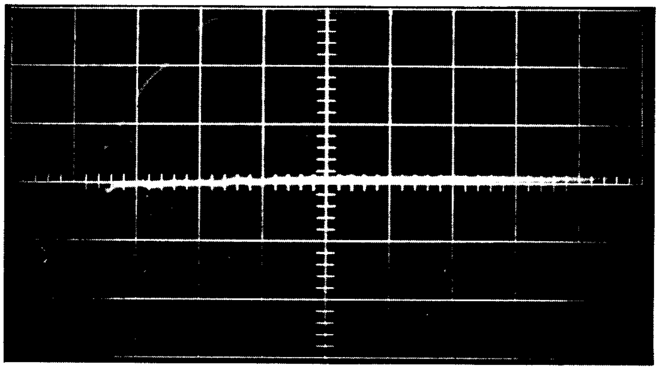
Manufacturer:	Mark I Engineering, Glendale, California
Specifications:	See manufacturer's specifications on opposite page
Device principle:	Three-terminal semiconductor turned on by zener diode-resistor network in gate circuit--device is polarized.
Available voltage ratings:	.6 to 400 volts
Permissible surge current:	150 amperes
Will interrupt power follow current:	No
December 1964 price:	\$14.10 for quantities up to 24 \$11.28 for quantities 100 and up.



100 volts applied surge

Turn-on in 40 ns with 80 volt peak

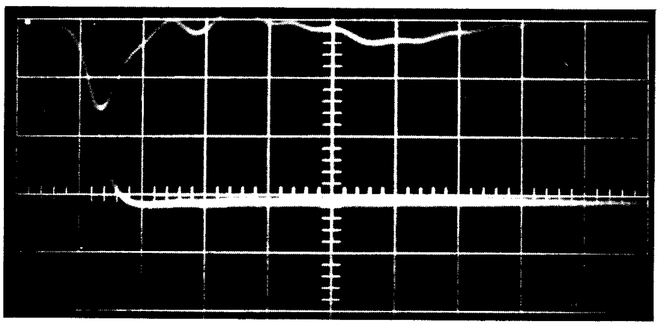
20 volts/div.
0.1 µs/div.



300 volts applied surge

Turn-on in 30 ns with 120 volt peak

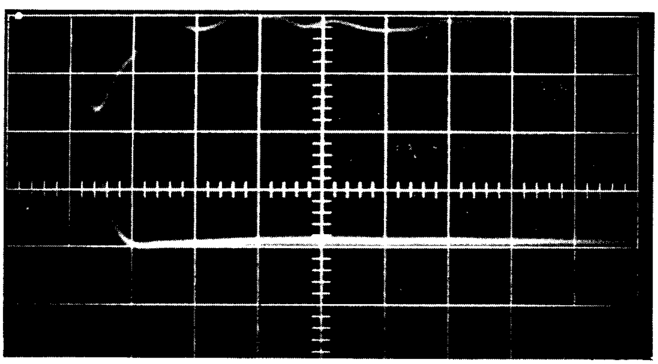
50 volts/div.
0.1 µs/div.



1500 volts applied surge

Turn-on in 30 ns with 750 volt peak

500 volts/div.
0.1 µs/div.



4000 volts applied surge

Turn-on in 30 ns with 1600 volts peak

1000 volts/div.
0.1 µs/div.

Performance of MARK I ENGINEERING Semi-Conductor Protector

Oscillograms showing applied surge with and without protector

PERFORMANCE OF THE MARK I SCP

The device exhibits a remarkable consistency in the turn on time, as well as a sharp firing point. The device tested had a 30 volt steady state rating, and began firing with as little as 50 volts. The oscillograms reproduced on the opposite page show that, over a wide range of voltages, the time required for turn on varies only from 40 to 30 ns. Following turn on, where the voltage across the device begins to depart from the no-load surge, the voltage continues to rise for a short time to reach a peak in less than 50 ns. The value of this peak is then determined by the rate of rise of the voltage since it appears that the time to peak is essentially constant for this device.

A volt-time characteristic would essentially be drawn as an almost vertical line at 30 or 50 ns, depending upon the definition of the "volt at breakdown" which is the ordinate of this characteristic.

