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LOW FLUX NUCLEAR RADIATION EFFECTS
ON SEMICONDUCTOR DEVICES
(BMI-LF-1)

AEC Research and Development Report

ATOMICS INTERNATIONAL

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LOW FLUX NUCLEAR RADIATION EFFECTS
ON SEMICONDUCTOR DEVICES
(BMI-LF-1)

By
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ABSTRACT

The first of a series of irradiation experiments on electrical and electronic devices intended for SNAP reactor control systems is described.

Four types of semiconductor devices, 2N744 and 2N1072 transistors, PS760 diodes, and 1N2032 Zener diodes, were irradiated to 10^{16} nvt (>0.1 Mev) and 4.5×10^8 r (gamma) at the Battelle Memorial Institute Research Reactor.

Results are presented of in-pile measurements of the critical electrical characteristics, in the form of graphs produced automatically by a computer peripheral plotting facility.

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Figure 1. In-Pile Component Assembly

I. INTRODUCTION

A series of three irradiation experiments on SNAP program electronic components was performed for AI at the Battelle Memorial Institute Research Reactor (BMI) during 1962 and 1963. This report describes the first of these experiments, entitled "Low Flux Irradiation Experiment Number 1" (LF-1), which was designed to provide a detailed evaluation of the effects of reactor radiation upon semiconductor components for the SNAP 10A reactor control system. The measurement parameters, environment, and radiation dose were appropriately chosen for this purpose. Supplementary operational details, particularly with respect to the reactor facilities and dosimetry, are contained in Battelle Memorial Institute Report No. BMI-X-290.*

Tests were performed on four semiconductor component types: 2N744 and 2N1072 transistors, PS760 diodes, and 1N2032 Zener diodes. In each case, fifteen units were subjected to nuclear radiation, under the pressure

*S. J. Basham, et al, "Experimental Techniques Used in Vacuum Irradiations of Electronic Components at 150°F," BMI-X-290 (Sept. 4, 1964)

and temperature conditions described below. This quantity is a compromise between the desire for statistically significant results and the recognition of space and instrumentation limitations. Five additional units of each type, designated as control units, were maintained in an out-of-pile system under the same general environmental conditions. The measurements performed upon all units, and the associated bias conditions, are listed in Table 1.

II. ENVIRONMENTAL CONDITIONS OF EXPERIMENT

A. GENERAL ENVIRONMENT

The experimental facilities consisted of an in-pile component assembly, shown in Figure 1, and a control specimen bell-jar assembly. Temperature levels of the in-pile specimens were maintained at about 150°F by controlling the temperature of water circulating in a stainless steel coil located in the annular space between the specimen assembly and its containment chamber. This water coil acted essentially as a variable temperature radiation baffle.

TABLE 1
LF-1 IRRADIATION EXPERIMENT MEASUREMENTS

Component Type	Number	Measurement Types	Bias Conditions
PS760	20	{ Forward Voltage, V_F Reverse Current, I_R	Forward Current, $I_F = 5$ ma Reverse Voltage, $V_R = 10$ volts
1N2032	20	Zener Voltage, V_Z	Zener Current, $I_Z = 50$ ma
2N744	19*	{ d-c Short Circuit Forward Transfer Ratio, H_{FE} Base-Emitter Voltage, V_{BE} Collector Leakage Current, I_{CBO}	Collector Current, $I_C = 10$ ma Collector-Emitter Voltage, $V_{CE} \pm 1$ volt $I_C = 10$ ma $I_B = 1$ ma Collector-Base Voltage, $V_{CB} = 10$ volts Emitter Current, $I_E = 0$
2N1072	19†	{ H_{FE} I_{CBO} H_{FE}	$I_C = 160$ ma; $V_{CE} = 2$ volts $V_{CB} = 28$ volts $I_C = 16$ ma; $V_{CE} = 2$ volts

*Faulty bias control invalidated measurements on one in-pile specimen.

†Faulty bias control invalidated measurements on one control specimen.

TABLE 2

SPECIMEN TEMPERATURES AND SYSTEM VACUUM LEVELS, LOW FLUX EXPERIMENT NO. 1

Thermocouple Number	Specimen	Position 3 (55.8 Hours)				Position 2 (55.2 Hours)				Position 1 (92.1 Hours)			
		Mean Temp. (°F)	Variation (+°F) (-°F)		Vacuum	Mean Temp. (°F)	Variation (+°F) (-°F)		Vacuum	Mean Temp. (°F)	Variation (+°F) (-°F)		Vacuum
1	1N-2032 (dummy)	Thermocouple Open				--	--	--		--	--	--	
2	2N-1072 (dummy)	147	7	9		140	2	5		143	1	1	
3	PS-760 (4)	144	5	8		150	3	4		150	2	1	
4	2N-744	146	8	8		149	3	4		142	2	2	
5	PS-760	146	6	7		149	3	4		149	2	2	
6	1N-2032 (7)	145	5	8		150	2	3		152	2	1	
7	2N-1072 (10)	141	6	7		146	2	4		155	2	1	
8	PS-760 (11)	143	7	8		149	3	5		145	2	2	
9	Nickel lead (a)	141	5	6		156	2	4		169	1	1	
10	2N-744	142	7	7		149	1	2		150	1	1	
(Controller)													
11	1N-2032	160 (b)	1	1		154	1	1		155	1	1	
12	2N-744	160 (b)	1	1		153	1	1		154	1	1	
13	PS-760	149 (b)	2	2		143	1	1		144	1	1	
14	2N-1072	150(c)(b)	5	5		150	1	1		150	1	1	
(Controller)													

(a) This is a sample electrical lead.

(b) 20°F scatter early in the run (see text).

(c) This specimen operated near 200°F several hours before actual irradiation began (see text)

The water system consisted of a reservoir, centrifugal pump, electric preheater, lines leading to and from the coil in the test section, and a heat exchanger. The temperature of a selected specimen in the in-pile system was used to regulate the preheater output and consequently the water temperature. Chromel-Alumel thermocouples were attached to selected operating specimens by potting with epoxy resin, and the resulting average specimen temperatures are listed in Table 2. (The variations from the mean are the maximum in each case.) Confirmation of good thermal contact for the epoxied thermocouples was obtained by means of several thermocouples spot-welded to a group of uninstrumented specimens.

In the control specimen assembly, temperature was maintained by infra-red heat lamps mounted adjacent to the bell jar. Control was provided by instrumentation which varied the power input to the lamps on a signal from a thermocouple epoxied to a selected specimen, in this case the 2N1072 transistor.

To achieve a temperature of 150°F for the other units, it was necessary for the 2N1072 samples to be operated near 200°F for several hours before irradiation began. This was due to their relatively large size and absorbent coating. As a result, their recorded electrical characteristics were significantly affected. The scatter of 20°F in the bell-jar specimen temperatures early in the experiment was due to changes in the position of radiation baffles, mounted between the heat lamps and the specimens. After these adjustments, the baffles permitted uniform control-sample temperatures to be maintained for the remainder of the experiment.

The vacuum levels during the experiment are listed in Table 1. The best vacuum obtained during irradiation was 3.6×10^{-5} Torr; the worst was 8.2×10^{-5} Torr. The bell-jar system showed vacuums better than 8×10^{-6} Torr throughout the experiment and attained a vacuum of 1.2×10^{-6} Torr at one point.

B. RADIATION ENVIRONMENT

The nuclear environment was specified on the basis of several requirements:

- 1) At a fast neutron (energies above 0.1 Mev) exposure of approximately 10^{13} nvt, it was desired to have a neutron-to-gamma ratio of 10^6 .

- 2) A total fast-flux exposure of about 10^{16} nvt was required.

