AD-A085 973 HONEYWELL INC HOPKINS MN DEFENSE SYSTEMS DIV F/6 19/1
MANUFACTURING METHODS AND TECHNOLOGY PROGRAM FOR THE 10-KHZ TAP--ETC(U)
DEC 79 B E GOBLISH DAAG39-78-C-0010
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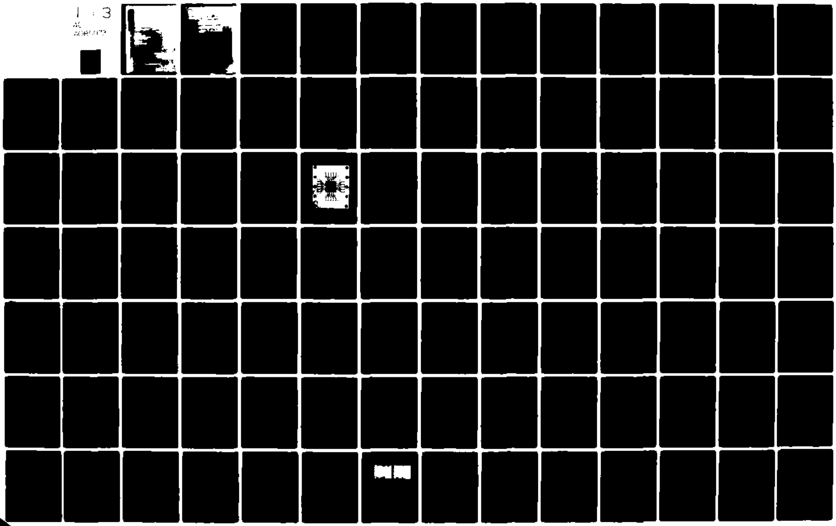

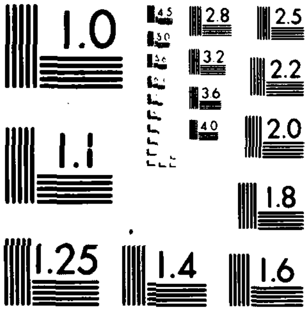

MICROCOPY RESOLUTION TEST CHART
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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER 18 HDL-CR-79-010-1	2. GOVT ACCESSION NO. AD-A085 973
	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) 6 MANUFACTURING METHODS AND TECHNOLOGY PROGRAM FOR THE 10-kHz TAPE-AUTOMATED BONDED HYBRID MICROCIRCUIT OSCILLATOR. ~~FINAL REPORT~~	5. TYPE OF REPORT ~~& PERIOD COVERED~~ 9 Final rept.
	6. ~~PERFORMING ORG.~~ REPORT NUMBER 14 2730-41637
7. AUTHOR(s) 10 Bernard E. Goblish	8. CONTRACT OR GRANT NUMBER(s) 15 DAAG39-78-C-0010 Pron:8183663703GGA9
9. PERFORMING ORGANIZATION NAME AND ADDRESS Honeywell Inc. Defense Systems Division Hopkins, MN 55343	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Program Element: P
11. CONTROLLING OFFICE NAME AND ADDRESS Harry Diamond Laboratories 2800 Powder Mill Road Adelphi, MD 20783	12. REPORT DATE 11 December 1979
	13. NUMBER OF PAGES 214 12 216
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report) Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

AMCMS Code: 49500539471
HDL Project: 42584A

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

Hybrid Circuits, Electronic Time Fuze, Oscillator, Tape-Automated Bonding, TAB, MM&T

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

A Manufacturing Methods and Technology (MM&T) program was conducted on a 10-kHz hybrid microcircuit oscillator for use in electronic time fuzes. The oscillator which was originally developed under contract DAAG39-77-C-0056, uses tape-automated bonding (TAB) techniques to eliminate the use of individually bonded wires. The processes and achievable production rates were investigated and a total of approximately 2000 circuits were

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built. Recommendations are made for the equipment to be used for volume production of the oscillator.

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1. INTRODUCTION

The Manufacturing Methods and Technology (MM&T) program on the 10-kHz Tape-Automated Bonded (TAB) Hybrid Microcircuit Oscillator (HMO) was initiated for the study of the design and fabrication of a hybrid microcircuit which used tape technology.

The program was divided into four phases:

I - Design Evaluation

II - Fabrication and Testing of the Engineer Sample

III - Fabrication and Testing of the Development Evaluation Group

IV - Pilot Production Lot

Detailed descriptions of the four phases are presented in section 3.

2. PROGRAM OBJECTIVE

The objective of the MM&T program was to define manufacturing methods for fabricating 110,000 TAB HMOs per month at an average cost of less than $4.00 each for 3 million units.

3. DETAILED DESCRIPTION

3.1 Phase I - Design Evaluation

3.1.1 Introduction

Phase I of the MM&T program laid the foundation for demonstration of large-volume fabrication of the 10-kHz HMO using TAB technology. The baseline design and fabrication processes selected realized major objectives of the study: large-volume fabrication rates (110,000 per month), and costs of less than $4.00 each for 3 million units. This phase also involved minor design modifications to accommodate manufacturing processes, analyses of anticipated learning curves and product cost, documentation update, design integrity tests, and selection of production equipment for use in phases III and IV.

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3.1.2 Summary

A management control system using 127 elements was developed to track the MM&T program activities.

The baseline documentation was finalized and all design modifications were incorporated. Design modifications consisted of designing a metal case to be used in place of the conductive painted plastic case and incorporating thick-film conductor pads to accommodate probes during the active trim.

The manufacturing flow chart was generated, and standard hours were derived for each of the manufacturing processes. Standard hour derivations showed a standard rate of 0.0731 hour per device.

The most costly processes noted from the standard hour calculations were (1) epoxy encapsulation, (2) final inspection, and (3) active trim. The bumping process was identified as the highest risk process due to the precise process control requirements.

An 85-percent learning curve is expected for subsequent large-scale production and is indicated by learning-curve analysis.

Design-to-cost analysis showed a labor and material cost of $3.65 per device for the first million TAB HMOs.

Design integrity testing was performed. Ninety-nine TAB HMOs were exposed to (1) temperature cycling (32 cycles, +71C to -55C, and 32 cycles, +125C to -55C), (2) moisture resistance (two 10-day tests per MIL-STD-883, Method 1004.1), (3) high-temperature storage (1000 hr at 125C), and (4) shock (three tests: first, 40 to 60 kg; second, 58 to 64 kg; and third, 75 to 80 kg). The electrical and mechanical performance of the TAB HMO through design integrity testing revealed considerable margin between the specification requirements and the baseline design performance.

3.1.3 Work Performed and Results Obtained

3.1.3.1 Development of the Management Control System

The management control system was developed using Mark III, a computer-aided planning technique. One hundred twenty-seven elements were used, allowing easy and accurate tracking of program activities. A copy of the Mark III management control chart was sent to Harry Diamond Laboratories (HDL) on 6 February 1978.

3.1.3.2 Baseline Documentation

Baseline documentation is found in appendix A. The documentation consisted of the following drawings:

Oscillator Source Control	11726813 (fig. A-1)
Schematic diagram, electrical	11711678 (fig. A-2)
Substrate and film resistors	11711674 (fig. A-3)
Thick-film dielectric	11711675 (fig. A-4)
Hybrid microcircuit R-film oscillator assembly	11711673 (fig. A-5)
Case	11711679 (fig. A-6)
Monolithic amplifier	28112362

All the drawings are included, with the exception of 28112362, which was modified to purchase wafers for use in Phase IV of the program.

The contractor's manufacturing methods notebook contains all documents defining manufacturing processes used during fabrication of the TAB HMO.

3.1.3.3 Design Modification and Documentation Update

During the development of the TAB HMO, the oscillator substrate was housed in a plastic case coated with a conductive paint. Severe cracking and crazing was noted in the paint after exposure to elevated temperatures for extended periods of time. A metal case (see fig. A-6) was designed to replace the plastic case.

Two conductor pattern layout changes were incorporated to accommodate the metal case and active laser trimming. Three thick-film metal pads allow the oscillator to be biased during active trimming via probes. Originally, biasing was to be achieved with a connector via the external terminals. The thick-film metal pads to which the external terminals are attached were moved in from the edge of the substrate, allowing more clearance between the terminals and the metal case.

The substrate length was increased from 0.765 to 0.780 in. to increase the clearance between the terminals and the metal case.

These modifications are reflected in figs. A-3 through A-6.

3.1.3.4 Manufacturing Flow Chart

The process flow can be divided into two major assembly operations: tape-automated bonding (TAB) steps, and assembly of the oscillator circuit. The wafer bumping processes of the TAB operation is detailed in fig. 1 to separate the steps that are performed at the integrated-circuit wafer level. Throughout this phase, the wafer yield was assumed to be 38 percent or 500, that visually passed electrically (per MIL-STD-883), out of a possible 1300 chips for a 3-in.-diameter wafer.

Continuation of the TAB processes is shown on the oscillator assembly flow chart, fig. 2. These process sequences were used in the assembly of more than 500 oscillators during the development program prior to the present MM&T phases. Yields for the oscillators assembled on the development programs averaged an overall 88 percent through final electrical test after epoxy encapsulation.

3.1.3.5 Identification of the Most Costly and Highest Risk Operations

Processes with the highest costs and risks were identified through a combination of the experience from the development build phases and the projection of the operating rates for the fully automated assembly process. Estimated assembly rates for production quantities of 1 million units shipped at the rate of 110,000 units per month are found in tables I and II.

The most costly operations are the epoxy encapsulation, 0.86 hour per 100 units; final inspection, 0.70 hour per 100 units; and active laser trim, 0.420 hour per units. The laser trimming operation is computer-controlled and repre-

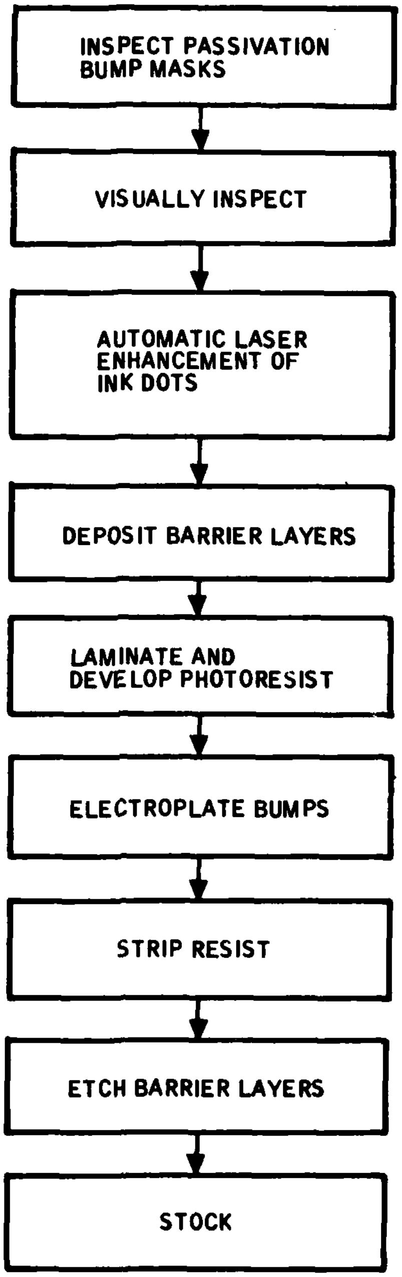


Figure 1. Wafer Bumping process.

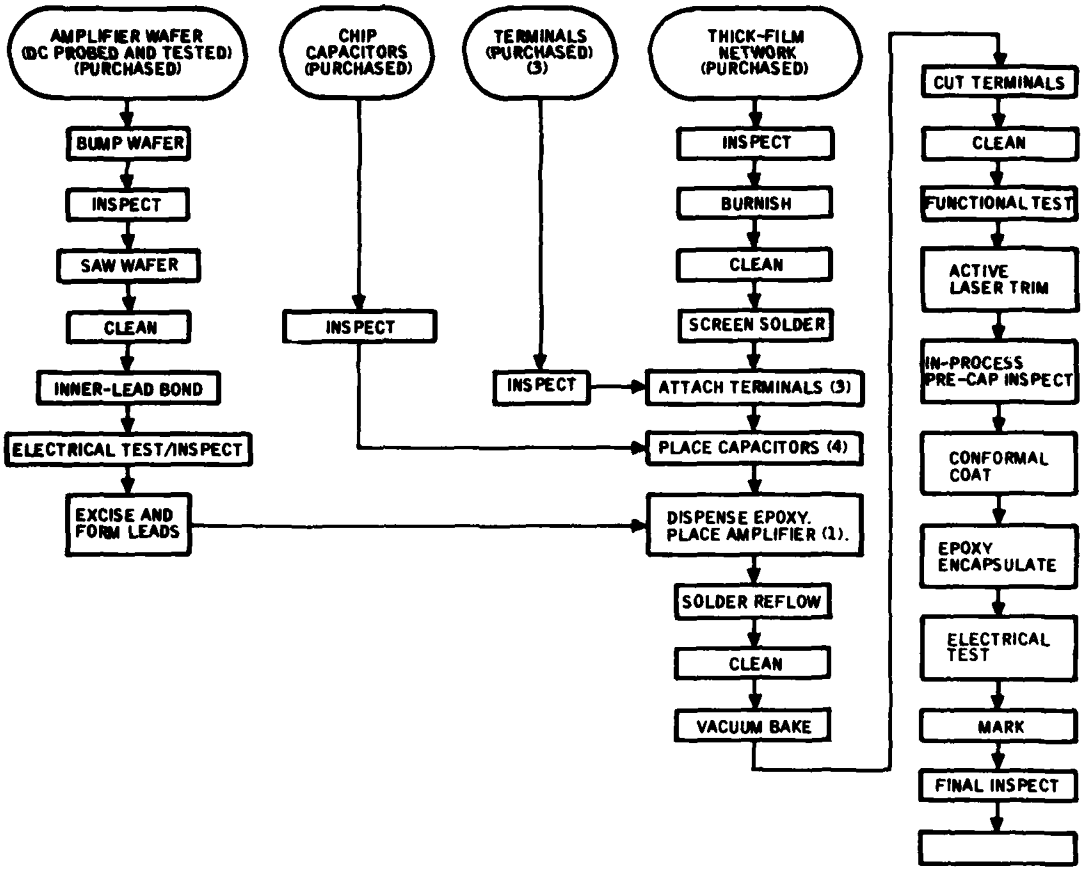


Figure 2. TAB oscillator process flow.

TABLE I. ASSEMBLY RATES

Standard per 100 Units	Operation Description	Rate per Hour
0.167	Burnish	600
0.167	Clean	600
0.290	Screen solder	345
0.167	Attach lead	600
0.400	Mount components - capacitors	250
0.400	Mount components - integrated circuits	250
0.280	Solder reflow	360
0.167	Clean	600
0.12	Vacuum bake	833
0.167	Cut leads	600
0.20	Test at 23.5V R.T. 7.2 s ea.	500
0.167	Conduct pre-cap inspection (Quality)	600
0.420	Active Trim (15 s ea.)	240
0.110	Inspect for damage	909
0.28	Apply conformal coating	360
0.12	Cure conformal coating	833
0.86	Encapsulate in epoxy	116
0.200	Conduct electrical test (Quality) on sample group A at 23.5V, and 25C	500
0.218	Mark	360
0.70	Final inspect (Quality)	140
	5.6 hr/100 units = 0.056 hr/unit	

TABLE II. TAB ASSEMBLY RATES

Standard Per 100 Chips	Operation Description	Wafers/Hour at 500 Chips/Wafer
0.03	Inspect bump mask and wafers	-
0.053	Deposit barrier layers	3.77
0.047	Laminate and develop photoresist	4.25
0.05	Electroplate bumps	4.0
0.023	Strip resist	8.7
0.06	Etch barrier layers	3.3
0.06	Conduct electrical tests on wafers	3.3
0.036	Inspect	5.6
0.010	Stock	-
0.085	Saw wafer	1.25
0.007	Clean	28.6
		Units in chips/hr
0.410	Bond inner lead	250
0.430	Conduct electrical test/inspection	230
0.400	Excise and form leads	250
0.010	Stock	-
	1.71 hr/100 chips = 0.0171 hr/chip	

sents the most expensive item of capital equipment used in the program. Improvements of the laser trim rates are planned by replacing the single-substrate state handler with a continuous feed carousel, and by modifying the laser trim program to trim to a preset voltage limit before proceeding in the trim measure mode.

The highest risk operations are the wafer bumping processes which are primarily the steps of deposition of the Ti-Pd-Au titanium-palladium-gold) barrier layers, photoresist image development, electroplating the gold bumps, and, finally, etching the Ti-Pd-Au barrier layers. These processes were major variables in the development phases of the XM587E2 redesigned oscillator program. The bumping process was identified as the highest risk operation because of the precise process control requirements necessary in the following areas.

- Wafer passivation porosity and vulnerability to subsequent bumping processes
- Wafer preparation prior to barrier-layer deposition
- Photoresist lamination and image development
- Contamination resulting in poor bump adhesion
- Etching processes used for removal of the Ti-Pd-Au barrier layers
- Annealing processes which prevent semiconductor characteristic degradation

3.1.3.6 Learning Curve Analysis

The measure of productivity used during the previous build phase in mid-1977 was the Earned Hour Ratio (EHR). EHR is defined as the factor used to convert from standard hours to total hours allowing for labor efficiency, rework, and support labor, or

$$EHR = \frac{1}{\text{Performance} \quad 1 - \left[(\text{Rework} + \text{Support})\right]}$$

where rework and support factors are percentages of total direct hours expressed as decimals. These factors are obtained from labor history on similar types of production.

Rework.--Rework is the effort required to change the configuration of hardware to correct error or incorporate non-customer-directed engineering modifications during and/or after first-pass activity. Labor hours consumed on units which are ultimately scrapped must be included in this term. Other rework terms are:

- Workmanship Rework - Activity resulting from operator error in following instructions and failure to apply accepted workmanship standards.
- Material Rework - Activity resulting from one or more deficiencies in the direct or indirect (burden) material used in fabrication.
- Engineering Rework - Activity resulting from Engineering Order (EO) (design or production process).

Support.--Support consists of the labor usually performed by the "setup man" and/or group leader in support of the production effort. It is made up of setup and teardown activities and group leader labor, as follows:

- Setup and Teardown - Setup is the preparatory task which must be performed on special tools or equipment before the operator/technician job can begin. Teardown is the disassembly, modification, or putting away of special tools or equipment after the job is completed.
- Group Leader - Consists of the activity by hourly personnel of group leader labor classification in the building of hardware.

Actual performance for the 3500-unit contract is shown in table III. The learning curve for this effort was 80 percent. It should be noted that hybrid circuits of this design had been built previously (2500 units, 1976), resulting in a lower learning curve slope than would be experienced for a program startup. A projection of EHR (fig. 3) was made by the contractor for sets (one each - interface, oscillator hybrids) over the production range of 14,000 to 225,000 units. Extrapolation of this 85-percent learning curve would result in an EHR factor of 1.2 at the 1-million-unit quantity. The standard assembly hours were calculated for the contractor's Florida Facility (HMEF) and Mexican Export Facility (MEF) with a 20/80 production volume split, respectively.

TABLE III. EHR FACTORS FOR MM&T OSCILLATOR FOR 1 MILLION UNITS

Factor	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Build schedule	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000	110,000
Cumulative	110,000	220,000	330,000	440,000	550,000	660,000	770,000	880,000	990,000	1,100,000	1,210,000	1,320,000
Standard	0.07311	0.07311	0.07311	0.07311	0.07311	0.07311	0.07311	0.07311	0.07311	0.07311	0.07311	0.07311
Standard hours	8042	8042	8042	8042	8042	8042	8042	8042	8042	8042	8042	8042
Efficiency	50%	50	60	70	75	80	85	85	90	90	90	90
Scrap	10%	10	10	8	5	4	3	3	3	2	2	2
Rework	30%	25	20	15	15	10	10	10	8	6	6	6
Group leader	20%	15	12	12	10	10	8	6	5	5	5	5
Earned hours ratio	5.0	4.0	2.77	2.10	1.88	1.62	1.49	1.45	1.31	1.31	1.31	1.31
Total hours	40 210	32,168	22,276	16,888	15,119	13,028	11,983	11,661	10,535	10,535	10,535	10,535
Cumulative hours		72,378	94,654	111,542	126,661	139,689	151,672	163,333	173,868	184,403	194,938	205,473
Man-months (172 hr per M/M)	233	187	129	98	88	76	69	68	61	61	61	61
Hours per unit	0.366	0.292	0.203	0.153	0.137	0.118	0.109	0.106	0.096	0.096	0.096	0.096
Labor cost/unit at $15.21/hr	$5.56	4.44	3.09	2.33	2.08	1.79	1.66	1.61	1.46	1.46	1.46	1.46

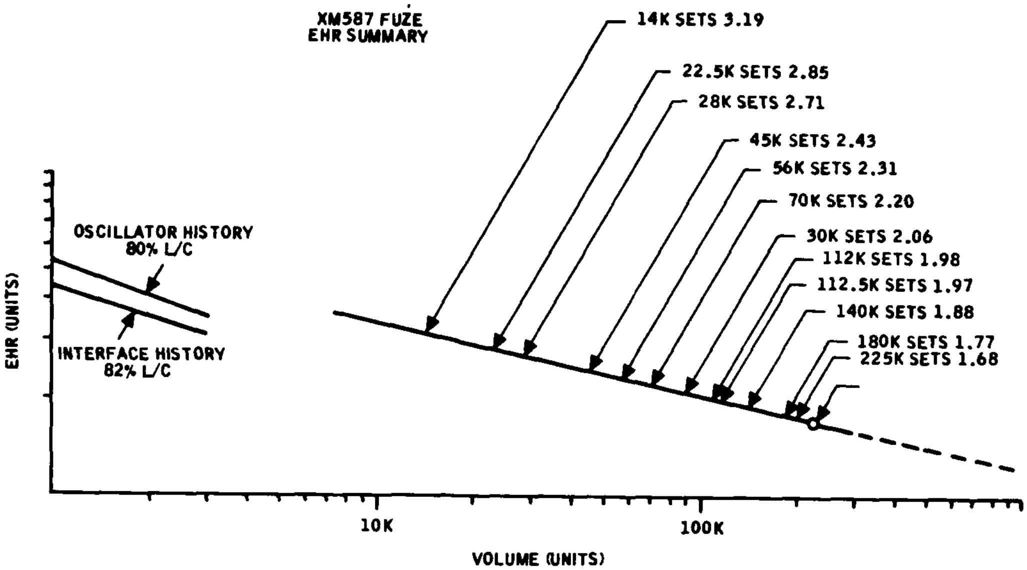


Figure 3. Earned hour ratio projection.

A second way to determine the learning curve slope was to calculate EHR factors from a simulated production program with monthly deliveries of 110,000 units of the MM&T hybrid oscillator. These data are shown in table IV. Estimates for the efficiency, scrap, rework, and group leader terms were based on performance experience on hybrid programs such as the Tadiran, System 60 hybrids which use solder reflow of components. The unit labor hours shown on the next to last line were multiplied by an assembly labor rate of $15.21 per hour to arrive at the cost per unit. This rate includes fringe, overhead, and administrative factors that are stated in the contractor's proposal pricing guidelines.

The estimated cost data for 12 monthly periods of 110,000 oscillator units per month were input to a computer program to calculate the learning curve slope. This program finds the best linear equation through the input cost data points by means of a least-squares curve-fitting routine.

A learning curve with a 75-percent slope was determined from this method. Showing the build requirements going from

0 to 110,000 units per month is unrealistic and results in a steeper slope over the first 3 months of production. A gradual buildup would be more typical.

TABLE IV. LEARNING CURVE CALCULATIONS

```
DEFINE FILE
1=XM587E


     L E A R N I N G   C U R V E   E Q U A T I O N

                    Y = A * X↑B

OPTION 1:  ESTIMATION OF A AND B FROM THE DATA

   N =   12  ACTUAL POINTS OF DATA

   A =    450.19  THEORETICAL COST TO PRODUCE UNIT NO. 1
   B =   -.41041  EXPONENT OF LEARNING CURVE SLOPE

% SLOPE = 75.241          INDEX OF DETERMINATION =  .926

ESTIMATED LOT COSTS FROM THE LEARNING CURVE EQUATION:
```

FIRST UNIT IN LOT	LAST UNIT IN LOT	ACTUAL COST OF LOT	ESTIMATED COST OF LOT	ALGEBRAIC MIDPOINT	AVERAGE COST/UNIT
1.	110000.	611600.00	715910.13	30414.92	6.51
110001.	220000.	488400.00	361664.28	150566.56	3.29
220001.	330000.	339900.00	291139.64	272388.86	2.65
330001.	440000.	256300.00	253098.15	383144.19	2.30
440001.	550000.	228800.00	228114.35	493559.59	2.07
550001.	660000.	196900.00	209996.77	603822.76	1.91
660001.	770000.	182600.00	196036.94	714004.53	1.78
770001.	880000.	177100.00	184828.76	824137.64	1.68
880001.	990000.	160600.00	175557.35	934239.34	1.60
990001.	1100000.	160600.00	167712.36	1044319.57	1.52
1100001.	1210000.	160600.00	160955.20	1154384.50	1.46
1210001.	1320000.	160600.00	155050.90	1264438.12	1.41

Improvement curves depend on the labor content of the task being performed. The cost constraints of the MM&T oscillator compel processes to be fully automated in all practical areas. Therefore, the use of automated processes reduces the sensitivity of the costs to improvement through experience. Comparing the learning curves generated in this analysis as shown in table V provides insights to major factors which affect them.

TABLE V. COMPARISON OF LEARNING CURVES

Device	Automated Process	Volume (units)	Learning Curve (percent)	Major Factor
XM587E2 Multichip oscillator	10% automated wire bond	1 to 3500	80	Low volume
XM587E2 Multichip oscillator	25% automated wire bond screen print	14,000 to 225,000	85	Manual assembly
MM&T oscillator	60% assembly	1 to 1.32 million	75	Rapid startup phase

The most probable learning curve slope for the MM&T oscillator would be the 85 percent for two basic reasons:

- Production buildup phases of 10,000, 30,000, and 60,000 units per month would precede the full requirement of 110,000 per month.
- Automation has been implemented for processes where it is practical and cost effective. Automation of all processes, including transfer equipment between stations, probably would increase the learning curve and the unit costs.

3.1.3.7 Design-to-Cost Analysis

The program goal to fabricate 110,000 devices per month on a 1-8-5 basis (one shift, 8 hours, 5 days) was used as a guideline for establishing the material and fabrication cost. This monthly rate is converted to an hourly rate by assuming an average of 4.3 production weeks per month or 172 production hours per month. The unyielded production rate is 640 devices per hour. A 95-percent yield is estimated; therefore, the production rate required is 672 devices per hour.

The parts list for the HMO assembly is shown in table VI with material costs. The material cost for the monolithic amplifier and metal case was estimated by the contractor, based on information supplied by the vendors.

Labor costs were obtained from the standard hours required for each manufacturing process and EHR figures derived in the learning curve analysis. The labor cost per device is shown in table III. A material and labor cost of $3.65 per device was calculated for the first 1 million TAB HMOs.

TABLE VI. OSCILLATOR ASSEMBLY PARTS LIST

Component	Description	Estimated Cost per Device per 1 Million Units
Substrate and film resistors	See dwg. no.11711674 (fig. A-3)	$1.19
U1	Monolithic amplifier, P/N 28112362	0.25
C1 and C2	470 pF±5%, TCC 0±30 ppm/C	0.11
C3	1000 pF±5%, TCC 0±30 ppm/C	0.055
C4	0.01µF±10%, TCC ±15%	0.055
Ceramic connector	Berg Electronics, P/N 75382	0.03
TAB leads	19-mm tape format, tin-plated copper, P/N 34038099-802	0.15
Case and clip	Formed metal can, electrical shield and ground	0.25
	Total	$2.09
	Yielded (95%)	$2.19

3.1.3.8 Selection and Design of Production Equipment

This activity spanned phases I and II of the MM&T program. Some delays resulted from the late go-ahead date of the program (1/24/78) and the time lost during the review and revision of the statement of work that preceded full funding of the program.

Pick and Place Equipment.--Substrate fixturing and capacitor load guides needed to be designed and fabricated. Capacitor variations and inspection criteria were required before this task could be started.

Screen Printer Tooling.--A nest plate was fabricated and used to screen substrates for this item.

Epoxy Dispenser Tooling.--This was planned as an addition to the Jade 4810 semiautomatic placement system scheduled for use during the Development Evaluation Group (DEG) lot build. No action occurred on this task during phase I except for preliminary discussions with Jade engineers.

Edge Chip Machine Tooling.--A quotation was received from Berg Corp. to lease a machine which can attach leads at the rate of 600 substrates per hour. This lease was contingent on purchase of 1 million leads per year and on negotiating the lease to extend over 2 to 3 years, when volumes were anticipated to reach these quantities.

Silicone Dipper.--Silicone is a baseline requirement to minimize effects of the epoxy encapsulation materials on the substrate resistor elements. An internal report was requested to determine the exact equipment requirements.

Solder Reflow Furnace.--The Watkins-Johnson model 4CR-48 does not require modification to solder reflow the oscillator units. The solder reflow room was rearranged to provide a more efficient and larger area for this processing.

Inner Lead Bonder.--An appropriation was authorized for purchase of an improved version of the model 1-1000 Jade automatic (ILB) bonder.

19-mm Tooling for the Jade 4810.--A quotation was received to modify the Jade semiautomatic excise/form/placement system to handle the 19-mm tape form and reel. A special substrate fixture was conceptually designed to handle the oscillator substrate with the Berg Corp. leads attached.

19-mm Tooling for Tape Testing.--A decision was made to purchase a new modular tape tester for 19-mm format tape, which at a later phase could be integrated into the feed track of the Jade 4810 system. The 19-mm tape format testable with the standard pogo pin test head is shown in fig. 4.

ESI Laser Tooling.--A substrate handling method was proposed using the carousel handler and special chuck assemblies. No formal design was done on this project because of limited manpower available.

3.1.3.9 Design Integrity Testing

Ninety-nine TAB HMOs were exposed to extensive environmental testing to verify that the baseline design could meet and exceed the environmental requirements of the Oscillator Source Control Drawing. The test sample consisted of HMOs fabricated for first-article testing during the development contact. This test sample consisted of HMOs which were encapsulated using two techniques: (1) epoxy only and (2) silicone and epoxy. The stress test sequence and the sample size submitted to each test is shown in fig. 5. Period (T) measurements were performed on the oscillators before and after environmental tests.

Shock.--Three successive shock tests ranging in shock levels from 40 to 80 kg verified that considerable margin exists between the specification requirements and the baseline design capability. The period drift after exposure to each shock test is summarized in table VII. The HMOs were encapsulated in nose cones using epoxy per ES2045-P. The orientation of the HMOs in the nose cone is shown in fig. 6. Electrical data obtained during the shock tests are contained in table VIII. Histograms displaying the period drift after each shock test are shown in figs. 7 and 8.

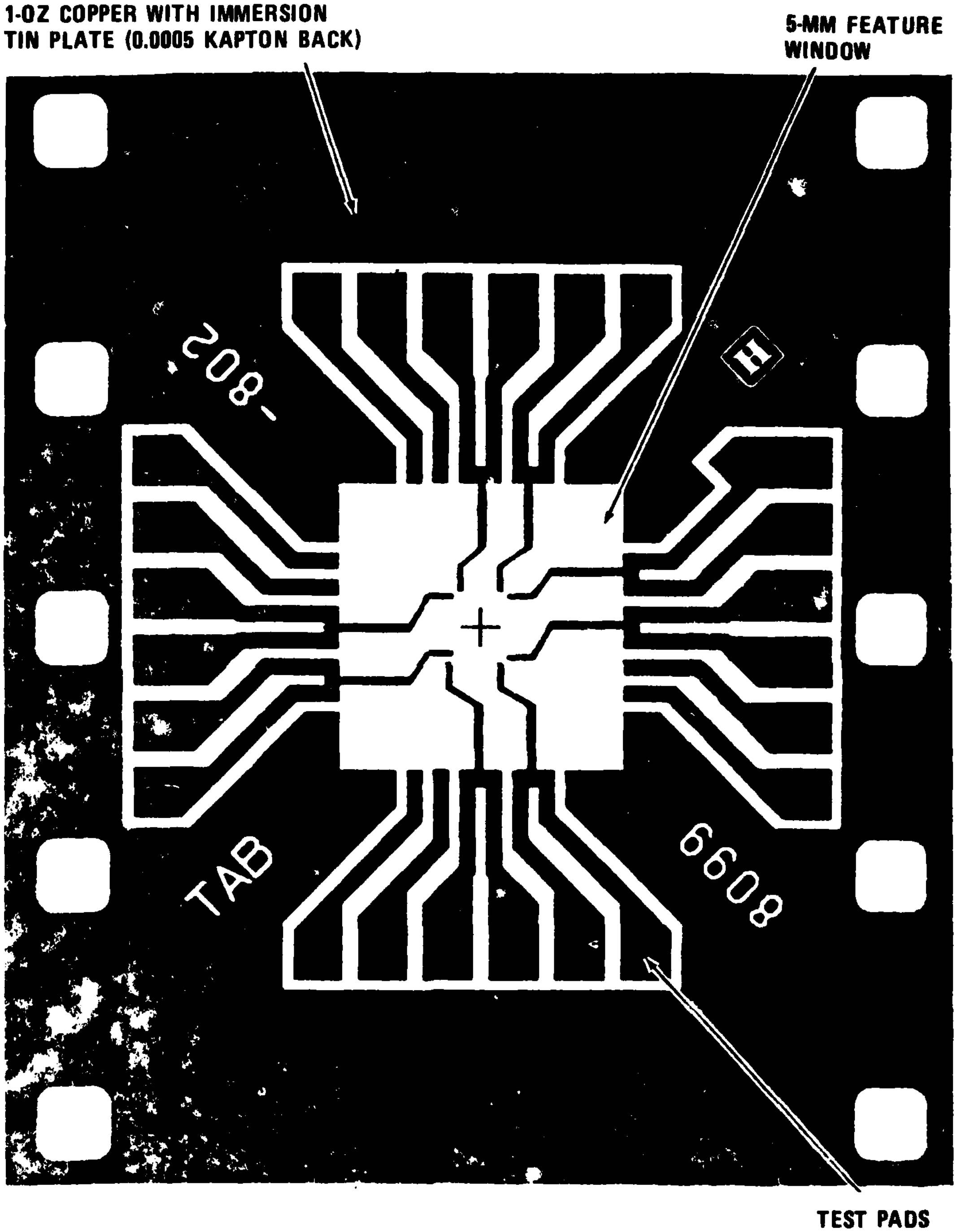
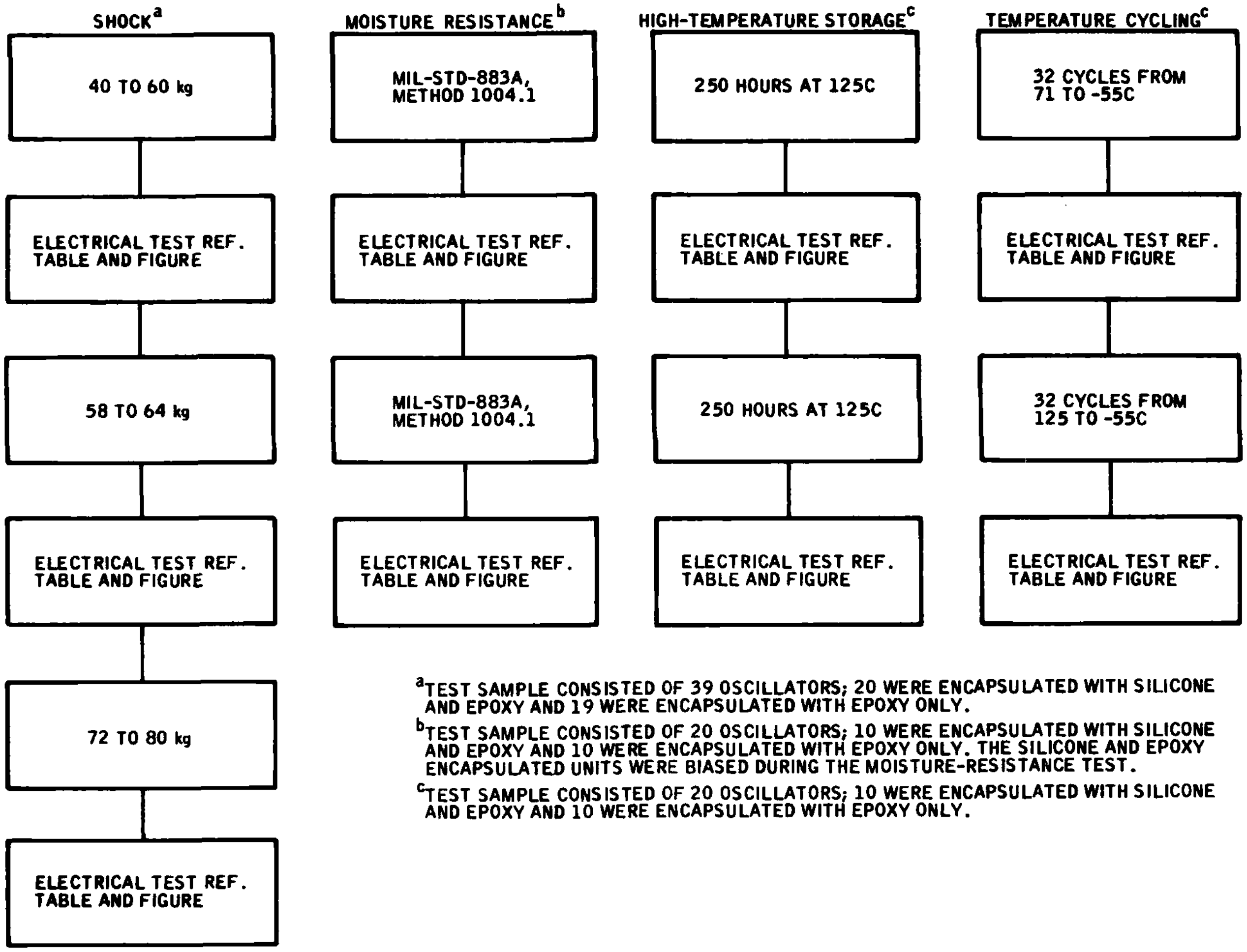


Figure 4. 19-mm tape format.



[a] TEST SAMPLE CONSISTED OF 39 OSCILLATORS; 20 WERE ENCAPSULATED WITH SILICONE AND EPOXY AND 19 WERE ENCAPSULATED WITH EPOXY ONLY.

[b] TEST SAMPLE CONSISTED OF 20 OSCILLATORS; 10 WERE ENCAPSULATED WITH SILICONE AND EPOXY AND 10 WERE ENCAPSULATED WITH EPOXY ONLY. THE SILICONE AND EPOXY ENCAPSULATED UNITS WERE BIASED DURING THE MOISTURE-RESISTANCE TEST.

[c] TEST SAMPLE CONSISTED OF 20 OSCILLATORS; 10 WERE ENCAPSULATED WITH SILICONE AND EPOXY AND 10 WERE ENCAPSULATED WITH EPOXY ONLY.

Figure 5. Diagram of stress testing.

TABLE VII. DESIGN INTEGRITY TEST: TOTAL TEST SAMPLES = 39

Test Sequence	Epoxy (19 samples)	Silicone/Epxoy (20 samples)
First shock test, 40 to 60 kg:		
Excludes $\bar{x}$ (10^{-9} s)	-18.56	-2.44
(Drift > 7200 x 10^{-9} s) σ	10.35	8.92
No. of devices with τ drift < 20 x 10^{-9} s	8	0
No. of devices with τ drift > 200 x 10^{-9}	1	0
Second shock test, 58 to 64 kg:		
Excludes $\bar{x}$ (10^{-9} s)	-24.64	3.18
(Drift > 200 x 10^{-9} s)σ	24.38	4.84
No. of devices with τ drift < 20 x 19^{-9} s	11	1
No. of devices with τ drift > 200 x 10^{-9} s	2	1
Third shock test, 72 to 80 kg:		
Excludes $\bar{x}$ (10^{-9} s)	27.94	12.56
(Drift > 200 x 10^{-9} s)σ	6.99	3.28
No. of devices with τ drift < 20 x 10^{-9} s	17	2
No. of devices with τ drift > 200 x 10^{-9} s	4	2

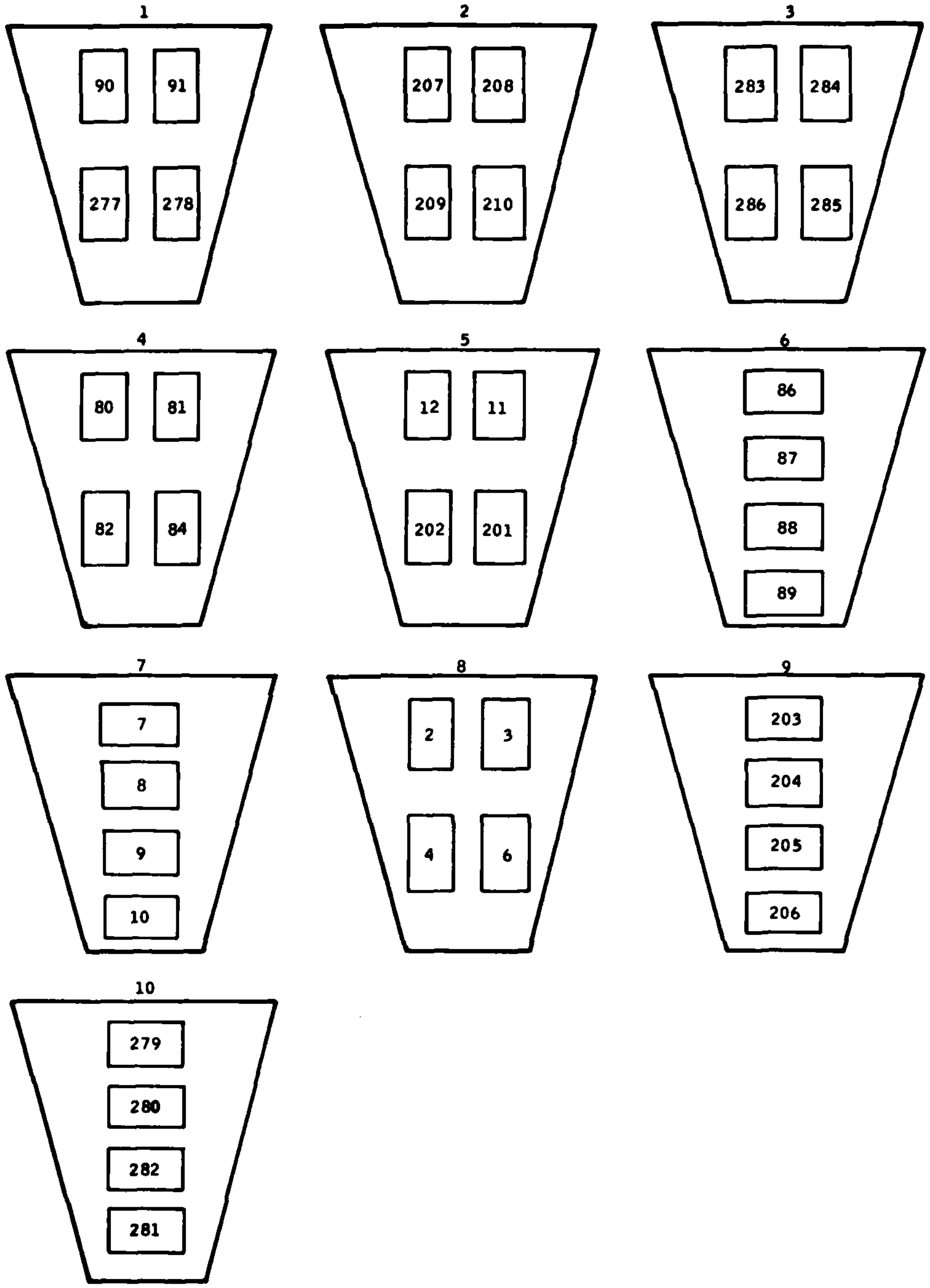


Figure 6. Orientation of HMOs as placed in nose cones for shock testing.

TABLE VIII. SHOCK TESTING ELECTRICAL DATA

Nose Cone No.[a]	S/N	Shock Level (kg)	First Shock Test			Second Shock Test			Third Shock Test		
			Initial τ (10^{-6} s)	After τ (10^{-6} s)	Δτ (10^{-9} s)	Shock Level (kg)	τ (10^{-6} s)	Δτ (10^{-9} s)	Shock Level (kg)	After τ (10^{-6} s)	Δτ (10^{-9} s)
8	2[b]	40	100.6072	100.5974	- 20.4	63	100.5773	- 20.1	80	122.5400	+ 22.0 μs[c]
8	3	40	99.0224	98.9912	- 31.2	↑	98.9823	- 8.9	↑	512.700	413.8 μs[c]
8	4	40	97.1340	97.0932	- 40.8	↓	97.0920	- 1.2	↓	97.1127	+ 20.7
8	6	40	98.6795	98.6407	- 38.8	63	98.6400	- 0.7	80	98.6593	+ 19.3
7	7	42	100.9516	100.9278	- 23.8	61	100.8998	- 28.0	75	100.9330	+ 33.2
7	8	42	99.1459	99.1248	- 21.1	↑	99.0906	- 34.2	↑	99.1232	+ 32.6
7	9	42	100.1758	100.1553	- 20.5	│	100.1398	- 15.5	↓	100.1689	+ 29.1
7	10	42	98.4644	98.4541	- 10.3	│	98.440	- 14.1	75	98.4662	+ 26.2
5	11	42	98.7002	98.6900	- 10.2	│	98.6847	- 5.3	78	98.7020	+ 17.3
5	12	42	98.1471	98.1335	- 13.6	│	98.1327	- 0.8	↑	98.1650	+ 32.3
4	80	42	96.2040	96.1865	- 17.5	│	[d]100.4219	4.23 μs	│	100.5183	+ 96.4[c]
4	82	42	98.6500	98.6382	- 11.8	↓	98.6065	31.7	↓	98.6284	+ 21.9
4	84	42	101.1323	101.1540	- 21.7	61	101.1621	+ 8.0	78	101.2061	+ 44.0
6	86	50	96.9580	96.9460	- 12.0	64	96.8968	- 49.2	75	96.9322	+ 35.4
6	87	50	96.4640	96.4591	- 4.9	↑	96.3805	- 78.6	↑	98.4043	+ 23.8
6	88	50	98.6982	98.6954	- 2.5	↓	98.6290	- 66.4	↓	98.6553	+ 26.3
6	89	50	96.9568	98.7455	[e]-211.0	64	98.6986	- 46.9	75	98.7264	+ 27.8
1	90	40	98.3245	98.3075	- 17.0	58	[d]106.7332	+ 8.43 μs	80	106.9563	+223.1[c]
1	91	40	100.4889	100.4730	- 15.9	58	100.4476	- 25.4	80	100.4768	+ 29.2
						↕			↕		
5	201[f]	42	98.8061	98.7997	- 6.4	61	98.7991	- 0.6	78	98.8160	+ 16.9
5	202	42	99.1756	99.1725	- 3.1	61	99.1706	- 1.9	78	99.1867	+ 16.1
9	203	45	98.4163	98.4008	- 15.5	63	98.4061	+ 5.3	75	98.4229	+ 16.8
9	204	45	100.5775	100.5617	- 15.8	↑	100.5678	+ 6.1	↑	100.5762	+ 8.4
9	205	45	98.9219	98.9095	- 12.4	↓	[d] 98.5146	-394.9	↓	98.6593	+144.7[c]
9	206	45	97.9537	97.9485	- 5.2	63	97.9562	+ 7.7	75	97.9665	+ 10.3
2	207	60	98.5852	98.5869	+ 1.7	60	98.5833	- 3.6	78	98.5973	+ 14.0
2	208	60	98.3261	98.3334	+ 7.3	↑	98.3365	+ 3.1	↑	98.3494	+ 12.9
2	209	60	97.0911	97.0965	+ 5.4	↓	97.0986	+ 2.1	↓	97.1137	+ 15.1
2	210	60	98.1400	98.1420	+ 2.0	60	98.1439	+ 1.9	78	98.1556	+ 11.7
1	277	40	98.0879	98.1017	+ 13.8	58	98.1056	+ 3.9	80	98.1235	+ 17.9
1	278	40	98.2474	98.2430	- 4.4	58	98.2376	- 5.4	80	98.2492	+ 11.6
10	279	(g)	98.1903	98.1736	- 16.7	61	98.1784	+ 4.8	72	98.1881	+ 9.7
10	280	(g)	98.7376	96.7324	- 5.2	↑	96.7449	+ 12.5	↑	95.7998	0.945 μs[c]
10	281	(g)	96.7496	96.7469	- 12.0	↓	96.7589	+ 12.0	↓	96.766	+ 7.3
10	282	(g)	98.8417	98.8293	- 12.4	61	98.8353	- 6.0	72	98.8457	+ 10.4
3	283	55	99.0264	99.0364	+ 10.0	59	99.0375	+ 1.1	75	99.0479	+ 10.4
3	284	55	96.6099	96.6153	+ 5.4	↑	96.6208	+ 5.5	↑	96.6310	+ 10.2
3	285	55	98.2536	98.2569	+ 3.3	↓	98.2600	+ 3.2	↓	98.2699	+ 9.9
3	286	55	97.9610	97.9631	+ 2.1	59	97.9599	- 3.2	75	97.9763	+ 16.4

[a] Reference fig. for HMO orientation in the nose cone. HMO S/N81 was electrically overstressed prior to the first shock test.

[b] S/N's 2 to 91: Encapsulated with epoxy only.

[c] HMO exhibited excessive period drift after the third shock test.

[d] HMO exhibited excessive period drift after the second shock test.

[e] HMO exhibited excessive period drift after the first shock test.

[f] S/N's 201 to 286: Encapsulated with silicone and epoxy.

[g] HMO was not exposed to the first shock test.

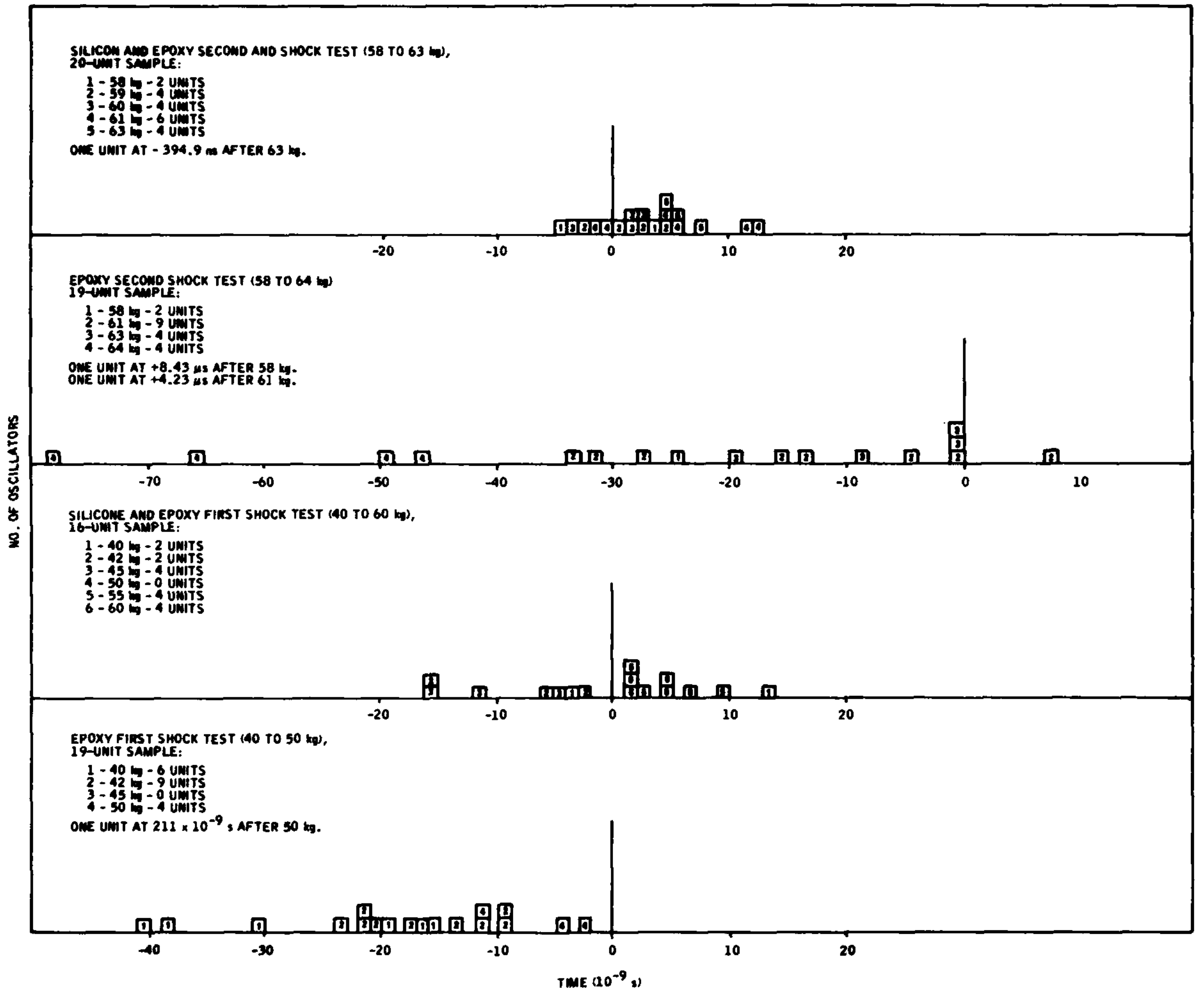
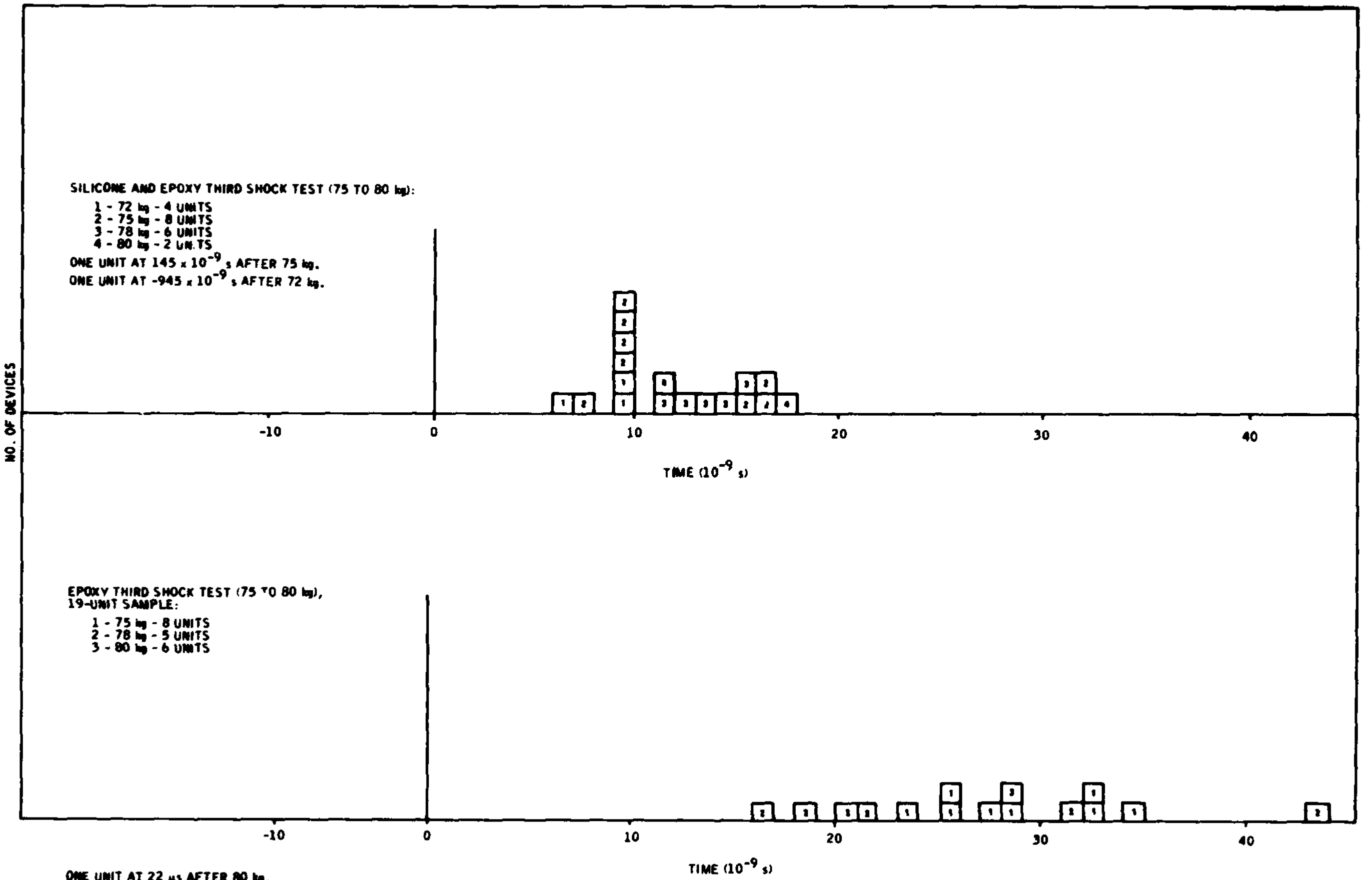


Figure 7. Histograms of period change through the first and second shock testing.