Thus, this device offers an extremely fast and effective voltage limiting, although high voltages will still be reached if the front of the surge is steep enough. For many practical circuits, however, 50 to 100 ns represents an extremely short rise time.

On the other hand, the device is not self-clearing, and will depend on fuses or breakers to clear power follow current.

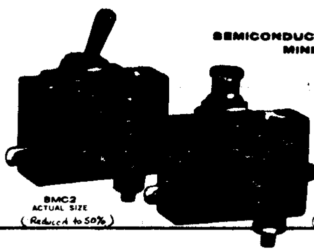
Furthermore, the device in its present form is polarized, so that application to AC circuits might require two back-to-back units or two units with two reverse diodes in series. The manufacturer does not make any statement on the performance of this device with reverse polarity over-voltages.

PRECISION CONTROLS

8 MC & 9 MC SERIES
SEMICONDUCTOR COMPONENT PROTECTORS
MINIATURE—PUSH-PULL OR TOGGLE

PRELIMINARY BULLETIN

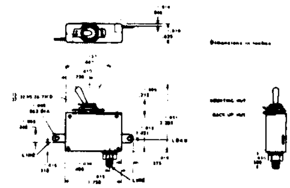
DO-CIRB-30A

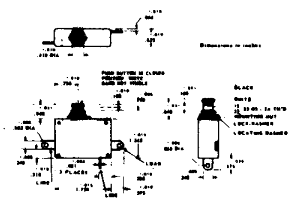


8MC2 ACTUAL SIZE (Reduced to 50%)

9MC2 ACTUAL SIZE (Reduced to 50%)

- **Nanosecond response—fastest acting circuit protector ever made**
- **Guards against transient and long-term overvoltage, overcurrent and overtemperature**
- **Eliminates semiconductor failures due to voltage transients**
- **Cost savings—allows use of lower rating components in circuit design**
- **Push-pull or toggle actuation**
- **Trip-free**





KLIXON® 8MC and 9MC Series Circuit Breakers are miniature, light-weight, ambient insensitive and combine electromechanical switching with matched semiconductor sensing for nanosecond response — the fastest acting circuit protector ever made.

These devices are available with either push-pull or toggle actuation and are specifically designed to protect semiconductor and other electrical systems against transient and long-term overvoltages and overcurrents. They may also be used for overtemperature protection when combined with the KLIXON 3BT or 4BT thermostat. Typical application includes: circuit protection of transistorized power supplies, computers, mobile communications equipment, servo controls, solid state inverters and converters, ground support equipment and other solid state electronic systems.

The 8MC1 (toggle) and 9MC1 (push-pull) provide combined overcurrent and overvoltage protection while the 8MC2 (toggle) and 9MC2 (push-pull) provide voltage limiting and automatic system recovery for short transients. The use of these protectors eliminates the need to derate circuit components to withstand infrequent transients in the system.

The diode unit built into the 8 and 9MC1 acts as the voltage sensor and triggers the electromechanical portion of the protector. In the 8 and 9MC2, the diode bypasses the voltage transient until the electromechanical device has time to operate. Result — matching of the electromechanical trip and diode characteristics provides maximum protection at minimum cost.

Typical features of these semiconductor component protectors include: wide choice of terminal configurations for ease of assembly; trip-free — cannot be maintained on fault even with pushbutton held in or toggle actuated; plus a threaded neck mount for simplified, single-hole panel mounting.

METALS & CONTROLS INC.
ATTLEBORO · MASSACHUSETTS U.S.A.
A CORPORATE DIVISION OF
TEXAS INSTRUMENTS
INCORPORATED

8MC1 AND 9MC1 PROVIDE COMBINED OVERCURRENT AND OVERVOLTAGE PROTECTION

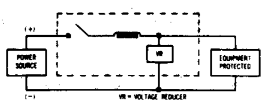


FIG. 1

8MC1 and 9MC1 — The semiconductor element in the 8 and 9MC1 reduces the output voltage within nanoseconds. This causes a large current flow from the power source to trip the protector. When the semiconductor component changes from non-conductive to conducting state, the voltage simultaneously drops below the normal circuit operating voltage. This prevents the transient from causing damage before the protector can trip and de-energize the system.

