UNCLASSIFIED

CONTINUATION OF SURGE LIFE OF TRANSIENT VOLTAGE SUPRESSOR

(FINAL REPORT)

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Prepared By

GENERAL SEMICONDUCTOR INDUSTRIES, INC.

For
GEORGE C. MARSHALL SPACE FLIGHT CENTER
HUNTSVILLE, ALABAMA 35812

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FOREWORD

This is the final summary report of work performed by General Semiconductor Industries, Inc., under Contract No. NAS8-31547, from George C. Marshall Space Flight Center, Alabama, to conduct a continued reliability study extension of Contract No. NAS8-30811. This reliability study is on the Surge Pulse Life of the General Semiconductor Industries, Inc., TransZorb .

This report includes a description of the transient voltage suppressors, conditions of the test, and analysis of the data gathered by the tests, a summary of the analysis and its implication on engineering design, and also a definition of the Mean Number of Peak Pulses Before Failure (MP^2BF). Also included is an analysis of failed devices and a sampling of the raw data.

Information gathered in this test is intended to be used as a guideline for engineering design in using transient voltage suppressors in space equipment applications.

The reliability analysis on this effort was performed at the University of Arizona in Tucson, Arizona, by Edward Haugen, Associate Professor in the College of Engineering Department of Aerospace and Mechanical Engineering, and Michael Jacob, a Graduate Research Assistant in the Doctoral Program.

TransZorb™ - Trademark of General Semiconductor Industries, Inc.

This final report was accomplished under the technical direction of Mr. Michael Nowakowski, Mr. Felminio Villella and Mr. Leon Hamiter of Marshall Space Flight Center, Huntsville, Alabama, and we thank Messers Nowakowski, Villella and Hamiter for their guidance and assistance in accomplishment of the work effort and the writing of this report.

Acknowledgement is also given to Richard Gadberry and Michael McMorris of General Semiconductor Industries, Inc., for their efforts in development of test equipment and performance of the tests respectively, and also to Joe Pizzicaroli for his efforts in conducting the analysis on the devices which failed during tests.

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SUMMARY

This report documents the efforts expended in testing, analyzing and development of a meaningful definition of the Mean Number of Peak Pulses Before Failure (MP^2BF) levels of a family of transient voltage suppressor devices, the TransZorb™.

This study is a continuation of the efforts initiated in NASA Contract No. NAS8-30811. The purpose of this continuation is to determine the ability of the transient suppressor to effectively and reliably protect against severe short term, millisecond range, transient voltages of the types resulting from inductive load switching and induced lightning.

In the Final Summary Report on Contract NAS8-30811, the Mean Number of Peak Pulses Before Failure reported for all four voltage level device types, the 6.8V, 33V, 91V, and 190V, required extensive extrapolation of the data presented mainly due to the fact that there were insufficient failures to produce a meaningful MP^2BF. The purpose of this study is to extend the number of pulses and subsequently extend the meaningfulness of the data presented.

This reliability study utilized existing pulse testing instrumentation, interfaced to an automatic sequencing test rack accommodating up to 50 devices. Tests were performed in step stress increments of 25% beginning at 25% and extending thru 100% rated I_{pp} for each voltage category. The four voltage types tested were the 6.8V, 33V, 91V, and 190V. Concurrent with the tests performed under Contract NAS8-30811, engineering efforts at General Semiconductor Industries, Inc., were addressing the problem of improving the reliability of the 190V types. The results of the previous program confirmed the requirement for improvement. The improved construction is not included in this study as this study includes only those devices used in the initial test.

As specified in Contract No. NAS8-31547, an additional 20,000 pulses were to be applied to the devices or were to be terminated upon failure of the entire lot, whichever occurs first.

Data gathered from this program was reduced to graphs plotting step stress levels vs MP^2BF. The meaningfulness of these curves has been extended to the extent of the additional number of pulses gathered. However, most lots tested at 75% Peak Pulse Current and below had relatively few failures under this new extended, long term pulse testing. Failures at the 100% I_{pp} level were virtually total and subsequently meaningful MP^2BF curves could be derived and presented.

1.0 WORK EFFORT

1.1 Background

1.1.1 Silicon Avalanche suppressor devices have been on the market for a period of many years; however, this is the first effort to gather long term reliability data, defining the MP^2BF at various stress levels.

1.1.2 Since a transient suppressor normally operates in the stand-by mode and conducts appreciably only in the presence of transient voltages, a meaningful measure of life expectancy for this device type would be MP^2BF instead of the conventional MTBF. Because the TransZorb™ transient voltage suppressor is a unique device having the capability of withstanding high power transients (1.5Kw for 1 millisecond pulses and 100,000 watts for 100 nanosecond pulses) it is anticipated that the components of this type will be needed for long term life space hardware to protect circuits subjected to a large number of transients over a broad spectrum of pulse width and amplitudes.

1.1.3 The TransZorb, an acronym for "transient absorber" was designed by General Semiconductor Industries, Inc., and developed initially for the telecommunication industry for protection against short term, high power transients originating from induced lightning. This device differs from other semiconductor components as it was designed specifically for transient suppression.

1.1.4 The first attempt to quantitatively describe the reliability of the TransZorb was performed under NASA Contract NAS8-30811 with the Final Report Surge Life of Transient Voltage Suppressor published in July 1976. In this previous effort to define the MP^2BF, the devices were tested to a maximum number of 5,760 pulses. This number was arbitrarily chosen and thought at the onset of the test to be a good number to produce sufficient failures for establishing good MP^2BF curves. However, the plot of the percent of maximum rated Peak Pulses Current versus the Mean Number of Peak Pulse Before Failure reported, required extensive extrapolation of data due to insufficient failures of tested devices. It is the intention of this study to gather sufficient data to produce a more meaningful reliability curve.

1.2 TransZorb™ Description

The Transient Voltage Suppressor used in this and the earlier report is the TransZorb which is characterized by the description above and also by its small size and fast response. Device characteristics for the types used in this study are given in the appendix.

1.3 Failure Modes

Failure modes and mechanisms for each device category will be defined and attempts will be made to establish some correlation between initial electrical parameters and the specific failure mode and/or mechanism.

1.4 Life Test Equipment

1.4.1 Surge pulse life tests were performed on TransZorbs with the automatic surge test apparatus capable of delivering accurate and reproducible surge pulses at current levels as required for the specific test current of the devices under test.

The Peak Pulse Current (I_{pp}) was adjustable over a wide output range to accommodate those levels required for the performance of this Contract. The waveform of the test current pulse is shown in Fig. 1.

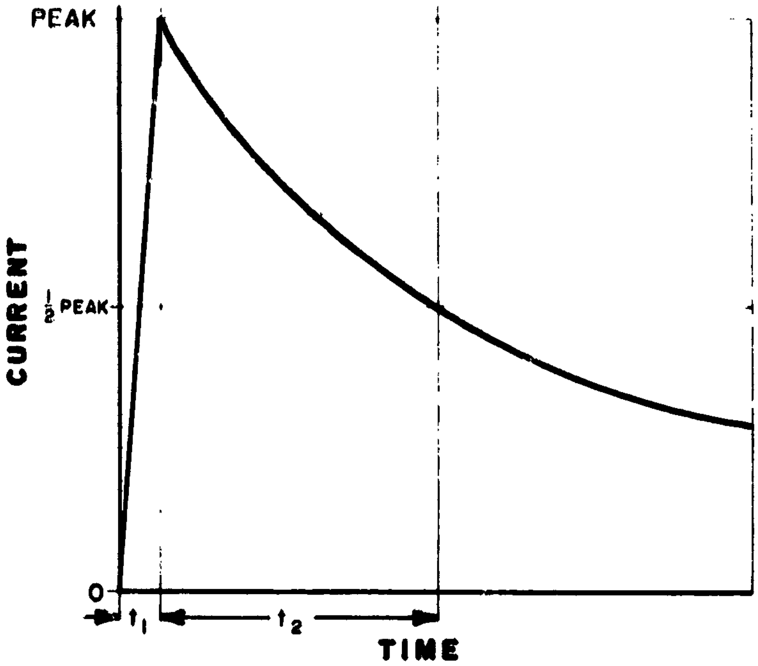
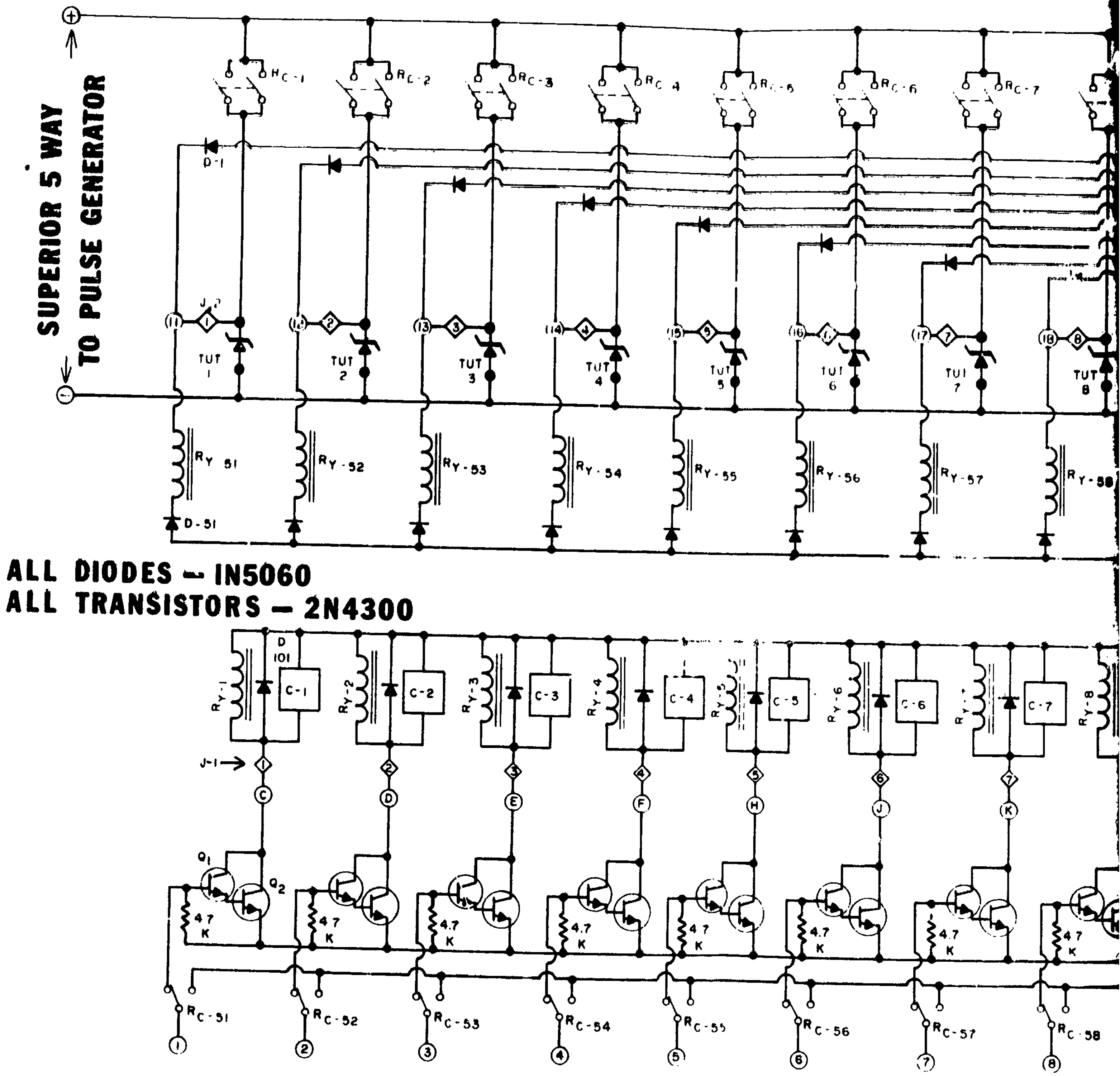


Fig. 1: Test Current Pulse Wave Form

The virtual rise-time of this pulse, t_1, is 10 microseconds while the time for decay to one-half crest value, t_2, is 1,000 microseconds. The pulse is also described as a 10x1000 pulse.

The test equipment was designed with a fault detector to de-energize devices under test which became no longer functional in either the open or the short mode. A schematic of the equipment used in the pulse testing is shown in Fig. 2 for the Pulse Sequencing Circuits and the device counter Failure Sensing and Pulse Limit Circuits are shown in Fig. 3.

1.4.2 With a master digital read-out counter, it was possible to accurately determine the number of pulses subjected to each device prior to failure.

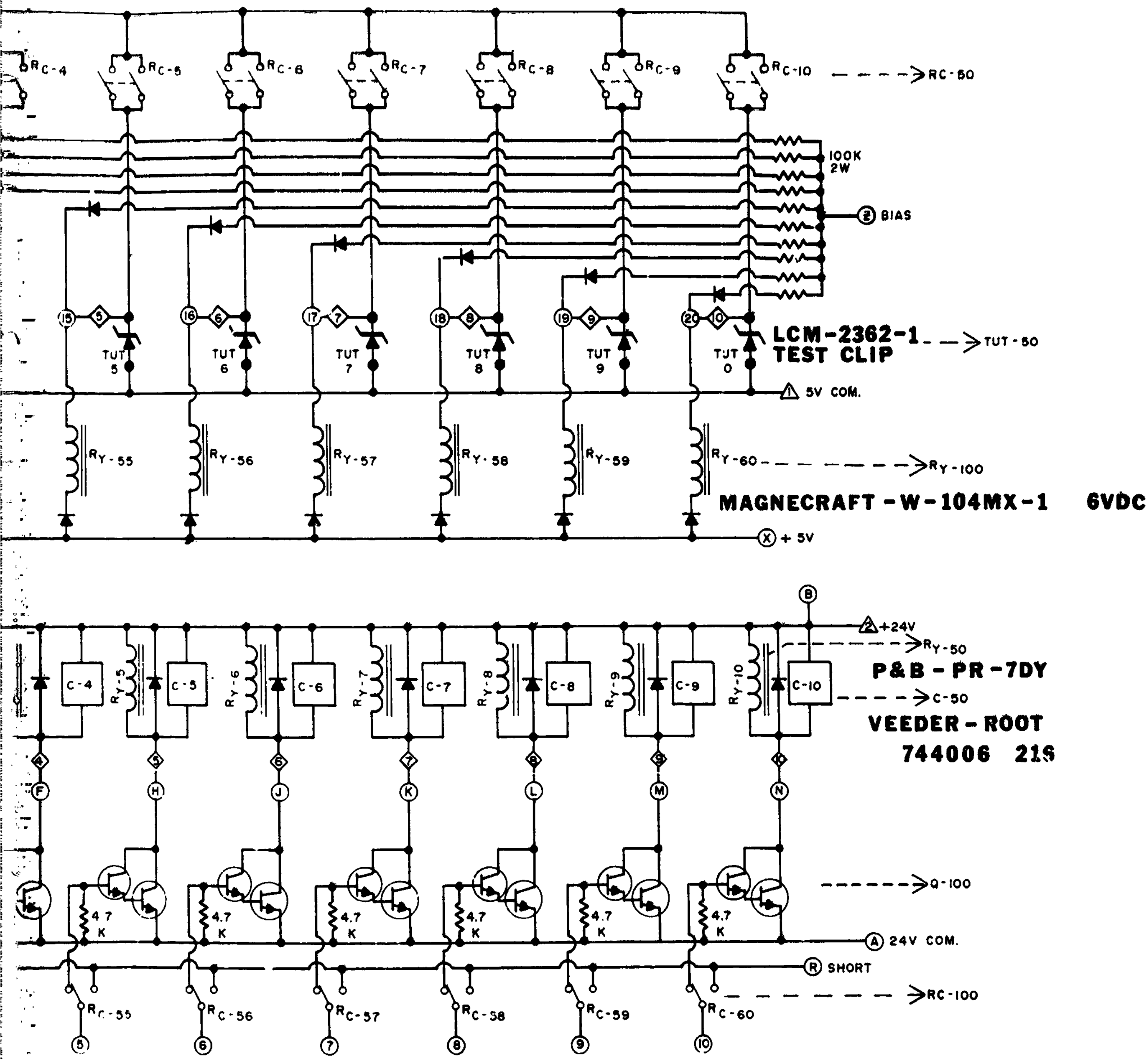


○ — VERO 10290 PC CARD PIN NUMBERS

◇ — AMPHENOL 57-40500 & 5730500

△ — CINCH JONES S-306-AB & P-306-CCT

Fig. 2:



D PIN NUMBERS

& 5730500

& P-306-CCT

Fig. 2: Pulse Sequencing Circuits

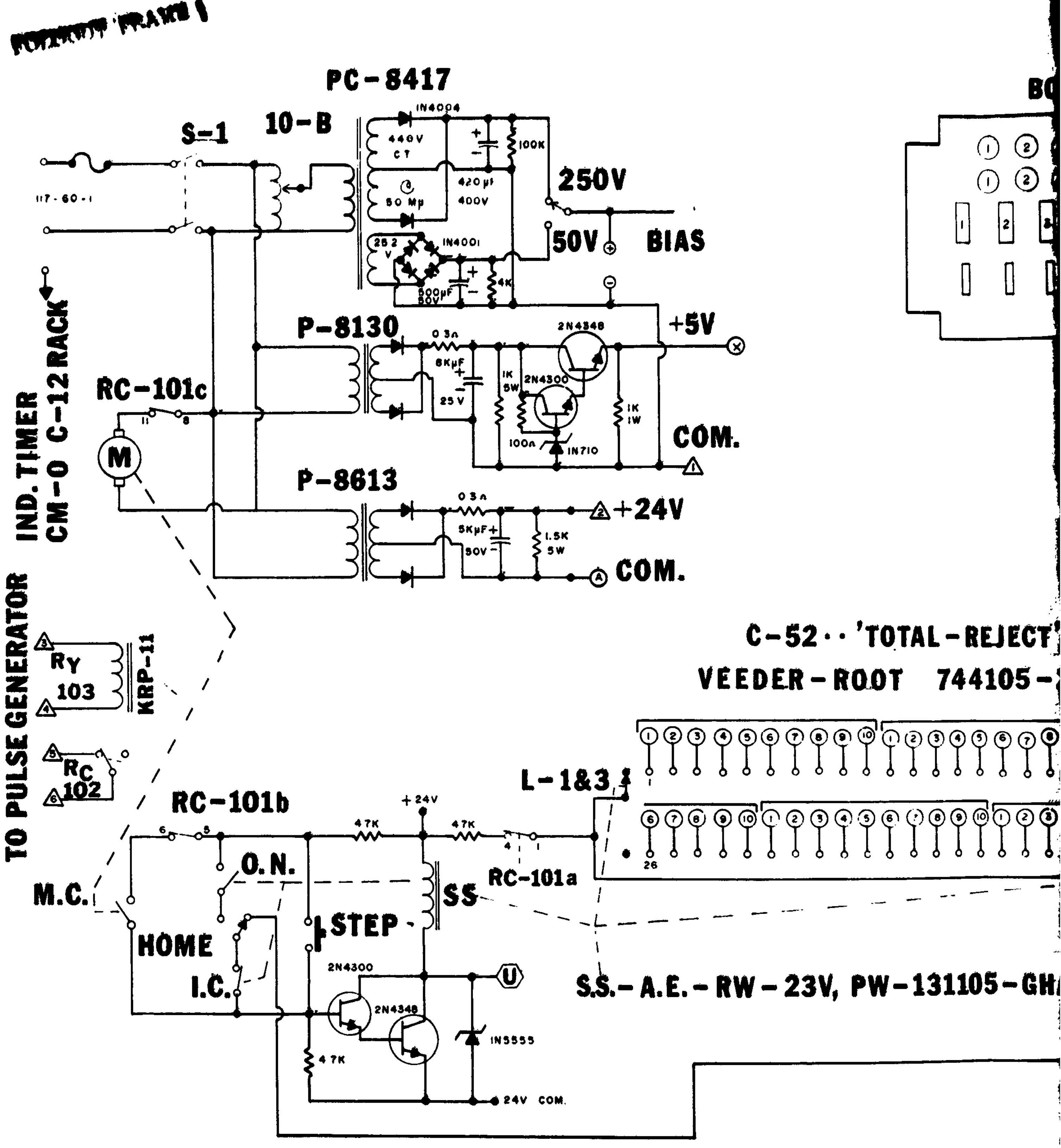
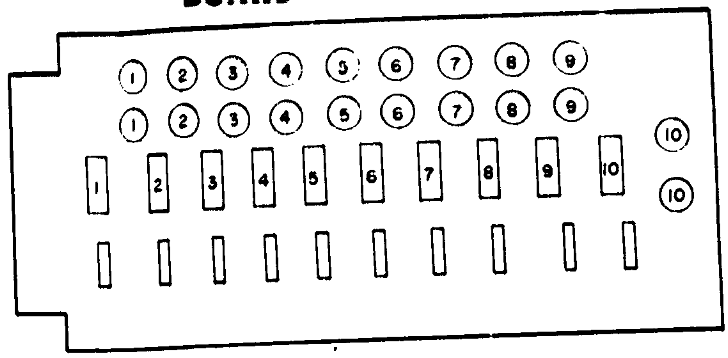


Fig. 3: Device Counter, Failure Sensing and Pulse Circuits

BOARD LAYOUT



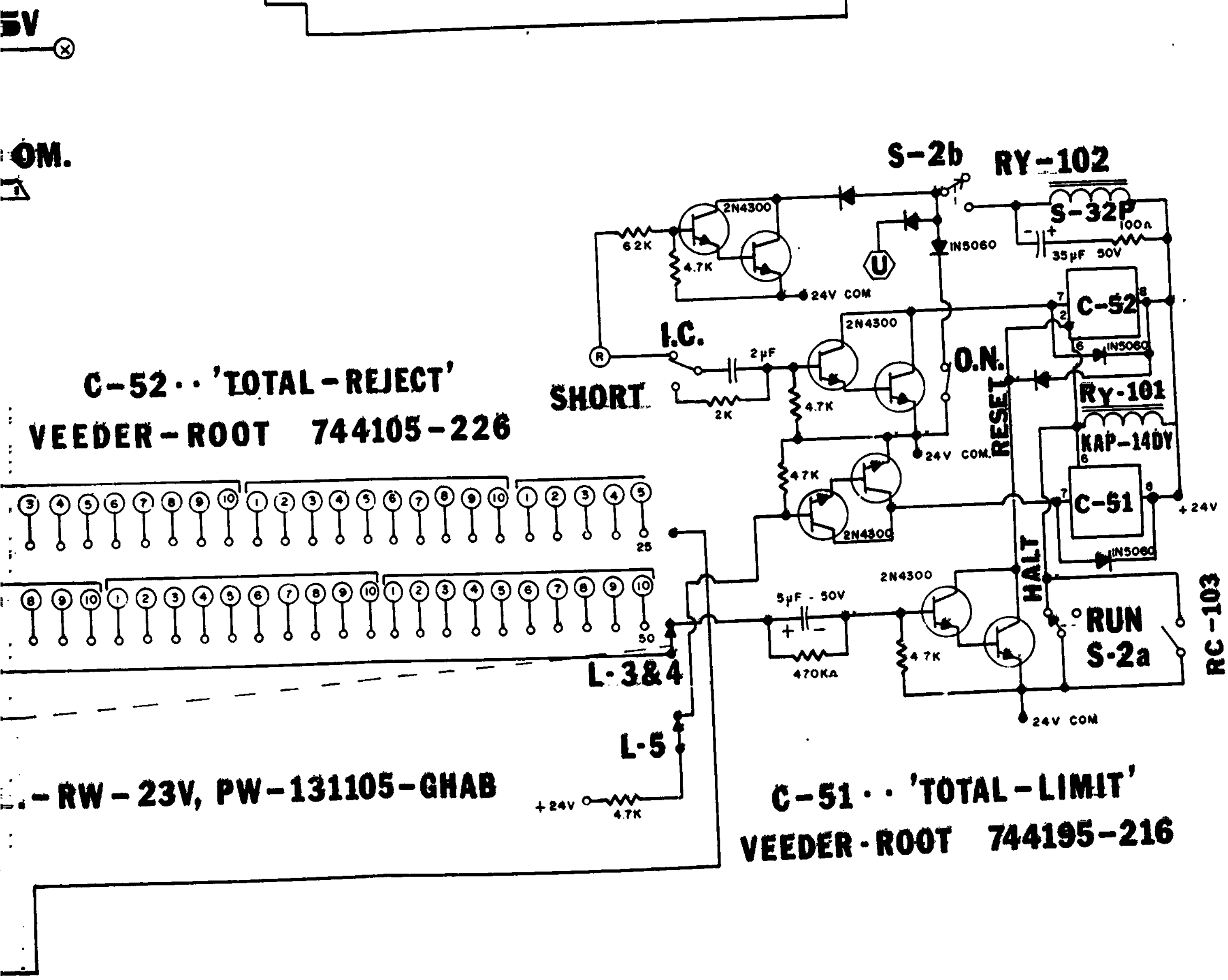


TABLE I

DEVICES TESTED ON THIS CONTRACT EFFORT

ORIGINAL PAGE IS OF POOR QUALITY

6.8V (1N5629A)					
25% PEAK PULSE CURRENT	-	50 Started	-	50 Completed	
50% " " "	-	49 Started	-	49 Completed	
75% " " "	-	50 Started	-	43 Completed[1]	
100% " " "	-	44 Started	-	0 Completed[2]	
33V (1N5645A)					
25% PEAK PULSE CURRENT	-	50 Started	-	50 Completed	
50% " " "	-	43 Started	-	43 Completed[3]	
75% " " "	-	49 Started	-	49 Completed	
100% " " "	-	25 Started	-	0 Completed	
91V (1N5656A)					
25% PEAK PULSE CURRENT	-	50 Started	-	50 Completed	
50% " " "	-	47 Started	-	47 Completed[4]	
75% " " "	-	23 Started	-	23 Completed[5]	
100% " " "	-	25 Started	-	0 Completed	
190V (1N5665)					
25% PEAK PULSE CURRENT	-	48 Started	-	48 Completed[6]	
50% " " "	-	32 Started	-	32 Completed[7]	
75% " " "	-	4 Started	-	4 Completed[8]	
100% " " "	-	25 Started	-	6 Completed	

[1] Unit, No. 121, had initial leakage out of spec. but drifted back in after 7,500 pulses. Unit, No. 107, drifted out of spec. on leakage at 10,000 and 15,000 pulse internal measurements.