ONE UNIT AT 22 μs AFTER 80 kg.
ONE UNIT AT 413 μs AFTER 80 kg.
*ONE UNIT AT 96 x 10^{-9} s AFTER 78 kg.
*ONE UNIT AT 223 x 10^{-9} s AFTER 80 kg.

*UNITS WHICH EXHIBITED EXCESSIVE DRIFT AFTER THE SECOND SHOCK TEST.

Figure 8. Histograms of period change through the third shock test.

Although excessive period change was noted in six HMOs after the third shock test, the devices remained functional. The specification requirement on τ drift is ± 20 x 10^{-9} s after exposure to 30-kg shock.

Temperature Cycling.--Twenty HMOs were exposed to 32 temperature cycles between +71C and -55C. Electrical measurements showed minor period drift during this temperature cycle test. Period drifts are summarized in table IX. All period drifts are noted in 10^{-9} s. Electrical data are contained in table X. A histogram displaying the period drift is shown in fig. 9.

TABLE IX. TEMPERATURE CYCLING PERIOD DRIFT SUMMARY

No. of Cycles	+71C to -55C				+125C to -55C			
	Epoxy		Epoxy/Silicone		Epoxy		Epoxy/Silicone	
	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
8	-6.08	10.24	-5.31	4.41	-87.26	10.01	4.57	5.56
16	-8.06	7.04	-2.75	3.38	-85.53	10.09	1.24	5.00
24	3.74	7.95	4.76	3.24	-41.3	8.95	20.21	5.23
32	-9.67	10.16	-0.63	2.59	-72.75	9.08	14.97	4.61

Subsequent to the 32 temperature cycles between +71C and -55C, the HMSs were exposed to an additional 32 temperature cycles between +125C and -55C. Electrical data obtained during this temperature cycle testing are contained in table XI. A histogram displaying the period drift is shown in fig. 10.

The specification requirement allows a period drift of ±250 x 10^{-9} s after eight cycles from +71C to -55C. No deterioration was noted in the oscillator performance during the extensive temperature cycle testing.

High-Temperature Storage.--Twenty hybrid microcircuit oscillators were exposed to elevated temperature (125C) for 500 hours. These devices were also exposed to 125C for 500 hours during the first-article testing of the

TABLE X. TEMPERATURE CYCLE (+71C TO -55C) ELECTRICAL DATA

S/N[a]	Initial τ (10^{-6} s)	After 8 Cycles τ (10^{-6} s)	After 8 Cycles $\Delta\tau$ (10^{-9} s)	After 16 Cycles τ (10^{-6} s)	After 16 Cycles $\Delta\tau$ (10^{-9} s)	After 24 Cycles τ (10^{-6} s)	After 24 Cycles $\Delta\tau$ (10^{-9} s)	After 32 Cycles τ (10^{-6} s)	After 32 Cycles $\Delta\tau$ (10^{-9} s)
13	98.4910	98.4800	-11.0	98.4795	-11.5	98.5078	+16.8	98.4815	+ 9.5
14	98.3645	98.3556	- 8.9	98.3570	- 7.5	98.3652	+ 0.7	98.3489	-15.6
15	96.2636	96.2475	-16.1	96.2437	-19.9	96.2698	+ 6.2	96.2492	-14.4
16	96.6658	96.6823	+16.5	96.6593	- 6.5	96.6615	- 4.3	96.6434	-22.4
17	100.5340	100.5200	-14.0	100.5230	-11.0	100.5382	+ 4.2	100.5215	-12.5
19	97.7659	97.7580	- 7.9	97.7641	- 1.8	97.7767	+10.8	97.7598	- 6.1
20	98.8367	98.8199	-16.8	98.8265	-10.2	98.8340	- 2.7	98.8170	-19.7
21	100.6365	100.6390	+ 2.5	100.6437	+ 7.2	100.6500	+13.5	100.6415	+ 5.0
22	100.1551	100.1492	- 5.9	100.1457	- 9.4	100.1539	- 1.2	100.1433	-11.8
23	98.2285	98.2293	+ 0.8	98.2185	-10.0	98.2219	- 6.6	98.2198	- 8.7
211[b]	98.9370	98.9218	-15.2	98.9251	-11.9	98.9337	- 3.3	98.9312	- 5.8
212	98.1983	98.1914	- 6.1	98.1952	- 3.1	98.2049	+ 6.6	98.1961	- 2.2
213	100.9317	100.9241	- 7.6	100.9285	- 3.2	100.9360	+ 4.3	100.9289	- 2.8
214	97.8729	97.8678	- 5.1	98.8711	- 1.8	97.8778	+ 4.9	97.8743	- 1.4
216	99.2537	99.2558	+ 2.1	99.2522	- 1.5	99.2618	+ 8.1	99.2564	+ 2.7
217	99.5289	99.5247	- 4.2	99.5288	- 0.1	99.5351	+ 6.2	99.5293	+ 0.4
218	101.1185	101.1124	- 6.1	101.1169	- 1.6	101.1252	+ 6.7	101.1189	+ 0.4
219	99.0495	99.0439	- 5.6	99.0467	- 2.8	99.0556	+ 6.1	99.0499	+ 0.4
220	102.7773	102.7748	- 2.5	102.7769	- 0.4	102.7830	+ 5.7	102.7789	+ 1.6
221	99.1924	99.1896	- 2.8	99.1913	- 1.1	99.1947	+ 2.3	99.1900	- 2.4

[a] S/N's 13 to 23: Encapsulated with epoxy only.

[b] S/N's 211 to 221: Encapsulated with silicone and epoxy.

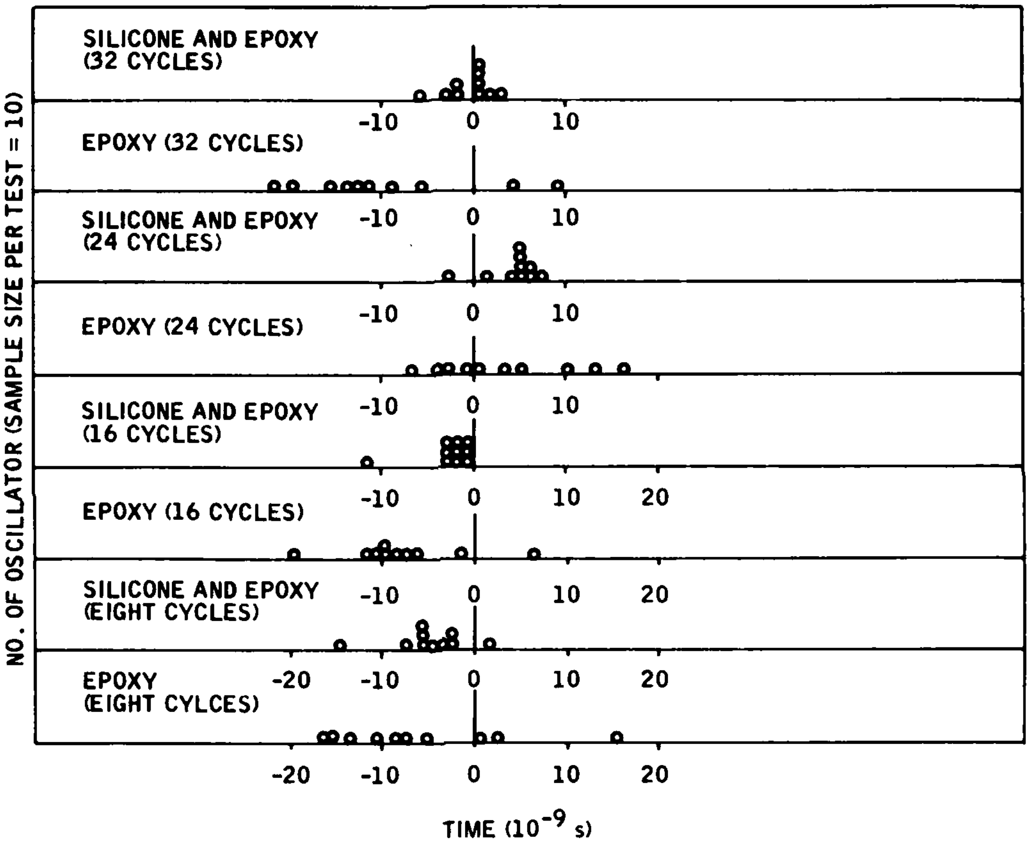


Figure 9. Histograms of period change during temperature cycling (+71C to -55C).

TABLE XI. TEMPERATURE CYCLE (+125C TO -55C) ELECTRICAL DATA

S/N[b]	Initial τ (10^{-6} s)	After 8 Cycles τ (10^{-6} s)	After 8 Cycles $\Delta\tau$ (10^{-9} s)	After 16 Cycles τ (10^{-6} s)	After 16 Cycles $\Delta\tau$ (10^{-9} s)	After 24 Cycles τ (10^{-6} s)	After 24 Cycles $\Delta\tau$ (10^{-9} s)	After 32 Cycles τ (10^{-6} s)	After 32 Cycles $\Delta\tau$ (10^{-9} s)
13	98.4815	98.3910	-90.5	98.3945	-87.0	98.4419	-39.6	98.4097	-71.8
14	98.3489	98.2628	-86.1	98.2680	-80.9	98.3080	-40.9	98.2800	-68.9
15	96.2492	96.1735	-75.5	96.1745	-74.7	96.2153	-33.9	96.1757	-73.5
16	96.6434	96.5543	-89.1	96.5558	-87.6	96.5974	-46.0	96.5679	-75.5
17	100.5215	100.4293	-92.2	100.4310	-90.5	100.4781	-43.4	100.4444	-77.1
19	97.7598	97.6920	-67.8	97.6924	-67.4	97.7353	-24.5	97.7062	-53.6
20	98.8170	98.7229	-94.1	98.7257	-91.3	98.7740	-43.0	98.7356	-81.4
21	100.6415	100.5428	-98.7	100.5431	-98.4	100.5907	-50.8	100.5620	-79.5
22	100.1433	100.0629	-80.4	100.0645	-78.8	100.1085	-34.8	100.0805	-62.8
23	98.2198	98.1216	-98.2	98.1211	-98.7	98.1637	-56.1	98.1364	-83.4
211[c]	98.9312	98.9365	+ 5.2	98.9329	+ 1.7	98.9560	+24.8	98.9473	+16.1
212	98.1961	98.2013	+ 5.2	98.1987	+ 2.6	98.2170	+20.9	98.2114	+15.3
213	100.9289	100.9298	+ 0.9	100.9275	- 1.4	100.9522	+23.3	100.9440	+15.1
214	97.8743	97.8808	+ 6.5	97.8830	+ 8.7	97.9004	+26.1	97.8959	+21.6
216	99.2564	99.2583	+ 1.9	99.2550	- 1.4	99.2719	+15.5	99.2669	+10.5
217	99.5293	99.5449	+15.6	99.5380	+ 8.7	99.5499	+20.6	99.5484	+19.1
218	101.1189	101.1303	+11.4	101.1242	+ 5.3	101.1447	+25.8	101.1398	+20.9
219	99.0499	99.0523	+ 2.4	99.0455	- 4.4	99.0647	+13.8	99.0610	+11.1
220	102.7789	102.7780	- 0.9	102.7756	- 3.3	102.7988	+19.9	102.7911	+12.2
221	99.1900	99.1875	- 2.5	99.1859	- 4.1	99.2004	+10.4	99.1978	+ 7.8

[a] S/N's 13 to 23: Encapsulated with epoxy only.

[b] S/N's 211 to 221: Encapsulated with silicone and epoxy.

[c] This temperature cycle test was performed subsequent to the +71C temperature cycle test.

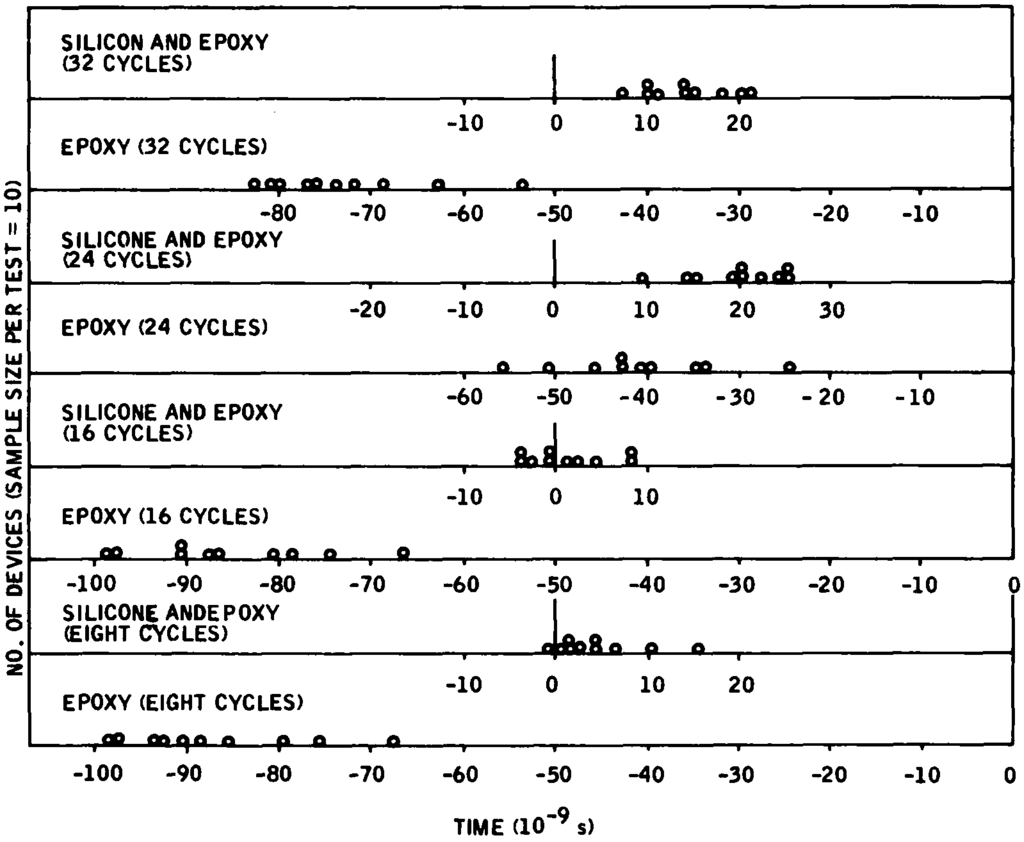


Figure 10. Histograms of period change during temperature cycling (+125C to -55C).

development program. Period drifts at high-temperature storage are summarized in table XII. Electrical data are contained in table XIII. A histogram displaying the period drift during high-temperature storage testing is shown in fig. 11.

TABLE XII. HIGH-TEMPERATURE PERIOD DRIFTS SUMMARY

Period	Epoxy		Epoxy/Silicone	
	$\bar{x}(10^{-9}$ s)	σ	$\bar{x}(10^{-9}$ s)	σ
After 250 hr	35.25	9.43	7.49	6.53
After 500 hr	63.41	13.56	16.35	7.18

The specification requirement allows a period drift of 250 x 10^{-9} s after 500 hours at 125C.

No deterioration was noted in the oscillator performance after 1000 hours of high-temperature storage exposure.

Moisture Resistance.--Twenty hybrid microcircuit oscillators were exposed to moisture-resistance testing per MIL-STD-883, Method 1004.1. The 10 devices, which were encapsulated with silicone/epoxy, were electrically functioning during the moisture-resistance exposure. All of these oscillators were also exposed to moisture-resistance testing (one cycle requires 10 days) during the first-article test of the development program. The moisture-resistance electrical data are contained in table XIV. Period drifts during moisture resistance testing are summarized in table XV, and figure 12 is a histogram displaying period drift.

One of the oscillators, S/N 39, which was encapsulated with epoxy only, did not function after exposure to the first moisture-resistance test. A 0-V output was noted with the shield of the oscillator connected to ground. However, when the shield was disconnected from ground, the oscillator output was normal and the period was 97.707 x 10^{-6} s. After a second exposure to moisture-resistance testing, this oscillator functioned properly.

TABLE XIII. HIGH-TEMPERATURE STORAGE (125C) ELECTRICAL DATA

S/N[a]	Initial τ $(10^{-6}\ \text{s})$	After 250 Hours		After 500 Hours	
		τ $(10^{-6}\ \text{s})$	$\Delta\tau$ $(10^{-9}\ \text{s})$	τ $(10^{-6}\ \text{s})$	$\Delta\tau$ $(10^{-9}\ \text{s})$
78	96.7623	96.7828	+20.5	96.7936	+31.3
92	97.9515	97.9872	+35.7	98.0139	+62.4
93	97.9592	98.0134	+54.2	98.0265	+67.3
94	98.4708	98.5125	+41.7	98.5439	+73.1
96	100.4295	100.4673	+37.8	100.4973	+67.8
97	98.9300	98.9537	+23.7	98.9828	+52.8
98	102.4922	102.5250	+32.8	102.5515	+59.3
99	97.9060	97.9445	+38.5	97.9769	+70.9
100	97.4613	97.4983	+37.0	97.5413	+80.0
101	100.0670	100.0670	+30.6	100.1362	+69.2
287[b]	98.8960	98.9057	+ 9.7	98.9129	+16.9
288	100.4755	100.4753	- 0.3	100.4832	+ 7.7
289	98.7735	98.7709	- 2.6	98.7803	+ 0.8
290	96.7285	96.7375	+ 9.0	96.7497	+21.2
291	99.4372	99.4469	+ 9.7	99.4560	+18.8
292	98.3602	98.3618	+ 1.6	98.3687	+ 8.5
293	99.2068	99.2107	+ 3.9	99.2192	+12.4
295	100.2980	100.3120	+14.0	100.3199	+21.9
296	99.9547	99.9716	+16.9	99.9827	+28.0
297	97.5263	97.5393	+13.0	97.5476	+21.3

[a] S/N's 78 to 101: Encapsulated with epoxy only.

[b] S/N's 287 to 297: Encapsulated with silicone and epoxy.

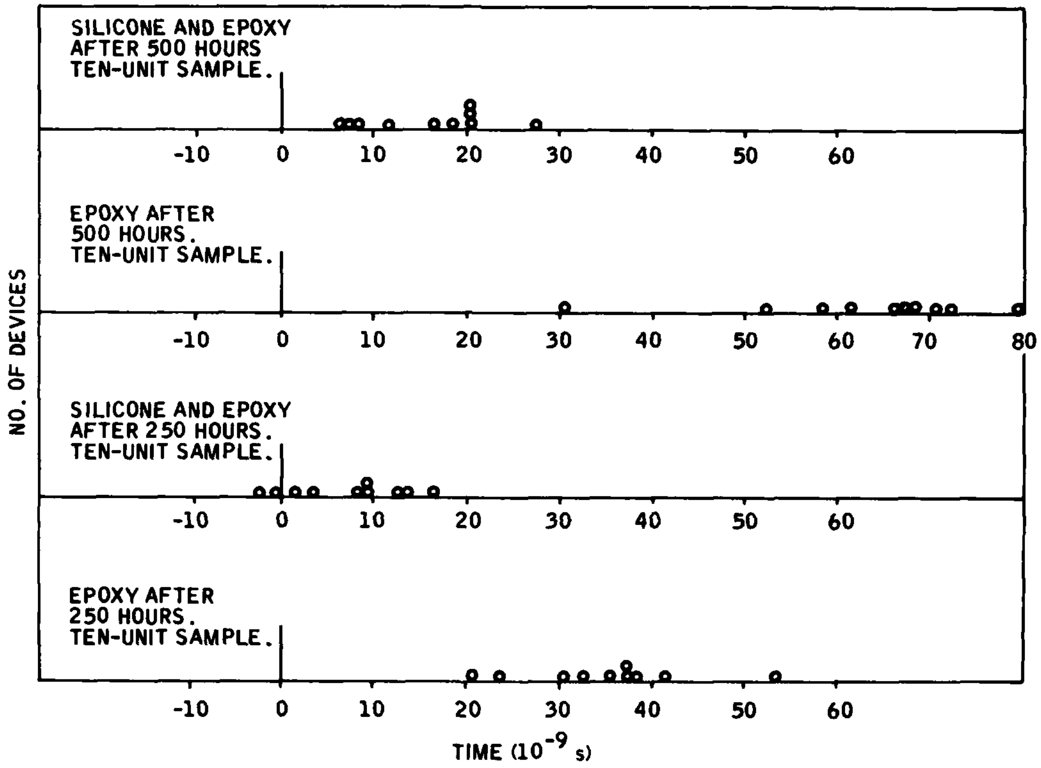


Figure 11. Histograms of period change through high-temperature storage tests at 125C.

TABLE XIV. MOISTURE-RESISTANCE ELECTRICAL DATA

S/N[a]	Initial	After First Moisture Resistance Exposure		After Second Moisture Resistance Exposure	
	τ (10^{-6} s)	τ (10^{-6} s)	$\Delta\tau$ (10^{-9} s)	τ (10^{-6} s)	$\Delta\tau$ (10^{-9} s)
27	98.1525	98.1586	+ 6.1	98.1596	+ 7.1
29	103.1142	103.1475	+33.3	103.1734	+ 59.2
30	99.9310	99.9145	-16.5	99.8542	- 76.8
31	96.6771	96.6885	+11.4	96.6766	- 0.5
32	98.3905	98.4800	+89.5	98.4469	+ 56.4
34	98.6698	98.7313	+61.5	98.7706	+100.8
36	96.7518	96.8246	+72.8	96.8717	+119.9
37	98.5155	98.5405	+25.0	98.5478	+ 32.3
38	98.9045	98.9486	+44.1	99.0019	+ 97.4
39	98.1664	(b)	(b)	98.0664[c]	-100.0
222[d]	99.2641	99.2908	+26.7	99.3034	+ 39.3
226	96.9590	96.9867	+27.7	97.0075	+ 48.5
228	102.9039	102.9280	+24.1	102.9576	+ 53.7
229	97.9935	98.0375	+44.0	98.0547	+ 61.2
231	96.9669	97.0024	+35.5	97.0202	+ 53.3
232	96.5999	96.6551	+55.2	96.6496	+ 49.7
233	100.7659	100.8136	+47.7	100.8326	+ 66.7
235	98.2289	98.2623	+33.4	98.2766	+ 47.7
236	96.9863	97.0107	+24.4	97.0255	+ 39.2
237	98.8035	98.8382	+34.7	98.8482	+ 44.7

[a] S/N's 27 to 39: Encapsulated with epoxy only.

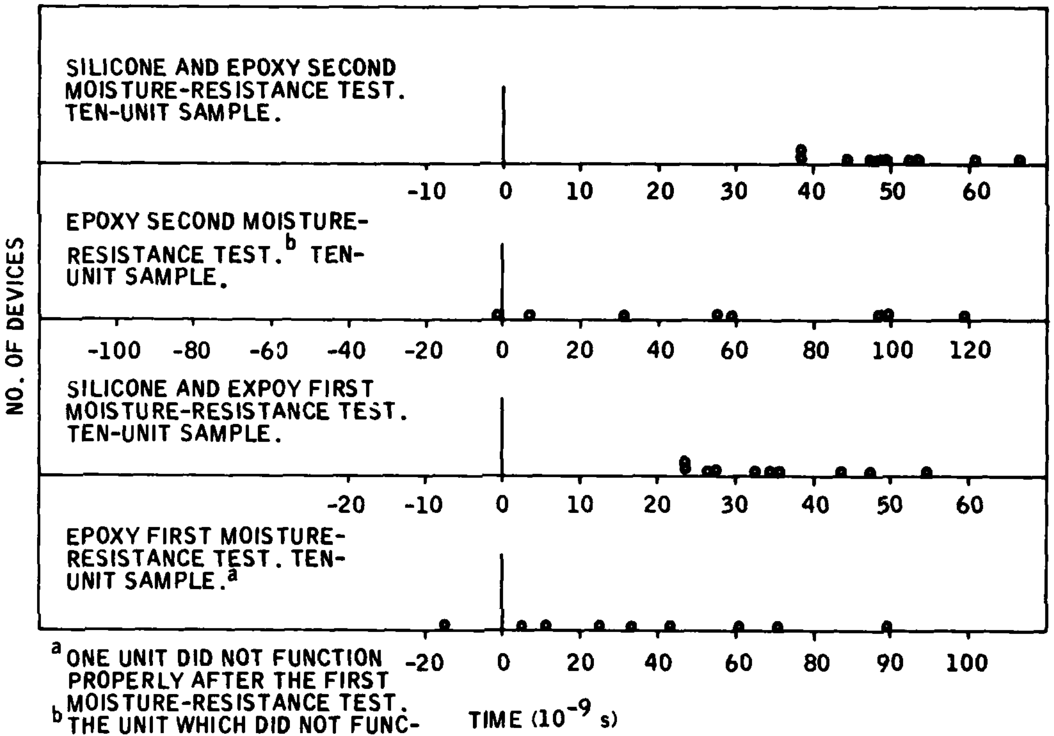
[b] This unit did not function properly with the shield connected to ground. When the shield was disconnected, the oscillator functioned: $\tau = 97.707 \times 10^{-6}$ s.

[c] The oscillator functioned properly during this electrical test.

[d] S/N's 222 to 237: Encapsulated with silicone and epoxy. The oscillators were biased electrically during the test.

TABLE XV. MOISTURE-RESISTANCE PERIOD DRIFT SUMMARY

Period	Epoxy		Epoxy/Silicone	
	$\bar{x}$	σ	$\bar{x}$	σ
After first moisture-resistance test	36.36	34.12	29.58	73.75
After second moisture-resistance test	35.34	10.57	50.40	8.78



[a] ONE UNIT DID NOT FUNCTION PROPERLY AFTER THE FIRST MOISTURE-RESISTANCE TEST.

[b] THE UNIT WHICH DID NOT FUNCTION AFTER THE FIRST MOISTURE-RESISTANCE TEST FUNCTIONED PROPERLY AFTER THE SECOND TEST.

Figure 12. Histograms of period change through moisture-resistance tests.

Moisture-resistance testing is not a requirement of the Source Control Drawing. However, moisture-resistance testing has proved chemical compatibility of the materials used in the baseline design of the TAB HMO.

It is recommended that the moisture-resistance test of MIL-STD-883, Method 1004.1, be incorporated in the Subgroup 2 tests of the Source Control Drawing. A maximum period drift of $\pm 250 \times 10^{-9}$ s should be specified for the allowable period drift during moisture-resistance exposure.

3.2 Phase II - Fabrication and Testing of the Engineering Sample

3.2.1 Introduction

Phase II of the MM&T program on the TAB HMO was composed of (1) fabrication of the TAB HMO engineering samples per the Oscillator Source Control Drawings, (3) maintaining a log book documenting yield information and process problems regarding the engineering sample build, (4) updating the baseline design drawing package, (5) updating the manufacturing methods notebook, and (6) reviewing the design to-cost analysis of the baseline design TAB HMO.

3.2.2 Summary

The TAB HMOs were fabricated per the baseline documentation established in phase I. The Oscillator Source Control Drawing and supporting design drawings, except for the monolithic amplifier, are contained in appendix A. The monolithic amplifier, dwg. 28112362, is documented in appendix B.

Sixty-one TAB HMOs were assembled, and 56 were acceptable for the final encapsulation process. (Three devices failed electrical testing prior to active trimming and two devices failed electrical testing prior to the final encapsulation process.) Twenty-six TAB HMOs were encapsulated using a plastic case painted with a conductive paint to form the shield. The metal case, which is also part of the baseline design, was not to be used during this phase because delivery was scheduled for the following phase. Another sample of 25 TAB HMOs was fabricated however, when the metal cases were subsequently received.

The 25 TAB HMOs were exposed to Group A and B tests of the Oscillator Source Control Drawing, 11726813. All devices except S/N 15 exhibited a 29.5 x 10^{-9} period change during voltage sensitivity testing (the specification requirement is 15 x 10^{-9} s at V_s = -23.5 to -17 Vdc). Failure analysis on S/N 15 is documented in appendix C. All TAB HMOs met Group B test requirements with the exception of device S/N 21. S/N 21 exhibited a -120.9 x 10^{-9} s period change during 30-kg shock testing (the specification is ±20 x 10^{-9} s). Failure analysis of this device revealed a crack in the 1000-pF capacitor in the twin-T network.

The baseline design drawing package was updated. The monolithic amplifier, dwg. 28112362, was revised and is presented in appendix B. The revisions were discussed with the integrated-circuit supplier, Motorola. This document was subsequently used to purchase the wafers for phase IV of the MM&T program.

The manufacturing methods notebook was updated. A specification for the internal visual requirements of the TAB HMO, dwg. 11711479, was generated and is presented in appendix D. This document was used for the pre-cap visual inspection during the Development Evaluation Group (DEG) build.

The design-to-cost figures showing labor and material costs of $3.65 were not changed as there were no significant material or process changes. The average cost per device for the third million oscillators, including general and administrative (G&A) expense and profit, was calculated at $3.79.

3.2.3 Detailed Description

3.2.3.1 Fabrication of TAB HMO Engineering Samples

Sixty-one TAB HMOs were fabricated. The fabrication flow and yield information are shown in table XVI.

3.3.3.2 Group A and B Testing of the TAB HMO Engineering Samples

Group A and B testing were performed as shown in fig. 13.

TABLE XVI. SUMMARY OF FABRICATION YIELD

Operation	No. of Devices	No. of Devices	Remarks
Burnish	61	61	
Clean	61	61	
Screen solder	61	61	
Attach lead	61	61	
Mount component - capacitors	61	61	
Mount component - integrated circuits	61	61	
Solder reflow	61	61	
Clean	61	61	
Cut lead	61	61	
Test			1 device had broken IC lead. 1 device had missing capacitor. 1 device had defective IC.
[a]Active trim	58	58	
Pre-cap inspection	58	58	
Test	58	56	1 device had period low. 1 device would not start.
Encapsulation	26	25	30 devices held for metal cases, 1 device electrically defective.
Group A tests	25	25	Ref. tables XVII through XX and figs. 13 and 14.
Group B tests	25	25	Ref. tables XXI through XXV and figs. 15 and 16.

[a] All operations to this point were performed at the contractor's St. Petersburg plant.

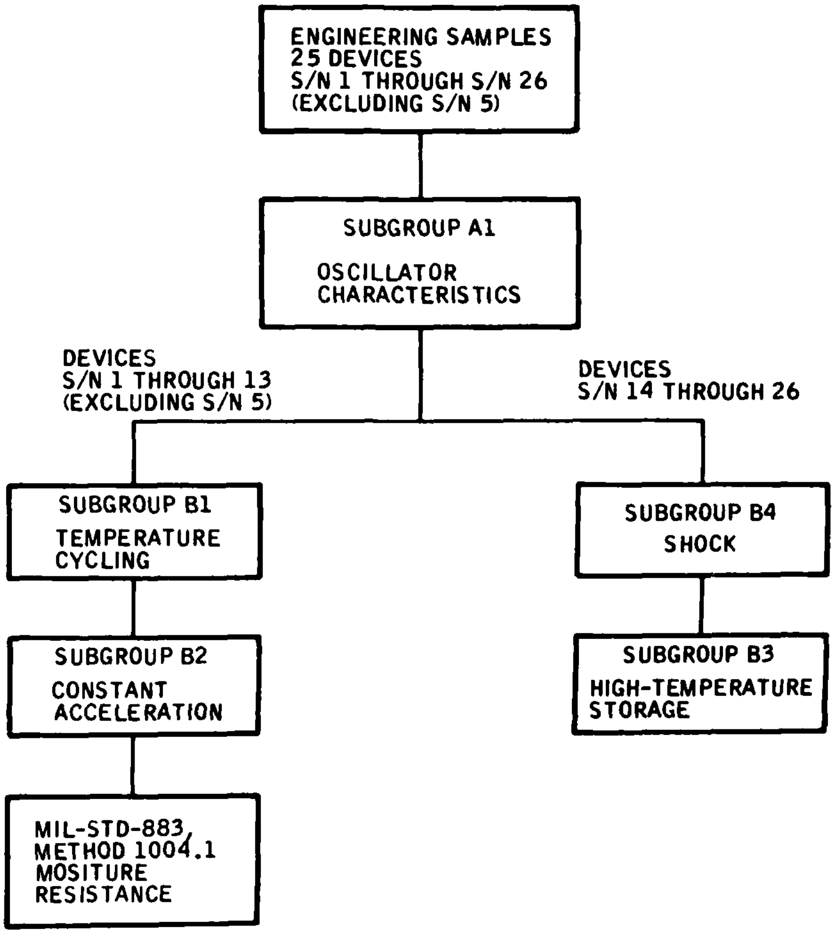


Figure 13. Flow diagram of electrical and environmental testing of engineering samples.

The electrical data obtained during Group A testing per dwg. 11726813 are contained in tables XVII through XX. Figs. 14 and 15 are histograms displaying the results of the temperature coefficient of period testing (TCT) and voltage sensitivity testing. TCT measurements were well within the ±75ppm/C specification requirement. Two devices (S/N 2 and S/N 11) exhibited an abnormal TCT at the cold temperatures and one device (S/N 15) had an abnormal TCT across the temperature range from 71C to -50C. Repeating the period measurements of these three devices verified the negative TCT. Device S/N 15 also exhibited a period change of 29.5 x

TABLE XVII. TEMPERATURE COEFFICIENT OF PERIOD DATA

S/N	T at 25C (10^{-6} s)	T at 45C (10^{-6} s)	TCT 25C to 45C (ppm/C)	T at 71C (10^{-6} s)	TCT 25C to 71C (ppm/C)	T at 0C (10^{-6} s)	TCT 25C to 0C (ppm/C)	T at -30C (10^{-6} s)	TCT 25C to -30C (ppm/C)	T at -50C (10^{-6} s)	TCT 25C to -50C (ppm/C)
1	97.9674	97.9864	9.7	98.0073	8.9	97.9290	15.7	97.8836	15.6	97.8588	14.8
2	98.1126	98.1298	8.8	98.1413	6.4	98.0904	9.1	98.0628	9.2	98.2400	-17.3
3	97.5592	97.5698	5.4	97.5761	3.8	97.5414	7.3	97.5146	8.3	97.5020	5.7
4	98.2500	98.2520	1.0	98.2468	- 0.7	98.2462	1.5	98.2396	1.9	98.2431	0.9
6	98.1725	98.1868	7.3	98.1950	5.0	98.1561	6.7	98.1298	7.9	98.1202	7.1
7	102.1566	102.1739	8.5	102.1864	6.3	102.1424	5.6	102.1112	8.1	102.0977	7.7
8	100.7563	100.7770	10.3	100.7924	7.8	100.7277	11.4	100.6862	12.6	100.6655	12.0
9	98.9520	98.9624	5.3	98.9726	4.5	98.9455	2.6	98.9248	5.0	98.9170	4.7
10	98.5092	98.5307	10.9	98.5476	8.5	98.4921	6.9	98.4582	9.4	98.4341	10.2
11	100.0415	100.0510	4.7	100.0518	2.2	100.0339	3.0	100.0880	- 8.4	100.3254	-37.8
12	99.7625	99.7743	5.9	99.7802	3.9	99.7519	4.3	99.7309	5.8	99.7278	4.6
13	98.8047	98.8224	9.0	98.8346	6.6	98.7858	7.7	98.7526	9.6	98.7330	9.7
14	98.4596	98.4779	9.3	98.4903	6.8	98.4364	9.4	98.4033	10.4	98.3879	9.7
15	98.1047	98.0752	-15.0	98.0874	- 3.8	98.2339	-52.7	98.2060	-18.8	98.1947	-12.2
16	98.1451	98.1653	10.3	98.1760	6.8	98.1195	10.4	98.0776	12.5	98.0564	12.1
17	99.9579	99.9771	9.6	99.9874	6.4	99.9361	8.7	99.8980	10.9	99.8915	8.9
18	97.7925	97.8157	11.9	97.8323	8.8	97.7671	10.4	97.7266	12.3	97.7111	11.1
19	99.1409	99.1619	10.6	99.1764	7.8	99.1157	10.2	99.0770	11.7	99.0805	8.1
20	99.0764	99.0943	9.0	99.1076	12.6	99.0565	8.0	99.0198	10.4	98.9943	11.0
21	96.5128	96.5437	16.0	96.5696	12.8	96.4797	13.7	96.4289	15.8	96.4268	11.9
22	98.1460	98.1632	8.8	98.1739	6.2	98.1285	7.1	98.0947	9.5	98.0790	9.1
23	97.4910	97.5047	7.0	97.5091	4.0	97.4737	7.1	97.4470	8.2	97.4346	7.7
24	97.6288	97.6364	3.9	97.6367	1.8	97.6193	3.9	97.6022	5.0	97.6346	7.9
25	98.1205	98.1475	13.8	98.1663	10.1	98.0881	13.2	98.0424	14.5	98.0449	10.3
26	98.0897	98.1017	6.1	98.1064	3.7	98.0777	4.9	98.0551	6.4	98.0438	6.2

TABLE XVIII. VOLTAGE SENSITIVITY TEST DATA[a]

S/N	T at -23.5 Vdc (10^{-6} s)	T at -17 Vdc (10^{-6} s)	ΔT at -23.5 to -17 Vdc (10^{-9} s)	T at -30 Vdc (10^{-6} s)	ΔT -23.5 to -30 Vdc (10^{-9} s)
1	97.9674	97.9745	7.1	97.9599	- 7.5
2	98.1126	98.1208	8.2	98.1053	- 7.3
3	97.5592	97.5702	11.0	97.5535	- 5.7
4	98.2500	98.2605	10.5	98.2446	- 5.4
6	98.1725	98.1810	8.5	98.1665	- 6.0
7	102.1566	102.1649	8.3	102.1500	- 6.6
8	100.7563	100.7650	8.7	100.7500	- 6.3
9	98.9520	98.9610	9.0	98.9455	- 6.5
10	98.5092	98.5198	10.6	98.5034	- 5.8
11	100.0415	100.0509	9.4	100.0344	- 7.1
12	99.7625	99.7725	10.0	99.7560	- 6.5
13	98.8047	98.8146	9.9	98.7979	- 6.8
14	98.4596	98.4698	10.2	98.4540	- 5.6
15[b]	98.1047	98.1342	29.5	98.0941	-10.6
16	98.1451	98.1566	11.5	98.1339	- 5.2
17	99.9579	99.9666	8.7	99.9515	- 6.4
18	97.7925	97.8028	10.3	97.7866	- 5.9
19	99.1049	99.1495	8.6	99.1344	- 6.5
20	99.0764	99.0843	7.9	99.0707	- 5.7
21	96.5128	96.5238	11.0	96.5069	- 5.9
22	98.1460	98.1547	8.7	98.1395	- 6.5
23	97.4910	97.5024	11.4	97.4849	- 6.1
24	97.6288	97.6378	9.0	97.6228	- 6.0
25	98.1205	98.1299	9.4	98.1145	- 6.0
26	98.0897	98.0992	9.5	98.0834	- 6.3
			$\bar{x} = 9.5$[c]		$\bar{x} = 6.2$
			$\sigma = 1.17$		$\sigma = 0.57$

[a] The specification limit is ± 15 x 10^{-9} s.

[b] The device does not meet the ± 15 x 10^{-9} s requirement between -23.5 and -17 Vdc.

[c] S/N 15 period change is excluded from $\bar{x}$ calculations.

TABLE XIX. RISE TIME, FALL TIME, AND TIME HIGH DATA

S/N	T_R at 25C (10^{-9} s)	T_R at 71C (10^{-9} s)	T_R at -50C (10^{-9} s)	T_F at 25C (10^{-9} s)	T_F at 71C (10^{-9} s)	T_F at -50C (10^{-9} s)	T_H at 25C (10^{-6} s)	T_H at 71C (10^{-6} s)	T_H at -50C (10^{-6} s)
1	260	260	280	225	240	220	52	46	47
2	450	480	500	240	250	230	51	51	50
3	350	190	200	230	240	220	52	44	46
4	300	330	320	240	240	220	51	52	50
6	220	300	320	230	250	230	51	52	50
7	310	320	340	250	250	230	53	47	49
8	340	280	330	250	250	230	48	53	51
9	300	290	350	240	240	250	52	45	48
10	530	560	600	230	250	230	51	52	47
11	680	700	800	200	250	250	48	47	51
12	500	500	520	240	250	230	52	52	47
13	250	240	260	190	240	220	46	52	51
14	320	350	350	230	240	230	52	53	46
15	320	320	350	270	280	280	46	46	47
16	260	240	300	250	280	280	49	50	50
17	260	250	280	240	250	240	47	46	51
18	300	290	340	250	270	250	51	52	48
19	380	390	440	200	250	240	47	46	50
20	320	310	340	200	250	240	50	46	49
21	420	440	460	230	250	230	45	44	50
22	280	270	280	230	240	230	51	52	49
23	225	220	230	245	250	230	45	44	50
24	380	380	440	200	245	240	50	51	47
25	380	400	430	220	240	230	46	47	50
26	260	260	280	230	240	230	52	52	46
Specification limit	3.0 x 10^{-6} s			3.0 x 10^{-6} s			35 to 60 x 10^{-6} s		

TABLE XX. SUPPLY CURRENT TEST DATA

S/N	I_s at 25C (mA dc)	I_s at 71C (mA dc)	I_s at -50C (mA dc)
1	1.82	1.81	1.76
2	1.76	1.74	1.67
3	1.91	1.89	1.80
4	1.81	1.78	1.74
5	1.83	1.82	1.74
7	1.83	1.79	1.75
8	1.82	1.81	1.74
9	1.81	1.80	1.76
10	1.77	1.77	1.70
11	1.73	1.72	1.59
12	1.71	1.68	1.62
13	1.83	1.81	1.76
14	1.73	1.76	1.69
15	1.70	1.68	1.60
16	1.79	1.73	1.67
17	1.86	1.84	1.75
18	1.72	1.71	1.64
19	1.82	1.80	1.73
20	1.87	1.84	1.75
21	1.75	1.72	1.64
22	1.87	1.84	1.78
23	1.81	1.79	1.75
24	1.81	1.80	1.70
25	1.80	1.79	1.68
26	1.87	1.86	1.78
Specification limit	2.7	2.7	2.7

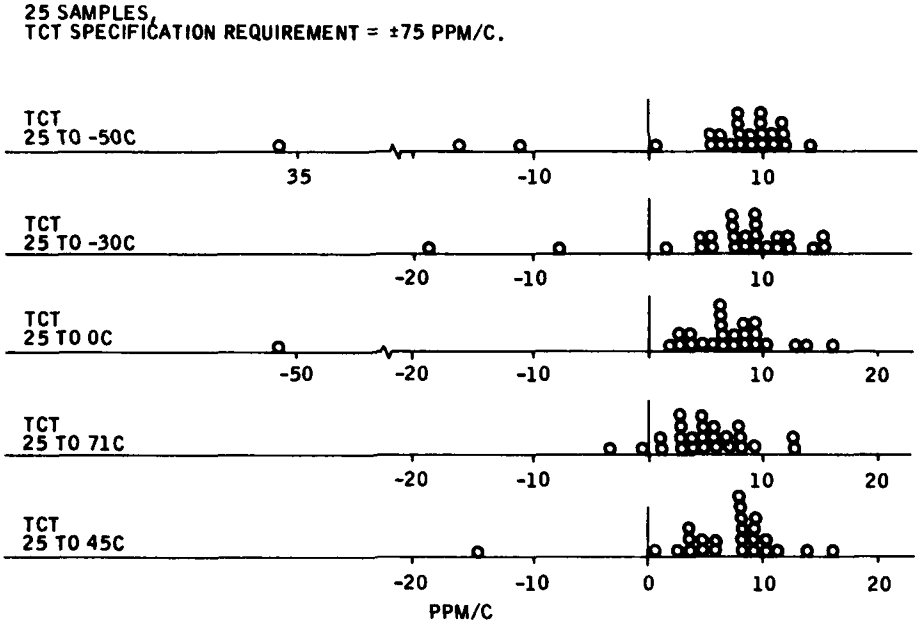


Figure 14. Histograms of the temperature coefficient of the period.

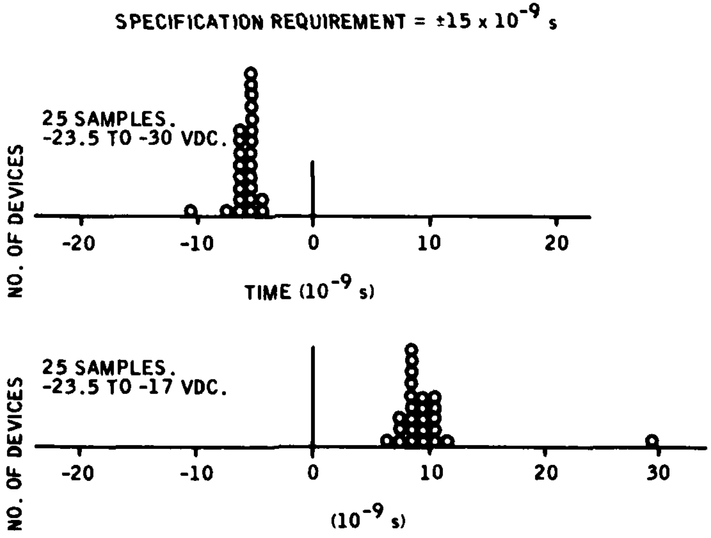


Figure 15. Histograms of voltage sensitivity.

10^{-9} s during voltage sensitivity testing between -23.5 and -17 Vdc. The specification requirement is ±15 x 10^{-9} s. Failure analysis of S/N 15 is documented in appendix C.

Temperature-cycle, constant-acceleration, moisture-resistance, 30-kg shock, and high-temperature storage test data are contained in tables XXI through XXV, respectively. The period drift noted during moisture-resistance, constant-acceleration, temperature-cycle, high-temperature storage, and 30-kg shock testing is displayed in histogram form in figs. 16 through 20.

The Group B test sequence is shown in fig. 13. One device (S/N 21) failed the 30-kg shock test. This device exhibited a -120.9 x 10^{-9} s period change, whereas the specification requirement is +20 x 10^{-9} s. Failure analysis revealed the period drift resulted from a crack in the body of the 1000-pF capacitor in the twin-T network. The remaining 24 TAB HMOs met the specification requirements for Group B testing.

TABLE XXI. TEMPERATURE CYCLE TEST DATA

S/N	T Pre- (10^{-6} s)	T Post- (10^{-6} s)	ΔT Pre-Post (10^{-9} s)
1	97.9674	97.9560	-11.4
2	98.1126	98.1017	-10.9
3	97.5592	97.5493	- 9.9
4	98.2500	98.2494	- 0.6
6	98.1725	98.1668	- 0.8
7	102.1566	102.1574	+ 0.8
8	100.7563	100.7542	- 2.1
9	98.9520	98.9502	- 1.8
10	98.5092	98.5080	- 1.2
11	100.0415	100.0392	- 2.3
12	99.7625	99.7584	- 4.1
13	98.8047	98.7968	- 7.9

$\bar{x}$ = - 4.8

σ = 4.29

Specification requirement = + 250

TABLE XXII. CONSTANT-ACCELERATION TEST DATA[a,b]

S/N	Socket	T Pre- (10^{-6} s)	T 350 RPS (10^{-6} s)	T Post- (10^{-6} s)	ΔT Pre-350 RPS (10^{-9} s)	ΔT Pre-Post (10^{-9} s)
1	2	97.9691	98.0104	97.9692	+41.3	+ 0.1
2		98.1152	98.1101	98.1133	- 5.1	- 1.9
3		97.5978	97.6136	97.6794	+ 5.8	+81.6
4		98.2601	98.2632	98.2599	+ 3.1	- 0.2
6	2	98.1/196.3	98.1/196.2	98.1/196.3	(c)	(c)
7	3	102.1700	102.1651	102.1694	- 4.9	- 0.6
8		100.7674	100.7645	100.7661	- 2.9	- 1.3
9		98.9619	98.9626	98.9627	+ 0.7	+ 0.8
10		98.5211	98.5195	98.5217	- 1.6	+ 0.6
11		100.0535	100.0510	100.0536	- 2.5	+ 0.1
12		99.7704	99.7699	99.7704	- 0.5	0.0
13	3	98.8092	98.8078	98.8098	- 1.4	+ 0.6
1[d]	3	97.9682	97.9654	97.9703	- 2.8	+ 2.1
2		98.1140	98.1131	98.1142	- 0.9	+ 0.2
3		97.5607	97.5588	97.5612	- 1.9	+ 0.5
4		98.2602	98.2633	98.2598	+ 3.1	- 0.4
6		98.1/196.3	98.1/196.2	98.1/196.3	(c)	(c)
7	3	102.1720	102.1691	102.1727	- 2.9	+ 0.7
8	2	100.7685	100.7600	100.7676	- 8.5	- 0.9
9		98.9628	98.9693	98.9634	+ 6.5	+ 0.6
10		98.5218	98.5201	98.5233	- 1.7	+ 1.5
11		100.0537	100.0502	100.0542	- 3.5	+ 0.5
12		99.7704	99.7701	99.7704	- 0.3	0.0
13	2	98.8093	98.8072	98.8098	- 2.1	+ 0.5
				$\bar{x}$	= - 1.3	0.4
				σ	= 3.63	0.79

[a] Testing performed by HDL.

[b] The period drift specification requirement is ± 50 x 10^{-9} s.

[c] S/N 6 is a no test; subsequently, S/N 6 functioned properly during moisture-resistance testing.

[d] Retest of S/N's 1 through 13 required because faulty test system ground caused erratic operation.

TABLE XXIII. MOISTURE-RESISTANCE TEST DATA[a]

S/N	T Pre- (10^{-6} s)	T Post- (10^{-6} s)	ΔT Pre-Post (10^{-9} s)
1	97.9702	97.9894	+19.2
2	98.1161	98.1421	+26.0
3	97.5615	97.5800	+18.5
4	98.2587	98.2837	+25.0
6	98.1807	98.2015	+20.8
7	102.1705	102.2119	+41.4
8	100.7657	100.7925	+26.8
9	98.9623	98.9954	+33.1
10	98.5221	98.5489	+26.8
11	100.0531	100.0779	+24.8
12	99.7707	99.7927	+22.0
13	98.8106	98.8324	+21.8
		$\bar{x}$ =	25.5
		σ =	6.41

[a] No specification requirement.

TABLE XXIV. 30-KG SHOCK TEST DATA

S/N	T Pre- (10^{-6} s)	T Post- (10^{-6} s)	ΔT Pre-Post (10^{-9} s)
14	98.4690	98.4654	- 3.6
15	98.0805	98.1000	+ 19.5
16	98.1500	98.1470	- 3.0
17	99.9637	99.9612	- 2.5
18	97.8014	97.8007	- 0.7
19	99.1488	99.1476	- 1.2
20	99.0850	99.0830	- 2.0
21	96.5241	96.4032	-120.9[a]
22	98.1537	98.1519	- 1.8
23	97.4980	97.4988	+ 0.8
24	97.6338	97.6344	+ 0.6
25	98.1276	98.1263	- 1.3
26	98.0958	98.0947	- 1.1
		$\bar{x}$ =	- 0.3[b]
		σ =	5.92
	Specification requirement	=	± 20

[a] S/N 21 period change exceeds the specification requirement.

[b] S/N 21 period change excluded from $\bar{x}$ calculation.

TABLE XXV. HIGH-TEMPERATURE STORAGE TEST DATA

S/N	T Pre- (10^{-6} s)	T Post- (10^{-6} s)	ΔT Pre-Post (10^{-6} s)
14	98.4681	98.5355	+67.4
15	98.0725	98.1307	+58.2
16	98.1500	98.1745	+24.5
17	99.9639	99.9931	+29.2
18	97.8045	97.8524	+47.9
19	99.1500	99.2298	+79.8
20	99.0854	99.1121	+26.7
22	98.1551	98.1890	+33.9
23	97.5003	97.5462	+45.9
24	97.6347	97.6897	+55.0
25	98.1325	98.1562	+23.7
26	98.0951	98.1175	+22.4

$\bar{x}$ = 42.9

σ = 19.15

Specification requirement = ± 250

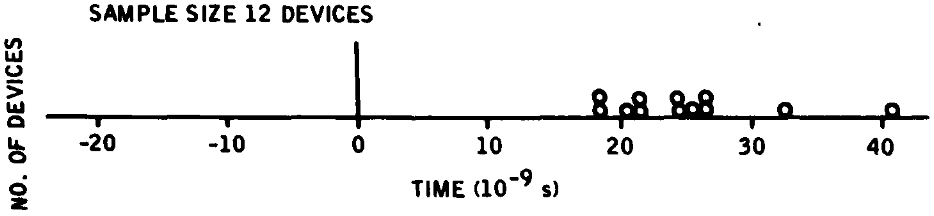


Figure 16. Histogram of period change during moisture-resistance storage testing.

