Manufacturing Methods And Technology Report
Contract DAAB07-75-C-0044

PHOTOLITHOGRAPHIC TECHNIQUES FOR SURFACE ACOUSTIC WAVE (SAW) DEVICES

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October 1976

Quarterly Report #5 for Period 30 July to 31 October 1976

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Prepared for Production Division Procurement and Production Directorate
USAECOM
Ft. Monmouth, NJ 07703

NOTICES

Acknowledgements

The authors wish to express their appreciation to T. W. Bristol and G. W. Judd for assistance in device test.

Disclaimers

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER (9)
4. TITLE (and Subtitle) (6) PHOTOLITHOGRAPHIC TECHNIQUES FOR SURFACE ACOUSTIC WAVE (SAW) DEVICES,		5. TYPE OF REPORT & PERIOD COVERED Quarterly rept. no. 5, 30 Jul [redacted] 31 Oct [redacted] 76
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) (10) A. R. Janus, R. J. Kolb and L. Dyal		8. CONTRACT OR GRANT NUMBER(s) (15) DAAB07-75-C-0044
9. PERFORMING ORGANIZATION NAME AND ADDRESS Hughes Aircraft Company Ground Systems Group Fullerton, California 92634		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 2759739 (11)
11. CONTROLLING OFFICE NAME AND ADDRESS Production Division, Procurement and Production Directorate, USAECOM, Fort Monmouth, New Jersey 07703		12. REPORT DATE Oct [redacted] 76
		13. NUMBER OF PAGES 32
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (12) 31 p.		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

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

- Surface Acoustic Wave Devices
- Bandpass Filters
- Tapped Delay Line Filters
- Pulse Compression Filters
- SAW Processing
- SAW Packaging

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

The object of the program is the establishment of a production capability for surface acoustic wave devices of varied design and material for the purpose of meeting estimated military needs for a period of two years after the completion of the contract and to establish a base and plans which may be used to meet expanded requirements. The primary requirement is the pilot line production of devices that are reliable, reproducible, and low cost. → OVER

172 370

1B

Cont'd

Fabrication for the 3rd, Confirmatory Phase of the program has been accomplished and environmental testing is nearing completion.

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Section 1.0

INTRODUCTION

This report presents the results of the Phase III effort in satisfying the requirements of a Manufacturing Methods and Technology Program devoted to testing a representative set of acceptable surface acoustic wave (SAW) device designs to prescribed environmental testing.

1.1 PROGRAM OBJECTIVES

The objective of this program is to establish a production capability for the purpose of meeting estimated military needs for a period of two years after the completion of the contract, and to establish a base and plans which may be used to meet expanded requirements. The manufacturing techniques will emphasize the fabrication of SAW devices that are reliable and reproducible at low cost.

Specific tasks include establishing and demonstrating a capability to manufacture the six SAW device designs on a pilot line basis using methods and processes suitable for a production rate of 150 devices per month for each type. In addition, engineering analysis and planning will be accomplished for expansion of the manufacturing capability to accommodate the production of such devices at a rate of 500 each per month.

1.2 PROGRAM PLAN

The program has been divided into four phases. The first addressed the design, fabrication and analytical testing of six prototype SAW devices that are representative of the current and potential application of the technology. While these device requirements do not represent the state-of-the-art in an R&D sense, they are of such complexity as to require a serious design effort in each case.

The second phase was utilized in the redesign of those devices that failed the intended design specification. The net result of this effort was a functional electrical specification adherence based on a cost effective packaging commitment.

The third phase is testing both the electrical and environmental commitment of the various devices to the specification. The final phase will test the reproducibility of those predetermined electrical and environmental requirements in a high volume production environment. A key result of this phase will be the establishment of meaningful manufacturing cost data on each device as well as a comparison of this data to the prior low volume efforts on the earlier phases.

1.3 PROGRAM ACCOMPLISHMENTS

Fabrication has been accomplished and environmental testing is now nearing completion in order to meet the requirements of the third, Confirmatory Phase of the program.

Section 2.0

CONFIRMATORY SAMPLE TESTING

The program specification (SCS-476, First Quarterly Report) details both the sequence and nature of environmental testing. The ensuing subsections describe these tests and the measured performance achieved to date.

2.1 TEST PROCEDURES

2.1.1 Test Sequence

Confirmatory samples were fabricated and are being tested according to the instructions given in Tables 2-II, 2-III and 2-IV of specification SCS-476. This test sequence is summarized in Table 2-I of this report. Applicable MIL-STD requirements for environmental testing are further defined in Table 2-II.

In order that the devices be life tested under operating conditions, each type of device was arranged in a series-parallel combination on a printed circuit board to present the proper impedance to the signal source. In this way, a CW signal of approximately 10 mW at center frequency was supplied throughout the life test cycle. One of these boards, partially loaded with devices, is shown in Figure 2-1.

Shock and vibration testing have been performed in accordance with the specified MIL-STD requirements. Appendix I contains a typical report filed by the Environmental Engineering Department on PC-LN and BP-LN devices.

