COST REDUCTION STUDY
FOR A
SARSAT 406 MHz EMERGENCY BEACON

bristol aerospace limited
WINNIPEG CANADA

Government of Canada Gouvernement du Canada

Department of Communications

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THIS REPORT CONTAINS MATERIAL OF POSSIBLE COMMERCIAL VALUE. THE SCIENTIFIC AUTHORITY SHOULD BE CONSULTED BEFORE RELEASE OUTSIDE THE DEPARTMENT.

CE RAPPORT CONTIENT DE L'INFORMATION QUI POURRAIT AVOIR DE LA VALEUR COMMERCIALE L'AUTHORITÉ SCIENTIFIQUE DOIT ÊTRE CONSULTÉ AVANT DIFFUSION À L'EXTÉRIEUR DU MINISTÈRE.

PREPARED BY: Bristol Aerospace Limited
Winnipeg, Manitoba

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DOC SCIENTIFIC AUTHORITY: Dr. E.J. Hayes

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Prepared by:

Engineering Division

Marketing/Contracts Department

WINNIPEG, CANADA

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1.0 INTRODUCTION

1.1 Purpose

This engineering report presents a study performed to fulfill the requirements of contract 135 V, 36001-3-2165 "Conceptual Design Study - Reduced Cost SARSAT 406 MHz Emergency Beacon".

1.2 Scope

The scope of this report is confined to analyzing methods and the impact of each to reduce the production cost of the electronics module developed by Bristol Aerospace Limited for experimental 406 MHz beacons. These methods are restricted to design changes of the electronics module and its enclosure. The design changes are initiated by either a system specification change or by modification of a design concept. The costs presented in this report are sufficiently accurate for relative cost comparisons but are not intended as an offer to manufacture or to be construed as an indication of selling price. They have been formulated on a premise that an appropriate facility would be used for production. The costs do not include any estimates for amortization of capital expenditures.

2.0 COST, SIZE AND WEIGHT SENSITIVITY ANALYSIS

The purpose of this section is to present the cost, size and weight of the SARSAT 406 MHz Beacon. This data will then be available for comparison purposes to determine what areas of the design and system specifications require further analysis.

The existing unit was partitioned into functional subsystems and analysed for cost of components, assembly, test, and calibration. The segmented costs are summarized in the tables of section 2.8 and ranked in order of decreasing cost in section 2.9. The impact of functional specifications are discussed in section 2.10.

External subsystems are defined and analyzed to fully represent an operating system.

2.1 Subsystem Partitioning

The SARSAT 406 MHz Beacon is partitioned as follows:

2.1.1 Existing Design

- case (for electronics only)
- voltage regulator for DTCXO
- CPU support
- digital controller
- temperature sensor
- D/A converter
- stable oscillator
- transmitter control
- test interface
- user interface (code/serial/power)
- thermal shield
- power switch
- Voltage regulator for PLL
- 406 protection
- 406 leveller
- 406 forward power detector
- 406 phase detector and modulator
- 406 loop amplifier and offlock detector
- 406 VCO

- 406 power amp
- 406 divider
- 406 harmonic filter
- 121 beacon oscillator and RF
- 121 beacon modulator
- 121 beacon regulator
- output interface (406/121/bracket)
- test interface

2.1.2 External to Existing Design

Subsystems external to the existing design are included in the sensitivity analysis.

These include:

- battery pack
- external user interface
    consisting of: antenna
    diplexer
    switches
    indicators
    connectors

An external case is not included. In an operational system the internal electronic case would be redesigned to function as the external enclosure.

2.2 Component Costs

The cost of components is summarized by the subsystem in Appendix A. The cost of the printed wiring board is divided into subsystems by an area as summarized in 2.6. The cost of multiway connectors and logic gates are similarly partitioned by distribution of function.

2.3 Assembly Costs

The cost of assembling, soldering, and inspecting the printed circuit boards is discussed in Appendix F. A uniform "cost per pin" is then applied to each board connection.

$$\frac{\text{cost of assembly}}{\text{number of pins}} = \text{cost/pin}$$

The assembly of the box and of the beacon into the box is costed from existing times.

man hours x rate = cost per unit
where a typical rate of $30/hour is used.

2.4 Test Costs

Circuit testing of the units is costed in Appendix D. Calibration of the beacon is a subsequent operation.

2.5 Calibration Costs

The current module has seven calibration points. Each is given a standard time which is priced at the standard labour rate.

- 121 Beacon Voltage Regulator:

Tuned with the transmitter for optimum power output at 20°C and checked at the temperature extremes.	3 minutes

- 121 Beacon Modulator:

Adjusted for 40% duty cycle	3 minutes

- 121 Beacon RF

The oscillator, trippler and output stages are tuned for optimum output at room temperature and checked at the temperature extremes.	9 minutes

- 406 V.C.O.

Tuned for centre frequency at 20°C.	1 minute

- 406 Modulator

Adjusted for specified deviation sensitivity at 20°C and checked at temperature extremes.	3 minutes

- 406 Leveller

Adjusted for proper output at room temperature.	3 minutes

- Stable Oscillator

Select C1, 2, 6, 21 for correct frequency and pulling range.	3 minutes
Cycle oscillator over the temperature range to prepare the correct compensating signal, then run thermal profiles as per SARSAT specification (47 minutes for calibration, 60 minutes for profiles).	107 minutes

2.6 Size Analysis

The board area occupied by subsystems are reported. The areas occupied by the circuits do not sum up to 100% of the board area because some of the area is used for mechanical support and for signal isolation. Realistic board costs were calculated by the formula:

$$\frac{\text{area of circuit}}{\text{area of all circuits}} \text{ x area of total PWB = subsystem area}$$

imperial dimensions are converted to SI in the last column by scaling with the factor $2.54^2 = 6.4516$.

DTCXO is the PWB containing oscillators, the CPU and timing and control circuits. It was found to have 27.52 square inches of circuitry on a 30.1 square inch board. 2.6 square inches are taken up by support flanges at the edges and free space between components.

RF Module is the PWB containing the modulated carrier oscillator amplifiers, switches, and supervision. This board contains 24.46 square inches of circuitry on the 30.1 square inch board. 5.6 square inches are used to support the board and separate the circuits.

SUBSYSTEM	DIMENSIONS (in.)	AREA OF (in^2)	% OF TOTAL CIRCUIT AREA	SUBSYSTEM AREA (in.)	(cm^2)
DTCXO PWB		30.1	100		
Voltage Regulator	1.75 x 1.25	2.19	7.9	2.38	15.36
CPU Support	1.5 x 1.25	1.88	6.8	2.05	13.23
Digital Controller	2.7 x 1.8 +	6.84	24.8	7.47	48.19
	1.0 x 0.4 +				
	0.7 x 2.25				
Temperature Sensor	1.3 x 0.8 +	2.72	9.9	2.98	19.23
	1.2 x 1.4 +				
D/A Converter	0.4 x 1.3 +	2.92	10.6	3.19	20.58
	2.4 x 1.0				
Stable Oscillator	2.5 x 1.5	3.75	13.6	4.09	26.39
Transmit Control	1.0 x 0.7 +	2.10	7.6	2.29	14.77
	2.0 x 0.7 +				
Test Interface	(1.0 x 3.25)x .75	4.32	15.7	4.77	30.58
	2.5 x 0.75				
User Interface	(1.0 x 3.25)x 0.25	0.81	2.9	0.87	5.61
RF Module PWB		30.1	100		
Power Switch	0.3 x 0.7	0.21	0.9	0.26	1.68
5 V Regulator	0.5 x 0.5	0.25	1.0	0.31	2.00
406 Protection	1.0 x 0.5	0.50	2.0	0.62	4.00
406 Leveller	0.75 x 0.70	0.53	2.2	0.65	4.19
406 Power Det	2.0 x 0.3	0.60	2.5	0.74	4.77
406 PH Det & Mod	2.5 x 1.0	2.50	10.2	3.08	19.87
406 Loop Amp & Det	0.75 x 1.5	1.12	4.6	1.38	8.90
406 VCO	1.5 x 1.0	1.50	6.1	1.85	11.94
406 Power Amp	1.0 x 2.75	2.75	11.2	3.38	21.81
406 Divider	1.0 x 0.75	0.75	3.1	0.92	5.94
406 Harmonic Filter	4.1 x 0.2	0.82	3.4	1.01	6.52
121 BCN OSC & RF	1.5 x 1.75	2.63	10.8	3.27	20.90
121 Modulator	2.2 x 0.9	1.98	8.1	2.44	15.74
121 Regulator	1.25 x 1.0	1.25	5.1	1.54	9.94
Output Interface	1.2 x 2.7	3.24	13.3	3.99	25.74
Test Interface	0.6 x 3.3	3.83	15.7	4.71	30.38
	2.5 x 0.75				

2.7 Weight Analysis

The assembled printed boards were weighed as well as the empty box and lithium battery. Because of the variability in weight due to solder build up, a sample of six sets of modules were weighed. The weights converged to the weights reported with a uniform deviation about the mean of less than 1%. The weight of the external user interface excluded the antennae since a part has not yet been selected. Weight is estimated from published weights of the components.

The weight will not be broken down by subsystem unless it contains major items. That is, section 2.8 shows the weight breakdown of the two total circuit boards, and major external subsystems.

2.8 COST, SIZE, AND WEIGHT SUMMARY CHART

CHART 1A

COST SENSITIVITY & PHYSICAL PARAMETER ANALYSIS

ITEM	SUBSYSTEM	COMPONENT COST		ASSEMBLY COST		TEST COST		CALIBRATION COST		TOTAL COST		SIZE cm²	WEIGHT gm
-	-	1K	10K	1K	10K	1K	10K	1K	10K	1K	10K	-	-
1	Volt Reg for DTCXO	11.28	9.79	8.54	6.81	2.58	1.88	--	--	22.40	18.48	15.36	
2	CPU Support	4.03	3.22	4.44	3.54	1.34	0.98	--	--	9.81	7.74	13.23	
3	Digital Controller	54.63	48.61	12.43	9.92	3.75	2.74	--	--	70.81	61.27	48.19	
4	Temperature Sensor	18.23	16.30	4.93	3.93	1.49	1.09	--	--	24.65	21.32	19.23	
5	D/A Converter	17.64	15.66	9.20	7.34	2.78	2.03	--	--	29.62	25.03	20.58	
6	Stable OSC	35.45	31.76	7.61	6.07	2.30	1.68	56.00	56.00	101.36	95.51	26.39	
7	Transmitter Control	5.88	5.34	3.23	2.58	0.98	0.71	--	--	10.09	8.63	14.77	
8	Test I/F	16.57	15.59	4.05	3.23	1.22	0.89	--	--	21.84	19.71	30.58	
9	User I/F	7.55	7.11	4.71	3.76	1.42	1.04	--	--	13.68	11.91	5.61	
10	Thermal Shield	0.66	0.61	0.11	0.09	0.03	0.02	--	--	0.80	0.72		
11	Total for Items 1-10	171.92	153.99	59.24	47.26	17.88	13.06	56.00	56.00	305.06	270.32	193.94	230

CHART 1B

COST SENSITIVITY & PHYSICAL PARAMETER ANALYSIS

ITEM	SUBSYSTEM	COMPONENT COST		ASSEMBLY COST		TEST COST		CALIBRATION COST		TOTAL COST		SIZE cm^2	WEIGHT gm
-	-	1K	10K	1K	10K	1K	10K	1K	10K	1K	10K	-	-
12	12 Volt Power Switch	0.78	0.68	1.64	1.31	0.50	0.36	--	--	2.92	2.35	1.68	
13	5 V Regulator for PLL	1.35	1.20	1.31	1.05	0.40	0.29	--	--	3.06	2.54	2.00	
14	406 Protection	1.18	1.00	3.29	2.62	0.99	0.72	--	--	5.46	4.34	4.00	
15	406 Leveller	4.41	3.97	3.50	2.79	1.06	0.77	1.50	1.20	10.47	8.73	4.19	
16	406 Forward Power Detector	1.42	1.24	1.21	0.96	0.36	0.27	--	--	2.99	2.47	4.77	
17	406 Phase Det. & Mod.	10.78	9.45	4.60	3.67	1.39	1.01	1.50	1.20	18.27	15.33	19.87	
18	406 Loop Amp & Lock Det.	5.03	4.43	3.50	2.80	1.06	0.77	--	--	9.59	8.00	8.90	
19	406 VCO	19.93	18.00	3.40	2.71	1.03	0.75	0.50	0.40	24.86	21.86	11.94	
20	406 Power Amp	41.22	37.71	3.40	2.71	1.03	0.75	--	--	45.65	41.17	21.81	
21	406 Divider	24.60	21.66	4.60	3.67	1.39	1.01	--	--	30.59	26.34	5.94	

CHART 1C

COST SENSITIVITY & PHYSICAL PARAMETER ANALYSIS

ITEM	SUBSYSTEM	COMPONENT COST		ASSEMBLY COST		TEST COST		CALIBRATION COST		TOTAL COST		SIZE cm^2	WEIGHT gm
-	-												
		1K	10K	1K	10K	1K	10K	1K	10K	1K	10K	-	-
22	406 Harmonic Filter	2.06	1.86	0.44	0.35	0.13	0.10	--	--	2.63	2.31	6.52	
23	121 Power Amp	30.01	27.59	7.12	5.68	2.15	1.57	4.50	3.60	43.78	38.44	20.90	
24	121 Modulator	8.72	7.63	4.60	3.67	1.39	1.01	1.50	1.20	16.21	13.51	15.74	
25	121 Regulator	3.58	3.18	2.85	2.27	0.86	0.63	1.50	1.20	8.79	7.28	9.94	
26	406/121 O/P I/F	6.37	5.26	0.44	0.35	0.13	0.10	--	--	6.94	5.71	25.74	
27	406/121 Test I/F	5.17	4.37	1.21	0.96	0.36	0.27	--	--	6.74	5.60	30.38	
28	Total for Items 12-27	166.61	149.23	45.12	35.99	13.62	9.94	11.00	8.80	238.95	205.98	194.32	230
29	Total for Items 1-27	338.53	303.22	104.36	83.25	31.50	23.00	67.00	64.80	544.01	476.30	388.26	460

CHART 1D

COST SENSITIVITY & PHYSICAL PARAMETER ANALYSIS

ITEM	SUBSYSTEM	COMPONENT COST		ASSEMBLY COST		TEST COST		CALIBRATION COST		TOTAL COST		SIZE cm^2	WEIGHT gm
-	-	1K	10K	1K	10K	1K	10K	1K	10K	1K	10K	-	-
30	Case	28.75	26.00	60.00	45.00	--	--	--	--	88.75	71.00	1400	775
31	Battery Pack	63.00	56.70	--	--	1.50	1.50	--	--	64.50	58.20	360	470
32	External User I/F	50.23	47.03	75.00	70.00	1.50	1.20	3.00	2.40	129.73	120.63		350
33	Total for Unit	480.51	432.95	239.36	198.25	34.50	25.70	73.00	69.60	826.99	638.09		2055

2.9 Subsystems of Greatest Cost/Size/Weight Impact

The subsystems are ranked in order of decreasing cost, second, in order of decreasing size, and third, in order of decreasing weight.

2.9.1 Subsystems in Order of Cost

SUBSYSTEM	1K	10K
External User Interface	129.73	120.63
Stable Oscillator	101.36	95.51
Case	88.75	71.00
Digital Controller	70.81	61.27
Battery	64.50	58.20
406 Power Amplifier	45.65	41.17
121.5 MHz Beacon Oscillator & RF	43.78	38.44
406 Divider	30.59	26.34
D/A Converter	29.62	25.03
406 VCO	24.86	21.86
Temperature Sensor	24.65	21.32
Voltage Regulator for DTCXO	22.40	18.48
Test Interface (DTCXO)	21.84	19.71
406 Phase Detector & Modulator	18.27	15.33
121.5 MHz Modulator	16.21	13.51
User Interface	13.68	11.91
406 Leveller	10.45	8.73
Transmit Control	10.09	8.63
CPU Support	9.81	7.74
406 Loop Amp & Detector	9.59	8.00
121.5 MHz Regulator	8.79	7.28
Output Interface	6.94	5.71
Test Interface (RF)	6.74	5.60

2.9.2 Subsystems in Order of Size

SUBSYSTEM	cm^2
Battery	
Digital Controller	44.13
Test Interference	30.39
Stable Oscillator	24.19
Output Interface	25.74
406 Power Amp	21.81
121 MHz Beacon OSC & RF	20.90
406 Phase Detector & Modulator	19.87
D/A Converter	18.84
Temperature Sensor	17.55
Test Interface	15.74
121 Modulator	15.74
Voltage Regulator (DTCXO)	14.13
Transmit Control	13.55
CPU Support	12.13
406 VCO	11.94
121 MHz Regulator	9.94
406 Loop Amp & Lock Det.	8.90
406 Harmonic Filter	6.50
406 Divider	5.94
User Interface	5.23
406 Power Detector	4.77
406 Leveller	3.99
406 Protection	3.99
5 V Regulator for PLL	1.99
Power Switch	1.68

2.9.3 Subsystems in Order of Weight

SUBSYSTEM	gm
Box	775
Battery	470
External User I/F	350
Digital Board	230
RF Board	230

2.9.4 Subsystems Appearing High on Cost, Size, and Weight Tables

	Cost		Size	Weight
	1 K	10 K		
External User I/F	129.73	120.63		350gm
Stable OSC	101.36	95.51	24.91cm^2	--
Case	88.75	71.00	1400cm^3	775gm
Digital Control	70.81	61.27	44.13cm^2	--
Battery	64.50	58.20	360cm^3	470gm
Test I/F	28.58	25.31	30.39cm^3	--
406 Power Amp	45.65	41.17	21.81cm^3	--
121.5 BCN OSC & RF	43.78	38.44	20.90cm^3	--
406 Divider	30.59	26.34	19.87cm^3	--

It is expected that these areas hold the greatest potential cost reduction. Less costly circuits also hold potential for reduced cost by redesign.

2.10.0 Specifications of Greatest Cost/Size/Weight Impact

2.10.1 Frequency Stability

Frequency stability approaching laboratory reference quality is impacting significantly on circuit complexity.

	1K	10K
Temperature Sensor	24.65	21.32
D/A Converter	29.62	25.03
Stable Oscillator	101.36	95.51
Digital Control	70.81	61.27
Calibration Profile	56.00	56.00
	\$282.44	\$259.13

2.10.2 Power Output

Power output levels for coherent carriers appear to be well above the threshold for reliable detection. The high battery drain which results limits the range of feasible batteries and impacts significantly on the battery size.

If a good fix on the beacon can be achieved within 1 or 2 passes of the satellite, then prolonged operation at 406 MHz is of minimal benefit.

2.10.3 Temperature Range

Temperature range covering the -40°C to 55°C range complicates the selection of components. Batteries and semiconductors are all more expensive if operation is to be expected over this range.

There may be merit in investigating a reduced temperature range unit for users who do no travel in extremely cold climates.

2.10.4 48 Hour Operation

The 48 hour operation of the beacon demands a battery of significant capacity. This capacity requirement would impact favourably on the beacon's size and weight if hours were reduced.

3.0 COST/BENEFIT ANALYSIS - SPECIFICATION IMPACT

Four specifications contributing most significantly to the beacons cost, size, and weight were presented in section 2.10. The redesign impact of relaxing these specifications will now be analyzed to determine the cost and benefit ramifications.

During analysis of each change, the following points will be considered and summarized in section 3.5. A number contained by brackets ( ) indicates a saving.

- component cost change
- assembly and test cost changes (which are a function of pin count, see Appendix F)
- calibration cost change
- size change
- weight change.

3.1 Reduce Medium Term Frequency Stability

The impact of reducing the frequency stability specification is presented in this section.

Circuit design changes presented are characteristic of the industry status but options should not be limited to these. A more accurate size and cost impact requires a comprehensive market survey of recently released products.

3.1.1 Reduction by a Factor of Two

A reduction of the medium term frequency stability by a factor of two, to 0.024 ppm/15 min., would not affect circuit topology. The primary improvement from this change would be a greater acceptance rate of units during the production cycle. Also, rework would be reduced. Therefore, it is expected that the quality assurance function would be streamlined. The documentation of the degree of savings during quality control is beyond the scope of this study.

3.1.2 Reduction by a Factor of Eight

A reduction of the medium term frequency stability by a factor of 8, to 0.1 ppm/15 min., would affect the following subsystems:

Stable Oscillator - new design
Temperature Sensor - new design
D/A Converter - delete
Digital Controller - reduce

The impact of this specification change is presented over section 3.1.2.1 through 3.1.2.4 and then summarized in 3.1.2.5.

3.1.2.1 Stable Oscillator Impact

This specification relaxation would allow a change in stable oscillator strategy. It may be feasible to implement a miniature crystal oscillator with linear compensation. Data obtained from an experiment on one crystal indicates a worst case drift of 0.05 ppm/15 min., may be feasible.

NOTE: This option of miniaturized crystal is speculative since only one crystal was analyzed.

Component cost change:

		1K	10K	PINS
delete	Y1	(12.25)	(11.15)	(2)
add	Y1	20.55	17.10	2
		8.30	5.95	-

Assembly cost change:

no impact

Test cost change:

no impact

Calibration cost change:

Reduce from 107 minutes to 60 minutes, which is the time allocated to run temperature profiles. This time may be shortened after a quality control analysis.

		1K	10K
delete	107 min.	(54.00)	(54.00)
add	60 min.	30.00	30.00
		(24.00)	(24.00)

Total cost change:

1K	10K
(15.70)	(18.05)

3.1.2.2 Temperature Sensor Impact

The miniature crystal requires linear temperature compensation which is applied by a thermistor or semiconductor junction. The slope of the compensation is ideally adjustable and set during a short calibration cycle.

Component cost change:

	1K	10K	PINS
delete existing sensor	(18.23)	(16.30)	(45)
add thermistor	7.75	6.98	2
add ¼ linear IC	0.80	0.72	4
add 4 resistors	0.24	0.20	8
add 1 trimmer resistor	0.93	0.87	3
add 2 capacitors	0.32	0.30	4
PWB 8 cm^2	0.68	0.50	
	(8.87)	(7.73)	(24)

Assembly cost change:

Pin count decrease of 24. Factor is $0.110/pin in 1,000 and $0.087/pin in 10,000. (Reference Appendix D.)