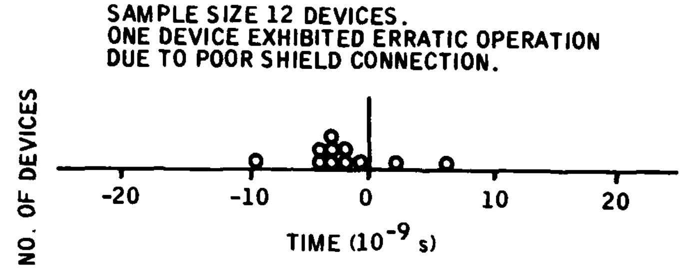


Figure 17. Histogram of period change during constant-acceleration testing.

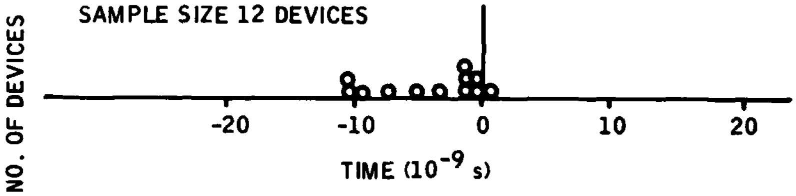


Figure 18. Histogram of period change during temperature cycle testing.

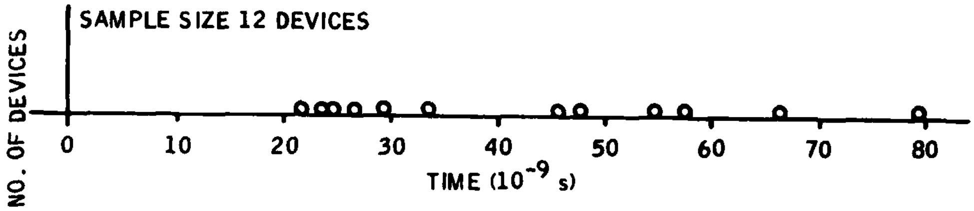


Figure 19. Histogram of period change during high-temperature storage testing.

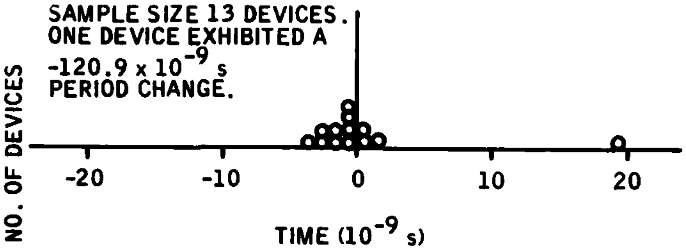


Figure 20. Histogram of period change during 30-kg shock testing.

3.2.3.3 Summary of Yield Information from the Log Book

The yield information recorded through all manufacturing processes which was obtained during the engineering sample build is shown in table XVI. The reasons for yield losses are noted in the remarks column. Twenty-six of 56 TAB HMOs were encapsulated with a plastic case using a conductive paint for shielding. The baseline design uses a metal case. However, a long lead time for delivery of the metal cases did not allow use in the engineering sample build. Fabrication of the 25 engineering samples in plastic cases with a conductive paint for shielding provided valuable information on the electrical characteristic of the tab hmo after incorporation of layout changes in the thick-film substrate. Twenty-five of the 30 remaining TAB HMOs were encapsulated in metal cases prior to the phase III DEG build.

3.2.3.4 Updating the Baseline Design Drawing Package

The monolithic amplifier dwg. 28112362, was revised and is presented as appendix C. A 14-page specification was generated to control the procurement of monolithic amplifiers at the wafer level. The document was discussed with the supplier, Motorola. Motorola was not in full agreement with the sampling plans used for qualification and sample testing on a lot basis. The document, however, was used to purchase the wafers for phase IV of the MM&T program.

3.2.3.5 Updating the Manufacturing Methods Notebook

A specification, "Internal Visual Requirements for Precision Oscillator, for Shock Application," dwg. 11711479, was generated. This specification is presented as appendix D. The document was used for pre-cap visual inspection during DEG build. Visual examination criteria of the inner lead bonds were not finalized in this document. Additional data were obtained at a later date to complete this item meainingfully.

3.2.3.6 Reviewing the Design-to-Cost Analysis

The design-to-cost analysis performed during phase I of the MM&T program revealed labor and material costs of $1.46 and $2.19, respectively. These costs were obtained for the first million TAB HMOs. The labor and material costs remained constant because there were no significant material or process changes. The average cost per device for the third million TAB HMOs was calculated at $3.79. The cost for the third million TAB HMOs was derived using a 92-percent learning curve for material, an 85-percent learning curve for labor, 18.15 percent for G&A expenses, and 15 percent for profit.

3.3 Phase III - Fabrication and Testing of the Development Evaluation Group

3.3.1 Introduction

Phase III of the MM&T study consisted of fabricating 651 TAB HMOs. One-hundred seventy-four of the devices were exposed to the first-article tests per the Oscillator Source Control Drawing, 1172813.

Data were accumulated during fabrication of the TAB HMOs which identified major problem areas resulting in yield loss.

Yield information on the inner-lead bonded amplifier was obtained and major differences between wafer testing and tape testing of the amplifiers were identified.

An electrical problem in the TAB HMOs was discovered during first-article testing. The electrical problem resulted from overtrimming a resistor. A screen was developed and incorporated to remove questionable devices from the lot.

Design-to-cost estimates were reviewed in light of data and minor processes modification.

3.3.2 Summary

Fabrication of the TAB HMOs for the Development and Evaluation Group (DEG) lot during phase III of the MM&T program was divided into two lots. The TAB HMOs were fabricated in two lots because of a shortage of inner lead bonded amplifiers. The shortage resulted from a low yield at tape testing and submission of a large sample to destructive lead-pull strength tests.

Yield information on tape testing the inner-lead bonded amplifiers revealed a sufficient loss due to low gain, marginal high-regulated voltage, and mechanical damage. Differences were noted between wafer testing and tape testing which contributed to the yield loss (i.e., the marginally high-regulated voltage). It was felt that the yield loss due to low gain was mainly caused by limitations of the tape tester. Investigations were instigated to determine the credibility of tape testing.

The yields of the first lot (557 devices) and second lot (437 devices) of the TAB HMOs were 80 and 46 percent, respectively. The major problem areas are summarized in table XXVIII.

One-hundred seventy-four TAB HMOs were submitted to first-article testing per the Oscillator Source Control Drawing, 1172813. Two problems were encountered during the first-article testing.

The first problem was encountered during the 30-kg shock test. Three of the 25 test specimens submitted to the 30-kg shock test failed. One device failed as a result of a broken tin-plated copper lead off the monolithic amplifier. The second TAB HMO failure exhibited an abnormal output signal. This condition is discussed in detail in sect. 3.3.3.5 of this report. The third TAB HMO exhibited a period change of $+48.3 \times 10^{-9}$ s. The maximum specification limit is $\pm 20 \times 10^{-9}$ s.

TABLE XXVI. INNER-LEAD BONDED AMPLIFIER YIELD

Description	Wafer		
	No. 1	No. 2	No. 3
Location of bumping	Honeywell Avionics Div.	Honeywell SSEC[a]	Honeywell SSEC[a]
Passivation	Si_3N_4	-	Si_3N_4
Wafers probed after bumping	No	No	Yes
Devices inner-lead bonded	700	332	731
Devices tape tested for electrical rejects	106	214	112
Devices used for pull strength tests	116	-	-
Mechanical rejects (cocked leads)	-	-	55
Damaged during handling	-	-	18
Devices used to check excising and forming equipment	35	-	19
Total number of electrically good devices	443	118	527
Yield after electrical tests on tape	63%	35%	72%

[a] Solid State Electronics Center, Plymouth, MN.

A second sample of 25 TAB HMOs was submitted to 30-kg shock testing subsequent to constant-acceleration testing. Eight devices from this sample exhibited period drifts greater than the ±20 x 10^{-9} s specification limit. Failure analysis revealed that the failures occurred as a sresult of poor adhesion between the epoxy and metal case. The metal case has a reflowed tin-plated surface. Investigations were instigated to correct this problem.

A third sample of 25 TAB HMOs was also submitted to a constant-acceleration testing. The sample was mounted on printed-circuit boards with a 0.020-inch spacer beneath them. The test specimens were placed in nose cones and encapsulated in epoxy to simulate the end-item use. All the devices met the specified limits.

The second problem encountered was related to the electrical performance of the TAB HMO. Applying the supply voltage to the oscillator with a slow ramp would cause the oscillator output signal period to increase approximately 10 percent and duty cycle to decrease approximately 50 percent. This failure mode resulted from excessive active trimming of R_3 in the twin-T network. A detailed analysis of this problem is contained insect. 3.3.3.5 of this report.

The DEG lot of TAB HMOs was screened to remove the devices which exhibited evidence of overtrimming. Approximately 5 percent of the TAB HMOs exhibited evidence of overtrimming. Investigations were instigated to eliminate this overtrimming problem.

Reviewing the design-to-cost analysis for the third million TAB HMOs revealed a unit cost of $3.69. The estimate is based on material and labor costs of $2.42 and $1.30, respectively, for the first million TAB HMOs. Calculations to estimate the cost of the third million TAB HMOs include an 85-percent learning curve for labor, a 92-percent learning curve for material, 18.15 percent for general and administrative (G&A) expense, and 15 percent for profit.

3.3.3 Detailed Description

3.3.3.1 Yield Information on Inner-Lead Bonded Amplifiers

Yield information of the inner-lead bonded monolithic amplifier is contained in table XXVI. Three wafers were bumped for the DEG lot fabrication of the TAB HMOs. The bumping process was performed by the contractor's St. Petersburg Florida, facility hybrid group and by its Solid State Electronics Center (SSEC) of Plymouth, Minnesota. All future wafer bumping will be performed by SSEC.

A considerable yield loss was experienced during electrical testing of the inner-lead bonded amplifier at the tape level. The yields at tape testing of wafers nos. 1, 2, and 3 were 63, 35, and 72 percent, respectively. Wafers nos. 1 and 2 were not electrically tested at the wafer level subsequent to the bumping process. However, wafer no. 3 was electrically tested at the wafer level subsequent to the bumping process. In the future, all wafers will be electrically tested subsequent to the bumping process.

The yield loss noted for inner-lead bonded amplifiers from wafer no. 1 resulted from the following: (1) 106 devices failed the electrical tests on tape (i.e., excessive ΔV_{reg} between -23.5 and -30 Vdc, excessive phase shift, and low gain). (2) 116 devices were used for amplifier lead-pull strength tests. During the inner-lead bonding process at the contractor's Phoenix, Arizona, facility, pull strength data showed evidence of gold bumps pulling from the silicon die at pull strengths below 20 grams. Subsequent pull strength testing conducted at the contractor's Phoenix, St. Petersburg, and Minneapolis plants used 116 inner-lead bonded amplifiers and verified that the low pull strengths were associated with the mounting technique and placement of the hook used during pull strength testing (i.e., if the hook is placed next to the edge of the die instead of at the midpoint of the lead, the gold bumps with the aluminum metallization and silicon will pull at considerably lower pull strength levels.)

The major portion of the 214 electrical rejects noted during tape testing of wafer no. 2 were attributed to low gain at -23.5 Vdc (i.e., the gain ranged from 36.5 to 36.98 dB, whereas the specification is 37.0 to 38.0 dB). It is felt that a test anomaly was responsible for this large fallout, as the electrical testing at the wafer level exhibited a 39 percent yield. This is a fairly good yield at the wafer level.

Inner-lead bonded amplifiers from wafer no. 3 also exhibited a high fallout during electrical testing at the tape level. Analysis of the electrical data showed a sufficient loss due to low gain and a high-regulated voltage at -23.5 Vdc. The electrical tests performed at the wafer level are not identical to those performed at the tape level.

Table XXVII shows the electrical testing performed at the wafer level versus tape level. The gain testing performed at the wafer level uses a ramp function, whereas at tape testing a 10-kHz sine wave is used. Performance of the gain test at 10 kHz, using either a ramp or sine wave input, should yield the same results, since 10 kHz is considered low frequency for the amplifier circuit. In the past, it has been a problem to obtain accurate measurements of the 10×10^{-3} V_{rms}, 10-kHz sine wave input signal on the tape tester. The tape tester has not been optimized to reduce noise levels which create problems in obtaining accurate measurements of low-level signals. An inaccurate input signal measurement on the tape tester is considered the primary reason for the yield loss due to low gain.

The allowable change in the regulated voltage (V_{reg}) is another difference noted between wafer and tape testing. Wafer testing allows a ±0.4 Vdc change in V_{reg} across the power supply voltage range from -17 to -30 Vdc. The tape

TABLE XXVII. ELECTRICAL WAFER TESTS PERFORMED AT THE WAFER LEVEL AND TAPE LEVEL

Wafer-Level Electrical Test Parameters	Tape-Level Electrical Test Parameters	Difference in Test Technique
Supply current at -30 Vdc	Supply current at -17, -23.5, and -30 Vdc	No. of test voltages
Regulated voltage at -17 Vdc	Regulated voltage at -23.5 Vdc	No. of test voltages
Regulated voltage at -17 to -30 Vdc	ΔRegulated voltage at -17 to -23.5, and -23.5 to -30 Vdc	Test voltages and allowable limits: ΔV_{reg} = 0.400 Vdc Wafer ΔV_{reg} = ± 0.15 Vdc Tape ΔV_{reg} = ± 0.15 Vdc
Voltage gain	Voltage gain	Wafer testing uses a ramp function: tape testing uses a 10-kHz sine wave.
Δ Voltage gain	-	Not performed on tape
-	Phase shift at -17, -23.5, and -30 Vdc	Not performed on wafer
-	Output voltage swing	Not performed on wafer
Output bias voltage	-	Not performed on tape
Threshold voltage	-	Not performed on tape
Input bias current	-	Not performed on tape
Hysteresis	-	Not performed on tape

test was set up to measure the change in V_{reg} between the nominal operating voltage, -23.5 Vdc, and the two extreme voltages, -17 and -30 Vdc. This did not contribute to yield loss.

The supply voltage at which the V_{reg} is initially measured is also different between wafer and tape testing (i.e., -17 Vdc at wafer testing versus -23.5 Vdc at tape testing.) This difference contributed to approximately 25 percent of the electrical rejects of wafer no. 3. The V_{reg} specification at wafer testing is -12.5 to -13.5 Vdc at a supply voltage of -17 Vdc, whereas the V_{reg} specification is -12 to -13.5 Vdc at a supply voltage of -23.5 Vdc. The V_{reg} electrical rejects ranged from 3 to 15 mVdc high. The tape test specification will be modified so that correlation is established for V_{reg} testing. One lot of TAB HMOs will be fabricated using inner-lead bonded amplifiers without tape testing to determine its validity.

3.3.3.2 Fabrication of the TAB HMOs for the Development Evaluation Group

The TAB HMOs for the Development Evaluation Group (DEG) were fabricated in two lots. The first lot consisted of 557 devices. Detailed information regarding the yield through the fabrication processes is contained in table XXVIII. The yield of the first lot was 80 percent. However, 66 of 113 devices which contributed to yield loss resulted from abnormal circumstances unrelated to material and/or process defects (i.e., 20 devices were used for pull strength tests during operation 100; 15 devices were removed for damaged integrated circuits during capacitor mounting, operation 050; 23 devices were overtrimmed due to an operator inadvertently increasing the laser trim bite to achieve a faster trim cycle, operation 120; eight devices were lost due to missing pins on the metal case, operation 165). A yield of 92 percent could have been achieved without these perturbations.

The second lot, which consisted of 436 devices, was fabricated 2 months after the first lot. Detailed information regarding the yield through the fabrication processes is contained in table XXIX. The yield of the second lot was 46 percent. Categorization of the defects resulting in yield

TABLE XXVIII. FABRICATION OF 557 TAB HMOs FOR THE DEG LOG BUILD

Operation No.	Operation Description	In	Out	In	Out	In	Out
010	Burnish	51	51	200	200	306	306
020	Clean	51	51	200	200	306	306
030	Screen solder	51	51	200	200	306	306
040	Attach lead	51	51	200	199	306	306
050 and 065	Mount components - capacitors	51	51	199	196	306	291
060	Mount components - integrated circuits	51	51	196	194	291	291
070	Solder reflow	51	51	194	194	291	291
080	Clean	51	51	194	194	291	291
085	Vacuum bake and cure epoxy	51	51	194	194	291	291
090	Cut leads	51	51	194	194	291	291
100	Test	51	30	194	184	291	282
120	Active trim	30	30	184	163	282	280
130	Perform pre-cap inspection	30	-	163	-	280	-
		Combine three sublots; 473 in - 454 out					
140	Apply conformal coating. Cure 1 hr at room temperature. Cure 2 hr at +200F.	454	454	-	-	-	-
		Split the lot					
140	Encapsulate in epoxy (Hysol ES4128). Cure 16 hours at 200F.	241	241	-	-	213	213
150	Mark	241	241	-	-	213	213
160	Final test	241	239	-	-	213	213
165	Inspect	Split the lot					
		155	147	84	84	213	213
170	Stock	147	-	84	-	213	-

Total 444

TABLE XXIX. FABRICATION OF 437 TAB HMOs FOR THE DEG LOG BUILD

Operation No.	Operation Description	In	Out	In	Out
010	Burnish	437	437	-	-
020	Clean	437	437	-	-
030	Screen solder	437	437	-	-
040	Attach lead	437	437	-	-
050 and 065	Mount components - capacitors	437	437	-	-
060	Mount components - integrated circuits	437	437	-	-
070	Solder reflow	437	437	-	-
080	Clean	437	428	-	-
085	Vacuum bake and cure epoxy	428	428	-	-
090	Cut leads	428	428	-	-
100	Test	428	387	-	-
120	Active trim	387	327	-	-
		Split the lot			
120	Perform pre-cap inspection	244	244	83	23
140	Apply conformal coat	244	244	23	23
140	Encapsulate in epoxy	244	244	23	23
150	Mark	244	244	23	23
160	Final test	244	180	23	23
165	Inspect	180	180	23	19
170	Stock	180	-	19	-
	Total	199			

loss of lot no. 2 is shown in table XXX. The low yield is attributed to four problem areas: (1) 60 devices were overtrimmed; (2) 60 devices failed internal visual inspection; (3) 66 devices failed final electrical testing; (4) 41 devices failed initial electrical tests.

Categorization of the defects resulting in yield loss is shown in table XXX.

The yield loss due to overtrimming can be eliminated by a modification of the present laser trimming program.

The yield loss occurring at internal visual inspection resulted from insufficient epoxy around the perimeter of the integrated circuit and insufficient solder wetting to the tin-plated copper leads at the outer lead bond. It is felt that the 20-mil-thick die was the major cause of these problem areas. The integrated circuits used for future HMO fabrication will be 10 mils thick.

The electrical failures occurring at final electrical testing are summarized as follows:

- Twenty-eight devices did not meet the 12×10^{-9} specification for voltage sensitivity between -17 and -23.5 Vdc. However, the devices did meet a 15×10^{-9} specification. These devices were considered acceptable and placed back in the lot. A specification change is being considered to increase the specification limit to 25×10^{-9} s.

- Thirteen devices failed due to a missing ground pin on the metal case. The vendor was informed that the leads are inadequately welded to the metal case. The lead attachment to the metal case is being reenforced by also soldering the lead to the metal case.

- Twelve devices failed electrically with the output latched up to $-V_{reg}$.

- The remainder of the electrical failures (25) resulted from the following causes: voltage sensitivity 15×10^{-9} s (8); period 107 μs (5); period <96 μs (4); high supply current (6); and improper placement of the substrate in the metal case (2).

TABLE XXX. CATEGORIZATION OF DEFECTIVE TAB HMOs WHICH CONTRIBUTED TO YIELD LOSS

Operation No.	Operation Description	First Build (Started 557)	Total Lost	Second Build (Started 437)	Total Lost
040	Attach lead	-	1	-	0
050	Mount components - capacitors	ICs were damaged	3 15	-	0
060	Mount components - integrated circuits	-	2	-	0
080	Clean	-	0	-	9
100	Electrical test	Pulled for pull strength tests	20	Electrically defective	41
		Missing cap	1	-	-
		Electrically defective	19	-	-
120	Active trim	Overtrimmed, bite size too large	23	Overtrimmed	60
130	Perform pre-cap inspection	-	19	Leads out of solder; thick die	60
160	Perform final electrical test	-	2	-	64
165	Perform final inspection	-	8	-	4
		Total	113		238

It is felt that modification of the laser trimming program, use of a 10-mil-thick integrated circuit, a voltage sensitivity specification change to 25 x 10^{-9} s, and adding solder to increase the bond strength between the pin and the metal case will result in a yield greater than 90 percent.

3.3.3.3 Results of First-Article Test

First-article test results are summarized in appendix E. One hundred fifty-eight TAB HMOs were exposed to electrical testing at -50, -30, 0, 25, 45, and 71C. Results of the temperature testing are summarized in table XXXI.

TABLE XXXI. RESULTS OF FIRST-ARTICLE TEMPERATURE TESTING

Temperature Range (C)	Range (10^{-9} s)	Specification Limits (10^{-9} s)	$\bar{x}$	σ
25 to 45	37.8 to - 25.8	±150	6.5	9.3
25 to 71	74.50 to - 65.7	±350	3.57	20.41
25 to 0	130.4 to - 67.9	±190	-20.47	18.75
25 to -30	115.1 to -162.9	±410	-51.99	34.40
25 to -50	114.6 to -240.8	±580	-71.94	53.17

Figs. 21 through 25 are histograms displaying the period changes with temperature.

Two devices, S/N 128 and S/N 151, failed at -50C temperature testing. Device S/N 128 latched up at approximately -21 V and pulled excessive current. Device S/N 128 functioned properly at room temperature. However, after decapsulation, electrical measurements revealed a defective integrated circuit.

```
 156 ITEMS

    MEAN =     .00650
ST. DEV. =     .00930

COEFFICIENT OF SKEWNESS =     .38499

XBAR + 1 SIGMA          .0158          XBAR - 1 SIGMA          -.0028
XBAR + 2 SIGMA          .0251          XBAR - 2 SIGMA          -.0121
XBAR + 3 SIGMA          .0344          XBAR - 3 SIGMA          -.0214

      -.02580    -.00060     .00420     .00860     .01430
      -.01220    -.00050     .00420     .00880     .01430
      -.00930    -.00030     .00440     .00880     .01440
      -.00870     .00000     .00450     .00880     .01440
      -.00830     .00020     .00450     .00890     .01500
      -.00800     .00060     .00480     .00900     .01520
      -.00780     .00070     .00500     .00910     .01530
      -.00680     .00100     .00540     .00920     .01570
      -.00670     .00110     .00560     .00920     .01610
      -.00650     .00130     .00560     .00930     .01640
      -.00650     .00140     .00560     .00930     .01670
      -.00640     .00160     .00590     .00940     .01870
      -.00570     .00160     .00600     .00960     .01970
      -.00550     .00190     .00610     .00970     .01990
      -.00520     .00190     .00610     .00980     .02000
      -.00520     .00190     .00620     .01010     .02060
      -.00460     .00220     .00640     .01030     .02160
      -.00460     .00240     .00640     .01030     .02240
      -.00450     .00250     .00650     .01040     .02320
      -.00300     .00280     .00690     .01060     .02470
      -.00280     .00290     .00700     .01070     .02490
      -.00270     .00290     .00710     .01090     .02510
      -.00260     .00300     .00740     .01100     .02570
      -.00200     .00310     .00750     .01130     .02580
      -.00190     .00310     .00770     .01140     .02700
      -.00180     .00310     .00780     .01170     .02850
      -.00170     .00320     .00800     .01170     .03410
      -.00160     .00330     .00810     .01170     .03790
      -.00120     .00370     .00820     .01220
      -.00110     .00370     .00820     .01270
      -.00110     .00380     .00820     .01290
      -.00060     .00400     .00840     .01390

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-.03
DEFINE UPPER GRAPH LIMIT !.0379


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    -.0200 -     -.0100    1  X
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     .0000 -      .0100   76  XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
XXXXXXXXXXXXXXXXXXXXXXXX
     .0100 -      .0200   31  XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
     .0200 -      .0300   12  XXXXXXXXXXXX
     .0300 -      .0400    2  XX

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    0 VALUE(S) ABOVE UPPER LIMIT
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Figure 21. Data and histogram of period change from
25 to 45C.

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 156 ITEMS

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ST. DEV. =    .02041

COEFFICIENT OF SKEWNESS =     .43942

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XBAR + 2 SIGMA        .0444          XBAR - 2 SIGMA        -.0372
XBAR + 3 SIGMA        .0648          XBAR - 3 SIGMA        -.0576

     -.06570     -.01190     -.00190      .00680      .02010
     -.04410     -.01150     -.00140      .00700      .02160
     -.03400     -.01150     -.00080      .00740      .02210
     -.02970     -.00990      .00010      .00760      .02230
     -.02570     -.00980      .00030      .00780      .02240
     -.02560     -.00880      .00060      .00790      .02240
     -.02450     -.00880      .00090      .00800      .02600
     -.02440     -.00870      .00110      .00820      .02680
     -.02430     -.00850      .00130      .00830      .02750
     -.02420     -.00810      .00130      .00890      .02800
     -.02330     -.00800      .00150      .00900      .03070
     -.02300     -.00790      .00150      .00940      .03110
     -.02300     -.00770      .00190      .01020      .03220
     -.02240     -.00680      .00250      .01030      .03290
     -.02020     -.00670      .00260      .01040      .03510
     -.01940     -.00610      .00300      .01040      .03570
     -.01910     -.00600      .00300      .01070      .03700
     -.01900     -.00570      .00300      .01080      .03720
     -.01860     -.00540      .00330      .01090      .04080
     -.01620     -.00530      .00330      .01100      .04400
     -.01590     -.00530      .00350      .01190      .04430
     -.01580     -.00520      .00350      .01190      .04480
     -.01580     -.00520      .00360      .01200      .04550
     -.01520     -.00500      .00370      .01300      .04760
     -.01500     -.00400      .00410      .01440      .04790
     -.01440     -.00380      .00410      .01720      .04970
     -.01410     -.00340      .00440      .01720      .06140
     -.01400     -.00330      .00460      .01730      .07450
     -.01400     -.00260      .00480      .01730
     -.01360     -.00240      .00580      .01840
     -.01320     -.00210      .00590      .01970
     -.01260     -.00190      .00660      .01980

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DEFINE UPPER GRAPH LIMIT !.0745


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    -.0500 -     -.0400    1  X
    -.0400 -     -.0300    1  X
    -.0300 -     -.0200   12  XXXXXXXXXXXX
    -.0200 -     -.0100   20  XXXXXXXXXXXXXXXXXXXX
    -.0100 -     -.0000   32  XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
     .0000 -      .0100   41  XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
     .0100 -      .0200   20  XXXXXXXXXXXXXXXXXXXX
     .0200 -      .0300   10  XXXXXXXXXX
     .0300 -      .0400    8  XXXXXXXX
     .0400 -      .0500    8  XXXXXXXX
     .0500 -      .0600    0
     .0600 -      .0700    1  X
     .0700 -      .0800    1  X

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    0 VALUE(S) ABOVE UPPER LIMIT
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Figure 22. Data and histogram of period change from 25 to 71C.

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 156 ITEMS

    MEAN =    -.02047
ST. DEV. =     .01875

COEFFICIENT OF SKEWNESS =   3.07360

XBAR + 1 SIGMA        -.0017           XBAR - 1 SIGMA       -.0392
XBAR + 2 SIGMA         .0170           XBAR - 2 SIGMA       -.0580
XBAR + 3 SIGMA         .0358           XBAR - 3 SIGMA       -.0767

      -.06790     -.03050     -.02330     -.01630     -.00850
      -.05970     -.03050     -.02330     -.01630     -.00820
      -.05870     -.02990     -.02320     -.01600     -.00820
      -.05630     -.02920     -.02270     -.01590     -.00790
      -.05350     -.02850     -.02230     -.01580     -.00790
      -.05280     -.02800     -.02200     -.01580     -.00790
      -.05250     -.02750     -.02200     -.01570     -.00770
      -.04930     -.02740     -.02160     -.01550     -.00710
      -.04800     -.02720     -.02140     -.01490     -.00680
      -.04650     -.02670     -.02100     -.01470     -.00620
      -.04240     -.02670     -.02030     -.01460     -.00600
      -.04090     -.02670     -.02020     -.01410     -.00600
      -.04080     -.02650     -.01970     -.01390     -.00590
      -.04070     -.02640     -.01960     -.01280     -.00580
      -.04060     -.02590     -.01950     -.01260     -.00520
      -.04050     -.02590     -.01940     -.01240     -.00420
      -.04030     -.02590     -.01920     -.01170     -.00390
      -.03980     -.02560     -.01910     -.01160     -.00260
      -.03970     -.02540     -.01890     -.01160     -.00130
      -.03960     -.02530     -.01890     -.01130     -.00070
      -.03890     -.02530     -.01880     -.01120     -.00020
      -.03810     -.02510     -.01880     -.01100     -.00010
      -.03780     -.02490     -.01880     -.01080      .00040
      -.03680     -.02490     -.01870     -.01040      .00240
      -.03630     -.02490     -.01830     -.01030      .00580
      -.03470     -.02480     -.01830     -.00990      .00730
      -.03460     -.02470     -.01830     -.00980      .02500
      -.03370     -.02430     -.01790     -.00980      .13040
      -.03370     -.02390     -.01760     -.00960
      -.03230     -.02340     -.01750     -.00920
      -.03200     -.02330     -.01740     -.00880
      -.03050     -.02330     -.01730     -.00880
DEFINE GRAPH INTERVAL     !
.01
DEFINE LOWER GRAPH LIMIT !-.07
DEFINE UPPER GRAPH LIMIT !.1304

     -.0700 -     -.0600    1  X
     -.0600 -     -.0500    6  XXXXXX
     -.0500 -     -.0400   10  XXXXXXXXXX
     -.0400 -     -.0300   17  XXXXXXXXXXXXXXXXX
     -.0300 -     -.0200   42  XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
     -.0200 -     -.0100   45  XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
     -.0100 -     -.0000   29  XXXXXXXXXXXXXXXXXXXXXXXXXXXXX
      .0000 -      .0100    4  XXXX
      .0100 -      .0200    0
      .0200 -      .0300    1  X
      .0300 -      .0400    0
      .0400 -      .0500    0
      .0500 -      .0600    0
      .0600 -      .0700    0
      .0700 -      .0800    0
      .0800 -      .0900    0
      .0900 -      .1000    0
      .1000 -      .1100    0
      .1100 -      .1200    0
      .1200 -      .1300    0
      .1300 -      .1400    1  X

     0 VALUE(S) BELOW LOWER LIMIT
     0 VALUE(S) ABOVE UPPER LIMIT
```

Figure 23. Data and histogram of period change
from 25 to 0C.

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```
 156 ITEMS

    MEAN =   -.05199
ST. DEV. =    .03440

COEFFICIENT OF SKEWNESS =    .36545

XBAR + 1 SIGMA       -.0176          XBAR - 1 SIGMA       -.0864
XBAR + 2 SIGMA        .0168          XBAR - 2 SIGMA       -.1208
XBAR + 3 SIGMA        .0512          XBAR - 3 SIGMA       -.1552

     -.16290     -.07360     -.05690     -.04230     -.02370
     -.13630     -.07330     -.05680     -.04220     -.02360
     -.13230     -.07290     -.05620     -.04190     -.02250
     -.12890     -.07200     -.05610     -.04130     -.02140
     -.12570     -.07170     -.05550     -.04100     -.02130
     -.11740     -.07150     -.05500     -.04090     -.02120
     -.11580     -.07040     -.05480     -.04040     -.02110
     -.10870     -.06980     -.05460     -.04000     -.01980
     -.10700     -.06870     -.05450     -.03950     -.01970
     -.10690     -.06860     -.05420     -.03770     -.01880
     -.10410     -.06840     -.05390     -.03680     -.01780
     -.10310     -.06810     -.05330     -.03590     -.01720
     -.10130     -.06670     -.05270     -.03570     -.01500
     -.09430     -.06650     -.05180     -.03570     -.01490
     -.09420     -.06600     -.05170     -.03460     -.01400
     -.09100     -.06580     -.04990     -.03320     -.01390
     -.09070     -.06480     -.04980     -.03200     -.01200
     -.09040     -.06460     -.04920     -.03130     -.01100
     -.08930     -.06420     -.04890     -.03110     -.00920
     -.08880     -.06420     -.04860     -.03100     -.00780
     -.08850     -.06400     -.04750     -.03080     -.00720
     -.08750     -.06390     -.04750     -.03050     -.00690
     -.08620     -.06350     -.04720     -.02990     -.00610
     -.08400     -.06290     -.04720     -.02980      .00280
     -.08080     -.06200     -.04690     -.02870      .00400
     -.07890     -.06200     -.04510     -.02840      .01090
     -.07880     -.06180     -.04390     -.02810      .05220
     -.07770     -.06020     -.04340     -.02730      .11510
     -.07770     -.05910     -.04320     -.02560
     -.07540     -.05890     -.04240     -.02510
     -.07430     -.05800     -.04240     -.02470
     -.07360     -.05760     -.04240     -.02410

DEFINE GRAPH INTERVAL     !.01
DEFINE LOWER GRAPH LIMIT !-.17
DEFINE UPPER GRAPH LIMIT !.1151


     -.1700 -     -.1600    1  ::
     -.1600 -     -.1500    0
     -.1500 -     -.1400    0
     -.1400 -     -.1300    2  ::::
     -.1300 -     -.1200    2  ::::
     -.1200 -     -.1100    2  ::::
     -.1100 -     -.1000    6  ::::::::::::
     -.1000 -     -.0900    5  ::::::::::
     -.0900 -     -.0800    7  ::::::::::::::
     -.0800 -     -.0700   14  ::::::::::::::::::::::::::::
     -.0700 -     -.0600   21  ::::::::::::::::::::::::::::::::::::::::::
     -.0600 -     -.0500   19  ::::::::::::::::::::::::::::::::::::::
     -.0500 -     -.0400   24  ::::::::::::::::::::::::::::::::::::::::::::::::
     -.0400 -     -.0300   15  ::::::::::::::::::::::::::::::
     -.0300 -     -.0200   17  ::::::::::::::::::::::::::::::::::
     -.0200 -     -.0100   11  ::::::::::::::::::::::
     -.0100 -     -.0000    5  ::::::::::
      .0000 -      .0100    2  ::::
      .0100 -      .0200    1  ::
      .0200 -      .0300    0
      .0300 -      .0400    0
      .0400 -      .0500    0
      .0500 -      .0600    1  ::
      .0600 -      .0700    0
      .0700 -      .0800    0
      .0800 -      .0900    0
      .0900 -      .1000    0
      .1000 -      .1100    0
      .1100 -      .1200    1  ::

     0 VALUE(S) BELOW LOWER LIMIT
     0 VALUE(S) ABOVE UPPER LIMIT
```

Figure 24. Data and histogram of period change from 25 to -30C.

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```
 156 ITEMS                      COEFFICIENT OF SKEWNESS =     .59900

    MEAN =    -.07194           XBAR + 1 SIGMA       -.0188          XBAR - 1 SIGMA        -.1251
ST. DEV. =     .05317           XBAR + 2 SIGMA        .0344          XBAR - 2 SIGMA        -.1783
                                XBAR + 3 SIGMA        .0876          XBAR - 3 SIGMA        -.2314

                                     -.24080    -.10560    -.08240    -.06030    -.03580
                                     -.19660    -.10540    -.08100    -.05890    -.03420
                                     -.18410    -.10340    -.07970    -.05840    -.03350
                                     -.18320    -.10310    -.07940    -.05830    -.03310
                                     -.18240    -.10300    -.07740    -.05690    -.03270
                                     -.16990    -.10200    -.07700    -.05690    -.03090
                                     -.15830    -.10130    -.07590    -.05690    -.03020
                                     -.14950    -.10070    -.07580    -.05460    -.02970
                                     -.14690    -.10070    -.07570    -.05420    -.02790
                                     -.14620    -.10050    -.07450    -.05380    -.02760
                                     -.14570    -.10030    -.07350    -.05220    -.02620
                                     -.14550    -.09830    -.07280    -.04960    -.02370
                                     -.14200    -.09750    -.07220    -.04800    -.02330
                                     -.13900    -.09450    -.07130    -.04790    -.02240
                                     -.13780    -.09400    -.07090    -.04720    -.01960
                                     -.13530    -.09390    -.06900    -.04620     .01610
                                     -.13330    -.09350    -.06800    -.04590    -.01340
                                     -.13320    -.09250    -.06790    -.04500    -.01240
                                     -.13130    -.09080    -.06790    -.04390    -.01240
                                     -.12730    -.09060    -.06750    -.04370    -.01000
                                     -.12390    -.09050    -.06710    -.04340    -.00080
                                     -.12180    -.08980    -.06690    -.04300     .00290
                                     -.12130    -.08910    -.06670    -.04270     .02420
                                     -.12040    -.08910    -.06490    -.04130     .06990
                                     -.11770    -.08670    -.06440    -.04040     .10760
                                     -.11560    -.08610    -.06390    -.03950     .10990
                                     -.11390    -.08570    -.06250    -.03870     .11100
                                     -.11270    -.08450    -.06240    -.03870     .11460
                                     -.11180    -.08420    -.06240    -.03770
                                     -.11020    -.08350    -.06170    -.03750
                                     -.10840    -.08260    -.06120    -.03720
                                     -.10640    -.08260    -.06070    -.03610

                                DEFINE GRAPH INTERVAL     !.01
                                DEFINE LOWER GRAPH LIMIT !-.25
                                DEFINE UPPER GRAPH LIMIT !.1146

                                    -.2500 -     -.2400    1  X
                                    -.2400 -     -.2300    0
                                    -.2300 -     -.2200    0
                                    -.2200 -     -.2100    0
                                    -.2100 -     -.2000    0
                                    -.2000 -     -.1900    1  X
                                    -.1900 -      .1800    3  XXX
                                    -.1800 -     -.1700    0
                                    -.1700 -     -.1600    1  X
                                    -.1600 -     -.1500    1  X
                                    -.1500 -     -.1400    6  XXXXXX
                                    -.1400 -     -.1300    6  XXXXXX
                                    -.1300 -     -.1200    5  XXXXX
                                    -.1200 -      .1100    6  XXXXXX
                                    -.1100 -     -.1000   13  XXXXXXXXXXXXX
                                    -.1000 -     -.0900   10  XXXXXXXXXX
                                    -.0900 -     -.0800   13  XXXXXXXXXXXXX
                                    -.0800 -     -.0700   13  XXXXXXXXXXXXX
                                    -.0700 -     -.0600   18  XXXXXXXXXXXXXXXXXX
                                    -.0600 -     -.0500   10  XXXXXXXXXX
                                    -.0500 -     -.0400   14  XXXXXXXXXXXXXX
                                    -.0400 -     -.0300   14  XXXXXXXXXXXXXX
                                    -.0300 -     -.0200    7  XXXXXXX
                                    -.0200 -     -.0100    5  XXXXX
                                    -.0100 -     -.0000    2  XX
                                    -.0000 -      .0100    1  X
                                     .0100 -      .0200    0
                                     .0200 -      .0300    1  X
                                     .0300 -      .0400    0
                                     .0400 -      .0500    0
                                     .0500 -      .0600    0
                                     .0600 -      .0700    1  X
                                     .0700 -      .0800    0
                                     .0800 -      .0900    0
                                     .0900        .1000    0
                                     .1000 -      .1100    2  XX
                                     .1100 -      .1200    2  XX

                                    0 VALUE :   BELOW LOWER LIMIT
                                    0 VALUE :   ABOVE UPPER LIMIT
```

Figure 25. Data and histogram of period change from 25 to -50C.

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Electrical measurements of device S/N 151 at -50C exhibited an abnormal output initially (i.e., the period was approximately 170 x 10^{-6} s and the duty cycle was 20 percent). However, after a short time, the oscillator functioned properly and would not exhibit the abnormal output. Subsequent electrical testing, in which the supply voltage was applied at a slower rate (30 to 50 ms), reproduced the abnormal output condition. This problem is discussed in detail in sect. 3.3.3.5 of this report.

Voltage sensitivity testing was performed on the 158 TAB HMOs at 25C. Figs.26 and 27 are histograms displaying the period changes while varying the supply voltage between -23.5 and -17.0 Vdc and -23.5 and -30.0 Vdc, respectively. A specification change is being considered to increase the allowable period change to ±25 x 10^{-9} s. This specification change is necessary, as the period change, when varying the supply voltage between -23.5 and -17.0 Vdc, is at the upper end of the specification limit (i.e., $x = 10.7$ and $\sigma = 2.07$). A considerable yield loss would be incurred with the present specification of ±12 x 10^{-9} s.

Twenty-five TAB HMOs were exposed to temperature-cycle testing. The period changes were well within the ±250 x 10^{-9}s specification requirements. Fig. 28 is a histogram displaying the period changes noted during the temperature-cycle testing.

Twenty-five TAB HMOs were exposed to 30-kg shock testing. Three devices (S/N's 90, 95, and 96) failed the ±20 x 10^{-9}s drift requirement. Device S/N 90 failed due to an abnormal output waveform. The period increased to 198.74 x 10^{-6} s and the duty cycle was approximately 20 percent. Detailed analysis is contained in sect. 3.3.3.5. Device S/N 95 failed due to a broken tin-plated copper lead on the integrated circuit. The lead break occurred near the bump on the integrated circuit. Five other leads were also badly deformed on the integrated circuit. It appears that the lead damage resulted from improper handling during the manufacturing process. It is interesting to note that this device was marked with red ink, indicating that it did not meet the epoxy die bonding criteria. This means that the device was visually examined by at least three people. Sixteen TAB

```
 158 ITEMS

    MEAN =     .01070
ST. DEV. =     .00207

COEFFICIENT OF SKEWNESS =     .90112

XBAR + 1 SIGMA         .0128          XBAR - 1 SIGMA         .0086
XBAR + 2 SIGMA         .0148          XBAR - 2 SIGMA         .0066
XBAR + 3 SIGMA         .0169          XBAR - 3 SIGMA         .0045

      .00340     .00930     .01000     .01090     .01200
      .00700     .00940     .01000     .01100     .01200
      .00740     .00940     .01010     .01100     .01200
      .00750     .00940     .01010     .01110     .01210
      .00750     .00940     .01010     .01110     .01220
      .00750     .00940     .01010     .01110     .01230
      .00790     .00950     .01010     .01110     .01230
      .00800     .00950     .01020     .01110     .01230
      .00810     .00950     .01020     .01110     .01240
      .00810     .00950     .01020     .01120     .01250
      .00810     .00950     .01020     .01130     .01270
      .00820     .00950     .01020     .01130     .01270
      .00850     .00960     .01020     .01130     .01270
      .00860     .00960     .01030     .01130     .01270
      .00860     .00960     .01030     .01130     .01310
      .00870     .00960     .01040     .01140     .01350
      .00880     .00970     .01040     .01140     .01360
      .00880     .00970     .01040     .01140     .01380
      .00880     .00970     .01050     .01150     .01390
      .00890     .00970     .01050     .01150     .01410
      .00890     .00970     .01050     .01150     .01410
      .00890     .00970     .01050     .01150     .01470
      .00900     .00970     .01060     .01150     .01500
      .00900     .00980     .01070     .01160     .01500
      .00900     .00980     .01070     .01160     .01590
      .00910     .00980     .01080     .01160     .01650
      .00910     .00990     .01080     .01170     .01660
      .00910     .00990     .01090     .01170     .01700
      .00920     .00990     .01090     .01180     .01760
      .00930     .00990     .01090     .01180     .01840
      .00930     .00990     .01090     .01190
      .00930     .01000     .01090     .01200

DEFINE GRAPH INTERVAL    '.001
DEFINE LOWER GRAPH LIMIT '.003
DEFINE UPPER GRAPH LIMIT '.0184

     .0030 -     .0040    1  X
     .0040 -     .0050    0
     .0050 -     .0060    0
     .0060 -     .0070    1  X
     .0070 -     .0080    6  XXXXXX
     .0080 -     .0090   17  XXXXXXXXXXXXXXXXX
     .0090 -     .0100   41  XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
     .0100 -     .0110   33  XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
     .0110 -     .0120   30  XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
     .0120 -     .0130   13  XXXXXXXXXXXXX
     .0130 -     .0140    5  XXXXX
     .0140 -     .0150    5  XXXXX
     .0150 -     .0160    1  X
     .0160 -     .0170    2  XX
     .0170 -     .0180    2  XX
     .0180 -     .0190    1  X
```

Figure 26. Data and histogram of voltage sensitivity testing: -23.5 to -17 Vdc.

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```
 158 ITEMS

    MEAN =    -.00537
ST. DEV. =     .00099

COEFFICIENT OF SKEWNESS =     .41324

XBAR + 1 SIGMA        -.0044          XBAR - 1 SIGMA        -.0064
XBAR + 2 SIGMA        -.0034          XBAR - 2 SIGMA        -.0074
XBAR + 3 SIGMA        -.0024          XBAR - 3 SIGMA        -.0083

       -.00820     -.00620     -.00540     -.00500     -.00470
       -.00800     -.00620     -.00540     -.00500     -.00460
       -.00790     -.00620     -.00530     -.00500     -.00460
       -.00730     -.00610     -.00530     -.00500     -.00460
       -.00720     -.00610     -.00530     -.00500     -.00450
       -.00720     -.00610     -.00530     -.00490     -.00450
       -.00710     -.00610     -.00530     -.00490     -.00450
       -.00700     -.00600     -.00530     -.00490     -.00450
       -.00690     -.00600     -.00520     -.00490     -.00450
       -.00690     -.00600     -.00520     -.00490     -.00450
       -.00680     -.00600     -.00520     -.00490     -.00450
       -.00680     -.00600     -.00520     -.00480     -.00450
       -.00680     -.00590     -.00520     -.00480     -.00450
       -.00680     -.00590     -.00520     -.00480     -.00450
       -.00680     -.00590     -.00520     -.00480     -.00450
       -.00670     -.00580     -.00520     -.00480     -.00440
       -.00670     -.00580     -.00510     -.00480     -.00440
       -.00670     -.00580     -.00510     -.00480     -.00440
       -.00650     -.00580     -.00510     -.00480     -.00440
       -.00650     -.00570     -.00510     -.00480     -.00430
       -.00640     -.00570     -.00510     -.00470     -.00430
       -.00640     -.00570     -.00510     -.00470     -.00430
       -.00640     -.00570     -.00500     -.00470     -.00420
       -.00640     -.00570     -.00500     -.00470     -.00420
       -.00640     -.00570     -.00500     -.00470     -.00420
       -.00640     -.00570     -.00500     -.00470     -.00410
       -.00640     -.00560     -.00500     -.00470     -.00400
       -.00630     -.00560     -.00500     -.00470     -.00380
       -.00630     -.00550     -.00500     -.00470     -.00290
       -.00630     -.00550     -.00500     -.00470     -.00010
       -.00620     -.00550     -.00500     -.00470
       -.00620     -.00550     -.00500     -.00470