2.1.2 Test Status

At this time, testing for the Confirmatory Phase has been partially completed. In the testing performed to date the number of defective parts has been equal to or less than the number allowed by SCS-476. The extent of this testing, compared to that required is compared in Table 2-III. In this table the program requirements have been somewhat rearranged in order to reflect the actual part flow and to incorporate pertinent assembly operations. In addition to a 100% precap visual, Quality Assurance is monitoring the First and Final Electrical testing. While the First Electrical test was performed on a go, no-go basis, tabular data is being taken during Final Electrical testing. This data is

TABLE 2-I. CONFIRMATORY SAMPLE INSPECTION

TDL 200	TDL 100	BP-LN	BP-Q	PC-LN	PC-Q	
7	7	10	10	10	10	Min. No. Wafers
7	7	15	15	10	10	Min. Die/Wafer
42	42	84	84	84	84	Operable Die
1	1	1	1	1	1	Undiced Wafer Del. for Inspection
7	7	10	10	10	10	Wafers for Inspection Table III
42	42	84	84	84	84	Dice, Mount and Bond
6	6	12	12	12	12	Group II, Table IV
36	36	72	72	72	72	Group I, Table IV
9	9	18	18	18	18	Group III, Table IV
9	9	18	18	18	18	Group IV, Table IV
6	6	12	12	12	12	Group V, Table IV
12	12	24	24	24	24	Group VI, Table IV
0 1 0 1	0 1 0 1	0 1 0 2	0 1 0 2	0 1 0 2	0 1 0 2	No. Defective (Max.)

presented in Table 2-IV for PC-LN, PC-Q and BP-LN subsequent to life test. It is noted that due to the nature of the VSWR measurement (superimposition of swept frequency measurement with return loss measurement), center frequency and bandwidth measurements are accounted for. Delay, verified to be within specification for each device mask, is not measured on all samples.

A review of the data in Table 2-IV shows that the rejects for each of the device types listed do not exceed the number permitted by the specification. With regard to PC-LN, it is noted the specification on near-in sidelobes was only narrowly achieved. It was also noted that in three instances, S/N 67, 5, 1, the insertion loss specification was exceeded by up to 5 dB. These units were then decapped in order to analyze the cause of the problem. After decapping, all three

TABLE 2-II. CONFIRMATORY SAMPLE INSPECTION REQUIREMENTS

Group	Test	MIL-STD	Method	Condition	Comment
I	Wire Bond	883	2011	D	2 gm tension
	First Electrical		--	--	See Note 1
II	Solderability	883	2003	--	--
III	High Temperature Storage	883	1008	A	72 hrs.
	Center Frequency Insertion Loss		--	--	--
IV	Life	202	108	--	85^oC
	Final Electrical		--	--	See Note 1
V	Hermeticity	202	112B	C A	fine gross See Note 2
	Short Circuit				See Note 3
VI	Vibration	202	201	--	Low frequency
	Short Circuit	--	--	--	See Note 3
	Shock	202	213	I	--
	Short Circuit	--	--	--	See Note 3
	Thermal Shock	202	107	A	10 cycles
	Short Circuit	--	--	--	See Note 3
	Moisture Resistance	202	106D	--	50V DC
	Final Electrical	--	--	--	See Note 1

Notes: 1. Test procedures described in Fourth Quarterly Report.
2. Packages 100% tested for fine and gross leak.
3. Swept frequency measurement.

TABLE 2-III. ECOM MMT STATUS PHASE III

	BP-Q	TDL-100	BP-LN	PC-Q	PC-LN	TDL-100
1. process wafer						
2. inspect (250X)						
3. dice						
4. component attach						
5. mount						
6. bond						
7. bond pull						
8. tune						
9. QA inspect (20X)						
10. seal						
11. leak test						
12. * first electrical						
13. temp. storage						
14. fo, loss						
15. life						
16. final electrical (life)						
17. vibration						
18. short circuit						
19. shock						
20. short circuit						
21. thermal shock						
22. short circuit						
23. moisture						
24. final electrical (env.)						
25. solderability						