	1K	10K
Assembly	(2.64)	(2.09)

Test cost change:

Pin count decrease of 24. Factor is $0.033/pin in 1,000 and $0.024/pin in 10,000. (Reference Appendix D.)

	1K	10K
Test	(0.79)	(0.58)

Calibration cost change:

Increase of one adjustment which is verified at temperature extremes, 10 minutes.

	1K	10K
10 minutes	5.00	5.00

Total cost change:

1K	10K
(7.30)	(5.40)

3.1.2.3 D/A Converter Impact

The D/A converter is not required.

Component cost change:

1K	10K
(17.64)	(15.66)

Assembly cost change:

1K	10K
(9.20)	(7.34)

Test cost change:

1K	10K
(2.78)	(2.03)

Total cost change:

1K	10K
(29.62)	(25.03)

Size change:

(20.58)cm^2

3.1.2.4 Digital Controller Impact

The digital controller is down sized by one EPROM, since a coefficient table is not required.

Component cost change:

	1K	10K	PINS
delete 1 memory	(14.29)	(12.86)	
delete 1 socket	(1.14)	(1.03)	(24)
	(15.43)	(13.89)	(24)

Assembly cost change:

Pin count is reduced by 24.

1K	10K
(2.64)	(2.09)

Test cost change:

1K	10K
(0.79)	(0.58)

Total cost change:

1K	10K
(18.86)	(16.56)

Size change:

(5)cm^2

3.1.2.5 Summary

The total impact of reducing the medium term frequency stability by a factor of 8 is:

	1K	10K	cm^2
Stable OSC.	(15.70)	(18.05)	
Temp. Sensor	(7.30)	(5.40)	
D/A Converter	(29.62)	(25.03)	(20.6)
Digital Controller	(18.86)	(16.56)	(5)
TOTAL	(71.48)	(65.04)	(25.6)

3.1.3 Search Impact of Reducing Frequency Stability

The search impact of reducing the medium term frequency stability specification is a far reaching topic to be addressed at the SARSAT system design level. The projected cost reduction of $65 - $72 per unit indicated in Section 3.1.2 and summarized in Section 3.5, has to be examined in light of the target application and search method. Presented in this report will be the general impact reducing stability has on each search method. The search activity for distress situations may take on one or more of the following methods; air, marine, or land.

Air search operations for downed aircraft or distressed marine vessels, although high in cost, present only small cost and time escalations with reduced location accuracy. Once a beacon is recognized by the satellite system, air search patrols are dispatched to the search zone. Subsequently, a search of an area of 20 km area rather than a 5 km radius does not present any major difficulty as long as the beacon is still operational. The search area is quickly processed due to the speed and visual vantage exhibited by an air search.

Marine search operations for distressed marine vessels present moderate cost and time escalations with reduced location accuracy. The escalation is a result of marine search vessels not having the large visual range or speed of an air search craft.

Land search operations for distressed people present large escalations, within its own category, in cost and time with reduced location accuracy. This search method would be performed on foot, horseback, or all-terrain vehicle. The cost per hour would not be as great as for an air search but the critical factor would be the time duration and size of the search team to find the distress situation.

In summary, the cost benefit trade off for frequency stability reduction has to be viewed in the following light. In the hand held application, a low cost unit is desirable but the search time may be elongated to an unacceptable length. For the airborne application, the search area has little affect on cost, as long as the beacon is operational. Thus a beacon intended for airborne applications could take advantage of the $65 - $72 per unit cost savings provided by reducing the frequency stability.

3.2 Reduce 406 Output from 5 W to 2 W

A reduction in power output of the 406 MHz beacon to 2 watts would impact the following subsystems:

406 Power Amp - redesign
406 VCO - redesign
Battery - down size

3.2.1 406 Power Amp and VCO Impact

The 406 power amp and 406 VCO redesign motivation can not be attributed fully to the reduction of the output power. The redesign concept presented may be applied to both the 5 Watt or 2 Watt versions. Both redesigned versions have the same component, assembly and test cost. The amplifier design strategies are addressed further in the redesign section 4.1.

3.2.2 Battery Impact

Assuming 60% collector efficiency in the redesigned VCO and Power Amp, the transmit current is reduced to:

$$I = \frac{2.5\ W}{0.6\ (10V)} = 417\ mA$$

with 1% duty cycle

$$I_{AVG} = 4.2\ mA \quad \text{(for transmitter)}$$

The above current reduction impacts battery capacity by reducing it to:

$$I_{AVG} \quad 37.5 - 20 + 4.2 = 21.7\ mA\ \text{(for beacon)}$$

$$21.7 \times 48 = 1.04\ A\ \text{hour}$$

Derated to -40°C

$$\frac{1.04}{0.35} = 2.97 = 3.0\ A\ \text{hour}$$

This beacon requires a 1¼ "C" lithium battery pack.

Cost change:

1K	10K
(1.50)	(2.70)

Size change:

(135)cm³

Weight change:

(170)gm

3.3 Raise Minimum Operating Temperature from -40°C to -20°C

Relaxing the minimum temperature limit from -40°C to -20°C would impact the following subsystems:

Battery - down size
Stable Oscillator - change crystal
D/A Converter - reduce

3.3.1 Battery Impact

The derated capacity of a lithium battery pack at -20°C is 70% of published capacity. The 1.8 A hour load demand could be provided by a:

$$\frac{1.8}{0.70} = 2.57 \text{ A hour battery}$$

This with other marginal improvements in efficiency would permit a fit with the 3/4 "C" battery whose capacity is 2.5 A hour.

Cost change:

1K	10K
(13.50)	(14.70)

Size change:

(200)cm^3

Weight change:

(290)gm

3.3.2 Stable Oscillator Impact

A better choice of crystal geometries is available in the reduced temperature range. With an alternate crystal the worst case slope is reduced from 1 ppm/°C to 0.5 ppm/°C. Its' characteristic drift is reduced from ±10 ppm to ± 3 ppm.

No cost impact.

3.3.3 D/A Converter

The reduced characteristic drift impacts the resolution of the D/A converter. Rather than a 40 ppm pulling range, now only a 12 ppm range is required. The 14 bit D/A converter can be reduced to 12 bits.

Component cost change:

		1K	10K	PINS
delete	U7	(3.19)	(2.88)	(16)

Assembly cost change:

Pin count reduced by 16.

1K	10K
(1.76)	(1.39)

Test cost change:

1K	10K
(0.53)	(0.38)

Total cost change:

1K	10K
(5.48)	(4.65)

Size change:

(4)cm^2

3.4 Reduce Operating Duration

3.4.1 Reduce Duration from 48 Hours to 24 Hours

A reduction of the operating duration from 48 hours to 24 hours impacts the battery subsystem.

Assuming a 5 Watt 406 MHz transmitter and the 20 mW 121.5 MHz beacon the required capacity is:

37.5 mA x 24 hour = 0.9 A hour

Derated to -40°C

$$\frac{0.9}{0.35} = 2.6 \text{ A hour}$$

Lithium "C" cells have the required capacity and are adequate to provide the 2.0 A peak loads.

Cost change:

1K	10K
(6.30)	(5.67)

Size change:

(165)cm^3

Weight change:

(240)gm

3.4.2 Reduce 406 Duration to 6 Hours

A reduction of the operating duration of the 406 transmitter to 6 hours, while keeping the 121 transmitter duration at 48 hours, would impact the battery subsystem.

After 6 hours, the digital controllers puts itself into a "sleep" mode whereby the following power saving is realized:

406 Transmitter	20 mA (Average)
Digital Controller	3 mA
	23 mA

It would be possible to save additional power, but this would require additional circuits which would negate any further cost savings.

The required battery capacity would be:

37.5 mA x 6 + 14.5 mA x 42 = 0.83 A hour

Derated to -40°C.

$$\frac{0.83}{0.35} = 2.4 \text{ A hour}$$

The required battery is the same as described in the previous section 3.4.1 where the total beacon duration was reduced to 24 hours.

3.5 Delete 121.5 MHz Function

Deletion of the lower frequency beacon would impact the electronic module as follows:

121 Beacon OSC & RF - delete
121 Beacon Modulator - delete
121 Beacon Regulator - delete
External User Interface - reduce
Output Interface - reduce
Battery - down size

The 121 subsystem deletions will be presented as a group in the next section with the balance of subsystems presented individually. The impact of deleting the 121.5 MHz function will then be summarized in Section 3.5.5.

3.5.1 Regulator, Modulator, and Oscillator Impact

There are three subsystems supporting the 121.5 MHz which are totally deleted. These subsystems are grouped and presented in this section.

Component cost change:

	1K	10K	PINS
delete 121 OSC. & RF	(30.01)	(27.59)	(65)
delete 121 Modulator	(8.72)	(7.63)	(42)
delete 121 Regulator	(3.58)	(3.18)	(26)
	(42.31)	(38.40)	(133)

Assembly cost change:

	1K	10K
121 OSC & RF	(7.12)	(5.68)
121 Modulator	(4.60)	(3.67)
121 Regulator	(2.85)	(2.27)
	(14.57)	(11.62)

Test cost change:

	1K	10K
121 OSC & RF	(2.15)	(1.57)
121 Modulator	(1.39)	(1.01)
121 Regulator	(0.86)	(0.63)
	(4.40)	(3.21)

Calibration cost change:

	1K	10K
121 OSC & RF	(4.50)	(3.60)
121 Modulator	(1.50)	(1.20)
121 Regulator	(1.50)	(1.20)
	(7.50)	(6.00)

Size change:

	cm²
121 OSC & RF	(20.90)
121 Modulator	(15.74)
121 Regulator	(9.94)
	(46.58)

3.5.2 External Use Interface Impact

The major function affected within the external user interface would be the diplexer.

The diplexer would be reduced to a simple matching circuit. A set of fixed value components would be used, which would minimize; component cost, tuning time, and vibration sensitivity.

Component cost change:

	1K	10K	PINS
Delete diplexer	(16.00)	(15.25)	(20)
add matching cct	2.25	2.01	8
	(13.75)	(13.24)	(12)

Assembly cost change:

	1K	10K
Reduce pin count by 12	(1.32)	(1.04)
Deletion of hand wound components	(7.50)	(7.50)
	(8.82)	(8.54)

Test cost change:

1K	10K
(0.40)	(0.29)

Calibration cost change:

1K	10K
(3.00)	(2.40)

Size change:

cm²
14.0

The increase in size represents the additional PWB size required as this function would be implemented internally.

3.5.3 Output Interface Impact

The output interface would be reduced by one connector.

Component cost change:

1K	10K	PINS
(3.19)	(2.63)	(2)

Assembly cost change:

1K	10K
(0.22)	(0.17)

Test cost change:

1K	10K
(0.07)	(0.05)

Size change:

cm^2
(12.9)

3.5.4 Battery Impact

Deletion of the 121.5 MHz beacon function reduces the energy demand on the battery pack.

The power requirement for the SARSAT beacon will now be:

48 hours x 27.5 mA = 1.32 A hour

Derated to -40°C

$$\frac{1.32}{0.35} = 3.77 \text{ A hour}$$

This beacon could be powered by a $1\frac{1}{4}$ "C" lithium battery pack.

Cost change:

1K	10K
(1.50)	(2.70)

Size change:

(135) cm^3

Weight change:

(170) gm

3.5.5 Summary

The total impact of deleting the 121.5 MHz function is:

	1K	10K	cm^2	gm
Delete 121 Subsystems	(68.78)	(59.23)	(46.6)	
External User Interface	(25.97)	(24.47)	14.0	
Output Interface	(3.48)	(2.85)	(12.9)	
Battery	(1.50)	(2.70)	(135)	(170)
	(99.73)	(89.25)	(180.5)	(170)

3.6 Delete User Interface Functions

Deletion of the user interface, emergency code function, would impact the following subsystems:

External User Interface - reduce

Component cost change:

	1K	10K	PINS
Reduce Connector by 6/37	(2.63)	(2.53)	(6)
Delete 5 Code Switches	(10.00)	(9.00)	
	(12.63)	(11.53)	

Assembly cost change:

	1K	10K
Est. Reduction by 15 minutes	(7.50)	(7.50)

Negligible test, size, and weight impact.

3.7 Cost/Benefit Analysis Summary

The cost, size, and weight impact of the preceding specification changes are summarized on the following table.

COST & PHYSICAL PARAMETER IMPACT - SPECIFICATION CHANGE

ITEM	SUBSYSTEM	Δ COMPONENT COST		Δ ASSEMBLY COST		Δ TEST COST		Δ CALIBRATION COST		Δ TOTAL COST		Δ SIZE cm^2	Δ WEIGHT gm
		1K	10K	1K	10K	1K	10K	1K	10K	1K	10K		
	REDUCE MEDIUM TERM FREQUENCY STABILITY BY A FACTOR OF 8												
6	Stable Oscillator	8.30	5.95	-	-	-	-	(24.00)	(24.00)	(15.70)	(18.05)	-	-
4	Temperature Sensor	(8.87)	(7.73)	(2.64)	(2.09)	(0.79)	(0.58)	5.00	5.00	(7.30)	(5.40)	-	-
5	D/A Converter	(17.64)	(15.66)	(9.20)	(7.34)	(2.78)	(2.03)	-	-	(29.62)	(25.03)	(20.6)	-
3	Digital Controller	(15.43)	(13.89)	(2.64)	(2.09)	(0.79)	(0.58)	-	-	(18.85)	(16.56)	(5)	-
	TOTAL	(33.64)	(31.33)	(14.48)	(11.52)	(4.36)	(3.19)	(19.00)	(19.00)	(71.48)	(65.04)	(25.6)	-
	REDUCE 406 OUTPUT FROM 5W TO 2W												
31	Battery	(1.50)	(2.70)	-	-	-	-	-	-	(1.50)	(2.70)	(135)	(170)
	RAISE LOWER OPERATING TEMPERATURE FROM -40°C TO -20°C												
31	Battery	(13.50)	(14.70)	-	-	-	-	-	-	(13.50)	(14.70)	(200)	(290)
5	D/A Converter	(3.19)	(2.88)	(1.76)	(1.39)	(0.53)	(0.38)	-	-	(5.48)	(4.65)	(4)	-
	TOTAL	(16.69)	(17.58)	(1.76)	(1.39)	(0.53)	(0.38)	-	-	(18.98)	(19.35)	(204)	(290)
	REDUCE 406 DURATION TO 6 HOURS												
31	Battery	(6.30)	(5.67)	-	-	-	-	-	-	(6.30)	(5.67)	(165)	(240)

COST & PHYSICAL PARAMETER IMPACT - SPECIFICATION CHANGE

ITEM	SUBSYSTEM	Δ COMPONENT COST		Δ ASSEMBLY COST		Δ TEST COST		Δ CALIBRATION COST		Δ TOTAL COST		Δ SIZE cm^2	Δ WEIGHT gm
		1K	10K	1K	10K	1K	10K	1K	10K	1K	10K		
DELETE 121.5 MHz FUNCTION													
23	121 OSC & RF	(30.01)	(27.59)	(7.12)	(5.68)	(2.15)	(1.57)	(4.50)	(3.60)	(43.78)	(38.44)	(20.9)	
24	121 Modulator	(8.72)	(7.63)	(4.60)	(3.67)	(1.39)	(1.01)	(1.50)	(1.20)	(16.21)	(13.51)	(15.7)	
25	121 Regulator	(3.58)	(3.18)	(2.85)	(2.27)	(0.86)	(0.63)	(1.50)	(1.20)	(8.79)	(7.28)	(9.9)	
32	External Interface	(13.75)	(13.24)	(8.82)	(8.54)	(0.40)	(0.29)	(3.00)	(2.40)	(25.97)	(24.47)	14.0	
26	Output Interface	(3.19)	(2.63)	(0.22)	(0.17)	(0.07)	(0.05)	-	-	(3.48)	(2.85)	(12.9)	
31	Battery	(1.50)	(2.70)	-	-	-	-	-	-	(1.50)	(2.70)	(135 cm^3)	(170)
	TOTAL	(60.75)	(56.97)	(23.61)	(20.33)	(4.87)	(3.55)	(10.50)	(8.40)	(99.73)	(89.25)	(45.4)	(170)
DELETE USER INTERFACE FUNCTIONS													
32	External Interface	(12.63)	(11.53)	(7.50)	(7.50)	-	-	-	-	(20.13)	(19.03)	-	-

4.0 COST/BENEFIT ANALYSIS - REDESIGN

The purpose of this section is to determine the cost and benefit ramifications of conceptual redesigns. Five major areas will be addressed, including the DTCXO card, ovenized oscillator, RF card, semi-custom chips, and packaging.

During analysis of each change, the following points will be considered and summarized in section 4.12.

- component cost
- assembly and test costs (which are a function of pin count, see Appendix F)
- calibration cost
- size
- weight

4.1 406 VCO and Power Amp Redesign

The 406 VCO and 406 power amplifier are recognized as having a significant component cost. In attempts to reduce this cost, a two transistor implementation will be analyzed. The existing oscillator requires about 13 dB gain factor from 100 mW to reach 2 Watts drive. A two stage amplifier would be required to achieve the necessary gain and the desired isolation. Alternatively, a 500 mW oscillator driving a single stage amplifier would produce adequate power.

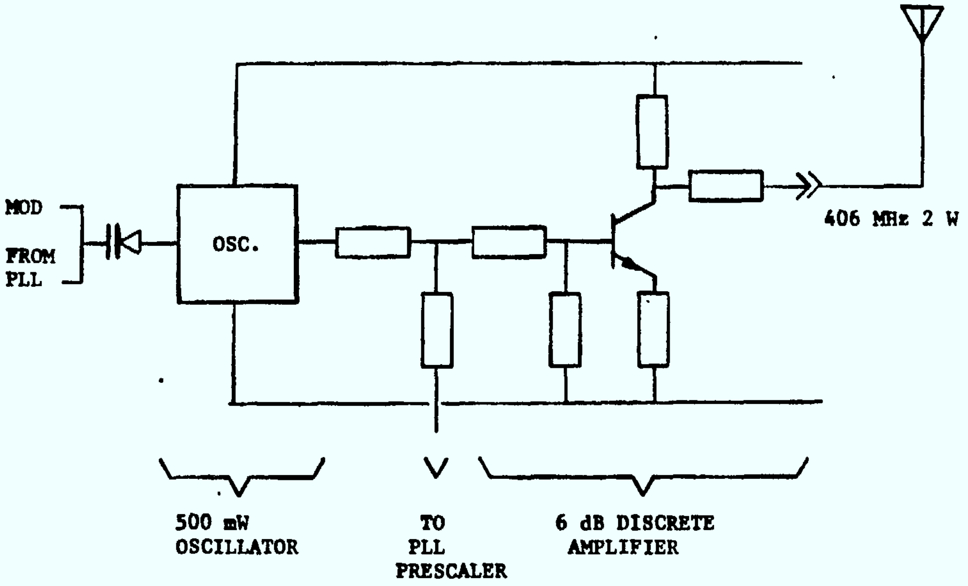


FIGURE 1: 406 VCO AND POWER AMP

4.1.1 406 VCO Redesign Impact

Component cost change:

	1K	10K	PINS
delete Q4	(1.79)	(1.61)	(3)
delete C 12, 16	(3.00)	(2.70)	(4)
add transistor	1.50	1.35	3
	(3.29)	(2.96)	(4)

Assembly cost change:

Pin count increase of 4.

	1K	10K
assembly	0.44	0.35

Test cost change:

	1K	10K
test	0.13	0.10

Calibration cost change:

No impact.

Total cost change:

1K	10K
(2.72)	(2.51)

4.1.2 406 Power Amp Redesign Impact

Component cost change:

	1K	10K	PINS
delete AR1	(39.00)	(36.00)	(7)
delete C11	(0.05)	(0.04)	(2)
delete C14, 15	(0.32)	(0.30)	(4)
add transistor	15.50	13.95	3
add 3 chokes	2.10	1.89	6
add 1 capacitor	0.16	0.15	2
add 1 trimmer cap	8.90	8.10	2
	(12.71)	(11.90)	0

No change in assembly or test cost.

Calibration cost change:

Increase by 1 adjustment at 3 minutes, 3/60 x $30 = $1.50

	1K	10K
calibration	1.50	1.50

Total cost change:

1K	10K
(11.21)	(10.40)

4.1.3 Total Impact

In summary, the total cost and size change for removing the hybrid and incorporating a two transistor stage VCO and power amp is:

	1K	10K
Cost	(13.93)	(12.91)
Size Change	(10)cm	

4.2 406 Divider Redesign

The 406 prescaler may be redesigned to take advantage of a newer lower priced divider than presently used. Below is a conceptual design.

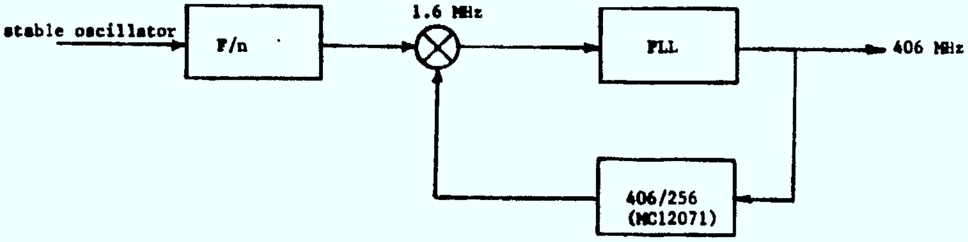


FIGURE 2: DIVIDER REDESIGN

Component cost change:

	1K	10K	PINS
delete divider U2	(1.56)	(1.41)	(14)
delete divider U3	(21.21)	(19.09)	(16)
add ½ Flip Flop	0.20	0.18	7
add ÷ 256	11.75	10.58	14
	(10.82)	(9.74)	(9)

Assembly cost change:

Pin count reduced by 9.

	1K	10K
assembly	(0.99)	(0.78)

Test cost change:

	1K	10K
test	(0.30)	(0.21)

Total cost change:

1K	10K
(12.11)	(10.73)

4.3 Temperature Sensor Redesign

The temperature sensor can be redesigned to use a thermistor rather than a crystal. The thermistor can be linearized by the microprocessor software, which impacts only development costs.

