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PRODUCTION ENGINEERING MEASURE RELIABILITY IMPROVEMENT JET ETCH TRANSISTOR

SECOND QUARTERLY REPORT

PERIOD: JULY 31, 1962 - OCTOBER 31, 1962

TO

U. S. ARMY ELECTRONICS MATERIEL AGENCY
PHILADELPHIA, PENNSYLVANIA

CONTRACT NO. DA-36-039-SC-86721

ORDER NO. 19043-PP-62-81-81



SPRAGUE ELECTRIC COMPANY
NORTH ADAMS, MASSACHUSETTS

PRODUCTION ENGINEERING MEASURE
RELIABILITY IMPROVEMENT
JET ETCH TRANSISTOR

Second Quarterly Report

Period: July 31, 1962 - October 31, 1962

Object of Study: To improve production techniques to increase the reliability of the jet etch transistor Type 2N1500.

Contract No. DA-36-039-SC-86721
Order No. 19043-PP-62-81-81

Controlling Specifications:
Signal Corps Industrial Preparedness Procurement Requirements
No. 15, 1 October 1958
Specification MIL-STD-129C, 11 July 1960, with Change Notice 1,
10 February 1961, and Addendum No. 1, 3 May 1961
Specification MIL-P-11268D (SigC), 26 September 1958
Specification MIL-I-45208 (Army), 26 December 1960

Report Prepared by:

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J. H. D. Folster

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SECTION 1

ABSTRACT

The optimum collector resistivity, the optimum collector thickness, the optimum electrical basewidth, and the proper emitter placement were determined during this quarter. Investigations leading to these determinations are described in this report.

Work has continued toward devising a method to stop automatically the delineation etching process after the collector junction has been delineated. Some progress has been made in this area, and work is continuing.

Two new process steps were introduced during the second quarter and descriptions of these are also given in this report.

The status of the program, life test results to date, and current failure rates are also presented.

SECTION 2

PURPOSE

The purpose of this contract is as follows:

- (1) To provide the engineering for improvement of production techniques to increase the reliability of the jet-etch transistor Type 2N1500 toward the objective of a maximum operating failure rate of 0.01% per 1000 hours at 90% confidence.
- (2) Specifically, to improve the following processes:
 - (a) Plating of gold ring
 - (b) Emitter pit contour
 - (c) Collector pit contour
 - (d) Pit plating
 - (e) Emitter and collector lead attaching
 - (f) Collector delineation

and, as a result of first quarter engineering experiments and life tests, to carry out the following added projects in order to:

- (g) Establish the optimum resistivity and thickness of the P-type bulk material.
 - (h) Establish the optimum N-type diffusion gradient.
 - (i) Establish the optimum emitter placement within this gradient in order to increase the physical base to the maximum allowable thickness without causing any detrimental effects to any parameters.
- (3) To produce and deliver 48 engineering sample units at times defined under the contract.

- (4) To prepare an inspection and quality control manual prior to the production run.
- (5) To perform a production-type run of units on authorization from the U. S. Army Electronics Materiel Agency.
- (6) To provide quarterly reports.
- (7) To prepare production engineering measure final reports in accordance with Step II of SCIPPR No. 15, Paragraph 3.8.

SECTION 3

NARRATIVE AND DATA

3.1 General

As the result of experiments conducted during the first quarter of this contract, and as reported in the First Quarterly Report, the following progress had been made before the start of the second quarter:

- (1) The method for satisfactory plating of the gold ring was achieved.
- (2) The optimum emitter pit contour was determined.
- (3) The optimum collector pit contour was determined.
- (4) The pit plating process was studied and improved.
- (5) The emitter and collector lead attaching process was studied and proved satisfactory for this application.

Some difficulty was encountered, however, in achieving a satisfactory method of delineating the collector electrode, an operation which must be carried out in order to isolate the PN junction on the collector side. Work in this area during the second quarter is described in this section.

Also, as a result of first quarter engineering experiments and life tests, experiments in three additional areas were carried out:

- (1) A determination of the optimum resistivity and thickness of P-type bulk material.
- (2) A determination of the optimum N-type diffusion gradient.
- (3) A determination of the optimum emitter placement within this gradient.

Details of work in these areas are provided in this section.

Two additional items not covered in the original proposal were introduced into the manufacturing process during this quarter. These were application of a special material and a power aging step. Details on these items are also provided in this section.

3.2 Collector Resistivity Evaluation

This evaluation was conducted to determine the optimum resistivity of the collector in order to provide maximum electrical performance and power handling capabilities. The initial step in this evaluation was the determination of parameter dependency upon the resistivity of the collector P-type material. To do this, transistors were fabricated with varying collector resistivity. The following six possible variables were held constant: P thickness, arsenic diffusion profile, gold-ring-to-emitter spacing, collector diameter, emitter diameter, and BV_{EBO} .

The following parameters were measured after encapsulation: BV_{CBO} , BV_{CES} , BV_{EBO} , h_{FE} , V_{BE} , V_{CE} , C_{OB} , C_{IB} , t_d , t_{on} , t_s , t_{off} , K'_s , and h_{fe} .