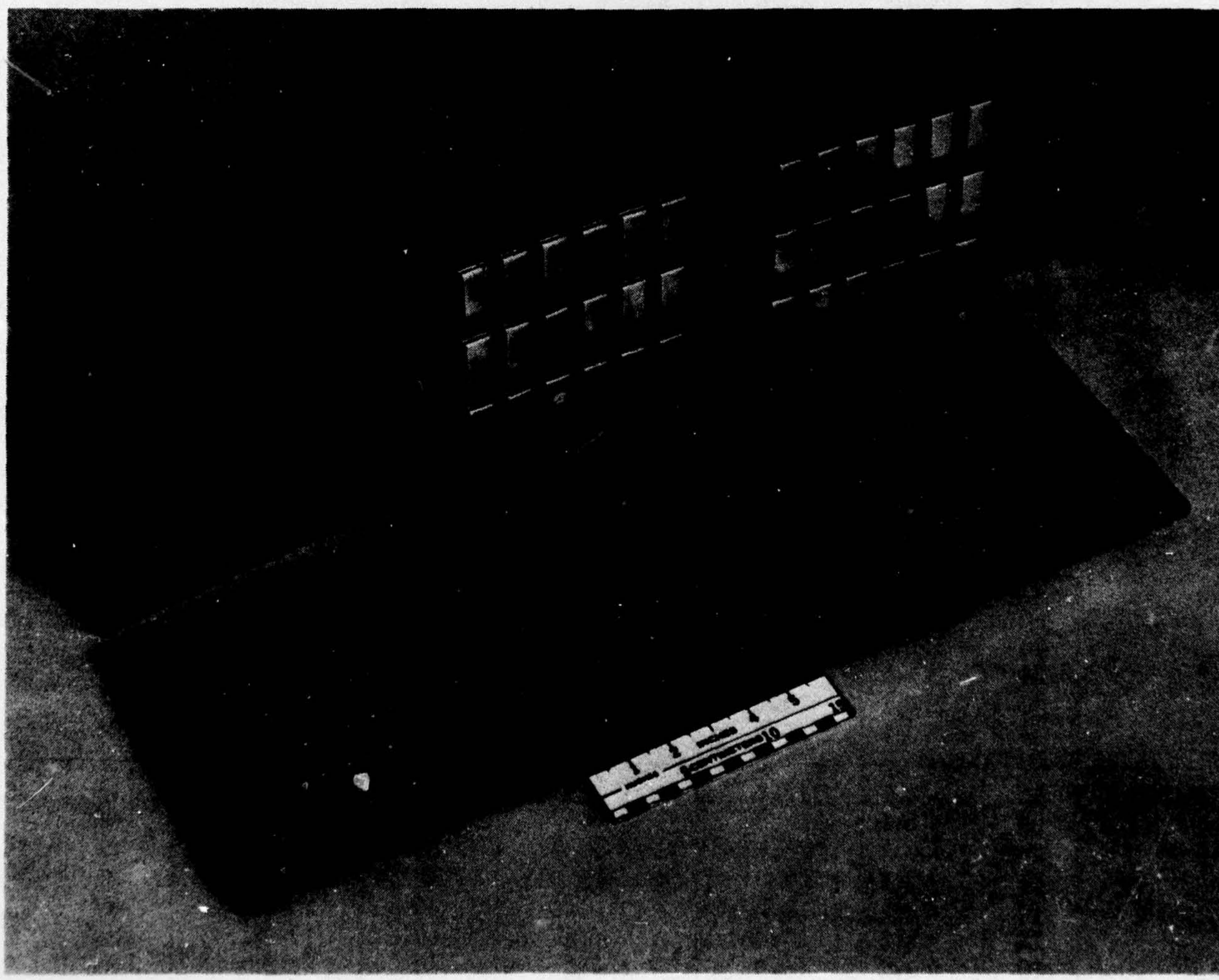
*Dual pathway is noted for steps 12 - 16 and 12, 17 - 24.

TABLE 2-IV. FINAL ELECTRICAL TEST DATA TAKEN SUBSEQUENT TO LIFE TEST

Device	S/N	VSWR	(dB) Ins. Loss	Sidelobes (dB) Lead	Sidelobes (dB) (dB) Trail	Sidelobes (dB) Far-Out	(dB) Feedthrough	(dB) Spurious
PC-LN	67	< 3:1	32.5	27	25	29	>50	38
	12	< 3:1	30.5	20	25	29	>50	35
	11	< 3:1	31.5	20	25	31	>50	38
	10	< 3:1	31.0	20	25	31	>50	36
	43	< 3:1	31.5	20	25	31	>50	36
	47	< 3:1	31.5	20	25	30	>50	35
	5	< 3:1	32.5	25	30	30	>50	42
	52	< 3:1	32.0	21	25	31	>50	35
	40	< 3:1	32.0	20	25	30	>50	39
	29	< 3:1	33.0	20	25	31	>50	35
	59	< 3:1	33.0	20	25	31	>50	35
	6	< 3:1	32.0	21	27	29	>50	36
	56	< 3:1	32.5	20	25	32	>50	36
	68	< 3:1	32.0	21	25	32	>50	39
	41	< 3:1	32.0	22	25	32	>50	38
	51	< 3:1	31.5	23	25	31	>50	32
	18	< 3:1	33.0	21	25	32	>50	35
	1	< 3:1	33.0	20	25	30	>50	39
PC-Q	39	< 2.5:1	48.5			30	>50	37
	48	< 2.5:1	45.5			29	>50	38
	23	< 2.5:1	45.0			28	>50	40
	7	< 2.5:1	47.0			28	>50	41
	62	< 2.5:1	47.0			32	>50	40
	5	< 2.5:1	46.0			33	>50	37
	2	< 2.5:1	46.0			28	>50	37
	19	< 2.5:1	46.0			30	>50	43
	41	< 2.5:1	47.5			30	>50	43
	12							
	33	< 2.5:1	46.0			29	>50	43
	43	< 2.5:1	46.5			30	>50	42
	16	< 2.5:1	46.5			33	>50	41
	45	< 2.5:1	47.0			28	>50	37
	24	< 2.5:1	46.0			28	>50	42
	31	< 2.5:1	45.5			30	>50	42
	35	< 2.5:1	45.0			29	>50	42
	30	< 2.5:1	52.0			31	>50	38
BP-LN	17	< 2:1	19.5			40	>50	39
	4	< 2:1	18.5			40	>50	35
	29	< 2:1	18.5			40	>50	35
	15	< 2:1	20.0			40	>60	38
	14	< 2:1	18.5			40	>60	36
	12	< 2:1	18.5			40	>50	38
	19	< 2:1	18.5			40	>50	36
	10	< 2:1	18.5			40	>50	35

TABLE 2-IV. FINAL ELECTRICAL TEST DATA TAKEN SUBSEQUENT TO LIFE TEST (Continued)