[2] Unit, No. 160, lost in handling.

[3] Seven failed during final V_C measurement of NASA Contract NAS8-30811.

[4] Two failed during final V_C measurement. Unit, No. 67, lost in handling.

[5] Sixteen failed during final V_C measurement in Contract NAS8-30811. Seven failed during initial V_C measurement for Contract NAS8-31547.

[6] Two units degraded on shelf between contracts.

[7] Six units failed on final V_C on Contract NAS8-30811. Twelve units failed on initial V_C on Contract NAS8-31547.

[8] Two failed on final V_C (first Contract). Three failed on initial V_C (second Contract). Sixteen degraded on shelf storage between first contract.

1.4.3 In the work performed in Contract NAS8-30811, the tests were automatically discontinued after 50% of the devices failed. In this study, devices were allowed to operate out through 20,000 additional pulses or the failure of all devices in that lot, whichever was first.

1.5 Devices Tested

The devices used in this test were those which were remaining from the previous Contract. The number of devices and the Peak Pulse Current Level for the devices are described in Table I. Since there were failures on earlier tests there were either 50 or less study devices in the work performed on this contract.

1.6 Peak Pulse Test Current

The Peak Pulse Current for the various levels of tests are shown in Table II. This represents the pulse exposure of the TransZorb™ at the 25% rated I_{pp} up through 100% of the rated I_{pp}.

TABLE II

TRANSZORB™ PULSE EXPOSURE

Group	Sample Size	% Rated Ipp	Peak Pulse Current in Amperes			
			1N5629A 6.8V	1N5645A 33V	1N5656A 91V	1N5665 190V
1	50	25	35.75	8.25	3.0	1.45
2	50	50	71.5	16.5	6.0	2.9
3	50	75	107.2	24.75	9.0	4.35
4	50	100	143.0	33.0	12.0	5.8

1.7 Initial Electrical Measurements

1.7.1 Prior to initiating the surge testing, all devices were measured and electrical parameters were recorded. The data taken includes; Breakdown Voltage (BV) at the specified Test Current level (It), Reverse Leakage Current (Ir) at the Reverse Stand-Off Voltage (Vr), and Clamping Voltage (Vc), at the 100% I_{pp} level. These parameters are those which are characteristic of Transient Voltage Suppressors.

1.7.2 Specifications described in the preceding paragraph are substantially different from those of a voltage regulator. An impedance at the knee and impedance at the test current are not very meaningful for a Transient Suppressor.

1.8 Operational Life Tests

1.8.1 Starting with the 6.8V group, the fifty devices from the previous Contract, NAS8-30811, were placed on test as described in paragraph 1.4 above and pulsed at the 25% I_{pp} level. Measurements of all parameters, including Breakdown Voltage, Reverse Leakage Current, and Clamping Voltage were measured at 7,500 additional pulses. The devices were then returned to life tests and electrical parameters were measured after a total additional 10,000 pulses, then 12,500, at 15,000 and at 20,000 pulses. The time interval between pulses was 1 minute. Total incurred pulses per device were 25,760.

1.8.2 After tests were completed on the 25% 6.8V group, the second group of devices was placed on test at 50% of the I_{pp} level with the measurements at the same intervals as described above. This process was repeated for the 75% and 100% I_{pp} levels for the 6.8V device. After tests were completed for the 6.8V devices, the same procedure was repeated for the 33V types and subsequently the 91V and 190V types.

1.9 Test Anomalies

1.9.1 The significant anomalies are defined in Table I in the footnotes at the bottom of the Table, with the major anomaly being failure of 16 devices of the 75% I_{pp} group in the 91V (1N5656A) type. Sixteen of the devices failed during final Vc measurement in Contract NAS8-30811 and seven failed during initial Vc measurement for the present Contract. This yielded only 23 devices for starting out of which all 23 completed the test. This could have been due to the fact that the failed devices were part of a different parent population. In the 33V group, seven devices were lost on final Vc measurement of Contract NAS8-30811; however, the remaining 43 devices completed an additional 20,000 pulses without failure. In the 190V group (1N5665), six units failed on final Vc measurement on Contract NAS8-30811 while 12 units failed on initial Vc and were performed in the present Contract. Out of the 75% I_{pp} group of the 190V (1N5665) type, there are only 4 devices started of which all 4 completed a full 20,000 pulses. Of this lot, 16 devices degraded on shelf storage between the time lapse of the end of Contract NAS8-30811 and the present effort.

1.9.2 It is of interest to note that at 100% Peak Pulse Current Levels all devices in the 6.8V, 33V, and 91V types failed. However, 6 out of 25 in the

190V group did complete a full 20,000 pulses without failure.

2.0 EVALUATION

2.1 Device Failure Profile

2.1.1 For statistical purposes there were insufficient failures in all lots, with the exception of the 100% I_{pp}, to be significant. Because of this, only the 100% I_{pp} level will be considered in this failure study. The Pulse Level at which failures occurred and the failure sequence for each of the 6.8V, 33V, 91V and 190V types are given in Tables III thru Table VI, inclusive. This information quantitatively yields the sequence of failure and the total pulses incurred by each device prior to failure. The Mean Surge Level of Pulse Failure $\bar{x}$ is also given on the Tables.

2.1.2 The information contained in each of these four tables includes the devices which were tested in both Contract Nos. NAS8-30811 and also the present effort. All cummulative failures are included in these Tables.

2.2 Failure Trends

2.2.1 It is interesting to observe from inspection of the information given in the aforementioned Tables that as the device breakdown voltage increases, the incurred pulses at which failure begins decreases. For example: The first six volt device failed on the 834th pulse, whereas the first 190V device failure occurred on the 38th pulse. For the 33V and 91V data, this appears to be reversed in that the 33V devices began failing earlier than the 91V devices.

2.3 Reliability Analysis

2.3.1 Qualifications of Analysis

The reduction of data and subsequent analysis of the test results contained on this study contract was performed by Professor Edward B. Haugen and Michael Jacob, at the University of Arizona. Mr. Jacob is a Graduate Student in the Doctoral Program, working toward his Degree in Reliability Analysis.

2.3.2 Objectives

The goal of this study was to obtain a meaningful curve for each TransZorb™ type and for the establishment of a meaningful MP^2BF for each voltage category and also an extrapolation from the curves of engineering use criteria. An idealized curve plotting the percent of rated Peak Pulse Current vs Mean Number of Peak Pulses Before Failure is shown in Fig. 4

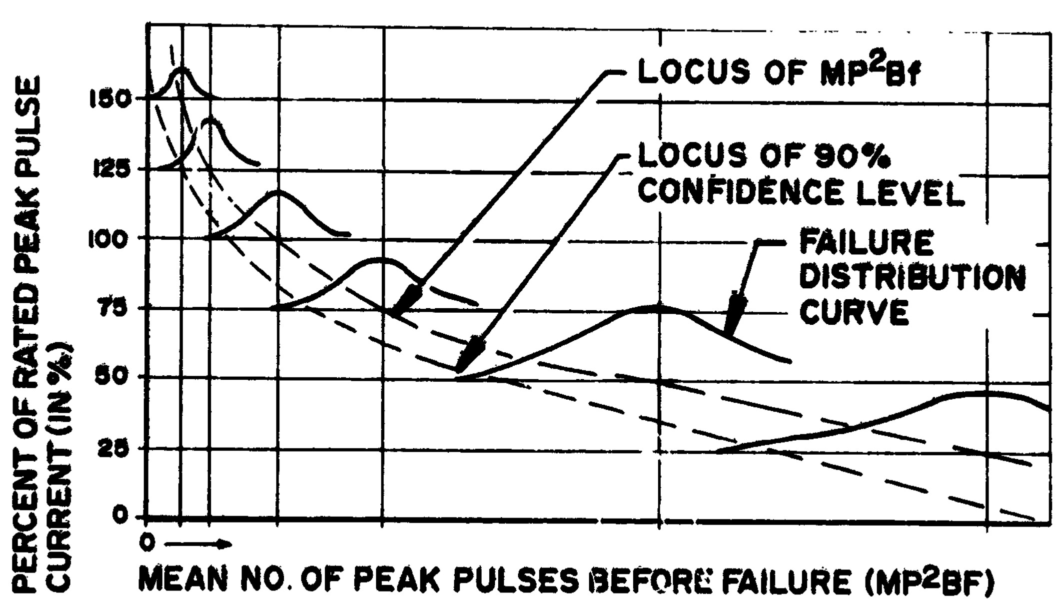


Fig. 4: Loci of Mean No. of Peak Pulses to Failure and 90% Confidence Level For Ideal Case

With a sufficient number of pulses, it should be possible to plot this curve for each of the device types selected for this test. This study is a continuation of Contract No. NAS8-30811 with sufficient number of pulses to extend the meaningfulness of the curve with a total of 26,760 pulses per device. As shown earlier in Table I, there were insufficient failures at the 75% Peak Pulse Current Level and below to produce meaningful data. The 100% Peak Pulse Current produced failures in all of the device categories in sufficient numbers to yield a meaningful curve.

2.3.3 Discussion of Tables III, IV, V, and VI

This information was gathered by pulsing each of the voltage categories at 100% of the Peak Pulse Rated Level, up through 25,760 pulses or complete failure of the lot, whichever occurs first. For the 6.8V, 33V, and 91V types, there was failure on all devices. However, six of the 190V devices survived a full 25,760 pulses. Due to certain anomalies, including loss of devices in handling and unexplained failures in testing, all of the 50 devices starting on the test were not accounted for. Nevertheless, the number is sufficient to represent meaningful data. In each group represented in the Tables, there appears to be a normal progression of failures as pulses were incurred by the devices.

2.3.4 Discussion of Tables VII thru X

Tables VII thru X represent an initial statistical analysis of the breakdown voltage of each device type. The Mean Breakdown Voltage and Standard Deviations are listed for the initial measurements

TABLE III

PULSE LEVEL AT WHICH FAILURE OCCURRED

DEVICE TYPE: 6.8V TRANSZORB™

(1N5629A)

FAILURE SEQUENCE	PULSES INCURRED	FAILURE SEQUENCE	PULSES INCURRED
1	834	26	9637
2	2054	27	9776
3	2581	28	9824
4	2767	29	10079
5	4201	30	10136
6	5762	31	10175
7	5806	32	10254
8	5899	33	10263
9	6214	34	10287
10	6658	35	10641
11	7206	36	11112
12	7591	37	11618
13	7853	38	11693
14	7861	39	11999
15	7922	40	12611
16	8380	41	12761
17	8454	42	12945
18	8603	43	13020
19	8842	44	13870
20	8883	45	14629
21	8966	46	15006
22	9209	47	15425
23	9387	48	20102
24	9453	49	20540
25	9454		

$n = 49 \qquad \bar{x} = 9100$

TABLE IV

PULSE LEVEL AT WHICH FAILURE OCCURRED
DEVICE TYPE: 33V TRANSZORB™

(1N5645A)

FAILURE SEQUENCE	PULSES INCURRED	FAILURE SEQUENCE	PULSES INCURRED
1	151	25	1615
2	152	26	1961
3	193	27	2008
4	503	28	2011
5	519	29	2059
6	920	30	2059
7	951	31	2063
8	962	32	2154
9	1098	33	2154
10	1113	34	2184
11	1129	35	2204
12	1194	36	2234
13	1216	37	2237
14	1254	38	2246
15	1267	39	2353
16	1317	40	2351
17	1328	41	2359
18	1361	42	2387
19	1374	43	2422
20	1375	44	2424
21	1424	45	2433
22	1474	46	2700
23	1492	47	2843
24	1520	48	2872

$n = 48 \quad \bar{x} = 1659$

TABLE V

PULSE LEVEL AT WHICH FAILURE OCCURRED
DEVICE TYPE: 91V TRANSZORB™

(1N5656A)

FAILURE SEQUENCE	PULSES INCURRED	FAILURE SEQUENCE	PULSES INCURRED
1	496	24	2227
2	547	25	2569
3	637	26	2607
4	678	27	2610
5	745	28	2627
6	852	29	2681
7	942	30	2683
8	1114	31	2687
9	1233	32	2708
10	1246	33	2822
11	1309	34	2965
12	1311	35	3173
13	1342	36	3177
14	1361	37	3195
15	1371	38	3410
16	1392	39	3469
17	1411	40	3664
18	1592	41	3785
19	1698	42	5081
20	1780	43	5209
21	2118	44	5495
22	2122	45	9698
23	2150	46	9895

$n = 46 \quad \bar{x} = 2562$

TABLE VI

PULSE LEVEL AT WHICH FAILURE OCCURRED
.3VICE TYPE: 190V TRANSZORB™
(1N5665)

FAILURE SEQUENCE	PULSES INCURRED	FAILURE SEQUENCE	PULSES INCURRED
1	38	22	419
2	60	23	422
3	72	24	425
4	86	25	439
5	95	26	1383
6	152	27	2307
7	183	28	2357
8	190	29	2381
9	195	30	2390
10	228	31	2605
11	254	32	2936
12	258	33	3994
13	258	34	3037
14	260	35	3047
15	308	36	4812
16	373	37	4815
17	375	38	5037
18	390	39	5037
19	396	40	5037
20	402	41	5093
21	406	42	5093

$n = 42 \quad \bar{x} = 1638$

TABLE VII

6.8V (1N5629A) STATISTICAL ANALYSIS OF BREAKDOWN VOLTAGE

PULSES		MEAN BV (VOLTS)	Standard Deviation
1N5629A	25%		
Initial		6.802	.105
7,500		6.798	.101
10,000		6.802	.099
12,500		6.790	.099
15,000		6.796	.103
Final		6.802	.103
1N5629A	50%		
Initial		6.796	.094
7,500		6.798	.096
10,000		6.796	.094
12,500		6.798	.097
15,000		6.798	.098
20,000		6.782	.101
1N5629A	75%		
Initial		6.792	.09
7,500		6.782	.089
10,000		6.784	.091
12,500		6.772	.087
15,000		6.763	.09
20,000		6.802	.085
1N5629A	100%		
Initial		6.748	.11
7,500		-	-
12,500		-	-

TABLE VIII

33V (1N5645A) STATISTICAL ANALYSIS OF BREAKDOWN VOLTAGE

PULSES		MEAN BV (VOLTS)	Standard Deviation
1N5645A	25%		
Initial		33.12	.57
7,500		33.13	.57
10,000		33.11	.57
12,500		33.14	.57
15,000		33.17	.57
Final		33.15	.57
1N5645A	50%		
Initial		33.24	.48
7,500		33.20	.48
10,000		33.19	.47
12,500		33.20	.48
15,000		33.19	.47
Final		33.22	.48
1N5645A	75%		
Initial		32.76	.35
7,500		32.77	.35
10,000		32.74	.35
12,500		32.74	.36
15,000		32.73	.35
Final		32.72	.35

TABLE IX

91V (1N5656A) STATISTICAL ANALYSIS OF BREAKDOWN VOLTAGE

PULSES		MEAN BV (VOLTS)	Standard Deviation
1N5656A	25%		
Initial		88.5	1.17
7,500		88.5	1.19
10,000		88.38	1.17
12,500		88.6	1.17
15,000		88.58	1.17
Final		88.60	1.17
1N5656A	50%		
Initial		88.98	1.71
7,500		89.06	1.71
10,000		89.04	1.71
12,500		89.00	1.7
15,000		88.85	1.69
1N5656A	75%		
Initial		88.78	1.5
7,500		88.74	1.53
10,000		88.78	1.53
12,500		88.78	1.53
15,000		88.74	1.53
Final		88.70	1.53

TABLE X

190V (IN5665) STATISTICAL ANALYSIS OF BREAKDOWN VOLTAGE

PULSES	MEAN BV (VOLTS)	Standard Deviation
IN5665 25%		
Initial	179.1	29.7
7,500	184.7	4.5
10,000	184.2	4.5
12,500	184.0	4.68
15,000	185.5	4.3
Final	187.1	4.2
IN5665 50%		
Initial	185.8	4.3
7,500	185.9	5.0
10,000	186.1	5.0
12,500	186.5	4.7
15,000	185.9	4.8
Final	187.2	4.8
IN5665 75%		
Initial	94.65	68.33
7,500	-	-
10,000	-	-
12,500	-	-
15,000	-	-
Final	-	-
IN5665 100%		
Initial	187.9	2.16

at the 7,500 Pulse Level, 10,000 Pulse Level, 12,500 Pulse Level, 15,000 Pulse Level and 20,000 Pulse Level of the Surge Testing performed in this effort. Slight changes in the Mean Breakdown Voltage (BV) and the Standard Deviation can be accounted for due to temperature variations at the time tests were taken, also in variations in the accuracy of the equipment at the time tests were made. The most significant change is represented by the 190V (1N5665) types. The high voltage types are more prone to voltage change because of junction surface sensitivity. Through adsorption and/or loss of electron-hole pair generators, the surface resistivity can be altered and subsequently the Breakdown Voltage changed, as is observed in Table X.

2.3.5 Discussion of Tables XI, XII, XIII and XIV

Although the Reverse Leakage Current for these devices are specified as 1000μA at standoff voltage for the 6.8V device and 5μA for the 33V, 91V and 190V types, the typical ratings are much lower than the maximum specified value. This is reflected in the Mean Ir as shown in Tables XI through XV.

2.3.6 It is of interest to note that at 100% Peak Pulse Current Levels, all devices in the 6.8V, 33V, and 91V types failed. However, 6 out of 25 in the 190V group did complete a full 20,000 cycles without failure.

TABLE XI

6.8V(1N5629A) STATISTICAL ANALYSIS OF REVERSE LEAKAGE CURRENT

PULSES		MEAN (I_r (μA)	Standard Deviation
1N5629A	25%		
Initial		228.	139.
7,500		224.	137.
10,000		224.	135.
12,500		226.	137.
15,000		225.	135.
Final		230.	138.
1N5629A	50%		
Initial		258.	151.
7,500		254.	142.
10,000		254.	142.
12,500		253.	142.
15,000		262.	145.
20,000		272.	149.
1N5629A	75%		
Initial		281.	211.
7,500		279.	180.
10,000		294.	194.
12,500		282.	173.
15,000		298.	195.
20,000		287.	183.
1N5629A	100%		
Initial		320.	183.
7,500		-	-
12,500		-	-

TABLE XII

33V (1N5645A) STATISTICAL ANALYSIS OF REVERSE LEAKAGE CURRENT

PULSES		MEAN (I_r (μA)	Standard Deviation
1N5645A	25%		
Initial		.247	.763
7,500		.195	.589
10,000		.208	.528
12,500		.213	.527
15,000		.211	.572
Final		.207	.507
1N5645A	50%		
Initial		.232	.306
7,500		.221	.287
10,000		.223	.280
12,500		.224	.279
15,000		.229	.295
Final		.241	.317
1N5645A	75%		
Initial		.035	.053
7,500		.033	.052
10,000		.032	.054
12,500		.036	.056
15,000		.033	.054
Final		.035	.055

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TABLE XIII

91V (1N5656A) STATISTICAL ANALYSIS OF REVERSE LEAKAGE CURRENT

PULSES		MEAN (I_r (μA)	Standard Deviation
1N5656A	25%		
Initial		.162	.681
7,500		.147	.670
10,000		.147	.673
12,500		.154	.678
15,000		.151	.672
Final		.155	.692
1N5656A	50%		
Initial		.049	.047
7,500		.044	.038
10,000		.041	.034
12,500		.043	.043
15,000		.041	.047
Final		.042	.052
1N5656A	75%		
Initial		.048	.026
7,500		.038	.020
10,000		.042	.024
12,500		.040	.024
15,000		.036	.022
Final		.037	.023

TABLE XIV

190V (1N5665) STATISTICAL ANALYSIS OF REVERSE LEAKAGE CURRENT

PULSES		MEAN I_r (μA)	Standard Deviation
1N5665	25%		
Initial		.174	.292
7,500		.230	.373
10,000		.214	.383
12,500		.232	.401
15,000		.164	.278
Final		.118	.237
1N5665	50%		
Initial		.183	.415
7,500		.366	.958
10,000		.393	1.062
12,500		.300	.920
15,000		.369	.975
Final		.279	.945
1N5665	75%		
Initial		-	-
7,500		-	-
10,000		-	-
12,500		-	-
15,000		-	-
Final		-	-
1N5665	100%		
Initial		.130	.424

2.3.7 Discussion of Normal Distribution Curves

Fig. 5 through Fig. 8 represent the Normal Distribution Curves for the 100% Peak Pulse Current Plot of the failures for the 6.8V, 33V, 91V and 190V device types. In all cases there were sufficient failures to yield a reasonably sufficient number to permit statistical evaluation. The curve on Fig. 5 represents the fit of the data to the normal distribution for the 6.8V (1N5629A), 100% Peak Pulse Current tests. From inspection of the curve the data does appear to fit the normal distribution reasonably well with a very good fit between approximately 5,000 pulses and 13,000 pulses. The extreme ends of the curve have points which deviate substantially from the rest. Fig. 6 represents the fit of the data to the normal distribution for the 33V (1N5645A), 100% Peak Pulse Current tests. It can be observed from inspection that there appears to be two distinct populations with the Mean Failure Point for one occurring at approximately 1,250 pulses and the Mean Failure Point for the other distribution occurring at approximately 2,200 pulses. Again, as compared with Fig. 5, the few devices at the extreme ends of the curve do not fit with the balance of the distribution. Fig. 7 illustrates the fit of the data to the normal distribution for the 91V (1N5656A), 100% Peak Pulse Current tests. The data appears to give a reasonable fit to the normal distribution. Again, as compared to the 6.8V and the 33V type devices, there are outlyers at the extreme ends of the distribution. Fig. 8 represents the fit of the data to the normal distribution for the 190V (1N5665) 100% Peak Pulse Current tests. From inspection it