DEFINE GRAPH INTERVAL      '.0005
DEFINE LOWER GRAPH LIMIT '-.0085
DEFINE UPPER GRAPH LIMIT '-.00011+

   -.0085 -     -.0080    1  X
   -.0080 -     -.0075    2  XX
   -.0075 -     -.0070    4  XXXX
   -.0070 -     -.0065   11  XXXXXXXXXXX
   -.0065 -     -.0060   21  XXXXXXXXXXXXXXXXXXXXX
   -.0060 -     -.0055   21  XXXXXXXXXXXXXXXXXXXXX
   -.0055 -     -.0050   26  XXXXXXXXXXXXXXXXXXXXXXXXXX
   -.0050 -     -.0045   46  XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
   -.0045 -     -.0040   22  XXXXXXXXXXXXXXXXXXXXXX
   -.0040 -     -.0035    2  XX
   -.0035 -     -.0030    0
   -.0030 -     -.0025    1  X
   -.0025 -     -.0020    0
   -.0020 -     -.0015    0
   -.0015 -     -.0010    0
   -.0010 -     -.0005    0
   -.0005 -     -.0000    1  X
```

Figure 27. Data and histogram of voltage sensitivity testing: -23.5 to -30 Vdc.

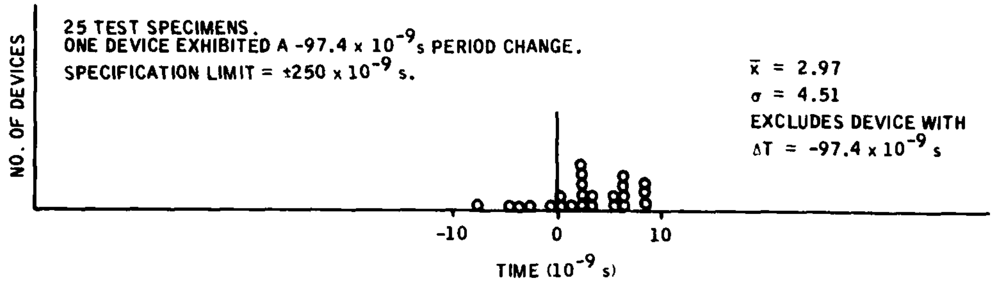

Figure 28. Histogram of period change during temperature-cycle testing: specification limit = ±250 x 10^{-9} s.

HMOs, which were electrically defective, were decapsulated and examined for lead deformation. No evidence of lead deformation was noted.

Device S/N 96 exhibited a period drift of +48.3 x 10^{-9} s. Two hours later, after removal from the brown sugar, the period drift was 2.1 x 10^{-9} s. Twenty days later, the period drift was -4.4 x 10^{-9} s. Additional testing (application of the supply voltage exponentially with τ = 0.968 s) revealed that this failure was not related to the abnormal output waveform. The excessive period drift of S/N 96 could be due to a test error. Fig. 29 is a histogram displaying period changes during 30-kg shock testing.

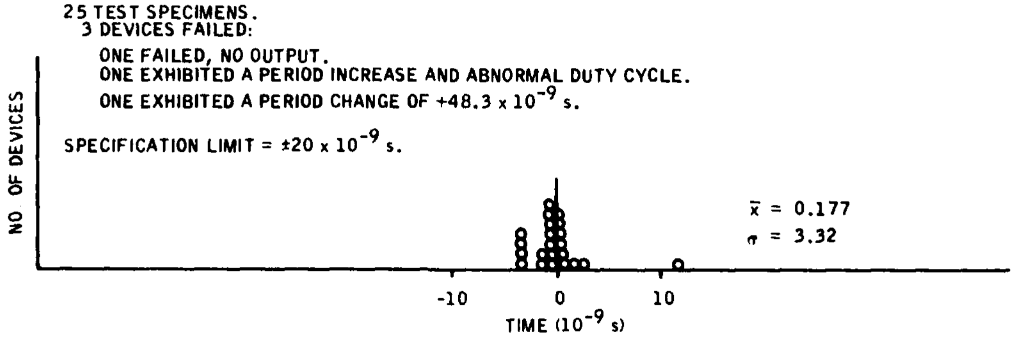

Figure 29. Histogram of period change during 30-kg shock testing: first sample.

A second sample of 25 TAB HMOs, which had previously been exposed to constant-acceleration tests, was exposed to 30-kg shock testing. Eight of the 25 test specimens exhibited period drifts greater than the 20 x 10^{-9} s specification limit. Fig. 30 is a histogram displaying the period drifts noted during the 30-kg shock test. Failure analysis revealed the period shifts were due to insufficient adhesion of the epoxy to the tin-plated metal case. The metal case had a reflow tin plate.

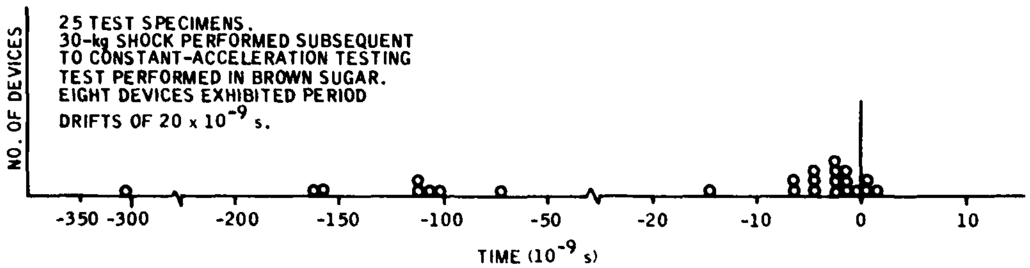

Figure 30. Histogram of period change during 30-kg testing: second sample.

A third sample of 25 TAB HMOs was pulled from the lot and exposed to 30-kg shock testing. The 30-kg shock testing on the TAB HMOs was performed subsequent to a constant-acceleration testing performance at 12,500 g. The 25 TAB HMOs met the 20 x 10^{-9} s specification limits. Fig. 31 is a histogram displying the period drift during shock testing. This sample was mounted on printed-circuit boards and encapsulated with epoxy in nose cones. The TAB HMOs were held off the printed-circuit board with a 0.020-in. spacer. This allowed the epoxy to completely surround the test specimens on the printed-circuit boards. It is felt that this encapsulating technique for shock testing simulates the end-item use more closely. The first and second shock tests were performed by supporting the TAB HMO test specimens in brown sugar. Further investigations are being performed to improve the adhesion of the epoxy to the tin-plated metal case.

Twenty-five TAB HMOs were exposed to constant-acceleration testing by HDL. One device exhibited a period change greater than the ±40 x 10^{-9} s specification limit. The

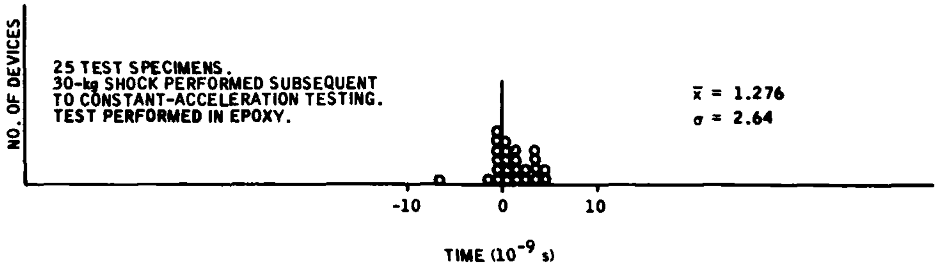

Figure 31. Histogram of period change during 30-kg shock testing: third sample.

period change occurred during the 350-RPS test. Device S/N 27B exhibited a -99 x 10^{-9} s period drift during the spin test. Additional testing revealed the following: (1) retesting immediately showed a -193 x 10^{-9} s drift, (2) retesting after testing 22 other devices showed period drift of -1.3 x 10^{-9} s, (3) retesting after several hours showed a -1.5 x 10^{-9} s drift. Failure analysis was not performed on this device. Fig. 32 is a histogram displaying the period drift during the constant-acceleration testing.

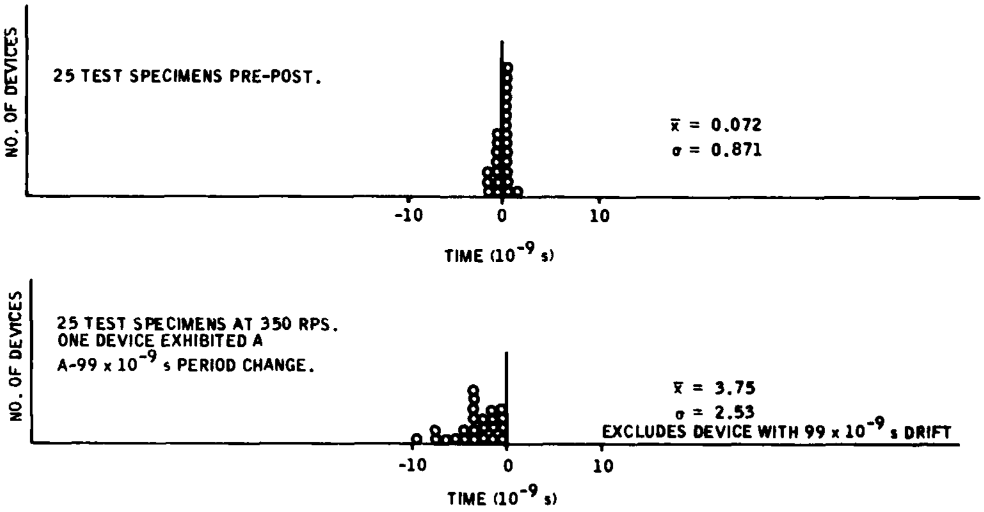

Figure 32. Histogram of period change during constant-acceleration testing.

Twenty-five TAB HMOs were exposed to high-temperature storage testing. The period changes were within the ±250 x 10^{-9} s specification requirement. Fig. 33 is a histogram displaying the period drift noted during high-temperature storage testing.

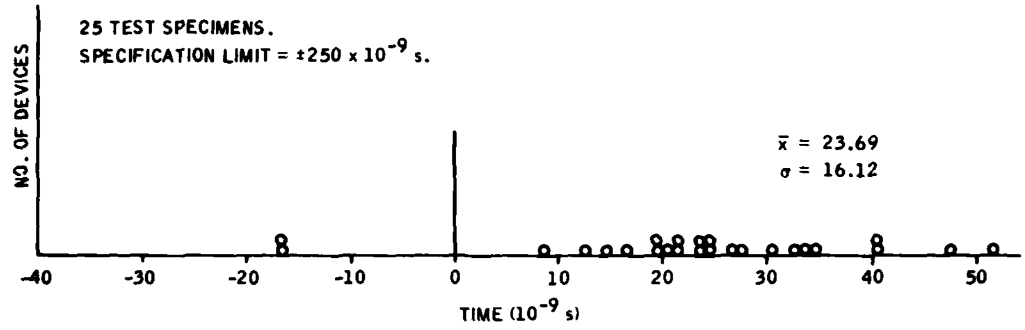

Figure 33. Histogram of period change during high-temperature storage testing.

Twenty-five TAB HMOs were exposed to moisture-resistance testing per MIL-STD-883, Method 1004-2. The test is not a specification requirement. However, it is being considered for incorporation in the Oscillator Source Control Drawing. Fig. 34 is a histogram displaying the period drift noted during the moisture-resistance testing.

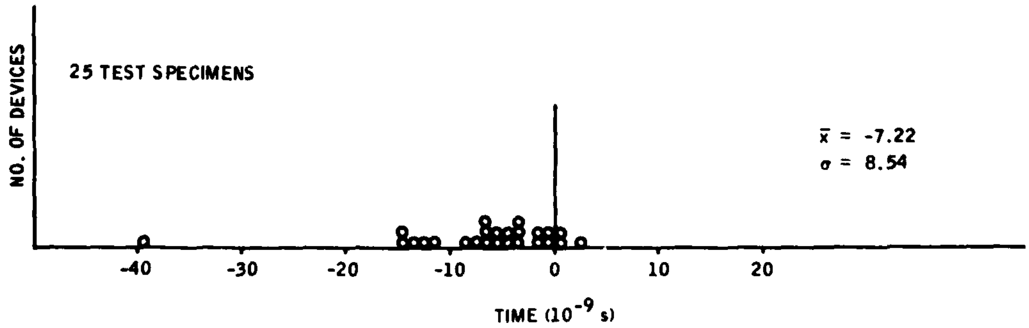

Figure 34. Histogram of period change during moisture-resistance testing.

3.3.3.4 Analysis of the Abnormal TAB HMO Output Signal as a Function of the Power Supply Voltage Rise Time

1. Electrical testing of the TAB HMO was initally using test equipment where the supply voltage has been applied in a few microseconds or less. However, recently when 25 TAB HMOs were sent to HDL for constant-acceleration testing, it was noted that application of the supply voltage with a slower rise time (i.e., 30 to 50 ms) resulted in an abnormal output signal. The period was greater and the duty cycle was approximately 20 percent instead of the typical 50 percent. Figs. 35 and 36 show the TAB HMO output signal in its normal state and failed state, respectively. Three of the 25 TAB HMOs sent to HDL for constant-acceleration testing exhibited the abnormal output signal.

2. A group of 36 TAB HMOs from the DEG lot were electrically tested using a power supply where the voltage rise was exponential. The voltage rose from 0 to -23.5 Vdc in approximately 50 ms. The TAB HMOs functioned properly.

3. The reported failures of S/N 151 (no output at -50C) and S/N 90 (excessive period drift during 30-kg shock) during first-article testing were not verified initially. However, application of the supply voltage exponentially in 30 to 50 ms resulted in an abnormal output signal similar to that noted in the constant-acceleration test specimens. Figs. 35 and 36 show the output signals of S/N 90.

4. It was felt that the abnormal output signal of the TAB HMO resulted because the sum of the Twin-T network attenuation $\left[|A_{vTT}(\omega)|\right]$ plus the gain of the amplifier $\left[|A_{vA}(\omega)|\right]$ was considerably less than 1.5 dB. Fig. 37 shows the basic building blocks of theTAB HMO. After decapsulating S/N 90, the a-c voltage was measured at the amplifier output. When the oscillator was functioning properly, a 3.2 V_{p-p} sine wave was observed, whereas if the abnormal oscillator output existed, a 0.5 V_{p-p} sine wave was present at the amplifier output.

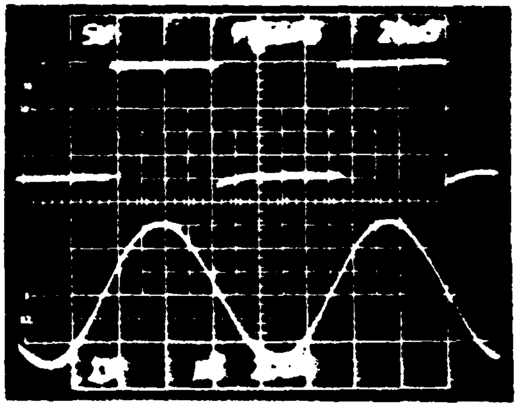

Figure 35.
HMO in normal state. The upper trace shows the TAB HMO output signal when the oscillator functions properly. The lower trace shows the amplifier output signal.

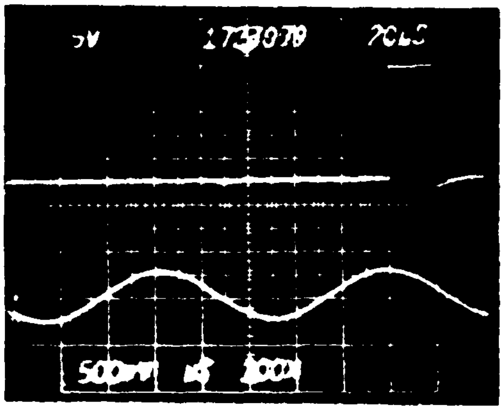

Figure 36.
HMO in failed state. The upper trace shows the abnormal output signal of the TAB HMO. The lower trace shows the amplifier output signal when the oscillator is not functioning properly.

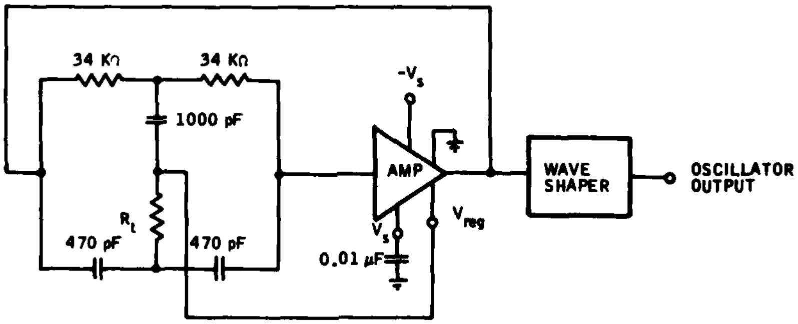

Figure 37. Basic building blocks of the HMO.

Subsequent to isolating the amplifier and the twin T network, the following electrical measurements were performed:

$|A_{vA}(\omega)| = 37.5$ dB (specification limits are 37.5 ±0.5 dB)

$\Delta|A_{vA}(\omega)| = 1.41$ dB (specification limits are 1.5 ±0.3 dB)

$|A_{vTT}(\omega)| = -37.0$ dB (adjusted by trimming R_T)

Therefore,

$$|A_{vA}(\omega)| + |A_{vTT}(\omega)| = 0.5 \text{ dB}$$

The 0.5-dB excess gain was not sufficient to assure oscillator stability.

Previous circuit analysis of the twin-T network showed the twin-T network attenuation increases approximately 1 dB for a 400Ω change in R_T in the range from 15.4 kΩ to 16 kΩ. Use of this information allowed adjustment of the twin-T network attenuation. The following information was obtained by placing a resistor in parallel with R_T (R_T = 15.782 kΩ) to decrease the attenuation of the twin-T network:

$$R_T || \ 1.321 \text{ M}\Omega \rightarrow \Delta|A_{vTT}(\omega)| = 0.46 \text{ dB}$$

Therefore,

$$|A_{vTT}(\omega)| = -36.54 \text{ dB}$$

and

$$|A_{vA}(\omega)| + |A_{vTT}(\omega)| = 0.96 \text{ dB}$$

Device S/N 90 functioned properly at this time and the abnormal output signal could not be reproduced:

$$R_T || \ 3.228 \text{ M}\Omega \rightarrow \Delta|A_{vTT}(\omega)| = 0.2 \text{ dB}$$

Therefore,

$$|A_{vTT}(\omega)| = -36.8 \text{ dB}$$

and

$$|A_{vA}(\omega)| + |A_{vTT}(\omega)| = 0.7 \text{ dB}$$

Device S/N 90 functioned properly at this time, and the abnormal output signal could not be reproduced:

$$R_T || \ 7.24 \text{ M}\Omega \rightarrow |A_{vTT}(\omega)| = 0.1 \text{ dB}$$

Therefore,

$$|A_{vTT}(\omega)| = -36.9 \text{ dB}$$

and

$$|A_{vA}(\omega)| + |A_{vTT}(\omega)| = 0.6 \text{ dB}$$

The abnormal output signal could be reproduc-d by applying the supply voltage exponentially in 50 ms.

These data show that R_T was being overtrimmed. These data also show that an excess gain of approximately 0.7 dB required to assure oscillator stability. Since it was felt that initial gain measurements of the amplifier and twin-T network could have a tolerance of ±0.1 dB, this makes it very difficult to put an exact value on the excess gain required. However, based on electrical data and theoretical calculations, a minimum gain of 1 dB is required to assure oscillator stability.

5. Device S/N 151 was analyzed in a way similar to S/N 90. After decapsulation, S/N 151 would only operate intermittently. The amplifier output was a 0.5 V_{p-p} sine wave. The abnormal output of the oscillator had a period of 2.272×10^{-6} s. This was considerably greater than previously noted. Subsequent to isolating the amplifier and the twin-T network, the following measurements were performed:

$$|A_{vA}(\omega)| = 37.35 \text{ dB}$$

$$\Delta|A_{vA}(\omega)| = 1.46 \text{ dB}$$

$$|A_{vTT}(\omega)| = -37.6 \text{ dB}$$

Therefore,

$$|A_{vA}(\omega)| + |A_{vTT}(\omega)| = -0.25 \text{ dB}$$

These data show a negative excess gain, which means the oscillator should not have run under any circumstances. Electrically, several changes were noted after decapsulation, which may contribute to erroneous data. The analysis terminated after replacing the ceramic capacitor, as the oscillator would not operate. (An attempt was being made to adjust the twin-T network to determine whether S/N 151 would function similar to S/N 90.)

6. Device S/N 32 (one of the three devices returned from HDL) was analyzed in a way similar to S/N 90. However, the sequence of testing the individual building blocks was changed to eliminate replacing the ceramic capacitors for the final attenuation measurements of the twin-T network.

Initial electrical measurements were as follows:

Normal output $T = 98.7982 \times 10^{-6}$ s

Abnormal output $T = 130.3811 \times 10^{-6}$ s and 20 percent duty cycle

No electrical measurements after decapsulation were as follows:

Normal output $T - 98.7854 \times 10^{-6}$ s

Abnormal output $T = 109.620 \times 10^{-6}$ s and 20 percent duty cycle

The following information was obtained by placing a resistor in parallel with R_T ($R_T = 15.933$ kΩ) to decrease the attenuation of the twin-T network:

$$R_T || 600 \text{ k}\Omega \rightarrow \Delta|A_{vTT}(\omega)| = 1.1 \text{ dB}$$

$$R_T || 1.334 \text{ M}\Omega \; \Delta|A_{vTT}(\omega)| = 0.45 \text{ dB}$$

Device S/N 32 functioned properly at this time, and the abnormal output signal could not be reproduced. However, placing a discrete resistor in parallel with R_T required soldering to the capacitor terminations. At this point, one of the ceramic capacitors fractured, which precluded the determination of the excess gain margin between the twin-T network and the amplifier. Additional electrical measurements were performed which showed that the amplifier gain was within specification limits, $|A_{vA}(\omega)| = 37.24$ dB.

7. The analysis performed previously (nos. 4, 5, and 6) revealed that the amplifier gains are well within the specified limits. It appears that the instability of the TAB HMO output signal, noted when applying the supply voltage exponentially in 30 to 50 ms, results from excessive trimming of R_T.

The trim procedure used on the TAB HMO is initiated as shown in fig. 38.

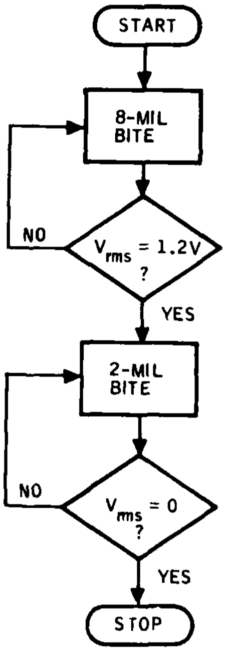

Figure 38. TAB HMO resistor trim procedure.

Fig. 39 shows the resistance changes per a 0.4-mil laser bite in R_T. The information was obtained from the substrates used during the development stages of the TAB HMO. The resistors were trimmed as shown in fig. 40.

Fig. 39 shows a range in resistance changes from 8 Ω to 92 Ω. A large variation in ΔR is noted from 0.4-mil bite to 0.4-mil bite. Variations in the intensity of the laser beam may be a possible explanation for the large variations in ΔR. Circuit analysis shows that increasing R_T 100 Ω will increase the attenuation of the twin-T network approximately 0.25 dB. The information obtained implies that a 2-mil bite would result in a larger ΔR and contribute to an overtrim condition.

The substrates used for the DEG lot TAB HMO exhibited R_T resistor trimming as shown in fig. 41.

A comparison of the resistors used in the development build and the DEG lot build showed the sheet resistivity was greater in the DEG lot build. The trim sensitivity decreases as the sheet resistivity of the resistor increases. This would also increase the chances for an overtrim condition.

3.3.3.5 Recommended Screening Method for TAB HMOs Which Exhibit Evidence of Excessive Active Trimming

The following screening method was recommended to identify TAB HMOs in theDEG lot which exhibit evidence of overtrimming. The TAB HMOs were screened by applying the supply voltage through the RC time constant as shown in fig. 42 (τ = 0.968 s). The power supply voltage of -17.5 V was used during the test to allow the voltage at the TAB HMO to reach approximately -17 Vdc in 4τ. This allows for the voltage drop across the resistor.

3.3.3.6 Results of Screen on TAB HMOs from the DEG Lot

The results from the screen are shown in table XXXII.

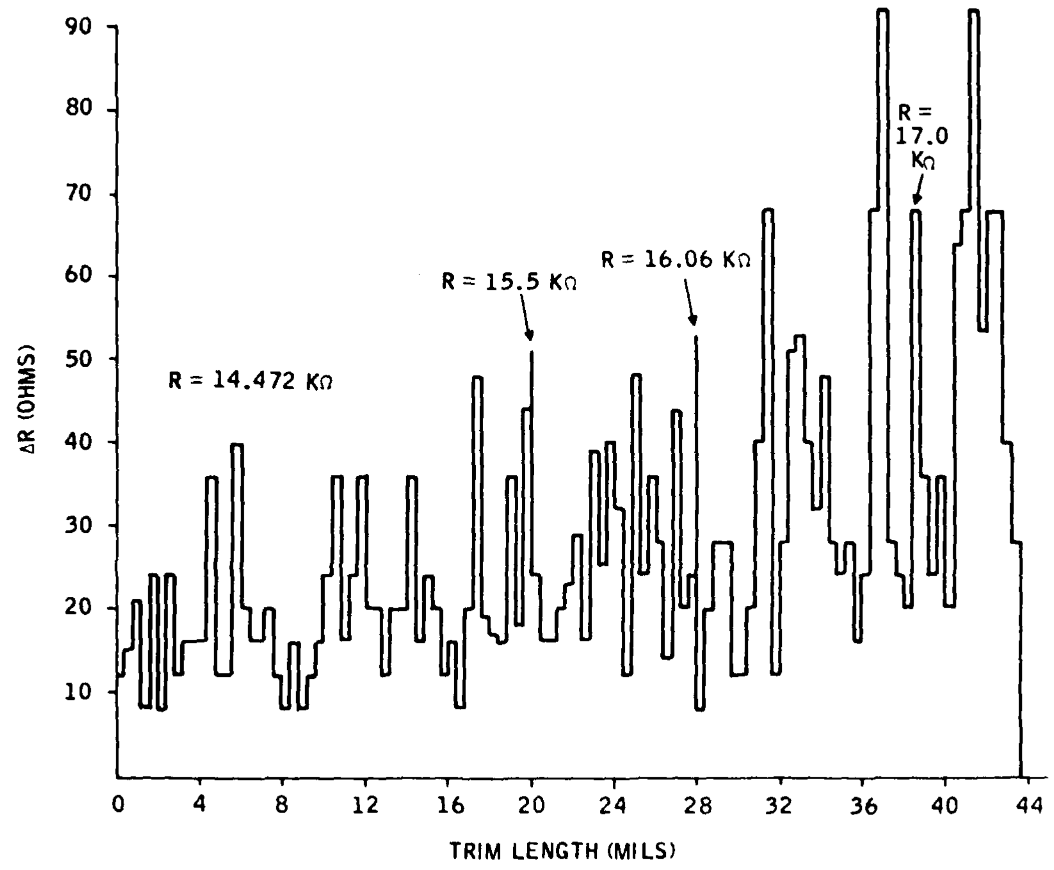

Figure 39. Resistance change vs. 0.4-mil laser trim bite. Note that R_T changes from 14.472 to 17.548 kΩ.

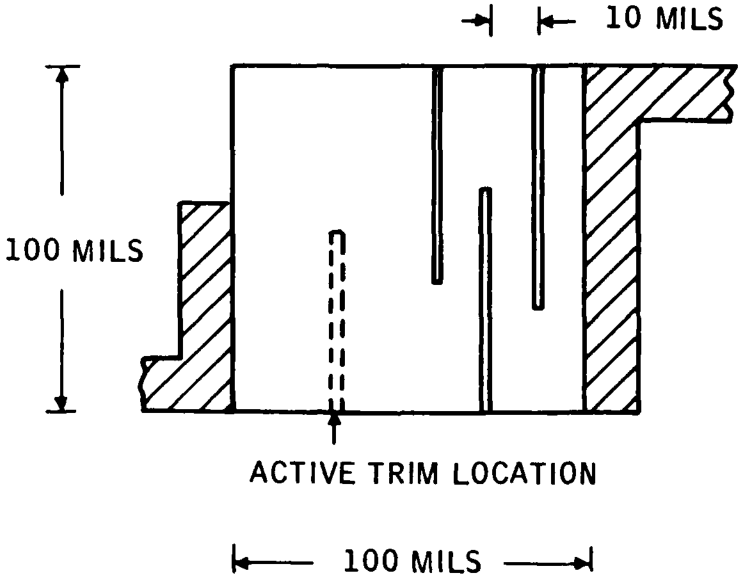

Figure 40. TAB HMO resistor trim:10-mil slice.

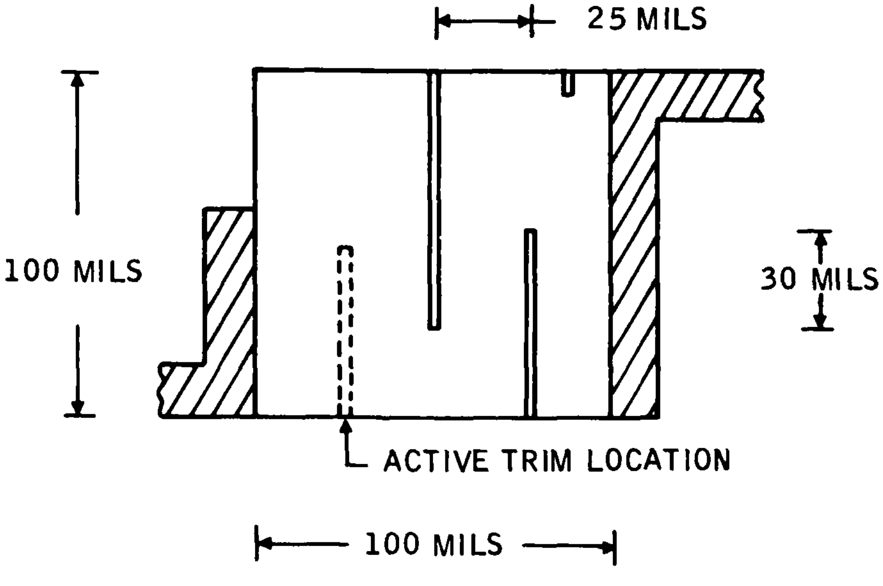

Figure 41. TAB HMO resistor trim:25-mil slice.

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MANUFACTURING METHODS AND TECHNOLOGY PROGRAM FOR THE 10-KHZ TAP--ETC(U)
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UNCLASSIFIED 2730-41637 HDL-CR-79-010-1 NL

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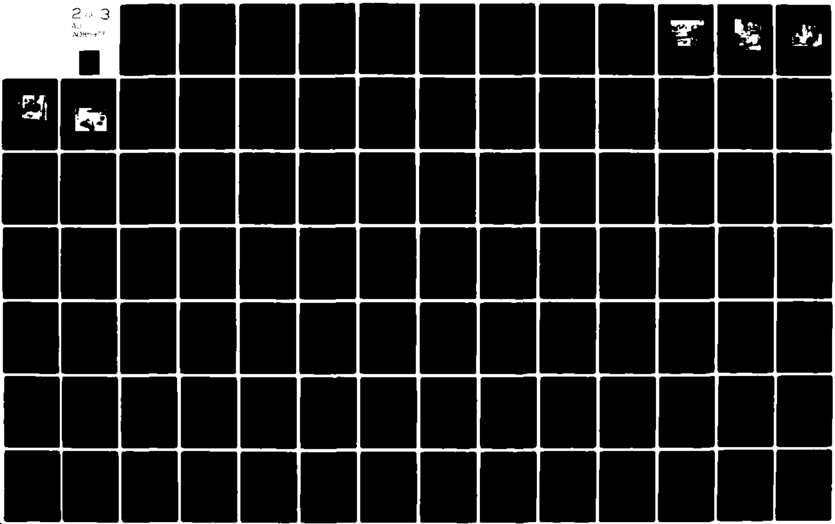

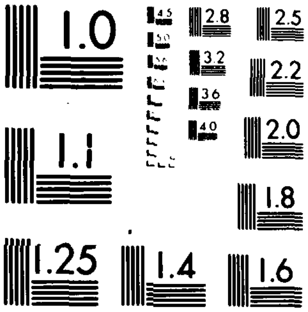

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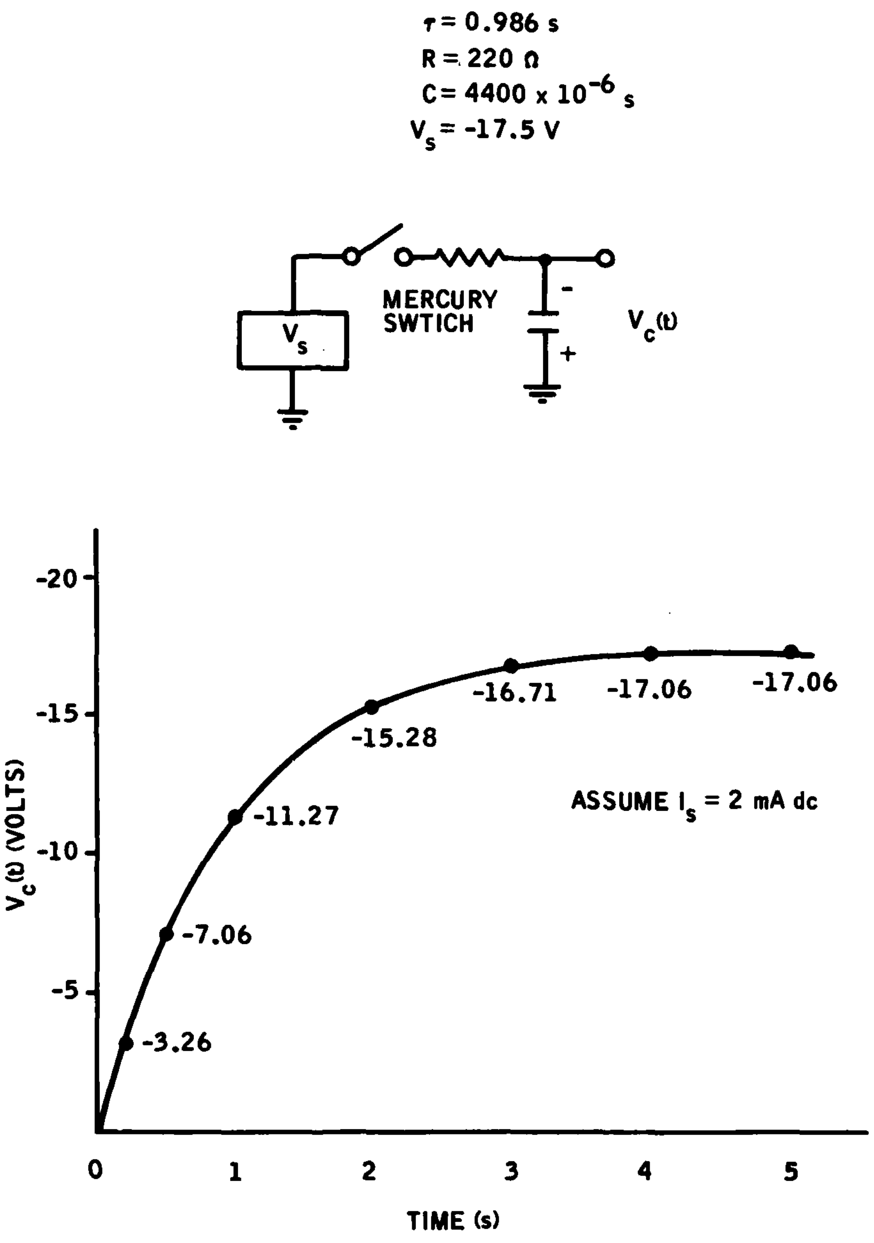

Figure 42. Exponential voltage rise time used to screen TAB HMO.

TABLE XXXII. SCREENING RESULTS FROM DEG LOT

Group	No. Submitted	No. Failed
TAB HMOs from stock	456	23
Test specimens from high-temperature storage testing	25	1
Test specimens from temperature-cycle and moisture-resistance testing	25	3
Test specimens from 30-kg shock testing	22	1
Test specimens from second 30-kg shock testing	25	0
Test specimens from solderability testing	8	1
Spares	12	1

3.3.3.7 Reviewing the Design-to-Cost Analysis

Earlier design-to-cost analyses did not include material costs that were required, such as solder pastes, epoxy, and conformal coating. The wafer bumping costs also show up as a material cost since the Honeywell Solid State Electronic Center has been performing the wafer bumping. Further investigations of some of the equipment used to fabricate the TAB HMOs revealed lower production rates. However, further investigation of other production processes revealed that larger production rates could be achieved. Table XXXIII and fig. 43 show the production rates. Material costs are shown in table XXXIV and fig. 43. The present labor and material costs per device are $1.30 and $2.42, respectively. These costs were obtained for the first million TAB HMOs. The cost for the third million TAB HMOs was calculated at $3.69 per device. This cost was derived from a 92-percent learning curve for material, an 85-percent learning curve for labor, a G&A rate of 18.15 percent, and a profit of 15 percent.

TABLE XXXIII. TAB HMO ASSEMBLY RATES AND HYBRID ASSEMBLY RATES

TAB Assembly Rates

Standard per 100 Chips	Operation Description	Wafers per Hour at 490 Chips per Wafer
0.036	Inspection	5.6
0.036	Prepare wafer	5.6
0.085	Saw wafer	1.25
0.007	Clean	28.6
0.410	Bond inner lead	250 Chips/hour
0.430	Electrical test/inspect	230 Chips/hour
1.004 Total		

Hybrid Assembly Rates

Standard per 100 Units	Operation Description	Rate per Hour
0.61	Burnish	164
0.31	Clean	322
0.33	Screen solder	300
1.0	Excise and form leads	100
	Dispense epoxy	
	Place amplifier	
0.40	Mount capacitors	250
0.43	Attach leads	232
0.167	Inspect	600
0.28	Solder reflow	360
0.31	Clean	300
0.01	Cure epoxy	
0.42	Cut terminals	238
0.20	Electrical test	500
0.76	Active trim	130
0.17	Pre-cap inspect	600
0.24	Apply conformal coating	400
0.04	Cure	
0.50	Encapsulate in epoxy	200
0.02	Cure	
0.40	Mark	250
0.40	Electrical test	250
0.20	Final inspect	500
7.197 Total		

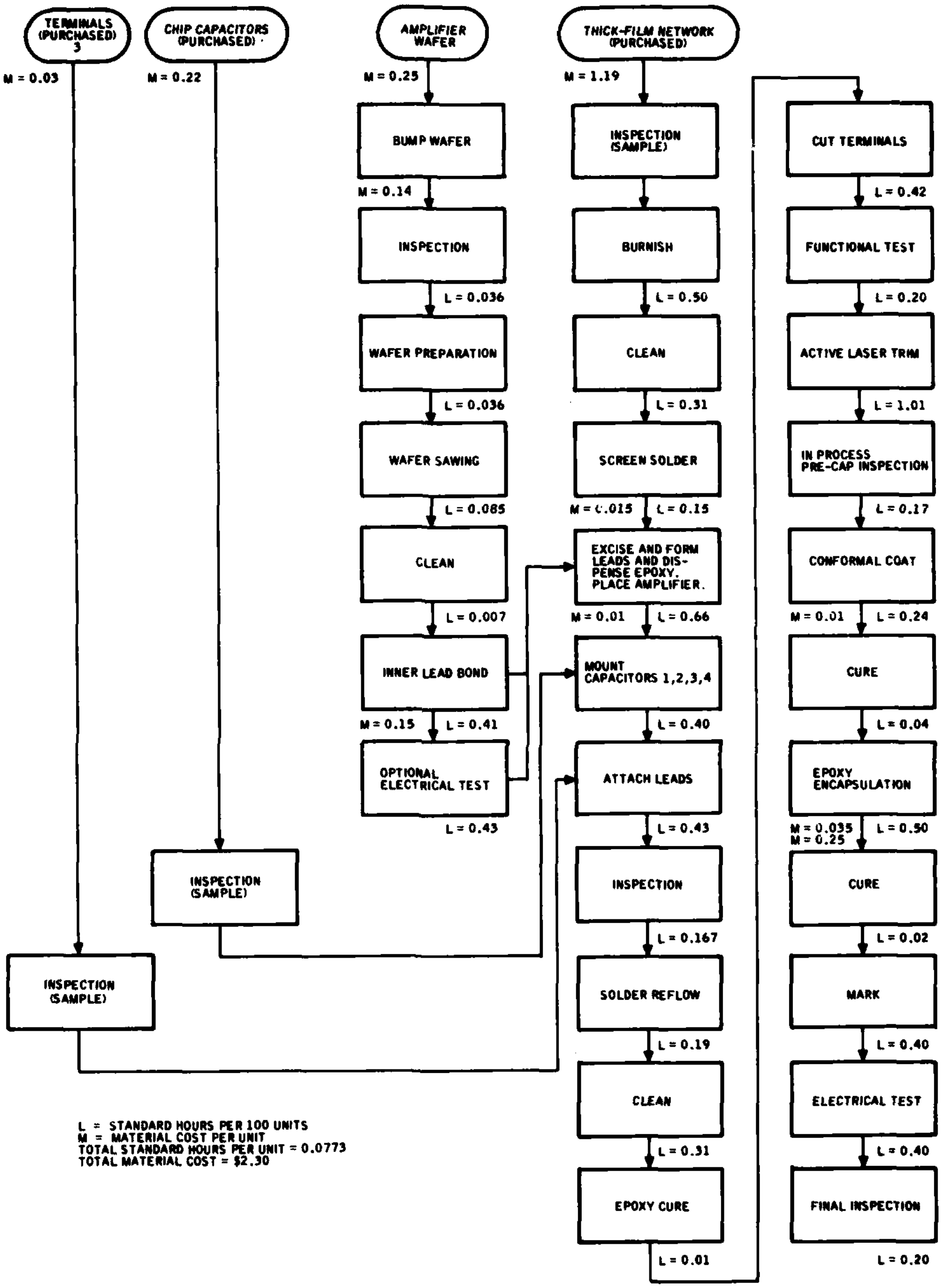

Figure 43. TAB HMO process flow chart.

TABLE XXXIV. OSCILLATOR ASSEMBLY PARTS LIST

Component	Description	Estimated Cost per Device per 1 Million Units
Substrate and film resistors	Dwg. no. 11711674 (fig. A-3)	$1.19
U1	Monolithic amplifier, P/N 28112362	0.25
C1 and C2	470 pF ± 5%, TCC 0 ± 30 ppm/C	0.11
C3	1000 pF ± 5%, TCC 0 ± 30 ppm/C	0.055
C4	0.01 µF ± 10%, TCC ± 15%	0.055
Ceramic connector	Berg Electronics, P/N 75382	0.03
TAB leads	35-mm Tape Format, tin-plated copper, P/N 34028099	0.15
Case and clip	Formed metal can, electrical shield and ground	0.25
Conformal coat	Dow Corning R6100	0.01
Epoxy	Hysol E54128	0.035
Solder paste	Dupont 8956	0.015
Epoxy	Ablestik 789-3	0.01
Die bumping	Honeywell SSEC[a]	0.14
	Total	2.30
	Yielded 95%	2.42

[a] Solid State Electronics Center, Plymouth, MN.

3.4 Phase IV - Pilot Production Lot

3.4.1 Introduction

This phase of the MM&T program consisted of fabricating a pilot production lot of 1919 TAB HMOs. The lot was split into three separate groups for three separate purposes. The first group of 400 was fabricated to support HDL needs on another program; the second group of 120 was fabricated for use in modifying the active trim procedure; and the third group of 1145 was fabricated to demonstrate fabrication rates achievable with the manufacturing equipment selected for the pilot lot.

Yield information was obtained on all three fabrication cycles and is presented later in this section.

3.4.2 Summary

In phase IV of the MM&T study, 1919 TAB HMOs were fabricated. The TAB HMOs were fabricated in three separate groups. The first group of 400 TAB HMOs was fabricated to accommodate HDL needs for another program. The second group of 120 TAB HMOs was fabricated to modify the active trimming procedure. Serious discrepancies were discovered in the active trimming procedure during the first-article tests performed in phase III. Section 3.3 contains detailed information on this subject.

The third group of 1145 TAB HMOs was fabricated at the same time that the achievable rates with the manufacturing equipment selected for the pilot lot were demonstrated. Selection of the equipment was based mainly on availability. One-hour fabrication rates were monitored on the following processes: (1) inner-lead bonding, (2) screen printing solder paste, (3) excising-forming the integrated-circuit leads and placement of the TAB integrated circuit, and (4) active trimming. The solder reflow process was monitored for 30 min.

The hourly rates established during the pilot lot demonstration were used to define the equipment required to produce 110,000 units per month on a 1-8-5 basis. The hourly rates were also used to determine the average price for the third million TAB HMOs.

The acquisition and maintenance costs of the dedicated equipment for large-scale production were identified. Alternate equipment was recommended to reduce acquisition and maintenance cost.

3.4.3 Worked Performed and Results Obtained

The pilot production lot consisted of three fabrication cycles. Yield information of the three fabrication cycles is contained in table XXXV. The major portion of the yield loss was noted at the first functional test, active trimming, and final electrical testing.

3.4.3.1 Fabrication of 400 TAB HMOs

Four hundred TAB HMOs were fabricated. Data were obtained on the equipment selected for the pilot lot demonstration. It was determined that the Browne CP10 pick-and-place machine would not be used during the pilot lot demonstration because of many mechanical design deficiences. The Jade 4810 mass bonder revealed that modifications were required to increase its rate.

The laser trimming problem discovered during phase III was partially solved. Refer to sect. 3.3, and, more specifically, 3.3.3.5, this problem. Additional checkpoints were added in the software, and the final laser bite length was decreased. Start voltage data on the 346 TAB HMOs and further investigation of the oscillator twin-T network attenuation revealed errors between the calculated trim point and the actual trim points achieved. Approximately 10 percent of the TAB HMOs would not function properly as a result of the inaccurate laser trim. The laser trimming procedure was modified during the subsequent fabrication of 120 TAB HMOs.

3.4.3.2 Fabrication of 120 TAB HMOs

One hundred twenty TAB HMOs were fabricated to verify that modifications in the Jade 4810 mass bonder and laser trimming procedure were acceptable for the pilot lot demonstration. Modifications to the epoxy dispensing mechanism on the Jade 4810 mass bonder increased the yield. The modification in the laser trimming procedure consisted of shutting off the supply voltage to the TAB HMO after each laser trim bite. This allowed an accurate a-c voltage measurement to be obtained. The a-c voltage measurement is the information which determines whether or not trimming should

TABLE XXXV. SUMMARY OF TAB HMO FABRICATION FOR PHASE IV

Operation No.	Operation Description	Fabrication of 400 TAB HMOs		Fabrication of 120 TAB HMOs		Pilot Demonstration Run	
		In	Out	In	Out	In	Out
10	Burnish	522	522	446	446	1375	1375
20	Clean	522	522	446	446	1375	1375
30	Screen solder	522	522	446	446	1375	1375
40	Mount components - integrated circuits	522	522	446	446	1375	1364
50	Mount components - capacitors	522	509	446	446	1364	1364
60	Attach lead	509	509	446	446	1364	1364
70	Solder reflow	509	509	446	446	1364	1329
80	Clean	509	509	446	446	1329	1329
85	Cure epoxy	509	509	446	446	1329	1329
90	Cut leads	509	509	446	446	1329	1329
100	Test	509	462	446	425	1329	1280
110	Inspect	462	462	425	425	1280	1257
120	Active trim	462	444	(278) 147	— (a)→ 142	1535	1464
130	Perform pre-cap inspection	444	421	142	122	1464	1456
140	Apply conformal coat	421	421	122	122	1464	1456
150	Encapsulate in epoxy	421	421	122	122	1456	1445
160	Mark	421	421	122	122	1445	1445
170	Final test	421	402	122	120	1445	1397
180	Final inspect	402	402	120	120	1397	1397

[a] These units were trimmed with the last group of TAB HMOs.

continued. It appears that noise from the laser system was injected in the undamped circuit of the TAB HMO, resulting in an erroneous a-c voltage measurement. Electrical data obtained on the twin-T network attenuator showed 1.3 dB excess gain, which was very close to the predicted 1.5 dB. The start voltage ranged from 8 to 13 V. The previous laser trimming technique had a start voltage range from 8 to 17 V. The electrical data verified that the modified laser trimming procedure was accurately trimming the TAB HMOs.

3.4.3.3 Pilot Demonstration Run

The fabrication processes for the TAB HMO are shown in fig. 43. During the pilot lot demonstration, fabrication rates were monitored on (1) inner-lead bonding, (2) screen printing solder paste, (3) excising/forming the integrated-circuit lead and placement of the TAB integrated circuit, (4) solder reflowing, and (5) active trimming.

The inner-lead bonding was performed on a Cii Honeywell Bull inner-lead bonder. The machine, shown in fig. 44, is semiautomatic. However, all alignment steps are manual. An inner-lead bonding rate of 250 devices per hour was achieved. During that hour, the operator had to stop twice to clean the thermode on the bonder. Thermode cleaning required approximately 7 min. each time. The thermode requires cleaning, as the tin from the tin-plated copper lead frame collects on it.

An Auto Roll screen printer shown in fig. 45, was used for the solder screen printing process. The substrates were placed on the stage and removed manually. A screen printing rate of 632 devices per hour was achieved.

Excising/forming the integrated-circuit leads and placement of the integrated circuit were performed with a Jade 4810 mass bonder. This wquipment is shown in fig. 46. A fabrication rate of 150 devices per hour was achieved. The Jade 4810 mass bonder was designed for thermocompression bonding of gold-plated copper leads to gold thick-film conductors. The bonder was modified to accommodate fabrication of the TAB HMO. However, the 4810 mass bonder was considerably less than ideal. A machine designed specifically for this process of the TAB HMO could easily achieve five times the fabrication rate achieved by the Jade 4810 mass bonder.

A Watkins Johnson reflow furnace (fig. 47) was used for the solder reflow process. The solder reflow process was

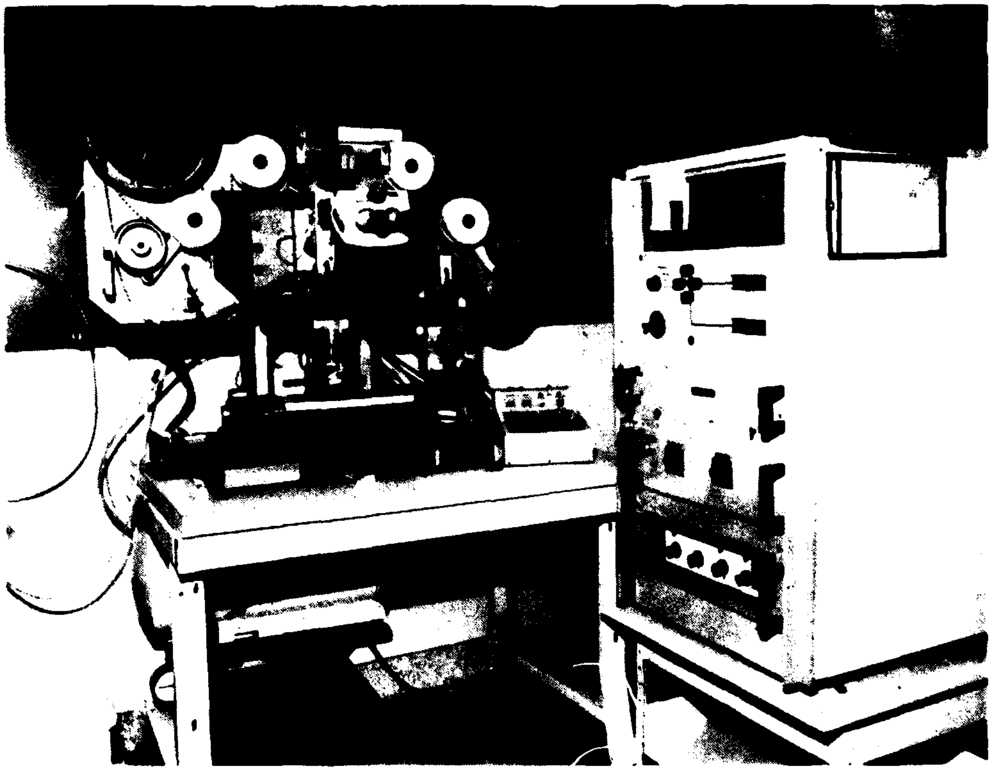

Figure 44. Cii Honeywell Bull inner-lead bonder.

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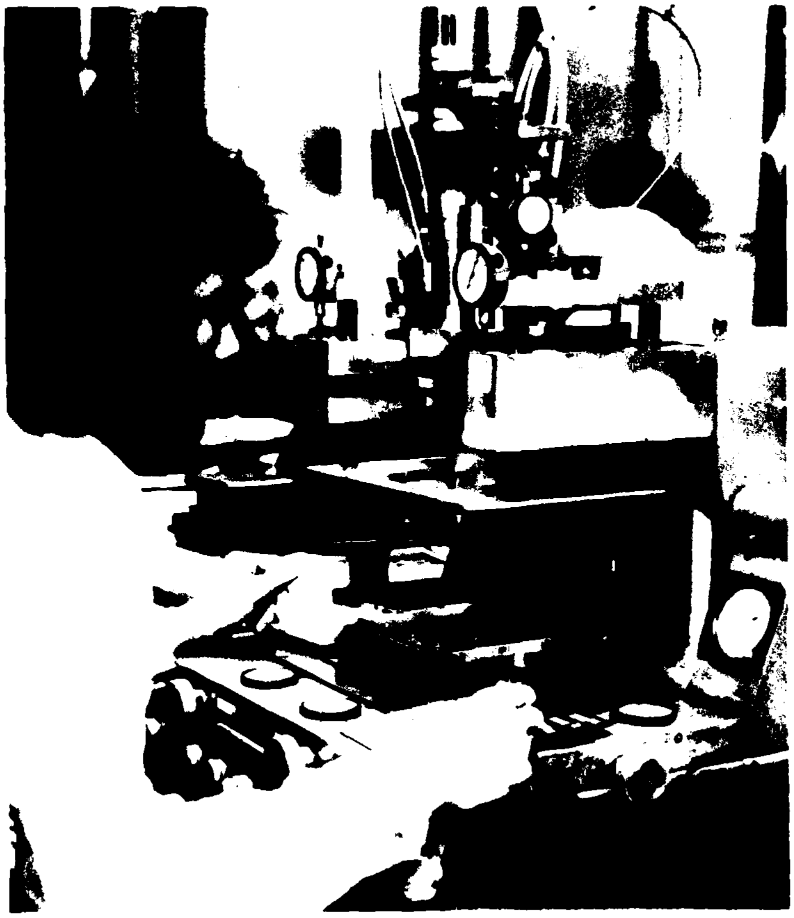

Figure 45. Auto Roll screen printer.

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Figure 46. Jade 4810 mass bonder.

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Figure 47. Watkins Johnson reflow furnace.

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monitored for 30 min., since sufficient quantities of TAB HMOs were not available for 1 hour of continuous loading. It was found that ideal solder wetting could be achieved if the solder paste did not sit in air for extended periods of time. A fabrication rate of 528 devices per hour was achieved. The furnace can reflow at a rate of 1000 devices per hour.

An ESI Model 25 laser system was used for laser trimming the TAB HMO. This system is shown in fig. 48. Laser trimming was performed using the associated circuit shown in fig. 49. The foltage follower buffers the amplifier output to eliminate loading effects. The relay is used to turn the voltage source off after each laser bite. It is necessary to turn the voltage source off as noise induced from the laser trimming creates erroneous voltage measurements which enhance overtrimming.

Figure 48. ESI model 25 laser system.

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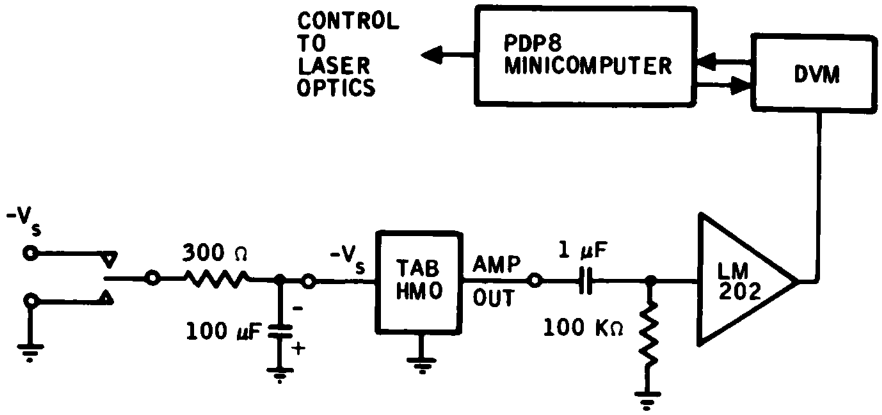

Figure 49. TAB laser trimming associated circuit.

Theoretically, the oscillator circuit was designed to allow 1.5 ± 0.2 dB excess gain to assure stable operation. Stable operation of the circuit is expressed by the following equation:

$$\left|A_{vA}\ (\mathrm{dB})\right| - \left|A_{vTT}\ (\mathrm{dB})\right| = 1.5 \pm 0.2\ \mathrm{dB}$$

where

A_{vA} = Amplifier gain

A_{vTT} = Twin-T network gain

Analysis of start voltage data showed the oscillator circuit would remain stable with a lower limit of 0.9 dB excess gain. Circuit analysis showed a gain change of approximately -0.5 dB per 130-ohm change in the trim resistor of the twin-T network. The trim rate should be controlled to maintain an excess gain margin of 1.1 dB.

The present trim resistor in the twin-T network has a trim sensitivity of approximately 100 ohms per 0.001 in. when approaching the final trim location.

The flow diagram of the trimming sequence used on the Model 25 ESI laser system is shown in fig. 50. Small changes in the voltage monitored during the trimming process, with an abrupt change at the final trim point, complicate decreasing the trim time.

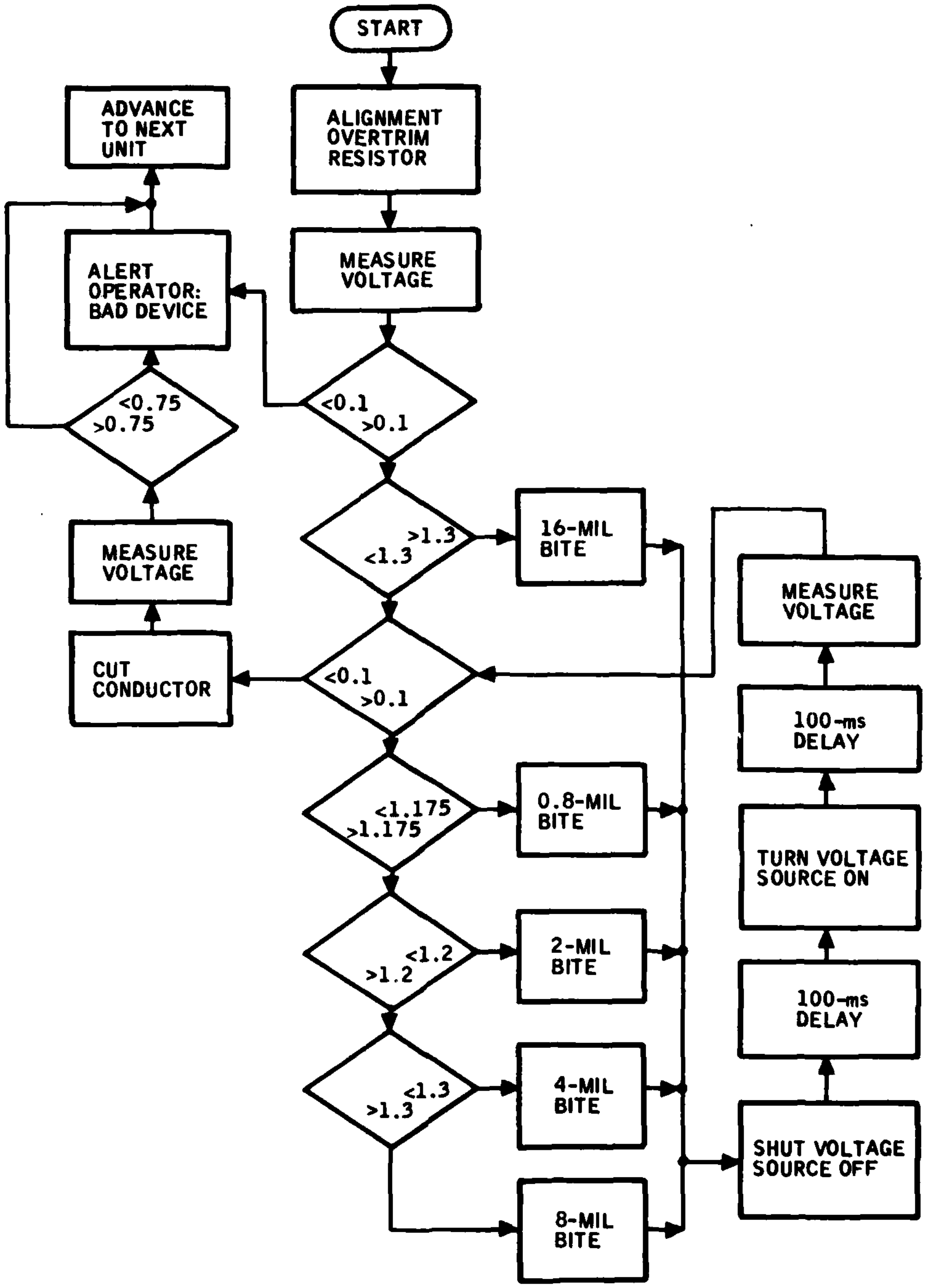

Figure 50. Flow diagram of laser trimming sequence.

During the final build phase, evidence of overtrimming was noted.

The laser trim program should include a feature to notify the operator that the final trim point was achieved with a bite size greater than 0.0008 in. If the final trim is reached with a bite size of 0.002 in., there is a possibility of overtrimming.

Reduction in the laser trim bite would prevent overtrimming. However, the reduction in the laser trim bite increases the total laser trim time per unit. The major portion of the laser trim time is required for access time between the test equipment and the minicomputer. It is felt that modifications in the active trim circuit hardware could increase the active trim rate.

3.4.3.4 <u>First-Article Test Results</u>

Appendix F summarizes the first-article test. One hundred fifty-eight TAB HMOs were electrically tested at -50C, -30C, 0C, 25C, 45C, and 71C. Temperature testing results are summarized in table XXXVI.

TABLE XXXVI. RESULTS OF TAB HMO FIRST-ARTICLE ELECTRICAL TESTING

Temperature range (C)	Range (10^{-9} s)	Specification limits		
		(10^{-9} s)	$\bar{x}$	σ
25 to 45	- 88.2 to 103.0	± 150	- 24.4	18.1
25 to 71	- 59.0 to 184.9	± 350	44.4	43.2
25 to 0	- 17.5 to 131.1	± 190	42.5	23.2
25 to -30	-260.5 to -24.0	± 410	-112.4	53.6
25 to -50	-335.6 to 43.0	± 580	-150.4	71.0

The histograms of figs. 51 through 55 display the period changes with temperature.