From these measurements, it was found that the optimum resistivity was in the range of 1.0 - 2.0 ohm-cm. This is the lowest resistivity at which the electrical characteristics of the 2N1500 unit are maintained.

3.3 Collector Thickness Evaluation

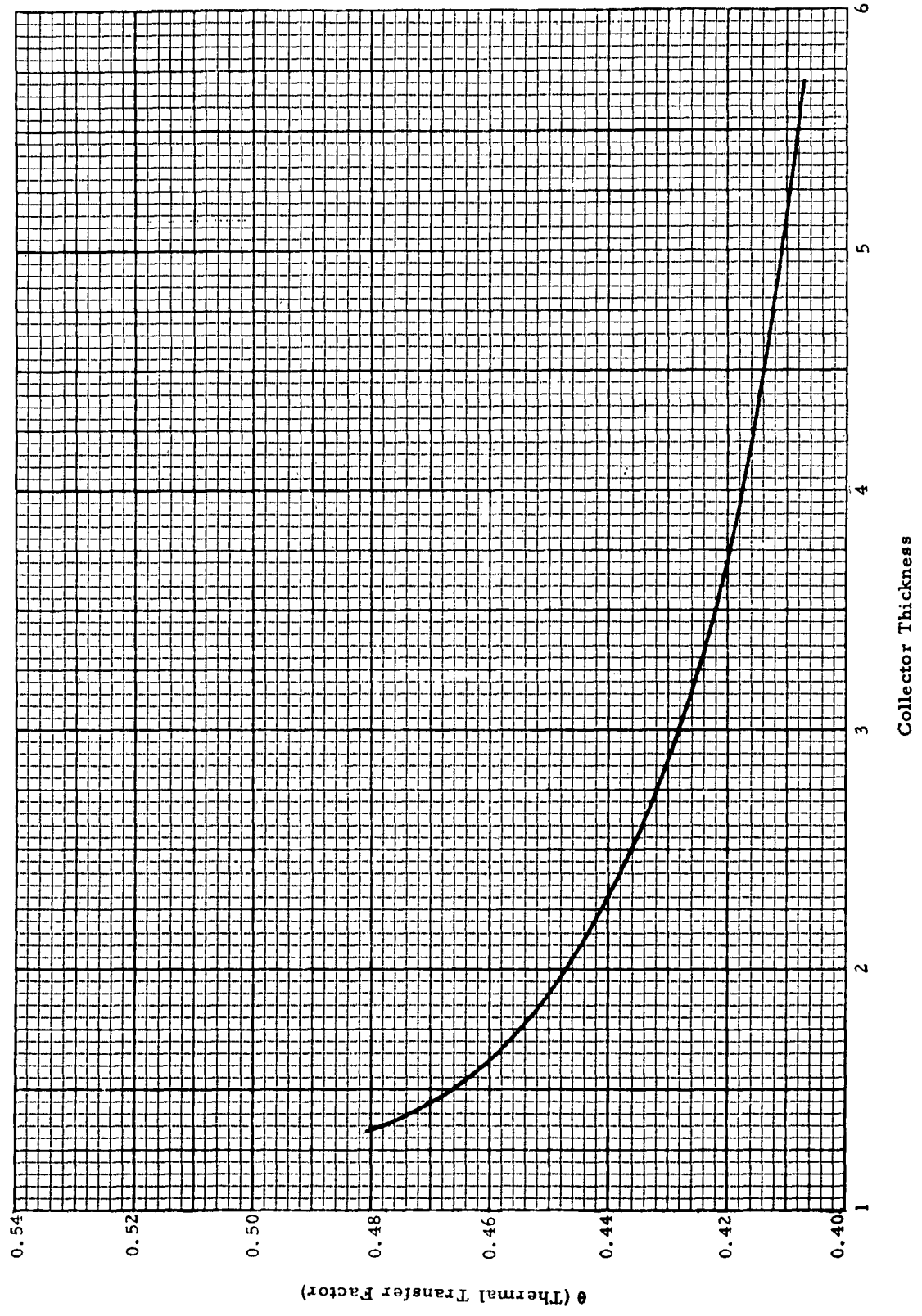
This evaluation was conducted to determine the optimum thickness needed to produce maximum capability of the unit. To do this, it was necessary to determine parameter dependency upon collector body thickness. This was accomplished by fabricating a group of transistors with varying collector thicknesses and then running a series of measurements on them while holding certain possible variables constant.

The following five possible variables were held constant: collector resistivity and diffusion lot, gold ring inside diameter, collector diameter, emitter diameter, and BV_{EBO} . The following parameters were measured after encapsulation: BV_{CBO} , BV_{CES} , BV_{EBO} , h_{FE} , V_{CE} , V_{BE} , C_{OB} , C_{IB} , t_d , t_{on} , t_s , t_{off} , and θ (thermal transfer factor).

The conclusion reached from this study was that for the maximum reliability of the transistor, the maximum collector thickness at which this transistor can be made and still maintain the registered characteristics of the 2N1500 unit should be used. This is because, as shown in Figure 1, θ (thermal transfer factor) decreases with increasing collector thickness. The established thickness is in the range of 0.12 - 0.14 mils.