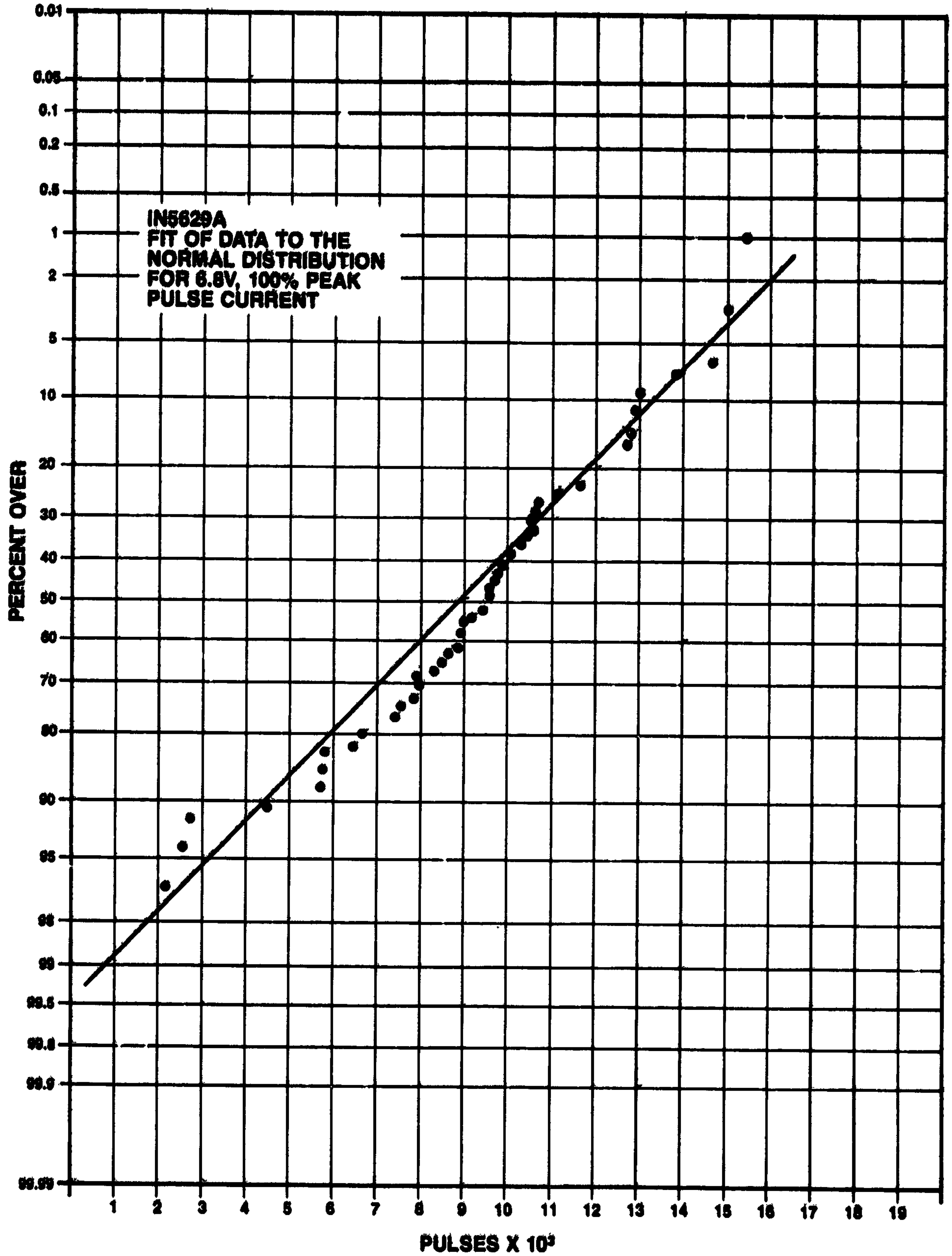

Fig. 5: Fit of Data to Normal Distribution Curve for 6.8V (IN5629A) TransZorb™

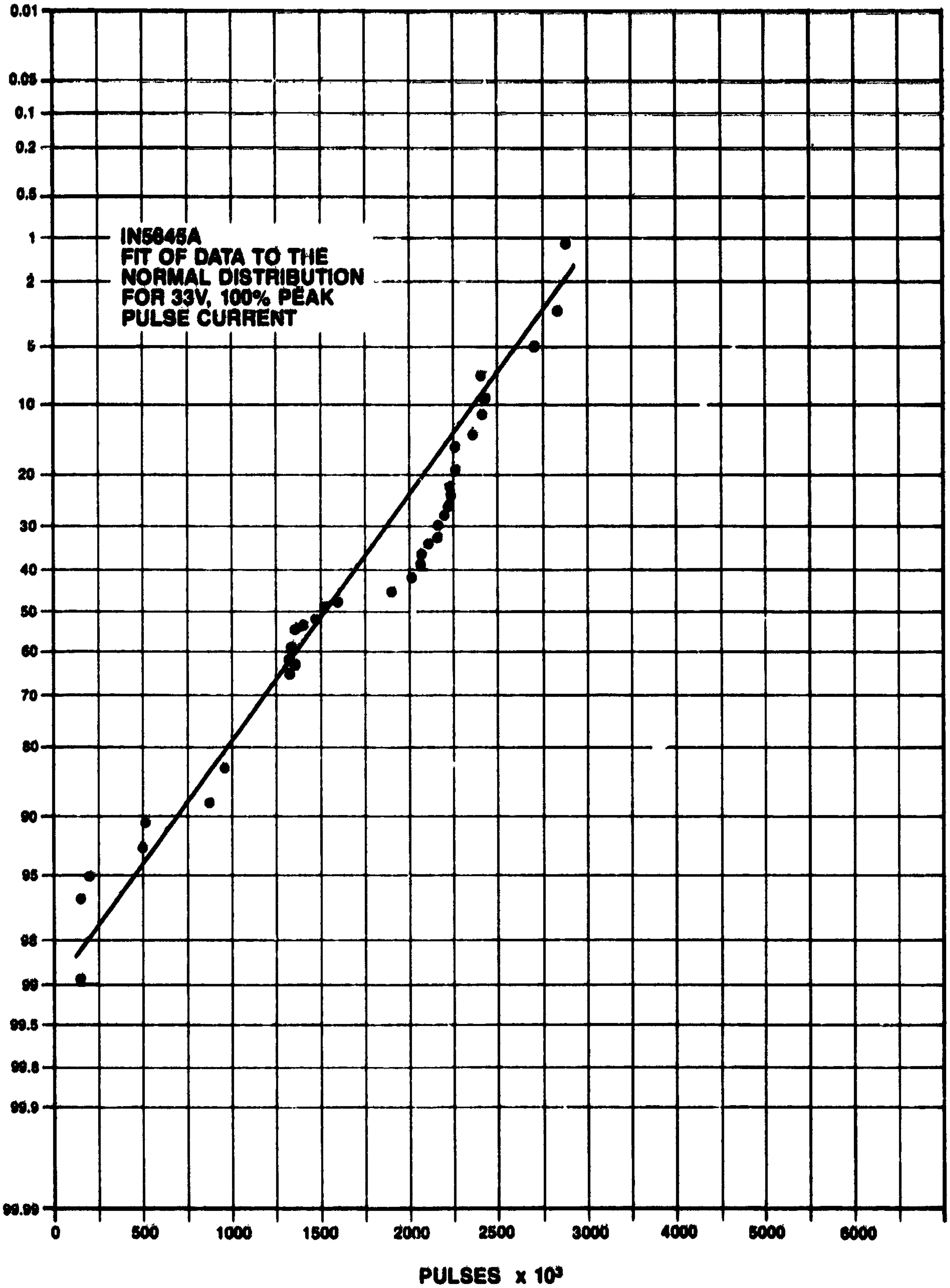

Fig. 6: Fit of Data to Normal Distribution Curve for 33V (IN5645A) TransZorb ™

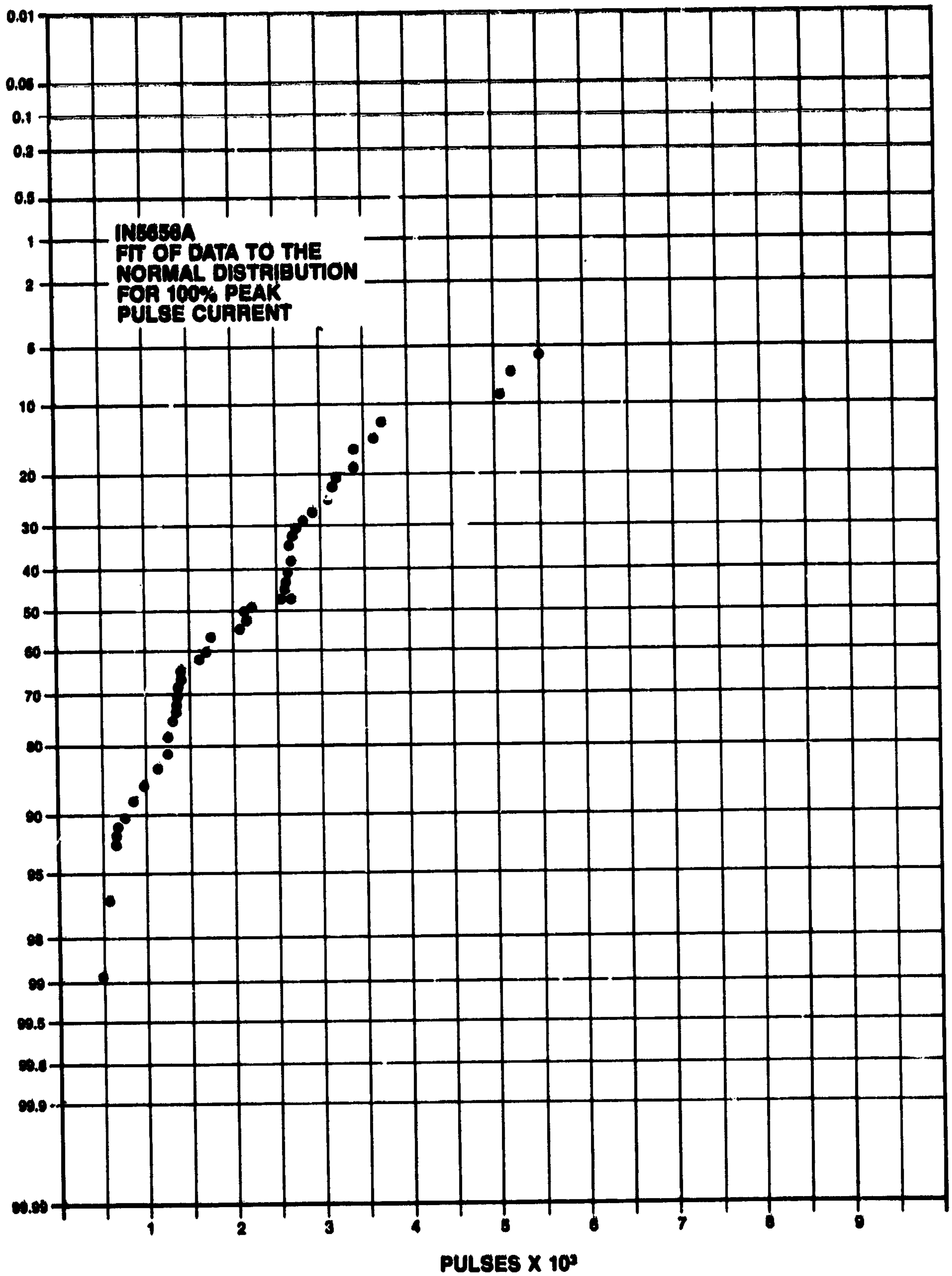

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Fig. 7: Fit of Data to Normal Distribution Curve for 91V (IN5656A) TransZorb™

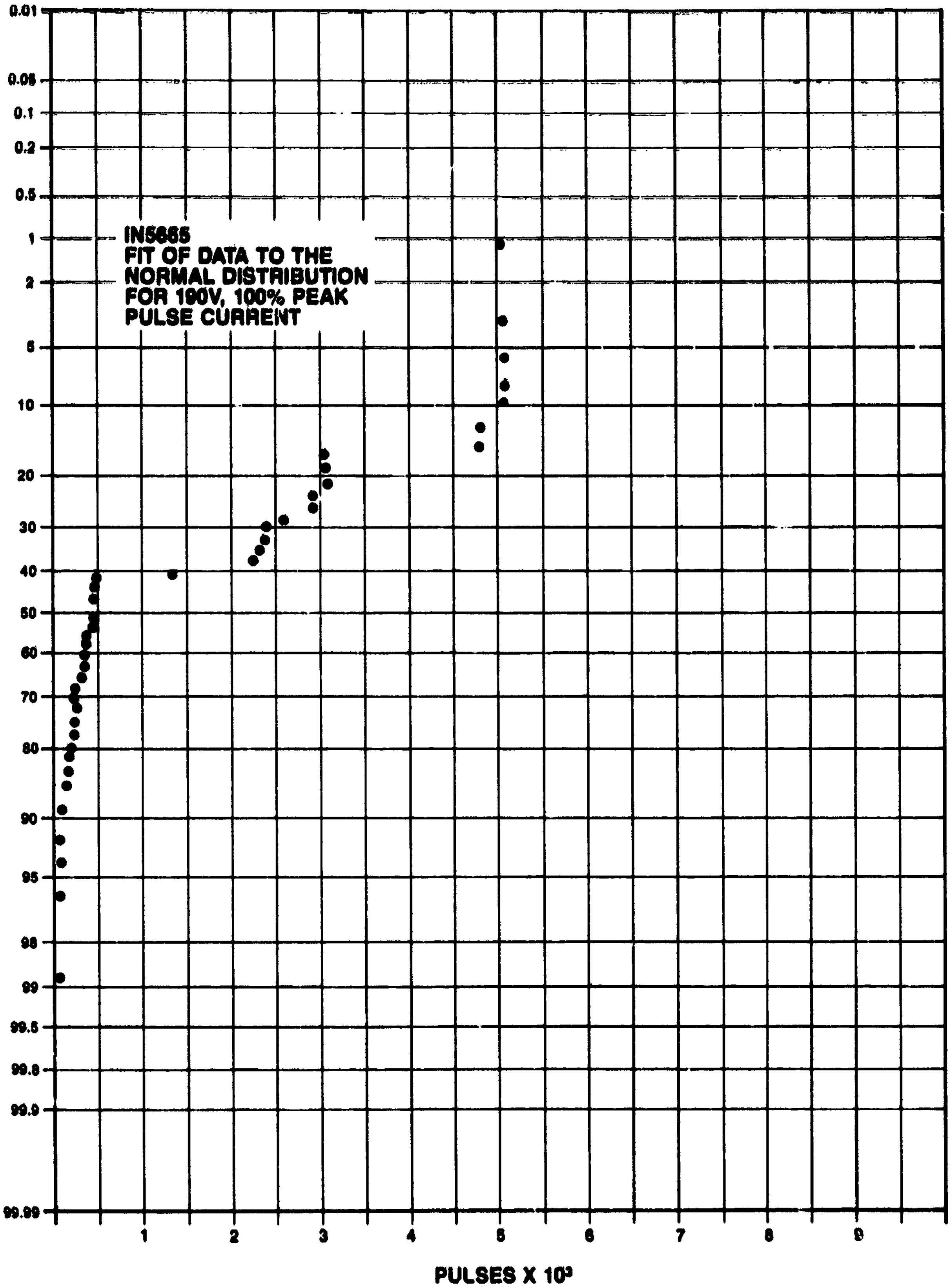

Fig. 8: Fit of Data to Normal Distribution Curve for 190V (IN5665) TransZorb™

appears that there ar· three distinct parent populations represented by this curve, one group having a relatively high early failure rate, under 500 pulses, the second group in the 2,000 to 3,000 pulse range for failures and the third group at approximately 5,000 pulses prior to failure.

2.3.8 Data Reduction and Fabrication of MP^2BF Curves

Results are given in Fig. 9 through Fig. 12 inclusive, summarizing MP^2BF at the various levels of Ipp for all devices in the current effort and also including the tests performed in Contract NAS8-30811. The MP^2BF curves are plotted with both Mean and a 90% confidence level for each device type. The solid portion of the line in the curves is derived from the data and the dotted portion of the line represents extrapolated data from those lots in which there were none or insufficient failures to generate meaningful data.

2.4 Design Engineering Criteria

2.4.1 Application of Data

TransZorb™ Transient Voltage Suppressors were designed to protect voltage sensitive elements from transients and over the past several years many applications have been found for their use. These uses are rather extensive in electronic equipment containing sensitive electronic components such as integrated circuits and MOS device types. Some ICs have been destroyed with transient energies in the range of 10 to 100 microjoules with MOS devices destroyed with lower transient energies. Most larger power semicon-

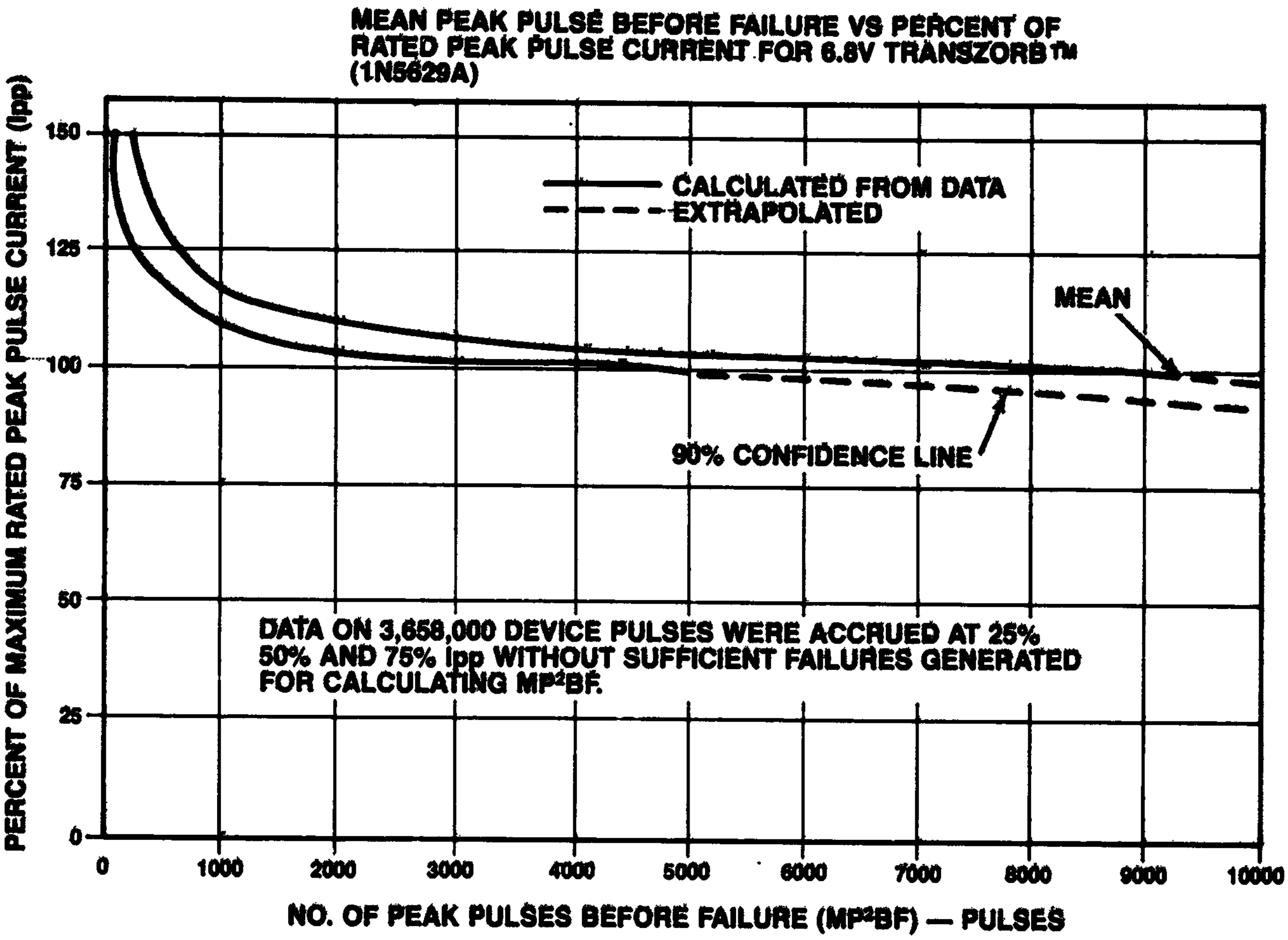

Fig. 9: Summary for 6.8V TransZorb™ (1N5629A)

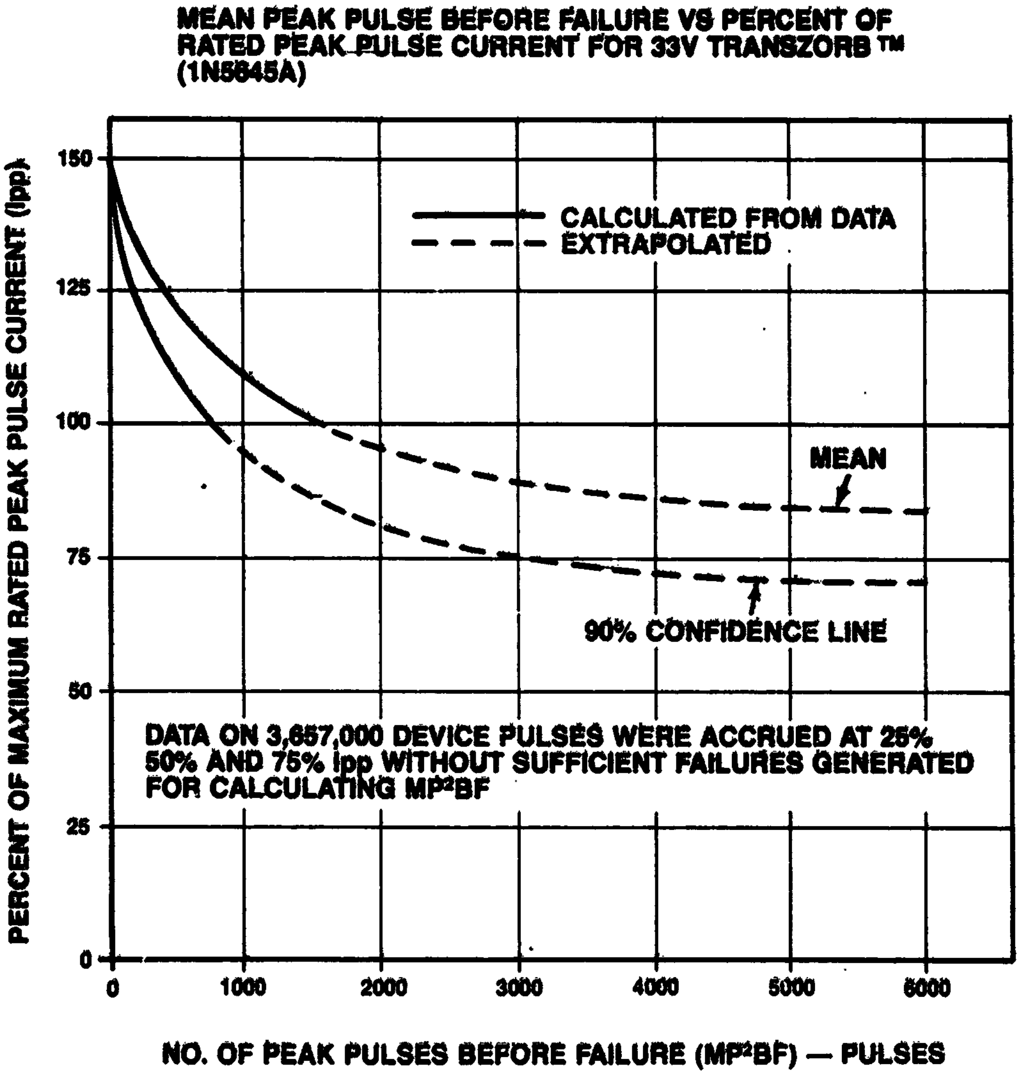

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Fig. 10: Summary for 33V TransZorb ™ (1N5645A)