A conceptual gate oscillator incorporating the thermistor could form the temperature to frequency transducer.

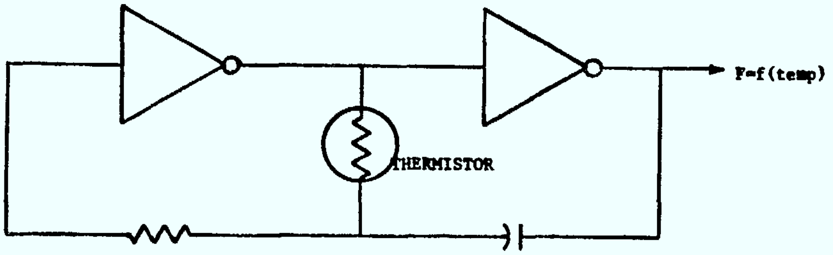


FIGURE 3: TEMPERATURE SENSOR

Component cost change:

	1K	10K	PINS
delete existing sensor	(18.23)	(16.30)	(45)
add ½ Quadgate	0.11	0.10	7
add thermistor	7.75	6.98	2
add Resistor RN	0.06	0.05	2
add capacitor CN	0.54	0.49	2
PWB 7 cm^2	0.68	0.44	
	(10.45)	(9.12)	(32)

Assembly cost change:

Pin count reduced by 32.

	1K	10K
assembly	(3.52)	(2.78)

Test cost change:

	1K	10K
test	(1.06)	(0.77)

Total cost change:

1K	10K
(15.03)	(12.67)

4.4 Digital Controller Consolidation

A digital consolidation is analyzed for impact. The consolidation of hardware and tasks is targeted to reduce parts count and calibration time.

Hardware modification involves the implementation of a single chip microcomputer. This chip utilizes on board ROM, thereby reducing parts count.

Task consolidation involves letting the single chip microcomputer perform more functions during production calibration. This involves a self calibration technique whereby an external reference frequency is fed onto the beacon. The unit then has the capability to measure its own frequency, and subsequently formulate and program its own calibration table.

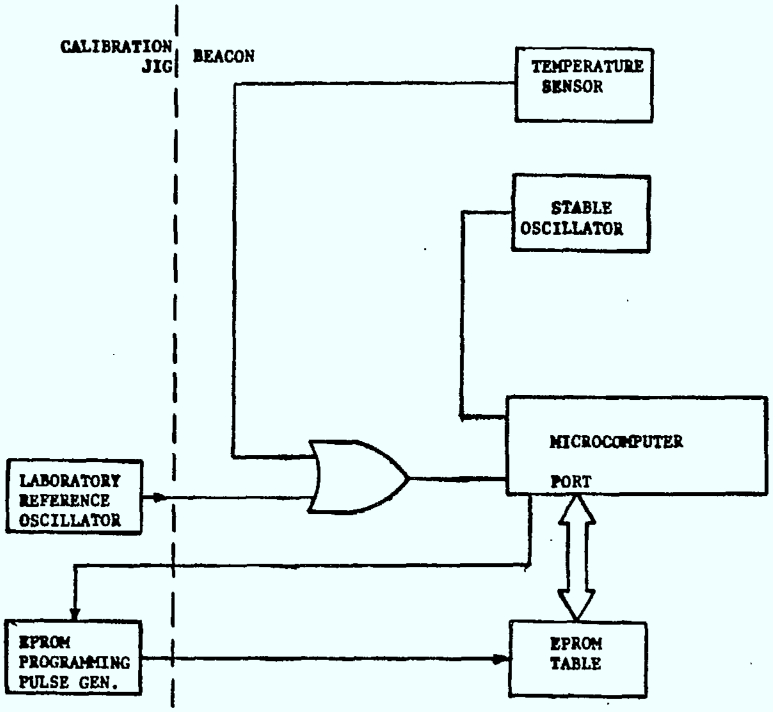


FIGURE 4: DIGITAL CONSOLIDATION

Component cost change:

	1K	10K	PINS
delete Processor	(16.62)	(14.96)	(40)
delete 1 Memory	(14.29)	(12.86)	
delete 1 socket	(1.14)	(1.03)	(24)
delete 1¼ Quadgate	(0.58)	(0.53)	(17½)
add Processor C/W ROM	16.00	14.40	40
add 1 Quadgate	0.46	0.42	14
	(16.17)	(14.56)	(27½)

Assembly cost change:

Pin count reduced by 27½.

	1K	10K
assembly	(3.03)	(2.39)

Test cost change:

	1K	10K
test	(0.91)	(0.66)

Calibration cost change for stable oscillator. Reduce from 107 minutes to 72 minutes, where 60 minutes are required for two profiles and 12 minutes for the self-calibration process.

	1K	10K
delete 107 minutes	(54.00)	(54.00)
add 72 minutes	36.00	36.00
	(18.00)	(18.00)

Total cost change:

1K	10K
(38.11)	(35.61)

Size change:

(4)cm^2

4.5 Test Interface Redesign

The test interface can be redesigned to utilize a method that is not a permanent fixture on the beacon. Using a bed of nails is such a method. The impact of this redesign, is to delete subsystems 8 and 27.

Component cost change:

	1K	10K	PINS
delete subsystem 8	(16.57)	(15.59)	(37)
delete subsystem 27	(5.17)	(4.37)	(11)
	(21.74)	(19.96)	(48)

Assembly cost change:

Pin count is reduced by 48.

	1K	10K
assembly	(5.28)	(4.18)

Test cost change:

	1K	10K
test	(1.58)	(1.15)

Providing optimum performance, full custom LSI makes the most efficient use of silicon and is, therefore, cheapest in very large volumes. However, because development requirements are greater, this approach is not cost effective until annual production exceeds 30,000 to 50,000 units. This is illustrated by Figure 5 which shows the relative costs of all three custom IC approaches.

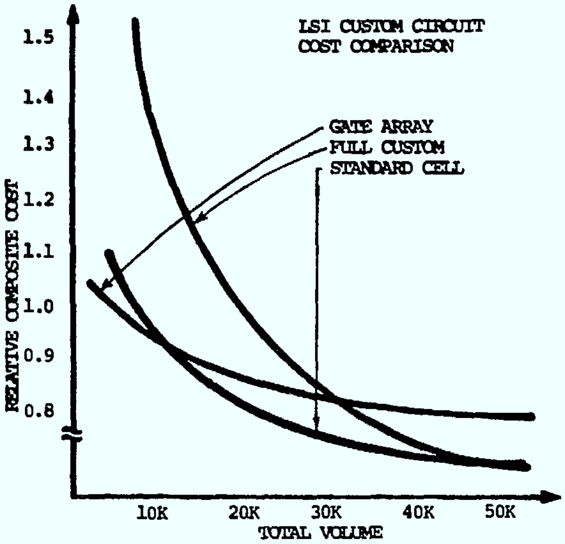


FIGURE 5: LSI COST COMPARISON

Array devices consist of uncommitted component, or logic arrays, whose final interconnection can be customer specified at the final stages of fabrication. Such arrays are currently manufactured in MOS, CMOS, and bipolar process technologies by approximately 50 vendors in North America. Development costs are typically in the $10,000 to $30,000 range and development times in the order of a few months. It is worth noting that CMOS arrays can accommodate both analog and digital circuits on the same chip.

Standard cell components employ fully customized process mask sets which are derived from precharacterized functional cells (e.g. counter cell, shift register cell, or CPU cell) contained in the vendor's "cell library". The range of process technologies includes MOS, CMOS, and bipolar as in the case of arrays, although the number of standard cell IC vendors is less than half that for arrays. Typical development costs range from $25,000 to $50,000 with development times in the order of 4-6 months.

Total cost change:

1K	10K
(28.60)	(25.29)

Size change:

(46)cm^2

4.6 Case Redesign

The case can be redesigned to function as an external enclosure containing the electronics, battery pack, and user interface. A new case design is presented in Appendix C, section 4.0. An average cost of the two presented designs will be used.

Component cost change:

	1K	10K
delete existing design	(28.75)	(26.00)
add new case	2.30	2.30
	(26.45)	(23.70)

Assembly cost change:

	1K	10K
delete existing assembly	(60.00)	(45.00)
add new case	14.50	14.50
	(45.50)	(30.50)

Total cost change:

1K	10K
(71.95)	(54.20)

Weight change: (600) gm

4.7.0 Semicustom and Custom Chips

4.7.1 Technology Selection

A very promising approach to reducing the size and cost of the beacon involves the use of custom LSI technology. This encompasses two different approaches, full custom and semicustom. The latter approach further subdivides into two fundamental classes, array devices and standard cell components.

Based on a variety of considerations, including development time, vendor experience, reliability, and annual volumes below 10,000 units, the semicustom approach seems the most appropriate.

4.7.2 Semicustom Chip-Digital

A semicustom gate array may be used to gather miscellaneous digital functions together onto one chip. Functions that can be incorporated in whole or in part are CPU support, temperature sensor, D/A converter, and the 121 modulator (where it is converted to a digital technique). The only limiting factor in grouping miscellaneous functions is the pin count.

Component cost change:

	1K	10K	PINS
CPU support			
delete timer U2	(1.45)	(1.31)	(16)
temperature sensor			
delete divider U3	(0.70)	(0.63)	(14)
D/A converter			
delete U4, 5, 6, 7	(12.76)	(11.52)	(64)
delete U8	(0.40)	(0.36)	(14)
121 Modulator			
delete subsystem	(8.72)	(7.63)	(42)
Semicustom chip			
add chip	9.00	8.00	32
PWB decrease by 40cm^2	(3.40)	(2.52)	
	(18.43)	(15.97)	(118)

Assembly cost change:

	1K	10K
CPU support	(1.76)	(1.39)
Temperature sensor	(1.54)	(1.22)
D/A converter	(8.58)	(6.79)
121 Modulator	(4.62)	(3.65)
Semicustom Chip	3.52	2.78
	(12.98)	(10.27)

Test cost change:

	1K	10K
CPU support	(0.53)	(0.39)
Temperature sensor	(0.46)	(0.33)
D/A converter	(2.57)	(1.87)
121 Modulator	(1.39)	(1.01)
Semicustom Chip	1.06	0.77
	(3.89)	(2.83)

Total cost change:

1K	10K
(35.30)	(29.07)

Size change:

CPU support	(5)
Temperature sensor	(5)
D/A converter	(18)
121 Modulator	(16)
Semicustom Chip	4
	(40)cm^2

4.7.3 Semicustom Chip-Analog

A semicustom analog chip may be used to consolidate simple analog functions. Such functions that can be incorporated in whole or in part are the DTCXO voltage regulator, 12 volt power switch, 5 volt P.L.L. regulator, and the 10 volt 121 beacon regulator. The limiting factors in grouping miscellaneous analog functions are the pin count, total resistance required, and the total capacitance required.

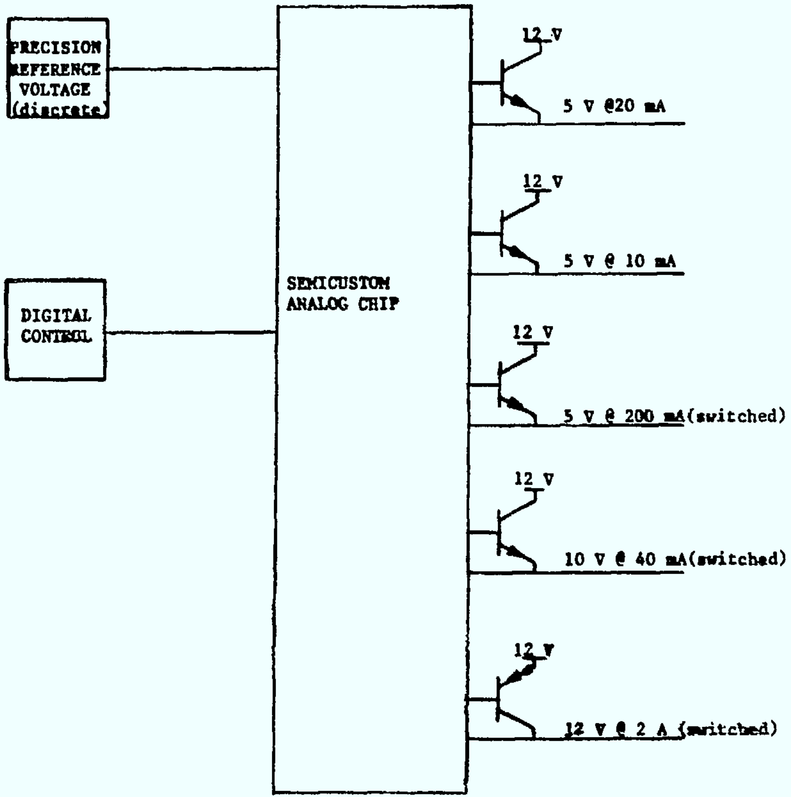


FIGURE 6: ANALOG CHIP CONCEPT

Component cost change:

	1K	10K	PINS
delete ½ DTCXO Volt Reg.			
- delete 3/4 U1	(2.39)	(2.15)	(10)
- delete Q5,6	(0.46)	(0.42)	(6)
- delete C38,39	(0.10)	(0.08)	(4)
- delete C29,30,34,27	(0.64)	(0.60)	(8)
- delete R52,53,54,55 56,59,61,51,58	(0.54)	(0.45)	(18)
- delete PWB 8cm²	(0.68)	(0.50)	
delete 12 volt, power SW	(0.78)	(0.68)	(15)
delete 5 V P.L.L. Reg.	(1.35)	(1.20)	(12)
delete 10V 121 Bcn Reg.	(3.58)	(3.18)	(26)
add Semicustom Analog Chip	10.00	9.00	28
add 3 transistors	0.69	0.63	9
add 1 transistor	0.77	0.70	3
add 5 capacitors	0.80	0.75	10
add 5 resistors	0.30	0.25	10
	2.04	2.07	(39)

Assembly cost change:

	1K	10K
½ DTCXO Volt Reg.	(5.06)	(4.00)
12 V Power Switch	(1.65)	(1.31)
5 V P.L.L. Reg.	(1.32)	(1.04)
121 Bcn Reg.	(2.86)	(2.26)
Semicustom	3.08	2.44
additional cct	3.52	2.78
	(4.29)	(3.39)

Test cost change:

	1K	10K
½ DTCXO Volt Reg.	(1.52)	(1.10)
12 V Power Switch	(0.50)	(0.36)
5 V P.L.L. Reg.	(0.40)	(0.29)
121 Bcn Reg.	(0.86)	(0.62)
Semicustom	0.92	0.67
additional cct	1.06	0.77
	(1.30)	(0.93)

Total cost change:

1K	10K
(3.55)	(2.25)

Size change:

½ DTCXO Volt Reg.	(8.0)
12 V Power Switch	(1.7)
5 V P.L.L. Reg.	(2.0)
121 Bcn Reg.	(9.9)
Semicustom Chip	4
additional cct	5
	(12.6)cm^2

4.8 Oven Stabilized Oscillator Design

4.8.1 Investigation and Concept Presentation

Two methods of implementing an oven stabilized oscillator were studied. These two methods are foam type and Dewar flask.

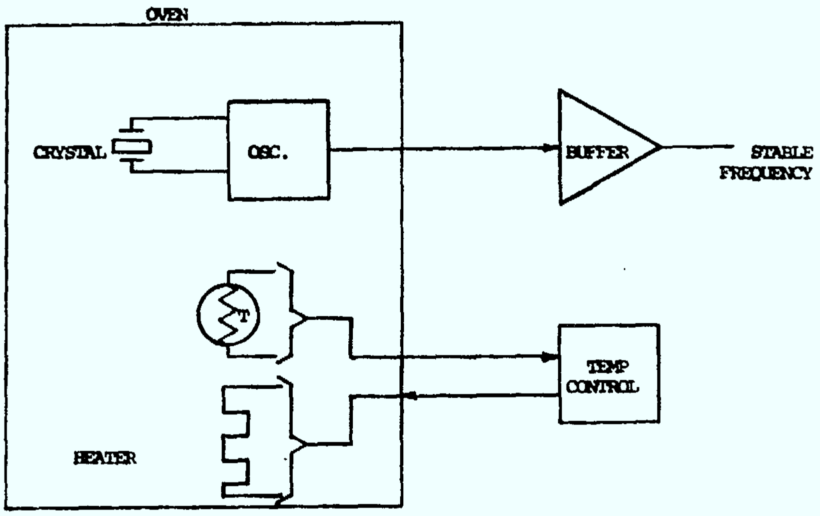
Investigation of the foam method of oven implementation yielded the following observations:

- calculations imply that a 200 mW oven can be achieved.
- it is a feasible approach if the circuitry inside can be reduced in size to fit within a 2 cm^3 cavity.
- the external size of the foam oven would be a 7½ cm cube.
- the foam method caters to low cost, high volume applications.

Investigation of the Dewar flask method of oven implementation yielded the following observations:

- power requirement would be 200 mW.
- shock and vibration performance is a major concern.
- major tooling and development costs would have to be incurred to prepare for volume production.
- problems have been reported in maintaining adequate vacuum over 5 year storage.

Given the aforementioned observations, it was concluded that the Dewar flask method offered no advantages over the foam method. Therefore, a conceptual cost analysis was only performed for the foam method. A conceptual block diagram design for a foam implementation of an oven stabilized oscillator is shown below.



4.8.2 Cost, Size, and Weight Impact

Component cost change:

	1K	10K	PINS
delete ½ of Volt Reg.	(5.64)	(4.90)	(39)
delete temp. sensor	(18.23)	(16.30)	(45)
delete D/A converter	(17.64)	(15.66)	(84)
delete Stable oscillator	(35.45)	(31.76)	(70)
delete Thermal shield	(0.66)	(0.61)	
reduce Dig. Ctrl by U9,10,15	(16.01)	(14.42)	(41)
add crystal	12.75	11.15	2
add osc. cct	9.50	8.00	30
add thermistor	7.75	6.98	2
add temp. control	8.50	7.00	30
add foam oven	1.00	1.00	
	(54.63)	(49.52)	(215)

Assembly cost change:

	1K	10K
delete ½ of Volt Reg.	(4.29)	(3.39)
delete temp. sensor	(4.93)	(3.93)
delete D/A converter	(9.20)	(7.34)
delete Stable oscillator	(7.61)	(6.07)
delete Thermal shield	(0.11)	(0.09)
reduce Dig. Controller	(4.51)	(3.57)
add Ovenized osc.	7.04	5.57
add foam oven	0.11	0.09
	(23.72)	(18.73)

Test cost change:

	1K	10K
delete ½ of Volt Reg.	(1.29)	(0.94)
delete temp. sensor	(1.49)	(1.09)
delete D/A converter	(2.78)	(2.03)
delete Stable osc.	(2.30)	(1.68)
delete Thermal shield	(0.03)	(0.02)
reduce Dig. Controller	(1.35)	(0.98)
add Ovenized osc.	2.11	1.54
add foam oven	0.03	0.02
	(7.10)	(5.18)

Calibration cost change for the stable oscillator is reduced from 110 minutes to 60 minutes, which is the timer required for two profiles. The calibration required for the ovenized oscillator is 3 minutes to tune the centre frequency.

	1K	10K
Stable Oscillator	(25.00)	(25.00)
Oven Oscillator	1.50	1.50
	(23.50)	(23.50)

Total cost change:

1K	10K
(108.95)	(96.93)

Size change:

delete ½ of Volt Reg.	(7.0)
delete temp. sensor	(19.2)
delete D/A converter	(20.6)
delete Stable osc.	(26.4)
reduce Dig. Controller	(4.0)
add foam oven	58.0
	(19.2)

NOTE: The ovenized oscillator is contained within the foam oven. The size given for the foam oven pertains to the area on the circuit board. The foam oven has a volume of 440 cm^3 which involves a vertical height of 7.6 cm.

Weight change:

No appreciable impact.

4.8.3 Battery Impact

The power budget for an oven stabilized oscillator incorporated into the beacon is presented below:

Control	3.0 mA
Oven (200 mWatts @ 12V)	16.6 mA
121 Beacon	10.0 mA
406 Transmitter	20.0 mA
	49.6 mA

The resultant power requirement over a 48 hour duration is,

48 x 0.0496 = 2.4 A hour @ 20°C

or $\frac{2.4}{0.35}$ = 6.9 A hour @ -40°C

The battery pack required by the present beacon design contains 5 lithium "D" cells, with a capacity of

8.3 A hours

(Reference Appendix B, Battery Study)

Hence, there is no impact on battery size, weight or cost for the oven stabilized oscillator implementation.

4.8.4 References

References used in researching the Dewar flask approach were:

A. Stahl, and M. Brunet, "An Ultrastable Crystal Oscillator for Beacons (Program SARSAT)", Proceedings of the 37th Annual Symposium on Frequency Control, June 1983.

N. Levanon, J. Afanasjevs, S. D. Ellington, R. A. Oehlkers, V. E. Suomi, E. W. Lichfield, and M. W. Gray, "The Twerle Balloon-to-Satellite Data Transmitting System", IEEE Transactions on Geoscience Electronics, January 1975.

4.9 Custom Hybrid

The potential for cost reduction by implementing a custom amplifier hybrid are presently viewed as promising. However, the time frame required to quantify these potential savings is beyond the time limit for this report.

A saving of 30% per subsystem would be necessary to merit the development effort and stock support involved. The same technology could be applied to the 406 MHz V.C.O. and the R.F. section of the 121.5 MHz Beacon. Resulting in reduced size, cost and tuning time.

4.10 Low Cost Components

The use of low cost components was analyzed for cost saving potential. This entails the purchase of 0 - 70°C temperature range components and perform incoming testing in lieu of purchasing extended temperature range parts. Essentially, the testing process and associated cost would be transferred from the component vendor to the unit manufacturer. The capital equipment expenditures required to perform this task are factored into the component price to remove the possibility of distorted comparisons.