- 3) The exposure was to be programmed to permit four to ten measurements of specimen performance at approximately equal intervals in each decade of fast-flux exposure above 10^{10} nvt.

To satisfy these requirements, the in-pile system was moved through three positions which were chosen by means of preirradiation dosimetry measurements with an empty mockup assembly. A thorough analysis of the threshold detector technique used to measure neutron fluxes and to describe the neutron energy spectrum in the mockup is included in the BMI report previously discussed.

To obtain a detailed description of the radiation environment throughout the specimen assembly, a map of the integrated fast neutron flux distribution was determined by nickel dosimeter wires. Measured threshold flux values thus determined were corrected to integral fast-flux greater than 0.1 Mev by the fast neutron spectra measured in the mockup dosimetry. The overall average of the specimens is listed as the mean fast neutron dose in Table 3.

A 15-mil cadmium sleeve was placed around the specimen assembly to reduce activation from the thermal flux. On the basis of both the mockup dosimetry and a subsequent flux mapping with aluminum-cobalt wires, it was determined that the fast-to-thermal flux ratios were from 40 to 100 for all specimens. In this context, subcadmium flux is taken as equivalent to the thermal flux.

TABLE 3
LF-1 IRRADIATION HISTORY

Date	Time	Reactor Power (% of 2 Mw)	Time at Power (hr)	Position	Mean Fast Neutron Dose* (nvt)	Mean Gamma Dose (* and †) (Roentgen)
9-25-62	0202	100	-	Start III	-	-
9-27-62	0943	-	55.68	End III	1.49×10^{12}	6.26×10^6
9-27-62	0943	100	-	Start II	-	-
9-29-62	1653	-	55.76	End II	1.33×10^{14}	4.71×10^7
9-29-62	1653	100	-	Start I	-	-
10-3-62	1325	-	92.53	End I	1.04×10^{16}	4.50×10^8

* The doses listed are totals for each position only. The integrated dose is the sum of these three values.

† The gamma "dose" is a measure of the radiation field, not the energy absorbed by the specimens.

Gamma exposure rates were measured in the mockup with 10-cm³ graphite-walled ionization chambers, calibrated against copper-modified ferrous sulfate chemical dosimeters at the BMI Co⁶⁰ Irradiation Laboratory. In-pile dose rate measurements were corrected for the fast-neutron sensitivity of the chambers. The mean gamma doses are listed in Table 3.

The data graphs, pages 25 through 200, present the measured semiconductor parameters

as a function of fast neutron exposure. To permit an approximate correlation of a gamma exposure to these neutron exposures, the mean gamma dose is plotted as a function of mean neutron dose in Figures 2(a) and (b). However, an exact correlation requires the use of the normalization factors listed in Table 4. These factors express the ratio of specimen dose to mean dose for each specimen at each of the three positions.

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(b) Position III and II

8-14-64 7623-0521-2

(a) Position II and I

Figure 2. Gamma Dose as a Function of Fast Neutron Dose

TABLE 4
NORMALIZATION FACTORS

SPECIMEN IDENTIFICATION	NORMALIZATION FACTORS					
	Position III		Position II		Position I	
	Neutron	Gamma	Neutron	Gamma	Neutron	Gamma
PS760-1	1.51	1.22	1.47	1.22	1.54	1.37
PS760-2	1.34	1.18	1.35	1.17	1.38	1.27
PS760-3	1.21	1.15	1.21	1.11	1.20	1.16
PS760-4	1.07	1.14	1.05	1.05	1.06	1.04
PS760-5	0.91	1.06	0.92	1.00	0.92	0.95
PS760-6	0.79	1.00	0.79	0.94	0.79	0.85
PS760-7	0.71	0.96	0.69	0.88	0.69	0.76
PS760-8	1.21	0.97	1.22	1.04	1.21	1.14
PS760-9	1.14	0.95	1.13	1.03	1.15	1.09
PS760-10	1.11	0.94	1.09	1.01	1.08	1.03
PS760-11	1.01	0.90	1.00	0.97	1.01	0.95
PS760-12	0.91	0.90	0.92	0.97	0.93	0.95
PS760-13	0.83	0.88	0.83	0.93	0.85	0.87
PS760-14	0.74	0.85	0.75	0.88	0.75	0.80
PS760-15	0.67	0.82	0.68	0.83	0.67	0.73
1N2032-1	1.64	0.97	1.66	1.22	1.68	1.37
1N2032-2	1.51	0.95	1.48	1.17	1.53	1.27
1N2032-3	1.27	0.94	1.32	1.11	1.32	1.16
1N2032-4	1.12	0.90	1.13	1.05	1.15	1.04
1N2032-5	0.94	0.88	0.95	1.00	0.96	0.95
1N2032-6	0.81	0.85	0.79	0.94	0.79	0.85
1N2032-7	0.71	0.82	0.69	0.88	0.70	0.76
1N2032-8	1.05	1.22	1.05	1.04	1.08	1.14
1N2032-9	1.02	1.18	1.02	1.03	1.03	1.09
1N2032-10	0.96	1.15	0.96	1.01	0.96	1.03
1N2032-11	0.89	1.14	0.87	0.97	0.90	0.95
1N2032-12	0.81	1.14	0.79	0.97	0.81	0.95
1N2032-13	0.74	1.06	0.73	0.93	0.74	0.87
1N2032-14	0.67	1.00	0.68	0.88	0.68	0.80
1N2032-15	0.62	0.96	0.62	0.83	0.62	0.73
2N744-1	1.71	1.22	1.69	1.22	1.68	1.37
2N744-2	1.58	1.18	1.58	1.17	1.54	1.27
2N744-3	1.34	1.15	1.35	1.11	1.35	1.16
2N744-4	1.17	1.14	1.20	1.05	1.15	1.04
2N744-5	0.97	1.06	1.00	1.00	0.98	0.95
2N744-6	0.84	1.00	0.86	0.94	0.88	0.85
2N744-7	0.72	0.96	0.75	0.88	0.73	0.76
2N744-8	1.11	0.97	1.09	1.04	1.13	1.14

TABLE 4
NORMALIZATION FACTORS (Continued)

SPECIMEN IDENTIFICATION	NORMALIZATION FACTORS					
	Position III		Position II		Position I	
	Neutron	Gamma	Neutron	Gamma	Neutron	Gamma
2N744-9	1.07	0.95	1.05	1.03	1.06	1.09
2N744-10	0.97	0.94	0.94	1.01	0.96	1.03
2N744-11	0.87	0.90	0.87	0.97	0.87	0.95
2N744-12	0.81	0.88	0.79	0.93	0.80	0.87
2N744-13	0.74	0.85	0.71	0.88	0.73	0.80
2N744-14	0.67	0.82	0.65	0.83	0.66	0.73
2N1072-1	1.17	1.22	1.13	1.04	1.20	1.14
2N1072-2	1.14	1.18	1.13	1.03	1.14	1.09
2N1072-3	1.03	1.15	1.02	1.01	0.98	1.03
2N1072-4	0.84	1.14	0.87	0.97	0.87	0.95
2N1072-5	0.77	1.06	0.79	0.93	0.77	0.87
2N1072-6	0.71	1.00	0.69	0.88	0.67	0.80
2N1072-7	0.60	0.96	0.64	0.83	0.60	0.73
2N1072-8	1.41	0.97	1.43	1.22	1.44	1.37
2N1072-9	1.27	0.95	1.32	1.17	1.27	1.27
2N1072-10	1.12	0.94	1.20	1.11	1.15	1.16
2N1072-11	1.07	0.90	1.09	1.05	1.09	1.04
2N1072-12	0.94	0.90	0.98	1.05	0.97	1.04
2N1072-13	0.81	0.88	0.87	1.00	0.87	0.95
2N1072-14	0.77	0.85	0.79	0.94	0.76	0.85
2N1072-15	0.67	0.82	0.68	0.88	0.66	0.76

III. DISCUSSION OF TEST RESULTS

An automatic data acquisition system was employed in which both the measured parameters and the bias conditions were monitored with digital voltmeters. These circuits produced data to $\pm 0.1\%$ precision, with bias conditions controlled to better than $\pm 1\%$. All data were recorded directly on punch cards and were later both reduced and plotted by an IBM 7090 computer. Table 5 is a list of the resulting graphs. Each graph, except for those noted in the table, has two "dummy points" inserted to set limits on the ordinate scale. These points can be identified by their coincidence on the abscissa scale and their location in the low dose range.