```
 157 ITEMS

    MEAN =    -.02443
ST. DEV. =     .01814

COEFFICIENT OF SKEWNESS =   -.55444

XBAR + 1 SIGMA        -.0063            XBAR - 1 SIGMA        -.0426
XBAR + 2 SIGMA         .0119            XBAR - 2 SIGMA        -.0607
XBAR + 3 SIGMA         .0300            XBAR - 3 SIGMA        -.0788

     -.08820     -.03730     -.02790     -.01790     -.00690
     -.06850     -.03660     -.02760     -.01770     -.00650
     -.06830     -.03630     -.02760     -.01750     -.00490
     -.06820     -.03560     -.02720     -.01750     -.00480
     -.06500     -.03550     -.02710     -.01720     -.00400
     -.06040     -.03540     -.02690     -.01720     -.00390
     -.05790     -.03510     -.02570     -.01610     -.00380
     -.05780     -.03500     -.02520     -.01610     -.00230
     -.05630     -.03500     -.02410     -.01610     -.00220
     -.05620     -.03460     -.02400     -.01580     -.00220
     -.05530     -.03420     -.02400     -.01570     -.00170
     -.05140     -.03410     -.02390     -.01570     -.00130
     -.05120     -.03340     -.02340     -.01430     -.00100
     -.05060     -.03340     -.02310     -.01420     -.00100
     -.04970     -.03330     -.02280     -.01370     -.00050
     -.04920     -.03300     -.02270     -.01360     -.00040
     -.04910     -.03290     -.02240     -.01320     -.00030
     -.04860     -.03270     -.02220     -.01300      .00040
     -.04590     -.03250     -.02180     -.01280      .00090
     -.04570     -.03240     -.02170     -.01090      .00100
     -.04480     -.03120     -.02140     -.01070      .00150
     -.04410     -.03110     -.02100     -.01070      .00160
     -.04290     -.03080     -.02100     -.01040      .00200
     -.04260     -.03060     -.02050     -.01010      .00250
     -.04070     -.03020     -.02040     -.00980      .00290
     -.04040     -.03010     -.02000     -.00970      .00340
     -.04040     -.02970     -.01910     -.00930      .00420
     -.04020     -.02920     -.01900     -.00830      .00710
     -.03970     -.02890     -.01880     -.00820      .01030
     -.03960     -.02880     -.01880     -.00810
     -.03860     -.02820     -.01840     -.00810
     -.03760     -.02800     -.01820     -.00750

DEFINE LOWER GRAPH LIMIT !-.09
DEFINE UPPER GRAPH LIMIT !.0103

    -.0900 -     -.0850    1  X
    -.0850 -     -.0800    0
    -.0800 -     -.0750    0
    -.0750 -     -.0700    0
    -.0700 -     -.0650    3  XXX
    -.0650 -     -.0600    2  XX
    -.0600 -     -.0550    5  XXXXX
    -.0550 -     -.0500    3  XXX
    -.0500 -     -.0450    6  XXXXXX
    -.0450 -     -.0400    8  XXXXXXXX
    -.0400 -     -.0350   11  XXXXXXXXXXX
    -.0350 -     -.0300   19  XXXXXXXXXXXXXXXXXXX
    -.0300 -     -.0250   14  XXXXXXXXXXXXXX
    -.0250 -     -.0200   17  XXXXXXXXXXXXXXXXX
    -.0200 -     -.0150   19  XXXXXXXXXXXXXXXXXXX
    -.0150 -     -.0100   12  XXXXXXXXXXXX
    -.0100 -     -.0050   10  XXXXXXXXXX
    -.0050 -     -.0000   15  XXXXXXXXXXXXXXX
    -.0000 -      .0050   10  XXXXXXXXXX
     .0050 -      .0100    1  X
     .0100 -      .0150    1  X

    0 VALUE(S) BELOW LOWER LIMIT
    0 VALUE(S) ABOVE UPPER LIMIT
```

Figure 51. Data and histogram of period change from 25 to 45C.

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```
 157 ITEMS

    MEAN =     .04439
ST. DEV. =     .04318

COEFFICIENT OF SKEWNESS =      .65380

XBAR + 1 SIGMA          .0876           XBAR - 1 SIGMA          .0012
XBAR + 2 SIGMA          .1308           XBAR - 2 SIGMA        -.0420
XBAR + 3 SIGMA          .1739           XBAR - 3 SIGMA        -.0851

     -.05900       .00840       .03140       .05560       .08100
     -.03340       .00910       .03170       .05690       .08100
     -.02340       .00920       .03240       .05720       .08130
     -.02080       .01010       .03260       .05720       .08230
     -.01880       .01100       .03420       .05830       .08690
     -.01800       .01230       .03460       .05900       .08800
     -.01640       .01280       .03500       .05970       .08830
     -.01420       .01500       .03520       .05990       .09030
     -.01350       .01560       .03520       .06090       .09060
     -.01350       .01770       .03630       .06160       .09150
     -.01310       .01840       .03650       .06180       .09220
     -.01100       .01870       .03700       .06200       .09270
     -.01080       .01880       .03730       .06220       .09340
     -.01070       .01920       .03750       .06220       .09390
     -.01020       .01970       .03760       .06280       .09440
     -.01010       .02020       .03860       .06320       .09500
     -.00960       .02320       .03940       .06390       .10000
     -.00850       .02380       .04040       .06390       .10460
     -.00790       .02490       .04060       .06400       .10460
     -.00680       .02500       .04130       .06710       .11270
     -.00590       .02510       .04170       .06760       .12110
     -.00410       .02640       .04340       .06800       .13910
     -.00330       .02690       .04770       .06920       .13970
     -.00260       .02770       .04890       .06940       .14740
     -.00150       .02850       .04990       .07120       .14890
     -.00090       .02910       .05040       .07120       .15030
     -.00050       .02940       .05120       .07180       .15060
      .00080       .03000       .05160       .07340       .18090
      .00090       .03080       .05300       .07420       .18490
      .00170       .03100       .05300       .07830
      .00330       .03120       .05310       .07910
      .00780       .03130       .05380       .08030

DEFINE GRAPH INTERVAL     !.01
DEFINE LOWER GRAPH LIMIT !-.06
DEFINE UPPER GRAPH LIMIT !.1849

    -.0600 -     -.0500    1  X
    -.0500 -     -.0400    0
    -.0400 -     -.0300    1  X
    -.0300 -     -.0200    2  XX
    -.0200 -     -.0100   12  XXXXXXXXXXXX
    -.0100 -     -.0000   11  XXXXXXXXXXX
    -.0000 -      .0100    8  XXXXXXXX
     .0100 -      .0200   12  XXXXXXXXXXXX
     .0200 -      .0300   12  XXXXXXXXXXXX
     .0300 -      .0400   22  XXXXXXXXXXXXXXXXXXXXXX
     .0400 -      .0500    8  XXXXXXXX
     .0500 -      .0600   15  XXXXXXXXXXXXXXX
     .0600 -      .0700   16  XXXXXXXXXXXXXXXX
     .0700 -      .0800    7  XXXXXXX
     .0800 -      .0900    8  XXXXXXXX
     .0900 -      .1000   10  XXXXXXXXXX
     .1000 -      .1100    2  XX
     .1100 -      .1200    1  X
     .1200 -      .1300    1  X
     .1300 -      .1400    2  XX
     .1400 -      .1500    2  XX
     .1500 -      .1600    2  XX
     .1600 -      .1700    0
     .1700 -      .1800    0
     .1800 -      .1900    2  XX
```

Figure 52. Data and histogram of period change from 25 to 71C.

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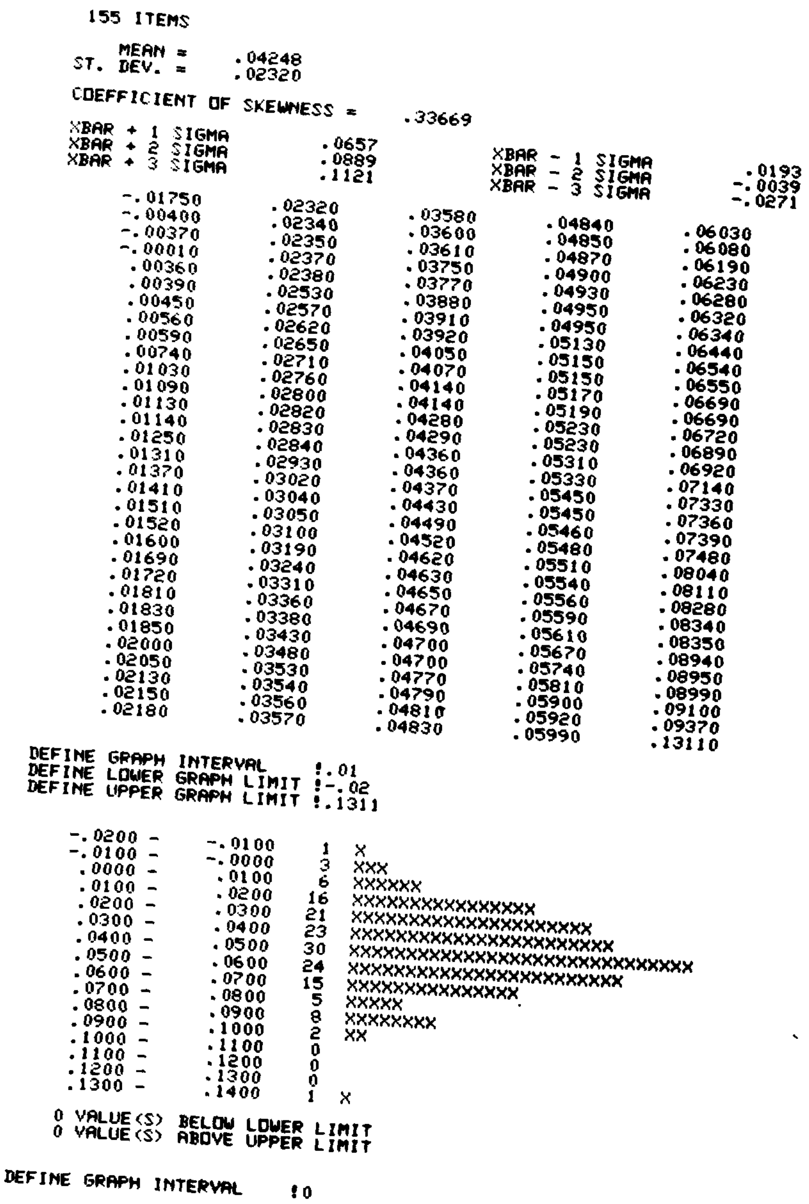

```
 155 ITEMS

    MEAN =      .04248
ST. DEV. =      .02320

COEFFICIENT OF SKEWNESS =        .33669

XBAR + 1 SIGMA            .0657
XBAR + 2 SIGMA            .0889      XBAR - 1 SIGMA       .0193
XBAR + 3 SIGMA            .1121      XBAR - 2 SIGMA      -.0039
                                     XBAR - 3 SIGMA      -.0271
      -.01750       .02320       .03580       .04840       .06030
      -.00400       .02340       .03600       .04850       .06080
      -.00370       .02350       .03610       .04870       .06190
      -.00010       .02370       .03750       .04900       .06230
       .00360       .02380       .03770       .04930       .06280
       .00390       .02530       .03880       .04950       .06320
       .00450       .02570       .03910       .04950       .06340
       .00560       .02620       .03920       .05130       .06440
       .00590       .02650       .04050       .05150       .06540
       .00740       .02710       .04070       .05150       .06550
       .01030       .02760       .04140       .05170       .06690
       .01090       .02800       .04140       .05190       .06690
       .01130       .02820       .04280       .05230       .06720
       .01140       .02830       .04290       .05230       .06890
       .01250       .02840       .04360       .05310       .06920
       .01310       .02930       .04360       .05330       .07140
       .01370       .03020       .04370       .05450       .07330
       .01410       .03040       .04430       .05450       .07360
       .01510       .03050       .04490       .05460       .07390
       .01520       .03100       .04520       .05480       .07480
       .01600       .03190       .04620       .05510       .08040
       .01690       .03240       .04630       .05540       .08110
       .01720       .03310       .04650       .05560       .08280
       .01810       .03360       .04670       .05590       .08340
       .01830       .03380       .04690       .05610       .08350
       .01850       .03430       .04700       .05670       .08940
       .02000       .03480       .04700       .05740       .08950
       .02050       .03530       .04770       .05810       .08990
       .02130       .03540       .04790       .05900       .09100
       .02150       .03560       .04810       .05920       .09370
       .02180       .03570       .04830       .05990       .13110

DEFINE GRAPH INTERVAL      !.01
DEFINE LOWER GRAPH LIMIT   !-.02
DEFINE UPPER GRAPH LIMIT   !.1311

     -.0200 -     -.0100    1  X
     -.0100 -     -.0000    3  XXX
      .0000 -      .0100    6  XXXXXX
      .0100 -      .0200   16  XXXXXXXXXXXXXXXX
      .0200 -      .0300   21  XXXXXXXXXXXXXXXXXXXXX
      .0300 -      .0400   23  XXXXXXXXXXXXXXXXXXXXXXX
      .0400 -      .0500   30  XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
      .0500 -      .0600   24  XXXXXXXXXXXXXXXXXXXXXXXX
      .0600 -      .0700   15  XXXXXXXXXXXXXXX
      .0700 -      .0800    5  XXXXX
      .0800 -      .0900    8  XXXXXXXX
      .0900 -      .1000    2  XX
      .1000 -      .1100    0
      .1100 -      .1200    0
      .1200 -      .1300    0
      .1300 -      .1400    1  X

    0 VALUE(S) BELOW LOWER LIMIT
    0 VALUE(S) ABOVE UPPER LIMIT

  DEFINE GRAPH INTERVAL     !0
```

Figure 53. Data and histogram of period change from 25 to OC.

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```
 155 ITEMS

    MEAN =    -.11236
ST. DEV. =     .05355

COEFFICIENT OF SKEWNESS =   -.35076

XBAR + 1 SIGMA          -.0588          XBAR - 1 SIGMA        -.1659
XBAR + 2 SIGMA          -.0053          XBAR - 2 SIGMA        -.2195
XBAR + 3 SIGMA           .0483          XBAR - 3 SIGMA        -.2730

      -.26050     -.15330     -.12340     -.09770     -.06140
      -.25900     -.15190     -.12310     -.09760     -.06110
      -.23180     -.15080     -.12300     -.09660     -.06080
      -.22610     -.15040     -.12150     -.09650     -.06060
      -.22310     -.14890     -.12110     -.09590     -.05790
      -.22130     -.14810     -.12000     -.09490     -.05710
      -.21930     -.14670     -.11920     -.09380     -.05710
      -.21070     -.14610     -.11860     -.09190     -.05690
      -.20950     -.14600     -.11430     -.08870     -.05570
      -.20890     -.14570     -.11380     -.08660     -.05260
      -.19540     -.14520     -.11370     -.08400     -.05160
      -.18970     -.14430     -.11350     -.08340     -.05110
      -.18940     -.14410     -.11250     -.08170     -.05070
      -.18810     -.14410     -.11140     -.08090     -.04860
      -.18520     -.14200     -.11130     -.07970     -.04580
      -.18450     -.13990     -.10930     -.07830     -.04170
      -.18400     -.13830     -.10930     -.07810     -.04070
      -.17750     -.13790     -.10870     -.07800     -.03980
      -.17670     -.13430     -.10870     -.07800     -.03810
      -.17400     -.13360     -.10710     -.07480     -.03660
      -.17350     -.13350     -.10650     -.07170     -.03480
      -.17150     -.13310     -.10370     -.06900     -.03400
      -.17090     -.13260     -.10370     -.06840     -.03150
      -.16610     -.13150     -.10350     -.06830     -.03100
      -.16220     -.13090     -.10290     -.06800     -.02950
      -.16160     -.12920     -.10290     -.06400     -.02890
      -.16130     -.12700     -.10270     -.06290     -.02770
      -.15970     -.12640     -.09990     -.06290     -.02710
      -.15930     -.12540     -.09970     -.06230     -.02420
      -.15800     -.12510     -.09960     -.06230     -.02400
      -.15420     -.12340     -.09950     -.06220      .01280

DEFINE GRAPH INTERVAL    !.025
DEFINE LOWER GRAPH LIMIT !-.3
DEFINE UPPER GRAPH LIMIT !.0128

     -.3000 -     -.2750   0
     -.2750 -     -.2500   2  XX
     -.2500 -     -.2250   2  XX
     -.2250 -     -.2000   6  XXXXXX
     -.2000 -     -.1750   9  XXXXXXXXX
     -.1750 -     -.1500  16  XXXXXXXXXXXXXXXX
     -.1500 -     -.1250  26  XXXXXXXXXXXXXXXXXXXXXXXXXX
     -.1250 -     -.1000  28  XXXXXXXXXXXXXXXXXXXXXXXXXXXX
     -.1000 -     -.0750  23  XXXXXXXXXXXXXXXXXXXXXXX
     -.0750 -     -.0500  25  XXXXXXXXXXXXXXXXXXXXXXXXX
     -.0500 -     -.0250  15  XXXXXXXXXXXXXXX
     -.0250 -     -.0000   2  XX
     -.0000 -      .0250   1  X

     0 VALUE(S) BELOW LOWER LIMIT
     0 VALUE(S) ABOVE UPPER LIMIT
```

Figure 54. Data and histogram of period change from 25 to -30C.

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```
 155 ITEMS

    MEAN =    -.15038
ST. DEV. =     .07101

COEFFICIENT OF SKEWNESS =   -.18393

XBAR + 1 SIGMA        -.0794          XBAR - 1 SIGMA        -.2214
XBAR + 2 SIGMA        -.0084          XBAR - 2 SIGMA        -.2924
XBAR + 3 SIGMA         .0627          XBAR - 3 SIGMA        -.3634

      -.33560      -.20500      -.16800      -.13280      -.08160
      -.33240      -.20500      -.16750      -.13250      -.08120
      -.32490      -.20270      -.16670      -.13220      -.07860
      -.31490      -.20050      -.16520      -.13210      -.07700
      -.29260      -.19760      -.16490      -.13160      -.07700
      -.29040      -.19740      -.16310      -.13110      -.07590
      -.29000      -.19690      -.15990      -.12890      -.07520
      -.27950      -.19680      -.15970      -.12810      -.07470
      -.27150      -.19560      -.15920      -.12700      -.07430
      -.26240      -.19470      -.15690      -.12340      -.07340
      -.26240      -.19460      -.15580      -.12080      -.07250
      -.25220      -.19430      -.15560      -.12000      -.06870
      -.24570      -.19240      -.15230      -.11940      -.06600
      -.24360      -.19200      -.15070      -.11700      -.05750
      -.24350      -.19090      -.14850      -.11660      -.05610
      -.23780      -.18920      -.14570      -.11300      -.05530
      -.23490      -.18890      -.14520      -.11210      -.05470
      -.23080      -.18870      -.14280      -.10740      -.05340
      -.22440      -.18820      -.14240      -.10580      -.04780
      -.22280      -.18740      -.14070      -.10250      -.04540
      -.22140      -.18700      -.14050      -.09950      -.04440
      -.22100      -.18410      -.14030      -.09680      -.04380
      -.22090      -.18270      -.13950      -.09670      -.04290
      -.21740      -.18040      -.13880      -.09670      -.04210
      -.21540      -.17730      -.13720      -.09350      -.04160
      -.21420      -.17600      -.13580      -.08970      -.03950
      -.21330      -.17580      -.13450      -.08930      -.03820
      -.21220      -.16950      -.13410      -.08770      -.03800
      -.21170      -.16940      -.13380      -.08750      -.03560
      -.20830      -.16860      -.13360      -.08710       .01020
      -.20810      -.16850      -.13350      -.08370       .04300

DEFINE LOWER GRAPH LIMIT !-.35
DEFINE UPPER GRAPH LIMIT !.043

     -.3500 -     -.3250    2  XX
     -.3250 -     -.3000    2  XX
     -.3000 -     -.2750    4  XXXX
     -.2750 -     -.2500    4  XXXX
     -.2500 -     -.2250    6  XXXXXX
     -.2250 -     -.2000   17  XXXXXXXXXXXXXXXXX
     -.2000 -     -.1750   23  XXXXXXXXXXXXXXXXXXXXXXX
     -.1750 -     -.1500   18  XXXXXXXXXXXXXXXXXX
     -.1500 -     -.1250   26  XXXXXXXXXXXXXXXXXXXXXXXXXX
     -.1250 -     -.1000   11  XXXXXXXXXXX
     -.1000 -     -.0750   18  XXXXXXXXXXXXXXXXXX
     -.0750 -     -.0500   11  XXXXXXXXXXX
     -.0500 -     -.0250   11  XXXXXXXXXXX
     -.0250 -     -.0000    0
     -.0000 -      .0250    1  X
      .0250 -      .0500    1  X

     0 VALUE(S) BELOW LOWER LIMIT
     0 VALUE(S) ABOVE UPPER LIMIT

DEFINE GRAPH INTERVAL    !0
```

Figure 55. Data and histogram of period change from 25 to -50C.

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Four devices failed electrically during the temperature testing. Device S/N 92 failed the voltage sensitivity test at -30 Vdc. The period changed 99 x 10^{-12} where the specification limit is ± 20 x 10^{-9} s. Failure analysis shows that the twin-T network was not properly trimmed. The attenuation of the twin-T network was -25 dB, whereas a properly trimmed twin-T network has an attenuation of -36 dB. It is felt that the probes on the laser system made intermittent contact, resulting in an improper trim.

Device S/N 158 did not function at 25C. Failure analysis revealed etched aluminum metallization paths on the integrated circuit.

Device S/N 110 failed electrically at 0, -30, and -50C. Failure analysis revealed a broken tin-plated copper lead off the integrated circuit.

Device S/N 53 also failed electrically at 0, -30, and -50C. Failure analysis revealed that the twin-T network attenuation was -37.8 dB and the amplifier gain was 37.4 dB. This indicates that either the twin-T network was overtrimmed or the trimmed resistor drifted after laser trimming.

Voltage sensitivity was performed on the 158 TAB HMOs at 25C. The histograms of figs. 56 and 57 display period changes between -23.5 and -17.0 Vdc and -23.5 and -30 Vdc, respectively.

Twenty-five TAB HMOs were exposed to temperature-cycle testing. The period changes were within the ± 250 x 10^{-9} s specification. Fig. 58 is a histogram displaying period changes exhibited during temperature-cycle testing.

Twenty-five TAB HMOs were exposed to 30-kg shock testing. Six devices (S/N's 76, 77, 78, 82, 94, and 96) failed the ± 20 x 10^{-9} s specification. The fig. 59 histogram displays the period changes during 30-kg shock testing. The period drifts of the six failures ranged from 33.6 x 10^{-9} s to 255.6 x 10^{-9} s. Failure analysis revealed that the period shifts were due to insufficient adhesion of the epoxy to the tin-plated metal case. The reflow tin plating was partially stripped after similar failures occurred during phase III of

```
 157 ITEMS

    MEAN =      .00835
 ST. DEV. =     .00146

COEFFICIENT OF SKEWNESS =     .27040

XBAR + 1 SIGMA          .0098          XBAR - 1 SIGMA          .0069
XBAR + 2 SIGMA          .0113          XBAR - 2 SIGMA          .0054
XBAR + 3 SIGMA          .0127          XBAR - 3 SIGMA          .0040

       .00460      .00720      .00790      .00890      .00950
       .00520      .00720      .00790      .00890      .00960
       .00560      .00720      .00790      .00890      .00960
       .00560      .00720      .00790      .00900      .00970
       .00580      .00720      .00800      .00900      .00970
       .00590      .00730      .00810      .00910      .00970
       .00600      .00730      .00810      .00910      .00990
       .00600      .00730      .00820      .00910      .00990
       .00620      .00730      .00820      .00920      .01000
       .00620      .00740      .00830      .00920      .01000
       .00620      .00740      .00830      .00920      .01010
       .00630      .00740      .00830      .00920      .01010
       .00630      .00740      .00840      .00920      .01010
       .00630      .00740      .00840      .00920      .01010
       .00640      .00740      .00850      .00920      .01010
       .00640      .00750      .00850      .00930      .01010
       .00640      .00750      .00850      .00930      .01010
       .00650      .00750      .00860      .00930      .01010
       .00650      .00760      .00860      .00930      .01020
       .00650      .00760      .00860      .00930      .01020
       .00670      .00760      .00860      .00930      .01030
       .00680      .00760      .00870      .00940      .01060
       .00680      .00770      .00870      .00940      .01060
       .00680      .00770      .00870      .00940      .01070
       .00690      .00770      .00870      .00940      .01080
       .00690      .00770      .00870      .00940      .01080
       .00690      .00770      .00880      .00940      .01150
       .00700      .00770      .00880      .00940      .01300
       .00710      .00770      .00880      .00940      .01370
       .00710      .00780      .00880      .00950
       .00710      .00780      .00880      .00950
       .00710      .00780      .00890      .00950

DEFINE GRAPH INTERVAL    !.001
DEFINE LOWER GRAPH LIMIT !.004
DEFINE UPPER GRAPH LIMIT !.0137

      .0040 -     .0050   1  X
      .0050 -     .0060   5  XXXXX
      .0060 -     .0070  21  XXXXXXXXXXXXXXXXXXXXX
      .0070 -     .0080  41  XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
      .0080 -     .0090  31  XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
      .0090 -     .0100  37  XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
      .0100 -     .0110  18  XXXXXXXXXXXXXXXXXX
      .0110 -     .0120   1  X
      .0120 -     .0130   0
      .0130 -     .0140   2  XX
```

Figure 56. Data and histogram of voltage sensitivity testing from -23.5 to -17 Vdc.

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```
 156 ITEMS

    MEAN =    -.00513
ST. DEV. =     .00211

COEFFICIENT OF SKEWNESS =   6.50226

XBAR + 1 SIGMA        -.0030          XBAR - 1 SIGMA        -.0072
XBAR + 2 SIGMA        -.0009          XBAR - 2 SIGMA        -.0093
XBAR + 3 SIGMA         .0012          XBAR - 3 SIGMA        -.0115

      -.00980     -.00600     -.00550     -.00490     -.00410
      -.00930     -.00600     -.00550     -.00490     -.00410
      -.00920     -.00600     -.00540     -.00480     -.00400
      -.00810     -.00590     -.00540     -.00480     -.00400
      -.00780     -.00590     -.00540     -.00480     -.00400
      -.00750     -.00590     -.00540     -.00480     -.00400
      -.00750     -.00590     -.00540     -.00480     -.00390
      -.00740     -.00590     -.00540     -.00470     -.00370
      -.00730     -.00590     -.00540     -.00470     -.00370
      -.00710     -.00590     -.00540     -.00470     -.00370
      -.00700     -.00580     -.00540     -.00470     -.00360
      -.00700     -.00580     -.00530     -.00470     -.00360
      -.00690     -.00580     -.00530     -.00460     -.00360
      -.00690     -.00580     -.00530     -.00460     -.00360
      -.00690     -.00570     -.00520     -.00460     -.00360
      -.00680     -.00570     -.00520     -.00460     -.00360
      -.00670     -.00570     -.00520     -.00460     -.00360
      -.00670     -.00570     -.00520     -.00460     -.00350
      -.00660     -.00570     -.00520     -.00460     -.00340
      -.00650     -.00570     -.00520     -.00450     -.00330
      -.00640     -.00560     -.00510     -.00450     -.00330
      -.00640     -.00560     -.00510     -.00450     -.00320
      -.00630     -.00560     -.00500     -.00450     -.00320
      -.00620     -.00560     -.00500     -.00450     -.00310
      -.00620     -.00550     -.00500     -.00450     -.00300
      -.00620     -.00550     -.00500     -.00450     -.00280
      -.00620     -.00550     -.00500     -.00440     -.00280
      -.00620     -.00550     -.00500     -.00430      .01620
      -.00610     -.00550     -.00500     -.00420
      -.00610     -.00550     -.00500     -.00420
      -.00610     -.00550     -.00500     -.00420
      -.00610     -.00550     -.00490     -.00420

DEFINE GRAPH INTERVAL     !