The cost per unit of extended temperature range components is:

Annual Volume of Units	1K	10K
70 Components per unit	$158	$142

The expected fixed and variable costs based on a 10 year amortization of capital expenditures are as follows:

Fixed Costs	Annual Cost
Tester	40,000
Test design & programming	30,000
Jigs & fixtures	10,000
Chamber	2,000
	$82,000
Variable Costs (based on through-put of 70,000 components per annum)	
Operators	60,000
Equipment & services	60,000
	$120,000

The final cost per unit of using reduced temperature range components is:

	1K	10K
Low cost components	$95	$85
Fixed cost	82	8
Variable costs	120	120
Total	297	213

The cost change per unit, using low cost components is:

	1K	10K
Add Low cost components	297	213
Delete Extended range components	(158)	(142)
Net Change	+139	+71

In conclusion, it is shown that the unit cost actually would increase if low cost components were used. This concept would not be useful until an extremely large volume of components were processed.

4.11 Optional Data Interface

The option data interface was analyzed for potential cost savings. The interface presents a cost as listed below.

	1K	10K	PINS
Component	0.78	0.73	10.5
Assembly	1.16	0.91	
Test	0.35	0.25	
	2.29	1.89	

The cost of the optional data interface represents only 0.3% of the unit cost. Thus, there is no motive to remove this feature. Also, it is used to facilitate the calibration communication process (part of the test interface). This method is probably the most cost effective way to implementing such a process.

4.12 Cost/Benefit Analysis Summary

COST & PHYSICAL PARAMETER IMPACT - REDESIGN

ITEM	SUBSYSTEM	COMPONENT COST		ASSEMBLY COST		TEST COST		CALIBRATION COST		TOTAL COST		SIZE cm²	WEIGHT gm
-	-	1K	10K	1K	10K	1K	10K	1K	10K	1K	10K	-	-
		406 VCO AND POWER AMP. REDESIGN											
19	406 VCO	(3.29)	(2.96)	0.44	0.35	0.13	0.10	-	-	(2.72)	(2.51)	-	-
20	406 Pwr Amp.	(12.71)	(11.90)	-	-	-	-	1.50	1.50	(11.21)	(10.40)	(10)	-
	TOTAL	(16.00)	(14.86)	0.44	0.35	0.13	0.10	1.50	1.50	(13.93)	(12.91)	(10)	-
		406 DIVIDER REDESIGN											
21	406 Divider	(10.82)	(9.74)	(0.99)	(0.78)	(0.30)	(0.21)	-	-	(12.11)	(10.73)	-	-
		TEMPERATURE SENSOR REDESIGN											
4	Temp. Sensor	(10.45)	(9.12)	(3.52)	(2.78)	(1.06)	(0.77)	-	-	(15.03)	(12.67)		

COST & PHYSICAL PARAEMTER IMPACT - REDESIGN

ITEM	SUBSYSTEM	COMPONENT COST		ASSEMBLY COST		TEST COST		CALIBRATION COST		TOTAL COST		SIZE cm^2	WEIGHT gm
–	–	1K	10K	1K	10K	1K	10K	1K	10K	1K	10K	-	-
		DIGITAL CONTROLLER CONSOLIDATION											
3	Digital Controller	(16.77)	(14.56)	(3.03)	(2.39)	(0.91)	(0.66)	-	-	(20.11)	(17.61)	(4)	-
6	Stable Oscillator	-	-	-	-	-	-	(18.00)	(18.00)	(18.00)	(18.00)	-	-
	TOTAL	(16.17)	(14.56)	(3.03)	(2.39)	(0.91)	(0.66)	(18.00)	(18.00)	(38.11)	(35.61)	(4)	-
		TEST INTERFACE REDESIGN											
8 & 27	Test I/F	(21.74)	(19.96)	(5.28)	(4.18)	(1.58)	(1.15)	-	-	(28.60)	(25.29)	(46)	
		CASE REDESIGN											
30	Case	(26.45)	(23.70)	(45.50)	(30.50)	-	-	-	-	(71.95)	(54.20)		(600)

COST & PHYSICAL PARAEMTER IMPACT - REDESIGN

ITEM	SUBSYSTEM	COMPONENT COST		ASSEMBLY COST		TEST COST		CALIBRATION COST		TOTAL COST		SIZE cm²	WEIGHT gm
–	–	1K	10K	1K	10K	1K	10K	1K	10K	1K	10K	–	–
	SEMICUSTOM CHIP-DIGITAL												
2	CPU Support	(1.45)	(1.31)	(1.76)	(1.39)	(0.53)	(0.39)	–	–	(3.74)	(3.09)	(5)	
4	Temp. Sensor	(0.70)	(0.63)	(1.54)	(1.22)	(0.46)	(0.33)	–	–	(2.70)	(2.18)	(5)	
5	D/A Converter	(13.16)	(11.88)	(8.58)	(6.79)	(2.57)	(1.87)	–	–	(24.31)	(20.54)	(18)	
24	121 Modulator	(8.72)	(7.63)	(4.62)	(3.65)	(1.39)	(1.01)	–	–	(14.73)	(12.29)	(16)	
	Semi Chip	9.00	8.00	3.52	2.78	1.06	0.77	–	–	13.58	11.55	4	
	PWB	(3.40)	(2.52)	–	–	–	–	–	–	(3.40)	(2.52)		
	TOTAL	(18.43)	(15.97)	(12.98)	(10.27)	(3.89)	(2.83)	–	–	(35.30)	(29.07)	(40)	

COST & PHYSICAL PARAEMTER IMPACT - REDESIGN

ITEM	SUBSYSTEM	COMPONENT COST		ASSEMBLY COST		TEST COST		CALIBRATION COST		TOTAL COST		SIZE cm^2	WEIGHT gm
–	–	1K	10K	1K	10K	1K	10K	1K	10K	1K	10K	–	–
		SEMICUSTOM ANALOG CHIP											
7	DTCXO Volt Reg.	(4.81)	(4.20)	(5.06)	(4.00)	(1.52)	(1.10)	-	-	(11.39)	(9.30)	(8.0)	
12	12 Volt Pwr. Switch	(0.78)	(0.68)	(1.65)	(1.31)	(0.50)	(0.36)	-	-	(2.93)	(2.35)	(1.7)	
13	5 V P.L.L. Reg.	(1.35)	(1.20)	(1.32)	(1.04)	(0.40)	(0.29)	-	-	(3.07)	(2.53)	(2.0)	
25	121 Bcn Reg.	(3.58)	(3.18)	(2.86)	(2.26)	(0.86)	(0.62)	-	-	(7.30)	(6.06)	(9.9)	
	Semi Chip	10.00	9.00	3.08	2.44	0.92	0.67	-	-	14.00	12.11	4	
	Additional ccts	2.56	2.33	3.52	2.78	1.06	0.77	-	-	7.14	5.88	5	
	TOTAL	2.04	2.07	(4.29)	(3.39)	(1.30)	(0.93)	-	-	(3.55)	(2.25)	(12.6)	

COST & PHYSICAL PARAEMTER IMPACT - REDESIGN

ITEM	SUBSYSTEM	COMPONENT COST		ASSEMBLY COST		TEST COST		CALIBRATION COST		TOTAL COST		SIZE cm²	WEIGHT gm
–	–	1K	10K	1K	10K	1K	10K	1K	10K	1K	10K	-	-
		OVENIZED OSCILLATOR											
1	Volt Reg.	(5.64)	(4.90)	(4.29)	(3.39)	(1.29)	(0.94)	-	-	(11.22)	(9.22)	(7.0)	
4	Temp. Sensor	(18.23)	(16.30)	(4.93)	(3.93)	(1.49)	(1.09)	-	-	(24.65)	(21.32)	(19.2)	
5	D/A Converter	(17.64)	(15.66)	(9.20)	(7.34)	(2.78)	(2.03)	-	-	(29.62)	(25.03)	(20.6)	
6	Stable Oscillator	(35.45)	(31.76)	(7.61)	(6.07)	(2.30)	(1.68)	(25.00)	(25.00)	(70.36)	(64.51)	(26.4)	
10	Thermal Shield	(0.66)	(0.61)	(0.11)	(0.09)	(0.03)	(0.02)	-	-	(0.80)	(0.72)	-	
3	Dig. Controller	(16.01)	(14.42)	(4.51)	(3.57)	(1.35)	(0.98)	-	-	(21.87)	(18.97)	(4.0)	
	Ovenized Oscillator	38.00	33.13	7.04	5.57	2.11	1.54	1.50	1.50	48.65	41.74	-	
	Foam Oven	1.00	1.00	0.11	0.09	0.03	0.02	-	-	1.14	1.11	58.0	
	TOTAL	(54.63)	(49.52)	(23.72)	(18.73)	(7.10)	(5.18)	(23.50)	(23.50)	(108.95)	(96.93)	(19.2)	

5.0 DISCUSSION

This section contains recommended design changes which will substantially reduce the cost, size, and weight of the beacon.

5.1 Specification Change

There is one specification change which presents a substantial cost saving. This is the reduction of the medium term frequency specification by a factor of 8. The cost reduction potential is:

	1K	10K	Size cm^2
Reduction	(71)	(65)	(25.6)

In addition, there are further cost savings not addressed under the scope of this report. These include:

- reduced quality control due to higher probability of meeting spec., and
- reduced component handling cost due to a lower parts count.

5.2 Design Change

There are two overall design methodologies which incorporate an optimum combination of design changes discussed previously in Section 4.

First, the unit may be modified to incorporate all reasonable size and cost saving changes. The resultant impact is as follows:

REDESIGN PRESENT CONCEPT	1K	10K	SIZE (cm^2)	(gm)
406 VCO & Power Amp	(13.93)	(12.91)	(10)	
406 Divider	(12.11)	(10.73)		
Temperature Sensor	(15.03)	(12.67)		
Digital Controller	(38.11)	(35.61)	(4)	
Test Interface	(28.60)	(25.29)	(46)	
Case	(71.95)	(54.20)		(600)
Digital Chip	(35.30)	(29.07)	(40)	
Analog Chip	(3.55)	(2.25)	(13)	
TOTAL CHANGE	(218.58)	(183.73)	(109)	(600)

Second, the unit may be modified to incorporate an alternate stable oscillator technique (oven stabilized) plus reasonable size and cost changes, the resultant impact is as follows:

OVEN STABILIZED CONCEPT	1K	10K	SIZE (cm^2)	(cm^3)	(gm)
406 VCO & Power Amp	(10.60)	(10.41)	(10)		
406 Divider	(12.11)	(10.73)			
Ovenized Oscillator	(108.95)	(96.93)	(19)	380	
Test Interface	(28.60)	(25.29)	(46)		
Case	(71.95)	(54.20)			(600)
TOTAL CHANGE	(232.21)	(197.56)	(75)	380	(600)

In summary, it has been shown the two design methodologies (incorporate all reasonable changes on present concept or implement oven stabilized oscillator concept) have similar impact potential.

	1K	10K	SIZE (cm^2)	(cm^3)	(gm)
Redesign Present Concept	(218.58)	(183.73)	(109)		(600)
Oven Stabilized Concept	(232.21)	(197.56)	(75)	380	(600)

The cost reduction presented by both methods are within 8% of each other, which is likely the range of error in the cost data.

The size reduction presented indicates the present design concept has a greater potential to reduce area and volume.

APPENDIX A

SUBSYSTEM DETAILED COMPONENT COST

SUBSYSTEM DETAILED COMPONENT COST

This Appendix contains a detailed component cost breakdown of the beacon. The data is presented in subsystems which were chosen to give a convenient functional partitioning of the beacon. Following is a list of guidelines used in generating the subsequent table.

- cost were obtained using data bases maintained by Bristol Aerospace and by a number of official price and delivery enquiries. The use of these costs should be restricted to budgetary purposes within the report.
- costs do not include margins for shipping, handling, quality assurance, or capital equipment.
- the cost of the printed wiring board (PWB) has been amortized over the subsystems using the following constants:

Estimated total cost of both PWB's

in 1,000 quantities = \$33.00
in 10,000 quantities = \$24.50

PWB unit cost

$$\text{in } 1{,}000 \text{ quantities} = \frac{\$33.00}{388 \text{ cm}^2} = 8.5¢/\text{cm}^2$$

$$\text{in } 10{,}000 \text{ quantities} = \frac{\$24.50}{388 \text{ cm}^2} = 6.3¢/\text{cm}^2$$

		PIECE COST		UNIT COST		LEADS
		1K	10K	1K	10K	
1. VOLTAGE REGULATOR						
14 Resistors 5%	R 47,48,59,56 57,45,51,62, 52,61,53,54, 55,56	0.06	0.05	0.84	0.70	28
3 Resistors 1%	R 46,49,50	0.06	0.05	0.18	0.15	6
H Capacitors 638	C 36,37,38,39	0.05	0.04	0.20	0.16	8
6 Capacitors CK	C 26,27,29,30, 34,35	0.16	0.15	0.96	.80	12
1 Diode	CR 7	0.08	0.07	0.08	0.07	2
1 Reference	VR 1	4.18	3.71	4.18	3.71	2
2 Transistors	Q 5,6	0.23	0.21	0.46	0.42	6
1 Linear I.C.	UI	3.18	2.87	3.18	2.87	14
7.9% PWB	= 14.13 cm^2	0.085	0.063	1.20	0.89	-
				11.28	9.79	78
2. CPU SUPPORT						
5 Resistors 5%	R 35,36,37,38,39	0.06	0.05	0.35	0.25	10
3 Capacitors CK	C 23,24,32	0.16	0.15	0.48	0.45	6
1 Capacitor Electrolytic	C40	0.37	0.33	0.37	0.33	2
1 Timer	U2	1.45	1.31	1.45	1.31	16
¼ Quadgate	U10	0.46	0.42	0.12	0.11	3.5
1 Transistor	Q4	0.23	0.21	0.23	0.21	3
6.8% PWB	12.13 cm^2	1.03	0.76	1.03	0.76	--
				4.03	3.22	40.5
3. DIGITAL CONTROLLER						
1 Resistor 5%	R 44	0.06	0.05	0.06	0.05	2
1 Dip Socket	XU 11	2.28	2.06	2.28	2.06	40
2 Dip Socket	XU 9,14	1.14	1.03	2.28	2.06	48
3 Capacitors	C 15,33,14	0.16	0.15	0.48	0.45	6
1 Processor	U 11	16.62	14.96	16.62	14.96	--
2 Memories	U 9,14	14.29	12.86	28.58	25.72	--
1¼ Quadgate	U 10,15	0.46	0.42	0.58	0.53	17.5
24.8% PWB	44.13 cm^2	0.085	0.063	3.75	2.78	--
				54.63	48.61	113.5

		PIECE COST		UNIT COST		LEADS
		1K	10K	1K	10K	
4. TEMPERATURE SENSOR						
2 Resistors 5%	R 16,17	0.06	0.05	0.12	0.10	4
3 Resistors 1%	R 13,14,15	0.06	0.05	0.18	0.15	6
3 Capacitors CK	C 10,11,18	0.16	0.15	0.48	0.45	6
1 Capacitor CN	C 9	0.99	0.90	0.99	0.90	2
1 Capacitor CN	C 12	0.27	0.25	0.27	0.25	2
1 Capacitor Electrolytic	C 19	1.48	1.34	1.48	1.34	2
1 Divider	U 3	0.70	0.63	0.70	0.63	14
1 Transistor	Q 3	0.80	0.72	0.80	0.72	3
1 Crystal	Y 2	10.95	9.95	10.95	9.95	2
1 Diode	CR 5	0.07	0.07	0.07	0.07	2
1 Choke	L 3	0.70	0.63	0.70	0.63	2
9.9% PWB	17.55 cm²	0.085	0.063	1.49	1.11	--
				18.23	16.30	45
5. D/A CONVERTER						
4 Multipliers	U 4,5,6,7	3.19	2.88	12.76	11.52	64
1 Flip Flop	U 8	0.40	0.36	0.40	0.36	14
1 Resistor 5%	R 12	0.06	0.05	0.06	0.05	2
1 Capacitors CK	C 25	0.16	0.15	0.16	0.15	2
1 Capacitor X	C 13	2.66	2.39	2.66	2.39	2
10.6% PWB	18.84 cm²	0.085	0.063	1.60	1.19	--
				17.64	15.66	84
6. STABLE OSCILLATOR						
1 Resistors 5%	R 40	0.06	0.05	0.06	0.05	2
6 Resistors 1%	R 2,3,4,5,6,7	0.06	0.05	0.36	0.30	12
6 Capacitors	C 1,2,6,21,3,5	0.99	0.90	4.95	4.50	10
5 Capacitors CK	C 17,8,4,7,28	0.16	0.15	0.80	0.75	10
1 Capacitor CN	C 22	0.54	0.49	0.54	0.49	2
2 Chokes	L 1,2	0.70	0.63	1.40	1.26	4
¼ Quadgate	U 16	0.22	0.20	0.06	0.05	3.5
2 Transistors	Q 1,2	0.80	0.72	1.60	1.44	6
3 Diodes	CR 2,3,6	0.08	0.07	0.24	0.21	6
1 Varactor	CR 1	6.65	6.00	6.65	6.00	2
1 Capacitor Electrolytic	C 20	1.48	1.34	1.48	1.34	2
1 Crystal	Y 1	12.25	11.15	12.25	11.15	2
1 Connector	E1-8	3.00	2.70	3.00	2.70	8
13.6% PWB	24.19 cm²	0.085	0.063	2.06	1.52	--
				35.45	31.76	69.5

			PIECE COST		UNIT COST		LEADS
			1K	10K	1K	10K	
7.	TRANSMIT CONTROL						
	5 Resistors 5%	R 8,41,42,43,9	0.06	0.05	0.30	0.25	10
	¼ Resistor Hybrid	U 12	0.47	0.43	0.12	0.11	4
	½ Quadgate	U 16	0.22	0.20	0.11	0.10	7
	¼ Quadgate	U 10	0.46	0.42	0.12	0.11	3.5
	5/15 Interboard I/F	J 1	12.25	11.76	4.08	3.92	5
	7.6% PWB	13.55 cm²	0.085	0.063	1.15	0.85	--
					5.88	5.34	29.5
8.	TEST INTERFACE						
	2 Resistors 5%	R 10,11	0.06	0.05	0.12	0.10	4
	¼ Resistor Hybrid	U 13	0.47	0.43	0.12	0.11	4
	6/15 Interboard I/F	J 1	12.25	11.76	4.90	4.70	6
	23/37 User I/F Jack	J 2	16.23	15.58	10.09	9.69	23
	8.9% PWB	15.74 cm²	0.085	0.063	1.34	0.99	--
					16.57	15.59	37
9.	USER INTERFACE						
	¼ Resistor Hybrid	U 12	0.47	0.43	0.12	0.11	4
	1 Diode	VR 2	0.10	0.09	0.10	0.09	2
	¼ Quadgate	U 10	0.46	0.42	0.12	0.11	3.5
	1/37 User I/F	J 2	16.23	15.58	0.44	0.42	1
9.1	Code Jack						
	1¼ Resistor Hybrid	U 12,13	0.47	0.43	0.59	0.54	20
	5/37 User I/F Jack	J 2	16.23	15.58	2.19	2.11	5
	2.9% PWB	5.23 cm²	0.085	0.063	0.44	0.33	--
9.2	Power						
	1 Capacitor CK	C 31	0.16	0.15	0.16	0.15	2
	4/37 User I/F Jack	J 2	16.23	15.58	1.76	1.68	4
	2/15 Interboard I/F	J 1	12.25	11.76	1.63	1.57	2
					7.55	7.11	43.5

	PIECE COST		UNIT COST		LEADS
	1K	10K	1K	10K	
10. THERMAL SHIELD					
1 Aluminum Box 104 cm²	0.03	0.03	0.03	0.03	--
2 Aluminum Rivets	0.005	0.005	0.01	0.01	--
2 Aluminum Spacers	0.01	0.01	0.02	0.02	1
2 Screw, Nut, Washers Set (4/40)	0.10	0.10	0.10	0.10	--
1 Aerobic Foam 58 cm³	0.50	0.45	0.50	0.45	--
			0.66	0.61	1
11. SUBTOTAL			171.92	153.99	541
12. 12 VOLT POWER SWITCH					
3 Resistors 5% R 32,31,63	0.06	0.05	0.18	0.15	6
1 Capacitor CK C 40	0.16	0.15	0.16	0.15	2
½ Hex Buffer U 9	0.59	0.53	0.30	0.27	7
0.9% PWB 1.68 cm²	0.085	0.063	0.14	0.11	--
			0.78	0.68	15
13. 5V P.L.L. REGULATOR					
1 Resistor 5% R 27	0.06	0.05	0.06	0.05	2
1 Capacitor CK C 21	0.16	0.15	0.16	0.15	2
1 Diode CR 13	0.08	0.07	0.08	0.07	2
1 Transistor Q 6	0.11	0.10	0.11	0.10	3
1 Transistor Q 7	0.77	0.70	0.77	0.70	3
1.0% PWB 1.99 cm²	0.085	0.063	0.17	0.13	--
			1.35	1.20	12
14. 406 PROTECTION					
6 Resistors 5% R 33,36,30, 35,34,38	0.06	0.05	0.30	0.25	12
1 Quadgate U 7	0.22	0.20	0.22	0.20	14
2 Capacitors CK C 22,23	0.16	0.15	0.32	0.30	4
2.0% PWB 3.99 cm²	0.085	0.063	0.34	0.25	--
			1.18	1.00	30