In addition, overcurrent protection is provided by selecting a current rating to match normal load requirements.

8MC2 AND 9MC2 PROVIDE VOLTAGE LIMITING AND AUTOMATIC RECOVERY FOR SHORT TRANSIENTS

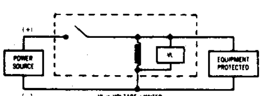


FIG. 2

8MC2 and 9MC2 — The 8 and 9MC2 clamp the output voltage level by the semiconductor component connected across the line. The arresting action prevents damage to other components until the protector trips and de-energizes the system. For short transients, the output voltage is held to a permissible value and the system automatically recovers to normal operation. For longer transients, the semiconductor suppresses the voltage until tripping action takes place.

OVERTEMPERATURE PROTECTION OF POWER CIRCUITS WITH 8 OR 9 MC CIRCUIT BREAKER – 3BT OR 4BT THERMOSTAT COMBINATION

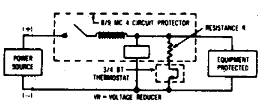


FIG. 3

In addition to overcurrent and overvoltage protection, 8MC or 9MC circuit breakers may be combined with KLIXON 3BT or 4BT thermostats, Fig. 3, to guard against damaging overtemperature in a component. Miniature size and fast response allows the thermostat to be mounted in the critical hot area adjacent to the component while the circuit breaker is mounted in a remote location.

The smallest snap-acting thermostats ever made — the KLIXON 3BT and 4BT "Tiny-Stat" series are SPST, hermetically-sealed devices that are factory calibrated to close the circuit on temperature rise at any point up to 350°F. When an overtemperature condition occurs in the component, the thermostat snaps the circuit closed. This action causes a current overload which trips the circuit breaker and de-energizes the equipment component.

This circuit concept (Fig. 3) has the advantage of being able to effectively switch a power circuit with a small, highly responsive thermostat. Also, if more than one critical component has to be protected, additional KLIXON 3BT or 4BT thermostats may be mounted in the desired locations and connected in parallel.

To insure fast tripping action, the minimum current through the thermostat should be two times the rated current of an 8MC or 9MC with instantaneous trip characteristics. In the time delay version of the 8MC and 9MC, the minimum current through the thermostat should be five times the rated current of the circuit breakers.

In Fig. 3, the thermostat current is a function of the circuit breaker resistance, thermostat resistance (0.02 ohms nominal), series resistance and line voltage. The series resistance R, is selected to cause the circuit breaker to trip instantly and to limit the current through the thermostat to 50 amps at 30 v-dc or 30 amps at 125 v-ac. After tripping, the circuit breaker cannot be reset until the component has cooled to a predetermined temperature (30°F nominal temperature differential) at which the thermostat will automatically open.

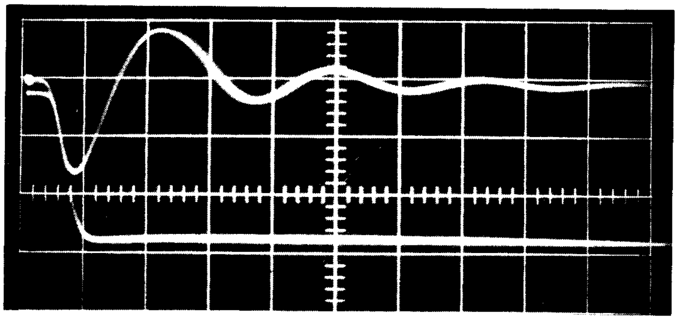
Note that the 3BT or 4BT may be used with the standard 2MC or 3MC magnetic circuit breaker (described in bulletin CIRB-28) with a current or voltage coil.

For additional details on the 3BT and 4BT, see data bulletin PRET-12.