Device	S/N	VSWR	(dB) Ins. Loss	Sidelobes (dB) Lead	Sidelobes (dB) (dB) Trail	Sidelobes (dB) Far-Out	(dB) Feedthrough	(dB) Spurious
BP-LN (continued)	37	< 2:1	19.0			>40	>50	37
	2	< 2:1	19.5			>40	>60	36
	1	< 2:1	18.5			>40	>50	35
	20	< 2:1	18.5			>40	>60	35
	22	< 2:1	18.5			>40	>60	36
	21	< 2:1	18.5			>40	>60	35
	24	< 2:1	18.5			>40	>60	35
	8	< 2:1	20.0			>40	>50	37
	7	< 2:1	19.0			>40	>60	36
	18	< 2:1	18.5			>40	>60	36



76-12-018

Figure 2-1. Typical Printed Circuit Board Layout for Life Test units tested out at the insertion loss listed in Table 2-IV. These insertion losses did not change when the units were resealed. The cause of observed changes is not presently understood and is under investigation. Finally, the high spurious reject, S/N 51, is felt to be due to a triple transit echo caused by the use of insufficient absorber material on the end of the crystal (Quarterly Report No. 4).

The single reject in the PC-Q category was found to have two open transducers. The fact that both transducers were open can probably be more easily attributed to an assembly oversight that it can to the life test condition.

With regard to the BP-LN devices, the insertion loss is seen to be consistently at the low end of the specification range. Measurement of the metallization thickness indicates 2000Å, somewhat higher than the thickness obtained on the Phase II prototype devices.

2.2 RESOLUTION OF PHASE II PROBLEMS

Circuit testing indicates that the imposition of a ground pad at the mask level between input and output transducers on the TDL devices has been successful in reducing feedthrough to acceptable levels. Continued experience with the TDL-200 devices has shown VSWR levels of the Second Phase to be marginal. An iron core torroid was therefore substituted for the plastic core unit at approximately the same inductance in order to achieve a reduced capacitance that greatly facilitated the tuning operation.

Section 3.0

DEVICE FABRICATION

Device fabrication has been completed for the Phase III delivery. Environmental testing is now underway in order to comply with the requirements of this Confirmatory Phase.

3.1 PHOTOLITHOGRAPHIC YIELD

During the fabrication effort required during the Third Phase of the program, preliminary estimates were made of the number of acceptable devices at the wafer level prior to dicing. This level was determined on the basis of visual inspection at 250X. The results are shown in Table 2-V. Excessive particulate contamination during processing was experienced during the fabrication of the PC-LN devices causing a reduced yield. The relatively high yield on the TDL devices can be attributed to the fact that up to a maximum of two defective taps were scribed as necessary during inspection. Prior experience has shown that this procedure will not degrade device performance.

3.2 PACKAGE SEALING

Due to the limited quantities involved, hand solder-sealing is being employed on this program. The nature of this operation calls for a 100% gross and fine leak test as a normal procedure. With the #20221 platform - 20216 cover combination, originally designed for seam welding, up to 40% rework has been required on the BP and PC devices. Better results are anticipated on the TDL packages, whose design lends itself more readily to the hand soldering operation.

TABLE 2-V. PHOTOLITHOGRAPHIC YIELDS - PHASE III

Device	No. Die/Wafer	Apparent Yield (%)
PC-Q[1]	20	64
PC-LN[1]	45	58
BP-Q	33	67
BP-LN	32	64
TDL-100	9	78
TDL-200	12	77

[1]Standard quartz substrate dimension - 2.0 x 2.0 x 0.025"
Standard lithium niobate substrate dimension - 2.1 x 1.75 x 0.020"

Section 4.0

CONCLUSIONS

Environmental testing required for the third, Confirmatory Phase samples is nearing completion. To date, this effort is proceeding satisfactorily.

4.1 PLANS FOR THE NEXT QUARTER

The next quarter's activity will involve the completion of environmental test with the shipment of fifty devices of each of the six designs. Subsequent to this, the pilot production run will start.