		PIECE COST		UNIT COST		LEADS
		1K	10K	1K	10K	
15. 406 LEVELLER						
4 Resistors 5%	R 26,66,25,21	0.06	0.05	0.18	0.15	8
1 Resistor 1%	R 28	0.06	0.05	0.06	0.05	2
1 Resistor Trimmer	R 7	0.93	0.87	0.93	0.87	3
3 Capacitors CK	C 18,20,17	0.16	0.15	0.48	0.45	6
1 Diode Zener	VR 1	0.85	0.77	0.85	0.77	2
1 Diode	CR 8	0.52	0.47	0.52	0.47	2
2 Transistors	Q 10,11	0.14	0.13	0.28	0.26	6
1 Transistor	Q 9	0.77	0.70	0.77	0.70	3
2.0% PWB	3.99 cm^2	0.085	0.063	0.34	0.25	--
				4.41	3.97	32
16. 406 FWD POWER DETECTOR						
2 Resistors 5%	R 59, W 1	0.06	0.05	0.12	0.10	4
1/15 Connector	J1-14	7.23	6.94	0.48	0.46	1
2 Transistors	Q 22,24	0.21	0.19	0.41	0.38	6
2.5% PWB	4.77 cm^2	0.085	0.063	0.41	0.30	--
				1.42	1.24	11
17. 406 Ø DETECTOR & MODULATOR						
5 Resistors 5%	R 22,23,24,4,2	0.06	0.05	0.30	0.25	10
3 Resistors 1%	R 3,1,5	0.06	0.05	0.18	0.15	6
1 Resistor Trimmer	R 9	0.93	0.87	0.93	0.87	3
1 Capacitor CK	C 13	0.16	0.15	0.16	0.15	2
1 Filter	FL 1	2.50	2.25	2.50	2.25	2
1 Quadgate	U 1	4.82	4.34	4.82	4.34	14
1/3 Hex Buffer	U 9	0.59	0.53	0.20	0.18	5
10.2% PWB	19.87 cm^2	0.085	0.063	1.69	1.26	--
				10.78	9.45	42
18. 406 LOOP AMP & LOCK DETECTOR						
4 Resistors 5%	R 6,11,10,12	0.06	0.05	0.24	0.20	8
3 Capacitors CK	C 1,2,3	0.16	0.15	0.48	0.35	6
1 Capacitor 638	C 4	0.05	0.04	0.05	0.04	2
3 Diodes	CR 1,2,3	0.08	0.07	0.24	0.21	6
1 Diode High Speed	CR 4	0.52	0.49	0.52	0.49	2
1 Diode Current Source	CR 5	2.06	1.85	2.06	1.85	2
3 Transistors	Q 1,2,3	0.23	0.21	0.68	0.63	6
4.6% PWB	8.90 cm^2	0.085	0.063	0.76	0.56	--
				5.03	4.43	32

		PIECE COST		UNIT COST		LEADS
		1K	10K	1K	10K	
19. 406 V.C.O.						
4 Resistors 5%	R 17,14,16,18	0.06	0.05	0.24	0.20	8
1 Capacitor 638	C 10	0.05	0.04	0.05	0.04	2
2 Capacitor 301	C 12,16	1.50	1.35	3.00	2.70	4
1 Capacitor Trim	C 9	8.90	8.10	8.90	8.10	2
2 Inductors	L 2,3	0.70	0.63	0.70	0.63	4
1 Tuned Stub	Z 1	1.65	1.65	1.65	1.65	4
1 Diode	CR 6	0.08	0.07	0.08	0.07	2
1 Varactor	CR 7	2.50	2.25	2.50	2.25	2
1 Transistor	Q 4	1.79	1.61	1.79	1.61	3
6.1% PWB	11.94 cm²	0.085	0.063	1.02	0.75	--
				19.93	18.00	31
20. 406 P.A.						
2 Capacitors CK	C 14,15	0.16	0.15	0.32	0.30	4
1 Capacitor 638	C 11	0.05	0.04	0.05	0.04	2
1 IC	AR 1	39.00	36.00	39.00	36.00	7
11.2% PWB	21.81 cm²	0.085	0.063	1.85	1.37	--
				41.22	37.71	13
21. 406 DIVIDER (PRESCALER)						
2 Resistors 5%	R 13,19	0.06	0.05	0.06	0.05	4
2 Capacitors CK	C 5,7	0.16	0.15	0.32	0.30	4
1 Capacitor 638	C 6	0.05	0.04	0.05	0.04	2
1 Capacitor 301	C 8	0.89	0.80	0.89	0.80	2
1 Divider (Slow)	U 2	1.56	1.41	1.56	1.01	14
1 Divider (Fast)	U 3	21.21	19.09	21.21	19.09	16
3.1% PWB	5.94 cm²	0.085	0.063	0.51	0.37	--
				24.60	21.66	42
22. 406 HARMONIC FILTER						
1 Tuned Stub		1.51	1.45	1.51	1.45	4
3.4% PWB	6.5 cm²	0.085	0.063	0.55	0.41	--
				2.06	1.86	4

		PIECE COST		UNIT COST		LEADS
		1K	10K	1K	10K	

23. 121 oscillator & POWER AMP

9 Resistors 5%	R 44,45,65,46 47,48,49,67,51	0.06	0.05	0.54	0.45	18
6 Capacitors CK	C 26,32,30,33 34,29	0.16	0.15	0.96	0.90	12
5 Capacitor 638	C 28,37,44,42,36	0.05	0.04	0.25	0.20	10
1 Capacitor 301	C 43	1.50	1.35	1.50	1.35	2
1 Capacitor Trimmer	C 31	8.36	7.52	8.36	7.52	2
2 Inductors	L 7,4	0.70	0.63	1.40	1.26	4
3 Inductor Trimmers	L 1,6,5	3.94	3.75	11.82	11.25	6
1 Crystal	Y 1	1.40	1.06	1.40	1.06	2
1 Transistor	Q 16	0.40	0.36	0.40	0.36	3
2 Transistors	Q 17,18	1.07	0.96	2.14	1.92	6
10.8% PWB	20.90 cm²	0.085	0.063	1.78	1.32	--
				30.01	27.59	65

24. 121 MODULATOR

5 Resistors 5%	R 41,42,54,52,53	0.06	0.05	0.30	0.25	10
3 Resistors 1%	R 39,40,43	0.06	0.05	0.18	0.15	6
1 Resistor Trimmer	R 58	0.93	0.87	0.93	0.87	3
2 Capacitors	C 24,25	2.05	1.84	4.10	3.68	4
1 Capacitor Electrolytic	C 38	1.01	0.91	1.01	0.91	2
1 Diode	CR 14	0.08	0.07	0.08	0.07	2
1 PUT	Q 15	0.30	0.27	0.30	0.27	3
4 Transistors	Q 12,13,14,19	0.12	0.11	0.48	0.44	12
8.1% PWB	15.74 cm²	0.085	0.063	1.34	0.99	--
				8.72	7.63	42

25. 121 BEACON REGULATOR

3 Resistors 5%	R 50,37,55	0.06	0.05	0.18	0.15	6
1 Resistor 1%	R 57	0.06	0.05	0.06	0.05	2
1 Resistor Trim	R 56	0.93	0.87	0.93	0.87	3
1 Capacitor CK	C 39	0.16	0.15	0.16	0.15	2
1 Diode	CR 9	0.08	0.07	0.08	0.07	2
3 Transistors	Q 20,21,22	0.12	0.11	0.36	0.33	9
2/15 Connector	J1-2,8	7.23	6.94	0.96	0.93	2
5.1% PWB	9.94 cm²	0.085	0.063	0.85	0.63	--
				3.58	3.18	26

		PIECE COST		UNIT COST		LEADS
		1K	10K	1K	10K	
26. 406/121 OUTPUT I/F						
2 TNC Connectors	J 3,2	2.09	1.82	4.18	3.64	4
13.3% PWB	25.74 cm²	0.085	0.063	2.19	1.62	--
				6.37	5.26	4
27. TEST INTERFACE						
3 Resistors 5%	R 64,61,15	0.06	0.05	0.18	0.15	6
5/15 Connector	J1-3,7,4,5,15	7.23	6.94	2.41	2.31	5
15.7% PWB	30.39 cm²	0.085	0.063	2.58	1.91	--
				5.17	4.37	11
28. SUBTOTAL ITEMS 12-27				166.61	149.23	412
29. TOTAL ITEMS 1-27				338.53	303.22	953
30. METAL CASE						
Stainless Steel Bulk		15.00	13.50	15.00	13.50	
Paint		1.00	1.00	1.00	1.00	
Absorbant Foam		5.75	5.20	5.75	5.20	
14 Fasteners		.50	.45	7.00	6.30	
				28.75	26.00	
31. BATTERY						
1 OEM Lithium Pack		63.00	56.70	63.00	56.70	
32. EXTERNAL USER I/F						
1 Connector		16.23	15.58	16.23	15.58	
1 Manual Activation Alcott 13A-2T Switch		2.00	1.80	2.00	1.80	
1 Indicator LED		1.00	0.90	1.00	0.90	
5 Coding Switches		2.00	1.80	10.00	9.00	
Diplexer		-	-	16.00	15.25	
Antenna		5.00	4.50	5.00	4.50	
				50.23	47.03	
33. SUBTOTAL MECHANICAL ITEMS 30-32				141.98	129.73	

34. TOTAL FOR UNIT

	1K	10K	LEADS
11 DTCXO Board	171.92	153.99	541
28 RF Board	166.61	149.23	412
33 Mechanical	141.98	129.73	--
	480.51	432.95	953

APPENDIX B

BATTERY STUDY

TABLE OF CONTENTS

1.0 INTRODUCTION

The power requirements of the SARSAT 406 MHz Emergency Beacon are fitted to several battery types. Feasible types are studied for their individual merit in terms of:

- Temperature compatibility
- Safety
- Shelf life
- Size
- Weight
- Cost

The impact of varying:

- Temperature range
- Power

are then applied to battery selection.

2.0 POWER REQUIREMENTS

The power requirement for the SARSAT Beacon electronics is:

Standby current	7.5 mA
121.5 MHz Beacon Current	10.0 mA
406 MHz Beacon Avg. Current	20.0 mA
	37.5 mA

Energy consumed over 48 hours is:

48 (37.5) = 1800 mA hour
= 1.8 A hour

Given the following temperature range specifications:

Operating	-40°C to 55°C
Storage	-50°C to 85°C

the minimum energy capacity of a suitable battery pack is 1.8 A hour at its worst operating temperature. This temperature is typically at -40°C.

3.0 BATTERY OPTIONS

Several battery options were investigated and each of the following points are addressed:

- Characteristics
- Required cell capacity normalized to 20°C
- Available cells
- Recommended pack
- Size
- Weight
- Approximate cost in volume purchases.

3.1 Lithium/SO_2

Characteristics:

- produces 35% of standard capacity at -40°C.
- designed to contain its gaseous and corrosive products to 110°C, well in excess of the beacon design limit of 85°C.
- produces 100% of standard capacity at 55°C.
- cell resistance is relatively constant and low over the temperature range.
- stores without charge maintenance for up to 10 years at 20°C, up to 5 years at +50°C. The cell is not rechargeable.

NOTE:

> Storage life is defined as the period of time a battery can be stored in a beacon before it is internally depleted to the point where 48 hours of service cannot be expected.

Required cell capacity normalized to 20°C:

$$1.8 \text{ A hour @ } -40°\text{C} = \frac{1.8}{35\%} = 5.2 \text{ A hour @ } 20°\text{C}$$

Available cells capable of meeting capacity requirement:

1¼ C size 2.8 V, 4.4 A hour, R_s = 160 m
D size 2.8 V, 8.3 A hour, R_s = 133 m

Recommended pack:

5 D cells in series, packaged side by side in a brick.

Size:

assembled in a brick 6.02 x 3.33 x 16.7 cm = 335 cm^3

Weight:

5 x 80 gm = 400 gm

Cost:
$63.00/5 cell pack in 1,000, $56.70/pack in 10,000's

3.2 Alkaline/MnO_2

Characteristics:

- produces less than 5% of standard capacity at -40°C.
- cell resistance increases at low temperature to the point where acceptable R_s at room temperature (20°C) is unacceptable below 0°C.
- performance above 45°C is not reported presumably because it is unfavourable. It is expected that high temperature failure would result from package failure rather than from changes in chemical activity or pressure on the package due to gas generation from the chemical reaction.
- stores for up to 3 years without cell maintenance charging. The cell is not rechargeable.

Required cell capacity normalized to 20°C:

1.8 A hour @ -40°C $= \frac{1.8}{5\%} =$ 36 A hours @ 20°C

Available cells close to meeting capacity requirement:

C size MN1400 1.5 V, 5 A hour, $R_s = 0.3$
D size MN1300 1.5 V, 10 A hour, $R_s = 0.2$

Recommended pack:

40 cell pack
MN1300 R_s @ -40°C = 0.5
connect 4 cells parallel and 10 cells series in a matrix result 40 A hour $R_s = 1.25\ \Omega$ @ 20°C

Size:

$40 \times 72.5\ cm^3 = 2{,}900\ cm^3$

Weight:

40 x 125 gm = 5 kg

Cost:

40 x $1.00/cell = $40.00/40 cell pack

3.3 Gell Cell (Sealed Lead/Acid)

Characteristics:

- produces 60% of standard capacity at -40°C.
- the integrity of the seal and the absorption of products of overcharge and discharge is reliable to 60°C.
- cell resistance is acceptable at the temperature extremes.
- must be float charged or maintained in some other way in order to retain charge longer than 2 months.
- mechanically survives up to 5 years in a charged condition.

Required cell capacity normalized to 20°C:

$$1.8\ \text{A hour @ } -40°\text{C} = \frac{1.8}{40\%} = 4.5\ \text{A hour @ } 20°\text{C}$$

Available cells capable of meeting capacity requirement:

Globe GC645 6 V, 4.5 A hour, $R_s = 0.03$
GC1245 12 V, 4.5 A hour, $R_s = 0.06$

Recommended packs:

2 GC645 cells in series pack
Single GC1245 cell.

Size:

GC645 pack, $2 \times (15.2 \times 3.4 \times 10.1)\ cm = 1008\ cm^3$
GC1245 pack, $15.2 \times 6.5 \times 10.2\ cm = 1008\ cm^3$

Weight:

GC645 pack, 2.08 kg
GC1245 pack, 2.04 kg

Cost:

$35.00/pack

3.4 Nickel/Cadmium

Characteristics:

- produces 50% of standard capacity at -40°C and at 55°C.
- cell resistance is an order of magnitude better than necessary over the temperature range.
- stores for up to 3 months without charge maintenance.
- cells can be discharged and recharged from 100 to 500 times depending on method of construction and discharging conditions.

Required cell capacity normalized to 20°C:

$$1.8 \text{ A hour @ } -40°\text{C} = \frac{1.8}{50\%} = 3.6 \text{ A hour @ } 20°\text{C}$$

Available cells capable of meeting capacity requirement:

Union Carbide R 3.5 1.25 V, 3.5 A hours, R_s = 0.048
CH4T 1.25 V, 4 A hours, R_s = 0.009

Recommended pack:

12 CH4T cells, connect 6 cells in series column and 2 columns in parallel result R_s = 0.054

Size:

3.3 x 12.2 x 19.8 cm = 797 cm^3

Weight:

12 x 153 gm = 1.8 kg

Cost:
12 x $9.70/cell = $120.00/pack

3.5 Silver Oxide

Characteristics:

- produces no power at -40°C, cell resistance is high over its active range.
- if temperature range were reduced to -20°C, it would be interesting to see if a hybrid battery could be implemented using this chemistry for low power circuits and a charger for a high rate source to be used in high power low duty cycle circuits.
- stores for up to 2 years without charge maintenance.
- the battery is not rechargeable.
- not chemically active at -40°C.

3.6 Mercuric Oxide and Lechanche

Characteristics:

- both cell types are not chemically active at -40°C.

4.0 SAFETY

4.1 Lithium

There are three chemical reactions used for Lithium activated cells.

1. $LiSO_2$ - is electrically the most attractive.

$2Li \quad 2Li^+ + 2e$ at the anode and

$2SO_2 + 2e \quad S_2O_4$ at the cathode yield

$2Li + 2SO_2 \quad Li_2S_2O_4$ across the cell.

The free SO_2 in the active (charged) state tends to leak out, form Sulphur based acid and cyanide. Early versions of this cell provided no containment mechanism for these components under pressure but current productions hermetically seals them. Venting in environmental overstress prevents them from exploding. When discharged, all of both components are consumed making disposal safe.

Presently, a 6 volt (2 "C" cell) Lithium/SO_2 battery pack has been certified for use in ELT's onboard aircraft. Also, a 6 volt (2 "D" cell) battery pack is undergoing certification testing.

2. Lithium Thionyl Chloride is environmentally the most attractive. The cell reaction:

$$4Li + 2SOCl_2 \quad S + 4LiCl + SO_2$$

Produces SO_2 (the corrosive agent) in the discharging process. Hence the cell is non pressurized in the charged state until it reaches 79°C, the boiling point of $SOCl_2$. Regrettably, the internal resistance of the cell and the rate of ionization are not adequate for our application.

3. Lithium Iodine is potentially the best compromise between the features of the above chemistries.

The cell reaction:

$$2Li + CTC \cdot nI_2 \quad CTC \cdot (n-1)I_2 + 2LiI$$

CTC = conductive charge transfer complex.

Produces no gaseous products and exists in the solid state in both charged and discharged conditions. Its cell resistance can be made low and its capacity is proportional to temperature and active over the range. It is also rechargeable.

The package is hermetically sealed to contain the reactive Lithium and Iodine. Cells of the required capacity are expected to be available within calendar 1984. Balanced chemistry insures safe disposal in sanitary landfills since all components are consumed through discharge.

4.2 Alkaline

Potassium Hydroxide and Manganese Dioxide are relatively safe. The corrosive products are contained in a non-consumed shell and sealed against leakage by cold forming around an insulating anulus. Under extreme environmental conditions seepage of electrolyte is common and the terminals are frequently insulated as a result. No significant internal cell pressure is present and the spent batteries are readily accepted in sanitary landfills.

4.3 Gell Cell

Sealed versions are relatively reliable in containing the acid electrolyte and gaseous products of overcharging.

4.4 Nickel Cadmium

Electrolyte seepage is successfully prevented in premium cells. Rupture from forced discharge is not a significant problem.

5.0 IMPACT OF VARYING SPECIFICATIONS

5.1 Temperature Range

Reducing the temperature range would reduce the size of all batteries being considered and introduce some new options.

Reduction to -20°C:

-	Lithium cells produce 60% normal capacity and a 3 A hour hour unit would be adequate. Now a C cell would do (5 C cells).	Capacity Gain 5.2 - 3 = 2.2 A
-	Alkaline cells produce 30% normal capacity and R_s is 250 m . 6 A hour battery is needed. Now 10 D cells will do the job. Size and weight are ¼ the -40°C implementation.	Capacity Gain 36 - 6 = 30 A hour
-	Gell cells produce 65% normal capacity and 2.25 A hour where 5.1 A hour are required. Now 12 3.5 cells will do.	Capacity Gain 3.6 - 2.25 = 1.35 A hour
-	Silver oxide produce 35% normal capacity and the only viable cell is the S42 12.5 A hour where 5.1 A hour are needed. Cell resistance is not reported. This battery would weigh 10 (146 g) = 1.5 kg and occupy 15.3 x 12.0 x 3.1 cm = 570 cm^3.	New Option
-	Mercuric oxide is not considered because the silver oxide is superior in all points.	

Reduction to 0°C

-	Lithium cells product 75% normal capacity or 2.4 A hours are required. Now a 3/4 C cell would do and a 5 cell pack would weigh 180 g.	Capacity Gain 5.2 - 2.4 = 2.8 A hour

- Alkaline cells produce 60% normal capacity and 3 A hour will do. A C cell battery is adequate. 10 cells weigh 650 g except all resistance is too high D cells are still required.	No Advantage
- Gell cells produce 85% normal capacity and 2.1 A hour will do. 2 GC626 packs are required and weigh 820 g.	4.5 - 2.6 = 1.9 A hour
- NiCd cells produce 100% normal capacity but performance drops at 55°C.	3.6 - 2.25 = 1.35 A hour
- Silver oxide produces 70% normal capacity or 2.7 A hour is adequate. There is not cell constructed in this range. The 12.5 A hour introduced for -20°C operation will give extended service.	

5.2 Transmitted Power Reduction

Reduce output power to:

		Capacity Advantage
2 watts	- peak current = 600 mA - 48 hr capacity = 1.2 A hour	1.8 - 1.2 = 0.6 A hour
1 watt	- peak current = 300 mA - 48 hr capacity = 1.0 A hour	1.8 - 1.0 = 0.8 A hour

6.0 CUSTOM BATTERY

A custom battery could be implemented to be critically sized to the radio. A design of this package would not be undertaken until the load is "cast in stone" so to speak.

Setup costs: Custom dies @ $15,000 ea
minimum 4 required 4 (15 x 10^3) =
$60,000

Other costs: Material = equivalent to a hybrid battery
Type approval - D.O.T., F.A.A., etc.

Economics of scale do not begin to apply until a quarter million units are sold.

7.0 OBSERVATIONS

Given the existing temperature range and output requirements, the Lithium Sulphur Dioxide battery is clearly the best option.

Reducing output power reduces power demand by 0.8 A hour to 1.0 A hour.

Reducing the temperature range by increasing the low limit temperature reduces battery size and weight and introduces new options.

Alkaline batteries are feasible only if both the low temperature and high temperature limits are relaxed.

An inherently improved battery (Lithium iodine) is expected on the market within 1984 eliminating cause for concern of venting corrosive gas into the beacon.

8.0 BATTERY TESTING

8.1 Objective

A Lithium Sulphur Dioxide battery pack was tested at cold temperatures. The objective was to obtain low duty cycle pulsed load characteristics.