The exceptions are due to data which differ significantly from the average range for the component type.

For convenient presentation of the data, the control specimens were assigned a "dummy" dose rate: the mean value for the component type. By this choice, the graphed values represent the same degree of power aging and response to other nonnuclear stresses as do the comparable values for irradiated components.

A. PS760 DIODE

The specifications of this silicon computer diode, manufactured by Pacific Semiconductors, Inc., are listed below:

Operating Temperature Range:	-65°C to 150°C
Forward Characteristics:	20 ma @ 1.0 volt, 25°C
Maximum average current	100 ma @ 25°C 30 ma @ 150°C
Maximum peak current	320 ma @ 25°C
Inverse Characteristics:	5 ma maximum @ 50 volt, 25°C 25 ma maximum @ 50 volt, 100°C
Saturation Voltage, E_b :	60 volt @ 100 ma, 100 °C

The forward voltage of the in-pile specimens remained less than 1 volt up to 3×10^{13} nvt. At 10^{15} nvt the mean voltage was 3.1 volt, with a range of 2.0 volts to 6.3 volts; at higher doses voltages of over 20 volts were measured. The reverse current showed a slightly greater sensitivity to radiation damage. The preirradiation currents were all less than 3 ma; however, after 3×10^{13} nvt, a wide spectrum of values was obtained, with one as high as 19 ma. At 10^{16} nvt, all of the reverse currents were less than 20 ma.

TABLE 5
LIST OF GRAPHS FOR LF-1 IRRADIATION

<u>Graph Number</u>	<u>Component Identification</u>	<u>Measurement Type</u>
1	PS 760 # 1	V_F
2	PS 760 # 2	V_F
3	PS 760 # 3	V_F
4	PS 760 # 4	V_F
5	PS 760 # 5	V_F
6	PS 760 # 6	V_F
7	PS 760 # 7	V_F
8	PS 760 # 8	V_F
9	PS 760 # 9	V_F
10	PS 760 #10	V_F
11	PS 760 #11	V_F
12	PS 760 #12	V_F
13	PS 760 #13	V_F
14	PS 760 #14	V_F
15	PS 760 #15	V_F
16	PS 760 #16 (Control)	V_F
17	PS 760 #17 (Control)	V_F
18	PS 760 #18 (Control)	V_F
19	PS 760 #19 (Control)	V_F
20	PS 760 #20 (Control)	V_F
21	PS 760 # 1	I_R
22	PS 760 # 2	I_R
23	PS 760 # 3	I_R
24	PS 760 # 4	I_R
25	PS 760 # 5	I_R
26	PS 760 # 6	I_R

TABLE 5
LIST OF GRAPHS FOR LF-1 IRRADIATION (Continued)

<u>Graph Number</u>	<u>Component Identification</u>	<u>Measurement Type</u>
27	PS760 # 7	I _R
28	PS760 # 8	I _R
29	PS760 # 9	I _R
30	PS760 #10	I _R
31	PS760 #11	I _R
32	PS760 #12	I _R
33	PS760 #13	I _R
34	PS760 #14	I _R
35	PS760 #15	I _R
36	PS760 #16 (Control)	I _R
37	PS760 #17 (Control)	I _R
38	PS760 #18 (Control)	I _R
39	PS760 #19 (Control)	I _R
40	PS760 #20 (Control)	I _R
41	1N2032 # 1	V _Z
42	1N2032 # 2	V _Z
43	1N2032 # 3	V _Z
44	1N2032 # 4	V _Z
45	1N2032 # 5	V _Z
46	1N2032 # 6	V _Z
47	1N2032 # 7	V _Z
48	1N2032 # 8	V _Z
49	1N2032 # 9	V _Z
50	1N2032 #10	V _Z
51	1N2032 #11	V _Z
52	1N2032 #12	V _Z
53	1N2032 #13	V _Z
54	1N2032 #14	V _Z
55	1N2032 #15	V _Z
56	1N2032 #16 (Control)	V _Z
57	1N2032 #17 (Control)	V _Z
58	1N2032 #18 (Control)	V _Z
59	1N2032 #19 (Control)	V _Z
60	1N2032 #20 (Control)	V _Z
61	2N744 # 1	H _{FE}
62	2N744 # 2	H _{FE}
63	2N744 # 3	H _{FE}
64	2N744 # 4	H _{FE}
65	2N744 # 5	H _{FE}
66	2N744 # 6	H _{FE}
67	2N744 # 7	H _{FE}

TABLE 5
LIST OF GRAPHS FOR LF-1 IRRADIATION (Continued)

<u>Graph Number</u>	<u>Component Identification</u>	<u>Measurement Type</u>
68	2N744 # 8	H _{FE}
69	2N744 # 9	H _{FE}
70	2N744 #10	H _{FE}
71	2N744 #11	H _{FE}
72	2N744 #12	H _{FE}
73	2N744 #13	H _{FE}
74	2N744 #14	H _{FE}
75	2N744 #15 (Control)	H _{FE}
76	2N744 #16 (Control)	H _{FE}
77	2N744 #17 (Control)	H _{FE}
78	2N744 #18 (Control)	H _{FE}
79	2N744 #19 (Control)	H _{FE}
80	2N744 # 1	V _{BE}
81	2N744 # 2	V _{BE}
82	2N744 # 3	V _{BE}
83	2N744 # 4	V _{BE}
84	2N744 # 5	V _{BE}
85	2N744 # 6	V _{BE}
86	2N744 # 7	V _{BE}
87	2N744 # 8	V _{BE}
88	2N744 # 9	V _{BE}
89	2N744 #10	V _{BE}
90	2N744 #11	V _{BE}
91	2N744 #12	V _{BE}
92	2N744 #13	V _{BE}
93	2N744 #14	V _{BE}
94	2N744 #15 (Control)	V _{BE}
95	2N744 #16 (Control)	V _{BE}
96	2N744 #17 (Control)	V _{BE}
97	2N744 #18 (Control)	V _{BE}
98	2N744 #19 (Control)	V _{BE}
99	2N744 # 1	I _{CBO}
100	2N744 # 2	I _{CBO}
101	2N744 # 3	I _{CBO}
102	2N744 # 4	I _{CBO}
103	2N744 # 5	I _{CBO}
104	2N744 # 6	I _{CBO}
105	2N744 # 7	I _{CBO}
106	2N744 # 8	I _{CBO}
107	2N744 # 9	I _{CBO}

TABLE 5
LIST OF GRAPHS FOR LF-1 IRRADIATION (Continued)