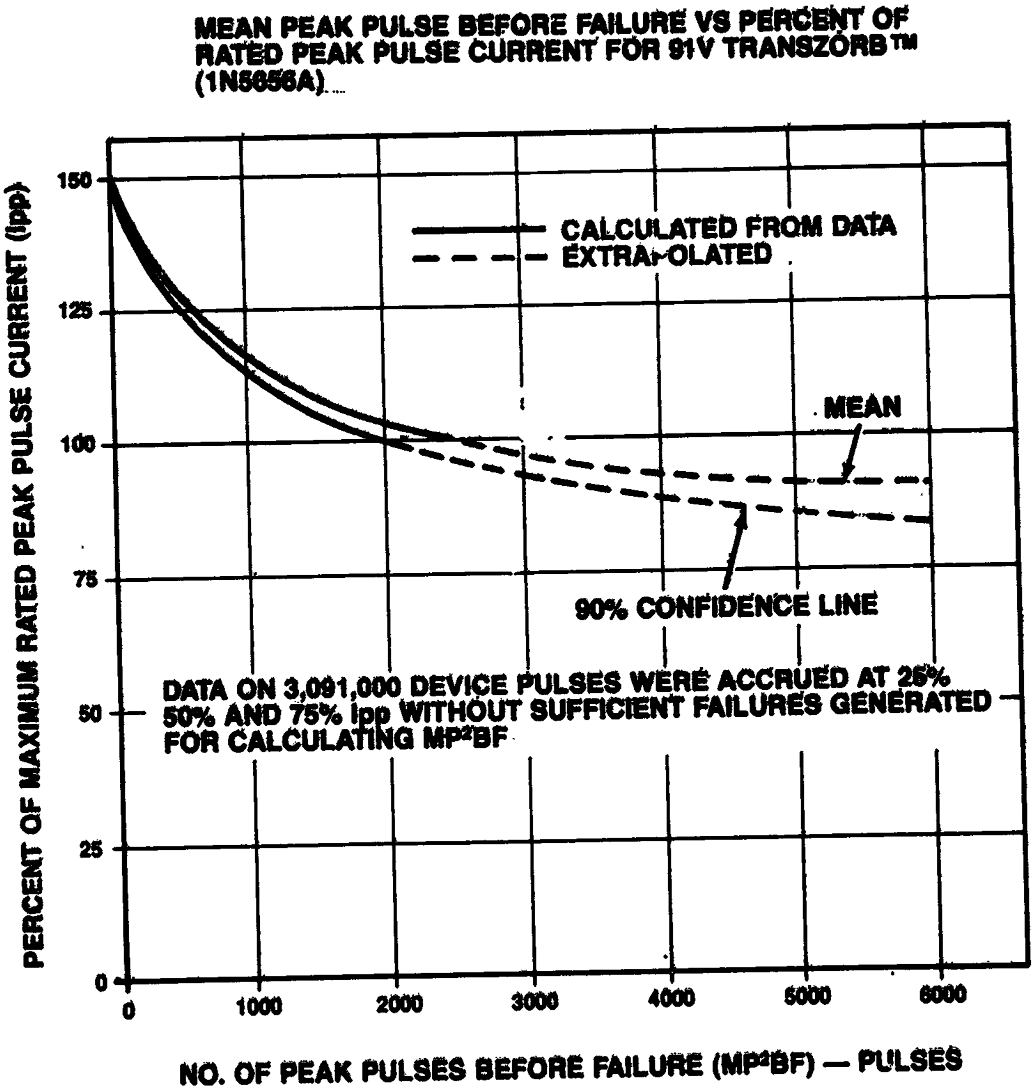

Fig. 11: Summary for 91V TransZorb ™ (1N5656A)

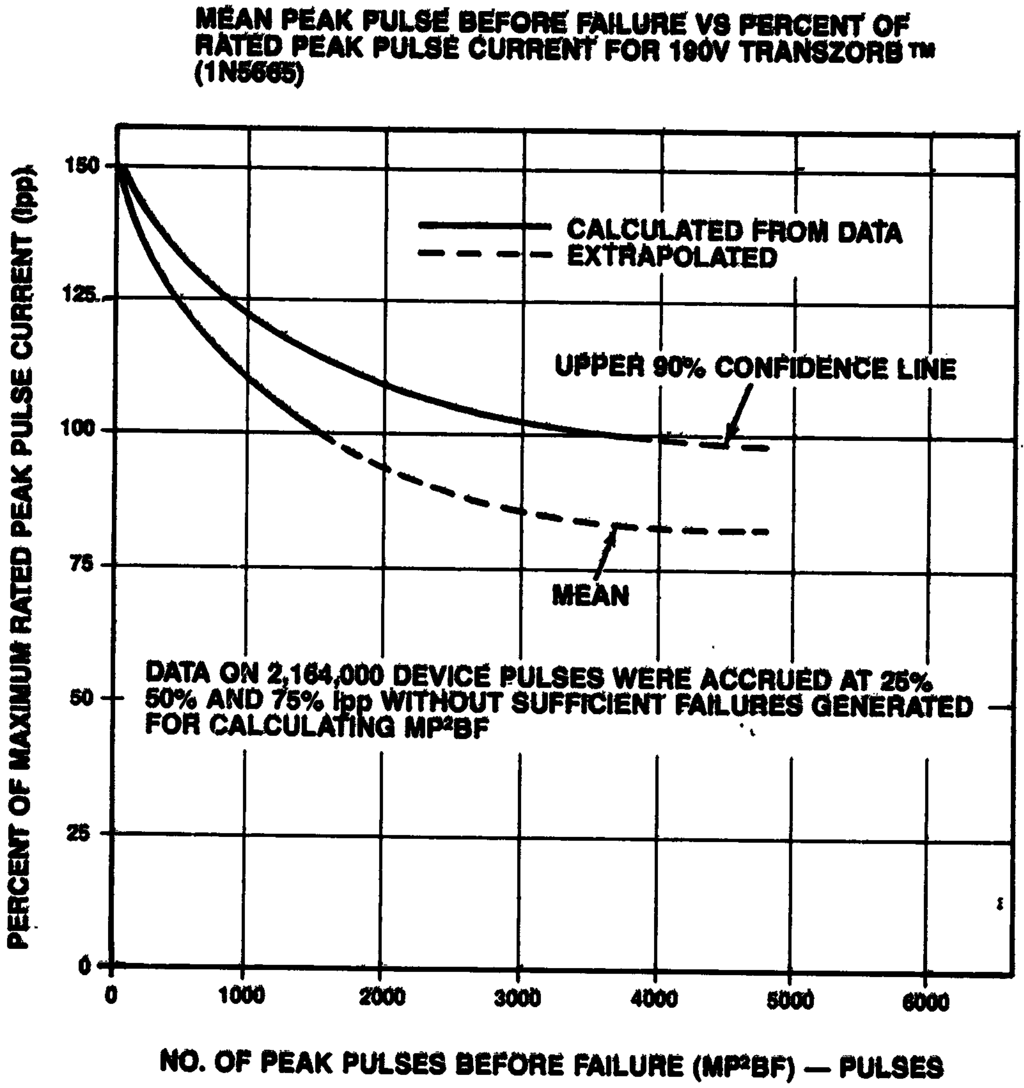

Fig. 12: Summary for 190V TransZorb™ (1N5665)

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ductors have not required the low clamping voltage protection offered by solid-state transient voltage suppressors because of their inherent hardness against transient voltages. Some power devices, especially fast switching transistors, can be quite vulnerable to transient voltages and these devices have been found to require transient voltage suppression. Since the largest demand for transient suppression is in the microcircuitry field which utilizes devices operating below 50V, this is within the operational range of the higher reliability TransZorb.™ In addition, the major portion of logic ICs are operated at 5V or lower which emphasizes a need for low voltage transient suppression. The reliability of the TransZorb Transient Voltage Suppressor, as shown in this report, is maximum in the low voltage area, where the greatest number of circuit requirements exists. Even at the overstressed conditions of 125% Rated Peak Pulse Current, as shown in Fig. 18, Page 31, of the Surge Life Transient Voltage Suppressor Final Report of Contract NAS8-30811, the 6.8V TransZorb does provide some protection.

2.4.2 Guidelines for TransZorb Selection

The TransZorb has been manufactured and in service on the market for more than six years with an excellent reported field history. Applications include providing protection from a broad spectrum of transient sources, including induced lightning, inductive switching, transients, high voltage disconnects, static discharge, and many others. In closed systems where transients are anticipated and can be well defined, it is much easier to select a device or combination of devices to protect the more sensitive elements of the system.

A general guideline for selecting the right Transient Voltage Suppressor is listed below with reference to the data sheet as listed in the appendix. Please refer to the appendix for optimum meaning of the selection criteria below.

2.4.2.1 Determine the Maximum D.C. or Continuous Operating Voltage, which is a nominal circuit voltage plus the tolerance, on the high side, giving maximum voltage of the circuit.

2.4.2.2 Select a Transient Voltage Suppressor to have a reverse standoff voltage equal to or greater than the maximum circuit voltage, as defined in the paragraph immediately above. This selection will allow for operating over the temperature range of $-65^{\circ}C$ to $+175^{\circ}C$.

2.4.2.3 Define the waveshape or source of the transient and duration of the pulse. Determine the maximum Peak Pulse Power of the transient. If the pulse is exponential decay, define the pulse time for decay to 50% of the crest value.

2.4.2.4 Check the Peak Pulse Current on the data sheet to assure that the current of the pulse is within the maximum rating of the suppressor for a 1 millisecond pulse. An example would be for the standard 1N5629A (6.8V), for a current rating of 143A maximum, or 100A maximum for the 1N5633A (10V), or, for example, 19.5A maximum for the 1N5651A (56V).

2.4.2.5 If the pulse decays exponentially, but different than the 1 millisecond which is specified on the data sheet, check the chart entitled Peak Pulse Power vs Pulse Time For Pulse Duration.

2.4.2.6 If the Peak Pulse Power is within the maximum rating of the suppressor, for example, 1.5kW per 1 millisecond, or 6.5kW for a 40 microsecond exponential decay pulse, use the device as selected. Determine the worst case Peak Pulse Power by multiplying the Maximum Clamping Voltage by the Peak Pulse Current for any given pulse duration.

2.4.2.7 If the pulse is a non-repetitive square wave, derate the Transient Suppressor to 66% of the maximum value under exponential decay conditions. If the pulse is a nonrepetivive one half sine wave, derate the suppressor Peak Pulse Power to 75% of the maximum capability.

2.4.2.8 If the pulse is a rapidly damped sine wave or rapidly damped square wave with one time constant of eight cycles or less, rate the device the same as if the device were subjected to only one pulse as defined in the paragraph above.

2.4.2.9 If the Peak Pulse Power of the incident pulse is greater than the rating of the suppressor, devices may be stacked in series to increase the power rating for voltages usually above 20 volts. An example of this would be a 1.5kW, 100V suppressor, which is inadequate, and a 3kW peak power is required. The most advantageous way to achieve this power level is to stack in series two each of a 50V $\pm$ 5% tolerance suppressor. The total Peak Pulse Power dissipation would then be twice that of a 1.5kW device, or 3kW. Stacking three each of a 33V $\pm$ 5% device would yield a 4.5kW Peak Pulse Power and stacking 4 each of the 25V $\pm$ 5% device would give a Peak Pulse Power of 6kW. The devices can be stacked almost without limit.

In practice they have been stacked to in excess of 180 devices with good reliability. However, 5% tolerance devices of the same voltage must be used to insure even loading of the devices. When the power rating is doubled, notice that the current rating is doubled also.

2.4.2.10 If it is impossible to achieve the necessary power rating by stacking the devices in series, parallel stacking can be done effectively for voltages below 100V. Close matching, about 20mV between each device, is necessary to assure even loading of the transient between the suppressors. This is usually done at the factory for optimum results.

2.4.2.11 Observe that the Maximum Clamping Voltage is 1.33 x the Breakdown Voltage. If this Maximum Clamping Voltage exceeds the circuit limitations, devices can be derated to reduce the clamping factor. For example, two devices in series have a clamping factor of approximately 1.2 as compared to the clamping factor of 1.3 for a single device.

2.4.2.12 If the suppressor is used on dc or low frequency signal lines, the capacitance of the suppressor will not attenuate or alter the circuit conditions. However, if the frequency is quite high, and insertion loss occurs, methods of effectively reducing capacitance by adding low capacitance diodes in series have been developed.

2.4.3 Guidelines for Protection Against Static Discharge

With the introduction of sensitive semiconductor devices such as metal oxide semiconductor structures, the requirement for static discharge protection has increased substantially. In order to understand the nature of the destructive levels of static discharge, one must bear in mind that the rise times are quite fast which produces the destructive effects. Studies performed by Van Keuren of RCA have shown that fast rise time short duration pulses have destroyed MOS semiconductor devices with energy levels less than 5μJ.[1] Some CMOS threshold levels as described by Van Keuren are shown in Table XV. Although the work performed by Van Keuren was primarily to study the effects of EMP (electromagnetic pulse) as generated by an exoatmospheric nuclear detonation, this is applicable to static discharge by virtue of the fast rise-time of static discharge.

The waveforms of static discharge are described by T. J. Tucker[2] and shown in Fig. 13. It is observed from these curves which show both calculated and experimental values that the fast rise-times are of the order of 1 to 2kV per nanosecond. Under these very fast-rise-times, inductance effects of the protector wiring can be detrimental. Generation of voltage determined by the inductance and time rate change of current can generate a secondary voltage which can be destructive to sensitive components.

[1] E. Van Keuren, Effects of EMP Induced Transients on Integrated Circuits, IEEE Electromagnetic Compatibility Symposium Record, 75CH1002-5 EMC, 1975

[2] T. J. Tucker, Spark Initiation Requirements of a Secondary Explosive, Annals of The New York Academy of Sciences, Volume 152, Article I, Pages 643-653, 1968

TABLE XV: CMOS FAILURE THRESHOLD LEVELS

	Pulse Widths	25nSEC	Min Values 100nSEC	1μSEC
CD4001A Input	Volts	350	150	60
	Pulse Current (Amps)	10	7	1.2
	Watts	3500	1050	72
	Microjoules	87.5	105	72
D4016 Input	Volts	105	120	20
	Pulse Current (Amps)	2.0	4.0	2.0
	Watts	300	480	40
	Microjoules	7.5	48	40
CD4049 Output	Volts	150	25	12
	Pulse Current (Amps)	15	6.0	3.0
	Watts	2250	150	36
	Microjoules	56.2	15	36
DC4050 Output	Volts	170	60	20
	Pulse Current (Amps)	13	7.5	3.0
	Watts	2210	450	60
	Microjoules	55.2	45	60
CD4050 Input	Volts	120	60	24
	Pulse Current (Amps)	4.0	4.0	2.0
	Watts	480	240	48
	Microjoules	12.0	24	48
CD4071 Input	Volts	80	150	250
	Pulse Current (Amps)	5.2	0.3	0.4
	Watts	416	45	100
	Microjoules	10.4	4.5	100

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This has been previously described and investigated by Clark and Winters [3].

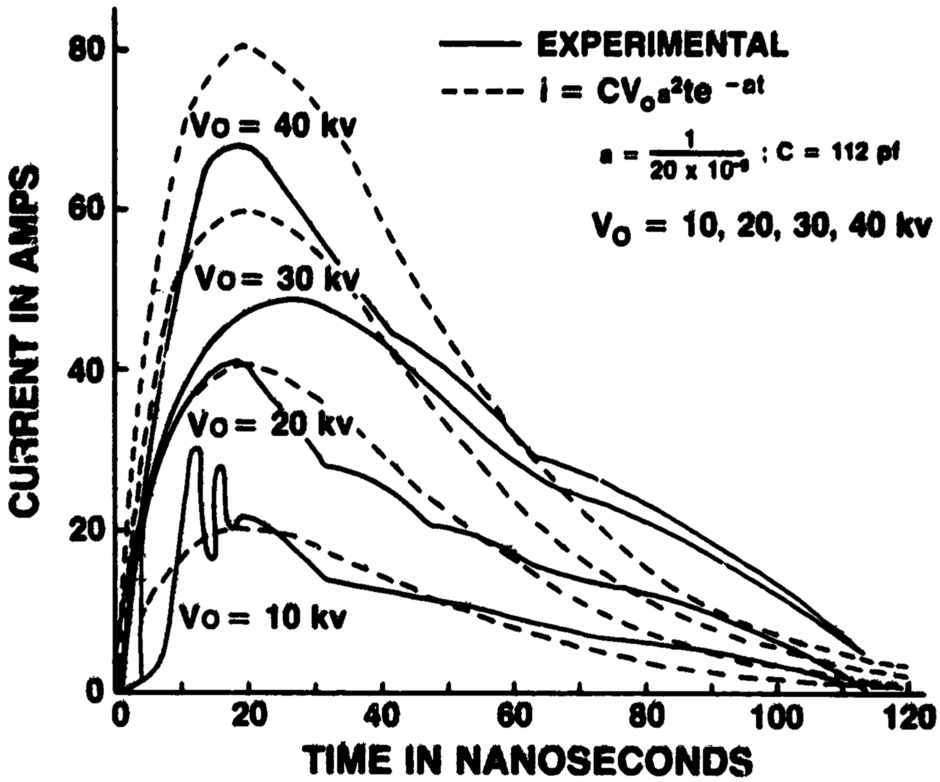

Fig. 13: Static Discharge Curve

(3) O.M. Clark and R.D. Winters, Feasibility Study for EMP Terminal Protection, Harry Diamond Laboratories, Contract No. DAAG39-72-C0044, 1973

3.0 Conclusion

3.1 Qualification of Results

All samples were pulsed out through a total of 25,760 pulses or until all devices in that lot failed, whichever occurred first. For the 100% peak pulse current groups, there were sufficient failures for an evaluation which would produce meaningful results. All devices in the 6.8V, 33V, and 91V, groups failed during 100% Peak Pulse testing. Most of the 190V types failed giving sufficient data for a sufficient evaluation. However, for the 75% peak pulse current levels and below there were insufficient failures for gathering meaningful results and subsequently it was necessary to extrapolate the MP^2BF curves at current levels of 75% Peak Pulse Current and below.

In Figures 14, 15, 16 and 17 are shown histograms and statistical curves on the failures patterns of the various device groups at 100% Peak Pulse Current. The 6.8V device types appear to follow a reasonably well developed pattern. However, the 33V devices appear to have representation from two different parent populations as observed on the histogram spread. The histogram and failure pattern of the 91V type as shown in Fig. 16 represents a relatively tight distribution compared to the other device types making it appear that the parent population was singular and the devices were approximately homogeneous in long term pulse characteristics. The 190V type obviously is representative of at least 3 parent populations based upon an inspection of the histogram profile. The 190V type has been redesigned since this program has commenced and the information

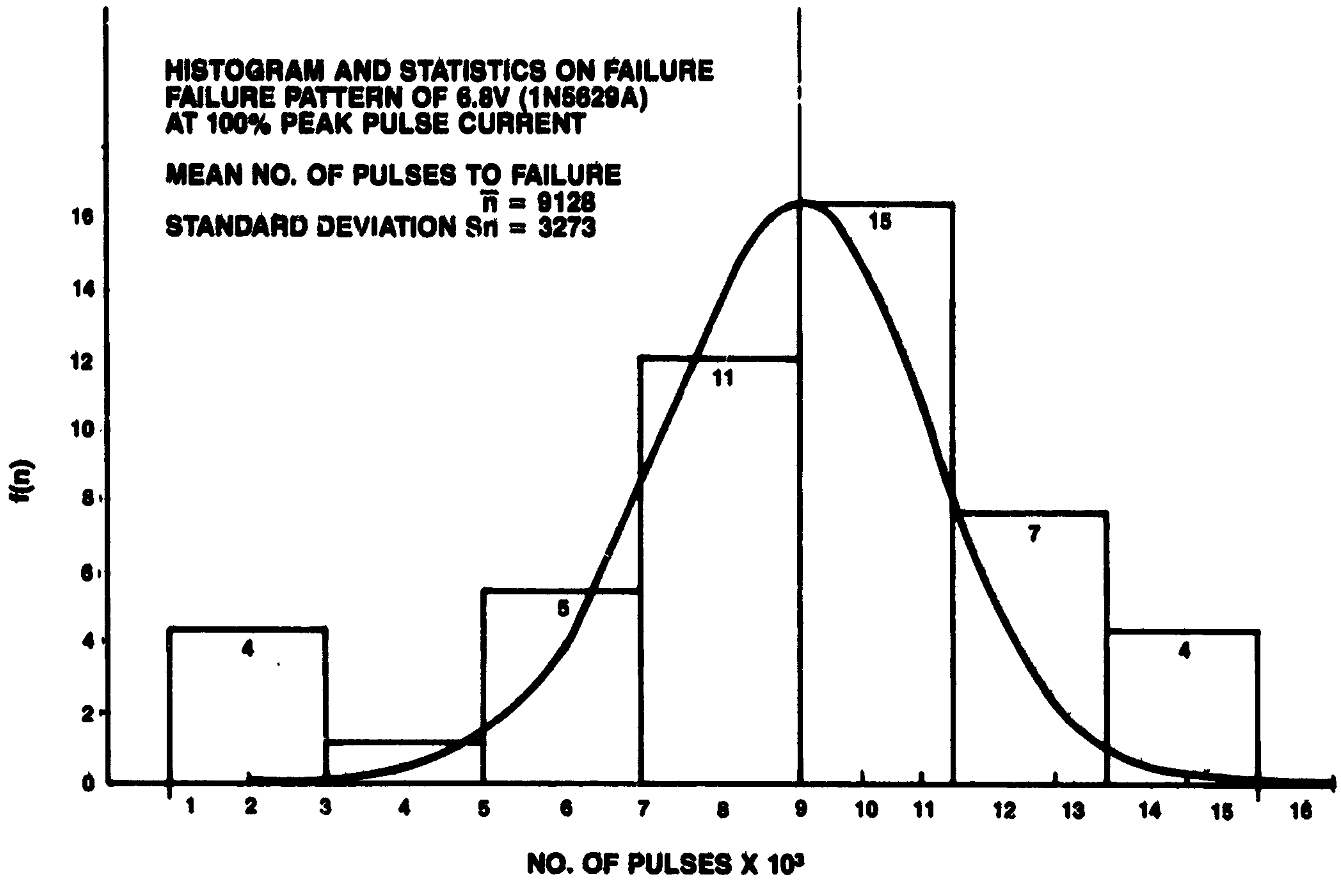

Fig. 14: Failure Statistics for 6.8V (IN5629A)

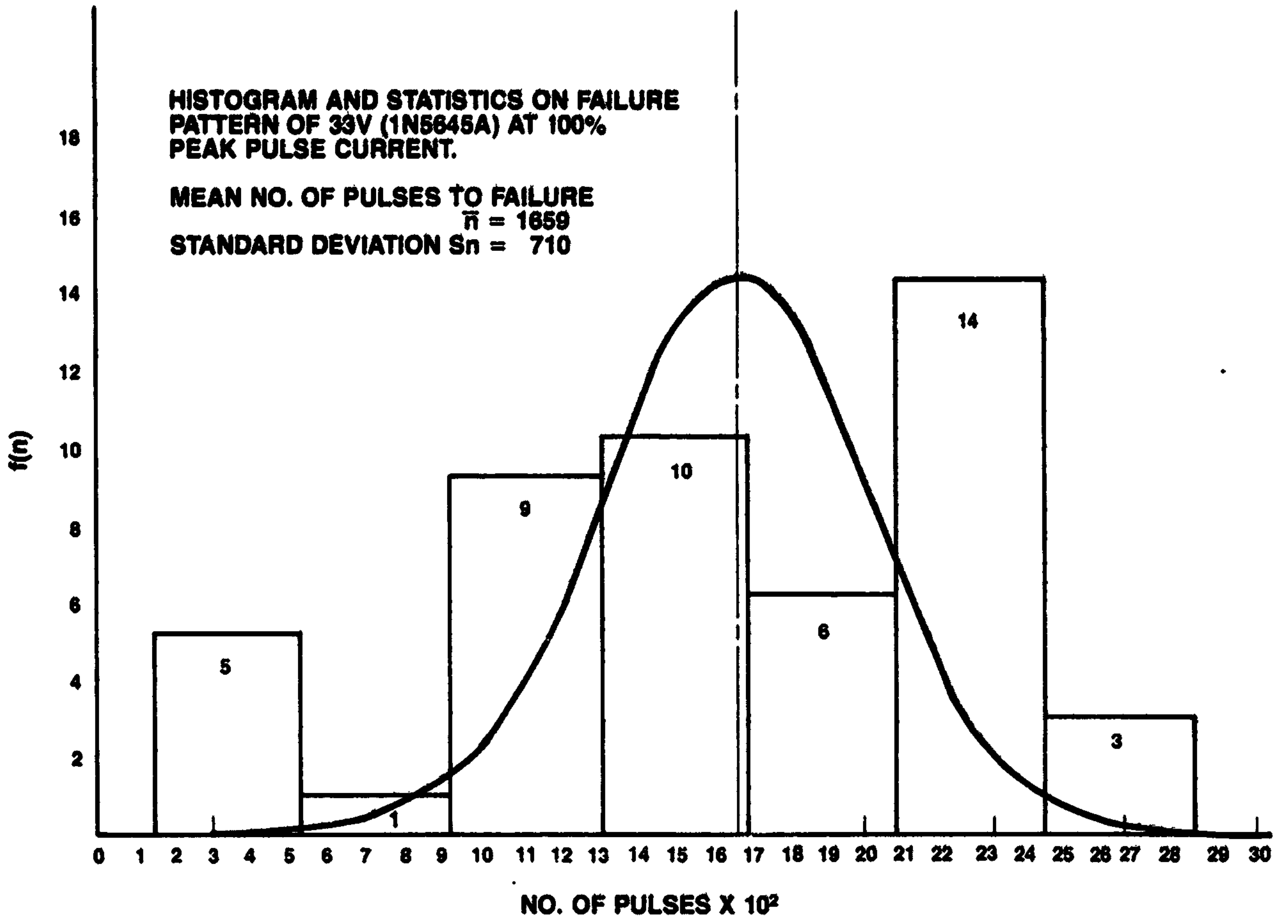

Fig. 15: Failure Statistics for 33V (IN5645A)