8.2 Cold Battery Test Set-Up

Electronics Module	P/N 606-90001-1 S/N 83-09-005	B.A.L.
Battery Pack	P/N ED 1192 S/N N/A	Eternacell
Chart Recorder	P/N 7404A S/N 1740A00663	H.P.
Input Amplifier	P/N 17401A S/N 1617A05728	H.P.
Ammeter	P/N 8 MkIII S/N P.O. 79167	Avometer
Current Probe	P/N P63021AM503 S/N 100	Tektronics
RF Power Meter	P/N 4381/10D S/N 2616	Bird
RF Power Load	P/N 160-20FN S/N 5306	Sierra

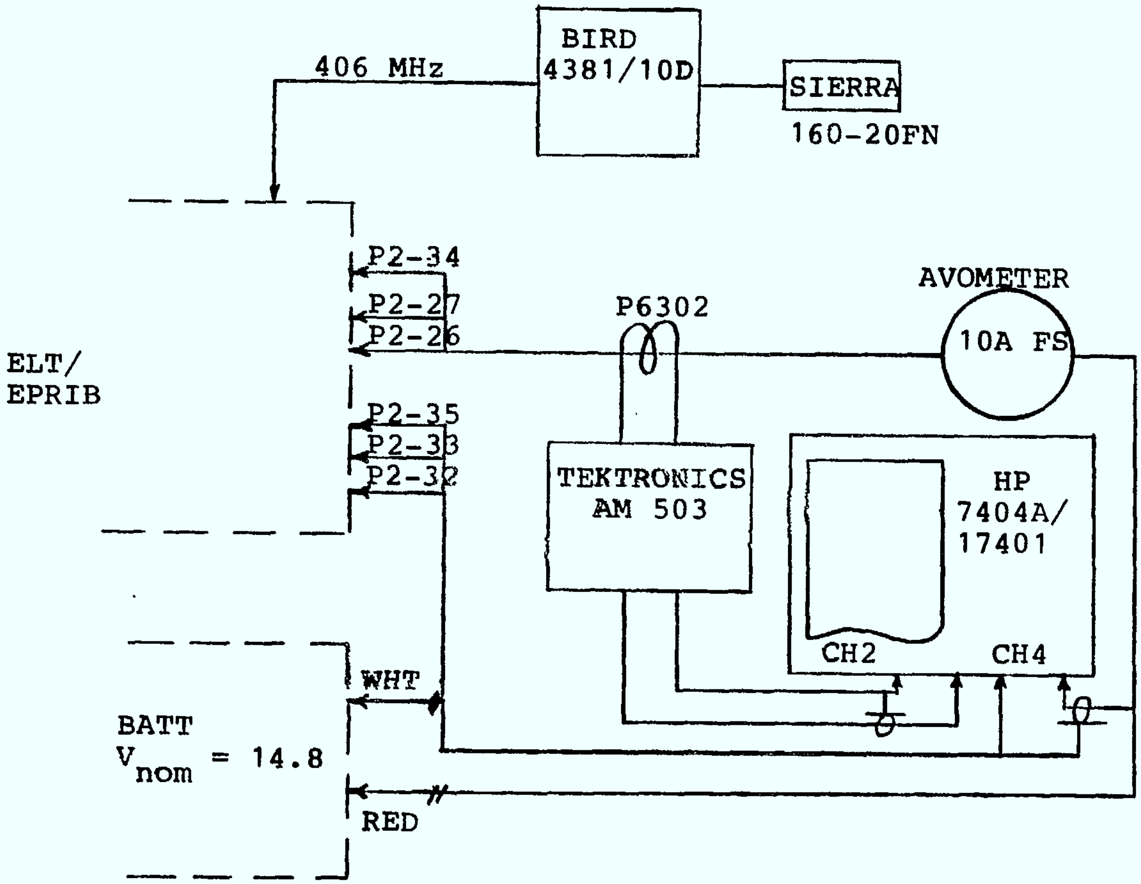


FIGURE 1: TEST SET UP

8.3 Cold Battery Test Procedure

The Electronics Module and Battery Pack were placed into an environmental chamber at -42°C for 1 hour. The harness and test set were then connected to pre-calibrated instruments as shown in the previous section.

The chart recorder was run for short periods at various times in the test coinciding with suspected milestones in the test.

The beginning of the test was recorded and subsequent recordings were taken at 4 hour intervals until about midnight and then commencing at 8:30 a.m. on subsequent days. Finally, the closing hour of the test was recorded.

Each recorded sample contained several transmit pulses with the chart running at low speed (5 mm/min) then one with the paper running at high speed (50 mm/sec).

The electronics module was configured to transmit a 406 MHz coded distress signal into a dummy load and an unmodulated 121.5 MHz locator beacon into an open circuit.

Ph indicating paper was introduced at the end of the test in an effort to detect corrosive by-products from the test.

8.4 Cold Battery Test Results

On start of test the voltage followed the slow start curve expected from long term storage but rose to 14.5 V in less than 20 sec.

The voltage dropped to 11 V on transmit 406 for the first several hours then slowly increased to 13 in 15 hours and 13.3 in 48. The idle state voltage remained substantially unchanged. This indicates a gradual reduction of internal resistance with use. It is unclear if this is due to cell heating as a result of the low duty cycle mass overload (36 times max continuous) or due to electrode/electrolyte stabilization. This could be determined by storing the battery at high temperatures (85°C) for an extended period and repeating the test at room temperature for 5 or 6 hours.

At the start of the test, voltage depletion during the overload cycle was detectable but not significant (crossed the width of the line on 200 mV/div'n) --- about 25 to 50 mV. At the end of the test this factor was more pronounced and, measured on expanded scale, was 100 mV.

It was deduced then that the ΔV on start of overload was an indication of cell resistance and ΔV over the overload duration is a measure of cell capacity. Since capacity at -40°C is 33% of capacity at 25°C, the amp hour rating must be derated to 2.6 from 8 for the sample. This indicates that increased voltage depletion could be expected in the overload at the end of the test where 1.4 Amp hours have been consumed or the battery is half discharged.

The wetted pH indicator paper introduced to the chamber and the experimenter's "sniff test" at end of cold cycle detected no SO_2 gas or acidic deposits.

Presented in Table 1 is the battery voltage readings taken periodically during the test. Vo was taken when the 406 transmitter was in standby and the 121 transmitter was operating. V406 was taken at the beginning of a 406 transmission.

Presented in Figures 2 and 3 are battery voltage and current chart recordings taken at the end of the 48 hour test.

TIME	BATTERY VOLTAGE		CHAMBER
	Vo	V406	TEMPERATURE
0 hours	14.1	11.2	-42°C
0.5 hours	--	11.4	-42°C
16.8 hours	14.6	13.0	-42°C
24.0 hours	14.6	13.2	-42°C
25.5 hours	14.6	13.2	-42°C
41.0 hours	14.7	13.3	-42°C
44.4 hours	14.6	13.3	-42°C
48.0 hours	14.8	13.2	-42°C

TABLE 1 - BATTERY VOLTAGE

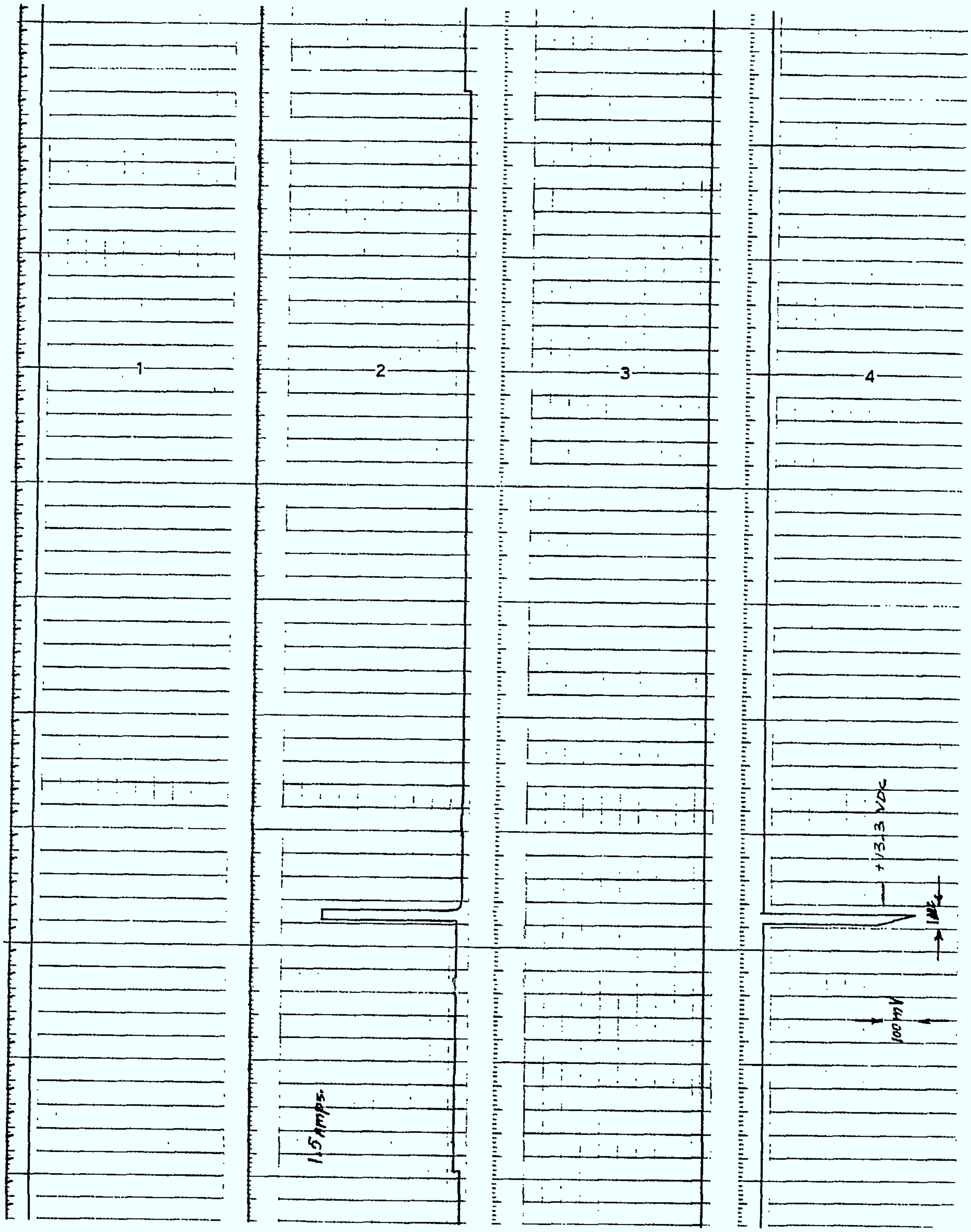


FIGURE 2 - VOLTAGE AND CURRENT CHART RECORDING

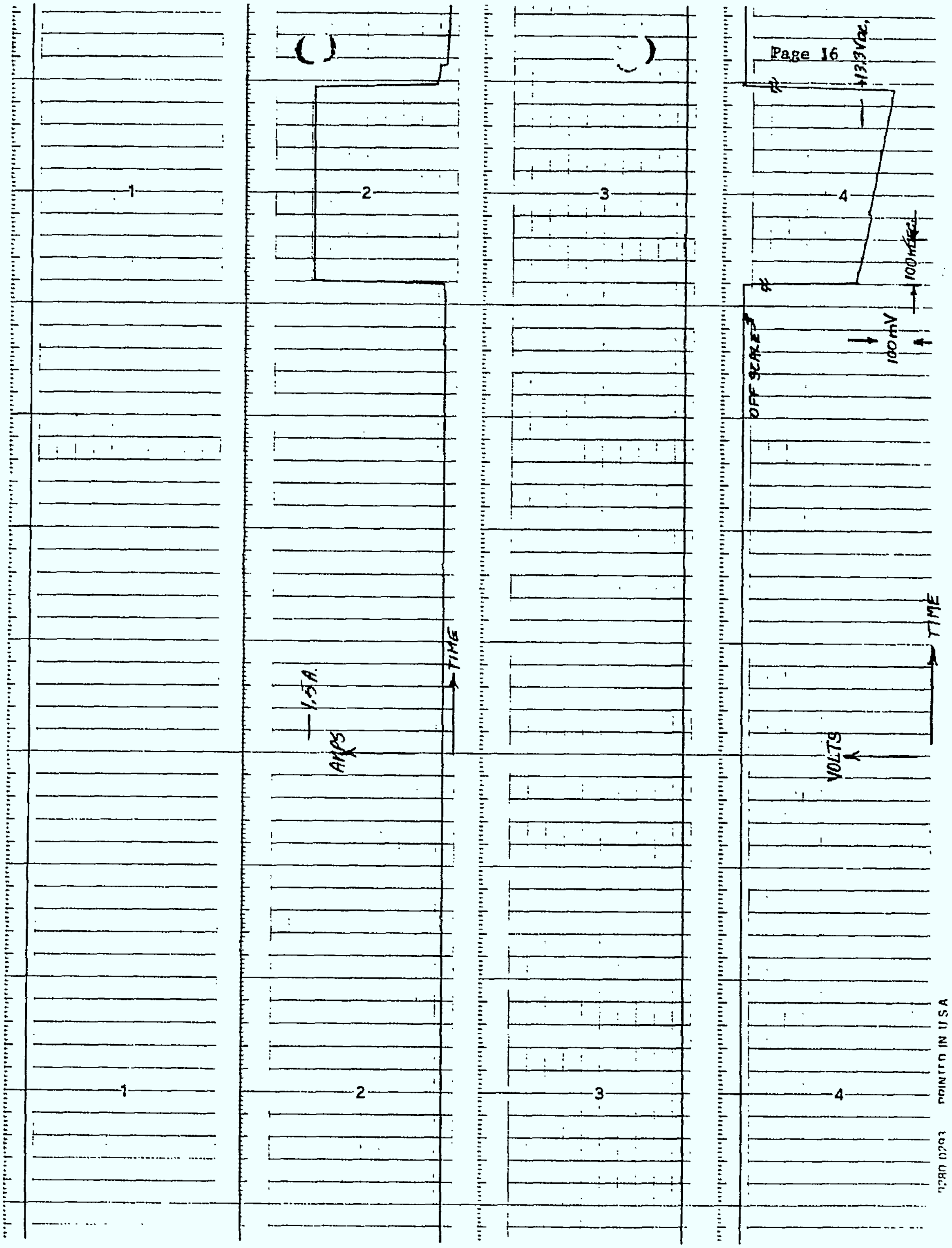


FIGURE 3 - VOLTAGE AND CURRENT CHART RECORDING (EXPANDED TIME SCALE)

8.5 Conclusions

The sample battery has a reserve capacity of about 1.2 A hour of which about 60% is usable. If the excess capacity is programmed to operate an oven, it could draw up to 15 mA continuously.

The sample battery's high internal resistance, which improved over the duration of the test, did not drop the operating voltage below the 10 volt threshold required for reliable operation.

The chemistry of the cells of the sample battery is such that SO_2 is free in the charged state and any leakage will expose the atmosphere to corrosive gases. While the probability of pressure relief exhausting large amounts of the gas is not significant, its debilitating character to the electronic circuitry in small amounts over extended periods is a concern which must be addressed. Separate packages would be adequate protection.

APPENDIX C

PACKAGING STUDY

TABLE OF CONTENTS

1.0 PACKAGING METHODOLOGY SELECTION

Three methods of packaging will be discussed. The outcome of which will be one method, where upon that method will be discussed in more detail. At present there are three approaches to electronics enclosure making, extruded or drawn cup boxes, sheet metal forming and plastic cases.

1.1 Die-Cast Aluminum

Die-cast aluminum boxes are the heaviest of all enclosures. The rigidity obtained by using die cast aluminum boxes often does not compensate for the weight and ease of manufacturing penalties. A die cast case is approximately three times the cost of a formed case.

The tooling cost for aluminum die cast boxes is somewhat higher than tooling cost for plastic boxes. The finished cast dimensions are not as predictable as in the case of most plastic materials. For example, dimensional accuracy for polycarbonate is ±0.002 in/in yet for die cast box, a tolerance of ±.10 in. over a length of six inches is not uncommon.

1.2 Formed Aluminum

Forming sheet aluminum boxes would result in lighter weight products. Because of the secondary mounting arrangements in order to hold various components such as battery pack, printed circuit board assemblies and input/output ports, the packaging is costly if not expensive. A usual rule of thumb is labor cost including forming is 10 times the material cost, depending on design, assembly techniques, material types and so on.

The resultant joints of a folded box usually do not provide adequate noise shielding to or from signal electronic equipment. As a result, sealing up the joints calls for secondary operations. Brazing may give the lowest cost of the exothermic fusing approaches, riveting is a quick way of mechanical fastening yet they all suffer from the same symptom as being labour-intensive.

To hold subassemblies inside the enclosure, brackets or similar mounting means are required. This in turn adds part count, assembly labour and possibly more errors. Another drawback is the requirement to surface finish the enclosure. An aluminum box, even without welded seams, still looks esthetically poor when compared to a nicely colored and finished plastic enclosure. To add finish onto the bare aluminum box adds another round of secondary operations which could price the aluminum case out of the competitive market place.

The only benefit in choosing sheet metal forming approach in terms of manufacturing economy lies in the quantity of production. If the quantity required is quite low, custom die cast aluminum box and plastic injection molded box due to their high initial mold costs will not be able to compete with formed sheet metal box. In our application here, the quantity projected is high enough to warrant the mold costs, therefore formed aluminum sheet metal approach is not recommended.

1.3 Molded Plastic

The high impact plastic injection molded enclosure offers the best solution in terms of all the required characteristics. Due to the initial tooling cost involved in making up the molds, a reasonable quantity of enclosures is required to justify the initial tooling costs. However, once the mold is done, the production stage is fairly straight forward. The injection molded parts can be designed to save many secondary subassembly operations. For example, most of the holes for mounting PCB, battery pack and so on, can be built into the case. Some processors can put in the screw inserts at the same time the case is made thus enabling appreciable savings.

The following is a list of advantages of plastic cases.

- Lower cost
- lightness
- reduction on secondary operations resulting in lowest overall assembly cost
- high precision part
- customer appeal.

2.0 INJECTION MOLDED PLASTICS

The purpose of this section is to present background information on injection molding, polycarbonate plastic, and methods of integral shielding.

2.1 Injection Molding

Injection molding is a process where melted or plasticized thermoplastic material is injected or forced into a cool mold where it chills enough to be removed in a solid state, duplicating the cavity of the mold. The mold may consist of a single or more cavities, each connected to flow channels or runners which direct the flow of the melted plastic to the individual cavities. The process is one of the most economical methods for mass producing a single item. The part removed from the mold is, in most cases, a finished product ready to be packed and shipped, or ready to be used as a part of an assembled unit.

In contrast to metal forming, there is very little if any wasted material in injection molding. Runners and sprues can be reground and reused. By using hot runner molds, the sprue and runner system remain in a melted state in the mold and become part of the next finished part. The hot runner can be considered an extension of the plasticizing chamber. Usually the part can be designed so there is no subsequent machining required. If this is not possible for a certain design, conventional cutting tools can be used, although some modifications of the cutting tip and periphery speeds are usually required to prevent a buildup of heat.

Materials having all shades of coloring can be purchased, or colourants can be premixed with clear pellets, to obtain a desired color. Post formed coloring process is eliminated and the color exists throughout the entire part.

Plastic material usually is purchased in pellet form, and heated in the injection heating chamber until it reaches a viscose state in which it can be forced to flow into mold cavities. Each plastic differs in its ability to flow under heat and pressure. For the best result, correct melting temperature, injection pressure and plunger speed must be determined by trial for the particular plastic and mold used. Some molding conditions require that both the speed and injection pressure vary during the filling process. A heat sensitive plastic may be degraded if too fast a fill rate is used. Forcing the plastic through orifices at too high a velocity increase the shear and temperature enough to cause overheating and burning. On the other hand, these walled parts required a fast fill rate to prevent chilling of the plastic before the cavity has properly filled.

In selecting the size of the injection molding machine and mold, economy plays an important role in determining whether a single or multiple mold should be used. Production rates, size of machine available, mold cost, part weight, etc. must all be taken into consideration to arrive at the best configuration of mold and machine. The general clamp size requirements are based on the number of tons/sq. in. of projected cavity area. Other factors such as wall thickness, type of material to be processed, mold runner and gate design will all affect the machine sizing estimate. High injection rates and lower viscosity materials both result in better fill characteristics and lower fill pressure.

The shot size and plasticating rates will determine the size of injection unit. A rule of thumb figure is to restrict the maximum shot size to 70% of the injectors' rated capacity to insure superior melt quality.

The cycle time, molding cycle and anticipated production rate requirement will determine the plasticating rate. Correct injector size can be selected after the throughput rate is found based on the manufacturers' plasticating specification sheet.

From mold making point of view, a shallow mold is easier to work on than a deep mold. For molded piece ejection, a normal rule of thumb is 1° draft angle. Generally speaking, mold making on deep and thin cases are much harder to make, thus die cost will increase predictably too. As the travel of the movable platen is long, there are a few drawbacks worth mentioning:

- The process cycle will be longer, thus the manufacturer's process cost will be higher.
- Heat loss along the plastic runner is increased, the cooled down hot plastic will affect the finish appearance, increasing rejects. To overcome this, the mold has to have more heat bands along the way, resulting in higher mold cost again.
- Even with the remedy efforts of heat bands, the chance of getting rejects is still great.

A typical molding cycle is as follows: The machine operator closes the safety gate, located at the clamp and mold area. This will activate the various circuits and inter-locking devices as the molding cycle begins. The clamp moves forward closing the mold halves and builds sufficient force to hold the mold halves closed against the high pressure injection of plastic melt into the mold cavity. When clamp tonnage builds to a preset value through a sensor, the injection sequence begins. The molten plastic is forced into the mold cavity by a forward moving plunger. The pressures are very high at this first stage. This is required to fill the mold cavity completely before the melt begins to cool. Pressure during this first stage can be as high as 30,000 psi.

After the cavity is almost filled the plastic pressure and fill rate are reduced substantially to make final filling. When the fill gate is cooled and solidified, the injection pressure is relieved.

The screw in the injection unit now begins to plasticate material for the next cycle. As the mold is sufficiently cooled the clamping mechanism begins to open the mold.