CIRCUIT PROTECTOR TYPE NUMBER		CURRENT PROTECTION	VOLTAGE LIMITING	VOLTAGE REDUCING	TEMPERATURE PROTECTION (has internal resistor)
TOGGLE	PUSH-PULL				
8MC1	9MC1	✓		✓	
8MC2	9MC2		✓		
8MC4	9MC4	✓			✓
8MC5	9MC5	✓		✓	✓
8MC	9MC	✓			

T.I. KLIXON SEMICONDUCTOR PROTECTOR

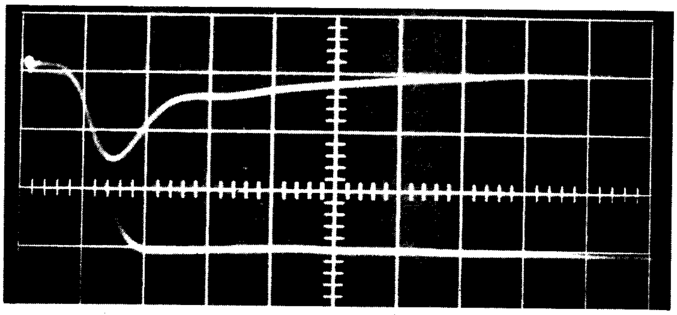
Manufacturer:	Metals and Controls of Texas Instruments, Inc.
Specifications:	See manufacturer's specifications opposite page
Device principle:	Two-terminal semiconductor turns on and clamps voltage; integral mechanical circuit breaker interrupts power follow current.
Available voltage ratings:	12 - 60 volts; 115 volts might be available
Permissible surge current:	Not specified
Will interrupt power follow current:	Yes
December 1964 price:	$20.40 in quantities up to 100 $16.85 in quantities 500 and up.



280 volts applied surge

Turn-on in 60 ns with 150 volts peak

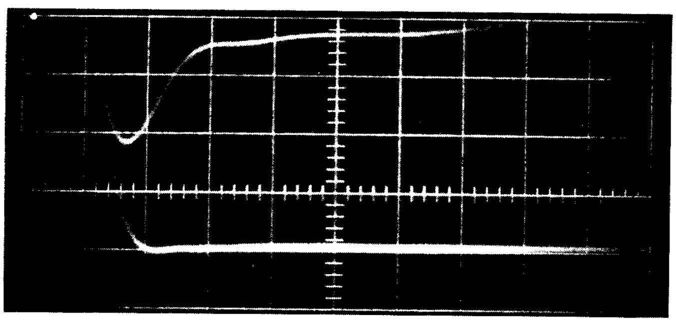
100 volts/div.
0.2 μs/div.



600 volts applied surge

Turn-on in 40 ns with 300 volts peak

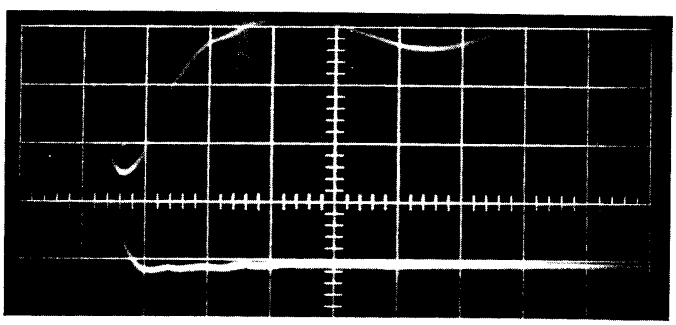
200 volts/div.
0.1 μs/div.



2000 volts applied surge

Turn-on in 40 ns with 1100 volts peak

500 volts/div.
0.1 μs/div.



4000 volts applied surge

Turn-on in 40 ns with 2500 volts peak

1000 volts/div.
0.1 μs/div.

Performance of T.I. KLIXON Semiconductor Protector

Oscillograms showing applied surge with and without protector

Performance of Klixon SCP

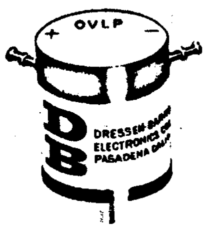
An overvoltage protector (type MC1) rated 30 volts DC was subjected to the test surges, as seen on the oscillograms on the opposite page. Turn-on occurred in less than 60 ns for all applied surges above 280 volts, which was the minimum surge voltage producing a firing, a rather high ratio to the rated DC voltage.