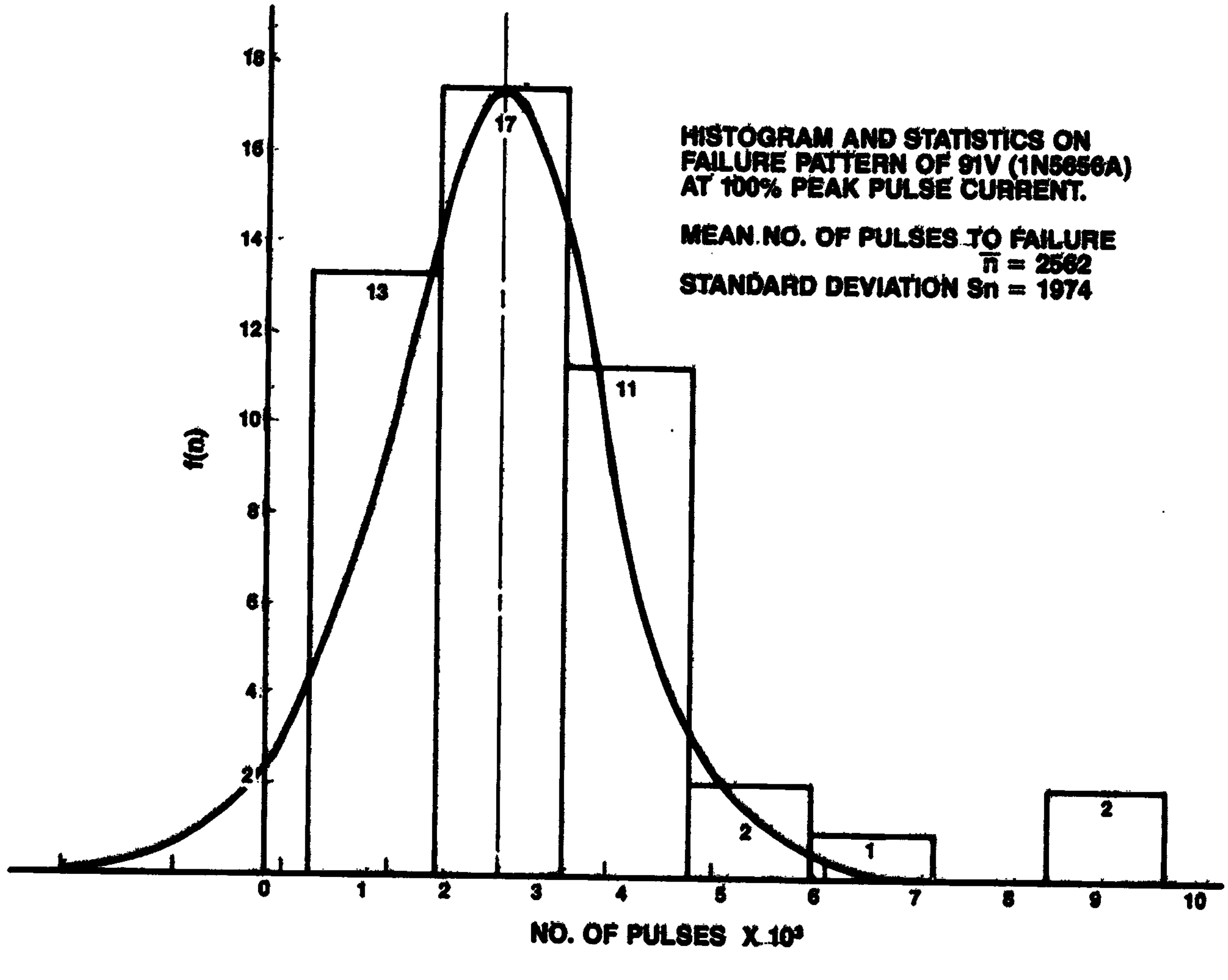

Fig. 16: Failure Statistics for 91V (1N5656A)

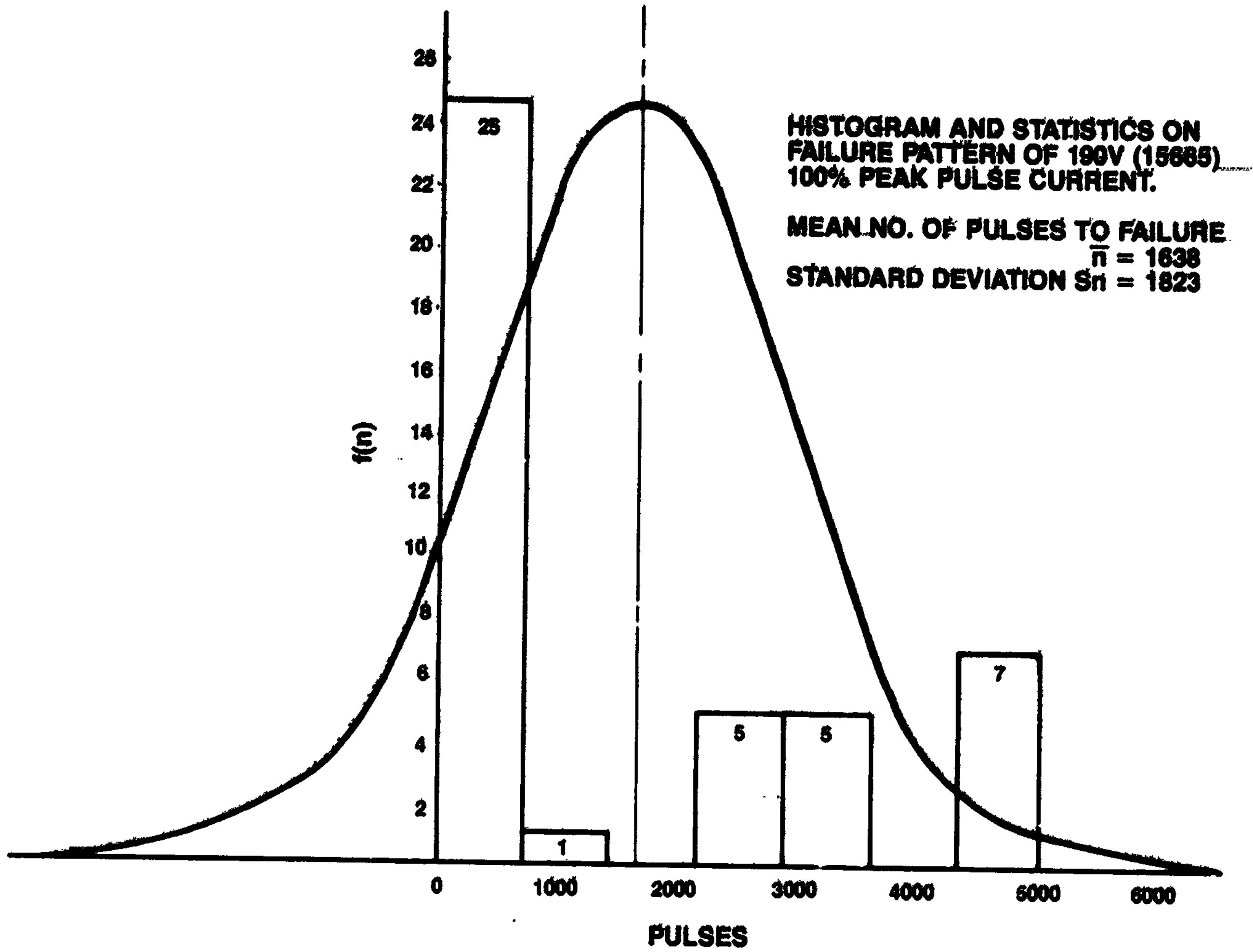

Fig. 17: Failure Statistics for 190V (IN5665)

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gathered in this testing program supported the need for redesign. Future efforts will probably be required to determine the reliability which is estimated to be approximately that of the 91V device types.

3.2 Test Limitations

The efforts described in this report represent one of the first attempts to perform a meaningful reliability study and analysis of solid state transient voltage suppressors. The maximum number of pulses was extended from 5,760 as defined in the original contract, NAS8-30811, to a total of 25,760 pulses as defined in the present effort. This appeared to be sufficient to describe the reliability at the 100% Peak Pulse Current level; however, additional testing would be required to define a meaningful reliability at lower current levels.

3.3 Failure Analysis

From analyzing the failures which were generated in this test, it was observed that all devices failed in the shorted mode which was expected. The two basic mechanisms of failure identifiable in transient voltage suppressors as shown in this study appear to be over stressing in excess of 100% of the Peak Pulse Current levels where devices failed short under a relatively small number of pulses and a long term wear out which exists under the maximum Peak Pulse Current levels. At the 75% Peak Current level, the devices appear to exhibit no failures and as a result none of these were analyzed during this effort. Of the devices which failed earlier in tests, 6.8V devices appeared to exhibit internal shorting as observed in the data published previously with 6 out of 10 devices shorting internally. The higher voltage devices, 33V through 190V types, exhibited a large number of shorts at the die edge. There appeared to be no difference in this pattern comparing the early failures with the later failures in terms of cumulative device test pulses. Under prolonged conditions under which the devices operated at full capacity, there definitely appears to be a change in the intermetallic structure as shown in the scanning electron photomicrographs in the failure analysis section in the Appendix. The mechanism which occurs appears to be such that there is an embrittlement and subsequent separation of the silicon junction from the silver heat sink beginning at the periphery which may slowly reduce the heat sinking ability of the device. Over a period of time, the temperature of the junction could continue to increase with subsequent over stressing due to elevated temperatures resulting in a fail-short mode.

3.4 Probable Cause of Failures

The low voltage devices show a higher degree of reliability than do the high voltage types. This phenomenon is characteristic of virtually all semiconductors. Avalanche breakdown occurs at macroplasma sites as determined by Chenowyth and MacKay, of Bell Telephone Laboratories, which result from a discontinuity within the crystal latice. Each of these sites carries a current of the order of 50 to 100 microamperes. For a given amount of power dissipation, a high voltage device will have fewer sites in parallel conduction, subsequently a higher dissipation at each site. Low voltage devices, such as 6.8V types experience a breakdown which is a combination of both avalanche and field emission due to the high electric field at breakdown, about 1 million volts per centimeter.

3.5 Failure Anomalies

Some anomalies which exist in the data need a few words of explanation. In Fig. 5, Fig. 6 and Fig. 7 the fit of the data to the normal distribution is shown for the 6.8V, 33V and the 91V types. For all three types, there appears to be a definite discontinuity at the extreme ends of the curve. This appeared to manifest itself in 30 failures and then followed by a few devices which outlasted the rest by a substantial margin at the completion of the test. The 33V type as illustrated in Fig. 6 and also in Fig. 15 definitely displayed the characteristics of two separate parent populations. Both the 6.8V and the 91V types appeared to fit good distribution curves as illustrated in Fig. 14 and Fig. 16, with the 6.8V manifesting premature failures and the 91V device manifesting samples which were exceptionally good at the high end of the curve. From Fig. 8 and Fig. 17 it is readily apparent that for the 190V types, three separate parent populations existed from which the samples were taken. The first group experienced relatively high mortality within the first 500 pulses. The second group extended out to failures in the 2,300 to slightly over 3,000 pulse range, whereas the balance extended out to the 5,000 pulse range prior to significant failures. It is interesting to note that out of the 190V types, six devices withstood the entire 25,760 pulses without failure.

3.6 Electrical Parameter Stability

Tables VII through X inclusively illustrate the statistical analysis of the Breakdown Voltage, including the Mean Breakdown Voltage and Standard Deviation for the 6.8V, 33V, 91V and 190V Transient Suppressor types. It can be seen from this data that there is extremely good stability in the Breakdown Voltage and Standard Deviation for the 6.8V, 33V, and 91V types, with a variation of the order of 1 part per 1,000 in the Breakdown Voltage. This can be readily accounted for by changes in temperature during the time of parameter measurement and also in slight drifting in the equipment inbetween the periods at which the readings were made. The 190V type does display a substantial drift in the upper direction from the initial to the final measurements. The higher voltage types are more prone to change because of the basic resistivity of which the junctions are made. The higher resistivity, the greater the sensitivity. Foreign materials adsorbing on the surface can alter the resistivity and substantially affect the Breakdown Voltage of the order of several percent. Tables XII, XIII and XIV list the Mean Leakage Current and the Standard

Deviation of this same parameter for all device types tested. It is observed from this data that the parameters are quite stable, however, some groups appear to be part of different parent populations. The 75% 33V type appears to be lower in Reverse Leakage Current than do the 25% and 50% group. This appears to be true of the 50% and 75% of Peak Pulse Current lots of the 91V type. The Standard Deviation is stable over the duration of the tests.

3.7 Statistical Presentation of Data

The graphs and Figures 9 through 12 inclusive, represent the anticipated life expectancy of the four TransZorb™ voltage types over a wide spectrum of transient exposure. The 6.8V device represents the highest reliability with the Mean Confidence extending in excess of 9,000 pulses and the 90% Confidence extending to almost 5,000 pulses at 100% Peak Pulse Level. The 33V TransZorb has a Mean Confidence of slightly over 1,500 pulses and a 90% Confidence of approximately 750 pulses, this is mainly due to the double distribution of the parent population. The 91V TransZorb by comparison with the 33V is substantially improved as to reliability. The Mean Confidence Level of the Mean Peak Pulse Before Failure is in excess of 2,500 pulses with a 90% Confidence of just slightly under 2,000 pulses. The 190V types appeared to have a relatively higher Mean and 90% Confidence values compared to the 33V type, mainly due to the additional parent population which had a relatively long life expectancy.

3.8 TransZorb Derating

From the summary of the curves for the Mean Peak Pulse Before Failure vs the Percent of Rated Peak

Current, it is readily observed that as the devices are derated below 100% of the maximum Peak Pulse Operating Level, the curves flatten out with apparent infinite life time below 75% Peak Pulse Current. The exception to this is the 33V as illustrated in Fig. 10. It is the opinion of the Author that this was a non homogeneous lot and that it is not representative of other device groups.

3.9 Relationship of the Results Found in This Report to In-Service Performance

The TransZorb™ was originally designed to provide protection against induced lightning in telecommunication systems. From an historical prospective, it has yielded a good performance record. These results have initially been qualitative; however, this study represents a substantial indepth quantative test to accurately define MP^2BF. While pulsed at 50% rated Peak Pulse Current and below, all devices appear to have infinite MP^2BF. For all types, with the exception of the 33V type as shown in Fig. 9 through Fig. 12, all devices can be expected to operate at 75% Peak Pulse Level and maintain a good performance record out through 10,000 pulses. When the Peak Pulse Current Levels are related to the actual in-service protection performance required under induced lightning conditions, the reliability of the TransZorb appears to be definitely commensurate with the intended use for which it was designed. The assumption is that the Maximum Peak Pulse Current of the TransZorb is factored into the worst case transient which could be expected. A plot of the Peak Current distribution for first return lightning strokes ① is shown in Fig. 18. It can

①From N. Cianos and E. T. Pierce, a Ground Lightning Environment for Engineering Usage, Stanford Research Institute, Prepared for McDonnell Douglas, under Contract No. L-2817-A3, 1972.

be seen from this graph that 99% of strokes are 140kA or less, with the 50% ordinate reflecting a Maximum Peak Current of 20kA. If the TransZorbs™ are in a circuit to protect against induced lightning from the 1% ordinate strokes, 50% of the strokes will have a Peak Value at less than 8% of the capability of the TransZorb. Also, with the TransZorb designed in such a protection circuit, only 1% of the strokes would equal to the worst case condition of the TransZorb.

3.10 Probability of TransZorb Performance

Based on the MP^2BF Curves shown in Fig. 9 through Fig. 12 the devices will safely operate at 100% Ipp to 1,000 pulses prior to failure. Exposed to pulses having a probability distribution such as that shown in Fig. 18, the life time of the TransZorb would be in excess of 100,000 pulses in protecting against induced lightning.

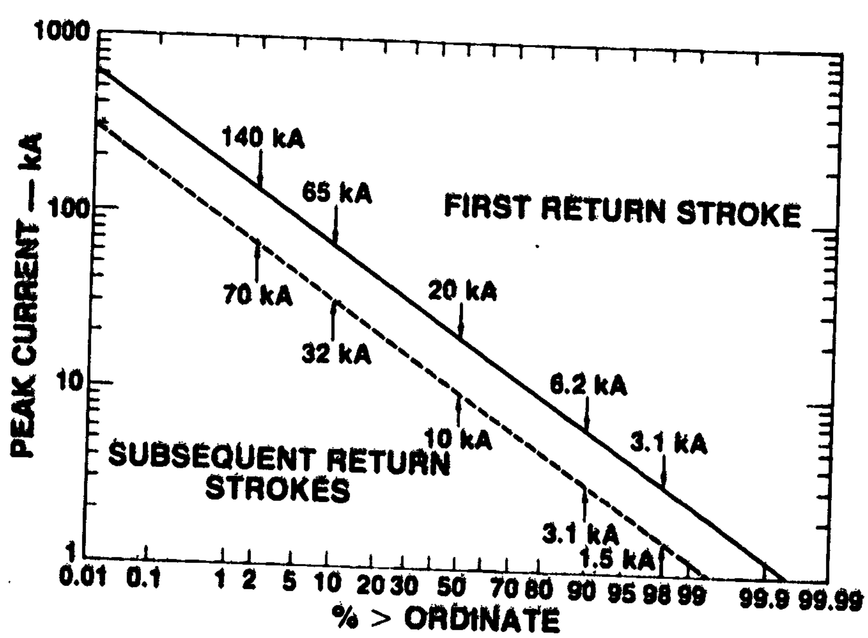

Fig. 18: Peak Current For Lightning Strokes

A P P E N D I X

4.0 FAILURE ANALYSIS

4.1 Device De-encapsulation

A sample of 10 devices from each of the 100% Ipp lots failing on surge tests were opened using a metal turning lathe. The devices were clamped firmly in the lathe collet and the tubulation and insulated lead subsequently removed with extreme caution using a very sharp pointed lathe tool especially fabricated for this purpose. The cap of the device was subsequently removed exposing the TransZorb™ cell and the silver internal lead. Device identity was maintained by careful handling and separate storage of all components.

4.2 Die (Silicon Junction) Removal

The shorted devices used in this failure analysis were next separated at the die/heatsink interface to expose the surface of the die which hopefully would yield some visible signs of failure. The ten devices selected were chosen randomly and to represent a sample over the time domain in which the failures occurred. The specific method of separating the silicon junction from the remainder of the component was accomplished with a hot soldering iron and two pairs of heavy duty tweezers. The base lead (cathode) was grasped firmly with a pair of tweezers and the base of the device was subsequently placed in firm contact with the hot soldering iron. The top lead was held firmly with the second pair of tweezers and a gentle but firm tension was placed on the opposing leads of the device. As the metal bond joining the cell approached the melting point, preferencial separation occurred at the lower (cathode)

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side of the die. Separation usually occurred at the die/heatsink interface. The net result was that the silicon chip was removed from the device with a minimum disturbance of the pn junction and evidence of failure.

4.3 Die Clean Up

The solder bonding material was removed from the die surface, using a saturated aqueous solution of tricholoracetic acid. This solution dissolves the heavy metals used in bonding the die/cell assembly. Approximately twenty-four to forty-eight hours of soaking at 25°C was sufficient to yield clean silicon die surfaces. No solvent is available which would thoroughly dissolve the elastomer coating on the junction. Removal of the elastomer coating was performed most effectively by mechanical means with a small hard-wood stick carefully sharpened to a fine point. Ultrasonic scrubbing was used to remove all loose material and subsequently expose the die as thoroughly as possible for observation and search for the failure stress point. The junctions were subsequently observed under 25X and 40X magnification for the specific areas of failure. The failure method of all devices was short and observations were made to locate small areas which had obvious evidences of melting.

4.4 Die Examination

All silicon junctions which were removed were carefully observed and examined for evidence of melted regions. Both the die edges and central regions were observed for melting which always occurs during the "fail-short" mode.

4.4.1 6.8V TransZorb™ Visual Appearance

The 6.8V catastrophic failures were examined under 40X magnification and all ten were found to have visible evidence of shorting. As to the location of the shorting area, three were located well within the periphery of the die edge and seven were located at the edge of the silicon die. Three of the seven edge shorts occurred at the corner. Typical failures are shown in Fig. 19 and in Fig. 20. Fig. 19 represents a typical internal short with the shorted region having dimensions of approximately .030 inches diameter. The edge failure as shown in Fig. 20 incurred not only a melted region but a fracture as well. These failures occurred at 8,380 pulses for the device shown in Fig. 19 and 10,641 pulses for the device shown in Fig. 20.

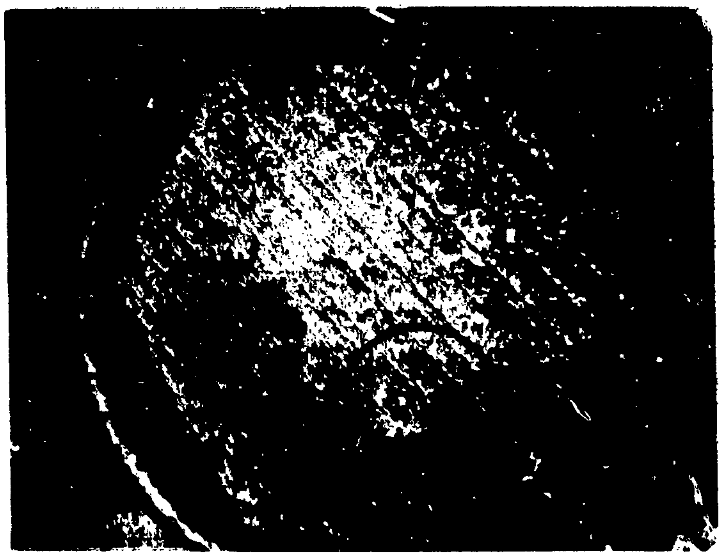

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Fig. 19: Shorted 6.8V Silicon Junction, Internal

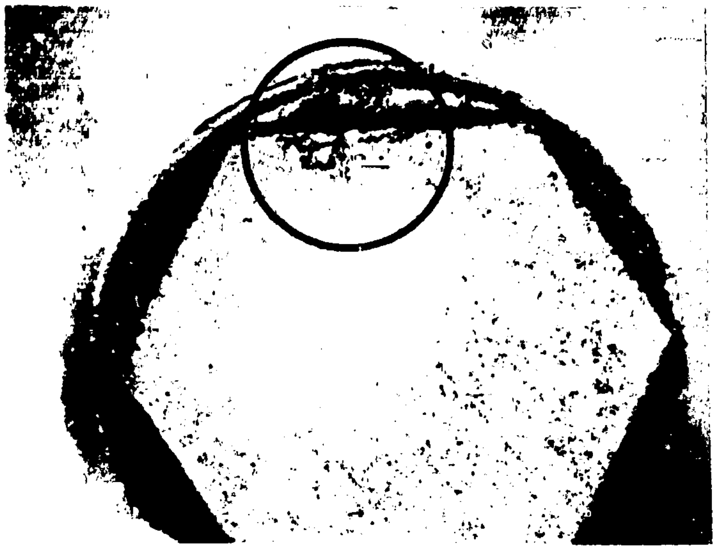

Fig. 20: Shorted 6.8V Silicon Junction, Peripheral

4.4.2 33V TransZorb™ Visual Appearance

The 33V failures were also examined under 40X magnification and found to have both internal and edge failures. Of the nine devices examined, one device had an internal failure, eight having edge failures of which six occurred at the corner. The internal failure, shown in Fig. 21 exhibits a fraccuring of the silicon die. The thermal shock generated during failure can produce severe fracture in the silicon junction. The melting point of silicon is in excess of 1,400°C and this thermal shock can and has fractured junctions upon failure.