<u>Graph Number</u>	<u>Component Identification</u>	<u>Measurement Type</u>
108	2N744 #10	I _{CBO}
109	2N744 #11	I _{CBO}
110	2N744 #12	I _{CBO}
111	2N744 #13	I _{CBO}
112	2N744 #14	I _{CBO}
113	2N744 #15 (Control)	I _{CBO}
114	2N744 #16 (Control)	I _{CBO}
115	2N744 #17 (Control)	I _{CBO}
116	2N744 #18 (Control)	I _{CBO}
117	2N744 #19 (Control)	I _{CBO}
118	2N1072 # 1	H _{FE}
119	2N1072 # 2	H _{FE}
120	2N1072 # 3	H _{FE}
121	2N1072 # 4	H _{FE}
122	2N1072 # 5	H _{FE}
123	2N1072 # 6	H _{FE}
124	2N1072 # 7	H _{FE}
125	2N1072 # 8	H _{FE}
126	2N1072 # 9	H _{FE}
127	2N1072 #10	H _{FE}
128	2N1072 #11	H _{FE}
129	2N1072 #12	H _{FE}
130	2N1072 #13	H _{FE}
131	2N1072 #14	H _{FE}
132	2N1072 #15	H _{FE}
133	2N1072 #16 (Control)	H _{FE}
134	2N1072 #17 (Control)	H _{FE}
135	2N1072 #18 (Control)	H _{FE}
136	2N1072 #19 (Control)	H _{FE}
137	2N1072 # 1	I _{CBO}
138	2N1072 # 2	I _{CBO}
139	2N1072 # 3	I _{CBO}
140	2N1072 # 4	I _{CBO}
141	2N1072 # 5	I _{CBO}
142	2N1072 # 6	I _{CBO}
143	2N1072 # 7	I _{CBO}
144	2N1072 # 8	I _{CBO}
145	2N1072 # 9	I _{CBO}
146	2N1072 #10	I _{CBO}

TABLE 5

LIST OF GRAPHS FOR LF-1 IRRADIATION (Concluded)

Graph Number	Component Identification	Measurement Type
147	2N1072 #11	I_{CBO}
148	2N1072 #12	I_{CBO}
149	2N1072 #13	I_{CBO}
150	2N1072 #14	I_{CBO}
151	2N1072 #15	I_{CBO}
152	2N1072 #16 (Control)	I_{CBO}
153	2N1072 #17 (Control)	I_{CBO}
154	2N1072 #18 (Control)	I_{CBO}
155	2N1072 #19 (Control)	I_{CBO}
156	2N1072 # 1	$H_{FE} (I_C = 16 \text{ ma})$
157	2N1072 # 2	$H_{FE} (I_C = 16 \text{ ma})$
158	2N1072 # 3	$H_{FE} (I_C = 16 \text{ ma})$
159	2N1072 # 4	$H_{FE} (I_C = 16 \text{ ma})$
160	2N1072 # 5	$H_{FE} (I_C = 16 \text{ ma})$
161	2N1072 # 6	$H_{FE} (I_C = 16 \text{ ma})$
162	2N1072 # 7	$H_{FE} (I_C = 16 \text{ ma})$
163	2N1072 # 8	$H_{FE} (I_C = 16 \text{ ma})$
164	2N1072 # 9	$H_{FE} (I_C = 16 \text{ ma})$
165	2N1072 #10	$H_{FE} (I_C = 16 \text{ ma})$
166	2N1072 #11	$H_{FE} (I_C = 16 \text{ ma})$
167	2N1072 #12	$H_{FE} (I_C = 16 \text{ ma})$
168	2N1072 #13	$H_{FE} (I_C = 16 \text{ ma})$
169	2N1072 #14	$H_{FE} (I_C = 16 \text{ ma})$
170	2N1072 #15	$H_{FE} (I_C = 16 \text{ ma})$
171	2N1072 #16 (Control)	$H_{FE} (I_C = 16 \text{ ma})$
172	2N1072 #17 (Control)	$H_{FE} (I_C = 16 \text{ ma})$
173	2N1072 #18 (Control)	$H_{FE} (I_C = 16 \text{ ma})$
174	2N1072 #19 (Control)	$H_{FE} (I_C = 16 \text{ ma})$

B. 1N2032 ZENER DIODE

The specifications of this 3/4-watt silicon regulator, manufactured by Transitron, are as follows:

Maximum temperature range ($^{\circ}\text{C}$)	-65 to 150
Zener voltage (volt at 10 ma, 25°C)	
Nominal ($\pm 5\%$)	5
Minimum	4.3
Maximum	5.4
Maximum average operating current (ma at 25°C)	150
	30
Maximum dynamic resistance (ohm)	55

The voltage regulation of the in-pile specimens was within the range of variation of the control units through 3×10^{13} nvt. However, the threshold for significant change in the Zener voltage varied from 5×10^{14} nvt to greater than 10^{16} nvt; furthermore, no consistent trend was observed beyond the threshold. In fact, this parameter decreased for nine of the specimens, five showed a slight ($\leq 1.5\%$ at 10^{16} nvt) increase, and one remained constant. The increasing voltage observed in five of the specimens could be attributed to temperature

variation. The magnitude of the changes observed is within the range given in the specifications of this model, except in the case of Unit 3, for which earlier data was anomalous. This explanation is supported by the fact that all five units were located in close proximity on the specimen assembly. The degree and character of the changes observed are shown in Table 6. The large variations of the control

sample voltages are due to the slow response and inefficiency of the heating circuit in the bell-jar system.

C. 2N744 TRANSISTOR

The specifications of the model tested are shown in Figure 3(a), (b). The measurements performed, and the associated bias conditions, are listed in Table 1.

TABLE 6
CHANGES IN IN2032 ZENER DIODE

Specimen Number	Mean Zener Voltage ⁽¹⁾ (volt)	Percent Variation ⁽²⁾	Dose for 1% Variation ⁽³⁾ (nvt)
1	5.66	0.35	8.5×10^{14}
2	5.30	0.28	9×10^{14}
3(4)	4.96	0.21	(6)
4(5)	5.21	0.33	(6)
5	5.04	0.31	(6)
6	5.77	0.29	(6)
7	5.55	0.36	5×10^{15}
8	5.51	0.24	5×10^{15}
9	5.84	0.57	8×10^{14}
10	5.14	0.20	6×10^{14}
11	5.02	0.20	10^{16}
12	5.05	0.32	(6)
13	5.44	0.55	7×10^{15}
14	5.63	0.30	5.5×10^{14}
15	5.38	0.23	5×10^{14}
16	4.95	0.71	Control
17	6.4	0.59	Control
18	5.34	0.64	Control
19	4.93	1.30	Control
20	5.26	1.18	Control

(1) Mean values measured up to 10^{13} nvt.

(2) Percent variations about the mean up to 10^{13} nvt.

(3) Dose levels at which the Zener voltage was 1% below the mean given in Column 2.

(4) Unit 3 shows anomalous data in the high 10^{11} nvt range. The indicated values discount this data.

(5) An anomalous point at 5.5×10^{10} nvt is probably a reading error, and is not considered in the computation of the mean.

(6) These units showed no decrease in Zener voltage up to 10^{16} nvt.