APPENDIX I
SHOCK AND VIBRATION TEST REPORT

HUGHES-FULLERTON
Hughes Aircraft Company
Fullerton, California

HUGHES
HUGHES AIRCRAFT COMPANY
GROUND SYSTEMS GROUP

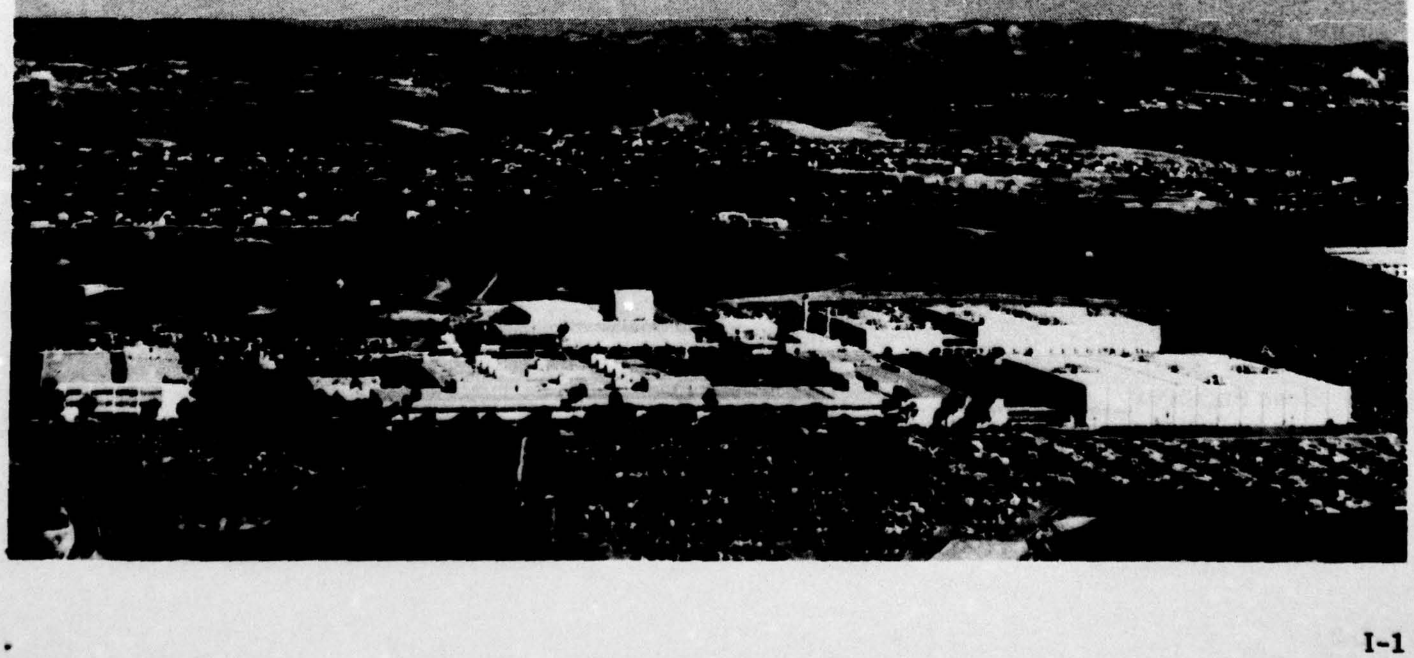
ENVIRONMENTAL TEST PROCEEDINGS

ACCOMMODATION TESTS

SAW MMT DEVICES

EL. 8731

JOURNAL NO. A 00380



ENVIRONMENTAL TEST PROCEEDINGS JOURNAL

Test Start Date: 11-4-76 Test Complete Date: ________ WA# 8731

Test Type

- [ ] Lt. Wt. Shock
- [ ] Vibration
- [ ] Inclination
- [ ] Md. Wt. Shock
- [ ] Bounce
- [ ] Road
- [ ] Other

Test Eng. D. BROWN C. A. # 1324-204-306217

GSI [ ] Yes [X] No P. R. # 662478

Test Requestor: KEN BLOSSOM Ext. 2614 Org. Code 19-66-26

Customer: ________ ~~P.O.~~ # ________

Address: ________ Part Number PC-LN - 24 PCS. BP-LN - 24 PCS.

Part Name SAW MMT DEVICES

Test Witnesses:

Monitored by:

Test Engineer ________ QA ________

Test Technician Ted Vandiver ________ AFQAR ________

HUGHES-FULLERTON
Hughes Aircraft Company
Fullerton, California

Test Procedure: **Date:** 11-4-76

List or attach pertinent specifications:

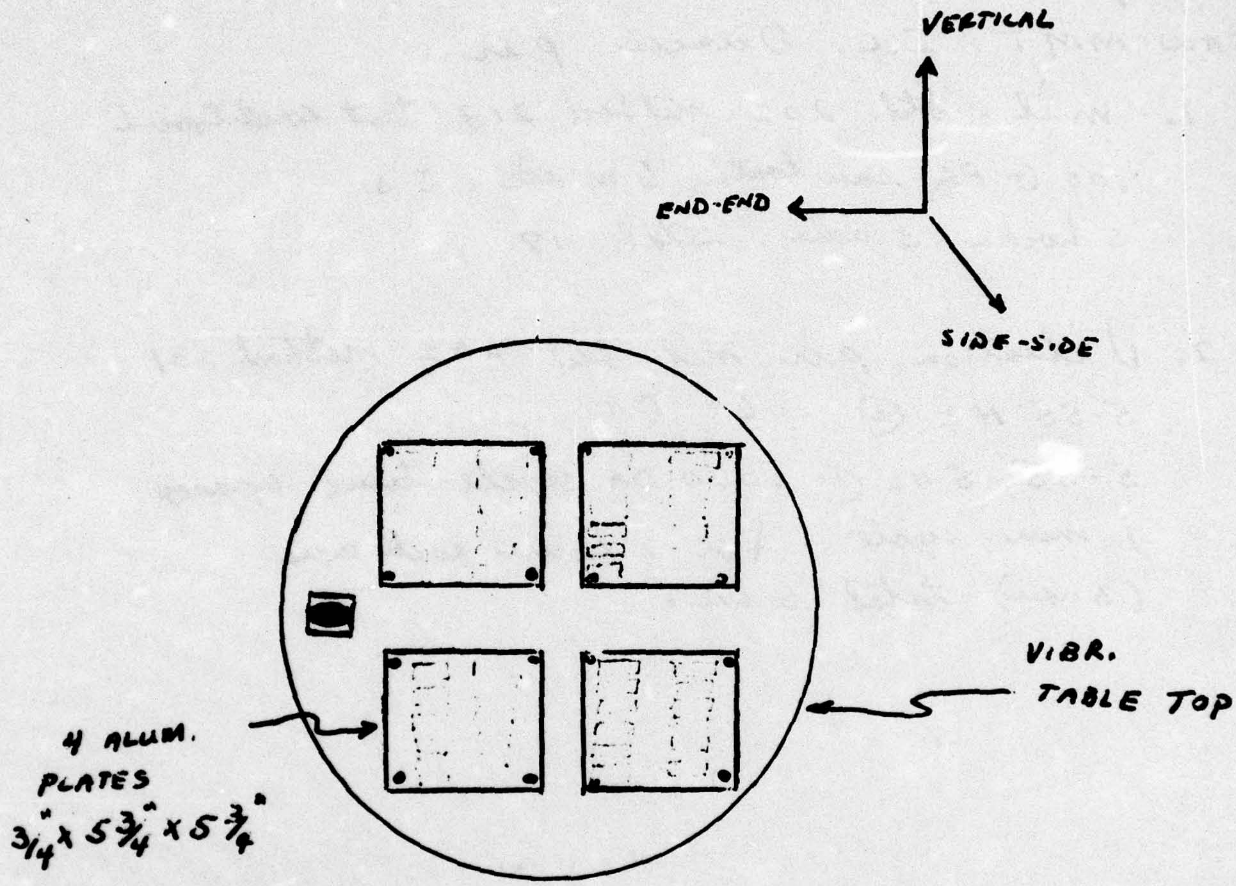
Perform shock and vibration test on 48 SAW MMT I.C. Devices per.