A voltage peak followed the turn-on in a short time, with increasing values as the steepness of the surge front was increased.

This device is combined with a circuit breaker which can also protect the load against overcurrents, in addition to tripping out the power-follow current after firing on a surge. In that respect, it offers attractive features for an otherwise unattractive price, but still a bargain compared to the voltage limiting only Dresser-Barnes units.

The device is again polarized, with no comment from the manufacturer on the performance with reverse polarity surges.

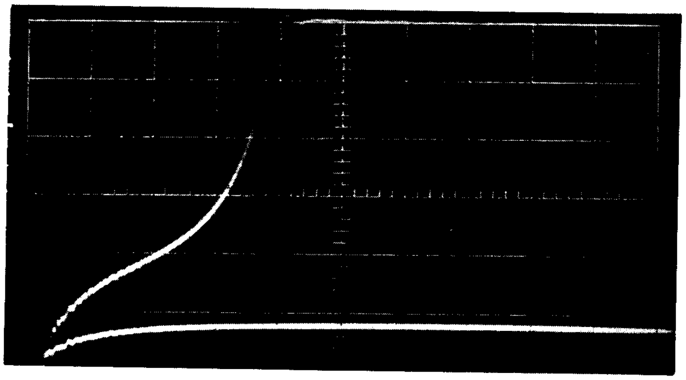
Overvoltage Load Protector



Protection of load against overvoltage transients from d-c source is application of Overvoltage Load Protector. It features 3-400v firing voltage, ±5% tolerance, surge current capacity of up to 100-amp for 8ms, and standby current drain of 3ma. Ambient temp range is 0-100°C on standard models and −55 to 100°C on special models. **Dressen-Barnes Electronics Corp.**, Dept. EE, 250 N. Vinedo Ave., Pasadena, Calif.

DRESSEN-BARNES Overvoltage Load Protector

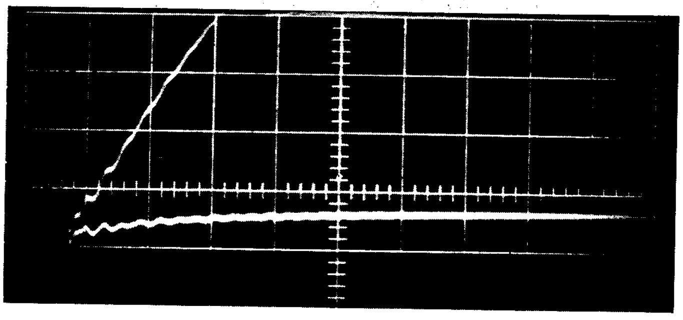
Manufacturer	Dressen-Barnes Electronics Corp. Pasadena, California
Specifications	See advertisement next page
Device principle	Semiconductor circuit turned on by surge. (2 semiconductors, several resistors and capacitors in encapsulated housing)
Available voltage rating	3 to 400 volts
Permissible surge current	100 amperes for 8 ms
Will interrupt power follow current	no--maximum continuous power follow current is 3 mA.
December 1964 prices	\$14.50 in quantities up to 25 \$13.50 in quantities above 100



280 volts applied surge

Slow turn-on

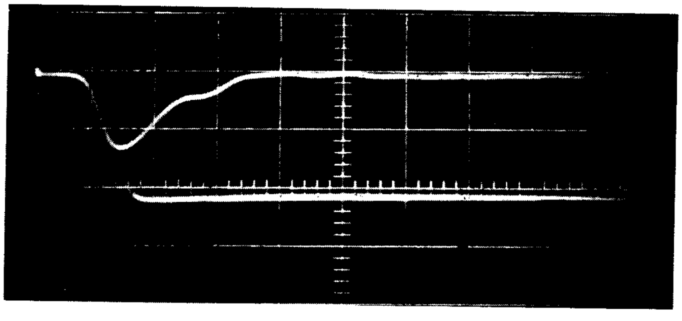
50 volts/div.
0.5 μs/div.