TYPES 2N743, 2N744 N-P-N EPITAXIAL DOUBLE-DIFFUSED MESA SILICON TRANSISTORS

TYPE 2N743, 2N744
BULLETIN NO. DL-S 60427, FEBRUARY 1961

VERY-HIGH-SPEED SWITCHING TRANSISTORS

- Guaranteed total switching times less than 52 nsec at 100 ma (2N743).
- Guaranteed total switching times less than 57 nsec at 100 ma (2N744).
- Guaranteed total switching times less than 40 nsec at 10 ma.
- Guaranteed dc design parameters at -55°C , $+25^{\circ}\text{C}$, $+170^{\circ}\text{C}$.
- Maximum $V_{CE(sat)}$ of 1 volt at 100 ma and $+170^{\circ}\text{C}$.
- Typical f_T of 400 mc.

environmental tests

Each unit is heat cycled from -65°C to $+175^{\circ}\text{C}$ for ten cycles. A rigorous tumbling test subjects each unit to 12 mechanical shocks of up to 500 G's to ensure mechanical reliability. Each unit is thoroughly tested to determine the electrical characteristics. Production samples are life tested at regularly scheduled periods to ensure maximum reliability under extreme operating conditions. Extended storage at $+300^{\circ}\text{C}$ is used to stabilize each device.

mechanical data

THE COLLECTOR IS IN ELECTRICAL CONTACT WITH THE CASE
All JEDEC TO-18 outline dimensions and notes are applicable.

absolute maximum ratings at 25°C ambient temperature (unless otherwise noted)

Collector-Emitter Voltage (see Note 1)	12 v
Collector-Base Voltage	20 v
Emitter-Base Voltage	5 v
Collector Current, continuous	200 ma
Total Device Dissipation at 25°C Ambient Temperature (see Note 2)	0.3 w
Total Device Dissipation at 25°C Case Temperature (see Note 3)	1.0 w
Collector Junction Operating Temperature	$+175^{\circ}\text{C}$
Storage Temperature Range	-65°C to $+300^{\circ}\text{C}$

Note 1: This is the voltage at which $|h_{FE}|$ approaches one when the emitter-base diode is open circuited.

Note 2: Derate linearly to 175°C ambient temperature at the rate of 2 mw/ $^{\circ}\text{C}$.

Note 3: Derate linearly to 175°C case temperature at the rate of 6.67 mw/ $^{\circ}\text{C}$.

Note 4: For correct measurement of I_{CES} , the base must be shorted to the emitter. The current meter must not be placed in the base-emitter short-circuit loop. I_{CES} may be used in place of I_{CBO} for circuit-stability calculations.

Note 5: To obtain f_T , the $|h_{fe}|$ response with frequency is extrapolated at 6 db/octave to $|h_{fe}|=1$ from a measurement of the frequency at which $|h_{fe}|=2$. The product of $f_T \times 1$ has been referred to as the gain-bandwidth product.

Figure 3(a). Transistor 2N744 Specifications

TYPES 2N743, 2N744

N-P-N EPITAXIAL DOUBLE-DIFFUSED MESA SILICON TRANSISTORS

electrical characteristics at 25°C ambient temperature

Parameter	Test Conditions	2N743		2N744		Units
		Min.	Max.	Min.	Max.	
I_{CES} Collector Reverse Current	$V_{CE} = 20 \text{ v}$, $V_{BE} = 0$ (see Note 4)	—	1	—	1	μa
I_{EBO} Emitter Reverse Current	$V_{EB} = 5 \text{ v}$, $I_C = 0$	—	10	—	10	μa
$\cdot BV_{CEO}$ Collector-Emitter Breakdown Voltage	$I_C = 10 \text{ ma}$, $I_B = 0$ (see Note 1)	12	—	12	—	v
h_{FE} DC Forward Current Transfer Ratio	$V_{CE} = 0.25 \text{ v}$, $I_C = 1 \text{ ma}$	10	—	20	—	
h_{FE} DC Forward Current Transfer Ratio	$V_{CE} = 0.35 \text{ v}$, $I_C = 10 \text{ ma}$	20	60	40	120	
$\cdot h_{FE}$ DC Forward Current Transfer Ratio	$V_{CE} = 1.0 \text{ v}$, $I_C = 100 \text{ ma}$	10	—	20	—	
V_{BE} Base-Emitter Voltage	$I_B = 1 \text{ ma}$, $I_C = 10 \text{ ma}$	0.70	0.85	0.70	0.85	v
$\cdot V_{BE}$ Base-Emitter Voltage	$I_B = 10 \text{ ma}$, $I_C = 100 \text{ ma}$	—	1.5	—	1.5	v
$ h_{fe} $ AC Common-Emitter Forward Current Transfer Ratio	$V_{CE} = 10 \text{ v}$, $I_C = 10 \text{ ma}$, $f = 100 \text{ mc}$	9	—	9	—	db
C_{ob} Common-Base Output Capacitance	$V_{CB} = 5 \text{ v}$, $I_E = 0$, $f = 1 \text{ mc}$	—	5.0	—	5.0	pf

electrical characteristics at high and low temperatures

Parameter	Test Conditions	2N743		2N744		Units
		Min.	Max.	Min.	Max.	
I_{CES} Collector Reverse Current	$V_{CE} = 20 \text{ v}$, $V_{BE} = 0$, $T_A = +170^\circ\text{C}$ (see Note 4)	—	100	—	100	μa
I_{CEX} Collector Reverse Current	$V_{CE} = 10 \text{ v}$, $V_{BE} = +0.35 \text{ v}$, $T_A = +100^\circ\text{C}$	—	30	—	30	μa
h_{FE} DC Forward Current Transfer Ratio	$V_{CE} = 0.35 \text{ v}$, $I_C = 10 \text{ ma}$, $T_A = -55^\circ\text{C}$	10	—	20	—	
$V_{CE(sat)}$ Collector-Emitter Saturation Voltage	$I_B = 1 \text{ ma}$, $I_C = 10 \text{ ma}$, $T_A = +170^\circ\text{C}$	—	0.35	—	0.35	v
$\cdot V_{CE(sat)}$ Collector-Emitter Saturation Voltage	$I_B = 10 \text{ ma}$, $I_C = 100 \text{ ma}$, $T_A = +170^\circ\text{C}$	—	1.0	—	1.0	v
V_{BE} Base-Emitter Voltage	$I_B = 1 \text{ ma}$, $I_C = 10 \text{ ma}$, $T_A = -55^\circ\text{C}$	—	1.1	—	1.1	v
$\cdot V_{BE}$ Base-Emitter Voltage	$I_B = 10 \text{ ma}$, $I_C = 100 \text{ ma}$, $T_A = -55^\circ\text{C}$	—	1.6	—	1.6	v

switching characteristics at 25°C ambient temperature

Switching Characteristics		Circuit Conditions**						2N743		2N744		Units
		I_C ma †	$I_{B(1)}$ ma †	$I_{B(2)}$ ma †	$V_{BE(1)}$ v	V_{CC} v	R_L Ω †	Typ	Max	Typ	Max	
t_{on}	Turn-on Time (see Circuit A)	3	1	—	0.5	3.4	1k	26		26		nsec
		10	3	—	1.5	3.0	250	11	16	10	16	nsec
		50	15	—	7.5	4.0	68	7		7		nsec
		100	40	—	20.0	6.0	50	6	12	6	12	nsec
t_{off}	Turn-off Time (see Circuit A)	3	1	—	0.5	3.4	1k	30		30		nsec
		10	3	—	1.5	3.0	250	15	24	17	24	nsec
		50	15	—	7.5	4.0	68	15		18		nsec
		100	40	—	20.0	6.0	50	18	40	23	45	nsec
τ_s	Storage-Time Constant (see Circuit B)	10	10	10		10	1k	7	14	9	18	nsec

* Semi-automatic testing is facilitated by using pulse techniques to measure these parameters. A 300 μsec pulse (approximately 2% duty cycle) is utilized.

† Approximate values.

** $V_{BE(1)}$ = prior base-emitter voltage, OFF state; $I_{B(1)}$ = base current, ON state; $I_{B(2)}$ = post base current, OFF state (not a steady-state value; occurs during t_{off} only).