1. mil - std. 202 method 213 test condition I 100 G PK sawtooth 6 m sec. ± 3 shocks 3 axis, total 18

2. Vibration per mil - std 202 method 201 5-55 HZ @ .060 DA.
5-55-5 HZ @ .060 DA cycle time approx. 1 min. cycle. for 2 hours each axis (3 axis) total 6 hrs.

Data Recorder Lel Vandinah
Page 2

Test Procedure Cont'd: Date: 11-4-76



Data Recorder:
Page 3

Test Data: Date: 11-4-76

Record all data and observations as test is conducted.

P/N BP-LN

S/N	26	63	46
	13	28	73
	34	48	71
	76	75	35
	57	56	38
	77	11	79
	44	42	
	70	44	
	45	43	

P/N PC-LN

S/N	30	2	14
	31	3	45
	49	36	64
	22	28	46
	23	58	13
	9	34	66
	26	32	
	48	20	
	38	61	

NOTE! (2) pins were broken during installation to connectors prior to Unit testing. 1 pin on S/N 36 & 1 pin on S/N 75

DFBrown

Data Recorder Zed Vandiver

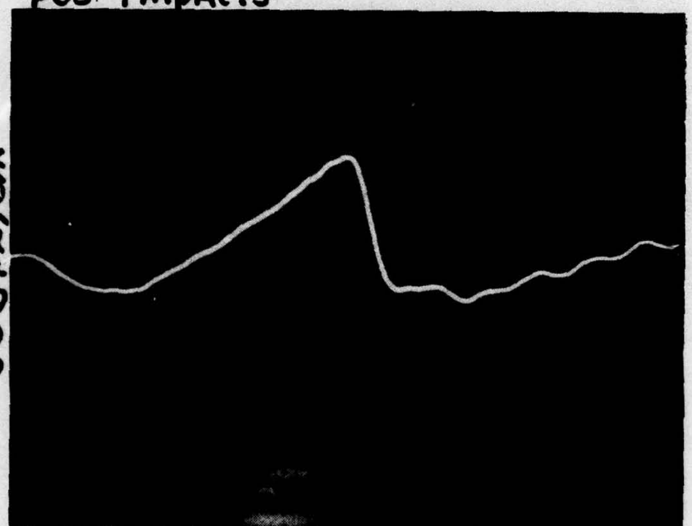
Page 4

Test Data Cont'd: Date: 10-9-76

SHOCK TEST PER MIL STD 202 method 213 TEST COND I 6msec 100GPK SAWTOOTH.

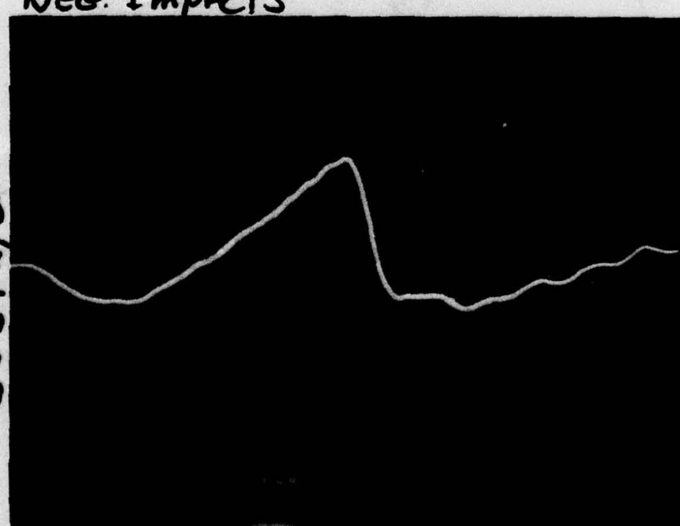
BP-LN P/N's Listed on PAGE 4 And P/N PC-LN S/N's Listed on PAGE 4 were subjected to ± 3 SHOCKS per Axis (3 AXIS TOTAL 18). NO APPARANT mechanical DAMAGE Noted.