θ (THERMAL TRANSFER FACTOR) VS COLLECTOR THICKNESS

Figure 1



3.4 Diffusion Gradient Evaluation

3.4.1 Electrical Basewidth Evaluation

This evaluation was conducted to determine the parameter dependency upon the electrical basewidth and from this to determine the optimum electrical basewidth needed to provide maximum performance and power handling capabilities. In order to do this, transistors were fabricated using material of varying arsenic diffusion gradient which gave a variation between emitter placement and junction depth. The following six possible variables were held constant: P resistivity, P thickness, collector diameter, emitter diameter, gold-ring-to-emitter spacing, and BV_{EBO} .

After manufacture, the following measurements were made: h_{FE} , V_{CE} , V_{BE} , BV_{CES} , BV_{CEO} , BV_{EBO} , BV_{CBO} , C_{ob} , C_{ib} , K'_s , t_d , t_{on} , t_s , t_{off} , h_{fe} , and θ (thermal transfer factor). The maximum electrical basewidth was determined from the data gained from these measurements. The maximum electrical basewidth is used because power dissipation improves as the basewidth is enlarged. This is shown in Figure 2, which is a curve of the electrical basewidth versus θ (thermal transfer factor).

The maximum electrical basewidth was determined to be in the range, 0.04 - 0.08 mils.

3.4.2 Emitter Placement Evaluation

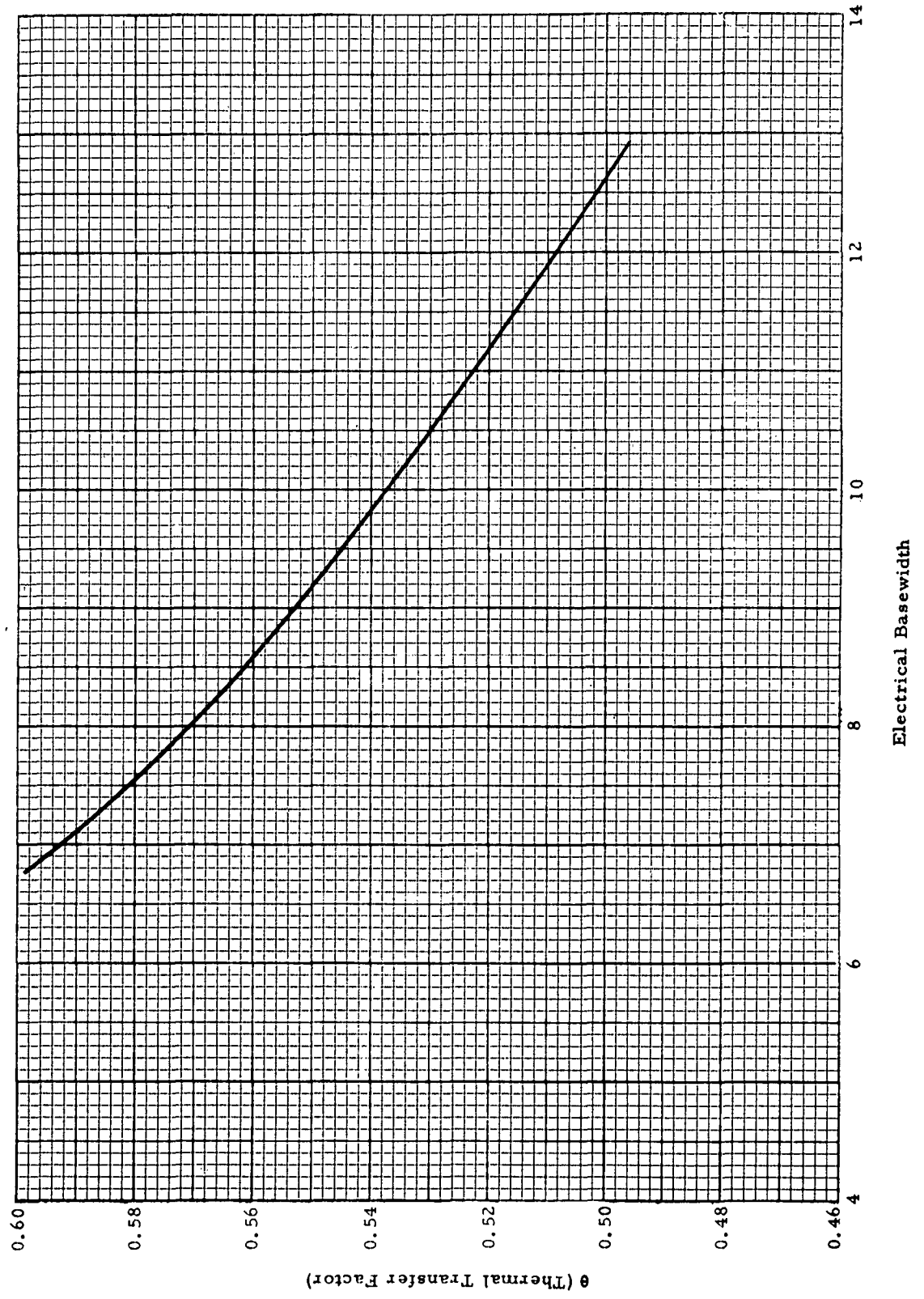
This evaluation was conducted to establish the proper emitter placement necessary to provide the optimum device performance. In order to make this determination, transistors were manufactured with the following five possible variables held constant: P resistivity, P thickness, emitter diameter, collector diameter, and gold-ring-to-emitter spacing. BV_{EBO} was varied.