Figure 3(b). Transistor 2N744 Specifications (Continued)

The large variations in gain exhibited by the control samples are due mainly to the inefficiency of the heating apparatus of the control system and the difficulty of performing high gain measurements using long cables. Some of the in-pile specimens show similar variations before the onset of degradation. As a consequence, the ratio (gain at 3×10^{13} nvt)/(preirradiation gain) is insufficiently well-defined to characterize the observed changes. Instead, the absolute gain at 3×10^{13} nvt has been chosen. The mean value at this dose level was 32, with a range of 22 to 47. The units in which the preirradiation gain was highest showed the largest percentage degradation, decreasing in several cases to lower values than the other units at 3×10^{13} nvt.

The base-to-emitter voltage, nominally 0.7 volts, increased less than 4% by 3×10^{13} nvt. Six specimens reacted erratically after 10^{14} nvt, primarily by a sharp decrease in this parameter. This can not be correlated to the changes in the leakage current, which were not significant until about 10^{16} nvt.

Two of the leakage current measurements, for Units 4 and 6, appear to be a result of failures in the measurement circuit, although the possibility of a leakage channel for Unit 4 cannot be dismissed. No attendant bias fluctuations were recorded. The remainder of the units show no radiation-related changes in I_{CBO} before 5×10^{15} nvt. In fact, the largest changes observed were in the control samples, where, as previously noted, the temperature control was less efficient.

D. 2N1072 TRANSISTOR

The specifications of the model tested are shown in Figure 4 (a) and (b). Measurements were made of gain for both high and low collector currents, 160 and 16 ma respectively. As in the case of the 2N744 transistors, difficulties were encountered in the measurement of the high predegradation gains.

In the high current case, the range of H_{FE} before degradation was about 28 to 62. After 3×10^{13} nvt, the mean gain was 9.5, with a range of only ± 1.5 . In the low current case, the spread of values was 14 to 53, while after 3×10^{13} nvt, the mean was 6.5, with a range of ± 1.5 .

The leakage currents of the control specimens show the effects of the high preirradiation temperatures described in Section 2A. The in-pile units exhibited a large increase in I_{CBO} during the time when the capsule was in Position II. No explanation of this phenomenon has been discovered. It is unlikely that temperature fluctuation is the cause since one of the affected specimens was monitored during irradiation, as shown in Table 2. Furthermore, the probability of a leakage channel being created and recovering, in all of the units at the same dose level, is quite small. Thus, confirmation by further testing is indicated before these values are accepted as design criteria, especially in switching circuits.

HIGH RELIABILITY TRANSISTORS

FOR —
GENERAL PURPOSE
HIGH CURRENT SWITCHING
CORE DRIVER APPLICATIONS
MEDIUM POWER AMPLIFIER
SERVICE TO 40 MC.

LOW SATURATION RESISTANCE AT HIGH CURRENTS

1 AMPERE SWITCHING AT RISE AND FALL TIMES
 OF 50 NANOSECONDS

DESIGNED FOR MILITARY APPLICATIONS

ABSOLUTE MAXIMUM RATINGS ($T_C = 25^\circ\text{C}$)

P_C^*	P_C^{**}	T_J	V_{CES}	V_{EBO}	I_C
12.5W	2.0W	150°C	75 V	6 V	2 A

ELECTRICAL CHARACTERISTICS

		MIN.	TYP.	MAX.	
h_{FE}	$V_{CE} = 5V$ $I_C = 750\text{mA}$	20	38	-	-
$V_{CE}(\text{Sat})$	$I_C = 750\text{mA}$	0.50	1.35	2.0	Vdc
$V_{BE}(\text{Sat})$	$I_B = 75\text{mA}$	0.70	1.0	1.8	Vdc
$t_d + t_r$	SEE TABLE I	-	80	100	nsec
$t_s + t_f$	PAGE 7	-	206	300	
I_{CBO}	$V_{CB} = 5V$	-	.023	0.1	μAdc
C_{ob}	$V_{CB} = 20V$	30	43	55	pf

* WITH HEAT SINK - DERATE AT $10^\circ\text{C}/\text{WATT}$

** WITHOUT HEAT SINK - DERATE AT $65^\circ\text{C}/\text{WATT}$

HIGH CURRENT SWITCHING
 and
 MEDIUM-POWER AMPLIFIER
 DIFFUSED-MESA
 TRANSISTOR

NPN SILICON

12.5 WATT
 75 VOLTS
 2 AMPS

TO-38 TYPE PACKAGE

THE COLLECTOR IS CONNECTED
 TO THE CASE.

DATA SHEET
 AUGUST - 1961

WESTERN ELECTRIC CO., INC., LAURELDALE, PENNA.

Figure 4(a). Transistor 2N1072 Specifications

2N1072 DIFFUSED - MESA TRANSISTOR

DATA SHEET CONTENTS	PAGES
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Outline Drawing	5
Typical Electrical Characteristic Curves	11-15
Reliability	16
Heat Sinks - Mountings and Connections	17-18

TYPICAL ELECTRICAL CHARACTERISTICS

(At a case temperature of 25°C unless otherwise specified.)

STATIC CHARACTERISTICS		⁺ MIN	⁺ MAX	PARAMETER DISTRIBUTIONS				
				5%	50%	95%		
Forward Current	$I_C=750\text{mA}_{dc}$	h_{FE}	20	-	26	38	60	-
Transfer Ratio	$V_{CE}=5\text{V}_{dc}$							
Saturation Voltages	$I_C=750\text{mA}_{dc}$ $I_B=75\text{mA}_{dc}$	$V_{CE(sat)}$	0.5	2.0	1.05	1.35	1.70	V_{dc}
		$V_{CE(sat)}$ at 150°C	-	3.0	-	2.5	-	
		$V_{BE(sat)}$	0.7	1.8	0.95	1.0	1.15	
Collector Reverse Current	$V_{CB}=5\text{V}_{dc}$	I_{CBO}	-	0.1	.014	.023	.045	μA_{dc}
Sustain Voltage	$I_C=50\text{mA}_{dc}$ $I_B=0.2\text{mA}_{dc}$	$V_{CE(sus)}$	-	-	28	33	37	V_{dc}

SWITCHING CHARACTERISTICS

Turn on Time	$V_{BE(0)}=0$ $I_{B(1)}=75\text{mA}_{dc}$ $R_C=25\Omega$ $V_{CC}=20\text{V}_{dc}$	$t_d + t_r$	-	100	69	79	95	nsec
Turn off Time	$I_{B(1)}=75\text{mA}_{dc}$ $I_{B(2)}=-75\text{mA}_{dc}$	$t_s + t_f$	-	300	163	206	284	nsec

SMALL SIGNAL CHARACTERISTICS

Capacitance	$V_{CB}=20\text{V}_{dc}$ $f=10\text{KC}$	C_{ob}	30	55	39	43	47	pf
	$V_{EB}=5\text{V}_{dc}$	C_{ib}	-	-	93	107	115	
Frequency Response	$I_E=-.5\text{A}_{dc}$ $V_{CE}=5\text{V}_{dc}$ $f=10\text{mc}$	f_t	-	-	61	70	78	mc

* Parameter Distributions are for guidance only and are not guaranteed.

+ Manufacturer's Test Specification Limit.

Figure 4(b). Transistor 2N1072 Specifications (Continued)

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IV. DATA GRAPHS

The following graphs, which show the computer-reduced data for all specimens, were plotted automatically by a peripheral plotting facility of the computer. The number of decades of neutron dose on each graph was chosen by the program to encompass the full range of measurements. However, the ordinate scale was chosen arbitrarily, by exercising a control option, so that all measurements of a given type may be conveniently compared. This option required the imposition of "dummy" data in the decade 10^9 to 10^{10} nvt which are readily identified by their coincidence on the abscissa scale.