POS. impacts



2msec/cm

NEG. Impacts



2msec/cm

INPUT SHOCK PULSE

Test Data Cont'd: Date: 11-4-76

ELAPSED TIME	
2372.7	STARTED SIDE-SIDE AXIS.
2374.7	COMPLETED SIDE-SIDE AXIS (2) HRS
2374.7	STARTED FRONT TO BACK AXIS
2376.7	COMPLETED FRONT TO BACK AXIS (2) HRS
2376.7	STARTED VERTICAL AXIS
2378.7	COMPLETED VERTICAL AXIS (2) HRS

11-19-76
Rec'd. 48 SAW MMT Devices. (2nd Set of Devices)
24 ea. BP-LN
24 ea PC-LN
Devices were mounted in individual sockets therefore S/N identification was not performed.
Due to 2 pins being broken on the previous series. It was requested that the devices be mounted prior to shipping to Envi. Eng for test.

11-22-76 Vibration test per Mil Std 202 Meth 201 5-55-5 HZ @ .06" DA in the three (3) mutually perpendicular axis was performed. No apparent damage resulted due to vibration.

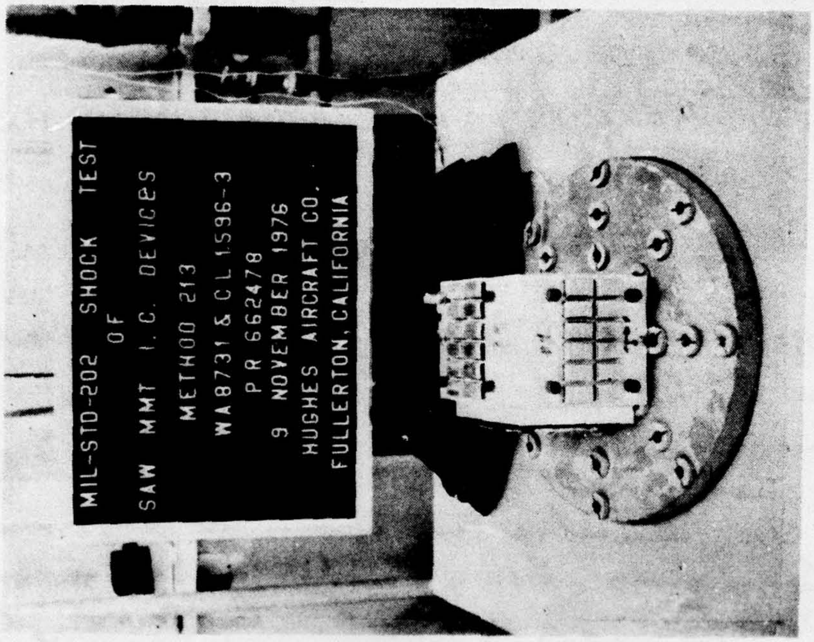
11-23-76 Test specimens returned for electrical performance test. No photographs of the test setup were made due to duplication. Refer to GS 76-11-213 Photograph for test configuration

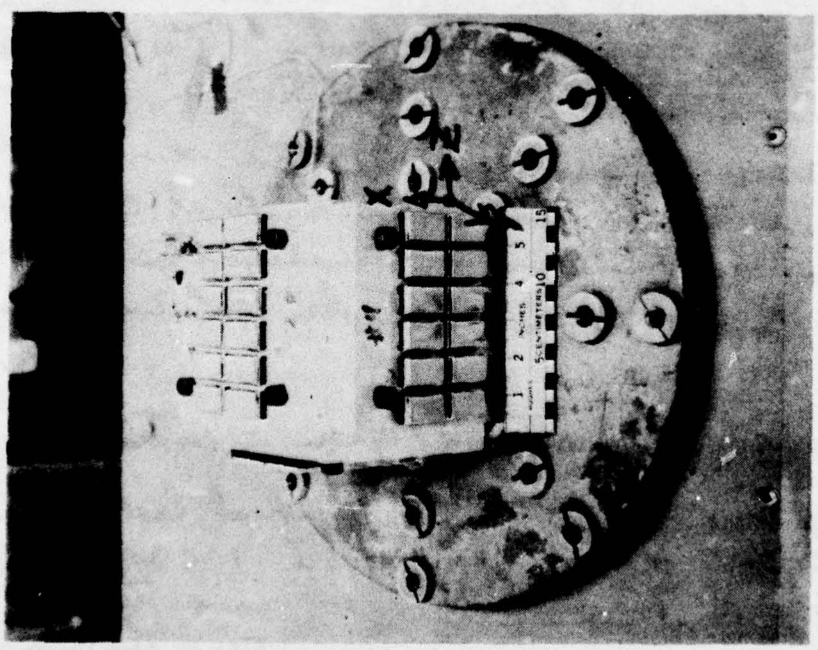
11-23/11-24
48 test specimens returned from electrical performance test.
48 test specimens subjected to shock testing per Mil Std 202 Method 213 Test Cond I 100G, 6 msec Sawtooth

Data Recorder D. Brown
Page 6

con't page 8

Test Data Cont'd: Date: 10-9-76





SHOCK test set up.

Test Data Cont'd: Date: 11-23-76

Each test specimen subjected to ± 3 shock in each of 3 mutually perpendicular axis.
Upon completion of testing units were visually inspected. No damage observed. No photograph was performed and photos of input pulse were not performed however pulse on page 7 is representative of pulse shape and amplitude during this test.
Test specimens returned for electrical testing.
WJB.

Received & mounted 24 SAW MMT Devices 12-21-76
P/N TDL-200 (12 TDL-100 AND 12 TDL-200)
Mounted devices on 5¾" square plate using double-faced tape
4 devices/plate on Six (6) plates.
Vibration to be perform per Mil-Std. 202 Method 201
Sweep 5-55-5HZ @ .06" D.A. in one (1) Min. for 2 HRS./Each of three (3) Axes, mutually perpendicular.