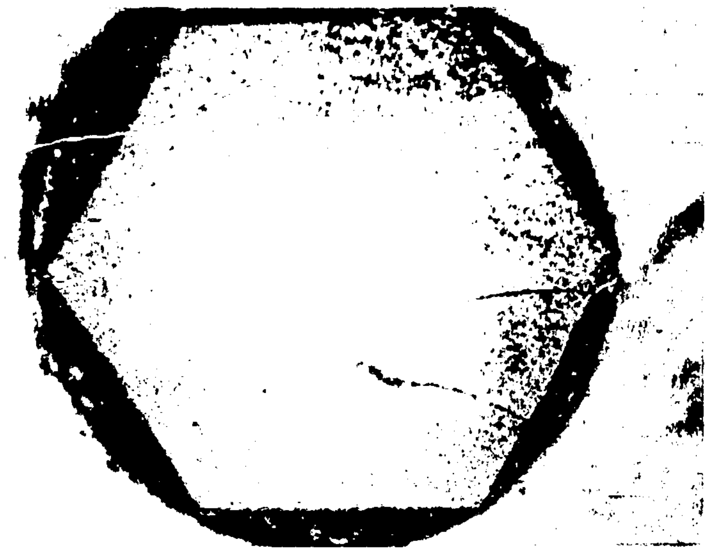

Fig. 21: Shorted 33V Silicon Junction, Internal

Fig. 22 represents a typical shorted silicon junction as it has occurred at the edge. Observe that the area of melt appears to be smaller than that of the 6.8V device owing to the current limiting the power supply and subsequently lower power dissipation during the shorted mode.

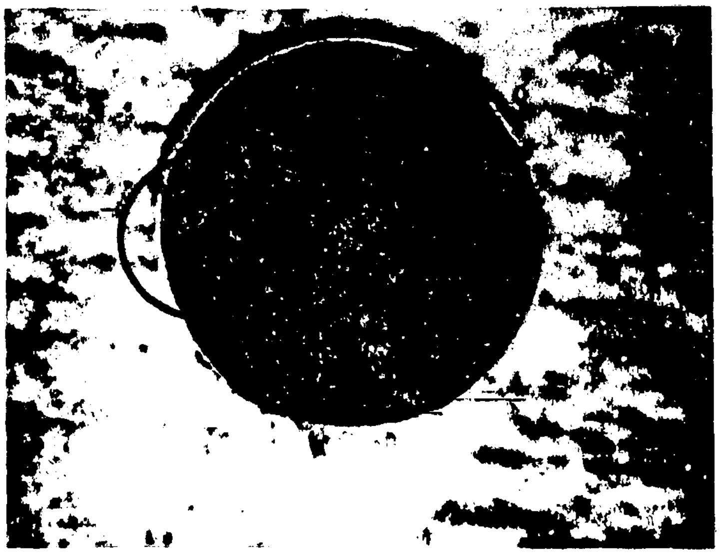

Fig. 22: Shorted 33V Silicon Junction, Peripheral

4.4.3 91V TransZorb™ Visual Appearance

The 91V devices were examined under 40X magnification in an attempt to observe characteristics of failure.. There were three out of eight which failed internally and five with edge failures, of which three were located at the corner. A view of the internal junction is shown in Fig. 23 and a typical corner failure is shown in Fig. 24. The region of the melt appears to be smaller, however, the internal short still generated substantial heat to cause fracturing of the die. The corner region of the melt is plainly visible as shown in Fig. 24. The internal failure occurred at 5,837 pulses with the peripheral failure occurring at 6,432 pulses.

Fig. 23: 91V Shorted Silicon Junction, Internal

Fig. 24: 91V Shorted Silicon Junction, Peripheral

4.4.4 190V TransZorb™ Visual Appearance

Of the 10 devices evaluated for failure, three had internal shorting with seven devices shorting at the edge. Of the seven edge shorts, four occurred at the corner. Fig. 25 illustrates the internal short with the small but prominant burn-through region plainly visible. The peripheral short is observed in Fig. 26 which was taken at 30X magnification. The short occurred at approximately the center of one of the hexagonal sides and a crack was formed which propogated across the entire surface of the die. The failures occurred at 8,317 pulses for the internal short and 7,706 pulses for the external short, as shown in Fig. 25 and Fig. 26 respectively. In comparing Fig. 19 with Fig. 25, the region of the melt at the failure point is substantially smaller for a 190V silicon junction. This is due to the fact that the test equipment has a current limited power source which has a maximum determined by the test pulse. This is 143A for the

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is 143A for the 6.8V device and slightly over 5A for the 190V device. As a result, the power dissipated is substantially higher for the lower voltage device when the short occurs than for the higher voltage device due to the much greater amount of current carried in the lower voltage circuit.

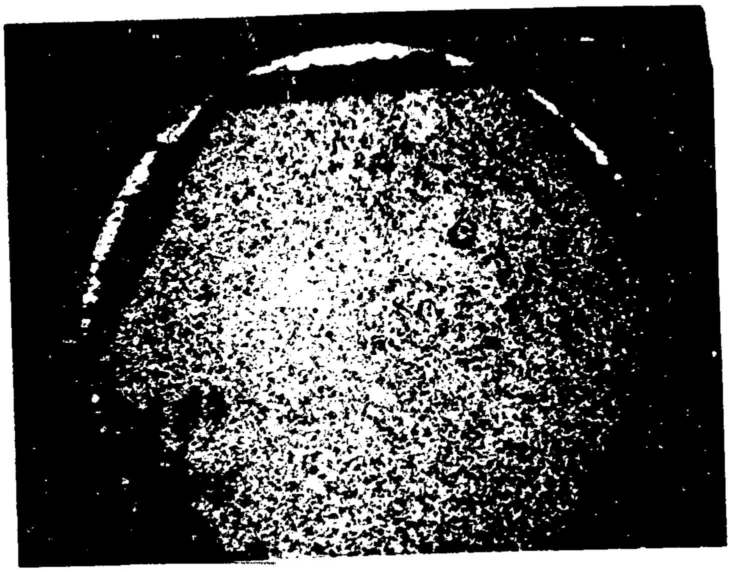

Fig. 25: 190V TransZorb™ Visual Appearance, Internal

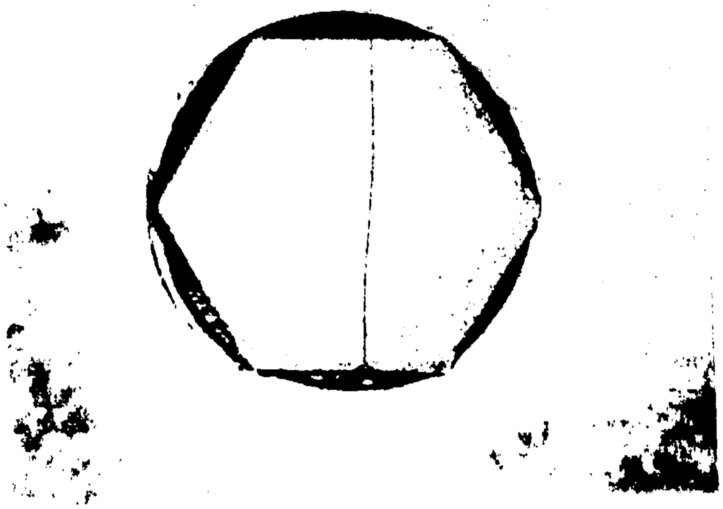

Fig. 26: 190V TransZorb Visual Appearance, Peripheral

Scanning Electron Microscope Analysis

As described in the previous effort under Contract No. NAS8-30811, two devices were mounted in plastic cylinders, cross sectioned, and subsequently etched, using specialized solutions to provide optimum visual resolution and structure of the metal silicon die and the adjacent silver heat sink. An etch solution designed specifically for bringing out the grain structure of the metallization bonding the silicon to its heat sink was applied to the exposed surfaces of the cross section. These samples were subsequently observed under 5,000X using a scanning electron microscope (SEM) Model 1000AMR. One of the samples, shown in Fig. 28, is the control, with no pulse testing whatsoever. The device shown in Fig. 27 received 4,000 pulses at 85% Peak Pulse Current.

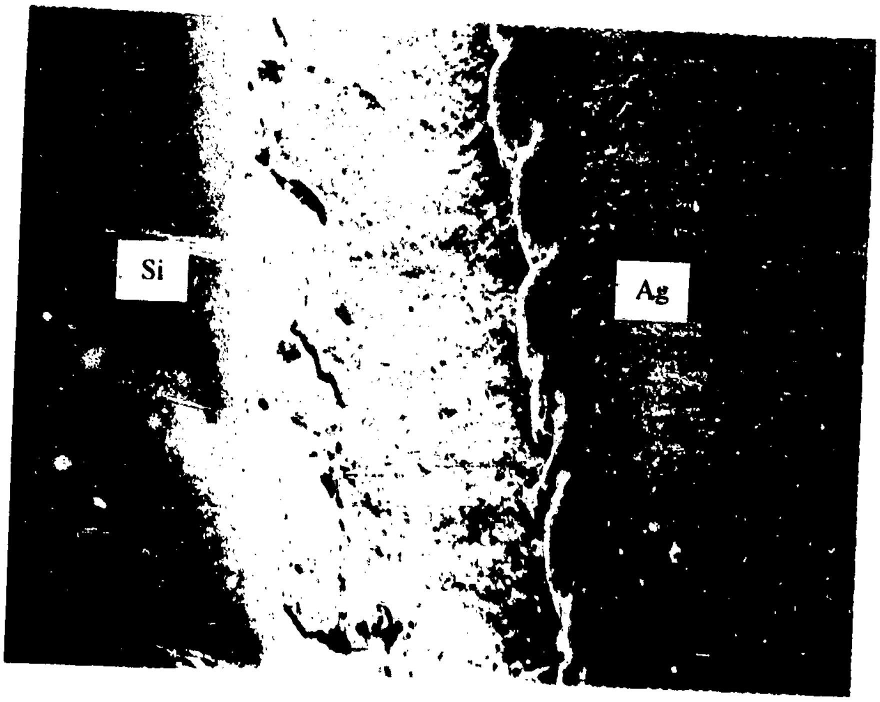

Fig. 27: 4,000 Pulses At 85% Ipp

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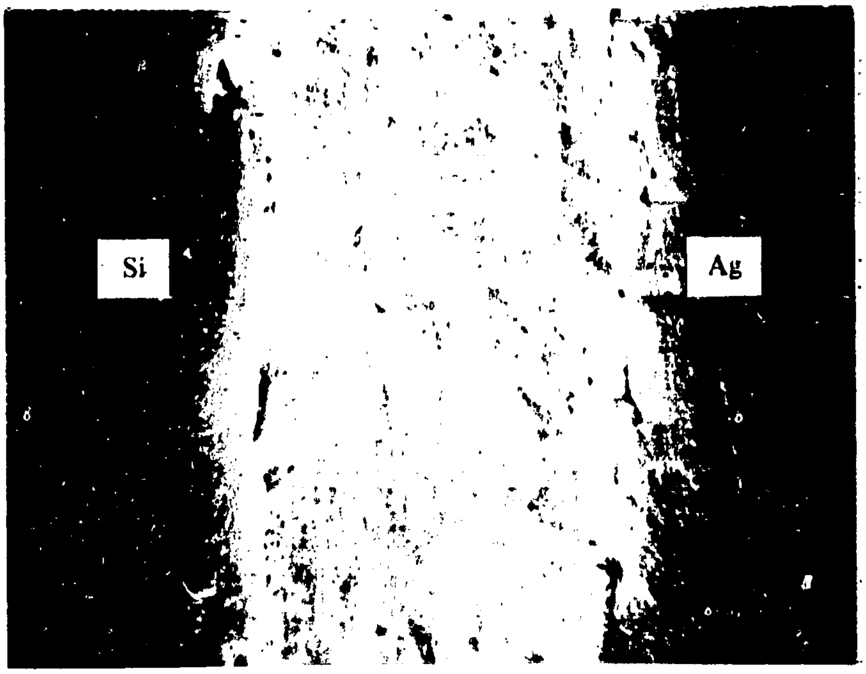


Fig. 28: Control, No Pulse Testing

The structure of the metallic bonding is obviously quite different for each of these two samples. This can be attributed to the thermal cycling which occurs during the Pulse Testing. The experimental device exhibited an apparent micro-fracture separation in the inter-metallics at the edge of the die only (within approximately .010 inches from the edge). There appeared to be no discontinuity in the bonding of the control sample at the outer edge or at any other point in the bonding.

4.5 Discussion of Failure Analysis Results

When the silicon junction of the Transient Voltage Suppressor fails, it appears that in all cases it fails in the shorted mode. During the process of failure, a single small area, of the order of .030 inches or smaller, is heated to a temperature well in excess of the melting point of silicon, which is over 1,400^{o}C. The exact reason for the failure is not too well understood. This could be a latent latice defect due to a microfracture, or perhaps, a screw dislocation or the presence of some other latent defect mechanism. The surface failures appear to be due to some discontinuity at the interface, the nature of which also is not too well understood. One possible explanation for the failures appears to lie in the SEM Analysis as shown in Fig. 27 and 28. Under long term high power pulsing, a change in the metallization of bonding structure appears to exist. With this change there appears to accompany a separation beginning at the periphery. This separation would continue to propogate toward the center of the junction as time progresses. Subsequent continued cycling would result in the periphery of the junction heating due to less heat sinking and subsequent greater probability of failure. This appeared to be the case in reviewing the number of edge failures compared to the internal failures. Of the 37 that were analyzed, ten had internal failures and twenty-nine had edge failures. This could indicate that the loss of heat sinking at the periphery could be a cause for this failure after long term cycling near the rated Peak Pulse Current of the device.

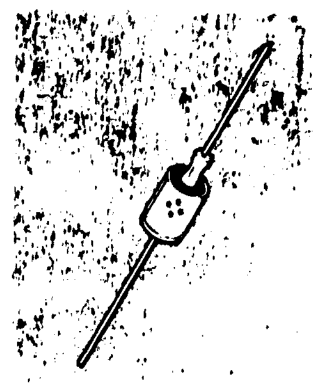
DESCRIPTION

This specification sheet defines a series of Silicon Transient Suppressors used in applications where large voltage transients can permanently damage voltage-sensitive components. The TransZorb is packaged in a hermetically sealed, glass-to-metal package. JAN and JANTX TransZorbs qualified to MIL S 19500/500 are also available.

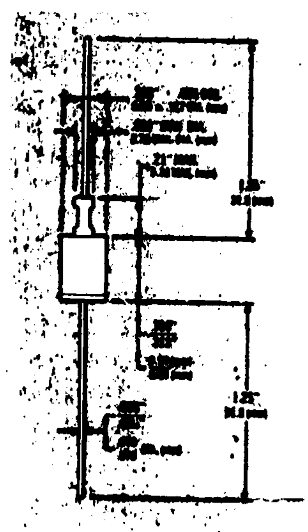
TransZorbs are characterized by their high surge capability, extremely fast response time, and low impedance, (R_{on}). Because of the unpredictable nature of transients and the variation of the impedance with respect to these transients, impedance per se is not specified as a parametric value. However, a minimum voltage at low current conditions (BV) and a maximum clamping voltage (V_C) at a maximum peak pulse current is specified. In addition, a maximum clamping ratio is indicated. In some instances the thermal effect (see V_C Clamping Voltage) may be responsible for 50% to 70% of the observed voltage differential when subjected to high current pulses or severe duty cycles thus making a maximum impedance specification insignificant. Curves depicting clamping voltage vs. various current pulses are available from the factory. Extended power curves vs. pulse time are also available.

The TransZorb has a peak pulse power rating of 1500 watts for one millisecond and therefore can be used in applications where induced lightning on rural or remote transmission lines presents a hazard to electronic circuitry (ref: R.E.A. specification P.E. 60). The response time of TransZorb clamping action is theoretically instantaneous (1×10^{-12} sec), therefore, they can protect Integrated Circuits, MOS devices, Hybrids, and other voltage-sensitive semiconductors and components. TransZorbs can also be used in series or parallel to increase the peak power ratings.

This series of devices has been proven very effective as EMP Suppressors. For the actual test results and application send for report number AD9092661. This specification sheet is only one of many series of Transient Voltage Suppressors available from General Semiconductor Industries.

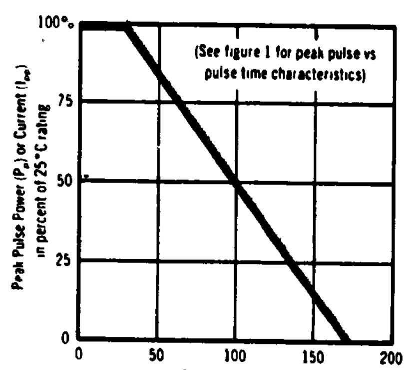


- **1500 watts peak power dissipation**
- **Available in ranges from 6.8V to 200V.**
- **DO-13 hermetically sealed package**



MAXIMUM RATINGS

- 1500 Watts of Peak Pulse Power dissipation at 25°C
- $t_{clamping}$ (0 volts to BV min): Less than 1×10^{-12} seconds
- Operating and Storage Temperatures: −65° to +175° C
- Forward surge rating: 200 amps, 1/120 second at 25° C
- Steady State power dissipation: 1 watt
- Repetition rate (duty cycle): .01%



Derating Curve

MECHANICAL CHARACTERISTICS

- Standard DO-13 package – glass and metal hermetically sealed
- Weight: 1.5 grams (approximate)
- Positive terminal marked with band
- Standard Polarity – Cathode to Case
- Body marked with Logo and type number

ELECTRICAL CHARACTERISTICS

- Clamping Factor: 1.33 @ Full rated power
  1.20 @ 50% rated power

Clamping Factor: The ratio of the actual V_C (Clamping Voltage) to the BV (Breakdown Voltage) as measured on a specific device. (See Figure 3 for test pulse wave shape.)

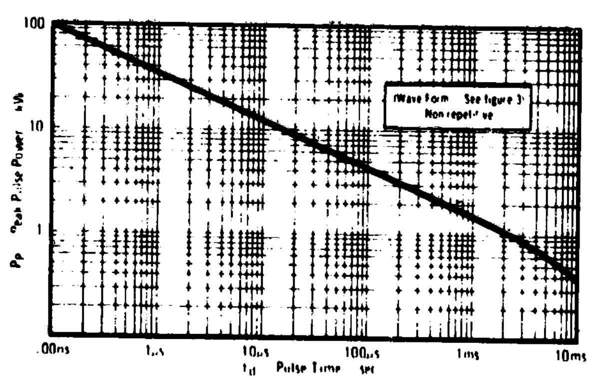


FIGURE 1 — Peak Pulse Power vs Pulse Time

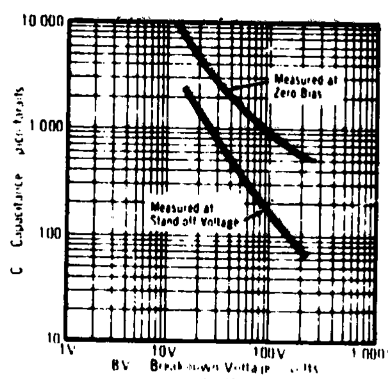


FIGURE 2
Typical Capacitance vs Breakdown Voltage

ABBREVIATIONS & SYMBOLS

V_R Stand Off Voltage. Applied Reverse Voltage to assure a nonconductive condition. (See Note 1)

BV(min) This is the minimum Breakdown Voltage the device will exhibit and is used to assure that conduction does not occur prior to this voltage level at 25 C.

V_C (max) Maximum Clamping Voltage. The maximum peak voltage appearing across the TransZorb when subjected to the peak pulse current in a one millisecond time interval. The peak pulse voltages are the combination of voltage rise due to both the series resistance and thermal rise.

I_{PP} Peak Pulse Current. See Figure 3

P_P Peak Pulse Power

I_R Reverse Leakage

Note 1

A TransZorb is normally selected according to the reverse "Stand Off Voltage" (V_R) which should be equal to or greater than the DC or continuous peak operating voltage level.

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ELECTRICAL CHARACTERISTICS at 25°C

JEDEC TYPE NUMBER	GENERAL SEMICONDUCTOR PART NUMBER	REVERSE STAND-OFF VOLTAGE (See Note 1) V_R VOLTS	BREAKDOWN VOLTAGE BV @ I_T VOLTS Min	BREAKDOWN VOLTAGE BV VOLTS Max	I_T mA	MAXIMUM CLAMPING VOLTAGE @ I_{PP} (See Fig. 3) V_C VOLTS	MAXIMUM REVERSE LEAKAGE @ V_R I_R μA	MAXIMUM PEAK PULSE CURRENT (See Fig. 3) I_{PP} A	MAXIMUM TEMPERATURE COEFFICIENT OF BV %/°C
1N5629	1.5K6.8	5.50	6.12	7.48	10	10.8	1000	139	.057
1N5629A*	1.5K6.8A	5.80	6.45	7.14	10	10.5	1000	143	.057
1N5630	1.5K7.5	6.05	6.75	8.25	10	11.7	500	128	.061
1N5630A*	1.5K7.5A	6.40	7.13	7.88	10	11.3	500	132	.061
1N5631	1.5K8.2	6.63	7.38	9.02	10	12.5	200	120	.065
1N5631A*	1.5K8.2A	7.02	7.79	8.61	10	12.1	200	124	.065
1N5632	1.5K9.1	7.37	8.19	10.0	1	13.8	50	109	.068
1N5632A*	1.5K9.1A	7.78	8.65	9.55	1	13.4	50	112	.068
1N5633	1.5K10	8.10	9.00	11.0	1	15.0	10	100	.073
1N5633A*	1.5K10A	8.55	9.5	10.5	1	14.5	10	103	.073
1N5634	1.5K11	8.92	9.9	12.1	1	16.2	5	93	.075
1N5634A*	1.5K11A	9.40	10.5	11.6	1	15.6	5	96	.075
1N5635	1.5K12	9.72	10.8	13.2	1	17.3	5	87	.078
1N5635A*	1.5K12A	10.2	11.4	12.6	1	16.7	5	90	.078
1N5636	1.5K13	10.5	11.7	14.3	1	19.0	5	79	.081
1N5636A*	1.5K13A	11.1	12.4	13.7	1	18.2	5	82	.081
1N5637	1.5K15	12.1	13.5	16.5	1	22.0	5	68	.084
1N5637A*	1.5K15A	12.8	14.3	15.8	1	21.2	5	71	.084
1N5638	1.5K16	12.9	14.4	17.6	1	23.5	5	64	.086
1N5638A*	1.5K16A	13.6	15.2	16.8	1	22.5	5	67	.086
1N5639	1.5K18	14.5	16.2	19.8	1	26.5	5	56.5	.088
1N5639A*	1.5K18A	15.3	17.1	18.9	1	25.2	5	59.5	.088
1N5640	1.5K20	16.2	18.0	22.0	1	29.1	5	51.5	.090
1N5640A*	1.5K20A	17.1	19.0	21.0	1	27.7	5	54	.090
1N5641	1.5K22	17.8	19.8	24.2	1	31.9	5	47	.092
1N5641A*	1.5K22A	18.8	20.9	23.1	1	30.6	5	49	.092
1N5642	1.5K24	19.4	21.6	26.4	1	34.7	5	43	.094
1N5642A*	1.5K24A	20.5	22.8	25.2	1	33.2	5	45	.094
1N5643	1.5K27	21.8	24.3	29.7	1	39.1	5	38.5	.096
1N5643A*	1.5K27A	23.1	25.7	28.4	1	37.5	5	40	.096
1N5644	1.5K30	24.3	27.0	33.0	1	43.5	5	34.5	.097
1N5644A*	1.5K30A	25.6	28.5	31.5	1	41.4	5	36	.097
1N5645	1.5K33	26.8	29.7	36.3	1	47.7	5	31.5	.098
1N5645A*	1.5K33A	28.2	31.4	34.7	1	45.7	5	33	.098
1N5646	1.5K36	29.1	32.4	39.6	1	52.0	5	29	.099
1N5646A*	1.5K36A	30.8	34.2	37.8	1	49.9	5	30	.099
1N5647	1.5K39	31.6	35.1	42.9	1	56.4	5	26.5	.100
1N5647A*	1.5K39A	33.3	37.1	41.0	1	53.9	5	28	.100
1N5648	1.5K43	34.8	38.7	47.3	1	61.9	5	24	.101
1N5648A*	1.5K43A	36.8	40.9	45.2	1	59.3	5	25.3	.101
1N5649	1.5K47	38.1	42.3	51.7	1	67.8	5	22.2	.101
1N5649A*	1.5K47A	40.2	44.7	49.4	1	64.8	5	23.2	.101
1N5650	1.5K51	41.3	45.9	56.1	1	73.5	5	20.4	.102
1N5650A*	1.5K51A	43.6	48.5	53.6	1	70.1	5	21.4	.102
1N5651	1.5K56	45.4	50.4	61.6	1	80.5	5	18.6	.103
1N5651A*	1.5K56A	47.8	53.2	58.8	1	77.0	5	19.5	.103
1N5652	1.5K62	50.2	55.8	68.2	1	89.0	5	16.9	.104
1N5652A*	1.5K62A	53.0	58.9	65.1	1	85.0	5	17.7	.104
1N5653	1.5K68	55.1	61.2	74.8	1	98.0	5	15.3	.104
1N5653A*	1.5K68A	58.1	64.6	71.4	1	92.0	5	16.3	004
1N5654	1.5K75	60.7	67.5	82.5	1	108.0	5	13.9	.105
1N5654A*	1.5K75A	64.1	71.3	78.8	1	103.0	5	14.6	.105
1N5655	1.5K82	66.4	73.8	90.2	1	118.0	5	12.7	.105
1N5655A*	1.5K82A	70.1	77.9	86.1	1	113.0	5	13.3	.105
1N5656	1.5K91	73.7	81.9	100.0	1	131.0	5	11.4	.106
1N5656A*	1.5K91A	77.8	86.5	95.5	1	125.0	5	12.0	.106
1N5657	1.5K100	81.0	90.0	110.0	1	144.0	5	10.4	.106
1N5657A*	1.5K100A	85.5	95.0	105.0	1	137.0	5	11.0	.106
1N5658	1.5K110	89.2	99.0	121.0	1	158.0	5	9.5	.107
1N5658A*	1.5K110A	94.0	105.0	116.0	1	152.0	5	9.9	.107
1N5659	1.5K120	97.2	108.0	132.0	1	173.0	5	8.7	.107
1N5659A*	1.5K120A	102.0	114.0	126.0	1	165.0	5	9.1	.107
1N5660	1.5K130	105.0	117.0	143.0	1	187.0	5	8.0	.107
1N5660A*	1.5K130A	111.0	124.0	137.0	1	179.0	5	8.4	.107
1N5661	1.5K150	121.0	135.0	165.0	1	215.0	5	7.0	.108
1N5661A*	1.5K150A	128.0	143.0	158.0	1	207.0	5	7.2	.108
1N5662	1.5K160	130.0	144.0	176.0	1	230.0	5	6.5	.108
1N5662A*	1.5K160A	136.0	152.0	168.0	1	219.0	5	6.8	.108
1N5663	1.5K170	138.0	153.0	187.0	1	244.0	5	6.2	.108
1N5663A*	1.5K170A	145.0	162.0	179.0	1	234.0	5	6.4	.108
1N5664	1.5K180	146.0	162.0	198.0	1	258.0	5	5.8	.108
1N5664A*	1.5K180A	154.0	171.0	189.0	1	246.0	5	6.1	.108
1N5665	1.5K200	162.0	180.0	220.0	1	287.0	5	5.2	.108
1N5665A*	1.5K200A	171.0	190.0	210.0	1	274.0	5	5.5	.108