Measurements were usually made with a precision far greater than the accuracy with which the plotted values may be determined; however, considering other sources of experimental error, this form of presentation gives a representative accuracy for the data.

BLANK

DIODE PS760, CAPSULE LF1

7557-20
030 000

Graph 1

DIODE PS760, CAPSULE LF1

7557-20
002 000

Graph 2

DIODE PS760, CAPSULE LF1

7557-20
004 000

Graph 3

DIODE PS760, CAPSULE LF1

7557-20
006 000

Graph 4

DIODE PS760. CAPSULE LF1

7557-20
008 000

Graph 5

DIODE PS760, CAPSULE LF1

7557-20
010 000

Graph 6

DIODE PS760, CAPSULE LF1

7557-20
012 000

Graph 7

DIODE PS760, CAPSULE LF1

7557-20
014 000

Graph 8

DIODE PS760, CAPSULE LF1

Graph 9

DIODE PS760, CAPSULE LF1

7557-20
018 000

Graph 10

DIODE PS760, CAPSULE LF1

020 000

Graph 11

DIODE PS760, CAPSULE LF1

7557-20
022 000

Graph 12

DIODE PS760, CAPSULE LF1

1337-ZU
024 000

Graph 13

DIODE PS760, CAPSULE LF1

7557-20
026 000

Graph 14

DIODE PS760, CAPSULE LF1

7557-20
028 000

Graph 15

DIODE PS760, CAPSULE LF1

7557-20
002 000

Graph 16

DIODE PS760, CAPSULE LF1

7557-20
004 000

Graph 17

DIODE PS760, CAPSULE LF1

006 000

Graph 18

DIODE PS760, CAPSULE LF1

7597-80
008 000

Graph 19

DIODE PS760, CAPSULE LF1

7557-20
010 000

Graph 20

DIODE PS760, CAPSULE LF1

7557-20
031 000

Graph 21

DIODE PS760, CAPSULE LF1

7557-20
003 000

Graph 22

DIODE PS760, CAPSULE LF1

7557-20
005 000

Graph 23

DIODE PS760, CAPSULE LF1

7557-20
007 000

Graph 24

DIODE PS760, CAPSULE LF1

7557-20
009 000

Graph 25

DIODE PS760, CAPSULE LF1

011 000

Graph 26

DIODE PS760, CAPSULE LF1

7557-20
013 000

Graph 27

DIODE PS760, CAPSULE LF1

7557-20
015 000

Graph 28

DIODE PS760, CAPSULE LF1

7557-20
017 000

Graph 29

DIODE PS760, CAPSULE LF1

7557-20
019 000

Graph 30

DIODE PS760, CAPSULE LF1

7557-PC
021 000

Graph 31

DIODE PS760, CAPSULE LF1

Y557-20
023 000

Graph 32

Graph 33

DIODE PS760, CAPSULE LF1

7557-20
027 000

Graph 34

DIODE PS760, CAPSULE LF1

7557-20
029 000

Graph 35

DIODE PS760, CAPSULE LF1

7557-20
003 000

Graph 36

DIODE PS760, CAPSULE LF1

005 000

Graph 37

DIODE PS760, CAPSULE LF1

7557-20
007 000

Graph 38

DIODE PS760, CAPSULE LF1

7557-20 L
009 000

Graph 39

DIODE PS760, CAPSULE LF1

7597-20
011 000

Graph 40

ZENER DIODE 1N2032, CAPSULE LF1

7557-22
002 000

Graph 41

Graph 42

ZENER DIODE 1N2032, CAPSULE LF1

7557-22
004 000

Graph 43

ZENER DIODE 1N2032, CAPSULE LF1

7557-20
002 000

Graph 44

ZENER DIODE 1N2032, CAPSULE LF1

7557-20
003 000

Graph 45

Graph 46

ZENER DIODE 1N2032, CAPSULE LFT

7557-22
009 000

Graph 47

Graph 48

ZENER DIODE 1N2032, CAPSULE LF1

7557-22
011 000

Graph 49

ZENER DIODE 1N2032, CAPSULE LF1

March 19, 1964 7557-22
J12 000

Graph 50

ZENER DIODE 1N2032, CAPSULE LF1

7557-22
J13 J00

Graph 51

Graph 52

ZENER DIODE 1N2032, CAPSULE CFI

7957-22
J15 000

Graph 53

ZENER DIODE 1N2032, CAPSULE LF1

7557-20
004 000

Graph 54

ZENER DIODE 1N2032, CAPSULE LF1

7557-20
005 000

Graph 55

ZENER DIODE 1N2032, CAPSULE LF1

7557-20
006 000

Graph 56

ZENER DIODE 1N2032, CAPSULE LF1

7997-20
007 000

Graph 57

ZENER DIODE 1N2032, CAPSULE LF1

7557-20
008 000

Graph 58

ZENER DIODE 1N2032, CAPSULE LF1

7557-20
000 000

Graph 59

ZENER DIODE 1N2032, CAPSULE LF1

7957-20
010 000

Graph 60

TRANSISTOR 2N744, CAPSULE LF1

7557-21
002 000

Graph 61

TRANSISTOR 2N744, CAPSULE LF1

7557-21
004 000

Graph 62

TRANSISTOR 2N744, CAPSULE LF1

7557-21
006 000

Graph 63

TRANSISTOR 2N744, CAPSULE LF1

7557-E3
002 000

Graph 64

TRANSISTOR ZN/44, CAPSULE LF1

7557-23
004 000

Graph 65

TRANSISTOR 2N744, CAPSULE LF1

7557-23
006 000

Graph 66

TRANSISTOR 2N744, CAPSULE LF1

7557-Z3
008 000

Graph 67

TRANSISTOR 2N744, CAPSULE LF1

7557-23
010 000

Graph 68

TRANSISTOR 2N744, CAPSULE LF1

7557-23
012 000

Graph 69

TRANSISTOR 2N744, CAPSULE LF1

7557-23
014 000

Graph 70

TRANSISTOR 2N744, CAPSULE LF1

7937-E3
016 000

7557-23
018 000

TRANSISTOR 2N744, CAPSULE LF1

7557-23
020 000

TRANSISTOR 2N744, CAPSULE LF1

7557-23
022 000

Graph 74

TRANSISTOR 2N744, CAPSULE LF1

7557-23
024 000

Graph 75

TRANSISTOR 2N744, CAPSULE LF1

7557-23
026 000

Graph 76

TRANSISTOR 2N744, CAPSULE LF1

7557-23
028 000

Graph 77

TRANSISTOR 2N744, CAPSULE LF1

7557-23
030 000

Graph 78

TRANSISTOR 2N744, CAPSULE LF1

7557-23
032 000

Graph 79

TRANSISTOR 2N744, CAPSULE LF1

7557-21
002 000

Graph 80

TRANSISTOR 2N744, CAPSULE LF1

7557-21
003 000

Graph 81

TRANSISTOR 2N744, CAPSULE LF1

7557-21
004 000

Graph 8Z

TRANSISTOR 2N744, CAPSULE LF1

7557-21
005 000

Group 83

TRANSISTOR 2N744, CAPSULE LF1

7557-21
006 000

Graph 84

TRANSISTOR 2N744, CAPSULE LF1

7557-21
007 000

TRANSISTOR 2N744, CAPSULE LF1

7557-21
008 000

Graph 86

TRANSISTOR 2N744, CAPSULE LF1

7557-21
009 000

Graph 87

TRANSISTOR 2N744, CAPSULE LF1