The following electrical parameters were measured after manufacture: h_{FE} , V_{CE} , V_{BE} , BV_{CES} , BV_{CBO} , BV_{CEO} , BV_{EBO} , C_{ob} , C_{ib} , K'_s , t_d , t_{on} , t_s , t_{off} , and h_{fe} . The θ (thermal transfer factor) was also measured.

The proper range of BV_{EBO} was selected on the basis of electrical performance. The lowest BV_{EBO} range was selected because θ (thermal transfer factor) decreases as emitter breakdown decreases. This is illustrated in Figure 3, which is a curve of θ (thermal transfer factor) versus BV_{EBO} . The acceptable range for BV_{EBO} was found to be 2.0 - 3.0 V at -100 μ a.

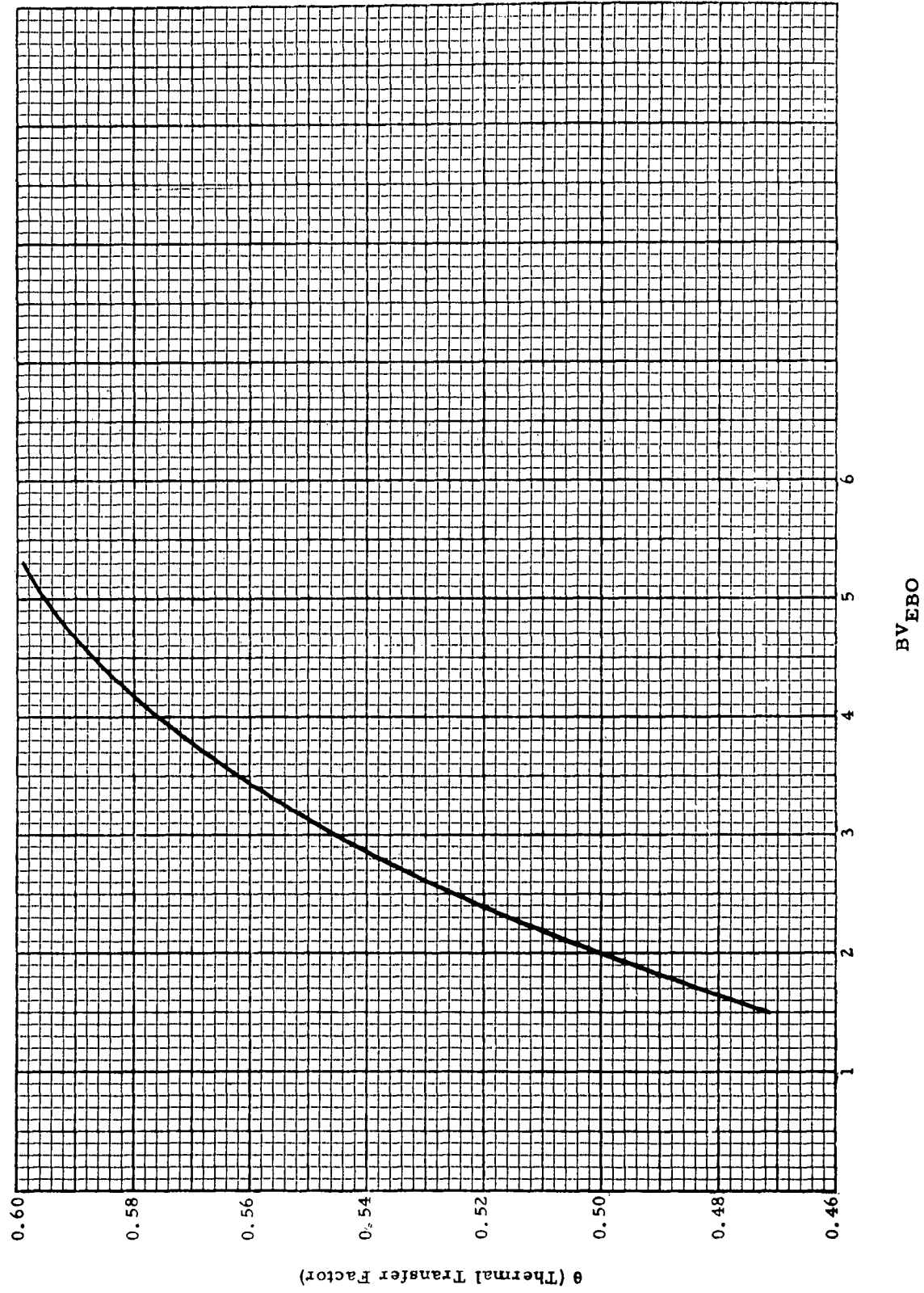
θ (THERMAL TRANSFER FACTOR) VS ELECTRICAL BASEWIDTH

Figure 2



θ (THERMAL TRANSFER FACTOR) VS BV_{EBO}

Figure 3



3.5 Collector Delineation

As reported in the First Quarterly Report, work in the area of collector delineation during the first quarter involved devising a method to stop automatically the delineation etching process after the collector junction has been delineated from the base. This problem has proved the most difficult of those encountered to date.