DEFINE GRAPH INTERVAL     !.0005
DEFINE LOWER GRAPH LIMIT !-.010
DEFINE UPPER GRAPH LIMIT !-.0028


     -.0100 -      -.0095    1  X
     -.0095 -      -.0090    2  XX
     -.0090 -      -.0085    0
     -.0085 -      -.0080    1  X
     -.0080 -      -.0075    1  X
     -.0075 -      -.0070    5  XXXXX
     -.0070 -      -.0065    9  XXXXXXXXX
     -.0065 -      -.0060   13  XXXXXXXXXXXXX
     -.0060 -      -.0055   24  XXXXXXXXXXXXXXXXXXXXXXXX
     -.0055 -      -.0050   30  XXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
     -.0050 -      -.0045   29  XXXXXXXXXXXXXXXXXXXXXXXXXXXXX
     -.0045 -      -.0040   15  XXXXXXXXXXXXXXX
     -.0040 -      -.0035   15  XXXXXXXXXXXXXXX
     -.0035 -      -.0030    7  XXXXXXX
     -.0030 -      -.0025    3  XXX
```

Figure 57. Data and histogram of voltage sensitivity testing from 23.5 to -30 Vdc.

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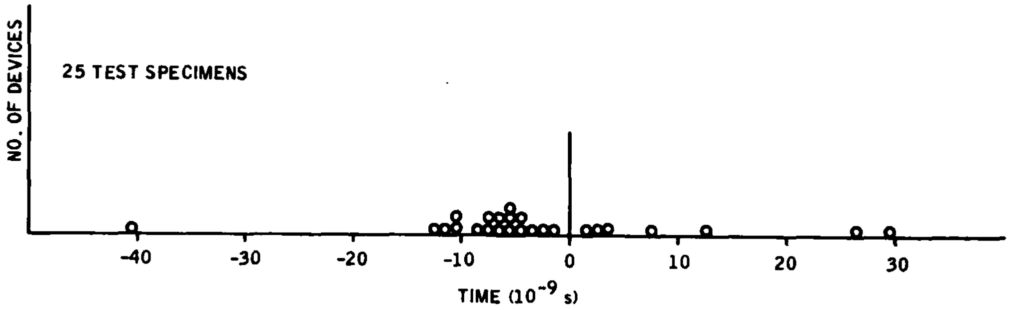


Figure 58. Histogram of period change during temperature-cycle testing.

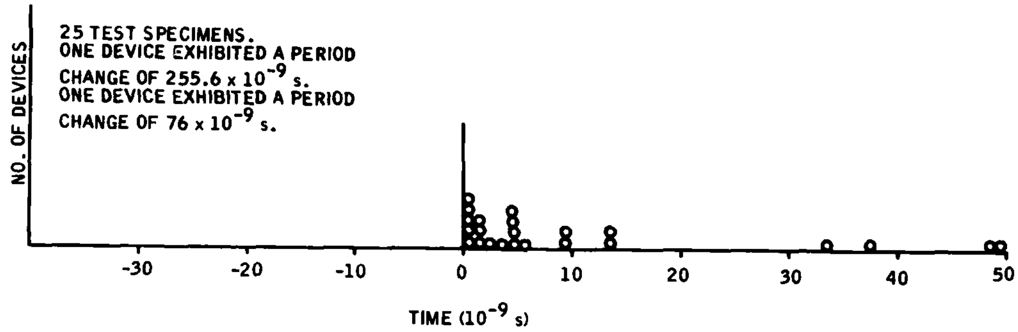


Figure 59. Histogram of period change during 30-kg shock testing with devices encapsulated in brown sugar.

the MM&T program. Another sample of 25 TAB HMOs was selected from the pilot production lot and exposed to 30-kg shock testing. However, the second sample for 25 TAB HMOs was encapsulated with epoxy in nose cones, whereas the first sample was encapsulated in brown sugar. The 25 TAB HMOs encapsulated in epoxy met the $\pm 20 \times 10^{-9}$ s specification. The fig. 60 histogram displays the period drifts of the 25 TAB HMOs which were encapsulated in epoxy.

Twenty-five TAB HMOs were exposed to constant-acceleration testing by HDL. The fig. 61 histogram displays the period change noted during the constant-acceleration testing. One device, S/N 32, exhibited a -63×10^{-9} s drift. This device was not analyzed.

Twenty-five TAB HMOs were exposed to high-temperature storage testing. The period changes were within the

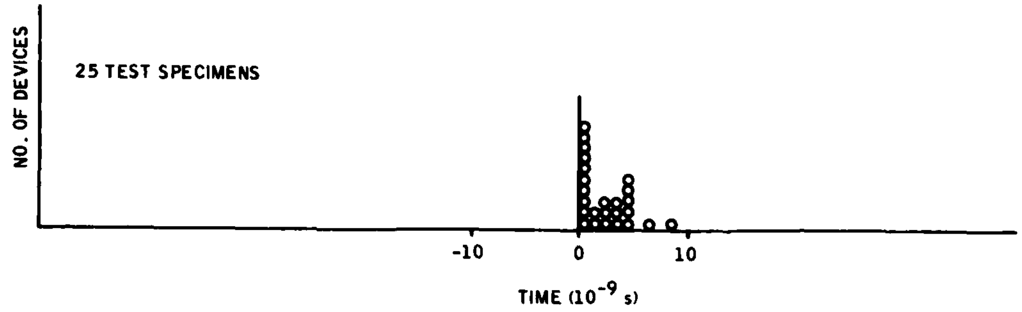


Figure 60. Histogram of period change during 30-kg shock testing with devices encapsulated in epoxy.

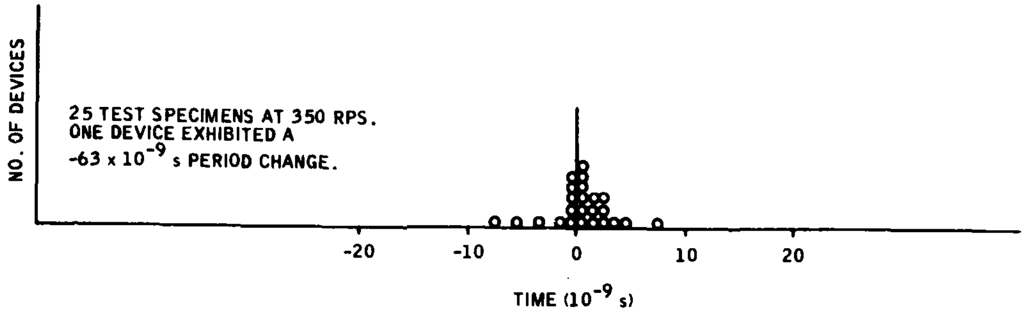


Figure 61. Histogram of period change during constant-acceleration testing.

± 250 x 10^{-9} s specification. The fig. 62 histogram displays period changes during the high-temperature storage testing.

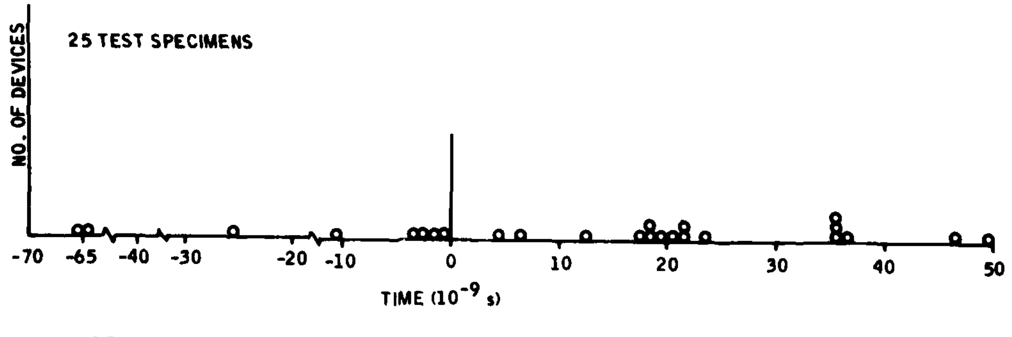


Figure 62. Histogram of period change during high-temperature storage testing.

3.4.3.5 Design-To-Cost Review

The materials required to fabricate a TAB HMO are shown in table XXXVII. Material prices were obtained from vendors at the 1-million piece-part price level. A total material cost of $2.48 per device was determined considering a yield of 92 percent.

TABLE XXXVII. TAB HMO ASSEMBLY PARTS LIST

Component	Description	Estimated Cost per Device per 1 million units
Substrate and film resistors	Dwg. no. 11711674 (fig. A-3)	$1.19
U1	Monolithic Amplifier, P/N 28112362	0.25
C1 and C2	470 pF ± 5%, TCC 0 ± 30 ppm/C	0.11
C3	1000 pF ± 5%, TCC 0 ± 30 ppm/C	0.055
C4	0.01 μF ± 10%, TCC ± 15%	0.055
Ceramic connector	Berg Electronics, P/N 75382	0.03
TAB leads	35-mm tape format, tin-plated copper, P/N 34028099	0.15
Case and clip	Formed metal can, electrical shield and ground	0.25
Conformal coat	Dow Corning R6100	0.01
Epoxy	Hysol E54128	0.035
Solder paste	Dupont 8956	0.015
Epoxy	Ablestik 789-3	0.01
Die bumping	Honeywell SSEC[a]	0.14
	Total	2.30
	Yielded 92%	2.48

[a] Solid State Electronics Center, Plymouth, MN.

The standard hours required for each assembly process of the TAB HMO are shown in table XXXVII. The labor cost for the first million TAB HMOs was $1.69 per device.

The average cost for the third million TAB HMOs was calculated at $4.10 per device. The cost of the third million TAB HMOs was derived from a 92-percent learning curve for material, an 85-percent learning curve for labor, G&A expense of 15 percent, a profit of 15 percent, and a 5-percent material acquisition.

TABLE XXXVIII. TAB HMO ASSEMBLY RATES AND HYBRID ASSEMBLY RATES

TAB Assembly Rates

Standard per 100 Chips	Operation Description	Wafers per hour at 490 Chips per Wafer
0.036	Inspect	5.6
0.036	Prepare wafer	5.6
0.085	Saw wafer	1.25
0.007	Clean	28.6
0.410	Bond inner lead[a]	250 Chips/hour
0.430	Electrical test/inspect	230 Chips/hour
1.004 Total		

Hybrid Assembly Rates

Standard per 100 Units	Operation Description	Rate per Hour
0.50	Burnish	200
0.31	Clean	322
0.15	Screen solder[a]	632
0.66	Excise and form leads[a]	150
	Dispense epoxy	-
	Place amplifier	-
0.40	Mount capacitors	250
0.43	Attach leads	232
0.167	Inspect	600
0.19	Solder reflow[a]	528
0.31	Clean	300
0.01	Cure epoxy	-
0.42	Cut terminals	238
0.20	Electrical test	500
1.01	Active trim[a]	99
0.17	Pre-cap inspect	600
0.24	Apply conformal coating	400
0.04	Cure	-
0.50	Encapsulate in epoxy	200
0.02	Cure	-
0.40	Mark	250
0.40	Electrical test	250
0.20	Final inspect	500
6.727 Total		

[a] Processes monitored during the pilot lot demonstration.

3.4.3.6 Dedicated Machines for Large-Scale Production

Achieving high TAB HMO production rates (115,000 per month on a 1-8-5 basis) depends to a large degree on equipment and loading. The prototype production run mixed production and laboratory tools. Table XXXIX lists this equipment and tabulates the numbers of each required for the above-mentioned production rates. Approximate acquisition and maintenance costs are also shown. A component placement machine is available which can make up to 2000 individual placements per hour. Modifications to this machine, which include excise and form tooling and an epoxy dispensor, would allow it to be used in assembling the TAB HMO at a rate of 400 to 600 circuits per hour. This machine supplants the projected four Jade 4810s and six operators shown in table XXXIX.

TABLE XXXIX. EQUIPMENT AND MAINTENANCE COSTS

Operation No.	Operation Description	Equipment Manufacturer	No. of Stations	Cost ($K)	Maintenance Cost per Mo. ($)
10	Burnish	Dremel	9	0.9	10
20	Clean	Bronson	3	5.1	50
30	Screen solder	Auto Roll	2	8.0	80
40	Mount components - TAB integrated circuits	Jade 4810	6	240.0	2,400
50	Mount components - capacitors	-	(a)	-	-
60	Attach lead	Berg Electronics	4	2.0	20
70	Solder reflow	Watkins Johnson	2	28.0	280
80	Clean	Branson	3	5.1	51
85	Cure epoxy	Blue M	4	4.0	40
90	Cut leads	-	4	1.2	12
100	Test	Custom	2	5.0	50
120	Active trim	ESI, Inc.	9	1,350.0	13,500
140	Apply conformal coating	Custom	2	0.5	5
	Encapsulate	Glenmark	9	3.6	36
	Cure	Blue M	8	4.8	48
150	Mark	Markem	8	8.0	80
160	Final test	Custom	4	100.0	1,000

[a] Six operators.

The present capacity (using present procedure) of the ESI laser trimmer is about 10,000 HMOs per month on a 1-5-8 basis. By revising the fixturing and procedure (doing four at one time), the capacity per machine could be increased substantially so that three machines could perform active trim at the rates proposed.

Encapsulation is another process step which can be automated to reduce cost. Currently available encapsulation dispensers can reduce the cost of this operation by a factor of four, based on loading two cases simultaneously. Greater savings can be achieved if larger case multiples are used.

Proper fixturing for dip encapsulation can be easily developed and fabricated to increase throughput. Encapsulant and epoxy cure cycles, however, are critical in that time at temperature must be minimized to reduce the possibility of thick-film metallization leaching effects. Therefore, increased batching must be done to handle the parts throughput to match the rest of the HMO production rates.

3.4.3.7 Evaluation of a Thick-Film Substrate Containing Conventional Thick-Film Resistors

A substrate was evaluated that contained the thick-film resistors of the twin-T network. One hundred substrates were purchased from State of the Art, Inc. The thick-film resistor ink was purchased from EMCA, Inc. Temperature coefficient of resistance (TCR) measurements were performed on three thick-film resistors of 10 substrates. Temperature coefficients of resistance data are contained in table XL. The data show that the conventional thick-film resistors did not meet the ± 25 ppm/C TCR specification required for the twin-T network. The resistor TCRs exceeded -25 ppm/C at -30 and -50C.

Twenty-five TAB HMOs were fabricated using the substrates from State of the Art, Inc. Detailed electrical measurements were performed on 10 TAB HMOs. Electrical measurements of the TAB HMOs are contained in table XLI. The electrical measurements were well within the oscillator performance specifications. The negative TCR of the resistors which exceeded the 25 ppm/C specification did not force the oscillator temperature coefficient of period above the specified limit. The negative TCR of the resistors is compensated by the positive temperature coefficient of capacitance in the NPO capacitor of the twin-T network.

It is felt that further investigations with conventional thick-film resistor inks would yield thick-film resistors that can meet the ± 25 ppm/C specification for the oscillator.

4. CONCLUSIONS AND RECOMMENDATIONS

The TAB HMO cost objective of $4.00 per device was exceeded by $0.10. However, the use of dedicated production equipment designed specifically for fabrication of the TAB HMO instead of the laboratory equipment and manual processes would reduce the labor cost by 30 percent. The major labor cost drivers are shown in the TAB HMO process flow diagram, fig. 43.

The major material cost driver was the substrate containing the thick-film conductors and resistors. The thick-film resistors are somewhat unique in that the temperature coefficient of resistance (TCR) must be less than 25 ppm/C. The thick-film substrate can easily achieve the 25 ppm/C TCR in the thick-film resistors. (The substrate was obtained on a "sole-source" contract.) An attempt was made to establish a second source to supply the substrates with conventional thick-film resistors. The thick-film resistors did not meet the 25 ppm/C TCR specification across the full tem-

TABLE XL. TEMPERATURE COEFFICIENT OF RESISTANCE DATA ON CONVENTAIONAL THICK-FILM RESISTORS

Serial Number	R at 25C (ohms)	TCR 25 to 45C (ppm/C	R at 45C (ohms)	TCR 25 to 71C (ppm/C)	R at 71C (ohms)	R at 25C (ohms)	TCR R at 25 to 0C (ppm/C)	R at 0C (ohms)	TCR 25 to -30C (ppm/C)	R at -30C (ohms)	TCR 25 to -50C (ppm/C)	R at -50C (ohms)	R at 25C (ohms)
1 R1	33,904.5	- 6.3	33,900.2	- 4.4	33,903.8	33,904.5	-19.3	33,920.2	-30.0	33,959.4	-37.4	33,998.3	33,904.9
R2	34,005.8	- 2.5	34,004.1	3.3	34,011.1	34,005.7	-15.2	34,018.1	-25.9	34,053.2	-33.2	34,089.2	34,003.7
R3	13,205.3	9.8	13,207.9	14.9	13,214.6	13,205.3	- 1.6	13,205.8	-12.5	13,214.2	-19.7	13,224.6	13,205.3
2 R1	33,924.1	- 1.3	33,923.2	4.6	33,931.5	33,923.8	-13.6	33,934.6	-23.8	33,967.5	-31.5	34,033.0	33,923.8
R2	33,966.9	4.3	33,969.8	10.0	33,982.9	33,966.8	- 8.1	33,973.4	-18.2	34,000.2	-25.8	34,031.6	33,967.4
R3	13,214.4	20.8	13,219.9	25.8	13,230.4	13,214.3	10.1	13,211.1	- 1.4	13,214.4	- 7.3	13,221.4	13,214.3
3 R1	33,900.6	- 4.3	33,897.7	1.6	33,903.1	33,900.5	-17.2	33,914.5	-27.5	33,950.9	-35.2	33,988.7	33,901.1
R2	33,986.0	0.3	33,986.2	5.9	33,995.4	33,986.5	-11.6	33,996.0	-22.4	34,027.7	-30.0	34,062.0	33,986.7
R3	13,216.6	15.9	13,220.8	21.4	13,229.9	13,216.4	- 5.0	13,214.8	- 5.0	13,220.0	-12.4	13,228.5	13,216.7
4 R1	33,946.7	- 5.3	33,943.1	0.5	33,947.5	33,946.3	-17.7	33,960.7	-28.0	33,997.8	-36.0	34,036.5	33,947.1
R2	33,997.6	- 6.2	33,993.4	- 0.01	33,997.5	33,997.4	-18.7	34,012.7	-29.0	34,050.9	37.0	34.090.6	33,997.9
R3	13,210.8	15.5	13,214.9	20.3	13,223,4	13,210.6	3.8	13,209.4	- 6.2	13,215.0	-13.7	13,224.0	13,210.8
5 R1	33,900.1	- 6.8	33,895.5	- 9.4	33,898.6	33,899.7	-19.8	33,915.8	-30.3	33,955.2	-38.1	33,995.4	33,900.6
R2	33,919.9	- 7.2	33,915.0	- 1.2	33,918.0	33,919.6	-20.4	33,936.2	-31.2	33,976.7	-39.1	34,017.7	33,919.9
R3	13,212.6	11.4	13,215.6	16.4	13,222.8	13,212.5	5.7	13,210.7	- 9.9	13,219.6	-18.0	13,230.1	13,209.4
6 R1	33,936.3	4.3	33,939.2	9.4	33,951.3	33,937.9	- 8.6	33,944.9	-20.0	33,974.6	-28.5	34,009.4	33,935.3
R2	33,983.9	6.2	33,988.1	11.5	34,002.3	33,983.8	- 6.0	33,988.7	-16.7	34,013.5	-24.6	34,045.6	33,983.5
R3	13,216.6	22.3	13,222.5	27.8	13,233.8	13,216.5	11.3	13,212.9	1.8	13,215.2	- 5.5	13,221.9	13,216.8
7 R1	33,936.9	- 4.1	33,934.1	1.7	33,939.7	33,936.6	-16.6	33,950.1	-26.8	33,985.7	-34.8	34,023.9	33.937.2
R2	33,948.8	- 5.0	33,945.4	1.4	33,951.1	33,947.7	-16.1	33,960.8	-26.7	33,996.7	-34.6	34,034.6	33,948.6
R3	13,211.4	14.0	13,215.1	19.0	13,223.2	13,211.1	2.2	13,210.4	- 7.3	13,216.3	-14.7	13,225.5	13,211.5
8 R1	33,913.4	- 2.4	33,911.8	3.8	33,919.5	33,913.0	-14.5	33,924.8	-24.9	33,958.6	-32.4	33,994.2	33,913.4
R2	33,956.6	- 1.0	33,955.9	4.9	33,964.4	33,956.4	-13.7	33,967.6	-24.0	34,000.7	-31.5	34,035.6	33,956.5
R3	13,211.4	24.6	13,217.9	28.9	13,229.4	13,211.2	12.0	13,207.4	3.1	13,209.0	- 4.1	13,215.2	13,211.7
9 R1	33,931.6	- 1.9	33,930.3	33.8	33,937.7	33,931.3	-14.5	33,943.1	-24.5	33,976.2	-32.2	34,012.1	33,931.9
R2	34,036.6	0	34,036.6	5.5	34,045.4	34,036.5	-12.5	34,046.7	-23.0	34,078.7	-30.8	34,114.0	34.037.4
R3	13,210.9	18.9	13,215.9	23.7	13,225.6	13,210.7	6.6	13,208.6	- 2.5	13,212.5	- 9.7	13,220.2	13,211.2
10 R1	34,012.3	- 1.5	34,012.2	5.5	34,021.1	34,012.1	-12.4	34,022.2	-22.5	34,053.5	-30.3	34,088.4	34,012.6
R2	33,977.2	- 2.1	33,975.8	3.9	33,983.4	33,976.9	-14.6	33,988.8	-24.8	34,022.5	-32.7	34,059.2	33,977.7
R3	13,218.2	18.5	13,223.1	23.3	13,232.7	13,218.3	6.6	13,216.2	- 2.9	13,220.4	-10.4	13,228.5	13,218.4

TABLE XLI. ELECTRICAL DATA ON TAB HMOs FABRICATED WITH CONVENTIONAL THICK-FILM RESISTORS

S/N	T at 25C and 23.5 Vdc (10^{-6} s)	Voltage Sensitivity		Temperature Sensitivity				
		ΔT 23.5 to 17 Vdc (10^{-9} s)	ΔT 23.5 to 30 Vdc (10^{-9} s)	ΔT 25 to 45C (10^{-9} s)	ΔT 25 to 71C (10^{-9} s)	ΔT 25 to 0C (10^{-9} s)	ΔT 25 to 30C (10^{-9} s)	ΔT 25 to -50C (10^{-9} s)
Specification Limits	96 to 107	± 25	± 20	± 150	± 350	± 190	± 410	± 580
1	101.637	7.1	7.4	10.6	32.8	8.0	63.8	147.8
2	101.343	7.3	6.8	28.1	71.1	23.7	2.4	51.1
3	100.097	6.5	8.0	42.3	109.2	26.1	21.6	26.2
4	98.832	5.1	8.7	41.3	103.3	31.2	2.5	51.6
5	99.843	8.6	6.4	30.8	81.2	21.2	2.7	50.0
6	101.354	8.6	5.1	24.4	61.8	6.6	34.7	97.0
7	99.318	10.3	5.9	47.7	121.6	29.2	20.4	23.3
8	101.697	9.9	6.0	77.2	15.7	61.1	93.0	4.3
9	100.594	6.5	7.1	43.4	103.2	29.1	10.1	73.1
10	101.880	7.5	7.9	42.2	96.9	17.3	3.5	54.0

TABLE XLI. - CONCLUDED

S/N	Supply Current at 23.5 Vdc			Rise Time			Fall Time			Time High		
	at 25C (mA dc)	at 71C (mA dc)	at -50C (mA dc)	at 25C (µs)	at 71C (µs)	at -50C (µs)	at 25C (µs)	at 71C (µs)	at -50C (µs)	at 25C (µs)	at 71C (µs)	at -50C (µs)
Specification Limits	2.7 mA dc max			3.0 µs max			3.0 µs max			35 µs min		-60 µs min
1	2.11	2.15	2.05	0.22	0.24	0.30	0.25	0.30	0.30	49	48	52
2	2.06	2.10	1.99	0.20	0.20	0.25	0.30	0.30	0.30	49	48	52
3	2.10	2.15	2.05	0.22	0.20	0.26	0.30	0.30	0.28	48	47	50
4	2.23	2.30	2.16	0.18	0.16	0.24	0.30	0.30	0.30	47	46	50
5	2.16	2.20	2.10	0.18	0.17	0.22	0.30	0.30	0.30	48	47	50
6	2.15	2.21	2.09	0.23	0.22	0.28	0.30	0.30	0.30	49	48	51
7	2.11	2.15	2.03	0.22	0.31	0.27	0.30	0.30	0.30	48	47	50
8	1.89	1.91	1.81	0.28	0.27	0.34	0.34	0.32	0.30	50	49	53
9	2.10	2.15	2.05	0.21	0.20	0.23	0.30	0.32	0.30	49	48	51
10	1.95	2.00	1.88	0.22	0.24	0.30	0.32	0.30	0.30	50	49	52

perature ranges. It is felt that further investigations would yield a conventional thick-film resistor ink which would meet the 25 ppm/C specification, and the substrate could be purchased for approximately $0.50 instead of $1.19.

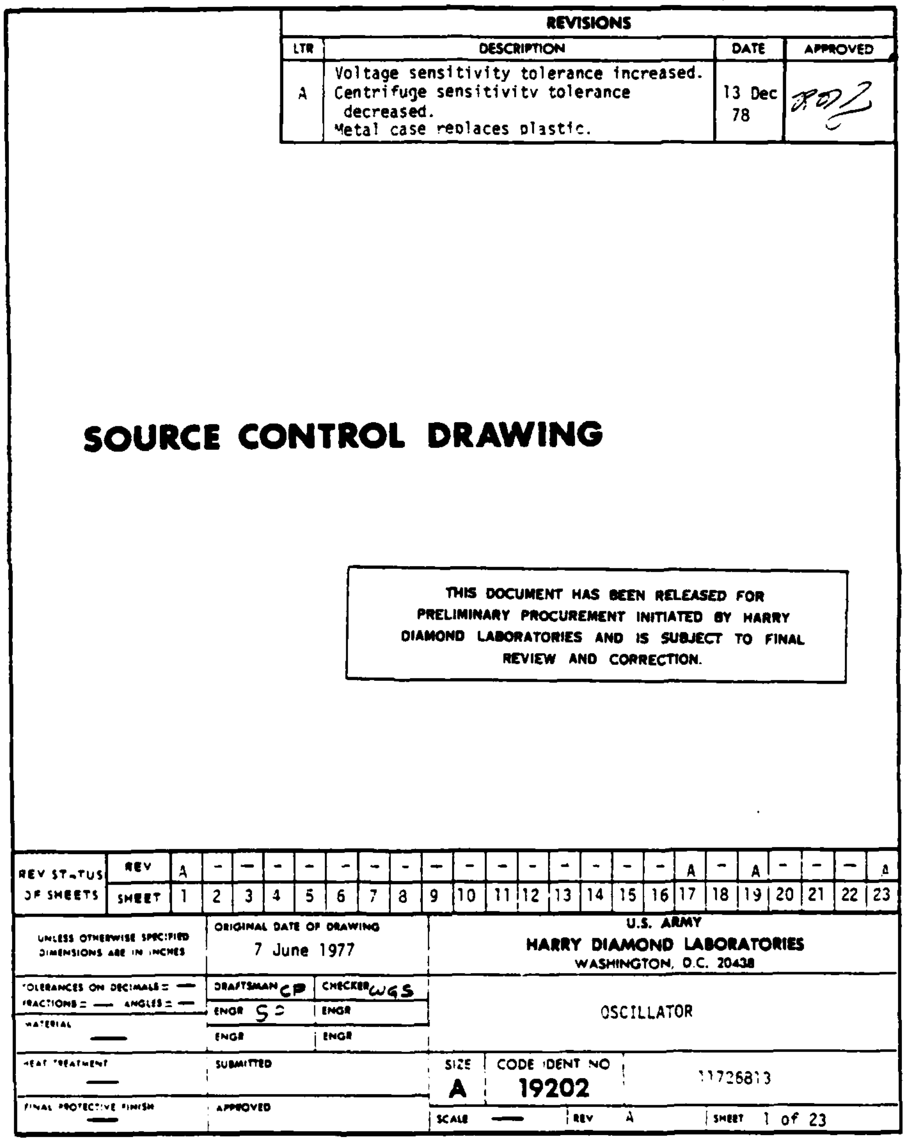
TABLE XLI. - CONCLUDED

S/N	Supply Current at 23.5 Vdc			Rise Time			Fall Time			Time High		
	at 25C (mA dc)	at 71C (mA dc)	at -50C (mA dc)	at 25C (µs)	at 71C (µs)	at -50C (µs)	at 25C (µs)	at 71C (µs)	at -50C (µs)	at 25C (µs)	at 71C (µs)	at -50C (µs)
Specification Limits	2.7 mA dc max			3.0 µs max			3.0 µs max			35 µs min		-60 µs min
1	2.11	2.15	2.05	0.22	0.24	0.30	0.25	0.30	0.30	49	48	52
2	2.06	2.10	1.99	0.20	0.20	0.25	0.30	0.30	0.30	49	48	52
3	2.10	2.15	2.05	0.22	0.20	0.26	0.30	0.30	0.28	48	47	50
4	2.23	2.30	2.16	0.18	0.16	0.24	0.30	0.30	0.30	47	46	50
5	2.16	2.20	2.10	0.18	0.17	0.22	0.30	0.30	0.30	48	47	50
6	2.15	2.21	2.09	0.23	0.22	0.28	0.30	0.30	0.30	49	48	51
7	2.11	2.15	2.03	0.22	0.31	0.27	0.30	0.30	0.30	48	47	50
8	1.89	1.91	1.81	0.28	0.27	0.34	0.34	0.32	0.30	50	49	53
9	2.10	2.15	2.05	0.21	0.20	0.23	0.30	0.32	0.30	49	48	51
10	1.95	2.00	1.88	0.22	0.24	0.30	0.32	0.30	0.30	50	49	52

perature ranges. It is felt that further investigations would yield a conventional thick-film resistor ink which would meet the 25 ppm/C specification, and the substrate could be purchased for approximately $0.50 instead of $1.19.

APPENDIX A

SOURCE CONTROL AND RELATED DRAWINGS FOR PRECISION OSCILLATOR,P/N 11726813



REVISIONS

LTR	DESCRIPTION	DATE	APPROVED
A	Voltage sensitivity tolerance increased. Centrifuge sensitivity tolerance decreased. Metal case replaces plastic.	13 Dec 78	

SOURCE CONTROL DRAWING

THIS DOCUMENT HAS BEEN RELEASED FOR PRELIMINARY PROCUREMENT INITIATED BY HARRY DIAMOND LABORATORIES AND IS SUBJECT TO FINAL REVIEW AND CORRECTION.

REV STATUS OF SHEETS												
REV	A	–	–	–	–	–	–	–	–	–	–	–
SHEET	1	2	3	4	5	6	7	8	9	10	11	12

REV STATUS OF SHEETS											
REV	–	–	–	–	A	–	A	–	–	–	A
SHEET	13	14	15	16	17	18	19	20	21	22	23

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES ON DECIMALS ± —
FRACTIONS ± — ANGLES ± —
MATERIAL —
HEAT TREATMENT —
FINAL PROTECTIVE FINISH —

ORIGINAL DATE OF DRAWING 7 June 1977
DRAFTSMAN CP
CHECKER WGS
ENGR SC
ENGR
ENGR
ENGR
SUBMITTED
APPROVED

U.S. ARMY
HARRY DIAMOND LABORATORIES
WASHINGTON, D.C. 20438

OSCILLATOR

SIZE A
CODE IDENT NO 19202
11726813
SCALE —
REV A
SHEET 1 of 23

Figure A-1. Source control drawing for precision oscillator, P/N 11726813.

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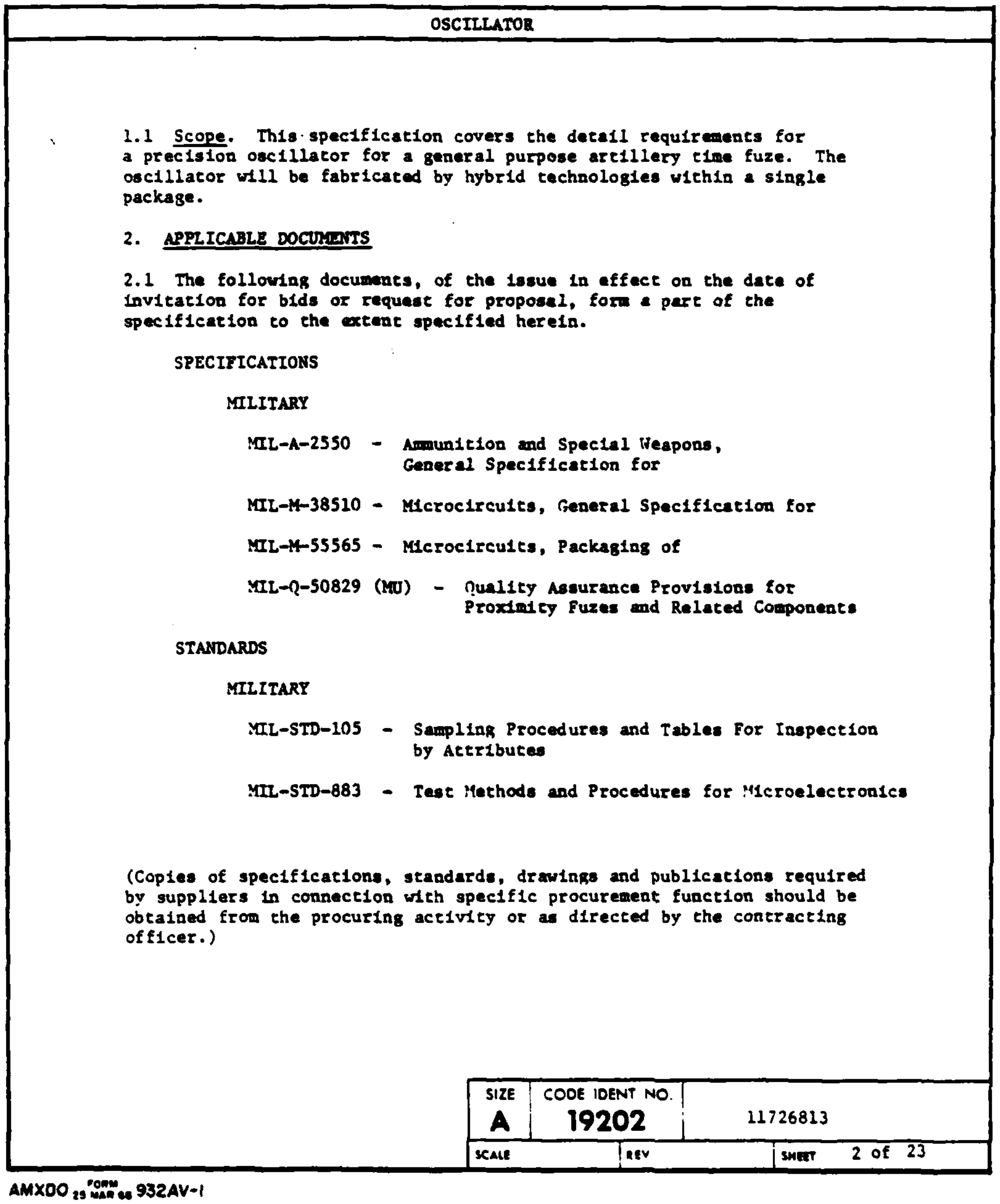
FROM COPY FURNISHED TO DDC



OSCILLATOR

1.1 Scope. This specification covers the detail requirements for a precision oscillator for a general purpose artillery time fuze. The oscillator will be fabricated by hybrid technologies within a single package.

2. APPLICABLE DOCUMENTS

2.1 The following documents, of the issue in effect on the date of invitation for bids or request for proposal, form a part of the specification to the extent specified herein.

SPECIFICATIONS

MILITARY

MIL-A-2550 - Ammunition and Special Weapons, General Specification for

MIL-M-38510 - Microcircuits, General Specification for

MIL-M-55565 - Microcircuits, Packaging of

MIL-Q-50829 (MU) - Quality Assurance Provisions for Proximity Fuzes and Related Components

STANDARDS

MILITARY

MIL-STD-105 - Sampling Procedures and Tables For Inspection by Attributes

MIL-STD-883 - Test Methods and Procedures for Microelectronics

(Copies of specifications, standards, drawings and publications required by suppliers in connection with specific procurement function should be obtained from the procuring activity or as directed by the contracting officer.)

SIZE	CODE IDENT NO.	
A	19202	11726813
SCALE	REV	SHEET 2 of 23

AMXDO FORM 25 MAR 68 932AV-1

Figure A-1.-Continued.

OSCILLATOR

3. REQUIREMENTS

3.1 Samples. The contractor is responsible for all requirements for providing and testing of samples as prescribed herein. When this specification is assigned to a subcontractor, it shall be the prime contractor's responsibility to insure that sample requirements are met. The prime contractor shall notify the Government at the time of assignment to a subcontractor whether the testing will be performed by the prime or by the subcontractor, as well as the method of control by the prime contractor.

3.1.1 First article sample. Prior to the start of regular production, except when production on a new contract at the same facility follows within 90 days production of acceptable material under this specification, the contractor shall manufacture and submit a first article sample of 174 units using as far as possible the methods and processes proposed for quantity production. When processes differ from the production processes, they shall be basically equivalent and the difference shall be fully described in documentation submitted with the first article sample. The sample shall conform to the requirements of this specification. Additional samples that may be required because of failure of the sample to meet the requirements of this specification shall be supplied by the contractor at his expense. Prior to approval of the first article sample, acquisition of parts and materials or initiation of production will be at the sole risk of the contractor.

3.1.2 Supplemental sample. At the Government's discretion a supplemental sample of 174 units may be required whenever there is a break in production continuity of 90 days or more, or a change in design, material or process which may affect safety, operability, reliability, or interchangeability as defined by the Requirements (3.3). In all cases, such changes will require prior approval of the procuring activity.

3.1.3 Comparison sample. Ten devices selected at random from each accepted lot (not from acceptance sample) or as specified by the Government Technical Agency shall be shipped within two working days after lot acceptance to the agency designated by the Government.

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A	19202	11726813
SCALE	REV	SHEET 3 of 23

AMXDO FORM 25 MAR 68 932AV-1

Figure A-1.-Continued.

OSCILLATOR

3.2 Construction. The device shall be constructed in accordance with the applicable drawings (sheets 22 and 23) to the extent prescribed herein.

3.2.1 Materials. Materials shall be those specified by the applicable drawings.

3.2.2 Dimensions and technical notes.

3.2.2.1 Listed. Those dimensions and technical requirements listed in the Classification of Defects are mandatory.

3.2.2.2 Unlisted. The contractor may propose changes to characteristics shown on the drawings for the purpose of adapting the item to established manufacturing practices. Such proposals must be accompanied by evidence that the change does not affect the function of the item and that all requirements will be met. If the Government confirms the contention of the contractor, the change will be approved for the duration of the contract. In case of dispute, the characteristics of the drawings shall apply. Approval of a change under provisions of this paragraph does not relieve the contractor from establishing and maintaining an adequate quality assurance program as elsewhere required. Provisions of this paragraph shall not be used to obtain approval for use of discrepant material (i.e., produced before approval is obtained); or for design changes, which should be requested in accordance with change provisions of the contract document.

Note: It is expected that the above changes will normally be accomplished prior to the construction of the First Article Approval Sample and reflected therein.

3.2.2.3 Interchangeability. While the dimensions and tolerances shown in the drawings and specifications will generally insure satisfactory products, the contractor is notified that some selection or matching may be required to obtain combinations which provide proper function or economic use of components. The contractor is responsible for selecting combinations of tolerances within the specified limits which satisfy his process needs and also meet the specified performance and fit requirements.

SIZE A	CODE IDENT NO 19202	11726813
SCALE	REV	SHEET 4 of 23

AMXDO FORM 25 MAR 66 932AV-1

Figure A-1.-Continued.

OSCILLATOR

3.3 Performance requirements. Performance requirements cited in Tables 1, 2, and 3 of this specification are mandatory.

3.4 Markings. The following minimum markings shall apply: part number, inspection lot identification code and manufacturer's identifications as described in MIL-M-38510.

3.5 Workmanship. All parts shall be manufactured and finished in a thoroughly workmanlike manner to insure satisfactory functioning and durability. (See MIL-M-38510, paragraph 3.7)

3.6 Additional requirements. The following paragraphs of MIL-M-38510 also form a part of this specification.

3.4.1.1 General
3.4.2.1 Change of product or process
3.5.2 Metals
3.5.3 Other materials
3.5.4 Design documentation including subparagraphs
3.5.5 Internal conductors
3.6 Marking of microcircuits including only 3.6.1, .2, .3, .4 and .8
3.7 Workmanship including 3.7.1, 3.7.1.1 and 3.7.1.2

4. QUALITY ASSURANCE PROVISIONS

4.1 Responsibility for inspection. Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all inspection requirements as specified herein. Except as otherwise specified in the contract or order, the supplier may use his own or any other facilities suitable for the performance of the inspection requirements specified herein, unless disapproved by the Government. The Government reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements.

4.1.1 Contractor quality assurance system. The contractor shall provide and maintain an adequate quality assurance system in compliance with MIL-Q-50829 (MU).

SIZE **A**	CODE IDENT NO. **19202**	11726813
SCALE	REV	SHEET 5 of 23

AMXDO FORM 25 MAR 68 932AV-1

Figure A-1.-Continued.

OSCILLATOR

4.2 Government verification. All quality assurance operations performed by the contractor will be subject to Government verification in compliance with MIL-Q-50829 (MU).

4.3 First article sample inspection. Inspection shall be as specified in this document and referenced paragraphs of MIL-M-38510. The tests shall be performed by the contractor under the observation of the Government QA representative and/or a representative of the cognizant technical agency. The contractor shall supply complete data in reproducible form on the contractor tests and examinations of the first article approval sample units. The data and tested samples shall be delivered to the technical agency.

4.3.1 First article lot formation. The contractor shall provide 174 devices for inspection in accordance with paragraph 3.1.1.

4.3.2 First article serialization. The devices to be used for tests with electrical limits or endpoints shall be serially numbered from 1 to 158 inclusive. The remaining 16 devices to be measured for solderability and lead strength may be mechanically representative electrical rejects and are to be numbered R1 to R16, inclusive.

4.3.3 First article sample tests. The first article sample shall be examined and tested in accordance with the Performance Requirements (3.3), Material and Component Certification (4.8.1) and the flow chart shown in Figure 1.

4.3.4 Approval of first article sample. If the sample passes the criteria of specified examinations and tests, it shall be approved. If the sample fails in any of the examinations and tests, failure analysis shall be conducted by the contractor under Government surveillance. The results of the tests and failure analysis of the units, together with the engineering analysis of the units, shall form a basis for corrective action. Depending upon the degree of corrective action deemed necessary by the Government, the first article sample may be:

SIZE A	CODE IDENT NO 19202	11726813
SCALE	REV	SHEET 6 of 23

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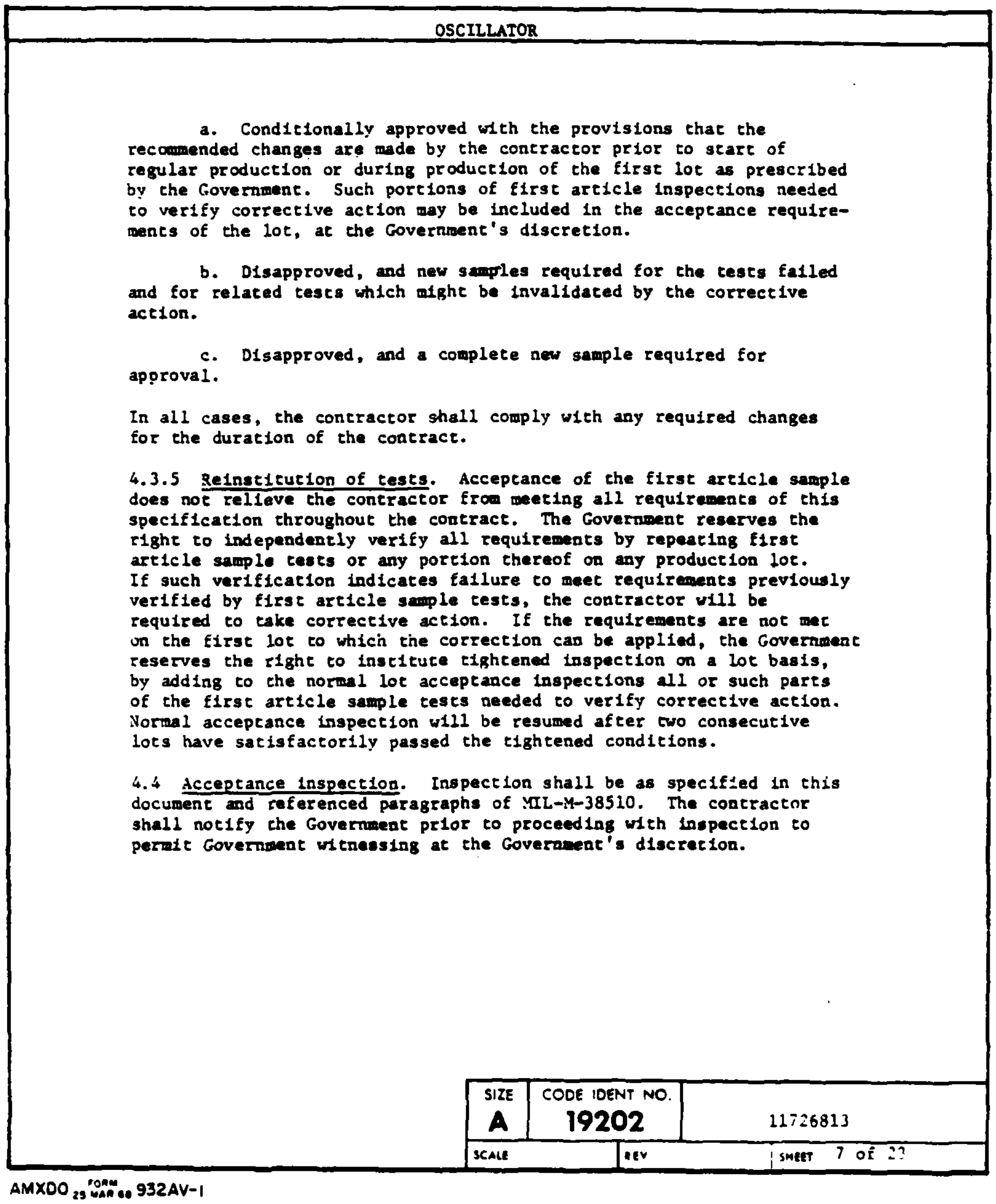
Figure A-1.-Continued.



OSCILLATOR

a. Conditionally approved with the provisions that the recommended changes are made by the contractor prior to start of regular production or during production of the first lot as prescribed by the Government. Such portions of first article inspections needed to verify corrective action may be included in the acceptance requirements of the lot, at the Government's discretion.

b. Disapproved, and new samples required for the tests failed and for related tests which might be invalidated by the corrective action.

c. Disapproved, and a complete new sample required for approval.

In all cases, the contractor shall comply with any required changes for the duration of the contract.

4.3.5 Reinstitution of tests. Acceptance of the first article sample does not relieve the contractor from meeting all requirements of this specification throughout the contract. The Government reserves the right to independently verify all requirements by repeating first article sample tests or any portion thereof on any production lot. If such verification indicates failure to meet requirements previously verified by first article sample tests, the contractor will be required to take corrective action. If the requirements are not met on the first lot to which the correction can be applied, the Government reserves the right to institute tightened inspection on a lot basis, by adding to the normal lot acceptance inspections all or such parts of the first article sample tests needed to verify corrective action. Normal acceptance inspection will be resumed after two consecutive lots have satisfactorily passed the tightened conditions.

4.4 Acceptance inspection. Inspection shall be as specified in this document and referenced paragraphs of MIL-M-38510. The contractor shall notify the Government prior to proceeding with inspection to permit Government witnessing at the Government's discretion.

SIZE A	CODE IDENT NO. 19202		11726813
SCALE		REV	SHEET 7 of 23

AMXDO FORM 25 MAR 68 932AV-1

Figure A-1.-Continued.

OSCILLATOR

4.4.1 Lot formulation. A lot shall consist of devices produced at one manufacturing location under the following conditions: continuous production, stabilized methods and techniques, and the same revision of drawings and specification except for those introduced without obsolescence.

4.4.2 Inspection lot size. An inspection lot is defined as a maximum of 20,000 devices or the quantity produced over a 30-calendar-day period whichever is smaller, presented for acceptance at one time. No minimum lot size is specified for procurements less than 50,000 units. Procurements for 50,000 units or more shall have a minimum lot size of 2000 for lot 1; 5000 for all subsequent lots.

4.4.3 Selection of sample. At the time a completed lot is presented to the Government for acceptance, the designated Government representative shall select from the lot a random sample of devices sufficient in number to conduct required tests (as shown in Tables 1, 2, and 3) on the lot to the maximum acceptance number for the specified LTPD. Choice of less than the maximum acceptance numbers will permit a smaller test sample as tabulated in MIL-M-38510 Table B-1. All devices to be used for tests with electrical limits or endpoints shall be serially numbered. The lot presented for acceptance shall be placed in bonded storage immediately after lot acceptance samples have been selected, and shall remain under Government control until all acceptance tests have been completed, or the lot has been rejected. All samples shall be in bonded storage except when actually under test or environmental conditioning. For sampling other than LTPD, MIL-STD-105 inspection level II applies.

4.4.4 Lot acceptance sample tests. The lot acceptance sample shall be examined and tested in accordance with the Performance Requirements (3.3), Material and Component Certification (4.8.1) and the flow chart shown in Figure 1. Where less than 174 devices are chosen for test, the device numbers and maximum accept numbers will be adjusted accordingly with the following provisions: (1) sequence of testing will be as shown in Figure 1 and (2) all group A tests will be performed on sequentially numbered devices beginning with number 1.

SIZE	CODE IDENT NO.	
A	19202	11726813
SCALE	REV	SHEET 8 of 23

AMXDO FORM 25 MAR 68 932AV-1

Figure A-1.-Continued.

OSCILLATOR

4.4.5 Lot acceptance approval. If the sample passes the criteria of the specified examinations and tests, the lot shall be approved. If the sample fails, resubmission procedures cited in MIL-M-38510 paragraph 4.3.3.1 are applicable.

4.4.6 Data recording. A written record shall be made of the results of all examinations and tests performed as specified elsewhere in section 4 of this specification. The test data shall be recorded on 80 column standard data processing punch cards, or other computer compatible input medium approved by the Government. Data from each operating test shall be recorded. Data layout of the card shall be approved by the Government. The completed cards shall be forwarded to the designated Government agency within two working days after the Government acceptance of the item or lot. If inspections are conducted on a sublot basis, the acceptance data for each sublot shall be so identified. (Engineering information, section 6).