15:33 Start Vibration. Cycling as noted above for 2 Hrs. along Vert. axis.

12-22-76

08:50 Completed Vert. axis. No apparent visual mechanical damage noted.

09:05 Start of side to side axis, Cycling as above for 2 Hrs.

11:05 Completed side to side axis.
No apparent visual mechanical damage noted.

11:16 Start of End to End axis for 2 Hrs. Same sweep & amplitude as above.

15:10 2 Hrs. Cycling completed. No apparent visual indication of mechanical damage noted.

Units to be returned for Electrical testing.

Data Recorder B. Nick.
Page 8

Test Equipment

Date: 11-4-76

	Equipment	Cal Due Date
[ ]	Shock Machine, LW High-Impact, BuShips 10-T-2145-L	
[ ]	Shock Machine, MW High-Impact, BuShips 807-655947	
[ ]	Vibration Table, Low Frequency, LAB RVH 72-5000	
[ ]	Vibration Table, Low Frequency, LAB RVH 72-2500	
[ ]	Vibration Table, Low Frequency, LAB RVH 48-1000	
[X]	Vibration Table, Low Frequency, LAB RVH ~~36-500~~ 24-100	apr 1, 77
[ ]	Inclination Test Machine, Hughes	
[ ]	Package Tester, LAB Type 1000 SC	
[ ]	Boost Pump, Sprague, Model 216-C-150	
[ ]	Boost Pump, Sprague, Model S-4406S-35	
[ ]	Gauge, Heise, 0-70 PSI, S/N 24927	
[ ]	Gauge, Heise, 0-70 PSI, S/N 24929	
[ ]	Gauge, Heise, 0-100 PSI, S/N 24932	
[ ]	Gauge, Heise, 0-500 PSI, S/N 24939	
[ ]	Gauge, Heise, 0-500 PSI, S/N 24244	
[ ]	Gauge, Marsh, 0-300 PSI, Type 220-4S	
[ ]	Gauge, Marsh, 0-1000 PSI, Type 220-4S	
[ ]	Gauge, Marsh, 0-1500 PSI, Type 220-4S	
[ ]	Gauge, Marsh, 0-3000 PSI, Type 220-4S	
[ ]	Gauge, Marsh, 0-5000 PSI, Type 220-4S	
[ ]	Gauge, Marsh, 0-10,000 PSI, Type 220-4S	
[ ]	Gauge, Sprague, 0-20,000 PSI	
[X]	Vibration Meter, Bell & Howell Type 1-157 H-307252 H-321866	Feb 9, 77 3-9-77
[ ]	Vibration Meter, CEC Type 1-117	
[X]	Vibration Pick Up, CEC Type 4-102A S/N 13844	oct 24, 77
[X]	Universal Timer, Dimco Gray Model 167	April 4., 78
[ ]	Vehicular Adaptor Plate, LAB 2-1/4" x 36" x 36"	
[ ]	Universal Eput Meter, Beckman Model 7360-43	
[ ]	Strobex, Bruel and Kjorr, Type 4910	
[ ]	Strobex, Bruel and Kjorr, Type 4911	
[ ]	Other	
[ ]	Other	
[ ]	Other	

Data Recorder: Ed Vandivort

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SHOCK TEST

EQUIPMENT	MANUFACTURER	MODEL	GOVT. OR HAC I. D. NO.	SERIAL NO.	CAL DUE DATE
accelerometer	Endevco corp.	2272	E066	AU30	5-9-77
charge amp.	Unholtz-Dickie	D-11	H-916102		5-2-78
Krohn-Hite Filter	Krohn-Hite	3322R	H-198585		10-20-77
wave form Synthesizer	Exact	201	H-305673		
Storage Scope	Hewlett Packard	Mainframe 141B Time Base 1421A Dual Amp 1402A	H-307288 H-307289 H-307290		11-18-76 11-18-76 11-18-76
oscillator	Spectral Dynamics	SD104A-5	H-300527		2-16-77
Power amp.	Unholtz-Dickie	TA 104	H-300574		Calib As Req'd
Shaker	Unholtz-Dickie	1003M	H-300515		Calib As Req'd
VIBRATION METER	BELL & HOWELL	1-157	H-321866	-	3-9-77
VIBRATION MACHINE	LAB	24-100	H-29009	-	4-1-77
TIMER	DIMCO GRAY	167	H-303363	-	4-4-78

APPENDIX II
MANPOWER SUMMARY

Appendix II

MANPOWER SUMMARY 11 JULY TO 29 OCTOBER 1976

Function	Name	Title	Man Hours
Photomask	G. Bair	Assistant Engineer	17
	R. West	Assistant Engineer	14
	W. Thompson	Technician	18
	E. Johnson	Technician	121
Fabrication	L. Dyal	Member Technical Staff	328
	I. Rios	Material Process Analyst	396
Test	R. Kolb	Member Technical Staff	108
Fixture Fabrication	W. Randall	Machinist	41
Assembly	A. Pincek	Group Head	35
	B. Grow	Technician	45
	F. Martin	Technician	46
	T. Bates	Technician	14
PC Board Design	L. Terrigno	Designer	62
	R. Keller	Designer	40

PUBLICATIONS, REPORTS AND CONFERENCES

On 19 August 1976, Mr. D. Biser of ECOM visited Hughes for a technical program review. On 17 September 1976, further technical discussions were held at Hughes with Mr. E. Mariani.