Delineation, as the term is used in this application, is defined as reducing the area of the interior diffused PN junction to the area of the collector solder drop. There must also be sufficient exposure of the junction to reduce reverse current to its normal saturation value.

Since normal etch plate line variations will cause the P thickness to vary, a timed etch with a fixed current will not properly delineate all units. What is required is a monitoring device which will control the etching of the individual units. Furthermore, the parameter chosen for the monitoring device to measure must exhibit a marked change from the undelineated state to the delineated state.

Two parameters were studied for possible use in this application. The first investigated was the reverse collector voltage at a fixed current level (V_{CB}). In this investigation, a control chassis was constructed to operate in the following way:

The unit was delineated initially with a timed etch method used to determine the period of delineation. Then a measuring circuit applied the necessary conditions. If V_{CB} rose to an empirically determined value, the measuring circuit automatically ended the delineation cycle. However, if V_{CB} remained under the value, a second, shorter timed etch was applied, and the unit was remeasured. This sequence continued until the measuring circuit determined that the unit was properly delineated.

During this quarter, some difficulty was experienced with the measuring circuit. A modification to this equipment is now being performed in order to ensure a more precise measurement. In this way, over and under etching will be minimized.

The second method studied uses DC inverse alpha (α_1) as the parameter to be measured. This method employs essentially the same alternate timed etch and measuring cycle as used in the first method studied. Although evaluation is not yet complete, early indications show that this system at least equals, and in some characteristics surpasses, the V_{CB} method.

There will be further investigation of the delineation process, however, because both of the methods now employed are dependent on each unit meeting a certain fixed parameter value. Since the units are not homogeneous in all characteristics, the present measuring devices inevitably make mistakes. Study will be continued during the third quarter.

3.6 Additional Process Steps

Two new steps were added to the process during the second quarter. These steps are described briefly below:

3.6.1 Application of Proprietary Material

During early environmental testing, a few units became opens. On analysis, it was found that these units opened because the moat had been made too deep and had thus rendered the unit structurally weak. To eliminate this problem, a special coating of proprietary material is now applied to all transistors.

3.6.2 Power Aging

The second new step introduced into the process is power aging, which is done in order to eliminate the units with deep moats. These deep moats occur occasionally because of the lack of control in the delineation process. It is hoped that with improvement of the delineation process this aging step can be eliminated. It will, however, be included as a process step until such improvement is made. The power aging condition is 120 mw for 10 hr.

3.7 Status of Life Testing

The life test program is proceeding on schedule with testing of Lots 1A1 through 6E1 either completed or proceeding. These units represent manufacturing from the beginning of the contract through October 30, 1962. The complete life test schedule as presented in the First Quarterly Report is repeated for convenience as Figure 4 of this report. A summary of life test results to date is found in Figure 5. This testing represents half of the lots scheduled for testing.

The units now on test represent 1900 units, which is 69% of the total of 2750 units scheduled for testing. Life testing of 1000 units, or 37% of the total, has been completed.

LIFE TEST SCHEDULE

FIGURE 4

Type of Test Mfg. Dates of Units	60 mw 25°C 1000 hr	60 mw 25°C 10,000 hr	75 mw 25°C 1000 hr	90 mw 25°C 1000 hr	100 mw 25°C 1000 hr	105 mw 25°C 1000 hr	120 mw 25°C 1000 hr	Step Stress Operating Life Test	Constant Stress *	85°C Storage	100°C Storage	120°C Storage	140°C Storage	θ p Method	θ VBE Method	Vibration and Shock
Prior to 5/30/62	1A1-25 pcs. 1C1-50 pcs.	1B1-50 pcs.	1C2-50 pcs.	1C3-50 pcs.	1A2-25 pcs.	1C4-50 pcs.	1C5-50 pcs.	1D1-100 pcs. (from 1D1)	1E1-100 pcs. (from 1D1)							
5/30/62 - 6/30/62	2A1-25 pcs.				2A2-25 pcs.											
6/30/62 - 7/30/62	3A1-25 pcs. 3C1-50 pcs.	3B1-50 pcs.	3C2-50 pcs.	3C3-50 pcs.	3A2-25 pcs.	3C4-50 pcs.	3C5-50 pcs.	3D1-100 pcs. (from 3D1)	3E1-100 pcs. (from 3D1)	3F1-25 pcs.	3F2-25 pcs.	3F3-25 pcs.	3F4-25 pcs.	3G1-25 pcs.	3G2-25 pcs.	3H1-50 pcs.
7/30/62 - 8/30/62	4A1-25 pcs.				4A2-25 pcs.											
8/30/62 - 9/30/62	5A1-25 pcs.				5A2-25 pcs.											
9/30/62 - 10/30/62	6A1-25 pcs. 6C1-50 pcs.	6B1-50 pcs.	6C2-50 pcs.	6C3-50 pcs.	6A2-25 pcs.	6C4-50 pcs.	6C5-50 pcs.	6D1-100 pcs. (from 6D1)	6E1-100 pcs. (from 6D1)							
10/30/62-11/30/62	7A1-25 pcs.				7A2-25 pcs.											
11/30/62-12/30/62	8A1-25 pcs.				8A2-25 pcs.											
12/30/62 - 1/30/63	9A1-25 pcs. 9C1-50 pcs.	9B1-50 pcs.	9C2-50 pcs.	9C3-50 pcs.	9A2-25 pcs.	9C4-50 pcs.	9C5-50 pcs.	9D1-100 pcs. (from 9D1)	9E1-100 pcs. (from 9D1)							
1/30/63 - 2/28/63	10A1-25 pcs.				10A2-25 pcs.											
2/28/63 - 3/30/63	11A1-25 pcs.				11A2-25 pcs.											
3/30/63 - 4/30/63	12A1-25 pcs.				12A2-25 pcs.											