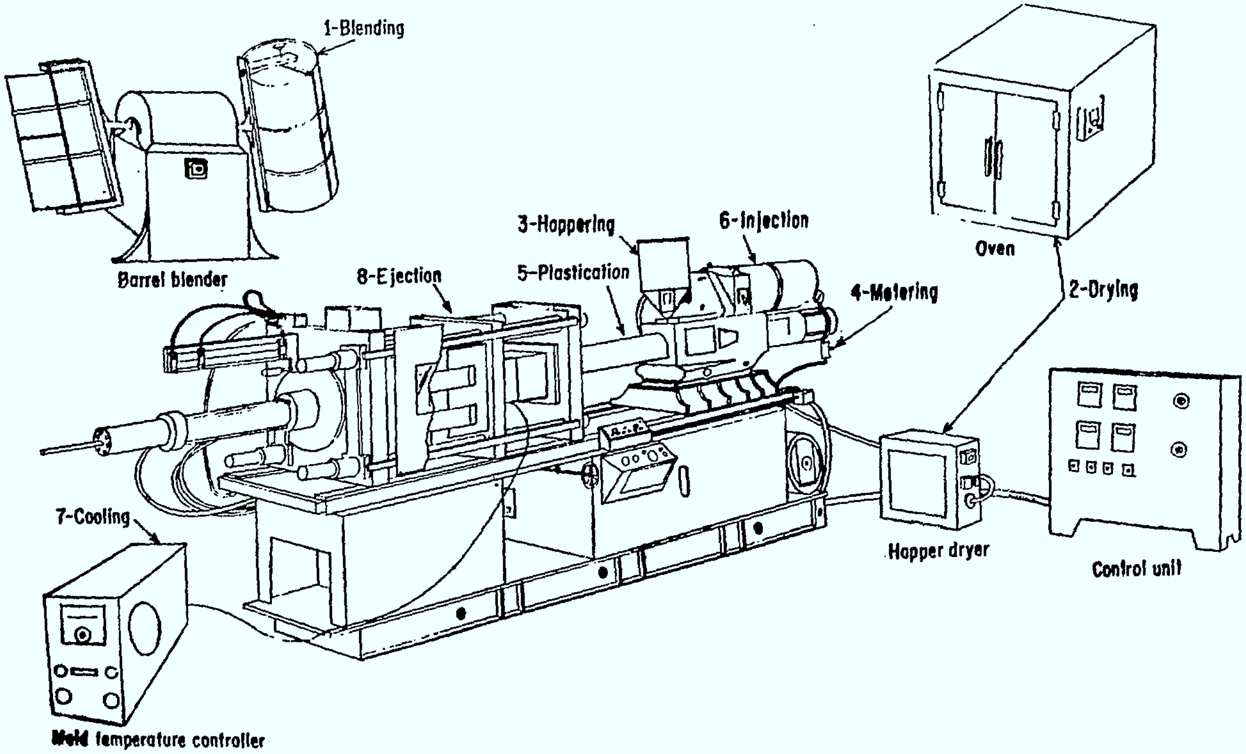


FIGURE 1: OVERVIEW OF INJECTION MOLDING MACHINE

The molded part normally remains on the moving platen when the mold is opened. Along in the retracting cycle the ejector pin within the mold will move forward to knock out the molded part automatically. The molded part will then drop onto a conveyer for the stripping operation, where flashes and runner gates will be removed and reground for future injection cycle. The whole injection process may be semiautomatic or automatic, the recycle of the machine is controlled by preset automatic timer.

The clamping systems can be one of the three designs: full hydraulic, mechanical and hydromechanical. Each system has its own merits and demerits.

2.2 Polycarbonate Characteristics

The increase in the cost of metal, combined with ever increasing cost for labor in such processes as finishing, coating and assembly have made the polycarbonate very attractive in large volumes. Polycarbonate, with its broad range of excellent properties is one of the materials considered as a metals replacement.

The use of value analysis survey to compare total costs as compared to "piece" or "part" costs have helped polycarbonate gained acceptance. The experience of weight and secondary operations savings by using polycarbonate has already put polycarbonate ahead of zinc die castings or other metal parts.

Polycarbonate provides a combination of transparency, remarkable toughness, heat resistance, dimensional stability and flame resistance. One example of its use is in making hard hats. Except in the presence of stress raisers such as sharp corners, it is extremely difficult to break polycarbonate.

Polycarbonates are polyesters of carbonic acid, which are derived from dihydroxyl compounds in which the hydroxyl groups are attached directly to aromatic rings.

Various starting materials can be used for the preparation of polycarbonate copolymers from aromatic dihydroxy compounds, such as hydro-quinone, dihydroxydiphenyl alkanes, dihydroxy - ciphenyl sulpoxide or sulfare, and the ring halogenerated or alkylated, compound derivatives.

Polycarbonate has a very good impact strength characteristic. Despite the rigidity of polycarbonate, it is not brittle. Using the standard I_{zod} impact test, 1/8 in molded polycarbonate bars gives values from 14 to 17.5 ft lb/in. of match which is higher than for most thermo-plastics. This transition occurs between 0.150 and 0.250 in of thickness. I_{zod} impact values using ASTM D-256 over a wide temperature range are shown.

The thermal stability of polycarbonate is excellent. It is known that polycarbonates have been molded at temperatures in excess of 625°F without reflecting symptoms of the occurrence of significant degradation of polymer.

Polycarbonate has good electrical properties which change only slightly over a wide range of temperatures, humidities and frequencies.

The following is a summary of advantages in using polycarbonate:

- Production tolerance0.002 in/in
- lightness
- rigidity
- creep resistance
- high heat resistance
- dimensional stability
- good electrical properties
- self extinguishing
- exceptional impact strength.

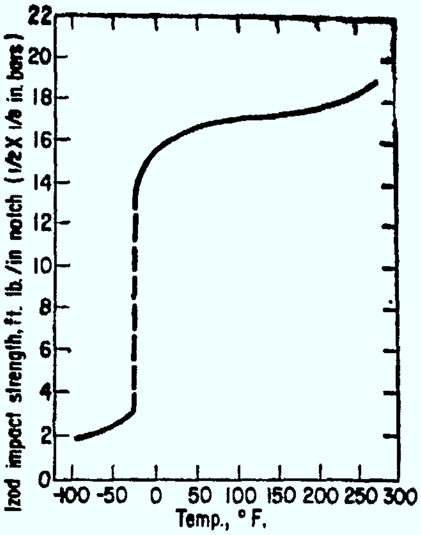


FIGURE 2: I_{zod} IMPACT STRENGTH VS TEMPERATURE

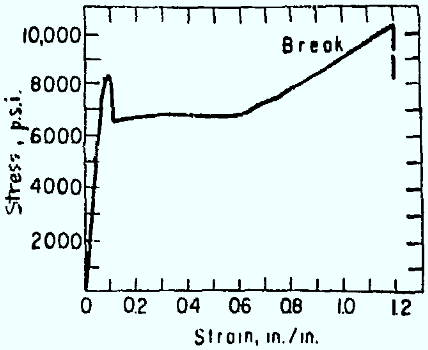


FIGURE 3: STRESS - STRAIN

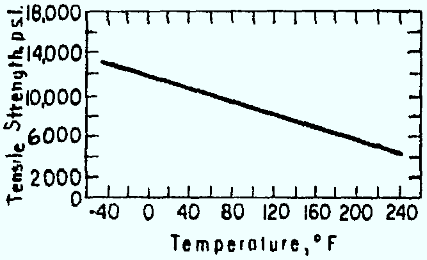


FIGURE 4: TENSILE STRENGTH VS TEMPERATURE

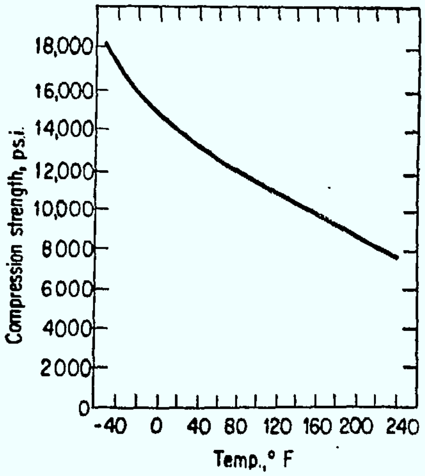


FIGURE 5: COMPRESSION STRENGTH VS TEMPERATURE

Materials					Polycarbonate				
					Unfilled molding and extrusion resins			Glass fiber-reinforced	
		Properties		ASTM test method	High-viscosity	Low-viscosity	PC-ABS alloy	10% glass	30% glass
Processing	1	Melting temperature, °C	T_m (crystalline)						
			T_g (amorphous)		150	140	150	150	150
	2	Processing temperature range, °F (C = compression, T = transfer, I = injection, E = extrusion)			I: 560	I: 520	I: 490-500 E: 450-485	I: 520-650	I: 560-650
	3	Molding pressure range, 10^3 p.s.i.			10-20	8-15	8-25	10-20	10-30
	4	Compression ratio			1.74-5.5	1.74-5.5			
	5	Mold (linear) shrinkage, in./in.		D955	0.005-0.007	0.005-0.007	0.005-0.009	0.002-0.005	0.001-0.002
Mechanical	6	Tensile strength at break, p.s.i.		D638	9500	9500	7000-7300	9500	19,000
	7	Elongation at break, %		D638	110	110	10-15	5	3-5
	8	Tensile yield strength, p.s.i.		D638	9000	9000	8500		
	9	Compressive strength (rupture or yield), p.s.i.		D695	12,500	12,500	11,000	13,500	18,000
	10	Flexural strength (rupture or yield), p.s.i.		D790	13,500	13,500	13,000-13,700	15,000	23,000
	11	Tensile modulus, 10^3 p.s.i.		D638	345	345	370-380	500	1250
	12	Compressive modulus, 10^3 p.s.i.		D695	350	350		520	1300
	13	Flexural modulus, 10^3 p.s.i.	73° F	D790	340	340	300-400	500	1100
			200° F	D790					
			250° F	D790					
			300° F	D790					
	14	Izod impact, ft.-lb./in. of notch (⅛ in. thick specimen)		D256A	16 @ ⅛ in.	14 @ ⅛ in.	10.5	1.2	2.0
	15	Hardness	Rockwell	D785	M70	M70	R117	M75	M92
			Shore	D2240					
Thermal	16	Coef. of linear thermal expansion, 10^{-6} in./in./°C		D696	68	68	83-67	38	22
	17	Deflection temperature under flexural load, °F	264 p.s.i.	D648	270	270	220-240	288	295
			66 p.s.i.	D648	280	280	225-250		305
	18	Thermal conductivity, 10^{-4} cal.-cm./sec.-cm.^{2}-°C		C177	4.7	4.7	6-9	4.8	5.2
Physical	19	Specific gravity		D792	1.2	1.2	1.12-1.20	1.27-1.28	1.4
	20	Water absorption (⅛-in. thick specimen), %	24 hr.	D570	0.15	0.15	0.21-0.24	0.15	0.14
			Saturation						
	21	Dielectric strength (⅛ in. thick specimen), short time, v./mil		D149	380	380	450	530	475

FIGURE 6: POLYCARBONATE PROPERTIES

2.3 Integral Shielding

There are three basic methods for integral shielding of plastic cases. These methods are vacuum plating, fibre filler, and spray.

The plating approach for shielding is not the most practical one. Due to the cavity on the molded pieces, there is a tendency that uniform plating thickness may not be achievable with the process. Another problem area is due to lack of qualified vacuum plating firms locally that in turn raise the cost of transportation as well as prolonged turn-around time.

Two alternate routes are being investigated. One is to use metal fibre fillers during injection molding stage. This process will undoubtedly give the best result in terms of EMI shielding. The cost is compatible to plating with out-of-town secondary plating process. There are various metallic fibres available in the market of which the ones with 70 dB shielding effectiveness will be suitable for the use.

The other alternative is to use spray coating to the required thickness. Again with the inside corners, the end result may not be as good as molded-in metal fibre process. The 2 mil coating of a nickel/acrylic composition provides a maximum sheet resistance of 1 /sq. The thicker the spray coating, the better the conductivity therefore better shielding. Graphite can also be used for spray coating. The major drawback with painting and other methods of depositing shielding materials on the enclosures is the inconsistency of paint specifications which result into unacceptable shielding uniformity. Such inconsistencies arise while cleaning and preparing the case prior to painting, in the mixing of the spray (both in terms of material ratio and degree of blending) and when attempting to deposit a uniform and repeatable spray coating on the enclosure. The incorrect handling of coated enclosures also may create problems.

3.0 DESIGN CONSIDERATIONS

The purpose of this section is to present background theory and design guidelines to be considered during package design. The areas discussed will be shock, vibration, and electromagnetic shielding compatibility.

3.1 Shock & Vibration Analysis

Shock is normally specified as the ability to perform after a number of shocks of a specified value and impulse time duration. The shocks are applied along each of the three mutually perpendicular axes.

Generally speaking shock is regarded as the application of a large force in a short period of time. From the theory of impulse we know that an object can momentarily remain in its position in space while the velocity of its parts change appreciably. The dynamic description of the resulting motions and forces and the establishment of suitable structures to withstand these motions and forces safely constitute the shock design problem.

Vibration is normally specified by a frequency in cycles per second coupled with a double amplitude in inches. The amplitude varies with frequency, the vibration requirements are normally given as a curve or series of curves. MIL-E-5400 provides three vibration curves (shown in figure 7). For example, the vibration requirements of an aircraft is in the medium range which is below 500 cps. In vibration problems theoretical infinite amplitudes are possible if the structure is tuned to the excitation.

The amplitude ratio of the steady state response to the static response of the system is called magnification factor. This factor is a function of the frequency ratio w/wn and the damping factor .

w = forcing frequency of the system.

wn = natural frequency of the system in the absence of driving force.

ζ = system damping factor as a ratio of the existing damping C and critically damped C_c, $C/_{C_c}$ where C_c is defined as the least amount of damping required to cause a displaced mass to return to equilibrium without oscillation.

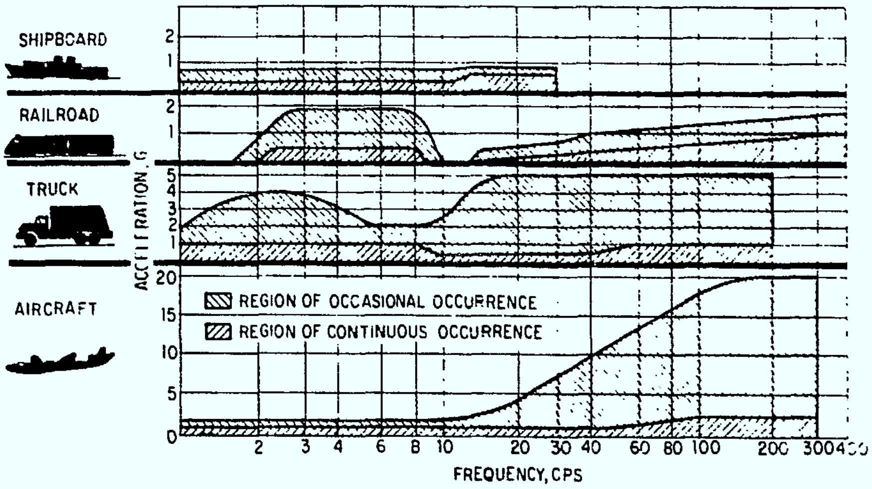


FIGURE 7: TRANSPORTATION VIBRATION SPECTRA

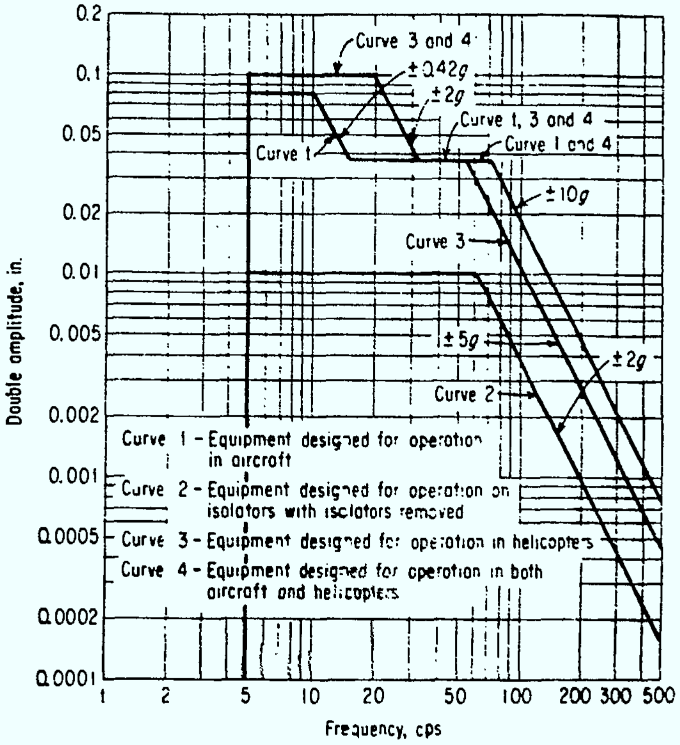


FIGURE 8: VIBRATION REQUIREMENTS

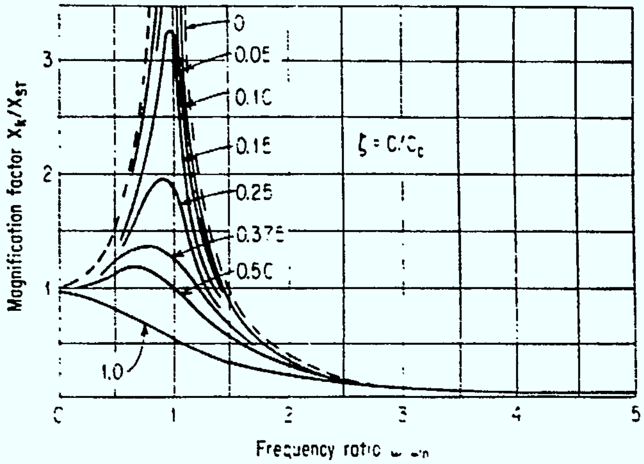


FIGURE 9: MAGNIFICATION FACTOR

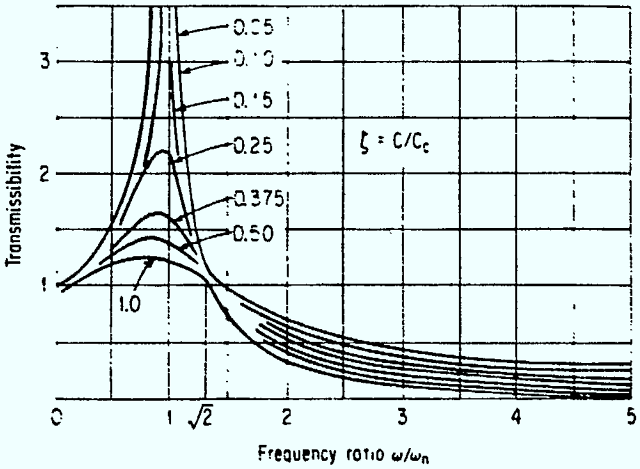


FIGURE 10: TRANSMISSIBILITY

At extremely low forced frequency, i.e. $w \cong 0$, the system will be deflected by only the static force. Hence the amplitude is nearly equal to unit for the very high forcing frequencies, $w/wn \gg 1$ the force oscillates so rapidly that the system simply has no time to follow and the amplitude is very small. At $w/wn = 1$, the forced frequency coincides with the natural frequency resulting in extremely large amplitude theoretically infinite. When the natural frequency is equal to the forcing frequency, it is called the resonant frequency by which a small force applied can make the amplitude very high.

The ratio of the transmitted force to the disturbing force is called transmissibility as shown in Figure 9. When $w/wn = \sqrt{2}$, $T = 1.0$. For $w/wn < \sqrt{2}$ the transmissibility is less than 1. In order to isolate the disturbing force, w/wn should be greater than $\sqrt{2}$. This phenomenon is called vibration isolation.

The primary object of a good shock design is to transmit rather than absorb disturbing energy. Second in line is to attempt to build any structure stronger and stiffer than the structure that supports it, thereby resulting in rigid-body response under shock. In our case, the PCB assembly is a subsystem with the plastic case as the supporting structure. The PCB assembly will follow the motion of the case if the mounting is stiff enough. This arrangement will ensure little relative motion in the subsystem and as a result the disturbing force would not generate additional shock further down the line. As a third rule, the hardware should be as hard as possible and as light as it can be. Greater shock reliability is obtainable by th use of stiff structure for support with natural frequencies above 35 cps, than with flexible supports which have lower than 35 cps natural frequencies.

fr (resonant freq) for PCB fixed mtg: with respect to length of mtg centre.

$$fr = \frac{k}{4\pi L^2}\sqrt{\frac{Eh^3g}{3W}} \qquad \text{Resonant Frequency}$$

$g = 386$ in/sec^2 Gravitational Constant

$k = 22.5$ Support Constant

$E = 1.8 \times 10^6$ psi modulus of elasticity

$h = 0.062''$ thickness

$W = 0.016$ psi, wt/in^2

L = length in inch = 2" centres

$$fr = \frac{22.5}{4\pi \times 2^2}\sqrt{\frac{1.8 \times 10^6 \times .062^3 \times 386}{3 \times .016}}$$

$$= 830 \text{ cps}$$

fr for PCB with fixed mtg centre with respect to Sag.

$$fr = \frac{1}{2\pi} \sqrt{\frac{g}{sag}} \qquad fr = \frac{1}{2\pi} \sqrt{\frac{k}{m}}$$

$g = 386 \text{ in/sec}^2$

$sag = .005 \text{ in}$

$$fr = \frac{1}{2\pi} \sqrt{\frac{386}{.005}}$$

$$= 44 \text{ cps}$$

$$T = \frac{1}{1 - (f/fr)^2}$$, Assuming No Damping

T = transmissivity

f = freq. of vibration cps for airborne operation, 400 cps

fr = resonant freq. cps, use 830 cps

$$T = \frac{1}{1 - \frac{(400)^2}{(830)^2}}$$

$$= 1.30$$

The g level which the PCB sees is 1.30 times as great as the g level applied to the unit. In this case, it is 50 g in three planes, i.e., 1.30 x 50 = 65 g to be experienced by the PCB assembly.

3.2 Electromagnetic Shielding Compatibility (EMC)

Electromagnetic Compatibility (EMC) is the ability of an electronic system or subsystem to reliably operate in its intended electromagnetic environment without either generating electrical noise or responding to external electrical noise. Electromagnetic Interference (EMI) is the impairment of the performance of an electronic system or subsystem by an unwanted electromagnetic disturbance. Electromagnetic Compatibility (EMC) is achievable through the reduction of the electromagnetic interference to below the level that disrupts the proper operation of the electronic system. Line filters and equipment shields normally are employed to accomplish this compatibility.

An EMI emitter is a system which generates electrical noise whereas EMI susceptor is a system which responds to external noise. The SARSAT Beacon is a system when in operation exhibits both emitter and susceptor characteristics. The RF circuit inside the enclosure radiates high frequency electrical noise, this noise will cause intermodulation with the surrounding circuits and interference with the nearby equipment outside the SARSAT Beacon.

On the other hand, communication signals, especially signals from RADAR at close proximity, will generate electrical noise which will interfere with the SARSAT Beacon functioning.