Vf at 100 AMPS PEAK, 8.3 MSEC SINE WAVE equals 3.5 VOLTS MAXIMUM

TransZorbs™ can be used in series or parallel to increase their power handling capability. No precautions are required when using TransZorbs in a series string and power dissipation for two or more devices of the same type is equally shared. When using TransZorbs in parallel it is necessary for the units to be closely matched (approx. 1 volt of each other) in order for equal sharing to take place. Matched sets can be ordered from the factory for a small additional charge.

*JAN and JANTX available per MIL S 19500/500

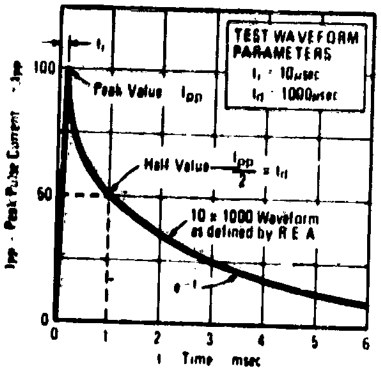
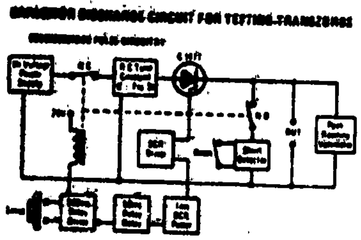
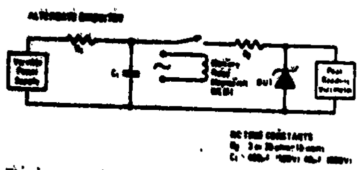


FIGURE 3 – Pulse-Wave Form





The most significant electrical characteristic of transient suppressors is the surge handling capability. All TransZorbs are subjected 100% to the Maximum Peak Pulse Current (Ipp) as indicated in the electrical characteristic table and the clamping voltage is monitored. This test should be part of the customer's quality control incoming inspection procedure.

Non standard voltage types between those tabulated may be specified as illustrated

Family Type — Nominal BV — Tolerance Suffix

1.5K 7.2 A

- BV: Will be Nominal BV ±5% for "A" suffix types and ±10% for non suffix types at the test current of the next lower standard voltage type
- V_R: Will be 85% of Nominal BV for "A" suffix type and 81% of Nominal BV for non suffix types
- V_C: Will be proportionally interpolated between the two neighboring standard types
- I_R: Will be that of the next lower standard type
- I_{PP}: Will be proportionately interpolated between the two neighboring standard types

For reverse polarity insert "R" in type number immediately after Nominal BV designation and before the "A" suffix. Example: 1.5K18RA

BIPOLAR APPLICATIONS

Electrical characteristics apply in both directions. For Bipolar use C or CA Suffix for types 1.5K7.5 through types 1.5K200.

Example: 1.5K7.5C – 1.5K200C
1.5K7.5CA – 1.5K200CA

NASA PULSE LIFE TEST   1N5629A   75% PEAK PULSE CURRENT   INITIAL*
STA#=1   RTN#=20

TEST #:		1	2
TEST ID:		VR	IR
UNITS:		V	A
SER	BIN		
101	1	6.800	152.5 U
102	1	6.600	248.5 U
103	1	6.850	695.5 U
104	1	6.750	170.5 U
105	1	6.750	319.5 U
106	1	6.750	290.0 U
107	1	6.500	995.0 U
106	1	6.800	188.3 U
109	1	6.750	231.0 U
110	1	6.750	120.8 U
111	1	6.650	268.0 U
112	1	6.850	168.7 U
113	1	6.800	267.5 U
114	1	6.850	275.5 U
115	1	6.850	113.7 U
116	1	6.800	296.5 U
117	1	6.700	149.1 U
118	1	6.800	226.0 U
119	1	6.850	148.1 U
120	1	6.850	100.8 U
121	2	6.850	F1.143 M
122	1	6.600	455.0 U
123	1	6.900	101.7 U
124	1	6.600	430.0 U
125	1	6.750	208.0 U
126	1	6.750	151.8 U
127	1	6.750	178.6 U
128	1	6.800	173.7 U
129	1	6.750	129.1 U
130	1	6.800	228.5 U
131	1	6.900	657.0 U
132	1	6.850	184.8 U
133	1	6.700	696.0 U
134	1	6.850	114.7 U
135	1	6.800	315.0 U
136	1	6.750	258.0 U
137	1	6.900	121.5 U
138	1	6.900	149.7 U
139	1	6.750	194.7 U
140	1	6 800	301.5 U
141	1	6.850	172.6 U
142	1	6.700	246.0 U
143	1	6.850	268.5 U
144	1	6.750	163.8 U
145	1	6.800	242.0 U
146	1	6.950	158.7 U
147	1	6.750	295.0 U
148	1	6.700	418.0 U
149	1	6.650	248.5 U
150	1	6.750	215.0 U

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

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NASA PULSE LIFE TEST   1N5629A   75% PEAK PULSE CURRENT   AFTER 7500 PULSES*

STA#=3   RTN#=20

TEST #.		1	2	
TEST ID		VR	IR	
UNITS		V	A	
SER	BIN			
101	1	6.800	171.7	U
102	1	6.600	270.5	U
103	1	6.800	691.0	U
104	1	6.750	174.7	U
105	1	6.750	323.0	U
106	1	6.750	280.5	U
107	1	6.500	996.0	U
108	1	6.800	198.6	U
109	1	6.700	243.0	U
110	1	6.750	129.9	U
111	1	6.650	348.5	U
112	1	6.850	185.0	U
113	1	6.800	284.5	U
114	1	6.800	243.5	U
115	1	6.850	121.8	U
116	1	6.800	291.5	U
117	1	6.700	154.7	U
118	1	6.750	230.0	U
119	1	6.850	151.7	U
120	1	6.850	110.2	U
121	1	6.850	785.0	U
122	1	6.600	499.0	U
123	1	6.900	112.0	U
124	1	6.600	435.5	U
125	1	6.750	215.5	U
126	1	6.700	156.3	U
127	1	6.750	191.9	U
128	1	6.800	178.3	U
129	1	6.750	138.0	U
130	1	6.800	257.0	U
131	1	6.850	584.5	U
132	1	6.850	193.7	U
133	1	6.700	644.5	U
134	1	6.850	126.0	U
135	1	6.800	323.0	U
136	1	6.750	268.5	U
137	1	6.850	127.9	U
138	1	6.900	153.6	U
139	1	6.750	200.3	U
140	1	6.800	305.5	U
141	1	6.850	183.3	U
142	1	6.650	240.0	U
143	1	6.850	273.5	U
144	1	6.700	176.5	U
145	1	6.800	241.5	U
146	1	6.950	161.8	U
147	1	6.750	307.0	U
148	1	6.700	419.0	U
149	1	6.650	258.0	U
150	1	6.750	221.5	U

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

NASA PULSE LIFE TEST   1N5629A   75% PEAK PULSE CURRENT   AFTER 10000 PULSES*

STA#=3   RTN#=20

TEST #		1	2
TEST ID		VR	IR
UNITS:		V	A
SER	BIN		
101	1	6.800	168.3 U
102	1	6.600	294.0 U
103	1	6.850	732.5 U
104	1	6.750	187.0 U
105	1	6.750	348.5 U
106	1	6.750	290.0 U
107	1	6.500	1.011 M
108	1	6.800	206.5 U
109	1	6.700	249.0 U
110	1	6.750	131.1 U
111	1	6.650	385.5 U
112	1	6.850	184.5 U
113	1	6.800	279.0 U
114	1	6.850	296.5 U
115	1	6.650	124.7 U
116	1	6.800	296.5 U
117	1	6.700	160.8 U
118	1	6.800	241.0 U
119	1	6.850	155.4 U
120	1	6.850	112.7 U
121	1	6.850	835.0 U
122	1	6.600	519.0 U
123	1	6.900	112.9 U
124	1	6.600	452.0 U
125	1	6.750	223.5 U
126	1	6.700	158.4 U
127	1	6.750	209.0 U
128	1	6.800	187.4 U
129	1	6.750	139.4 U
130	1	6.800	266.0 U
131	1	6.850	650.0 U
132	1	6.800	197.0 U
133	1	6.700	787.0 U
134	1	6.850	129.8 U
135	1	6.800	338.0 U
136	1	6.750	279.5 U
137	1	6.900	132.1 U
138	1	6.900	155.5 U
139	1	6.750	215.0 U
140	1	6.750	311.0 U
141	1	6.850	187.4 U
142	1	6.650	257.0 U
143	1	6.850	283.0 U
144	1	6.700	182.4 U
145	1	6.800	256.0 U
146	1	6.950	163.3 U
147	1	6.750	311.0 U
148	1	6.700	427.5 U
149	1	6.650	264.5 U
150	1	6.750	229.0 U

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

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NASA PULSE LIFE TEST 1N3629A 75% PEAK PULSE CURRENT AFTER 12500 PULSES*

STA#=3 RTN#=20

TEST #:		1	2
TEST ID:		VR	IR
UNITS:		V	A
SER	BIN		
101	1	6.800	176.0 U
102	1	6.600	281.0 U
103	1	6.800	664.5 U
104	1	6.750	178.7 U
105	1	6.700	308.0 U
106	1	6.750	281.5 U
107	1	6.500	985.5 U
108	1	6.800	212.0 U
109	1	6.700	252.0 U
110	1	6.750	133.3 U
111	1	6.650	353.5 U
112	1	6.800	189.6 U
113	1	6.750	276.5 U
114	1	6.800	251.0 U
115	1	6.850	124.9 U
116	1	6.800	292.5 U
117	1	6.700	159.9 U
118	1	6.750	236.5 U
119	1	6.800	155.5 U
120	1	6.850	115.1 U
121	1	6.850	715.0 U
122	1	6.600	509.5 U
123	1	6.850	115.4 U
124	1	6.600	439.0 U
125	1	6.700	228.0 U
126	1	6.700	161.0 U
127	1	6.700	206.0 U
128	1	6.800	181.1 U
129	1	6.750	141.1 U
130	1	6.800	264.5 U
131	1	6.850	579.0 U
132	1	6.850	203.5 U
133	1	6.700	657.5 U
134	1	6.850	130.7 U
135	1	6.800	319.0 U
136	1	6 750	279.0 U
137	1	6.850	134.9 U
138	1	6.969	155.0 U
139	1	6.750	197.0 U
140	1	6.750	313.5 U
141	1	6.850	192.5 U
142	1	6.650	241.5 U
143	1	6.850	280.5 U
144	1	6.700	186.6 U
145	1	6.800	247.0 U
146	1	6.950	162.5 U
147	1	6.750	313.5 U
148	1	6.700	425.5 U
149	1	6.650	268.0 U
150	1	6.750	233.0 U

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

NASA PULSE LIFE TEST 1N5629A 75% PEAK PULSE CURRENT AFTER 15000 PULSES*

STA#=1 RTN#=20

TEST #		1	2
TEST ID		VR	IR
UNITS		V	A
SER	BIN		
101	1	6.900	179.3 U
102	1	6.600	297.5 U
103	1	6.800	761.0 U
104	1	6.750	193.8 U
105	1	6.700	352.5 U
106	1	6.750	292.0 U
107	1	6.500	1.043 M
108	1	6.800	220.0 U
109	1	6.700	258.0 U
110	1	6.750	137.5 U
111	1	6.600	406.5 U
112	1	6.800	195.3 U
113	1	6.750	290.0 U
114	1	6.850	320.5 U
115	1	6.850	134.4 U
116	1	6.800	308.5 U
117	1	6.700	165.3 U
118	1	6.750	248.0 U
120	1	6.850	120.3 U
121	1	6.850	793.5 U
122	1	6.600	518.0 U
123	1	6.850	119.8 U
124	1	6.600	455.5 U
125	1	6.700	235.5 U
126	1	6.700	166.9 U
127	1	6.700	215.5 U
128	1	6.800	197.3 U
129	1	6.700	147.2 U
130	1	6.750	290.0 U
132	1	6.850	212.0 U
133	1	6.700	839.0 U
134	1	6.850	137.0 U
135	1	6.800	345.5 U
136	1	6.750	296.5 U
137	1	6.850	141.3 U
138	1	6.950	161.8 U
139	1	6.750	221.5 U
140	1	6.750	326.0 U
141	1	6.850	197.4 U
142	1	6.650	262.0 U
143	1	6.800	295.5 U
144	1	6.700	196.1 U
145	1	6.800	264.5 U
146	1	6.900	167.0 U
147	1	6.750	328.5 U
149	1	6.650	280.5 U

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

NASA PULSE LIFE TEST 1N5629A 75% PEAK PULSE CURRENT FINAL*
STA#=3 RTN#=20

TEST #:		1	2
TEST ID:		VR	IR
UNITS:		V	A
SER	BIN		
101	1	6.800	176.5 U
102	1	6.650	281.5 U
103	1	6.850	712.5 U
104	1	6.800	181.0 U
105	1	6.750	318.0 U
106	1	6.800	273.5 U
107	1	6.550	966.0 U
108	1	6.850	210.0 U
109	1	6.750	244.5 U
110	1	6.750	132.1 U
111	1	6.650	352.5 U
112	1	6.850	186.9 U
113	1	6.800	280.5 U
114	1	6.850	278.0 U
115	1	6.900	128.0 U
116	1	6.800	286.5 U
117	1	6.750	160.2 U
118	1	6.800	236.0 U
120	1	6.900	115.0 U
121	1	6.850	755.5 U
122	1	6.600	471.5 U
124	1	6.600	441.5 U
125	1	6.750	225.0 U
126	1	6.750	158.9 U
127	1	6.750	210.5 U
128	1	6.800	180.1 U
129	1	6.750	138.5 U
130	1	6.800	264.5 U
132	1	6.850	200.7 U
133	1	6.750	753.5 U
134	1	6.900	131.8 U
135	1	6.800	324.0 U
136	1	6.750	278.0 U
137	1	6.900	135.7 U
139	1	6.800	212.0 U
140	1	6.800	306.0 U
141	1	6.850	185.6 U
143	1	6.850	278.5 U
144	1	6.750	186.4 U
145	1	6.800	246.0 U
146	1	6.950	158.1 U
147	1	6.800	307.5 U
149	1	6.700	270.0 U

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

NASA PULSE LIFE TEST 1N5629A 100% PEAK PULSE CURRENT INITIAL*

STA#=1 RIN#=20

TEST #:		1	2
TEST ID:		VR	IR
UNITS		V	A
SER	BIN		
151	1	6.800	221.5 U
152	1	6.800	312.0 U
153	1	6.850	136.9 U
154	1	6.700	172.8 U
155	1	6.800	590.0 U
156	1	6.800	241.0 U
158	1	6.750	259.5 U
159	1	6.850	196.1 U
161	1	6.800	194.3 U
163	1	6.850	94.60 U
164	1	6.750	116.8 U
165	1	6.950	91.65 U
166	1	6.850	154.6 U
167	1	6.650	498.0 U
168	1	6.600	539.0 U
169	1	6.900	152.6 U
170	1	6.650	369.0 U
171	1	6.600	420.0 U
172	1	6.750	200.5 U
173	1	6.700	210.0 U
174	1	6.950	89.09 U
175	1	6.650	382.5 U
176	1	6.600	620.5 U
178	1	6.750	226.0 U
179	1	6.700	194.3 U
181	1	6.700	718.5 U
182	1	6.750	354.0 U
183	1	6.900	296.5 U
184	1	6.700	179.2 U
185	1	6.550	754.0 U
186	1	6.700	157.7 U
187	1	6.750	512.5 U
188	1	6.600	524.5 U
189	1	6.950	146.1 U
190	1	6.750	412.0 U
191	1	6.900	205.5 U
192	1	6.600	562.0 U
194	1	6.750	319.0 U
195	1	6.550	427.0 U
196	1	6.650	249.5 U
197	1	6.750	561.5 U
198	1	6.550	665.0 U
199	1	6.700	205.5 U
200	1	6.700	158.7 U

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

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NASA PULSE LIFE TEST 1N5629A 100% PEAK PULSE CURRENT AFTER 7500 PULSES*
STA#=3 RTN#=20

TEST #:		1	2
TEST ID:		VR	IR
UNITS:		V	A
SER	BIN		
159	1	6.850	193.6 U
168	1	6.650	547.5 U
172	1	6.800	217.0 U
179	1	6.750	200.5 U
194	1	6.750	319.0 U
200	1	6.750	161.5 U

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

NASA PULSE LIFE TEST 1N5629A 100% PEAK PULSE CURRENT AFTER 10000 PULSES *

STA#=1 RTM#=20

TEST #:		1	2
TEST ID:		VR	IR
UNITS:		V	A
SER	BIN		
159	1	6.850	193.0 U
179	1	6.750	214.0 U

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

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NASA PULSE LIFE TEST 1N5629A 100% PEAK PULSE CURRENT AFTER 12500 PULSES;*

STA#=1 RIN#=20

TEST #:		1	2
TEST ID:		VR	IR
UNITS:		V	A
SER	BIN		
159	1	6.900	199.4 U
179	1	6.750	214.0 U

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

NASA PULSE LIFE TEST 1N5645A 75% PEAK PULSE CURRENT INITIAL* *

STA#=3 RTN#=20

TEST #:		3	4	
TEST ID:		VR	IR	
UNITS:		V	A	
SER	BIN			
302	1	33.10	22.55	N
303	1	33.10	25.60	N
304	1	31.60	17.55	N
305	1	32.85	22.40	N
306	1	32.85	27.15	N
307	1	32.80	101.0	N
308	1	32.95	38.55	N
309	1	33.10	25.60	N
310	1	32.90	30.35	N
311	1	32.75	19.20	N
312	1	33.15	13.65	N
313	1	32.65	25.95	N
314	1	33.10	140.0	N
315	1	32.95	38.40	N
316	1	33.00	26.35	N
317	1	32.60	4.750	N
318	1	33.20	6.050	N
319	1	31.90	15.60	N
320	1	32.95	124.9	N
321	1	33.05	112.2	N
322	1	33.05	12.75	N
323	1	32.50	19.95	N
324	1	32.45	13.55	N
325	1	32.75	340.5	N
326	1	32.85	41.60	N
327	1	33.10	25.60	N
328	1	32.60	4.750	N
329	1	32.60	13.95	N
330	1	32.60	33.65	N
331	1	33.05	17.55	N
332	1	32.65	4.750	N
333	1	32.80	43.20	N
334	1	32.75	12.85	N
335	1	32.35	21.55	N
337	1	33.25	26.35	N
338	1	33.05	16.05	N
339	1	32.45	7.150	N
340	1	33.15	97.55	N
341	1	32.60	6.350	N
342	1	32.15	6.450	N
343	1	32.20	15.15	N
344	1	32.45	19.35	N
345	1	32.65	15.15	N
346	1	32.75	12.40	N
347	1	32.40	19.60	N
348	1	32.35	15.90	N
349	1	33.10	22.35	N
350	1	32.40	16.20	N
351	1	32.60	13.05	N

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

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NASA PULSE LIFE TEST 1N5645A 75% PEAK PULSE CURRENT AFTER 7500 PULSES;*

STA#=3 RTN#=20

TEST #		3	4	
TEST ID		VR	IR	
UNITS		V	A	
SER	BIN			
302	1	33.10	15.15	N
303	1	33.10	16.35	N
304	1	31.60	12.85	N
305	1	32.75	13.15	N
306	1	32.85	25.60	N
307	1	32.85	89.75	N
308	1	32.95	35.55	N
309	1	33.10	25.55	N
310	1	32.95	19.95	N
311	1	32.75	17.90	N
312	1	33.15	3.950	N
313	1	32.65	20.15	N
314	1	33.15	131.2	N
315	1	32.95	31.95	N
316	1	33.00	30.80	N
317	1	32.60	3.900	N
318	1	33.20	3.200	N
319	1	31.90	12.80	N
320	1	32.95	115.6	N
321	1	33.05	131.6	N
322	1	33.05	12.75	N
323	1	32.50	17.55	N
324	1	32.45	16.00	N
325	1	32.75	325.5	N
326	1	32.85	51.35	N
327	1	33.10	19.20	N
328	1	32.65	3.550	N
329	1	32.60	9.550	N
330	1	32.55	64.15	N
331	1	33.05	12.75	N
332	1	32.65	7.950	N
333	1	32.80	32.00	N
334	1	32.75	3.650	N
335	1	32.35	13.15	N
337	1	33.20	32.00	N
338	1	33.05	16.15	N
339	1	32.40	12.80	N
340	1	33.15	99.20	N
341	1	32.60	3.550	N
342	1	32.15	12.80	N
343	1	32.20	12.80	N
344	1	32.45	17.60	N
345	1	32.65	13.20	N
346	1	32.75	9.450	N
347	1	32.40	12.80	N
348	1	32.35	13.55	N
349	1	33.10	19.20	N
350	1	32.35	9.550	V
351	1	32.60	7.550	N

* Add 5,760 pulses from Contract No. NAS8-30811 total pulses.