400 volts applied surge

Turn-on in 90 ns with
360 volt peak

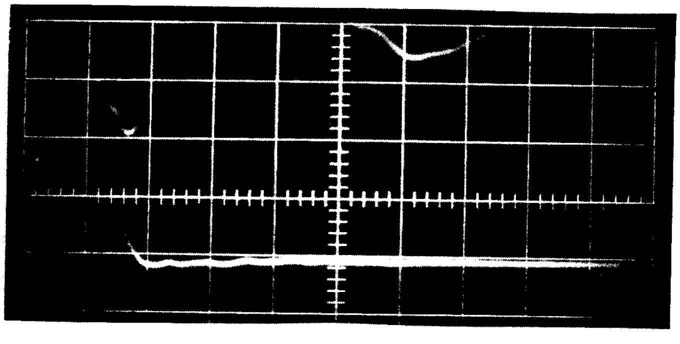
100 volts/div.
0.2 μs/div.



1100 volts applied surge

Turn-on in 40 ns with
700 volts peak

500 volts/div.
0.1 μs/div.



4000 volts applied surge

Turn-on in 30 ns with
2000 volt peak

1000 volts/div.
0.1 μs/div.

Performance of DRESSEN-BARNES OLP suppressor

Oscillograms showing applied surge with or without suppressor

Performance of Dressen-Barnes OLP Suppressor

The device under test was rated 200 volts DC; firing or turn-on occurred with a minimum surge of 280 volts, with a relatively slow turn-on, as seen in the first oscillogram on the opposite page. Increasing the crest of the surge to 400 volts and above produced turn-on in decreasing time, from 90 to 30 ns, followed by a peak voltage occurring in less than 50 ns.

The device exhibits remarkable speed in turning on; however, as the steepness of the applied surge is increased, the turn-on time decreases only very little, so that increasing voltage peaks will occur. The minimum surge which will trigger the suppressor is only 140% of the rated maximum voltage, a ratio comparable to that of the less complex and slightly less expensive Mark I suppressor.

The device is also implicitly polarized, and the manufacturer makes no comment on the performance with reverse polarity. It will probably withstand a certain level of reverse polarity, but another unit will be required to obtain protection in both directions.

HUNT SSS SWITCH (Power Device)

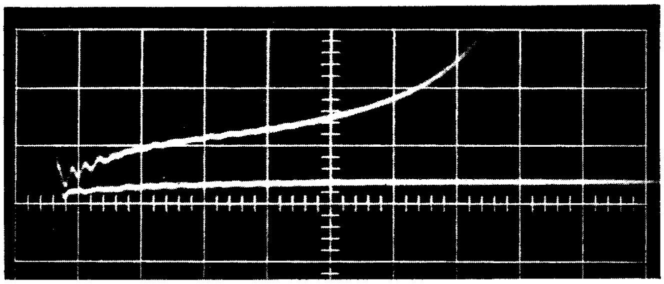
This device has been investigated in earlier reports;* as it exhibits a definite turn-on action similar to some of the other devices covered in this report, it has been subjected to the same test series, in order to allow direct comparison. While earlier references were made under the name of SSS switch, this particular device is now called "power device" by the manufacturer.

There are no specification sheets available from the manufacturer; their general catalog lists assembled hardware rather than components.

This switch consists of a 5 layer, 2 terminal device, somewhat similar in operation to the DIAC.

Prices quoted in 1964 were $2 each in quantities above 100.