4.5 Quality conformance inspection. Quality conformance inspection shall consist of Group A, B, and C inspections.

4.5.1 Group A inspection. Group A inspection shall consist of the examinations and tests specified in table 1.

4.5.2 Group B inspection. Group B inspection shall consist of the examinations and tests specified in table 2. Devices used for Group B inspection shall have been subjected to Subgroup A1 tests. Any device failing Subgroup A1 tests shall be removed from the Group B sample and replaced with a unit that has passed Subgroup A1 requirements. Such initial failures shall not be counted as Group B failures. With the Government's permission, the solderability and lead integrity tests may be conducted with electrical rejects. Group B tests are considered destructive tests, and separate devices shall be used in each of the subgroups.

SIZE A	CODE IDENT NO. 19202	11726313
SCALE	REV	SHEET 9 of 23

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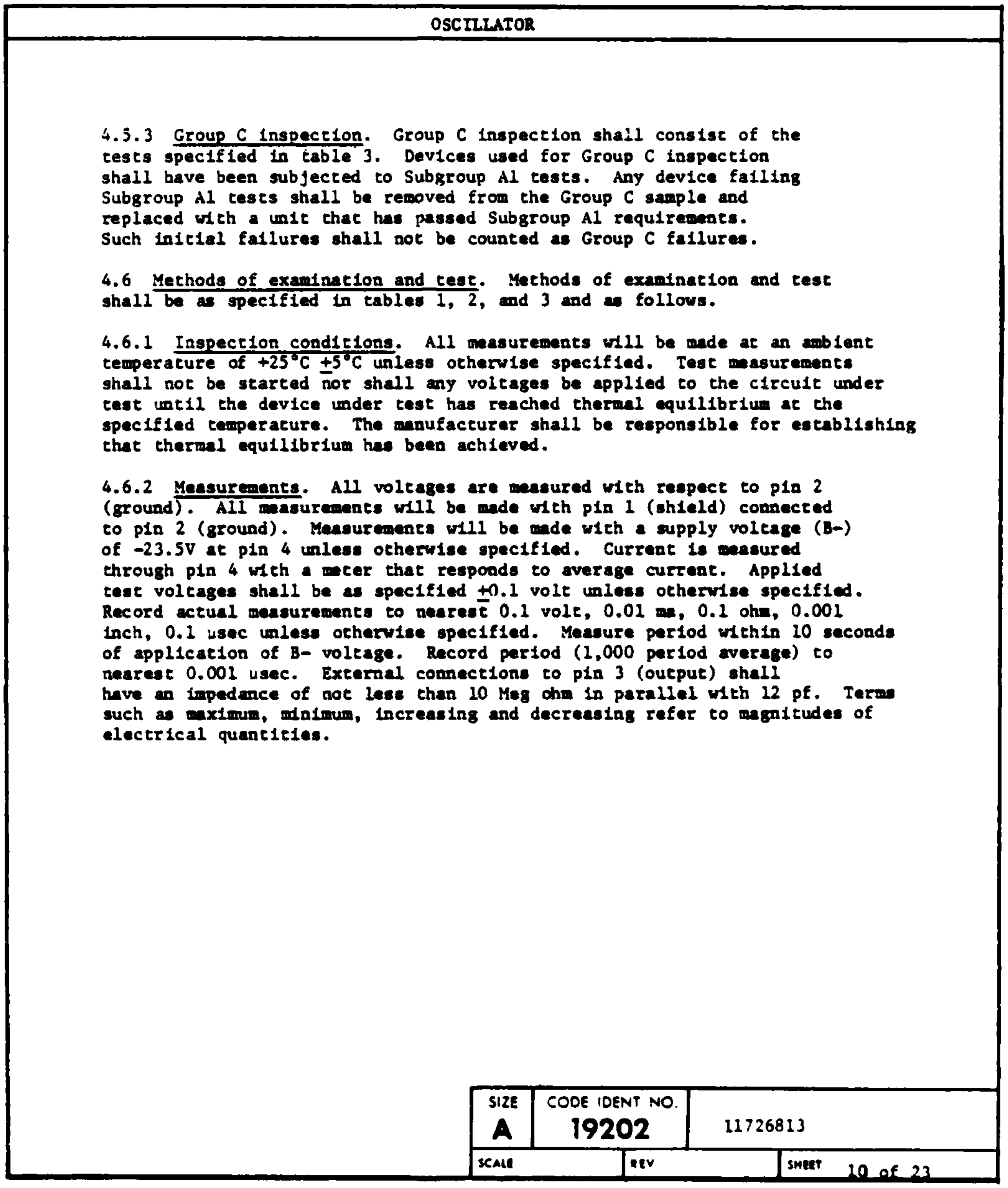
Figure A-1.-Continued.



OSCILLATOR

4.5.3 Group C inspection. Group C inspection shall consist of the tests specified in table 3. Devices used for Group C inspection shall have been subjected to Subgroup A1 tests. Any device failing Subgroup A1 tests shall be removed from the Group C sample and replaced with a unit that has passed Subgroup A1 requirements. Such initial failures shall not be counted as Group C failures.

4.6 Methods of examination and test. Methods of examination and test shall be as specified in tables 1, 2, and 3 and as follows.

4.6.1 Inspection conditions. All measurements will be made at an ambient temperature of +25°C ±5°C unless otherwise specified. Test measurements shall not be started nor shall any voltages be applied to the circuit under test until the device under test has reached thermal equilibrium at the specified temperature. The manufacturer shall be responsible for establishing that thermal equilibrium has been achieved.

4.6.2 Measurements. All voltages are measured with respect to pin 2 (ground). All measurements will be made with pin 1 (shield) connected to pin 2 (ground). Measurements will be made with a supply voltage (B-) of -23.5V at pin 4 unless otherwise specified. Current is measured through pin 4 with a meter that responds to average current. Applied test voltages shall be as specified ±0.1 volt unless otherwise specified. Record actual measurements to nearest 0.1 volt, 0.01 ma, 0.1 ohm, 0.001 inch, 0.1 µsec unless otherwise specified. Measure period within 10 seconds of application of B- voltage. Record period (1,000 period average) to nearest 0.001 usec. External connections to pin 3 (output) shall have an impedance of not less than 10 Meg ohm in parallel with 12 pf. Terms such as maximum, minimum, increasing and decreasing refer to magnitudes of electrical quantities.

SIZE	CODE IDENT NO.	
A	19202	11726813
SCALE	REV	SHEET 10 of 23

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Figure A-1.-Continued.

OSCILLATOR

4.6.2.1 Group A. All measurements will be made at a supply voltage of -23.5 volts unless otherwise specified. Measure rise time between -7.0V and -2.0V. Measure fall time between -2.0V and -7.0V. Measure time high at -5.0V thresholds starting at the positive going transition.

4.6.2.2 Group B. Measure periods TS1 and TS3 within one hour before acceleration and shock respectively. Measure periods TS2 and TS4 within one hour after acceleration and shock respectively.

4.6.2.3 Temperature control. Each group of period measurements listed below shall be made at the same temperature, within the tolerance specified.

Test Subgroup	Measurement Symbols	Temperature Tolerance
A1	TA. [illegible], TG	±1°C
B1	TT1, TT2	±2°C
B2	TS1, TS2	±2°C
B3	TT3, TT4	±2°C
B4	TS3, TS4	±1°C
C1	TGA, TGB	±2°C

4.7 Data recording. A written record shall be made of the results of all examinations and tests performed as specified elsewhere in section 4. Summary scores shall be recorded for each subgroup, and these scores plus the variables data identified in 4.7.1 and in the notes to figure 1 shall be delivered with each lot.

4.7.1 Variables data. The variables data required to be recorded for those devices in each subgroup called out in the notes to figure 1 are shown in Table 1 Subgroups A1, A2; in Table 2 Subgroups B1, B2, B3, B4; and in Table 3 Subgroup C1.

4.7.2 Data format. The variables data shall be tabulated in a format which will permit a single parameter for the complete sample to be summarized on a single page. A typical format including sample data is:

SIZE	CODE IDENT NO.		
A	19202	11726813	
SCALE	REV	SHEET 11 of 23	

AMXDO FORM 25 MAR 68 932AV-1

Figure A-1.-Continued.

APPENDIX A

OSCILLATOR

TABLE 1 SUBGROUP 1 TEST

Device Identification		Current IA, mA		
Date Code	Unit No.	-50°C	25°C	71°C
75-42	21	-2.3	-2.3	-2.6
75-42	22	-2.1	-2.2	-2.5

TABLE 2 and 3 TESTS

Device Identification		Period, Microseconds	
Date Code	Unit No.	Before Envir.	After Envir.
75-42	51	101.076	101.003
75-42	52	98.317	98.301

4.8 Additional provisions. The following paragraphs of MIL-M-38510 also form a part of this specification.

4.1	Responsibility for inspection (including all subparagraphs)
4.3.2.1	Disposal of samples
4.3.2.2	Destructive tests
4.3.3.1	Resubmission of failure lots
4.3.4	Test method deviation
4.3.5	Procedure in case of test equipment failure or operator error
4.4.2.1.6	Data

4.8.1 Material and component certification. Prior to acceptance under this procurement, the contractor shall demonstrate by means of certifications or statement of findings that only materials and components conforming to the item specification and drawings have been used.

SIZE A	CODE IDENT NO. 19202	11726813
SCALE	REV	SHEET 12 of 23

AMXDO FORM 25 MAR 68 932AV-1

Figure A-1.-Continued.

OSCILLATOR

5. PREPARATION FOR DELIVERY

5.1 Preparation for delivery shall conform to MIL-M-55565, level C.

5.1.1 In addition to the contract or purchase order number, the shipping label shall make reference to this specification.

6. NOTES

6.1 Items to be included in the procurement documents.

6.1.1 Documents. Procurement documents should specify the title, date, and number of this specification.

6.1.2 Samples. The number of units should be increased to include the samples as required in 3.1.1 and 4.4.3 since they are not included in the number of units required for delivery.

6.1.3 Government testing of comparison samples. These samples are subject to retesting by the Government to insure that first article approval requirements continue to be met. Failure of these samples will not affect the acceptance of the lot, but may indicate future mandatory action.

6.1.4 Data requirements. The following data are required by this specification to be furnished to the Government and should be entered on DD Form 1423 for each contract:

First Article Test Results (4.3)
Examination and Test Records on Data Processing Cards (4.4.6)
MIL-Q-50829 (MU), Par. 3.6.1 — Contractor-furnished Designs

6.2 Advisory documents. The following documents are not part of this specification, but may provide useful data to the contractor. Copies are available for reference at the Harry Diamond Laboratories.

SIZE A	CODE IDENT NO. 19202	11726813	
SCALE	REV	SHEET 13 of 23	

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Figure A-1.-Continued.

OSCILLATOR

6.2.1 Manufacturing process report or description of manufacture.

6.2.2 Quality assurance system documents obtained from previous contracts.

6.3 The following table is included for reference. All numbers are taken from LTPD Sampling Plans.

SUBGROUP	TEST	LTPD	MAX ACC NO	MAXIMUM QUANTITY	AQL
A1	Oscillator Characteristics	5	4	158	1.3
A2	Electrostatic Shield & Visual	20	1	18	2.0
B1	Temperature Cycling	15	1	25	1.4
B3	High Temperature Storage	15	1	25	1.4
B4	Shock	15	1	25	1.4
B5	Solderability	30	0	8	0.64
B6	Lead Integrity	30	0	8	0.64
C1	Gun Fire	10	1	38	0.94

6.4 Engineering information. Upon request, copies of the data collected in the acceptance of a lot will be made available to the Government representative. Additional data or data requiring special tests, when needed for engineering purposes, will be specifically defined by the contract.

6.5 *Results of Table 3, Subgroup C1 test. If the Government does* not return the devices to the contractor within 30 working days, Table 3 Subgroup C1 test will not be a requirement for acceptance.

6.6 Approved Source. Approved source of supply:

Honeywell, Inc.
Defense Systems Division
600 Second St. NE
Hopkins, MN 55343

SIZE A	CODE IDENT NO. 19202	11726813
SCALE	REV	SHEET 14 of 23

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Figure A-1.-Continued.

OSCILLATOR

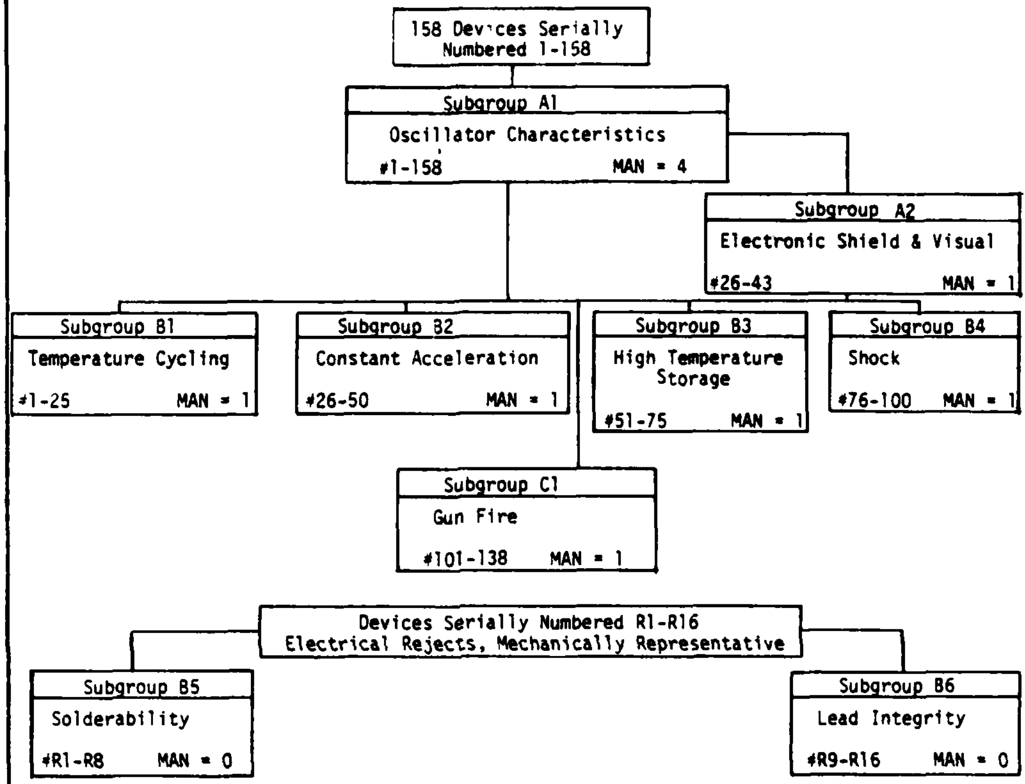

FIGURE 1 TEST FLOW CHART

SIZE	CODE IDENT NO.	
A	19202	11726813

SCALE	REV	SHEET 15 of 23

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Figure A-1.-Continued.

OSCILLATOR

Figure 1 Notes

1. Variables data shall be recorded for devices #1-25 in subgroups A1. GO/NO GO data will be recorded for all other devices except that variables data will be recorded for all failed devices.

2. Variables data shall be recorded on the first 10 devices in subgroups B1, B2, B3, B4, and C1. GO/NO GO data is acceptable for the remaining devices in these subgroups.

3. Thirty eight devices which successfully passed subgroup A1 tests will be supplied to HDL for vertical recovery firing the 57-mm projectile (Subgroup C1) and returned to the contractor for retesting.

4. Electrically defective devices from the same production lot from which the acceptable lot was formed may be used for subgroups B5 and B6.

SIZE A	CODE IDENT NO. 19202	11726813
SCALE	REV	SHEET 16 of 23

AMXDO FORM 25 MAR 68 932AV-1

Figure A-1.-Continued.

OSCILLATOR

TABLE 1: GROUP A INSPECTION

EXAMINATION OR TEST	CONDITIONS					LIMITS		
	MIL-STD-883 METHOD	SPECIFIC CONDITIONS	LTPD	MAX ACC NO	SYMBOL	MAX	MIN	UNITS
Subgroup 1			5	4				
Oscillator Characteristics		T=25 ±2°C						
		Period			TA	107.000	96.000	µs
		Period at B- = -17.0V			TJ	TA+.025	TA-.025	µs
		Period at B- = -30.0V			TG	TA+.020	TA-.020	µs
		Rise time			TRA	3.0		µs
		Fall time			TFA	3.0		µs
		Time High			THA	60.0	35.0	µs
		Supply current			IA	2.70		mA
		T=45 ±2°C						
		Period			TB	TA+.150	TA-.150	µs
		T=71 ±2°C						
		Period			TC	TA+.350	TA-.350	µs
		Rise time			TRC	3.0		µs
		Fall time			TFC	3.0		µs
		Time high			THC	60.0	35.0	µs
		Supply current			IA	2.70		mA
		T=0 ±2°C						
		Period			TD	TA+.190	TA-.190	µs
		T= -30 ±2°C						
		Period			TE	TA+.410	TA-.410	µs
		T= -50 ±2°C						
		Period			TF	TA+.580	TA-.580	µs
		Rise time			TRF	3.0		µs
		Fall time			TFF	3.0		µs
		Time high			THF	60.0	35.0	µs
		Supply current			IA	2.70		mA

SIZE	CODE IDENT NO.	
A	19202	11726813
SCALE	REV A	SHEET 17 of 23

AMXDO FORM 25 MAR 68 932AV-1

Figure A-1.-Continued.

OSCILLATOR

TABLE 1: GROUP A INSPECTION (continued)

EXAMINATION OR TEST	CONDITIONS		LTPD	MAX ACC NO	SYMBOL	LIMITS		UNITS
	MIL-STD-883 METHOD	SPECIFIC CONDITIONS				MAX	MIN	
<u>Subgroup 2</u>			20	1				
Electrostatic Shield Attachment		Measure resistance between pin 1 and top of package			R	5		ohms
External Visual	2009	Sheet 23						

SIZE	CODE IDENT NO.	
A	19202	11726813
SCALE	REV	SHEET 18 of 23

AMXDO FORM 25 MAR 68 932AV-1

Figure A-1.-Continued.

OSCILLATOR

TABLE 2: GROUP B INSPECTION

EXAMINATION OR TEST	CONDITIONS		LTPD	MAX ACC NO	SYMBOL	LIMITS		UNITS
	MIL-STD-883 METHOD	SPECIFIC CONDITIONS				MAX	MIN	
Subgroup 1			15	1				
Temperature Cycling	1010	Period before test Test condition A except step 3 Temp is 71 ±2°C and steps 1 and 3 stabilization times 15 minutes, 8 cycles.			TT1	107.00	96.000	µs
		Period after test			TT2	TT1+.250	TT1-.250	µs
Subgroup 2			15	1				
Constant Acceleration	2001	Period at 0 rps			TS1	107.000	96.000	µs
		Period at test 12500g's orientation Y1			TS2	TS1+.040	TS1-.040	µs
Subgroup 3			15	1				
High Temperature Storage	1008	Period before test Test condition B Test Duration 500 hrs			TT3	107.000	96.000	µs
		Period after test			TT4	TT3+.250	TT3-.250	µs
Subgroup 4			15	1				
Shock	2002	Period before test Test condition G one shock in orientation Z1			TS3	107.000	96.000	µs
		Period after test			TS4	TS3+0.020	TS3-0.020	µs

SIZE	CODE IDENT NO	
A	19202	11726813
SCALE	REV A	SHEET 19 of 23

AMXDO FORM 25 MAR 68 932AV-1

Figure A-1.-Continued.

OSCILLATOR

TABLE 2: GROUP B INSPECTION (continued)

EXAMINATION OR TEST	CONDITIONS		LTPD	MAX ACC NO	SYMBOL	LIMITS		UNITS
	MIL-STD-883 METHOD	SPECIFIC CONDITIONS				MAX	MIN	
<u>Subgroup 5</u> Solderability	2003	Pins 1,2,3,4	30	0				
<u>Subgroup 6</u> Lead Integrity	2004	Test condition B2 Pins 1,2,3,4	30	0				

SIZE A	CODE IDENT NO. 19202	11726813
SCALE	REV	SHEET 20 of 23

AMXDO FORM 23 MAR 68 932AV-1

Figure A-1.-Continued.

OSCILLATOR

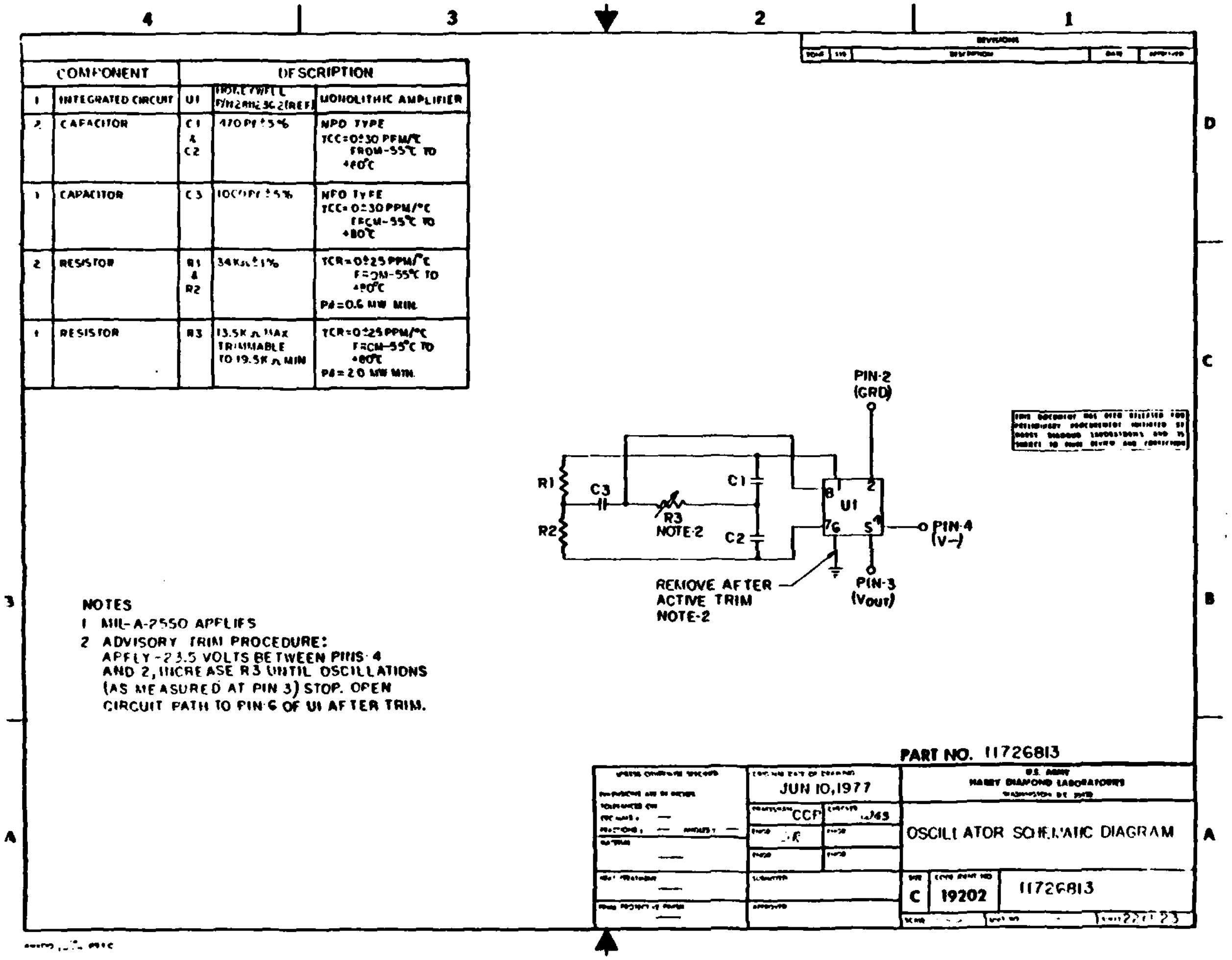
TABLE 3: GROUP C INSPECTION

EXAMINATION OR TEST	CONDITIONS		LTPD	MAX ACC NO	SYMBOL	LIMITS		UNITS
	METHOD	SPECIFIC CONDITIONS				MAX	MIN	
<u>Subgroup 1</u>			10	1				
Gun Fire		Period before test Government will fire devices in 57-mm gun Period after test			TGA TGB	107.000 TGA+.050	96.000 TGA-0.50	μs μs

SIZE	CODE IDENT NO.	
A	19202	11726813
SCALE	REV	SHEET 21 of 23

AMXDO [illegible]

Figure A-1.-Continued.



COMPONENT		DESCRIPTION		
1	INTEGRATED CIRCUIT	U1	HONEYWELL P/N 2HM23C2(REF)	MONOLITHIC AMPLIFIER
2	CAPACITOR	C1 & C2	470 PF ±5%	NPO TYPE TCC=0±30 PPM/°C FROM -55°C TO +80°C
1	CAPACITOR	C3	1000 PF ±5%	NPO TYPE TCC=0±30 PPM/°C FROM -55°C TO +80°C
2	RESISTOR	R1 & R2	34KΩ ±1%	TCR=0±25 PPM/°C FROM -55°C TO +80°C PA=0.6 MW MIN.
1	RESISTOR	R3	13.5K Ω MAX TRIMMABLE TO 19.5K Ω MIN	TCR=0±25 PPM/°C FROM -55°C TO +80°C PA=2.0 MW MIN.

NOTES
1 MIL-A-2550 APPLIES
2 ADVISORY TRIM PROCEDURE:
APPLY -23.5 VOLTS BETWEEN PINS 4 AND 2, INCREASE R3 UNTIL OSCILLATIONS (AS MEASURED AT PIN 3) STOP. OPEN CIRCUIT PATH TO PIN 6 OF U1 AFTER TRIM.

Figure A-1.-Continued.

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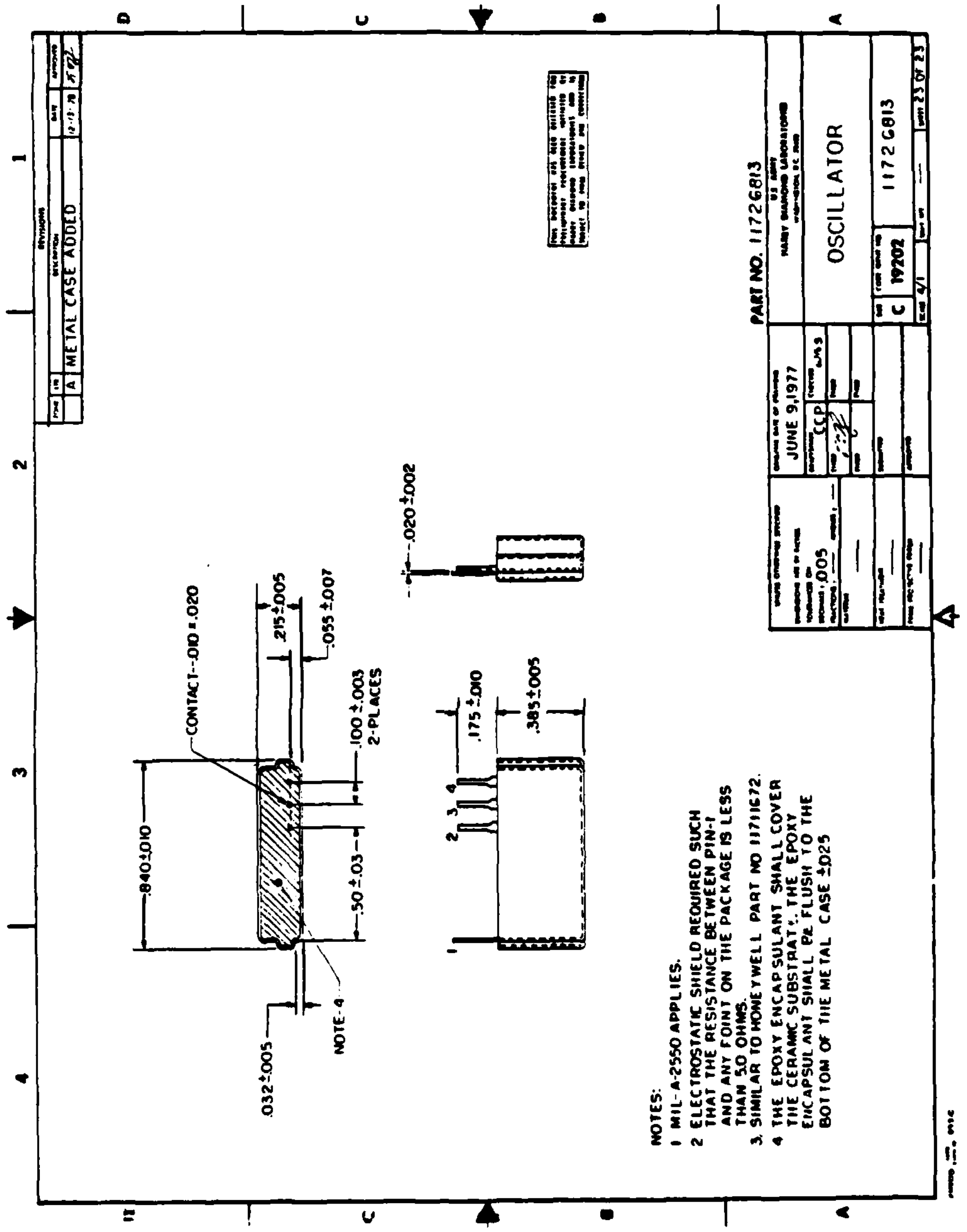

Figure A-1.-Concluded.

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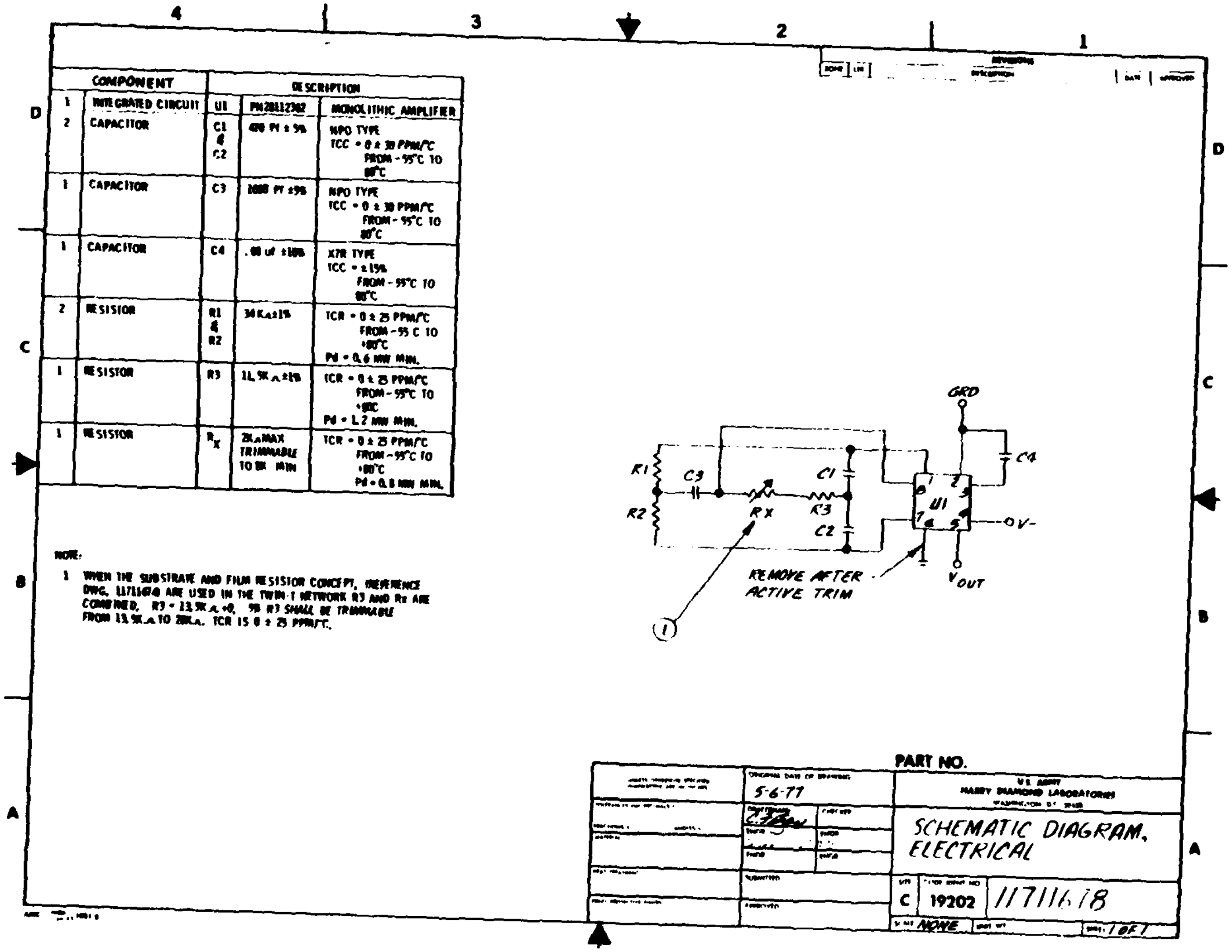
APPENDIX A



COMPONENT		DESCRIPTION		
1	INTEGRATED CIRCUIT	U1	PN28112302	MONOLITHIC AMPLIFIER
2	CAPACITOR	C1 & C2	470 PF ± 5%	NPO TYPE TCC = 0 ± 30 PPM/°C FROM -55°C TO 80°C
1	CAPACITOR	C3	1000 PF ±5%	NPO TYPE TCC = 0 ± 30 PPM/°C FROM - 55°C TO 80°C
1	CAPACITOR	C4	.08 uf ±10%	X7R TYPE TCC = ±15% FROM - 55°C TO 80°C
2	RESISTOR	R1 & R2	34 KΩ±1%	TCR = 0 ± 25 PPM/°C FROM -55 C TO +80°C Pd = 0.6 MW MIN.
1	RESISTOR	R3	11.9KΩ ±1%	TCR = 0 ± 25 PPM/°C FROM - 55°C TO +80C Pd = 1.2 MW MIN.
1	RESISTOR	R_X	2KΩ MAX TRIMMABLE TO 0K MIN	TCR = 0 ± 25 PPM/°C FROM -55°C TO +80°C Pd = 0.8 MW MIN.

NOTE:

1 WHEN THE SUBSTRATE AND FILM RESISTOR CONCEPT, REFERENCE DWG. 11711674 ARE USED IN THE TWIN-T NETWORK R3 AND Rx ARE COMBINED. R3 = 13.9KΩ +0, -5% R3 SHALL BE TRIMMABLE FROM 13.9KΩ TO 20KΩ. TCR IS 0 ± 25 PPM/°C.

Figure A-2. Electrical schematic diagram.

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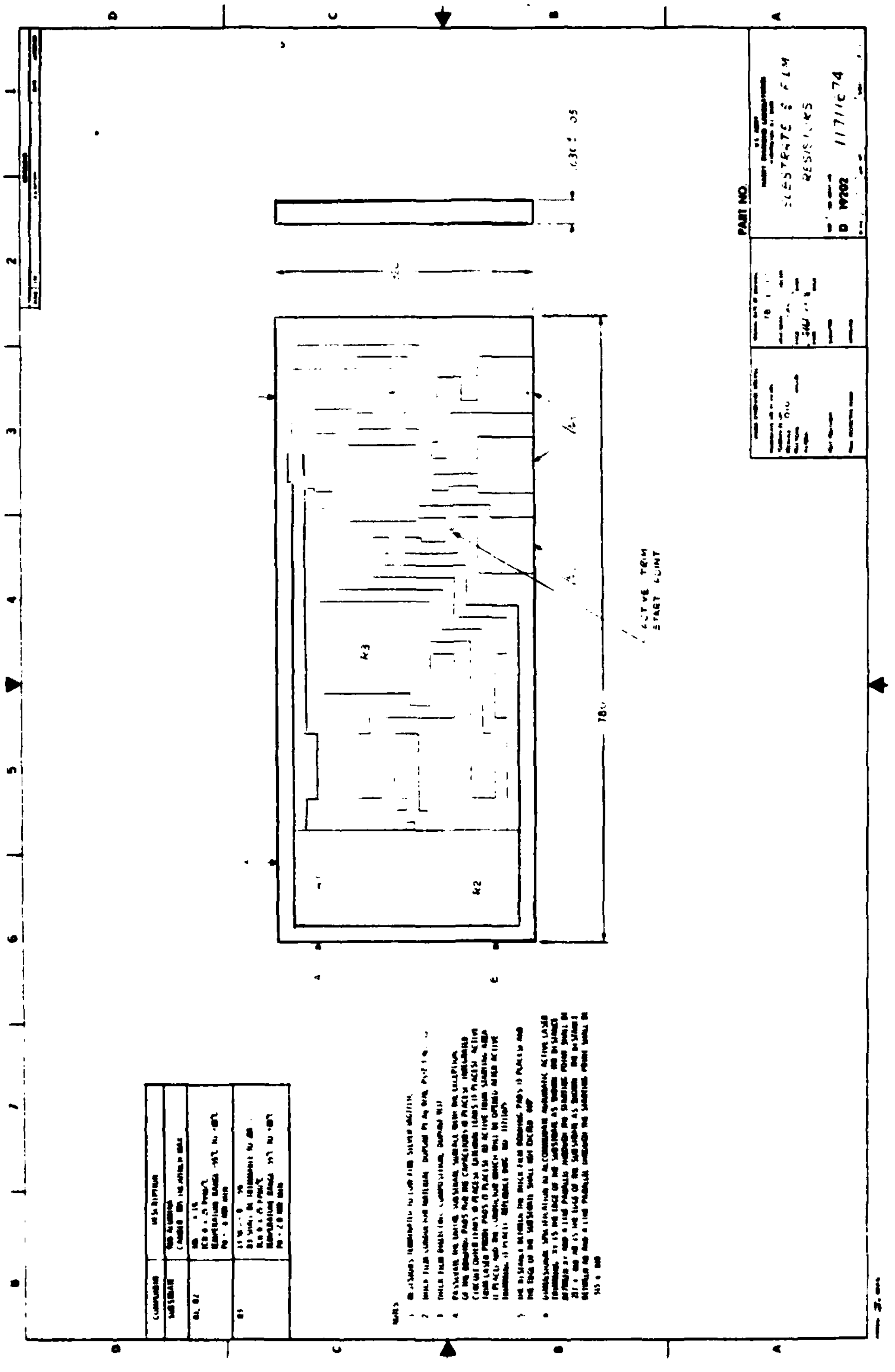

Figure A-3. Substrate and film resistors.

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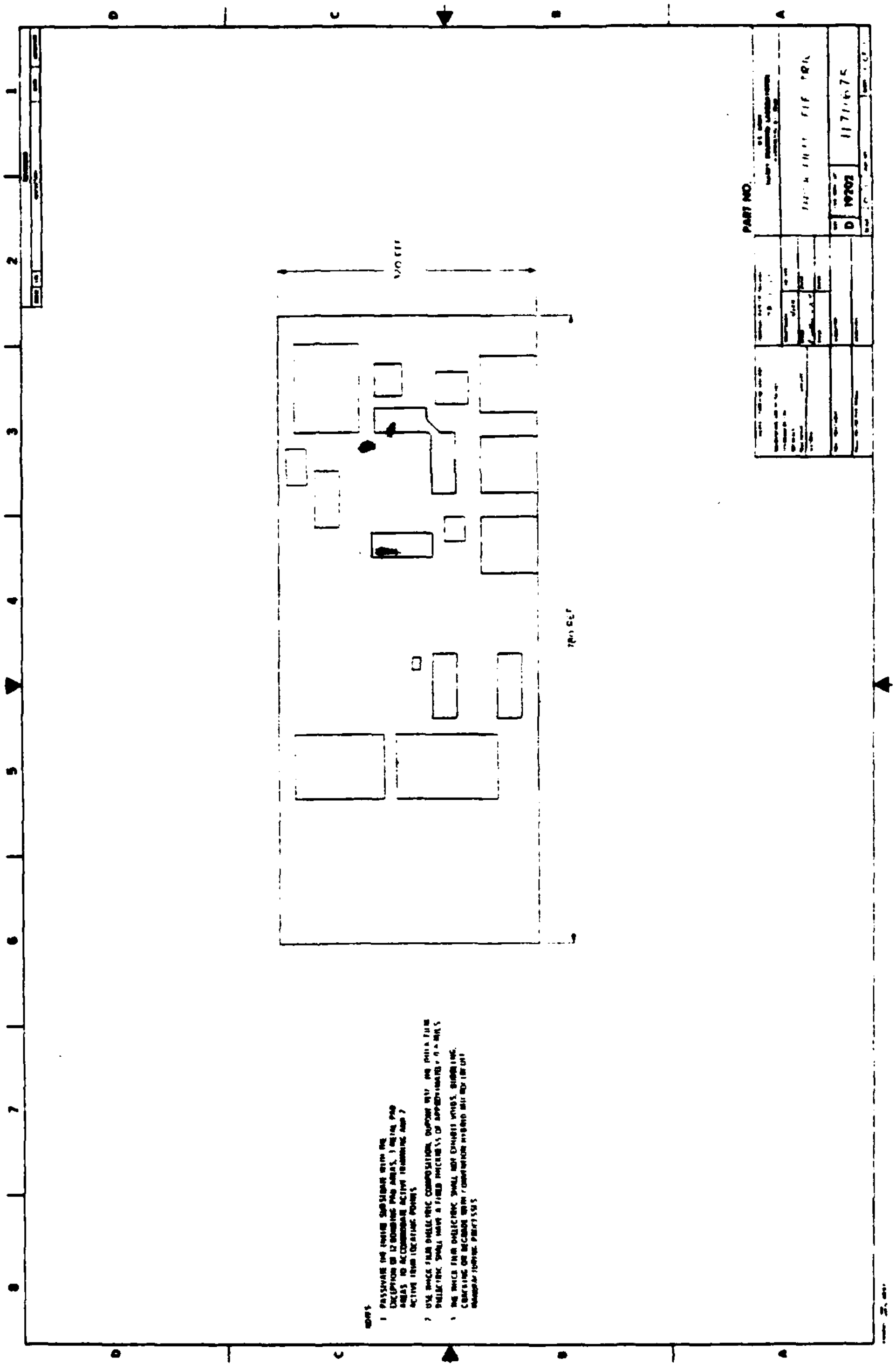

Figure A-4. Thick-film dielectric.

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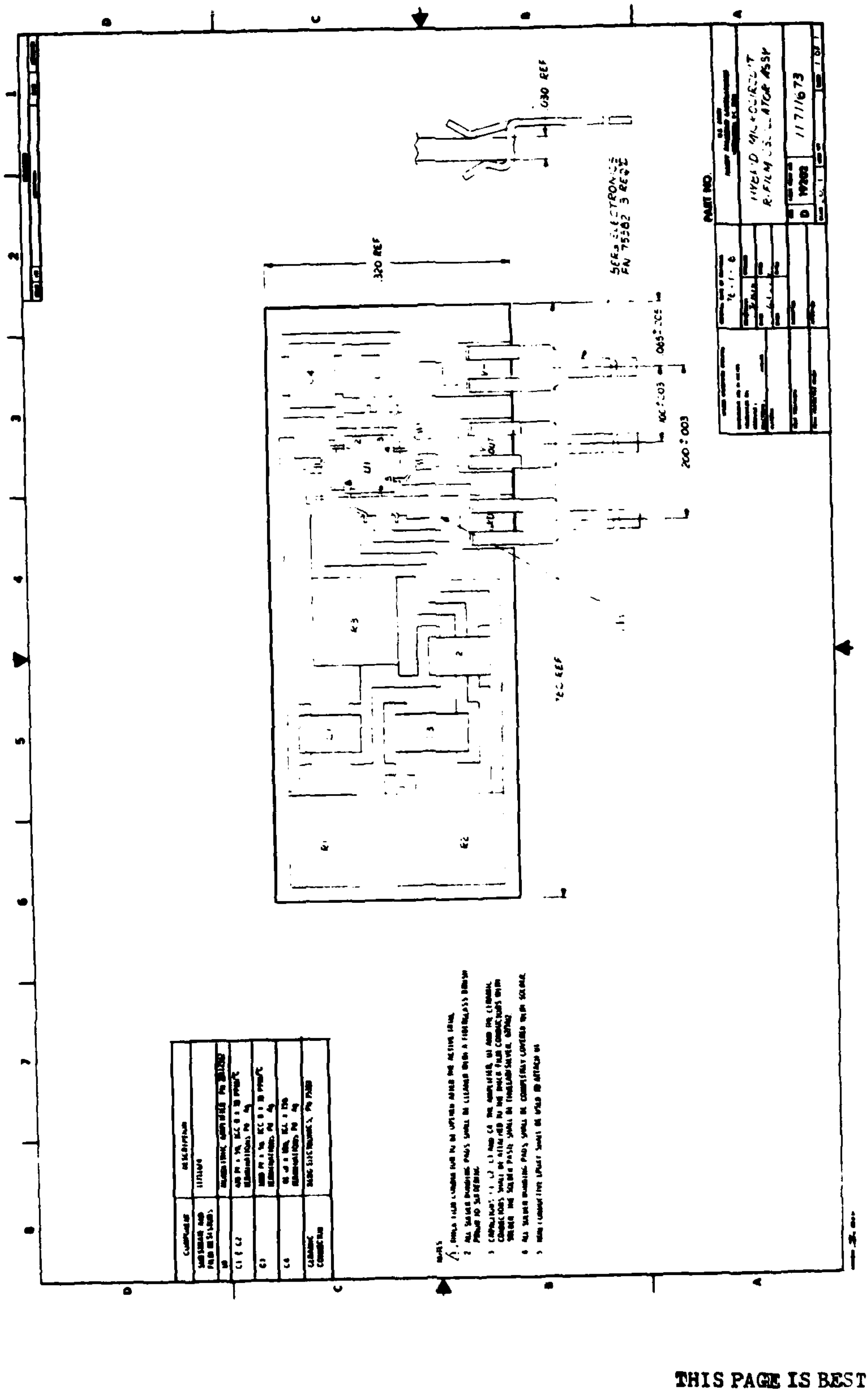

Figure A-5. Hybrid microcircuit R-film oscillator assembly.

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APPENDIX A

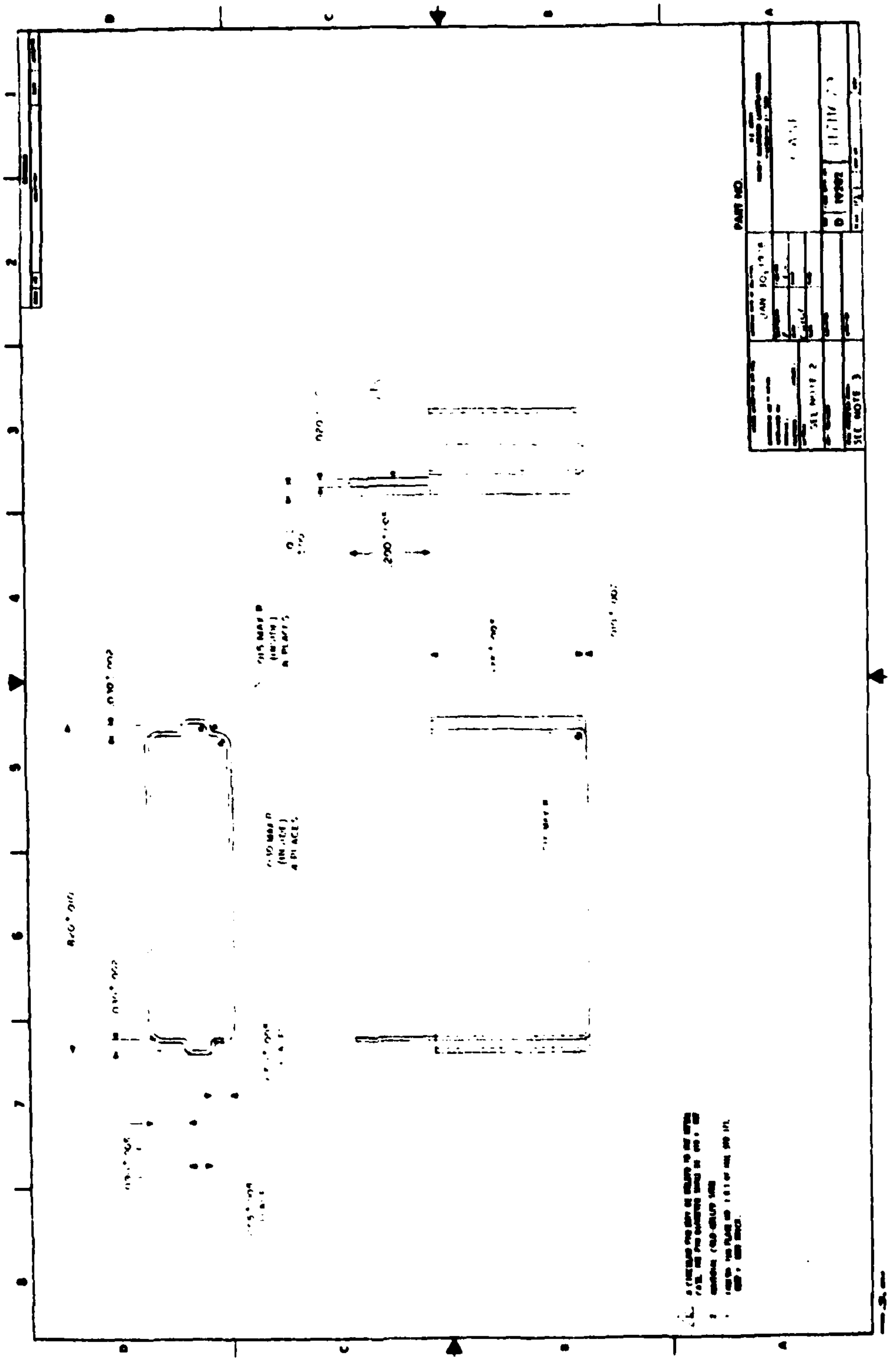

Figure A-6. Case.

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APPENDIX B

SOURCE CONTROL DRAWING FOR MONOLITHIC AMPLIFIER

APPLICATION	
NEXT ASSY	USED ON
	XM587

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED
A	ECO 78H2956	7-13-79	
B	ECO [illegible]	[illegible]	

DWG NO

REV																													
SHEET																													
REV	B	A	A	B	A	A	A	A	A	A	B	A	A	A	A														
SHEET	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29

TOLERANCES UNLESS NOTED OTHERWISE
X ±
XX ±
XXX ±
90° FORMED ANGLES + 2° − 1°

THIRD ANGLE PROJECTION

DRAWN BY		7-4-[illegible]
CHECKER		
DEV ENGR		
ENGRG MGT		

CONTRACT NO

AGENCY APPROVAL

Honeywell

DEFENSE SYSTEMS DIVISION
600 2ND STREET N E
HOPKINS MINNESOTA 55343

MONOLITHIC AMPLIFIER

SIZE	FSCM NO	DWG NO
A	08638	28112362

SCALE

SHEET 1 of 15

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APPENDIX B

1.0 SCOPE

This specification covers the requirements for a single, monolithic bipolar integrated circuit hereafter referred to as the component. The component will be purchased at the wafer level. This specification defines the qualification test, the sample tests, and the 100% wafer level tests. This component will be packaged in a hybrid microcircuit assembly for use in a general purpose artillery time fuze.

2.0 APPLICABLE DOCUMENTS

2.1 The following documents form a part of this drawing to the extent specified herein.

2.2 Military Specifications

MIL-STD-105	Sampling Procedures and Tables for Inspection by Attributes
MIL-STD-883	Test Methods and Procedures for Microelectronics
MIL-M-38510	Microcircuit, General Specification for

2.3 Honeywell Drawing

28115336	Circuit Diagram, Integrated Circuit, Bipolar Amplifier

Honeywell	REV	A	
DEFENSE SYSTEMS DIVISION 600 2ND STREET N.E. HOPKINS, MINNESOTA 55343	SIZE A	08638	DWG NO. 28112362
DRAWN			
ISSUED	SCALE		SHEET 2

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3.0 REQUIREMENTS

3.1 General

All requirements including order of precedence, symbols and abbreviations (unless otherwise specified in section 6, Notes) of this drawing shall be in accordance with MIL-STD-883.

3.2 Design, Construction, and Physical Dimensions

3.2.1 Die Size and Al Bonding Pad Configuration - The bonding pads shall be 5.0 x 5.0 mils aluminum (min.) and conform to Figure 1. The distance from the pad edge to the inside scribe edge will be no less than 2.0 mils. The scribe area of the chip will be such that a 6 mil total sawing area will result at the wafer level. The bonding pad location shown on Figure 1 is based on a chip size of 63 x 75 mils from the outside edges of a 3 mil scribe, however, the pads can be relocated resulting from a more dense active area design. The pads must remain in the same order and remain on the same side of the chip as shown in Figure 1 to assure it can be utilized in the existing hybrid substrate.

3.2.2 Glassivation - Silicon nitride is preferred. However, an alternate can be used and the thickness shall be 8000 angstroms ± 1000 angstroms.

3.2.3 Aluminum Metallization - The aluminum metallization thickness shall be a minimum of 9,000 angstroms.

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DRAWN			
ISSUED	SCALE		SHEET 3

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3.2.4 Glassivation Overlap onto Aluminum Bond Pads - The glassivation shall overlap onto the aluminum bond pad 0.0007 mil ± 0.1 mil on all sides. Reference Figure 2. The openings in the glassivation mask for the aluminum bonding pads shall be 3.6 mils by 3.6 mils centered on the aluminum bonding pad.

3.2.5 Wafer Thickness - Wafers shall be 14 mils ± 1.0 mil thick.

3.2.6 Bumping Mask - The openings in the bumping mask for the gold bump pads shall be 4.3 mils by 4.3 mils centered on the aluminum bonding pad. Reference Figure 2.

3.2.7 Probe Marks - Probe marks in the glassivation on the aluminum bonding pad are unacceptable. Probe marks in the aluminum bonding pad (aluminum metallization not covered by glassivation) shall not expose an underlying silicon area greater than 10% of the total bonding pad area.

3.3 Electrical Requirements

Maximum ratings - See Table I.

TABLE I. MAXIMUM RATINGS

CHARACTERISTICS	SYMBOL	RATING	UNIT
D.C. Supply Voltage	V_{DD}	-30	V
Temperature			
Operating	TA (OP)	-55 to +71	°C
Storage	TA (STG)	-55 to +125	°C

Honeywell	REV	B	
DEFENSE SYSTEMS DIVISION 600 2ND STREET N.E. HOPKINS, MINNESOTA 55343	SIZE A	08638	DWG NO. 28112362
DRAWN			
ISSUED	SCALE		SHEET 4

3.3.1 Performance Characteristics

3.3.1.1 Function - The component defined by this specification is an amplifier which will be used in conjunction with a twin T feedback loop to produce a 10 KHz oscillator. The component will provide the required gain to produce a 10 KHz sine wave and a squaring circuit to provide a 10 KHz square wave. The component gain shall be adjustable by shorting a pad to ground. This shall result in a gain reduction of 1.5 DB. Figure 3 illustrates the component function.

The capacitor pin out shall be such that a capacitor can be placed externally from the voltage regulator to ground. A regulator is required to achieve the specified performance and capacitive regulator filtering may be required (max. C = 0.01 uf).

The 10 KHz square wave output, PAD 5, shall be out of phase with the input of the amplifier, PAD 7.

3.3.1.2 Electrical Characteristics - See Table III. The amplifier shall be designed and analysis results provided to show the specifications in Table II are achieved. These parameters are difficult to measure, however, analysis results will suffice as testing is impractical.

TABLE II

	CONDITIONS	SYMBOL	MIN	MAX	UNITS
Capacitance (PAD 7)	f=10KHz V_{DD}=-17v to -30v T=-55°C to +71°C	C_{IN}		5	pf
Phase Margin		PM	10		Degrees
Voltage Phase Drift (PAD 7 to PAD 1)	V_{DD} from -17v to -30v			± .15	Degrees
Output Resistance	f=10KHz ± .1 KHz V_{DD} =-17v to -30v T = -55°C to +71°C	R_{OUT}		1	KΩ

Honeywell DEFENSE SYSTEMS DIVISION 600 2ND STREET N.E. HOPKINS, MINNESOTA 55343	REV A		
	SIZE A	08638	DWG NO. 28112362
DRAWN			
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The electrical characteristics which are to be tested are contained in Tables III, IV, and V with minimum and maximum limits.

3.3.1.3 Wafer Probe Tests - The wafers will be probed as specified in Table IV. The number of good die per wafer shall be recorded. The marking of failed die shall be as specified in the purchase order. Marking may not be permitted.

3.3.1.3.1 Gain (PAD 6 Open) - Connect PAD 7 to PAD 1 through a 70 KΩ resistor. Apply a supply voltage of -17 volts. Record the voltage at PAD 7 (V_{out} 2) and PAD 1 (V_{out} 1) and remove the 70 KΩ load. Apply the voltage recorded at PAD 7 plus 10 mv and measure output at PAD 1. The gain is determined as follows:

$$\frac{\text{Voltage at PAD 7 - Voltage at PAD 1}}{\text{10 mv}} = \text{Gain}$$

Voltages at PAD 7 and PAD 1 are with respect to V_{REG}.

3.3.1.3.2 Gain (PAD 6 Shorted) - The gain measurement of 3.3.1.3.1 at -17 volts is repeated with PAD 6 shorted to ground.

3.3.1.3.3 Input Impedance - The AC input impedance or an equivalent measurement shall be performed to assure a minimum input impedance of 3MΩ at 10 KHz. Depending on amplifier design, a D.C. input bias current measurement can be used to establish a minimum h_{fe} to assure the 3 MΩ requirement is achieved.

3.3.1.3.4 Supply Current - The supply current shall be tested by connecting PAD 1 to PAD 7 through a 70 KΩ resistor and applying V_{DD} = -30V. The D.C. current drain shall be less than 2.6 Ma.

3.3.1.3.5 Output Bias Voltage - The output bias voltage shall be tested by connecting PAD 1 to PAD 7 through a 70 KΩ resistor and applying VDD = -23.5V. The voltage at PAD 1 is VOB.

3.3.1.3.6 Threshold Voltage - Threshold voltage shall be measured by applying a signal between PAD 1 and PAD 8 from 0.8 volts to 3 volts and recording the ramp level where PAD 5 switches between -1.0 max. and -8.0 volts minimum.

3.3.1.3.7 Hystersis - The hystersis shall be measured by inputting a 10 KHz ramp between PAD 1 and PAD 8 from 0.8 volts to 3 volts. The ramp levels where PAD 5 switches to -1.0V and -8.0V shall be used to determine the hystersis.

3.3.1.3.8 Regulated Voltage - The regulator shall be tested by applying a V_{DD} of -17V and -30V. The change in voltage shall be measured at PAD 8 to PAD 2.

3.3.2 Qualification Testing - Thirty-eight functional dice from the first production wafer run shall be selected from the lowest acceptable yield wafer (acceptable yield as specified in the purchase order) and packaged for testing. The package shall be any type convenient to the supplier. The packaged parts are to be tested as specified in Table III and Table V. Packaging related failures are not relevant. Screen a sample of 38, accept on 1 reject on 2.

The calibration procedure for the oscillator run test shall be as follows:

1) Apply V_{DD} = -23.5 Volts.

2) Ground PAD 6.

3) Increase Resistor R4 (Table V) until oscillations at V_{out} have ceased ($<$ 100 MV P to P).

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DRAWN			
ISSUED	SCALE		SHEET 7

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4) Open PAD 6 and begin testing, oscillations should begin.

Honeywell will supply two twin T networks.

3.3.3 Sample Testing - A sample of 38 functional dice shall be selected from the lowest acceptable yield wafer from each production wafer run and subjected to the tests in Table III. Screen a sample of 38, accept on 1 reject on 2.

3.3.4 Data - The data and parts from the qualification and sample tests will be submitted to Honeywell.

3.3.5 Visual - Electrically acceptable dice will be subjected to visual inspection criteria per MIL-STD-883B, Method 2010.3, Test Condition B using AQL = 1.0, LTPD = 5.0.

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DRAWN			
ISSUED	SCALE		SHEET 8

TABLE III. ELECTRICAL CHARACTERISTICS

PARAMETER	CONDITIONS	SYMBOL	MIN	TYP	MAX	UNIT
INPUT IMPEDANCE (PIN 7)	f=10KHz ± .1KHz	R_{IN}	3			MΩ
	V_{DD}=-17v TO -30v T=-55°C TO +71°C	C_{IN}		2.5		pf
OUTPUT RESISTANCE (OUTPUT 1) (PIN 1)	f=10KHz ± .1KHz V_{DD}=-17v TO -30v T=-55°C TO +71°C	R_{OUT}		200		Ω
GAIN (PINS 7 TO 1) (1)	f=10KHz ± .1KHz V_{DD}=-17v	G_{v1}	37	37.5	38	db
VOLTAGE GAIN DRIFT (PINS 7 TO 1)	f=10KHz ± .1KHz V_{DD}=-30v	G_{v2}	$G_{v1-.1}$		$G_{v1+.1}$	db
TEMPERATURE GAIN DRIFT (PINS 7 to 1)	f=10KHz ± .1KHz V_{DD}=-17v T=-55°C TO +71°C	G_{v3}	$G_{v1-.2}$		$G_{v1+.2}$	db
PHASE MARGIN		PM		25		DEGREES
PHASE SHIFT (PINS 7 TO 1)	f=10KHz ± .1KHz V_{DD}=-17v	ϕ_1	175	180	183	DEGREES
VOLTAGE PHASE SHIFT DRIFT (PINS 7 TO 1)	f=10KHz ± .1KHz V_{DD}=-30v	ϕ_2		.1		DEGREES
TEMPERATURE PHASE SHIFT DRIFT (PINS 7 TO 1)	f=10KHz ± .1KHz V_{DD}=-17v T = -55°C T = +71°C	ϕ_3	ϕ_1-1.7 ϕ_1-1.0		ϕ_1+1.7 ϕ_1+1.0	DEGREES DEGREES
RISE TIME (PIN 5) (2)	f=10KHz ± .1KHz V_{DD}=-17v TO -30v T=-55°C TO +71°C	TRC			3	U SEC
FALL TIME (PIN 5) (2)	f=10KHz ± .1KHz V_{DD}=-17v TO -30v T=-55°C TO +71°C	TFC			3	U SEC

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HOPKINS, MINNESOTA 55343

REV A			
SIZE A	08638	DWG NO. 28112362	
DRAWN			
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TABLE III. ELECTRICAL CHARACTERISTICS (CONTINUED)

PARAMETER	CONDITIONS	SYMBOL	MIN	TYP	MAX	UNIT
TIME HIGH (PIN 5) (3)	f=10KHz ± .1KHz V_{DD}=-17v TO -30v T=-55°C TO +71°C	TH	35	50	60	U SEC
HYSTERSIS (PIN 5)	f=10KHz ± .1KHz V_{DD}=-17v TO -30v T=-55°C TO +71°C	HS	.160	.340	.630	VOLTS
VOLTAGE SWING (PIN 5)	f=10KHz ± .1KHz V_{DD}=-17v TO -30v T=-55°C TO +71°C	VS	OUTPUT SHALL SWING BETWEEN -1v AND -8v AS A MINIMUM			
SUPPLY CURRENT (4)	f=10KHz ± .1KHz V_{DD}=-17v TO -30v	IA			2.8	Ma
REGULATED VOLTAGE	V_{DD}=-23.5 T = 25°C	V_{REG1}	-13.6		-12.3	V
REGULATED VOLTAGE	V_{DD}=-23.5 T = +71°C	V_{REG2}	V_{REG1}-.46			V
REGULATED VOLTAGE	V_{DD}=-23.5 T=-55°C	V_{REG3}			V_{REG1}+.8	V
REGULATED VOLTAGE	V_{DD}=-30v T=-55°C TO +71°C		V_{REG1}-.71		V_{REG1}+.68	V
REGULATED VOLTAGE	V_{DD}=-17V T=-55°C TO +71°C		V_{REG1}-.71		V_{REG1}+.68	V

(1) With the trim line shorted to ground, $G_v = G_{v1}$ - (1.5 ± 0.1) db.

(2) Measure between -1.0 volts and -8.0 volts with a load of 1 MegΩ in parallel with 12 pf.

(3) Measure time high at -1.0 volts with a load of 1 MegΩ in parallel with 12 pf.

(4) Measure with a measure device that responds to average current.

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DEFENSE SYSTEMS DIVISION 600 2ND STREET N.E. HOPKINS, MINNESOTA 55343	SIZE A	08638	DWG NO. 28112362
DRAWN			
ISSUED	SCALE		SHEET 10

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TABLE IV. WAFER PROBE TESTS

PARAMETER	CONDITION		SYMBOL	MIN.	NOM.	MAX.	UNIT
	V_{Supply}	PAD 6					
GAIN PAD 7 TO PAD 1	-17V	Open	GV1	37	37.5	38.0	DB
	-30V	Open	GV2 Note 1	GV1-.3		GV1+.3	DB
	-17V	GRND	GV3 Note 1	GV1-1.6		GV1-1.4	DB
INPUT IMPEDANCE PAD 7 TO PAD 8	V_{Supply}=-23.5V			$3X10^6$			Ω
REGULATED VOLTAGE PAD 8 TO PAD 2	V_{Supply}=-23.5V		V_{REG1}	-13.6		-12.3	V
	V_{Supply}=-30V		V_{REG2}	V_{REG1}-.150			V
	V_{Supply}=-17V		V_{REG3}			V_{REG1}+.120	V
SUPPLY CURRENT	V_{Supply}=-30V		I_D			2.6	Ma
OUTPUT BIAS VOLTAGE PAD 1 TO PAD 8	V_{Supply}=-23.5V		V_{OB}	V_{REG1}+1.8	V_{REG1}+1.5	V_{REG1}+1.2	V
THRESHOLD VOLTAGE	V_{Supply}=-23.5V		V_{TH}	V_{OB}-.40		V_{OB}+.40	V
HYSTERSIS	V_{Supply}=-23.5V		HYS Note 2	.160	.340	.630	V

Note 1 - Specification is GV2 = GV1 ± .1 DB. The amplifier shall satisfy this requirement, however, to facilitate automatic testing, probe testing limits were relaxed to ± .3 DB.

Note 2 - $V_{TH1} - V_{TH2}$ = HYS

Honeywell DEFENSE SYSTEMS DIVISION 600 2ND STREET N.E. HOPKINS, MINNESOTA 55343	REV B		
DRAWN	SIZE A	08638	DWG NO. 28112362
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APPENDIX B

TABLE V. OSCILLATOR RUN TEST

PARAMETER	CONDITIONS	SYMBOL	MIN	MAX	UNITS
PERIOD	V_{DD} = -23.5V	TA	96	107	U SEC
PERIOD	V_{DD} = -30V	TG	TA-.015	TA+.015	U SEC
PERIOD	V_{DD} = -17V	TJ	TA-.015	TA+.015	U SEC
PERIOD	V_{DD} = -23.5V (-55°C)	TF	TA-.58	TA+.58	U SEC
PERIOD	V_{DD} = -23.5V (+71°C)	TC	TA-.35	TA+.35	U SEC

Honeywell	REV	A			
DEFENSE SYSTEMS DIVISION 600 2ND STREET N.E. HOPKINS, MINNESOTA 55343	SIZE A	08638	DWG NO. 28112362		
DRAWN					
ISSUED	SCALE			SHEET 12	

DSD AC 1/77

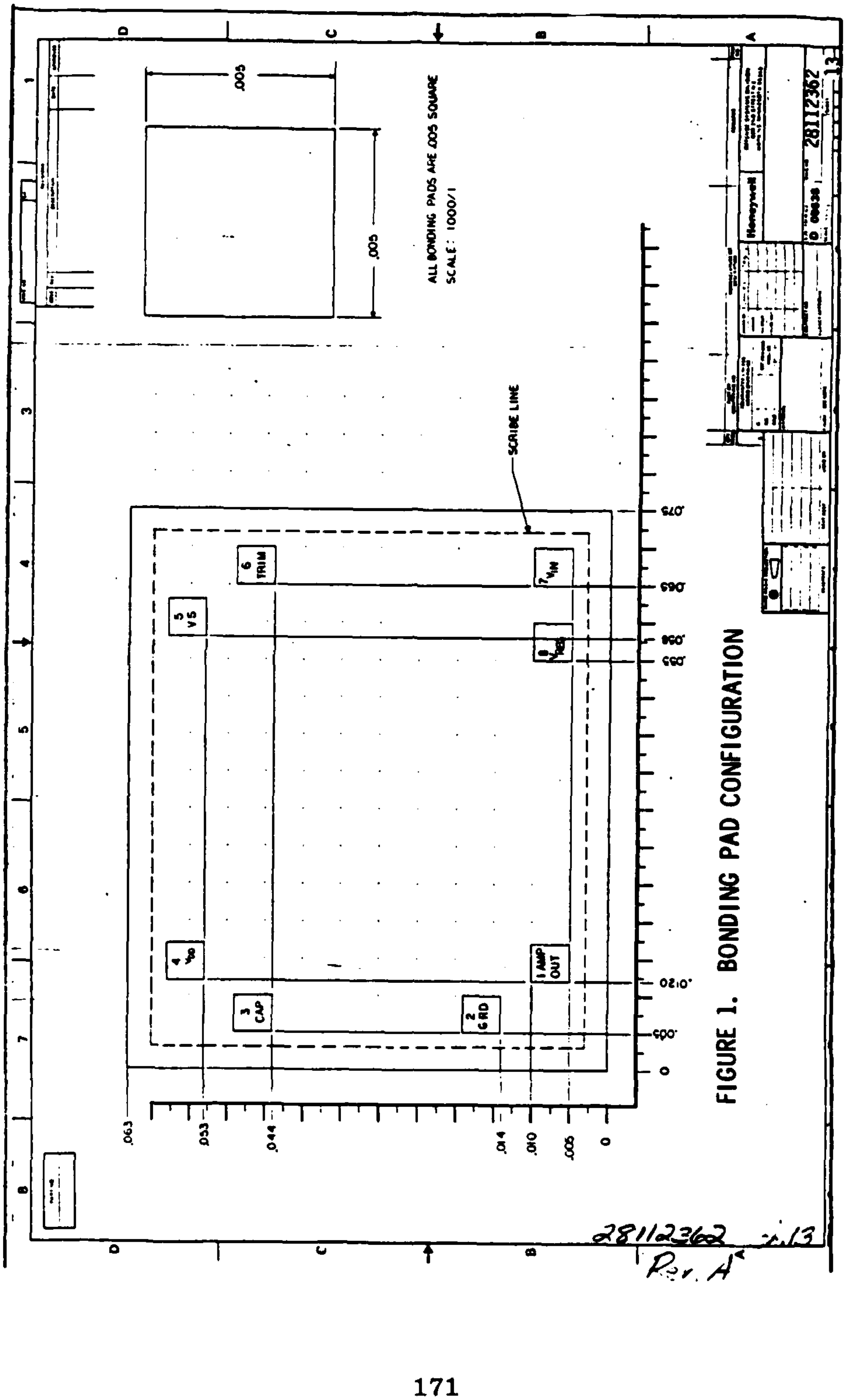


FIGURE 1. BONDING PAD CONFIGURATION

28112362 -.13
Rev. A

APPENDIX B

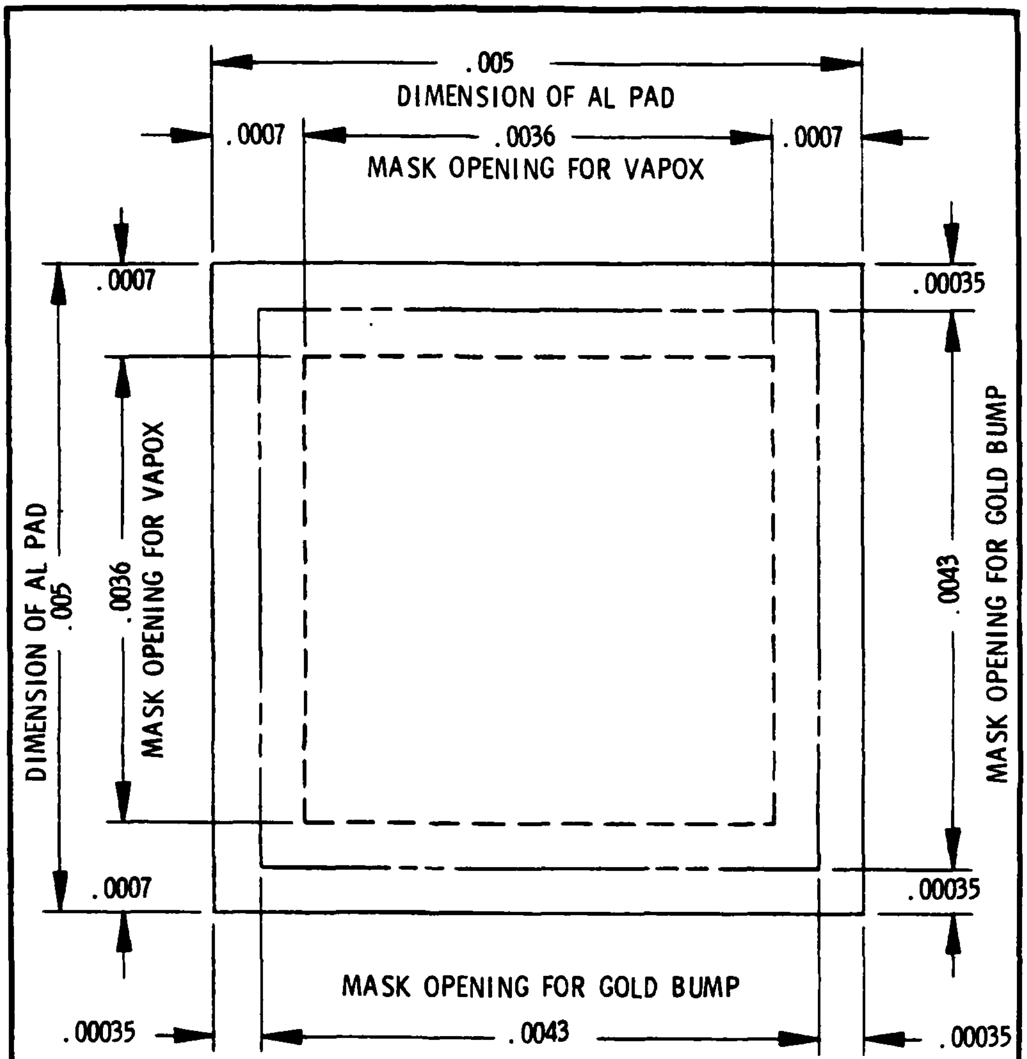
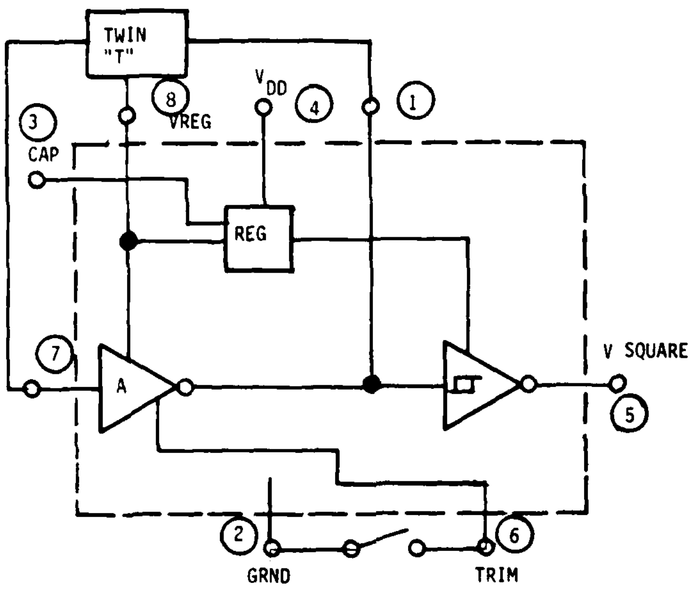


FIGURE 2. ALUMINUM BONDING PAD, GLASSIVATION OVERLAP AND BUMP MASK OPENING

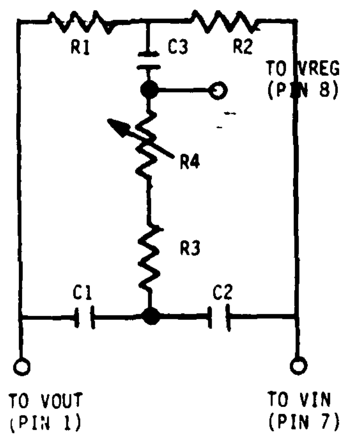
Honeywell DEFENSE SYSTEMS DIVISION 600 2ND STREET N.E. HOPKINS, MINNESOTA 55343	REV A		
	SIZE A	08638	DWG NO. 28112362
DRAWN			
ISSUED	SCALE		SHEET 14

DSD AC 1/77

OSCILLATOR BLOCK DIAGRAM



TWIN T NETWORK



TWIN T COMPONENT VALUES

ELEMENT	VALUE	TOLERANCE	TC PPM/°C
R1	34K	1%	0 ± 25
R2	34K	1%	0 ± 25
R3	11.5K	1%	0 ± 25
R4	2K-8K		0 ± 25
C1	470pf	5%	0 ± 30
C2	470pf	5%	0 ± 30
C3	1000pf	5%	0 ± 30

FIGURE 3

Honeywell DEFENSE SYSTEMS DIVISION 600 2ND STREET N.E. HOPKINS, MINNESOTA 55343	REV A		
DRAWN	SIZE A	08638	DWG NO. 28112362
ISSUED	SCALE		SHEET 15

DSD AC 1/77

APPENDIX C

FAILURE ANALYSIS REPORT OF THE VOLTAGE SENSITIVITY FAILURE ON TAB HMO S/N 15

Honeywell

DEFENSE SYSTEMS DIVISION

FAILURE ANALYSIS LAB
FAILURE ANALYSIS REPORT

DATE 6/12/78	PROJECT XM587	MALFUNCTION/F&A REPORT NUMBER	REPORT NUMBER 69422
PART NAME 10KHZ Hybrid Microcircuit Oscillator	DRAWING/PART NUMBER 11726813	GENERIC PART/NUMBER	
SERIAL NUMBER	MANUFACTURER Honeywell DSD		DATE CODE

1. BACKGROUND 2 ANALYSIS PROCEDURE 3. CONCLUSIONS 4. RECOMMENDATIONS (OPTIONAL) 5. EQUIPMENT USED (OPTIONAL)

BACKGROUND

One Tape Automatic Bonded (TAB) Hybrid Microcircuit Oscillator (HMO), which was one of the engineering samples fabricated for the XM587 Oscillator Manufacturing Methods & Technology (MM&T) Program, was submitted for failure analysis. The TAB HMO, SN15, failed voltage sensitivity testing during Group A electrical tests of HDL Dwg 11726813. SN#15 exhibited a 29.5 x 10^{-9} second period (τ) change when the power supply voltage was varied between -23.5Vdc and -17.0Vdc and a -10.6 x 10^{-9} second period change between -23.5Vdc and -30.0Vdc. The specification requirement is ±15 x 10^{-9} seconds.

ANALYSIS

The electrical data contained in Tables I, II, III, & IV were obtained during failure analysis of device SN #15.

TABLE I

ELECTRICAL DATA OBTAINED PRIOR TO DECAPSULATION

Vs (Vdc)	τ (10^{-6} second)	Is (mAdc)	$\Delta\tau$ (10^{-9} second)	Δ Is (mAdc)
-23.5	98.1352	1.708		
-17.0	98.1656	1.593	30.4	-.115
-30.0	98.1120	1.814	-23.2	.106

TABLE II

ELECTRICAL DATA AFTER PARTIAL DECAPSULATION

Vs (Vdc)	Vreg (Vdc)	Vz (Vdc)	Δ Vreg (Vdc)	Δ Vz (Vdc)
-23.5	-12.984	-13.635		
-17.0	-12.884	-13.537	-.100	-.098
-30.0	-13.055	-13.705	.071	.070

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TABLE III
ELECTRICAL DATA AFTER DECAPSULATION

Vs (Vdc)	τ (10^{-6} second)	Is (mAdc)	Vreg (Vdc)	Vz (Vdc)	$\Delta\tau$ (10^{-9} second)	Δ Is (mAdc)	Δ Vreg (Vdc)	Δ Vz (Vdc)
-23.5	98.1232	1.700	-12.981	-13.630				