* Power condition in constant stress test determined by results of step stress test.

FIGURE 5
LIFE TEST RESULTS TO DATE

<u>Lot</u>	<u>Number of Units</u>	<u>Type of Test</u>	<u>Status of Testing</u>	<u>Number of Failures</u>
1A1*	25	60 mw, 25°C, 1000 hr	Complete	2
1A2*	25	100 mw, 25°C, 1000 hr	Complete	8
1B1*	50	60 mw, 25°C, 10,000 hr	2000 hr	6
1C1	50	60 mw, 25°C, 1000 hr	Complete	1
1C2	50	75 mw, 25°C, 1000 hr	Complete	0
1C3	50	90 mw, 25°C, 1000 hr	Complete	0
1C4	50	105 mw, 25°C, 1000 hr	Complete	1
1C5	50	120 mw, 25°C, 1000 hr	Complete	3
1D1*	100	Step Stress OLT	Complete	99**
1E1*	100	Constant Stress***		
2A1	25	60 mw, 25°C, 1000 hr	Complete	0
2A2	25	100 mw, 25°C, 1000 hr	Complete	0
3A1	25	60 mw, 25°C, 1000 hr	Complete	0
3A2	25	100 mw, 25°C, 1000 hr	Complete	2
3B1	50	60 mw, 25°C, 10,000 hr	1000 hr	0
3C1	50	60 mw, 25°C, 1000 hr	Complete	0
3C2	50	75 mw, 25°C, 1000 hr	Complete	0
3C3	48	90 mw, 25°C, 1000 hr	Complete	0
3C4	50	105 mw, 25°C, 1000 hr	Complete	6
3C5	48	120 mw, 25°C, 1000 hr	Complete	3
3D1	100	Step Stress OLT	Complete	100**
3E1	100	Constant Stress	Complete	43**
3F1	25	85°C storage	On test	No results available
3G1	25	θ , β method	On test	No results available
3H1	50	Vibration and shock	On test	No results available
4A1	25	60 mw, 25°C, 1000 hr	Complete	0
4A2	25	100 mw, 25°C, 1000 hr	Complete	4
5A1	25	60 mw, 25°C, 1000 hr	On test	No results available
5A2	25	100 mw, 25°C, 1000 hr	On test	No results available
6A1	25	60 mw, 25°C, 1000 hr	On test	No results available

FIGURE 5 - page 2

LIFE TEST RESULTS TO DATE

<u>Lot</u>	<u>Number of Units</u>	<u>Type of Test</u>	<u>Status of Testing</u>	<u>Number of Failures</u>
6A2	25	100 mw, 25°C, 1000 hr	On test	No results available
6B1	50	60 mw, 25°C, 10,000 hr	On test	No results available
6C1	50	60 mw, 25°C, 1000 hr	On test	No results available
6D1	100	Step Stress OLT	On test	No results available
6E1	100	Constant Stress	This test will be run when results from 6D1 are known.	

*Initial production units

**Detailed results of this test are given in Figure 6.

***This test was not run because of the poor results obtained
from the test on Lot 1D1.

Results to date show a marked improvement in the reliability of the unit. This improvement is shown in Figure 6, which is a comparison of failures experienced in initial production units with failures experienced in later production units.

Figure 7 includes a detailed comparison of the results of the step stress tests on Lot 1D1 and 3D1. The units of Lot 1D1 were from initial production and were not treated with the proprietary material (see Section 3.6.1 of this report) while units of Lot 3D1 were from later production and received applications of this material. Figure 7 also shows the results of the constant stress test applied to Lot 3E1.

3.8 Test Data from Samples

Figures 8 and 9 are graphs showing the results of temperature step stress tests performed on units similar to the sample units shipped to the United States Army Electronics Research and Development Agency. Figure 8 is the graph of data from units similar to those shipped June 1, 1962. Figure 9 is the graph of data from units similar to those shipped July 31, 1962.

In this test, each group of units was first measured at room temperature and baked at 130°C for 2 hr. The units were then remeasured at room temperature. This procedure of alternate measuring and baking was carried out at 10°C increments up to a final temperature of 220°C.

If, at any measurement, I_{CBO} equaled or exceeded $2 \mu a$ at 5 V or if a 50% or greater change in β occurred, the unit was designated a failure.