NASA PULSE LIFE TEST 1N5645A 75% PEAK PULSE CURRENT AFTER 10000 PULSE *
STA#=1 RTN#=20

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

TEST #		3	4	
TEST ID		VR	IR	
UNITS.		V	A	
SER	BIN			
302	1	33.10	16.85	N
303	1	33.05	19.25	N
304	1	31.60	13.15	N
305	1	32.75	15.80	N
306	1	32.85	25.95	N
307	1	32.80	83.95	N
308	1	32.95	38.40	N
309	1	33.10	21.55	N
310	1	32.90	25.95	N
311	1	32.75	13.15	N
312	1	33.15	7.550	N
313	1	32.65	16.65	N
314	1	33.10	123.4	N
315	1	32.90	31.15	N
316	1	33.00	25.80	N
317	1	32.60	6.800	N
318	1	33.20	3.950	N
319	1	31.90	12.80	N
320	1	32.95	118.4	N
321	1	33.05	128.2	N
322	1	33.05	11.15	N
323	1	32.50	19.55	N
324	1	32.40	9.950	N
325	1	32.75	341.5	N
326	1	32.85	67.15	N
327	1	33.10	13.55	N
328	1	32.60	7.150	N
329	1	32.60	9.200	N
330	1	32.55	51.35	N
331	1	33.05	13.95	N
332	1	32.65	5.550	N
333	1	32.80	32.05	N
334	1	32.70	7.150	N
335	1	32.35	13.15	N
337	1	33.05	21.60	N
338	1	33.05	13.00	N
339	1	32.40	12.80	N
340	1	33.10	93.95	N
341	1	32.60	4.750	N
342	1	32.15	7.950	N
343	1	32.15	9.650	N
344	1	32.45	14.20	N
345	1	32.60	7.950	N
346	1	32.75	6.750	N
347	1	32.40	13.15	N
348	1	32.30	12.85	N
349	1	33.10	19.25	N
350	1	32.35	8.850	N
351	1	32.60	11.15	N

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NASA PULSE LIFE TEST 1N5645A 75% REF. PULSE CURRENT AFTER 12500 PULSES; *

STA#=3 RTN#=20

* Add 5,760 pulses from contract No. NAS8-30811 total pulses.

TEST #		3	4	
TEST ID		VR	IR	
UNITS		V	A	
SER	BIN			
302	1	33.05	14.35	N
303	1	33.05	22.20	N
304	1	31.60	17.75	N
305	1	32.70	12.75	N
306	1	32.85	25.65	N
307	1	32.80	87.15	N
308	1	32.95	19.15	N
309	1	33.10	10.15	N
310	1	32.90	22.35	N
311	1	32.75	12.80	N
312	1	33.15	6.350	N
313	1	32.60	17.15	N
314	1	33.10	118.8	N
315	1	32.90	39.15	N
316	1	33.00	32.00	N
317	1	32.60	3.550	N
318	1	33.20	6.550	N
319	1	31.90	7.150	N
320	1	32.95	113.4	N
321	1	33.05	153.6	N
322	1	33.05	9.600	N
323	1	32.50	16.35	N
324	1	32.40	15.15	N
325	1	32.70	341.0	N
326	1	32.85	128.2	N
327	1	33.20	26.35	N
328	1	32.65	12.95	N
329	1	32.60	6.800	N
330	1	32.55	87.95	N
331	1	33.10	19.20	N
332	1	32.65	6.400	N
333	1	32.80	27.55	N
334	1	32.75	7.950	N
335	1	32.35	19.20	N
337	1	33.20	25.65	N
338	1	33.05	19.40	N
339	1	32.40	11.15	N
340	1	33.15	102.4	N
341	1	32.60	9.650	N
342	1	32.10	4.050	N
343	1	32.15	12.55	N
344	1	32.45	19.35	N
345	1	32.60	6.350	N
346	1	32.70	6.600	N
347	1	32.40	19.20	N
348	1	32.30	12.75	N
349	1	33.10	16.75	N
350	1	32.35	6.400	N
351	1	32.55	16.35	N

NASA PULSE LIFE TEST 1N5645r [illegible] *

STA#=3 RTN#=20

TEST #.		3	4	
TEST ID		VR	IR	
UNITS.		V	A	
SER	BIN			
302	1	32.10	20.80	N
303	1	33.05	25.70	N
304	1	32.60	16.00	N
305	1	32.70	12.85	N
306	1	32.65	32.00	N
307	1	32.90	86.35	N
308	1	32.90	32.00	N
309	1	33.10	25.35	N
310	1	32.90	27.15	N
311	1	32.75	12.80	N
312	1	33.15	3.950	N
313	1	32.65	12.25	N
314	1	33.10	122.6	N
315	1	32.90	25.85	N
316	1	33.00	29.15	N
317	1	32.55	6.400	N
318	1	33.20	150.0	F
319	1	33.80	12.95	N
320	1	32.95	121.6	N
321	1	33.05	134.8	N
322	1	33.00	12.80	N
323	1	32.50	16.75	N
324	1	33.40	6.750	N
325	1	32.70	335.5	N
326	1	32.85	55.95	N
327	1	33.20	25.60	N
328	1	32.60	3.550	N
329	1	32.60	6.450	N
330	1	32.55	91.20	N
331	1	33.05	12.30	N
332	1	32.65	6.400	N
333	1	32.80	12.00	N
334	1	32.70	12.30	N
335	1	32.30	16.00	N
337	1	33.15	19.95	N
338	1	33.05	9.550	N
339	1	32.45	6.750	N
340	1	33.15	93.75	N
341	1	32.60	6.400	N
342	1	32.10	6.400	N
343	1	32.15	7.950	N
344	1	32.40	16.00	N
345	1	32.60	3.950	N
346	1	32.70	3.950	N
347	1	32.40	17.65	N
348	1	32.30	15.15	N
349	1	32.10	25.60	N
350	1	32.25	9.550	N
351	1	32.55	12.80	N

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

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NASA PULSE LIFE TEST 1N5645A 75% PEAK PULSE CURRENT FINAL *

STA#=7 RTN#=20

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

TEST #.		3	4	
TEST ID		VF	IR	
UNITS:		V	A	
SER	BIN			
302	1	33.25	25.60	N
303	1	33.05	20.75	N
304	1	31.60	12.75	N
305	1	32.70	13.00	N
306	1	32.85	28.75	N
307	1	32.80	83.15	N
308	1	32.90	27.95	N
309	1	33.05	22.40	N
310	1	32.90	22.35	N
311	1	32.75	16.00	N
312	1	33.10	11.20	N
313	1	32.60	13.15	N
314	1	33.10	127.0	N
315	1	32.90	25.95	N
316	1	32.95	23.15	N
317	1	32.55	10.70	N
318	1	33.15	7.950	N
319	1	31.85	5.150	N
320	1	32.90	116.8	N
321	1	33.00	147.2	N
322	1	33.00	12.80	N
323	1	32.45	23.20	N
324	1	32.40	14.35	N
325	1	32.70	336.0	N
326	1	32.80	94.55	N
327	1	33.10	16.35	N
328	1	32.60	12.80	N
329	1	32.55	13.15	N
330	1	32.55	71.95	N
331	1	33.00	12.80	N
332	1	32.60	6.400	N
333	1	32.80	32.00	N
334	1	32.70	10.00	N
335	1	32.30	11.15	N
337	1	33.25	32.00	N
338	1	33.05	12.75	N
339	1	32.40	7.950	N
340	1	33.10	104.0	N
341	1	32.60	6.400	N
342	1	32.10	3.950	N
343	1	32.15	15.00	N
344	1	32.45	18.00	N
345	1	32.60	6.350	N
346	1	32.75	9.550	N
347	1	32.40	12.80	N
348	1	32.30	16.00	N
349	1	33.10	23.20	N
350	1	32.35	12.80	N
351	1	32.60	9.550	N

NASA PULSE LIFE TEST INTERIM 1000 F ... PULSE ... INITIAL*
STA#=2. RTN#=20

TEST #		2	4
TEST ID.		VR	IR
UNITS		V	N
SER	BIN		
157	1	32.80	284.0 N
155	1	33.50	25.60 N
156	1	33.10	19.25 N
158	1	33.65	22.00 N
161	1	33.10	77.45 N
164	1	33.15	9.550 N
167	1	33.65	221.0 N
168	1	33.10	422.5 N
170	1	33.10	528.5 N
171	1	33.05	82.20 N
174	1	33.10	25.95 N
175	1	33.10	462.5 N
176	1	33.65	172.8 N
178	1	32.00	36.75 N
181	1	33.20	6.550 N
184	1	33.25	172.0 N
185	1	33.05	360.0 N
186	1	33.15	619.0 N
190	1	33.80	76.80 N
192	1	33.10	76.00 N
194	1	33.05	267.5 N
197	1	33.15	299.5 N
199	1	33.15	7.950 N
200	1	32.95	460.5 N
201	1	32.85	224.0 N

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

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NASA PULSE LIFE TEST   1N5645A   100% [illegible] PULSE CURRENT   AFTER 7500 PULSES*
STA#=7   RTN#=20

TEST #	3	4
TEST ID	VR	IR
UNITS	V	A
SER BIN		
176 1	33.60	175.2 N

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

NASA PULSE LIFE TEST 1N5656A 75% PEAK PULSE CURRENT INITIAL* *

STA#=2 RTN#=20

TEST #:		5	6	
TEST ID:		VR	IR	
UNITS:		V	A	
SER	BIN			
101	1	88.70	32.35	N
105	1	89.35	23.15	N
106	1	87.75	64.75	N
109	1	87.80	74.35	N
110	1	87.45	62.35	N
113	1	89.25	22.30	N
116	1	91.50	70.70	N
120	1	89.60	55.10	N
121	1	89.70	46.75	N
123	1	87.45	70.50	N
124	1	90.95	88.00	N
126	1	87.20	60.75	N
130	1	89.00	25.60	N
133	1	92.90	12.85	N
135	1	87.65	16.35	N
136	1	88.10	68.60	N
137	1	88.80	28.85	N
139	1	87.10	96.50	N
140	1	88.70	51.95	N
141	1	86.80	10.75	N
144	1	89.40	20.75	N
146	1	86.90	20.75	N
150	1	89.10	86.55	N

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

C.2

NASA PULSE LIFE TEST 1N5656A 75% PEAK PULSE CURRENT AFTER 7500 PULSES; *

STA#=3 RTN#=20

TEST #:		5	6	
TEST ID:		VR	IR	
UNITS:		V	A	
SER	BIN			
101	1	88.65	35.20	N
105	1	89.25	22.40	N
106	1	87.30	38.35	N
109	1	87.60	38.75	N
110	1	87.40	51.20	N
113	1	89.25	22.40	N
116	1	91.45	54.40	N
120	1	89.50	44.85	N
121	1	89.70	43.15	N
123	1	87.50	64.35	N
124	1	90.85	94.35	N
126	1	87.25	41.60	N
130	1	89.00	15.95	N
133	1	93.00	14.40	N
135	1	87.60	17.55	N
136	1	88.05	51.20	N
137	1	88.75	20.75	N
139	1	87.15	64.90	N
140	1	88.70	31.95	N
141	1	86.70	11.95	N
144	1	89.50	22.35	N
146	1	86.90	16.35	N
150	1	89.10	71.20	N

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

NASA PULSE LIFE TEST 1N5656A 75% PEAK PULSE CURRENT AFTER 10000 PULSE...*

STA#=2 RTN#=20

TEST #:		5	6	
TEST ID		VR	IR	
UNITS:		V	A	
SER	BIN			
101	1	88.80	42.35	N
105	1	89.50	21.55	N
106	1	87.35	47.15	N
109	1	87.80	53.15	N
110	1	87.45	52.90	N
113	1	89.30	20.70	N
116	1	91.65	55.55	N
120	1	89.60	52.35	N
121	1	89.70	34.35	N
123	1	87.55	93.05	N
124	1	90.80	101.6	N
126	1	87.30	44.80	N
130	1	89.00	18.35	N
133	1	93.05	11.15	N
135	1	87.65	16.90	N
136	1	88.10	52.80	N
137	1	88.80	19.95	N
139	1	87.20	66.35	N
140	1	88.75	31.90	N
141	1	86.80	8.750	N
144	1	89.55	25.00	N
146	1	87.00	22.75	N
150	1	89.30	77.55	N

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

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NASA PULSE LIFE TEST 1N5656A 75% PEAK PULSE CURRENT AFTER 12500 PULSES *

STA#=1 RTN#=20

TEST #		5	6	
TEST ID:		VR	IR	
UNITS		V	A	
SER	BIN			
101	1	88.85	42.75	N
105	1	89.20	17.55	N
106	1	87.40	46.95	N
109	1	87.80	48.10	N
110	1	87.45	52.70	N
113	1	89.35	20.75	N
116	1	91.70	57.55	N
120	1	89.65	54.30	N
121	1	89.70	31.95	N
123	1	87.60	94.35	N
124	1	90.85	104.1	N
126	1	87.25	39.60	N
130	1	89.15	19.75	N
133	1	93.25	14.00	N
135	1	87.65	15.15	N
136	1	88.05	45.40	N
137	1	88.75	17.55	N
139	1	87.10	54.35	N
140	1	88.70	27.30	N
141	1	86.75	7.950	N
144	1	89.50	25.60	N
146	1	86.90	17.55	N
150	1	89.20	70.15	N

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

NASA PULSE LIFE TEST 1N5656A 75% PEAK PULSE CURRENT AFTER 15000 PULSES.*

STA#=3 RTN#=20

TEST #:		5	6	
TEST ID:		VR	IR	
UNITS:		V	A	
SER	BIN			
101	1	88.70	27.15	N
105	1	89.35	22.35	N
106	1	87.25	44.60	N
109	1	87.75	46.40	N
110	1	87.35	49.55	N
113	1	89.25	16.05	N
116	1	91.50	55.20	N
120	1	89.50	53.80	N
121	1	89.65	33.55	N
123	1	87.50	71.95	N
124	1	90.80	94.35	N
126	1	87.25	35.55	N
130	1	89.00	15.15	N
133	1	93.00	12.80	N
135	1	87.65	10.35	N
136	1	87.95	42.75	N
137	1	88.65	12.85	N
139	1	87.10	57.55	N
140	1	88.60	19.80	N
141	1	86.70	9.600	N
144	1	89.45	26.95	N
146	1	86.90	22.35	N
150	1	89.20	67.15	N

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

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NASA PULSE LIFE TEST 1N5656A 75% PEAK PULSE CURRENT FINAL.*

STA#=3 RTN#=2

TEST #		5	6	
TEST ID		VR	IR	
UNITS		V	A	
SER	BIN			
101	1	88.70	38.35	N
105	1	89.40	17.15	N
106	1	87.20	45.60	N
109	1	87.75	49.55	N
110	1	87.30	44.75	N
113	1	89.30	17.15	N
116	1	91.55	51.20	N
120	1	89.55	51.20	N
121	1	89.60	25.60	N
123	1	87.55	79.55	N
124	1	90.70	96.20	N
126	1	87.20	33.55	N
130	1	88.75	17.55	N
133	1	92.95	7.050	N
135	1	87.65	12.95	N
136	1	87.95	44.35	N
137	1	88.70	19.20	N
139	1	87.20	60.80	N
140	1	88.65	25.55	N
141	1	86.65	4.750	N
144	1	89.50	30.35	N
146	1	86.90	19.20	N
150	1	89.15	68.75	N

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

NASA PULSE LIFE TEST   1N5656A   100% PEAK PULSE CURRENT   INITIAL.*

STA#=3   RTN#=20

TEST #:		5	6	
TEST ID:		VR	IR	
UNITS:		V	A	
SER	BIN			
152	1	87.50	33.50	N
153	1	86.65	38.40	N
156	1	87.85	63.95	N
158	1	88.30	44.75	N
162	1	88.15	68.35	N
163	1	90.05	29 30	N
165	1	87.55	32.80	N
168	1	91.25	34.40	N
171	1	87.45	46.00	N
173	1	87.45	30.35	N
176	1	87.65	38.35	N
178	1	90.05	44.75	N
179	1	87.50	38.40	N
181	1	88.20	57.55	N
183	1	87.55	105.6	N
184	1	89.00	53.95	N
186	1	87.95	41.55	N
188	1	89.45	38.45	N
189	1	87.30	51.50	N
190	1	87.75	52.00	N
193	1	89.10	71.15	N
195	1	87.75	47.90	N
196	1	88.60	32.00	N
198	1	88.75	44.75	N
310	1	89.90	17.55	N

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

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NASA PULSE LIFE TEST 1N5656A 100% PEAK PULSE CURRENT AFTER 7500 PULSES.*

STA#=1 RTN#=20

TEST #		5	6
TEST ID:		VR	IR
UNITS:		V	A
SER	BIN		
158	1	88.00	22.35 N
184	1	88.75	45.60 N
196	1	88.45	15.60 N
~~200~~ 310	1	89.35	17.55 N

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

NASA PULSE LIFE TEST 1N5656A 100% PEAK PULSE CURRENT AFTER 10000.*

*

STA#=3 RTN#=20

TEST #:		5	6
TEST ID:		VR	IR
UNITS		V	A
SER	BIN		
196	1	88.85	16.25 N
310	1	89.80	25.60 N

*

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

NASA PULSE LIFE TEST 1N5665A 75% PEAK PULSE CURRENT INITIAL*

STA#=1 RTN#=20

TEST #:		7	9
TEST ID:		VR	IR
UNITS:		V	A
SER	BIN		
322	1	191.1	61.95 N
324	2	F68.15	FO.R.
326	2	F52.40	FO.R.
337	1	192.1	29.85 N
339	2	F112.9	FO.R.
343	2	F19.60	FO.R.
344	2	F65.95	FO.R.
346	1	189.9	1.861 U
348	1	187.3	25.75 N
349	2	F88.80	FO.R.
354	2	F30.75	FO.R.
355	2	F49.85	FO.R.
357	2	F82.35	FO.R.
359	1	190.9	20.75 N
362	2	F12.05	FO.R.
363	2	F98.25	FO.R.
364	1	190.5	1.973 U
368	2	F9.700	FO.R.
371	2	F70.55	FO.R.
372	2	F20.10	FO.R.
373	1	188.8	1.456 U
374	2	F37.85	FO.R.
379	2	F25.80	FO.R.

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

NASA PULSE LIFE TEST 1N5665A 75% PEAK PULSE CURRENT AFTER 7500 PULSES *

STA#=2 RTN#=20

TEST #		7	8
TEST ID:		VR	IR
UNITS:		V	A
SER	BIN		
222	1	191.4	66.90 N
227	1	192.5	21.15 N
248	1	187.[illegible]	22.90 N
259	1	191.[illegible]	27.25 N

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

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NASA PULSE LIFE TEST 1N6665A 75% PEAK PULSE CURRENT AFTER 10000 PULSES*

STA#=1 RTN#=20

TEST #		7	9
TEST ID		VR	IR
UNITS		V	A
SER	BIN		
322	1	191.4	62.90 N
337	1	192.2	56.40 N
348	1	197.9	22.95 N
359	1	192.2	29.75 N

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

NASA PULSE LIFE TEST 1N5665A 75% PEAK PULSE CURRENT AFTER12500 PULSES *

STA#=2 RTN#=20

TEST #:		7	8
TEST ID:		VR	IR
UNITS:		V	A
SER	BIN		
322	1	192.2	27.95 N
337	1	193.1	26.80 N
346	1	187.8	26.70 N
359	1	191.9	27.95 N

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

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NASA PULSE LIFE TEST   1N5665A   75% PEAK PULSE CURRENT   AFTER 15000 PULSES:*

STA#=2   RTN#=20

TEST #:		7	9
TEST ID:		VR	IR
UNITS:		V	A
SER	BIN		
332	1	191.6	75.10 N
337	1	192.5	35.95 N
348	1	187.0	27.25 N
359	1	191.3	30.00 N

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

NASA PULSE LIFE TEST 1N5665A 75% PEAK PULSE CURRENT FINAL:*

STA#=1 RTN#=20

TEST #:		7	9	
TEST ID:		VR	IR	
UNITS:		V	A	
SER	BIN			
322	1	191.6	79.60	N
337	1	192.[illegible]	48.40	N
348	1	197.7	41.30	N
359	1	191.8	42.35	N

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

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NASA PULSE LIFE TEST 1N5655A 100% PEAK PULSE CURRENT INITIAL*

STA#=2 RTN#=20

TEST #:		7	8	
TEST ID:		VR	IR	
UNITS:		V	A	
SER	BIN			
381	1	195.5	21.55	N
382	1	187.9	27.80	N
384	1	188.5	92.75	N
386	1	196.3	33.60	N
388	1	187.9	32.80	N
390	1	190.2	39.95	N
394	1	187.1	2.200	U
397	1	182.8	29.15	N
398	1	189.5	29.15	N
400	1	190.2	57.85	N
401	1	188.0	25.60	N
402	1	190.8	20.20	N
405	1	187.0	26.40	N
406	1	189.3	37.50	N
408	1	187.4	36.60	N
409	1	188.8	29.60	N
412	1	184.8	42.40	N
413	1	188.7	29.05	N
414	1	187.1	27.95	N
415	1	185.3	38.40	N
420	1	184.7	214.5	N
423	1	188.2	30.40	N
424	1	190.4	35.15	N
426	1	191.8	62.30	N
428	1	189.3	36.40	N

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

NASA PULSE LIFE TEST 1N[illegible]A 100% PEAK PULSE CURRENT AFTER 7500 PULSES.*

STN#=2 RTN#=20

TEST #:		7	9	
TEST ID:		VR	IR	
UNITS:		V	A	
SER	BIN			
398	1	199.6	122.8	N
400	1	190.2	41.50	N
409	1	189.1	28.80	N
423	1	190.0	29.15	N
426*	1	192.2	64.90	N
428	1	190.0	31.15	N

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

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NASA PULSE LIFE TEST   1N5665A   100% PEAK PULSE CURRENT   AFTER 10000 PULSES *

STA#=2   RTN#=20

TEST #:		7	9	
TEST ID:		VR	IR	
UNITS:		V	A	
SER	BIN			
398	1	189.5	132.7	N
400	1	190.3	47.95	N
409	1	189.1	34.60	N
423	1	190.4	36.00	N
426	1	192.1	65.95	N
428	1	190.2	41.80	N

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

NASA PULSE LIFE TEST 1N5665A 100% PEAK PULSE CURRENT AFTER 12500 PULSES *
*

STA#=1 RTN#=20

TEST #:		7	8
TEST ID:		VR	IR
UNITS:		V	A
SER	BIN		
398	1	189.7	67.75 N
400	1	190.3	46.80 N
409	1	189.0	31.15 N
423	1	192.2	42.80 N
426•	1	191.6	59.75 N
428	1	190.9	42.35 N

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

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NASA PULSE LIFE TEST 1N5555A 100% PEAK PULSE CURRENT AFTER 15000 PULSES*
*

STA#=1 RTN#=20

TEST #:		7	8	
TEST ID:		VR	IR	
UNITS:		V	A	
SER	BIN			
398	1	188.7	264.0	N
400	1	190.3	42.50	N
409	1	189.1	28.00	N
423	1	190.7	30.1[illegible]	N
426	1	192.6	66.80	N
428	1	190.1	22.70	N

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses

NASA PULSE LIFE TEST   1N5665A   100% PEAK PULSE CURRENT   FINAL;*

*

STA#=1   RTN#=20

TEST #:		7	8
TEST ID:		VR	IR
UNITS:		V	A
SER	BIN		
398	1	189.1	62.35 N
400	1	189.7	39.15 N
409	1	188.9	28.10 N
423	1	192.0	36.75 N
426	1	191.6	55.95 N
428	1	190.2	33.55 N

*

* Add 5,760 pulses from Contract No. NAS8-30811 for total pulses.

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18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number).

(1) Transient Voltage Suppressor
(2) Mean Number of Peak Pulses Before Failure
(3) Reliability
(4) TransZorb

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This is the final summary report of work performed by General Semiconductor Industries, Inc., under Contract No. NAS8-31547, from George C Marshall Space Flight Center, Alabama, to conduct a continued reliability study extension of Contract No. NAS8-30811. This reliability study is on the Surge Pulse Life of the General Semiconductor Industries, Inc., TransZorb.

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