-17.0	98.1410	1.590	-12.871	-13.525	17.8	-.110	-.110	-.105
-30.0	98.1100	1.820	-13.073	-13.717	-13.2	.120	.092	.087

TABLE IV
ELECTRICAL DATA ON THE AMPLIFIER AFTER REMOVING THE CAPACITORS FROM THE TWIN-T NETWORK

Vs (Vdc)	Vin (mVrms)	Vout (mVrms)	A_v (db)	ΔA_v db	Vin (mVrms)	Vout (mVrms)	A_v (db)	ΔA_v (db)	Ø (°)	ΔØ (°)
-23.5	3.8	286.7	37.55		11.4	850.7	37.46		177.8	
-17.0	3.8	285.4	37.51	-.04	11.4	849.1	37.44	-.02	178.5	0.2
-30.0	3.8	285.8	37.53	-.02	11.4	850.3	37.45	-.01	177.6	-0.2

The period measurements in Table I show SN #15 exhibits period changes greater than ±15 x 10^{-9} seconds between both -23.5Vdc & -17.0Vdc and -23.5Vdc & -30Vdc. The electrical data after decapsulation, Table III, show that the period changes decreased considerably. Period measurements at -23.5Vdc, -17.0Vdc and -30.0Vdc were not performed at the substrate level prior to encapsulation during fabrication. The period change due to the encapsulant of this particular device is abnormally high. However, excessive period change was still noted after decapsulation.

Electrical measurements in Table III show two other abnormal conditions, 1) the power supply current at -17.0Vdc (Is = 1.590mAdc) is lower than normal and 2) the change in regulated voltage between -23.5Vdc and -30.0Vdc is typically greater than the change noted between -23.5Vdc and -17.0Vdc. This information in item 2 above was obtained from the electrical data taken during amplifier testing at the tape level.

Although the change in regulated voltage between -23.5Vdc and -17.0Vdc is greater than typically noted, exact correlation between period change and regulated voltage change is not apparent.(i.e. amplifier test data at the tape level show a greater change in the regulated voltage between -23.5Vdc and -30.0Vdc than between -23.5Vdc and -17.0Vdc, whereas the test data on the final oscillator assembly show a greater change in period between -23.5Vdc and -17.0Vdc than between -23.5Vdc and -30.0Vdc).

Honeywell **FAILURE ANALYSIS REPORT**

REPORT NUMBER 69422

DEFENSE SYSTEMS DIVISION

HF-119A REV 3/77

The electrical data obtained after removing the capacitors in the Twin-T network (Table IV) show excellent gain stability. However, the change in phase shift (Ø) between -23.5Vdc and -17.0Vdc appeared to be excessive (Ø = 0.7°). Theoretical calculations of the oscillator performance as a function of the amplifier phase shift show that a maximum allowable phase shift change of 0.15° is required to meet a ±15 x 10^{-9} second period change. However, electrical data obtained on the amplifier at the tape level show Ø ranges from 0° to -1.0°. These amplifiers were used to fabricate oscillators which met all of the Group A electrical tests of HDL Dwg 11726813.

Two possibilities exist 1) either the theoretical calculations are inaccurate or 2) the phase shift measurements are inaccurate. It is felt that the phase shift measurements are inaccurate.

CONCLUSIONS

Failure Analysis verified the excessive period change during voltage sensitivity testing. Electrical testing verified abnormal electrical performance of the monolithic amplifier. The supply current was lower than normal at -17.0Vdc (I_s = 1.590mAdc). The change in regulated voltage was greater between -23.5Vdc and -17.0Vdc than between -23.5Vdc and -30.0Vdc. Excessive change in phase shift was noted between -23.5Vdc and -17.0Vdc. Specification limits on the electrical parameters of the monolithic amplifier would not eliminate amplifiers of this type at tape level testing.

The TAB HMO, SN #15, should have been exposed to voltage sensitivity testing after encapsulation prior to Group A electrical testing. Room temperature electrical testing will be performed on all TAB HMO's prior to acceptance testing to preclude failures of this type in the future. However, further investigations are being performed to establish correlation between the period and phase shift changes noted during voltage sensitivity testing. This will allow incorporation of adequate specification limits which will preclude assembly of discrepant monolithic amplifiers on the thick film substrates.

Prepared by Jerry D Roth
J.D. Roth
Failure Analyst

B Goblish
B. Goblish
Design Engineer

Approved by DA Tabor
D.A. Tabor
Reliability Engineer

APPENDIX D

SOURCE CONTROL DRAWING GOVERNING INTERNAL VISUAL REQUIREMENTS FOR PRECISION OSCILLATOR, FOR SHOCK APPLICATIONS

REVISIONS

LTR	DESCRIPTION	DATE	APPROVED

Rev	–	–	–
Sheet	23	24	25

REV STATUS OF SHEETS																							
	REV	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
	SHEET	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ON:
DECIMALS ±
FRACTIONS ± ANGLES ±

MATERIAL

HEAT TREATMENT

FINAL PROTECTIVE FINISH

ORIGINAL DATE OF DRAWING

DRAFTSMAN [illegible] | CHECKER [illegible]

ENGR [illegible] | [illegible] 75

SUBMITTED

APPROVED

U.S. ARMY
HARRY DIAMOND LABORATORIES
WASHINGTON, D.C. 20438

INTERNAL VISUAL REQUIREMENTS FOR
PRECISION OSCILLATOR, FOR SHOCK
APPLICATIONS

SIZE	CODE IDENT NO.	
A	19202	11711479

SCALE | UNIT WT | SHEET 1 of 25

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APPENDIX D

1.0 **SCOPE**

1.1 This document establishes the requirements for the visual examination and acceptance criteria for a hybrid microcircuit intended for use in 30,000 g shock applications.

1.2 Purpose - The intent of this document is to establish criteria for examining the internal materials, construction and workmanship of the Precision Oscillator 11726813. This document is similar to MIL-STD-883, Method 2017 and will be used prior to capping or encapsulation to detect and eliminate devices with internal defects which could lead to device failures in normal application.

2.0 **APPLICABLE DOCUMENTS**

2.1 The following documents, of the issue in effect, form a part of this document to the extent specified herein.

STANDARDS

Military

MIL-STD-883	Test Methods and Procedures for Microelectronics
MIL-M-38510D	Microcircuits, General Specification For

SPECIFICATIONS

Harry Diamond Laboratories

11726813	Precision Oscillator

3.0 **REQUIREMENTS**

3.1 Equipment

3.1.1 Microscopes with the capability of 30X to 70X magnification (low magnification), and 75X to 150X magnification (high magnification). A microscope with magnification of 10X may be used for a general overview inspection.

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3.2 Procedure

3.2.1 General - The device shall be examined in a suitable sequence of observations within the specified magnification range to determine compliance with the requirements of the applicable drawing. Discrete active devices shall be examined in accordance with Para. 3.2.5.1. Passive chip components shall be inspected in accordance with Para. 3.2.5.2. Thick film networks shall be examined in accordance with Para. 3.2.5.4. If a specified visual inspection is in conflict with circuit design topology or construction, documented in the specific device documentation, the latter shall prevail.

3.2.2 Sequence of Inspection - The order in which criteria are presented is not a required order of examination. The inspection criteria of Para. 3.2.5.1, 3.2.5.2, 3.2.5.4 may be performed prior to die, chip, or substrate attachment.

3.2.3 Inspection Control - In all cases, examination prior to final preseal inspection shall be performed under the same quality program that is required at the final preseal inspection station. Care shall be exercised after inspections per 3.2.2 to insure that defects created during subsequent handling will be detected and rejected at final preseal inspection. During the time interval between internal visual inspection and preparation for sealing, devices shall be stored in a controlled environment. Devices shall be in covered containers when transferred from one controlled environment to another.

3.2.4 Magnification - "High magnification" inspection shall be performed perpendicular to the substrate surface with the device under illumination normal to the substrate surface. "Low magnification" inspection shall be performed with either a monocular, binocular or stereo microscope, and the inspection performed within an angle of 30 degrees from the perpendicular to the substrate surface with the device under suitable illumination.

3.2.5 Examination - Internal visual examination as required in 3.2.5.1 through 3.2.5.8 shall be conducted on each hybrid microcircuit. The magnifications required for each inspection shall be those identified in the particular test method used.

3.2.5.1 Microcircuit and Semiconductor Die or Chips - All microcircuit and semiconductor devices shall be examined in accordance with MIL-STD-883, Method 2010.3, Test Condition B (Para. 3.2).

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3.2.5.2 <u>Ceramic Chip Capacitors</u> - A minimum magnification of 30X is required. No device shall be acceptable which exhibits the following:

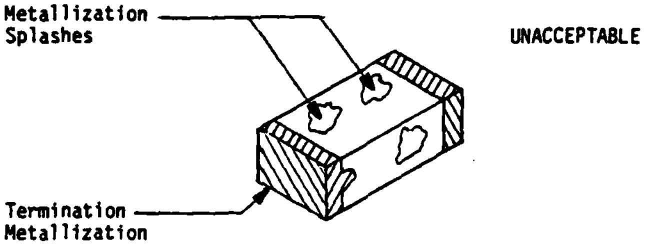
3.2.5.2.1 Nonconformance to outline drawing.

3.2.5.2.2 Lifting, blistering, or peeling of insulation.

3.2.5.2.3 Crack that is more than 50 percent of width on a side or extends around an edge.

3.2.5.2.4 Any capacitors which are warped in excess of 10 degrees at the center line.

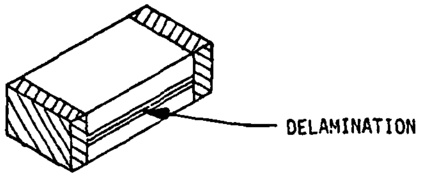
3.2.5.2.5 Excess flow and splashes of metallization material leaving less than 10 mils separation between the terminals.



3.2.5.2.6 Evidence of delaminations in the body of the capacitor.

(A delamination is defined as a separation <u>between</u> the plate layers that has not been vitrified together.)

UNACCEPTABLE



SIZE A	CODE IDENT NO. 19202	11711479	
SCALE	REV	SHEET 4	

3.2.5.2.7 Any voids and/or cavities found in the body of the capacitor that expose any part of the metal plates.

3.2.5.2.8 Voids in the termination metallization area exposing one plate in excess of 30% of the capacitor width.

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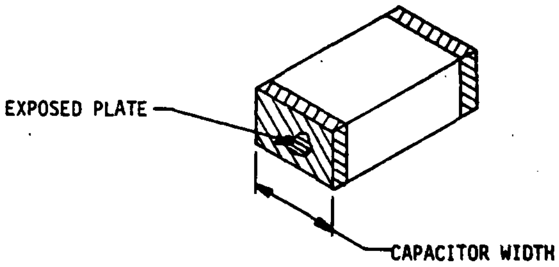

3.2.5.2.9 Voids in the termination metallization area exposing 10% or more of the total end or side area. Side area is defined as from edge to 10 mil up on capacitor body.

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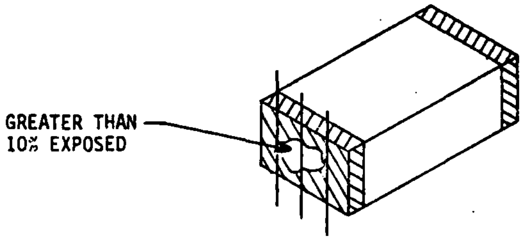

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A	19202	11711479
SCALE	REV	SHEET 5

3.2.5.2.10 Voids in the termination metallization which reduce the metallization of any given edge by more than 25%.

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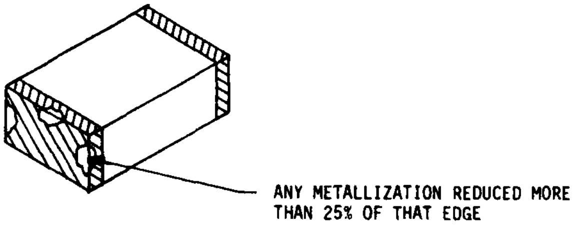

3.2.5.3 Component Mounting (Chip Capacitor) - A minimum magnification of 30X is required. No unit shall be acceptable which exhibits the following:

3.2.5.3.1 End terminated components which have a fillet length less than 75% of the visible bonding perimeter.

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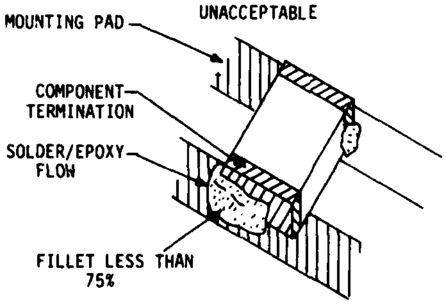

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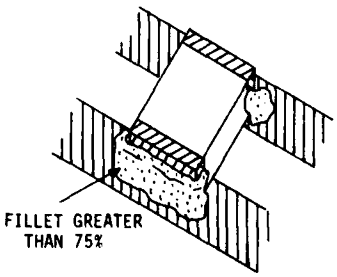
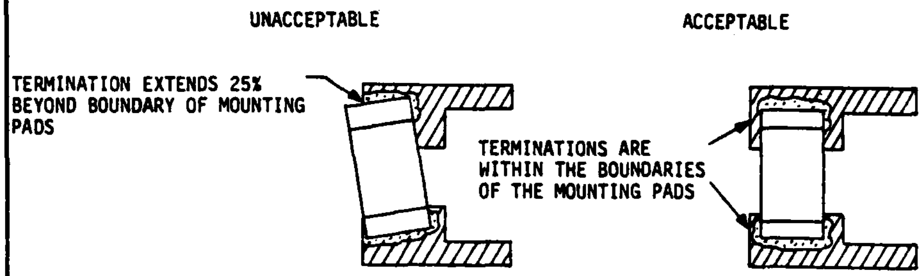
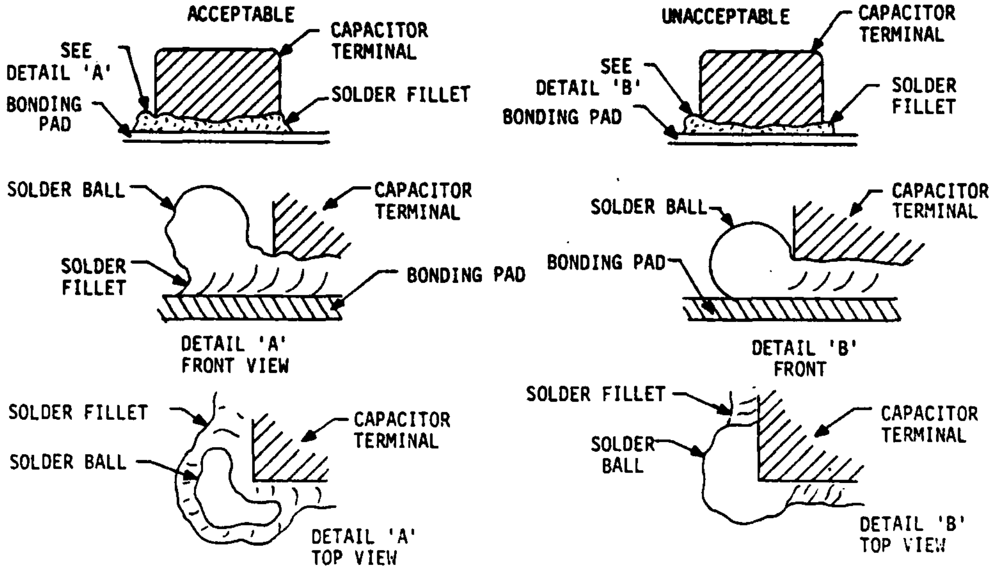


3.2.5.3.2 End terminated components whose terminations extend more than 25% beyond the circuit mounting pads at the outmost edges.



3.2.5.3.3 Balling of the solder around the terminal contact periphery that does not exhibit a fillet.



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A	19202	11711479
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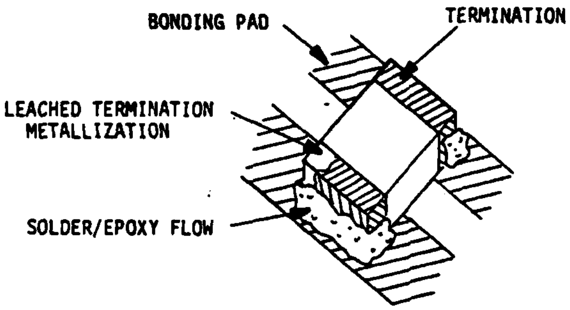
3.2.5.3.4 Evidence of leaching across the termination of the components and/or of the circuit bonding pad.

UNACCEPTABLE



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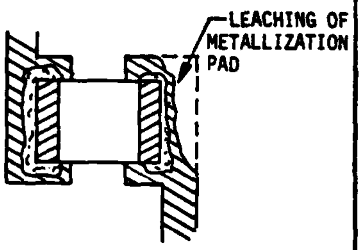

3.2.5.4 <u>Thick Film Networks</u>

3.2.5.4.1 <u>Substrates</u> - A minimum magnification of 30X is required. No unit shall be acceptable which exhibits the following:

3.2.5.4.1.1 Any evidence of substrate warpage in excess of 4 mils per inch.

3.2.5.4.1.2 Any crack, chipout, or pitting within the active circuit area.

3.2.5.4.1.3 Any crack outside the active circuit area that exceeds 5 mils in length or points toward the active circuit area within 3 mils of the active area.

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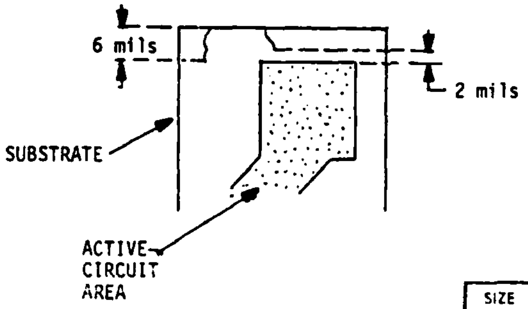

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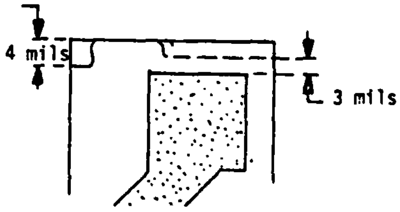

SIZE A	CODE IDENT NO. 19202	11711479
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3.2.5.4.1.4 Any chipout or pitting outside the active area that exceeds 10 mils in its longest dimension or is within 3 mils of the active circuit area.

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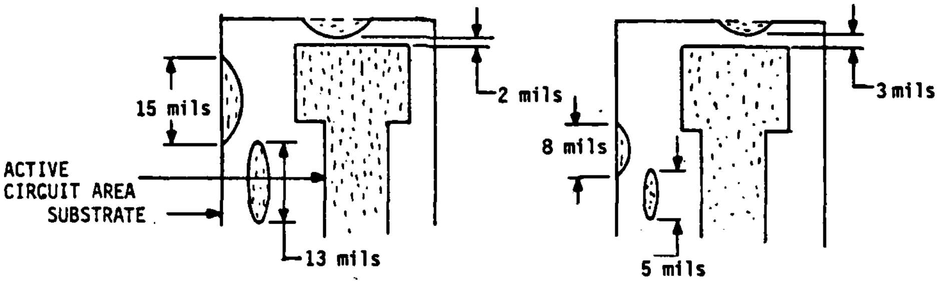
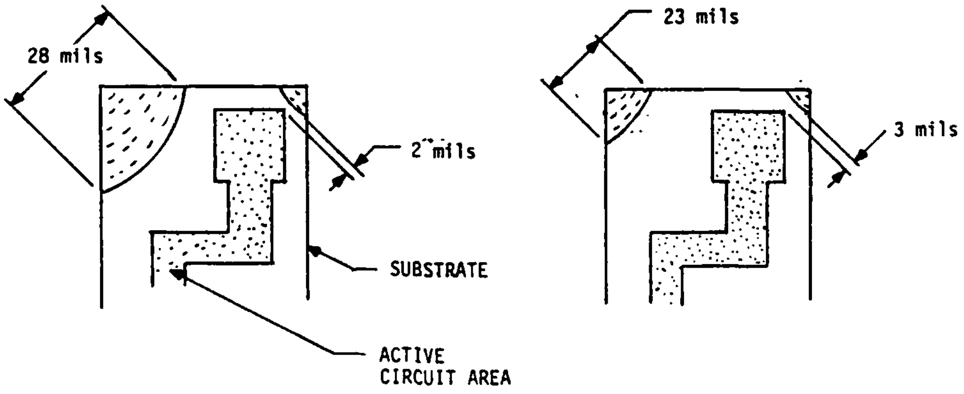


3.2.5.4.1.5 Any corner chipout which exceeds 25 mils across its diagonal or which extends within 3 mils of the active circuit area.

UNACCEPTABLE ACCEPTABLE



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3.2.5.4.1.6 Any crack which does not originate at an edge.

3.2.5.4.2 Thick Film Metallization - A minimum magnification of 30X is required. No unit shall be acceptable which exhibits the following:

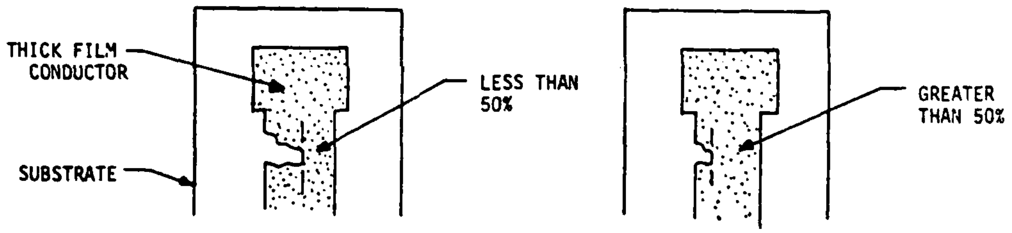
3.2.5.4.2.1 Any conductor pattern which has excessively ragged edges, or exhibits evidence of poor adhesion, peeling, lifting or blistering. Excessively ragged edges are those which have an uneveness with a peak to peak amplitude greater then 1.5 mils measured over a minimum of two peaks in each direction.

3.2.5.4.2.2 Pinholes or voids shall not be concentrated in one area and shall not exceed 10 percent of the area of a solder pad.

3.2.5.4.2.3 Any distinct color change in the metallization indicating exposure to excessive heat and/or the presence of chemical or corrosive action. Any evidence of metallization corrosion.

3.2.5.4.2.4 Any scratch or void in the conductor metallization which exposes the underlying substrate and leaves less than 50 percent of the undisturbed conductor pattern.

UNACCEPTABLE ACCEPTABLE



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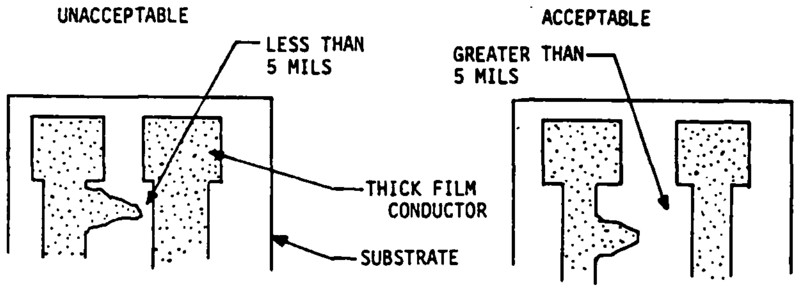
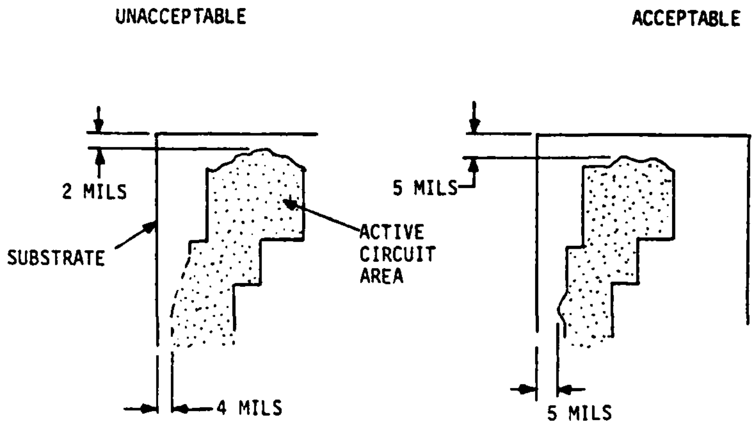
3.2.5.4.2.5 Any region in which the spacing between two conductors is reduced to less than 5 mils, or one quarter of the undisturbed spacing, whichever is less, whether caused by smears, misalignment, solder flow, metal tool marks, or other defects.



3.2.5.4.2.6 Any conductor which is within 5 mils of the edge of the substrate (unless specified by drawing).



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A	19202	11711479
SCALE	REV	SHEET 11

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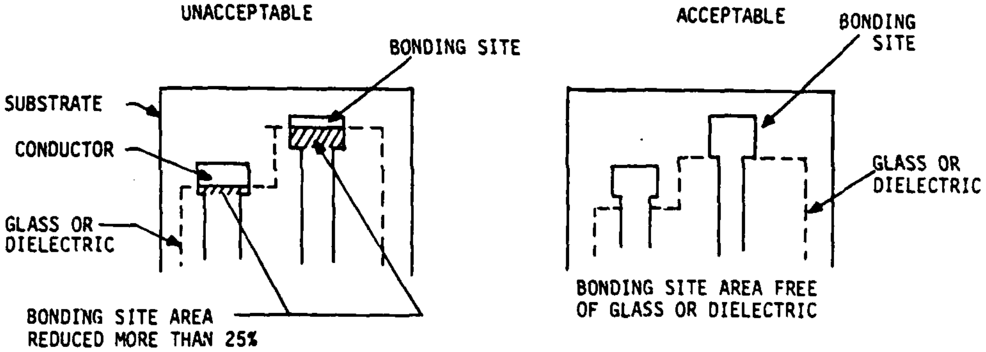
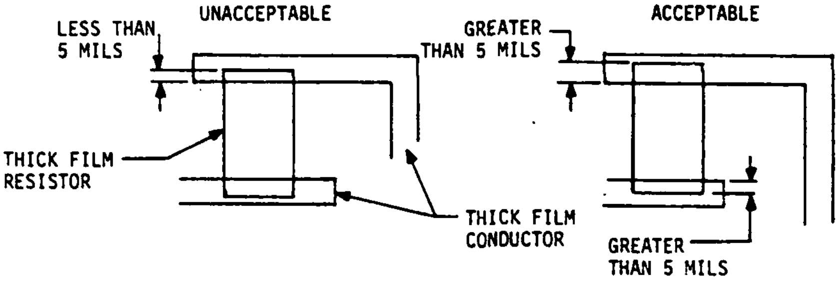
3.2.5.4.2.7 Bonding pads or sites which are reduced in area by more than 25 percent by scratches, voids, or excess flow or misregistration of insulating glass or dielectric.



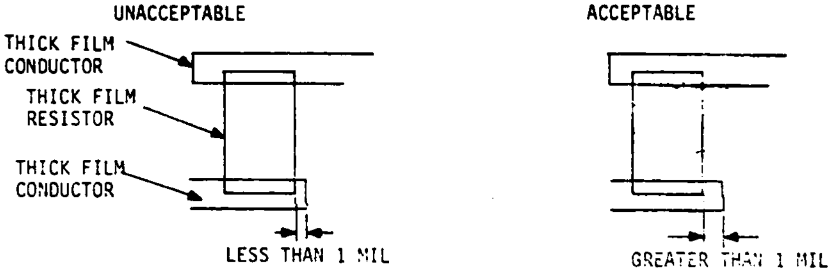
3.2.5.4.3 Thick Film Resistors - A minimum magnification of 30X is required. No unit shall be acceptable which exhibits the following:

3.2.5.4.3.1 Resistor patterns which have excessively ragged edges or exhibit evidence of poor adhesion, peeling, blistering, non-uniform thickness, or mechanical damage such as scratches, cracks, voids, or chipout areas. Excessively ragged edges are those which have an unevenness with a peak to peak amplitude greater than 2.5 mils measured over two peaks in each direction.

3.2.5.4.3.2 **Resistor patterns which do not overlap the conductor termination by a minimum of 5 mils at either end.**



3.2.5.4.3.3 Any resistor which does not have conductor overlap at the edge of the resistor pattern by a minimum of 1 mil.



3.2.5.4.3.4 Excessive "bleed" of resistor material or misalignment of patterns such that the conductor pattern is not visible at each end of the resistor.

SIZE	CODE IDENT NO.	
A	19202	11711479
SCALE	REV	SHEET 13

AMXDO FORM 932AV-1

AD-A085 973 HONEYWELL INC HOPKINS MN DEFENSE SYSTEMS DIV F/G 19/1
MANUFACTURING METHODS AND TECHNOLOGY PROGRAM FOR THE 10-KHZ TAP--ETC(U)
DEC 79 B E GOBLISH DAAG39-78-C-0010
UNCLASSIFIED 2730-41637 HDL-CR-79-010-1 NL

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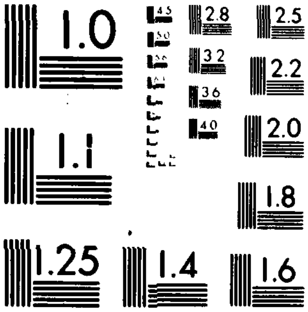
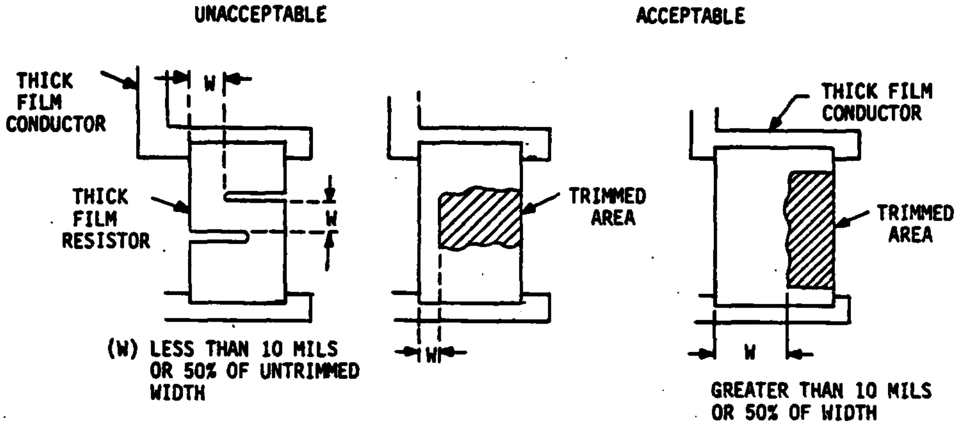
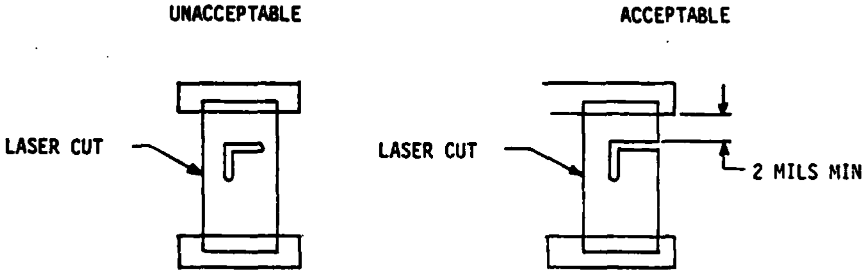


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

3.2.5.4.3.5 Any resistor in which the trimmed width (W) is less than 10 mils or 50% of the untrimmed resistor width, which ever is greater. Any resistor which has trimmed areas closer than 10 mils originating from opposite sides of the resistor.



3.2.5.4.3.6 Any resistor in which the laser cut does not begin at the edge of the resistor pattern or is trimmed such that less than 2 mils clearance exists between trimmed resistor area and conductor termination.



LASER TRIMMING

SIZE A	CODE IDENT NO. 19202	11711479
SCALE	REV	SHEET 14

3.2.5.4.3.7 Resistor material left in the kerf (trimmed area) of a resistor.

3.2.5.4.3.8 A scratch or void in the contact area reducing the resistor termination width by more than 25%.

3.2.5.4.4 Thick Film Insulating Glass - A minimum magnification of 30X is required. No unit shall be acceptable which exhibits the following:

3.2.5.4.4.1 Severe bubbling of the insulating glass.

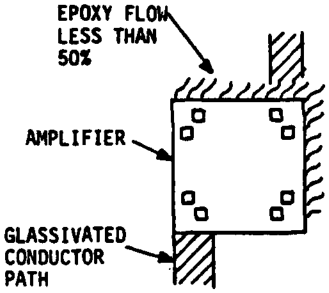
3.2.5.4.4.2 Cracking or fissuring of the insulating glass.

3.2.5.5 I.C. Amplifier Assembly to Substrate

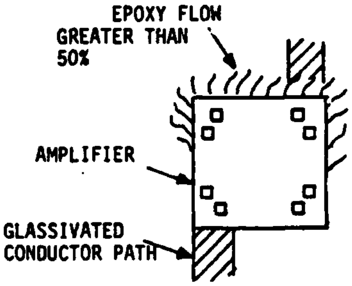
3.2.5.5.1 I.C. Attachment - A minimum magnification of 30X is required. No units shall be acceptable which exhibit the following:

3.2.5.5.1.1 Any non-conductive epoxy mount in which the epoxy is not visible around 50% of the I.C. periphery, or is continuous on two sides.

UNACCEPTABLE



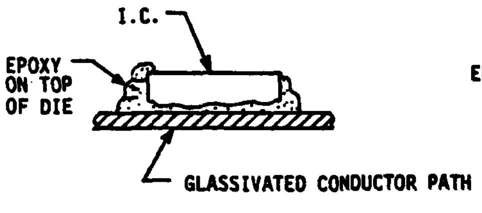
ACCEPTABLE



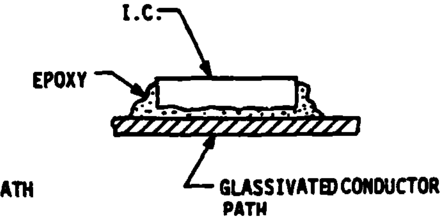
SIZE	CODE IDENT NO.	
A	19202	11711479
SCALE	REV	SHEET 15

3.2.5.5.1.2 Any non-conductive epoxy on the top surface of the I.C.

UNACCEPTABLE

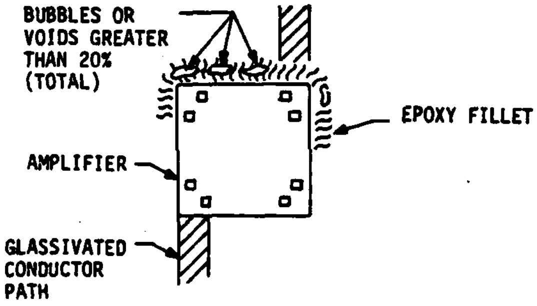


ACCEPTABLE

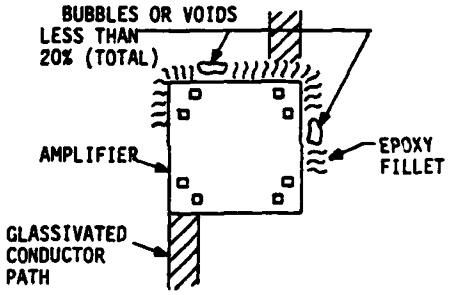


3.2.5.5.1.3 Bubbles and/or voids in the non-conductive epoxy which occupy more than a total of 20% of the die periphery.

UNACCEPTABLE



ACCEPTABLE



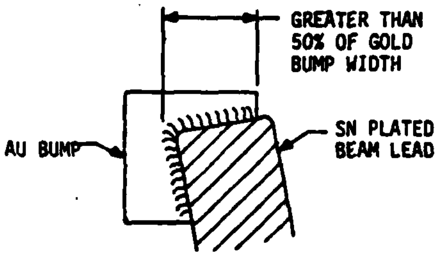
SIZE A	CODE IDENT NO. 19202	11711479
SCALE	REV	SHEET 15

3.2.5.5.1.4 Cracks in the non-conductive epoxy around the perimeter of the die greater than 5.0 mils in length or 10% of the contact periphery.

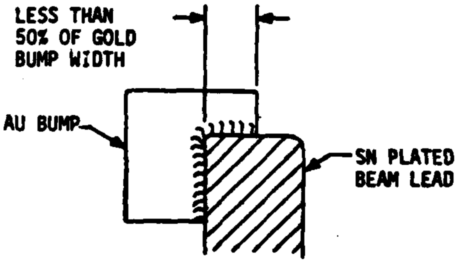
3.2.5.5.2 Inner Lead Bonds - Pertains to the tin plated copper beam lead bonded to the gold bump on the I.C. amplifier. A minimum of 75X is required. No units shall be acceptable which exhibit the following:

3.2.5.5.2.1 Devices whose terminations cover less than 50% of the gold bump bonding width.

ACCEPTABLE

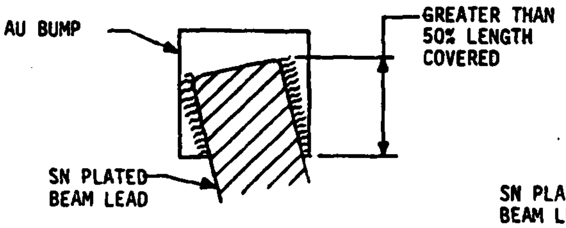


UNACCEPTABLE

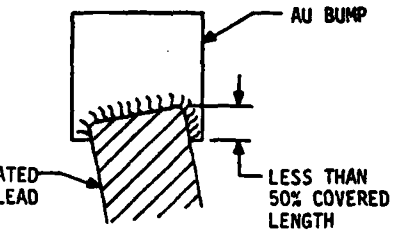


3.2.5.5.2.2 Devices whose terminations cover less than 50% of the gold bonding length.

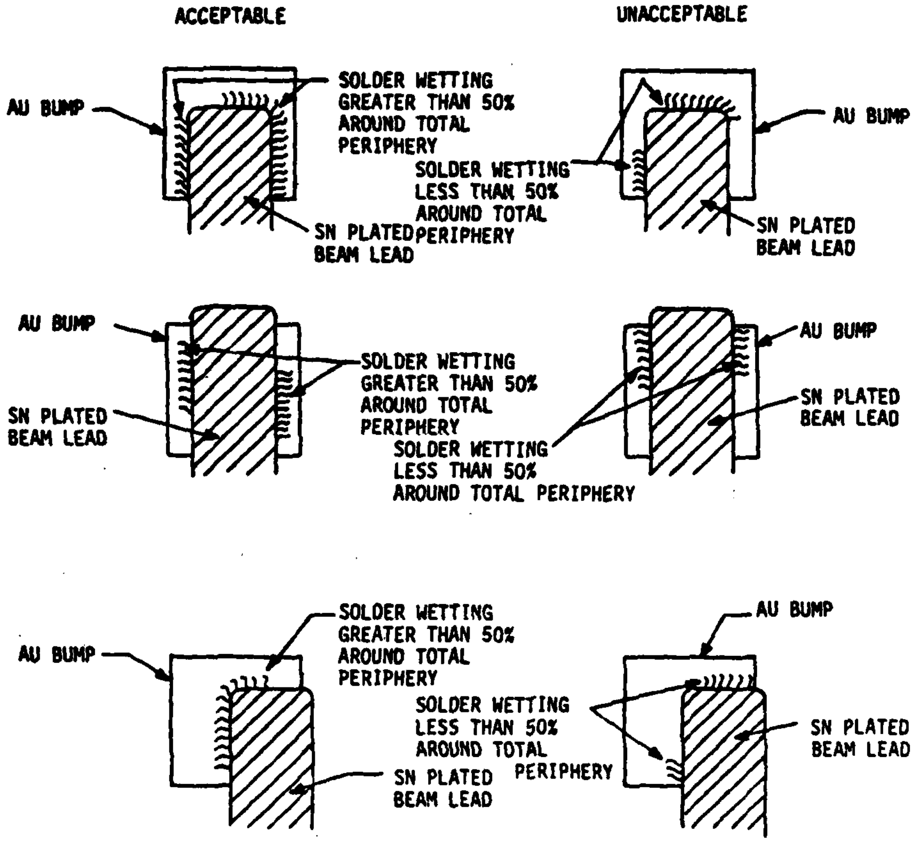
ACCEPTABLE



UNACCEPTABLE



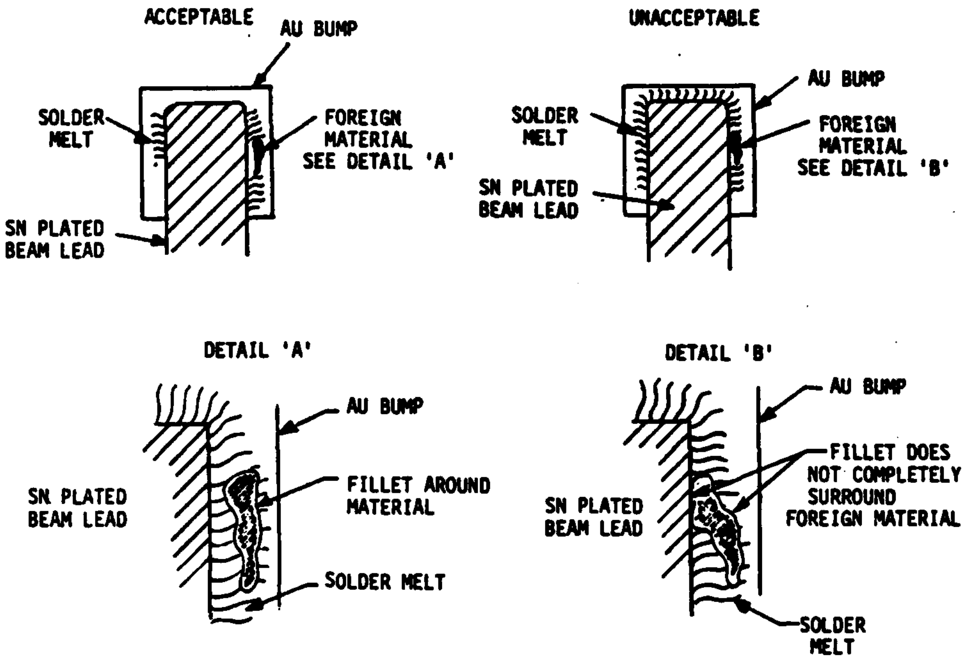
3.2.5.5.2.3 Devices where there is less than 50% solder wetting around the total bonding periphery between the tin plated beam lead and gold bump. The bonding periphery is defined as any portion of the outer perimeter of the beam lead making contact with the I.C. amplifier gold bump.



SIZE	CODE IDENT NO.	
A	19202	11711479
SCALE	REV	SHEET 13

AMXDO FORM 25 JAN 68 932AV-1

3.2.5.5.2.4 Foreign material in solder melt which does not exhibit a fillet.



3.2.5.5.2.5 Flaking of the solder material.

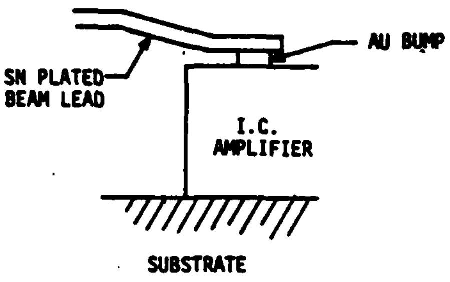
3.2.5.5.2.6 Balling of the solder around the contact periphery that does not exhibit a fillet.

3.2.5.5.2.7 Devices where there is evidence that the beam lead has lifted from the gold bump.

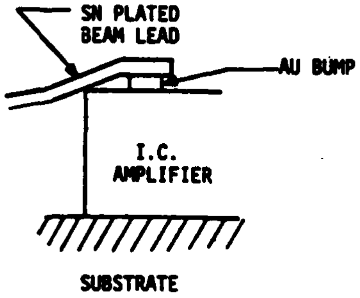
SIZE	CODE IDENT NO.	
A	19202	11711479
SCALE	REV	SHEET 19

3.2.5.5.2.8 Devices where there is evidence of shorting between the I.C. amplifier and tin plated beam lead.

ACCEPTABLE



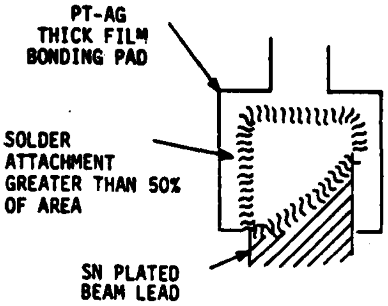
UNACCEPTABLE



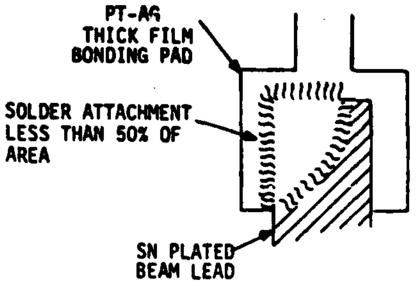
3.2.5.5.3 <u>Outer Lead Bonds</u> - Pertains to the tin plated copper beam lead bonded to the thick film conductor. A minimum of 30X is required. No units shall be acceptable which exhibit the following:

3.2.5.5.3.1 Devices in which solder attachment is not visible around 50% of the contact periphery and covering @ least 50% of the lead area between the beam lead and thick film bond pad.

ACCEPTABLE



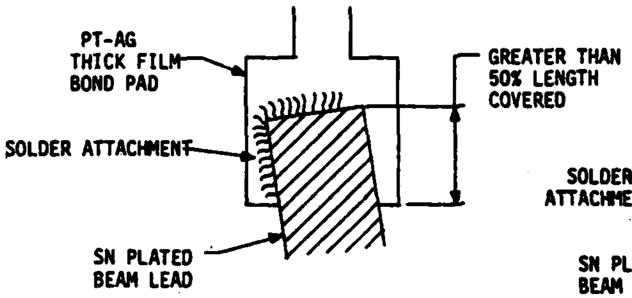
UNACCEPTABLE



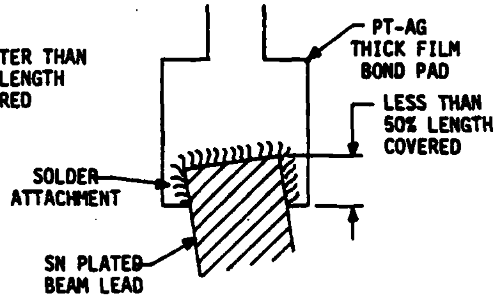
SIZE	CODE IDENT NO.	
A	19202	11711479
SCALE	REV	SHEET 20

3.2.5.5.3.2 Devices whose terminations cover less than 50% of the thick film bond pad length and width.

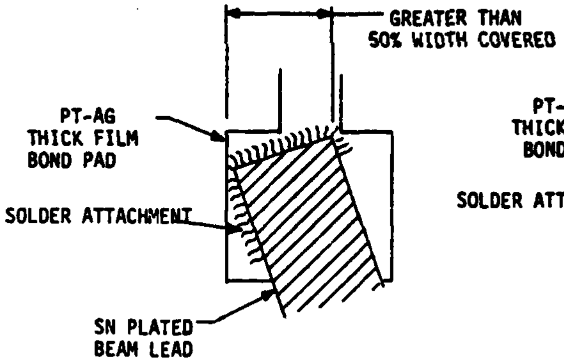
ACCEPTABLE



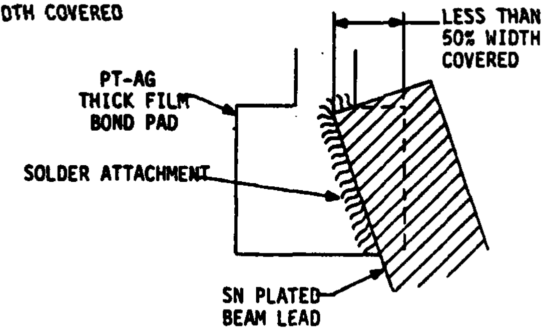
UNACCEPTABLE



ACCEPTABLE



UNACCEPTABLE



SIZE	CODE IDENT NO.	
A	19202	11711479
SCALE	REV	SHEET 21

3.2.5.5.3.3 Devices where there is evidence that the beam lead has lifted from the thick film pad.

3.2.5.5.3.4 Foreign material in solder melt which does not exhibit a fillet.

3.2.5.5.3.5 Flaking of the solder material.

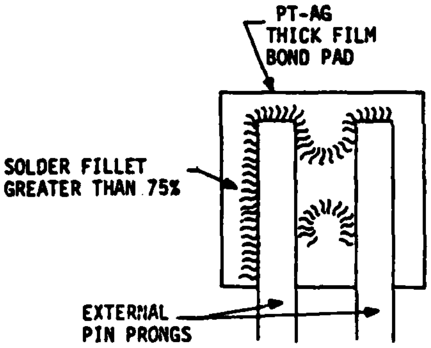
3.2.5.5.3.6 Balling of the solder around the contact periphery that does not exhibit a fillet.

3.2.5.5.3.7 Solder flows or splashes which leave less than 5.0 mils minimum separation between adjacent bond pads.

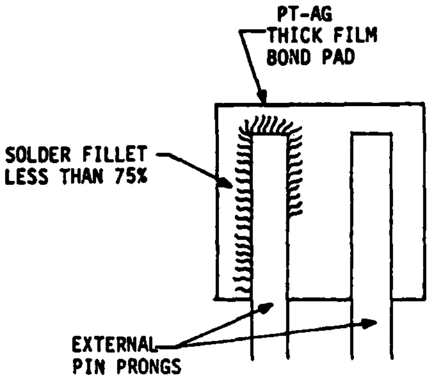
3.2.5.5.4 <u>External lead bonds</u> - Pertains to external pins bonded to the thick film conductor pads. A minimum of 30X is required. No units shall be acceptable which exhibit the following:

3.2.5.5.4.1 Devices in which solder fillet wetting is not visible around 75% of the contact periphery between the external pin and thick film bond pad.

ACCEPTABLE



UNACCEPTABLE



SIZE	CODE IDENT NO.	
A	19202	11711479
SCALE	REV	SHEET 22

3.2.5.5.4.2 Foreign material in solder melt which does not exhibit a fillet.

3.2.5.5.4.3 Excessive solder flow or splashes which reduces the original design spacing between adjacent conductors by more than 50%.

3.2.5.5.4.4 Flaking of the solder material.

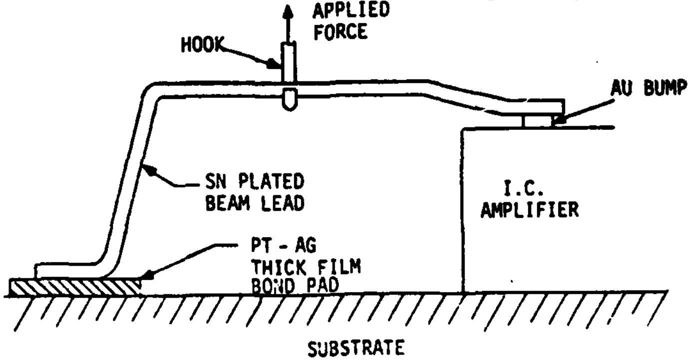
3.2.5.5.4.5 Balling of the solder around the contact periphery that does not exhibit a fillet.

3.2.5.6 Bond Strength Testing

3.2.5.6.1 A minimum of 13 completed devices shall be selected at random from each deliverable lot (units rejected during precap visual inspection, except inner or outer lead bond solder rejected devices, may be used) and subjected to a destructive bond pull test. A minimum of one internal bond shall be pulled from each device and proportionally increased to meet sample requirements as specified by the single sample plan of MIL-STD-105D - Level II, normal inspection, with an AQL = 1.0.

The AQL applies to the bond only and not to a completed device. Therefore for a lot of 200 completed devices or 1600 bonds, an AQL = 1.0 calls for a sample of 125 bonds to be pulled. For this case at least 16 completed devices would have to be subjected to bond strength testing.

3.2.5.6.2 Lead bond strength is to be tested by inserting a hook under the lead wire (attached to die, substrate or header at both ends) with the device clamped and the pulling force applied approximately in the center of the wire in a direction within 5 degrees of the normal to the die or substrate surface or normal to a straight line between the bonds. The force is to be applied gradually without shock.



3.2.5.6.3 The internal bond pulled to destruction shall be considered a failure if the tin plated beam lead breaks with an applied force of less than 20 grams or, either beam lead to thick film pad or beam lead to AU bump bonds lift with an applied force of less than 30 grams.

3.2.5.6.4 The minimum following data will be recorded for each conducted pull test:

1) Serial Number of Device
2) Break Force (in Grams)
3) Location of Break

3.2.5.7 Foreign Material - NOTE: Material shall be considered attached when it cannot be removed by anominal gas blow (approximately 20 Psig.). Conductive foreign material is defined as any substance which appears opaque under all conditions of lighting and magnification used in routine visual inspection.

3.2.5.7.1 Dice - (Foreign Material) - A minimum magnification of 75X is required. No unit shall be acceptable which exhibits the following:

3.2.5.7.1.1 Unattached foreign material on the surface of the die within the package.

3.2.5.7.1.2 Attached conductive foreign material that appears to bridge any two unpassivated metallization areas of a die.

3.2.5.7.2 General - (Foreign Material) - A minimum magnification of 30X is required. No unit shall be acceptable which exhibits the following:

3.2.5.7.2.1 Unattached foreign material within the package.

3.2.5.7.2.2 Attached conductive foreign material that appears to bridge any two unpassivated thick film or thin film material areas, two package leads, or any lead to package metallization.

3.2.5.8 General - A minimum magnification of 30X is required. No unit shall be acceptable which exhibits the following:

3.2.5.8.1 Cracking, chipping, or discoloration of any components or material unless allowed by another section of this specification.

3.2.5.8.2 Foreign deposits or residues on or within the package unless allowed by another section of this specification.

3.2.5.8.3 Cracked or broken glass seals in packages.

3.2.5.8.4 Bent, broken, or missing package leads.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 Process Control - Each completed hybrid circuit shall be inspected prior to encapsulation.

4.2 Acceptance - Acceptance of a hybrid microcircuit shall be based on satisfactory compliance with section 3.0.

5.0 PREPARATION FOR DELIVERY

5.1 This section is not applciable to this specification.

6.0 NOTES

6.1 Safety - The materials or processes referred to may be hazardous. The responsibility for safety rests with the user.

SIZE A	CODE IDENT NO. 19202	11711479
SCALE	REV	SHEET 25

APPENDIX E

PHASE III TEST AND DEMONSTRATION REPORT FOR TAB PRECISION OSCILLATOR, P/N 11726813

Lot performance test results are tabulated below. Explanatory notes follow.

Test Description	Sample Size	Accept No.	Reject No.	No. of Defects
Subgroup A1 (Oscillator Characteristics)	158	4	5	2
Subgroup A2 (Electronic Shield and Visual)	18	1	2	1
Subgroup B1 (Temperature Cycling)	25	1	2	0
Subgroup B2 (Constant Acceleration)	25	1	2	1
Subgroup B3 (High-Temperature Storage)	25	1	2	0
Subgroup B4 (Shock)	25	1	2	1
Subgroup B4 (Shock)	25	1	2	8
Subgroup B4 (Shock)	25	1	2	0
Subgroup B5 (Solderability)	8	0	1	8
Subgroup B6 (Lead Integrity)	8	0	1	-
Subgroup C1 (Gunfire)	38	1	2	-
Moisture Resistance	25	1	2	0

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APPENDIX E

Notes:

1. Unit no. 128 failed at -50C due to drawing excessively high current (I > 6.5 mA). Analysis showed a defective integrated-circuit amplifier.

   Unit no. 151 failed at -50C due to excessive period shift (> 400 μs). Analysis showed an overtrim condition on the thick-film resistor which adjusts the attenuation of the twin-T network.

2. Unit no. 41 ground pin fell off.

3. Unit no. 36 failed due to excessive period shift after acceleration. The failure mode could not be repeated upon subsequent testing.

4. Unit no. 90 failed due to excessive period shift. Analysis showed an overtrim condition of the thick-film resistor which adjusts the attenuation of the twin-T network.

   Unit no. 95 failed due to a broken beam lead from the integrated-circuit amplifier to the thick-film substrate.

   Unit no. 96 failed due to a marginally long period shift. The failure mode could not be repeated upon subsequent testing.

5. A second group of hybrids was subjected to a 30,000-g shock. These units were the same which were subjected to constant-acceleration testing at HDL. All eight failures showed excessively long period shift (∿100 ns) after shock. Failure analysis showed that the epoxy was not adhering to the metal case, causing a shift and undue stress on the substrate.

6. A third group of oscillators was randomly selected from the Development Evaluation Group (DEG) lot. These were subjected to a 12.5-kg constant-accelerative force for approximately 1 min. Testing after environmental conditioning showed minimal period shift, well within specification limits. The same units were then encased in epoxy in nose cones and subjected to 30,000-g shock testing.

7. All units failed due to not having any tin plate around the lead edges. It appeared as if the clips were stamped out after being plated.

8. The oscillators failed lead integrity because of the ground pins falling off the metal cases. The pins subsequently were soldered on rather than tack welded.

9. The 38-piece sample sent to HDL had not yet been subjected to gun fire testing at the time this report was written.

10. Same units as those subjected to temperature cycling. Unit no. 19 was replaced with Unit no. 153 because of the high period shift (0.092 μs, not a failure) experienced during temperature cycling.

(Signed) Thomas S. Zager
Honeywell Quality Representative
17 January 1979

APPENDIX F

PHASE IV PILOT LOT ACCEPTANCE REPORT FOR TAB PRECISION OSCILLATOR, P/N 11726813

Lot performance test results are tabulated below.

Test Description	Sample Size	Accept No.	Reject No.	No. of Defects
Subgroup A1 (Oscillator Characteristics)	158	4	5	4[a]
Subgroup A2 (Electronic Shield and Visual)	18	1	2	0
Subgroup B1 (Temperature Cycling)	25	1	2	0
Subgroup B2 (Constant Acceleration)	25	1	2	1[b]
Subgroup B3 (High-Temperature Storage)	25	1	2	0[c]
Subgroup B4 (Shock)	25	1	2	6[d]
Subgroup B4 (Shock)	25	1	2	0[e]
Subgroup B5 (Solderability)	8	0	1	8[f]
Subgroup B6 (Lead Integrity)	8	0	1	6[g]
Subgroup C1 (57-mm Gunfire)	38	1	2	-

---

[a] Units no. 92 and 158 failed to oscillate at ambient temperature; units no. 53 and 110 failed at -50C. The ambient temperature failures were caused by a broken beam lead and etched aluminum on several locations on the die. The low-temperature failures were attributed to overtrimmed and

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undertrimmed conditions of the twin-T attenuating network resistor.

[b] One unit failed due to a greater than 40-ns drift in period of oscillation after acceleration testing. Subsequent tests could not repeat the failure mode. No failure analysis disposition has been completed to date.

[c] Replaced unit no. 53, which failed the operating characteristics portion of tests, with unit no. 156.

[d] Replaced unit no. 92, which failed the operating characteristics portion of tests, with unit no. 157.

Units no. 76, 77, 78, 82, 94, and 96 drifted greater than 20 ns after shock. Failures are attributed to poor adhesion between the epoxy and plated case.

[e] Twenty-five units were drawn at random from the general lot and resubmitted for 30,000-g shock testing. These units differed from the first shock sample (Note c) in that they were encased in sand-filled epoxy as opposed to the first group being encased in brown sugar.

[f] All failed due to the ground posts not being solderable according to MIL-STD-883, Method 2003.

[g] Leads broke when subjected to lead integrity testing per MIL-STD-883, Method 2004 (three bends each).

[h] No gunfire test results had been collected at the time this report was written.

Replaced unit no. 110, which failed the operating characteristics portion of testing, with unit no. 155.

The phase IV envionmental test sample was proportionately drawn from three separate inships of oscillators. The three sublots were fabricated at separate times, therefore necessitating the drawing of proportionate samples from each lot. The sample size was based upon the proportion of the inshipped sublot to the total phase IV requirement. For example, one inship was a-proximately 130 pieces; the total phase IV requirement was approximately 1900 units; therefore, the 130-piece inship was approximately 7 percent of the total phase IV requirement. The environmental test sample for phase IV was 174 pieces. Seven percent of 194 is approximately 12 pieces; therefore, 12 pieces were drawn from the 130-piece inship to be included in the 174-piece environmental test sample.

(Signed) Thomas S. Zager
Honeywell Quality Representative
3 July 1979

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