FIGURE 6
COMPARISON OF FAILURES ON LIFE TEST

<u>Initial Production</u>				
<u>Test Conditions</u>	<u>Unit-Hours</u>	<u>Number of Failures</u>	<u>Lots</u>	<u>Failure Rate (%/1000 Unit-Hours)</u>
60 mw, 25°C, 1000 hr	75,000	7	1A1, 1B1	9.3
100 mw, 25°C, 1000 hr	25,000	8	1A2	32.0
<u>Later Production</u>				
<u>Test Conditions</u>	<u>Unit-Hours</u>	<u>Number of Failures</u>	<u>Lots</u>	<u>Failure Rate (%/1000 Unit-Hours)</u>
60 mw, 25°C, 1000 hr	175,000	1	1C1, 2A1, 3A1, 3C1, 4A1	0.57
100 mw, 25°C, 1000 hr	75,000	6	2A2, 3A2, 4A2	8.0

FIGURE 7

RESULTS OF STEP STRESS AND CONSTANT STRESS TESTS

Step Stress Test

<u>Condition</u>	<u>Number of Failures (No application of special material - Lot 1D1, 100 units)</u>	<u>Number of Failures (With special material added - Lot 3D1, 100 units)</u>
15 hr, 90 mw	1	1
15 hr, 105 mw	16	
15 hr, 120 mw	55	
15 hr, 135 mw	27	1
15 hr, 150 mw		4
15 hr, 165 mw		8
15 hr, 180 mw		45
15 hr, 195 mw		35
15 hr, 210 mw		6
Total	99	100

Note: One unit in Lot 1D1 ruined by testing error.

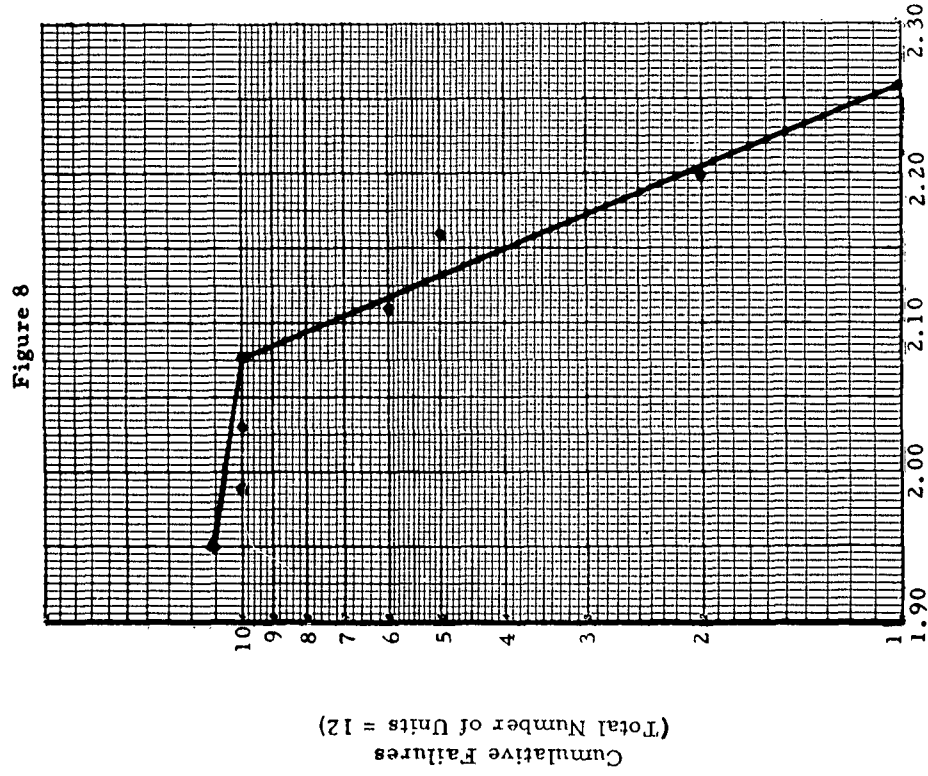
Constant Stress Test (Performed on Lot 3E1, 100 Units, 1000 Hr)

<u>Condition</u>	<u>Readout Time</u>	<u>Unit-Hours</u>	<u>Total Number of Failures at Readout</u>
150 mw	258 hr	25,800	13
150 mw	768 hr	56,550	43

Notes: (1) Test discontinued after 768 hr.
 (2) Unit measured every 16 hr up to 224 hr;
 three times per week after 224 hr.