Designing out electromagnetic emissions and susceptibilities characteristics is difficult. A number of specific areas where precautions can be taken during design stage can increase the systems electromagnetic compatibility (EMC). Notably are component selection and placement, circuit board layout and grounding techniques at board level design.

Our discussion will be centred on excluding external undesirable signals and entrapping of internally generated signals. Shielding is the principle means of achieving both desired functions. In using the mechanics of reflection, re-reflection and absorption, acceptable levels of electromagnetic compatibility can be obtained. The amount of signal attenuation from a shield depends on the material used, shielding thickness, distance from the emitter and the emitter's frequency.

Two main approaches are being used presently to impart metal shielding properties to plastics. One is to apply metalized surface coatings to the interior surface of plastic enclosure. The other is to incorporate conductive filler in the molded plastic to behave like a shield.

The conductive coating approach is the most widely used at present. A variety of techniques such as zinc arc spray, flame spray, conductive paints, vacuum metalizing, electroplating, electrode plating, sputter coating and ion plating. Some processes are expensive due to the high costs of capital equipments involved, for others the coatings are operator dependent or highly directional. Special surface preparations are used sometimes because of fear of flaking. Also the ability of the coatings to withstand the extreme environmental changes over time. Their shielding effectiveness may be reduced due to corrosion or chemical reactions.

Another widely-used approach is the conductive filler impregnated into the molded plastic. Here the correctly mixed polycarbonate resin, color pigments and conductive fillers are all premixed before the molding process. The finished part will have all the desired characteristics, thus eliminating secondary operations such as surface preparations and coating process. Some of the more common filler materials are stainless steel fibres, aluminum flakes, carbon fibres, silver coated glass spheres and nickel coated carbon fibres. For very high frequency with low peak output, aluminum flakes will be sufficient. One reason for this choice is due to the loading requirement to achieve continuously conductive plastic walls as well as uniform filler distribution and shielding. Flakes and fibres with long aspect ratios are reported to require less loading than spheres and short fibre in arriving at continuous conductivity. Filler materials also can alter the mechanical properties of the plastic. Further study with regard to the correct choice of filler materials is essential before major commitment is made.

One advantage of conductive filler approach is the availability of processors locally whereas for conductive coating process, the enclosures have to be shipped out of town, thus adding transportation cost on top of the coating costs. Another drawback is the waiting period for the coating process, sometimes coupling with some unforeseen mis-timing can cause schedule problems. The economic penalty is obviously in a situation like this.

There is also one area which needs to be inquired further. The geometry of the enclosure may hinder acceptable interior coating due to the bends and corners. There are possibilities that corners become weak in terms of EMC, careful co-ordination among manufacturer, processor and raw material supplier will ensure trouble-free implementation of desirable electromagnetic compatibility. At present, the zinc arc spray and conductive paints are the two most dominant processes in the market for plastic EMI shielding.

Regardless of which process to use, plastic EMI shielding is adequate for our applications.

4.0 CONCEPTUAL PACKAGING DESIGNS

4.1 Presentation of Designs

Two styles of packaging emerge as a result of this study. From our study, a single PCB roughly the same size as five 'D' cells placed together is sufficient to accomplish the job. The most ideal layout would be with an enclosure where a 5 'D' cell battery pack placed at bottom and printed circuit board assembly mounted over the battery pack. Single board approach is advantageous both in terms of cost and manufacturing ease.

The common features of these two packaging styles will be discussed followed by the discussion of differing features.

The enclosure material is chosen as polycarbonate with 30% fibre glass filled for the dimensional stability, high impact resistance, self extinguishing, light weight and ease of secondary processes. The wall is chosen as .125 inch thick for the optimum impact resistance. With injection molding approach, the pilot holes for inserts are built in to install inserts, the only operation required is to use a punch press to push inserts into the pilot holes. The cavity for switch mounting is easily included in the enclosure. The mounting bosses are all built in features at the injection mold making level, thus saving appreciable time for locating and drilling operations. Also the loose parts count will be reduced to a minimum.

Battery compartment will be totally separated from the rest of the components thereby reducing the possibilities of corrosion on components. The battery terminals will be welded-lead construction as supplied by the manufacturer. The material for the battery terminals will be beryllium copper for the strength and the electrical conductivity.

The newer lithium batteries are coming with better outgassing features, according to the battery manufacturers. In any event, the SO_2 corrosion problems would not be as severe as before, also the compartmentized separation will reduce the SO_2 corrosion on all other components to a minimum. Because of the possibilities of moisture combining with SO_2 gas resulting in H_2SO_3 which is a very corrosive acid, waterproofing the end cap is deemed necessary. Waterproofing can be achieved by installing an "O" ring between the cover and case.

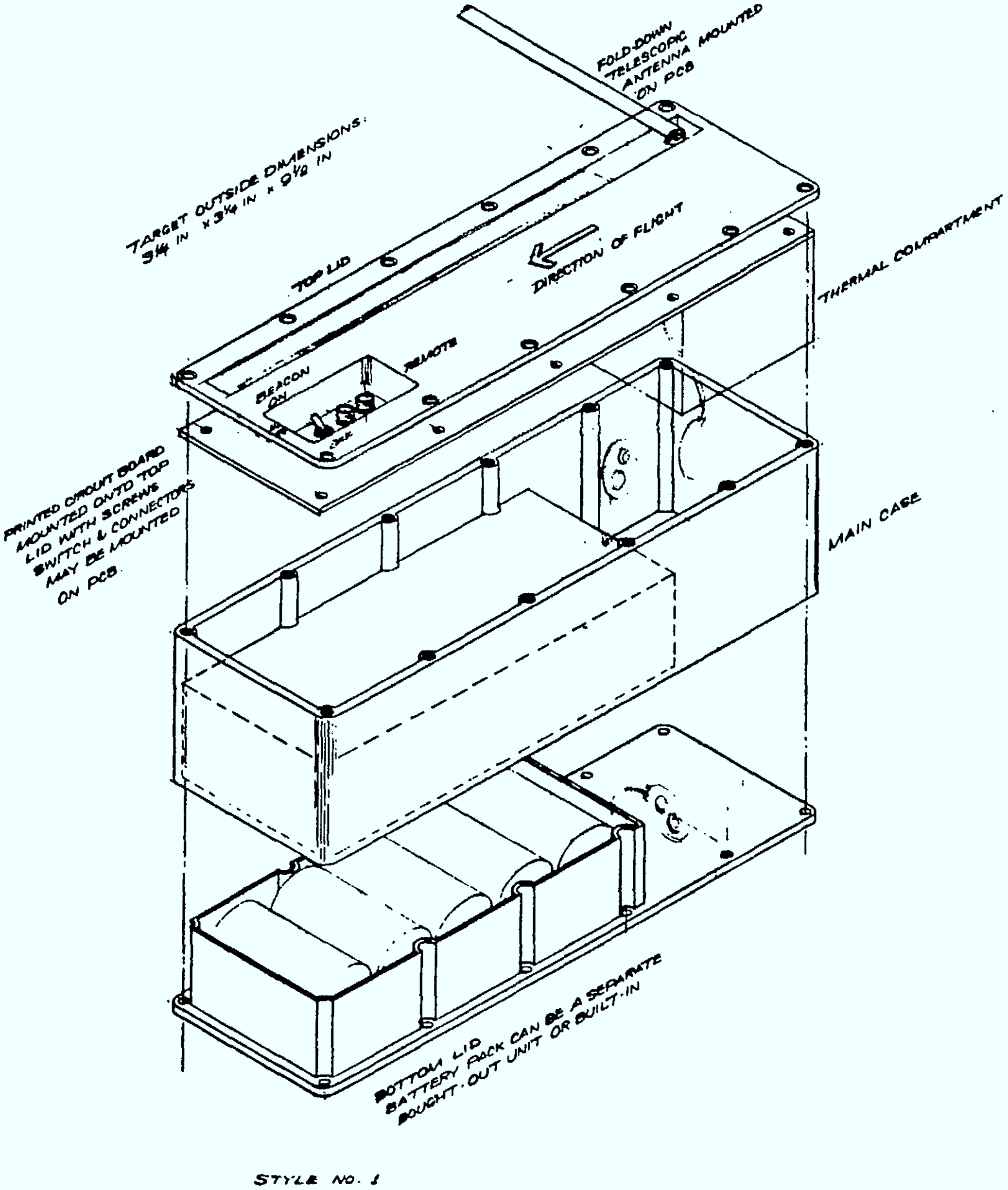


FIGURE 11: CONCEPTUAL DESIGN NO. 1

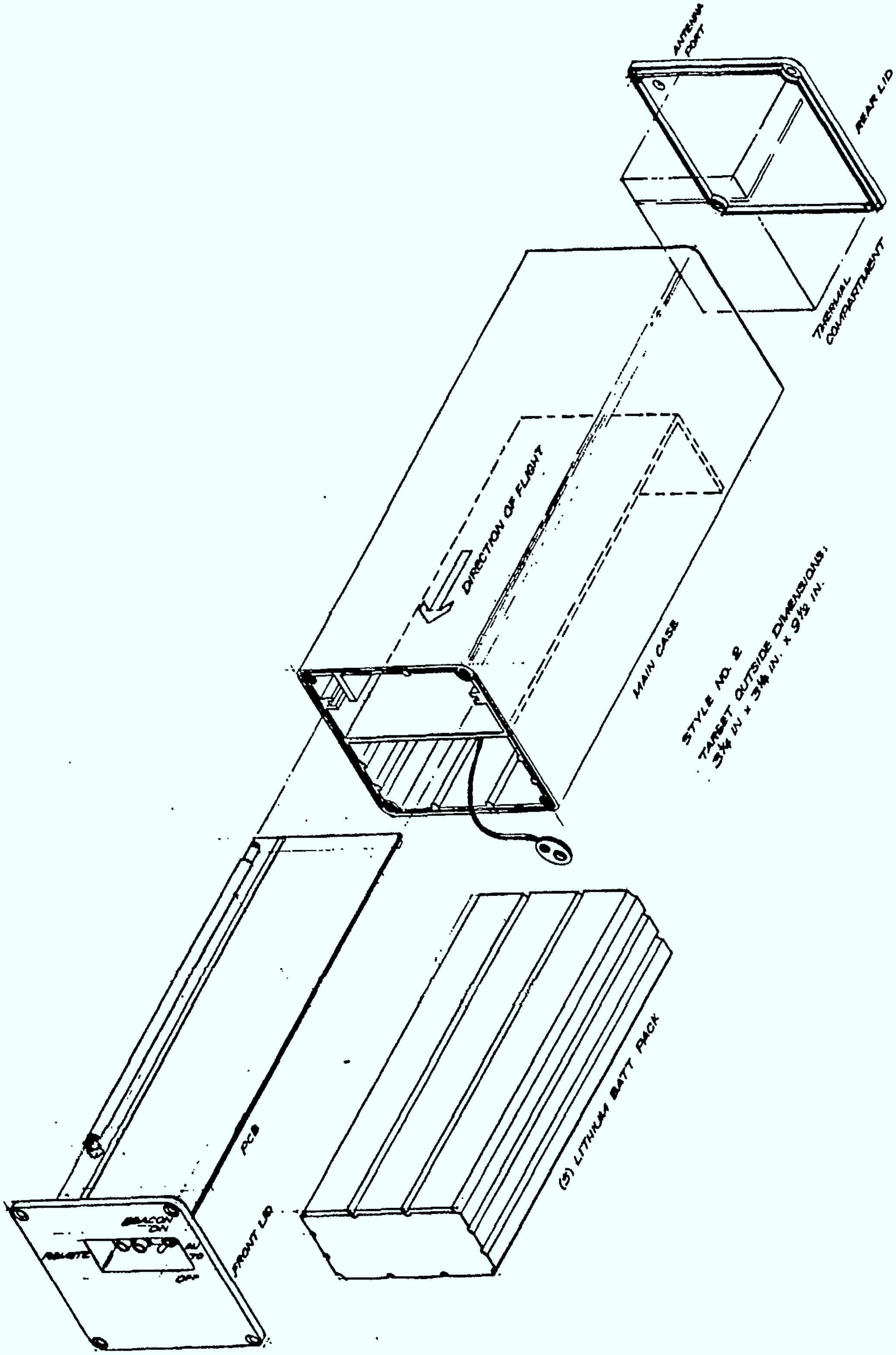


FIGURE 12: CONCEPTUAL DESIGN NO. 2

Design 1 comes with a basic case with top lid and bottom cover. The bottom cover has a built-in battery case where an off-the-shelf 5 'D' cell battery pack can be slid into place and locked in. The bottom cover is installed separately. The top lid comes with a slot for antenna protection when folded down for storage. There is also a pocket for switch and connectors used for remote control and antenna. The printed circuit board assembly will be mounted onto bosses molded on the top lid. The mounting spacing will be kept at optimum to give adequate rigidity. The flexing of printed circuit board is avoided, thus reducing the chance of component lead soldering cracking due to vibrational fatigue. By mounting the printed circuit board (3 in x 9 in) with 4 screws each row at 2¼ inch centre to centre distance, the board can be considered an integral part of the enclosure.

By mounting the printed circuit board rigidly against the enclosure lid, components such as toggle switch, LED indicator and RF output connector can all be mounted directly soldered onto circuit board. The respective holes will be prelocated and built into the lid with the accuracy of ± .002" for polycarbonate injection molded parts, the components locations, once correctly defined, will come out of the respective holes as the printed circuit board is being screwed down onto the bosses. The process is mass production oriented as all loose components are mounted onto one board. The individual hardwire soldering operation will be replaced by wave soldering. In terms of labour cost saving, it is quite substantial.

As for the power connection, a pair of printed circuit mountable small terminal blocks can give a fail safe connection, when the power cables come through the partition wall and into the terminal blocks.

The fold-down antenna can be a screw mountable type which will be screwed onto a printed circuit board at the right location. The enclosure lid will have a hole provided to allow the antenna to pass through. With the pivot arm at the correct height relating to the circular groove built in the enclosure lid, the antenna while not being used, can be collapsed and hidden in the groove.

In consideration of EMI shielding for intermodulation, a wall extending from the enclosure lid at proper locations with vacuum plated metallic surface is a low cost approach. This is because the wall or pocket is part of the injection molded case, very little tooling involved. The important thing is to calculate the exact isolation points so that printed wire board will have heavy ground strips to meet the shielding wall. A proper thickness monel wired elastomer strip about the width of the wall thickness should take care of the leakage problem.

If plating of plastic is not available for any reason, one may consider using the 3M copper shielding tape with adhesive back. The cost for both material and labour can be kept fairly low.

The obvious difference between Design 1 and Design 2 is the PCB mounting arrangement. In Design 2 the printed circuit board is to be slid into the (2) guiding slots provided on the case whereas in Design 1, the printed circuit board is held down by (10) screws onto the removeable lid. In terms of the assembly cost, the Design 2 is without question, faster than Design 1. However, the shock and vibration level of the equipment is more severe. From the article of shock and vibration discussion, loose parts in a highly vibration prone environment can have harmful effects on the operation of the equipment.

Due to the vibrational stress on the printed circuit board, the components soldered onto the board may have the following problems:

- Excessive bending of the printed circuit board may occur, thereby soldered terminals may come under severe stress resulting in cracked soldered terminals.
- The components will not be considered part of a rigid body anymore, thus at certain resonant frequencies, the components may vibrate at a much higher vibration which in turn can shorten the component life span unexpectedly.

The same reasoning may be applied to the battery pack too, sliding arrangement at best, will still have clearance along the slide rails. Therefore, the battery pack is subject to move in addition to the enclosure movement. Thus again, the vibration energy may become excessive.

4.2 Cost Estimate

Following is a rough cost estimate for non-recurring and recurring costs of the two conceptual designs.

Non-Recurring
Tooling Case (Design 1 or 2)

Main Case	$ 9,000
2 lids	$10,000
	$19,000

Recurring (Design 1)

Material	$2.30
PCB mounting	5 minutes
Power cable connections	2
Finsert installation	5
EMI shielding installation	5
Top lid installation	5
Bottom lid battery terminals	10
Battery pack connection	1
Bottom lid installation	5
	38 minutes
Total @ $30/hr	$19 + $2.30 = $21.30

Recurring (Design 2)

Material	$2.30
PCB sliding-in	1 minutes
Power cable connection	2
Finsert installation	4
EMI shielding installation	5
Battery pack sliding-in	1
Front lid installation	4
Rear lid cable connections	1
Rear lid installation	4
	22 minutes
Total @ $30/hr	$10 + $2.30 = $12.30

4.3 Adaptability to Distress Applications

The basic principle of the two presented packaging concepts, is to produce a fundamental package. This universal concept may then be readily incorporated into handheld, airborne, or marine applications.

The fundamental package is targeted at a handheld application. It is small, lightweight, manually activated, and incorporates the guarded fold-down antenna.

The handheld package is easily adapted to an airborne application by incorporating a mounting plate, alternate activation technique, and alternate antenna interface.

The mounting tray is a base which after locating and mounting in its designated location on the panel inside the plane will stay there fixed. The tray in its design purpose, should be strong and rigid. The mounting of the tray should be a conventional one, which is the screw-on way. The fastening of the beacon to this tray should be a quick release to enable emergency dismount. In an emergency, the time required to disengage the beacon can be assumed in seconds. Therefore a quick-release mechanism is an important feature in the overall beacon packaging.

The mounting tray is presented in Figure 13. A folded plate 1/8" thick aluminum folded as shown, with a hinged top strip formed to shape, is a good tray. The top strip is held to the tray by a quarter-turn fastener. The surface where the ELT and the strip meets will have a self adhesive glued neoprene foam tape to give a snug fit. The quarter-turn fastener is a good choice due to fast action, light weight, little space requirement, and good resistance to shock and vibration. While mounted in place, the fold-down telescopic antenna will be held inside the slot.

Using the same philosophy as above, the handheld package is easily adapted to a marine application. This is done by incorporating an alternate activation technique, and by packaging the unit into a buoyant enclosure which houses a waterproof antenna.

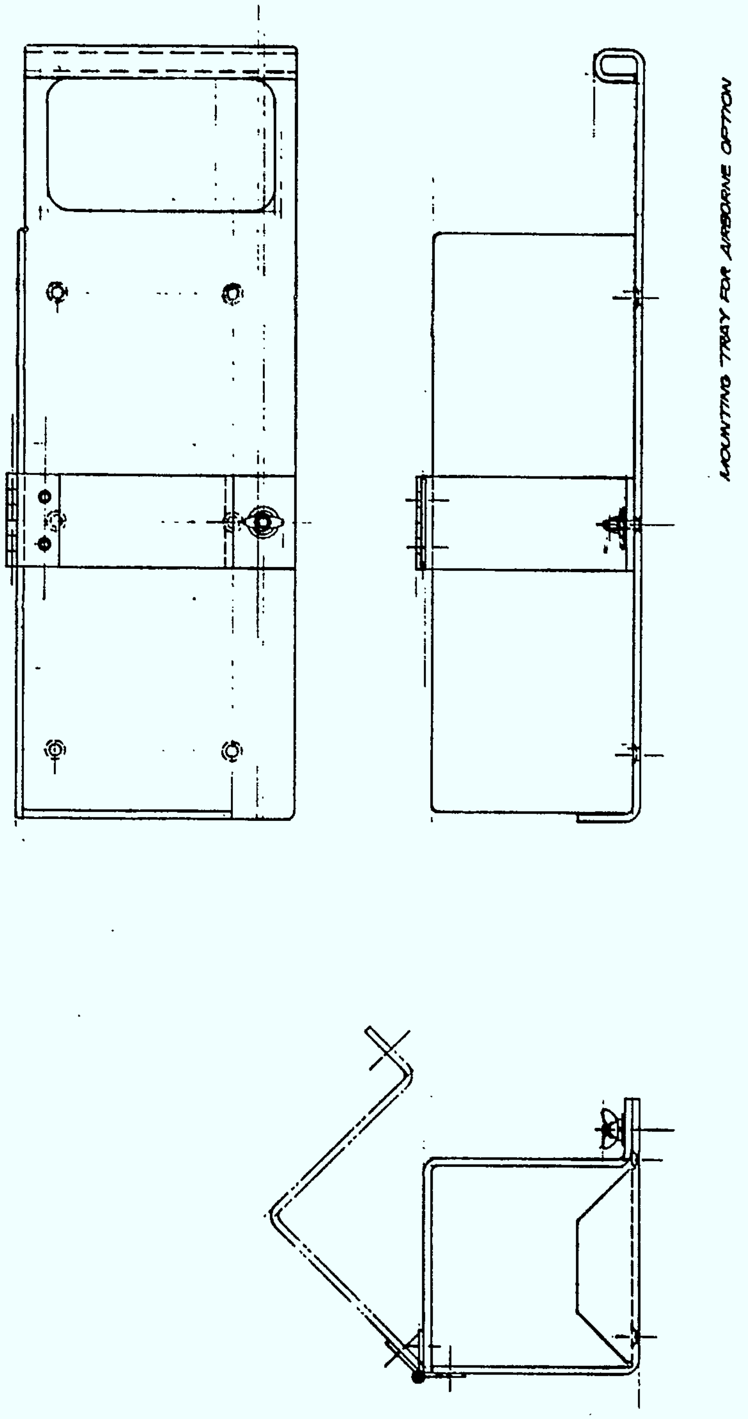


FIGURE 13: MOUNTING TRAY FOR AIRBORNE OPTION

APPENDIX D

ASSEMBLY AND TEST COST

ASSEMBLY AND TEST COSTS

A number of quotes were solicited from PWB assembly contractors. A summary of their quotes follows. Quotes which were not sufficiently detailed were disregarded for analysis purposes.

VENDOR	ASSEMBLY		TEST	
	1K	10K	1K	10K
A Durmitor	137.50	98.00	52.00	36.00
B Miltronics	38.89	35.30	11.00	10.00
C Sperry	154.74	134.10	-	-
D Anadel	86.80	65.61	-	-
AVERAGE	104.36	83.25	31.50	23.00

Number of pins to assemble = 953 per Appendix A.

	1K	10K	1K	10K
Average Cost/Pin	$0.10951	$0.08736	0.03305	0.02413