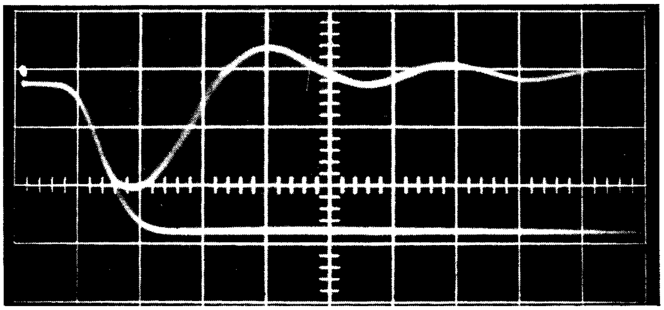
*See Tis 63GL97, 63GL144, and 64GL118



140 volts applied surge

Slow Turn-on

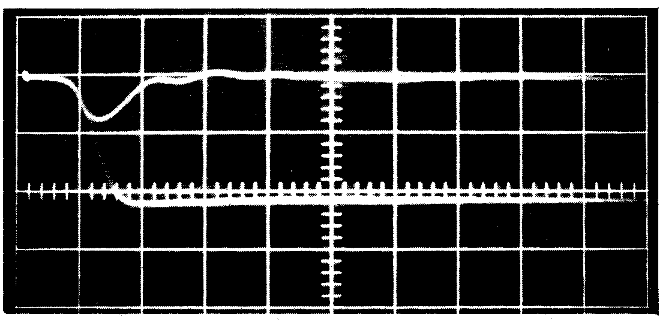
50 volts/div.
0.2 μs/div.



280 volts applied surge

Turn-on in 80 ns with 200 volt peak

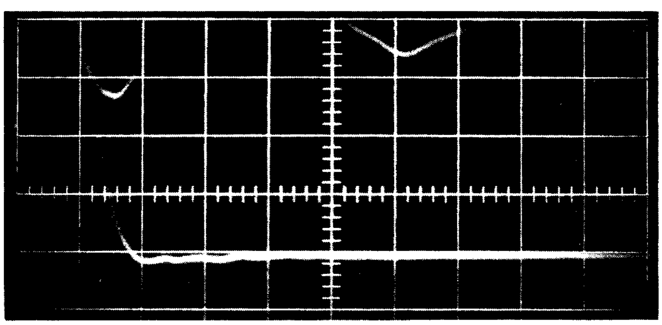
100 volts/div.
0.1 μs/div.



1100 volts applied surge

Turn-on in 50 ns with 400 volt peak

500 volts/div.
0.1 μs/div.



4000 volts applied surge

Turn-on in 50 ns with 1200 volts peak

1000 volts/div.
0.1 μs/div.

Performance of HUNT SSS Switch

Oscillograms showing applied surge with and without switch

PERFORMANCE OF HUNT DEVICE

The turn-on of the device occurs very rapidly for voltages above the rated turn-on. The oscillograms on the opposite page show how the turn-on, at first rather slow (1μs), soon takes less than 50 ns when the applied voltage is raised beyond 500 volts. The turn-on starts as the voltage trace departs from the no-load trace, and is complete, i.e., the voltage is essentially clamped to zero, in less than 100 ns after the start of the turn-on.

In contrast to some of the other semiconductor devices covered in this report, this one is not polarized. It is also very small and consists of a single component. The price is about 20% of that of the SCP and OLP semiconductor protectors, which are polarized.

On the other hand, this device is not self clearing, power follow current will be established and will have to be interrupted by external means. However, the device can be quickly turned off by applying a reverse polarity for a short time, so that it is conceivable that a small iscillatory circuit could be added to the device; the oscillations of this circuit following the "chop" action of the device could then be used to turn it off. But this is a conjecture and not an existing device, which is what this report is intended to cover.

In AC systems, of course, natural clearing will occur at the end of the first half cycle, so that power follow current is limited to the balance of the half cycle following the surge. This is discussed in detail in the reference reports.

GENERAL ELECTRIC THYRECTOR

This device does not exhibit a turn-on effect similar to the devices evaluated in this report and therefore cannot be directly compared to them as an individual component. Earlier reports* have presented its attractive characteristics through a comparison in a complete system such as the laboratory house model. The most significant characteristics are re-stated here for the convenience of the reader, while complete details will be found in the reference reports.

While there is some limitation in the ability to suppress surges close to the steady-state voltage, the Thyrector and other non-linear semiconductors offer attractive characteristics such as the absence of any time lag, in contrast to the volt-time effect of gaps and the turn-on time of switching semiconductors, plus the natural self-clearing action after disappearance of the surge so that there is no power-follow current. In addition, selenium devices have the unique possibility of self-healing after application of current pulses in moderate excess of their rating.

Typical prices range from $ .75 to $5 depending on ratings.

* See TIS 63GL97, 63GL144, 63GL118.