RESULTS OF TEMPERATURE STEP STRESS TEST

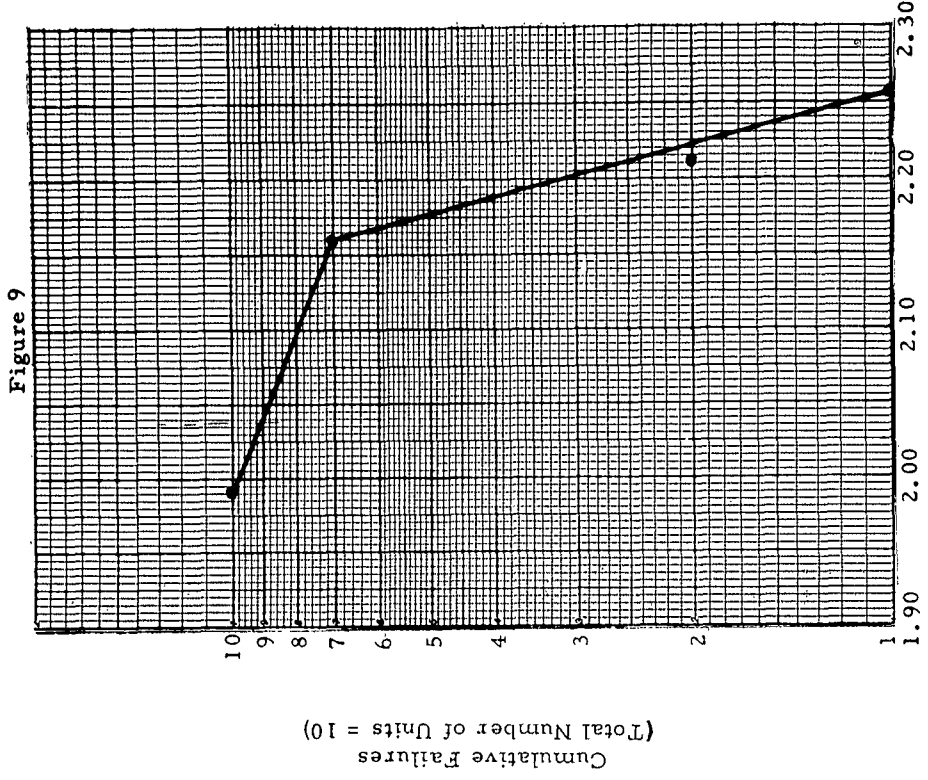
(Units shipped June 1, 1962)
(Average $\theta = 0.99$; Junction to Air)



$1/T \times 10^3$
(where T is the absolute temperature)

RESULTS OF TEMPERATURE STEP STRESS TEST

(Units shipped July 31, 1962)
(Average $\theta = 0.73$; Junction to Air)



$1/T \times 10^3$
(where T is the absolute temperature)

SECTION 4

CONCLUSIONS

- (1) The failure rates at both the 60 mw and 100 mw conditions have been improved during the last quarter.
- (2) It has been determined that the collector resistivity should be as low as possible without compromising the electrical characteristics of the 2N1500 unit.
- (3) It has also been established that the maximum collector thickness at which this transistor can be made and still maintain the registered electrical characteristics of the 2N1500 unit should be used.
- (4) Study during this quarter led to the conclusion that emitter breakdown should be held at the minimum point which allows the units to be characterized as the 2N1500 type.
- (5) It has been determined that the electrical basewidth should be as wide as possible while still retaining the high-frequency characteristics of the 2N1500 unit.
- (6) In each of the investigations leading to the preceding four conclusions, it was found that the best reliability was achieved when the volume of germanium which remained after fabrication was a maximum.
- (7) A total of 10 engineering test samples were shipped to the U. S. Army Electronics Research and Development Agency along with test data during the second quarter.

- (8) The estimated percentages of the overall progress on the major elements of the program are as follows:

<u>Factor</u>	<u>Relative Weight</u>	<u>% Completion</u>	<u>Percentage</u>
1. Pilot Design Optimization	<u>20</u>	90	18
2. Production Design Engineering	<u>10</u>		
3. Production Line De-bugging	<u>10</u>		
4. Production Run	<u>5</u>		
5. Interim Life Testing	<u>30</u>	37	11
6. Quarterly Reports	<u>10</u>	17	2
7. Final Determination of Reliability	<u>10</u>		
8. Final Report	<u>5</u>		
TOTALS	100		31

SECTION 5
PROGRAM FOR NEXT INTERVAL

- (1) Data generated by life, step stress, and environmental testing during the second quarter and early in the third will be studied. Following this, any corrective action necessary will be begun.
- (2) Manufacturing specifications will be written.
- (3) In-process quality control specifications will be written.

SECTION 6

CONFERENCES, PUBLICATIONS, AND REPORTS

- (1) A conference between representatives of the United States Army Electronics Materiel Agency and personnel of the Sprague Electric Company took place on September 19 and 20, 1962, at the Concord, New Hampshire, plant. The purpose of this conference was to review progress made on the contract during the first quarter. The USAEMA representatives suggested some specific experiments in connection with this project and Sprague agreed to perform them during the next quarter.

The First Quarterly Report was reviewed.

- (2) The First Quarterly Report, covering the period, April 30, 1962-July 31, 1962, was submitted for U. S. Army Electronics Materiel Agency approval. Approval was received, and the report was distributed per USAEMA instructions.

SECTION 7
IDENTIFICATION OF PERSONNEL

<u>Personnel</u>	<u>Hours</u>
J. Ayer	8.0
D. Baker	4.5
W. Boyd	128.0
L. Buttrick	16.3
G. Bouchard	12.0
E. Copeland	10.0
S. Cullen	13.4
R. Duquette	59.5
N. Edwards	39.0
R. Gagne	163.0
T. Gordon	4.5
F. Hammond	2.0
W. Hildreth	284.5
J. Krantz	63.0
J. Oliver	165.0
P. Pasho	12.0
B. Prescott	59.0
P. Rand	25.5
T. Richardson	92.0
L. Ritterbush	210.5
H. Smith	16.0
R. Stevens	50.0
L. Wells	4.0
TOTAL	1441.7

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