7557-21
010 000

Graph 88

TRANSISTOR 2N744, CAPSULE LF1

7557-21
011 000

Graph 89

TRANSISTOR 2N744, CAPSULE LF1

7557-21
012 000

Graph 90

TRANSISTOR 2N744, CAPSULE LF1

7557-21
013 000

Graph 91

TRANSISTOR 2N744, CAPSULE LF1

7597-E1
014 000

Graph 92

TRANSISTOR 2N744, CAPSULE LF1

'7557-E1
015 000

Graph 93

TRANSISTOR 2N744, CAPSULE LF1

7557-21
016 000

Graph 94

TRANSISTOR 2N744, CAPSULE LF1

9/97-21
017 000

Graph 95

TRANSISTOR 2N744, CAPSULE LF1

7557-21
018 000

Graph 96

TRANSISTOR 2N744, CAPSULE LF1

14557-21
019 000

Graph 97

TRANSISTOR 2N744, CAPSULE LF1

4657-21
020 000

Graph 98

TRANSISTOR 2N744, CAPSULE LF1

7557-21
003 000

Graph 99

TRANSISTOR 2N744, CAPSULE LF1

7557-21
009 000

Graph 100

TRANSISTOR 2N744, CAPSULE LF1

7557-21
007 000

Graph 101

TRANSISTOR 2N744, CAPSULE LF1

7557-23
003 000

Graph 102

TRANSISTOR 2N744, CAPSULE LF1

7557-Z3
005 000

Graph 103

TRANSISTOR 2N744, CAPSULE LF1

7557-23
007 000

Graph 104

TRANSISTOR 2N744, CAPSULE LF1

7557-23
009 000

TRANSISTOR 2N744, CAPSULE LF1

011 000

Graph 106

TRANSISTOR 2N744, CAPSULE LF1

013 000

Graph 107

TRANSISTOR 2N744, CAPSULE LF1

7557-23
015 000

Graph 108

TRANSISTOR 2N744, CAPSULE LF1

7557-23
017 000

Graph 109

TRANSISTOR 2N744, CAPSULE LF1

7557-Z3
019 000

Graph 110

TRANSISTOR 2N744, CAPSULE LF1

7557-23
021 000

Graph 111

TRANSISTOR 2N744, CAPSULE LF1

7557-23
023 000

Graph 112

TRANSISTOR 2N744, CAPSULE LF1

7557-23
025 000

Graph 113

TRANSISTOR 2N744, CAPSULE LF1

7557-23
027 000

Graph 114

TRANSISTOR 2N744, CAPSULE LF1

029 000

Graph 115

TRANSISTOR 2N744, CAPSULE LF1

7557-23
031 000

Graph 116

TRANSISTOR 2N744, CAPSULE LF1

033 000

Graph 117

TRANSISTOR 2N1072, CAPSULE LF1

7597-22
002 000

Graph 118

TRANSISTOR 2N1072, CAPSULE LF1

7557-22
004 000

Graph 119

TRANSISTOR 2N1072. CAPSULE LF1

006 000

Graph 120

TRANSISTOR 2N1072, CAPSULE LF1

7557-22
008 000

Graph 121

TRANSISTOR 2N1072, CAPSULE LF1

7557-22
010 000

Graph 122

TRANSISTOR 2N1072, CAPSULE LF1

7557-22
012 000

Graph 123

TRANSISTOR 2N1072, CAPSULE LF1

7557-EE
014 000

Graph 124

TRANSISTOR 2N1072, CAPSULE LF1

7557-22
016 000

Graph 125

TRANSISTOR 2N1072, CAPSULE LF1

7557-22
018 000

Graph 126

TRANSISTOR 2N1072, CAPSULE LF1

7557-22
020 000

Graph 127

TRANSISTOR 2N1072, CAPSULE LF1

7557-22
022 000

Graph 128

TRANSISTOR 2N1072, CAPSULE LF1

7557-22
024 000

Graph 129

TRANSISTOR 2N1072, CAPSULE LF1

7557-EE
026 000

Graph 130

TRANSISTOR 2N1072, CAPSULE LF1

7557-22
028 000

Graph 131

TRANSISTOR 2N1072, CAPSULE LF1

030 000

Graph 132

TRANSISTOR 2N1072, CAPSULE LF1

7557-22
032 000

Graph 133

TRANSISTOR 2N1072, CAPSULE LF1

7557-22
034 000

Graph 134

TRANSISTOR 2N1072, CAPSULE LF1

7557-22
036 000

Graph 135

TRANSISTOR 2N1072, CAPSULE LF1

7557-22
038 000

Graph 136

TRANSISTOR 2N1072, CAPSULE LF1

7557-20
003 000

Graph 137

TRANSISTOR 2N1072, CAPSULE LF1

7987-20
006 000

Graph 138

TRANSISTOR 2N1072, CAPSULE LF1

7557-20
000 000

Graph 139

TRANSISTOR 2N1072, CAPSULE LF1

7597-2U
012 000

Graph 140

TRANSISTOR 2N1072, CAPSULE LF1

7557-20
015 000

Graph 141

Graph 142

TRANSISTOR 2N1072, CAPSULE LF1

7557-20
021 000

Graph 143

TRANSISTOR 2N1072, CAPSULE LF1

7557-20
024 000

Graph 144

TRANSISTOR 2N1072, CAPSULE LF1

7557-20
027 000

Graph 145

TRANSISTOR 2N1072, CAPSULE LF1

7557-20
030 000

Graph 146

TRANSISTOR 2N1072, CAPSULE LF1

7857-20
033 000

Graph 147

Graph 148

TRANSISTOR 2N1072, CAPSULE LF1

1957-20
042 000

Graph 150

TRANSISTOR 2N1072, CAPSULE LF1

7557-20
049 000

TRANSISTOR 2N1072, CAPSULE LF1

7557-20
J48 J00

Graph 152

TRANSISTOR 2N1072, CAPSULE LF1

091 000

Graph 153

TRANSISTOR 2N1072, CAPSULE LF1

094 000

Graph 154

TRANSISTOR 2N1072, CAPSULE LF1

Graph 155

TRANSISTOR 2N1072, CAPSULE LF1

7557-22
003 000

Graph 156

TRANSISTOR 2N1072, CAPSULE LF1

7557-22
005 000

Graph 157

TRANSISTOR 2N1072, CAPSULE LF1

7557-22
007 000

Graph 158

TRANSISTOR 2N1072, CAPSULE LF1

7557-22
009 000

Graph 159

TRANSISTOR 2N1072, CAPSULE LF1

7557-22
011 000

Graph 160

TRANSISTOR 2N1072, CAPSULE LF1

7557-22
013 000

Graph 161

TRANSISTOR 2N1072, CAPSULE LF1

7557-22
015 000

Graph 162

TRANSISTOR 2N1072, CAPSULE LF1

7557-22
017 000

Graph 163

TRANSISTOR 2N1072, CAPSULE LF1

7557-22
019 000

Graph 164

TRANSISTOR 2N1072, CAPSULE LF1

7557-22
021 000

Graph 165

TRANSISTOR 2N1072, CAPSULE LF1

7597-82
023 000

Graph 166

TRANSISTOR 2N1072, CAPSULE LF1

7557-22
025 000

Graph 167

TRANSISTOR 2N1072, CAPSULE LF1

027 000

Graph 168

TRANSISTOR 2N1072, CAPSULE LF1

7557-22
029 000

Graph 169

TRANSISTOR 2N1072, CAPSULE LF1

7557-22
031 000

Graph 170

TRANSISTOR 2N1072, CAPSULE LF1

7557-22
033 000

Graph 171

TRANSISTOR 2N1072, CAPSULE LF1

7557-22
035 000

Graph 172

Graph 173

TRANSISTOR 2N1072, CAPSULE LF1

7557-22
039 000

Graph 174