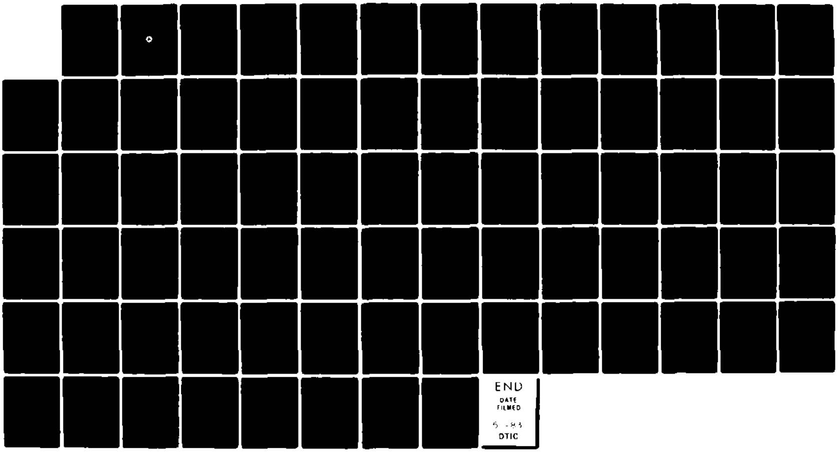
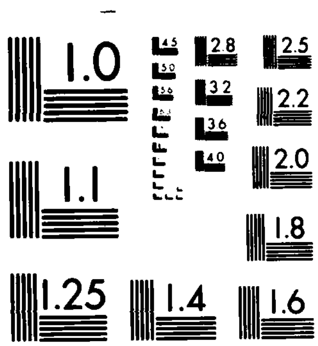
AD-A127 157 COST DEVELOPMENT OF THE DUAL-CHANNEL GPS (GLOBAL POSITIONING SYSTEM) NAVI..(U) ARINC RESEARCH CORP ANNAPOLIS MD K MARKIN ET AL. MAR 83 1378-51-6-2939 1/1

UNCLASSIFIED DOT/FAA/ES-83-1 DTFA01-80-C-10030 F/G 5/3 NL





MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

Report No. DOT/FAA/ES-83-1

(13)

AD A127157

COST DEVELOPMENT OF THE DUAL-CHANNEL GPS NAVIGATOR FOR GENERAL AVIATION APPLICATION

FINAL REPORT

K. Markin
D. Swann

March 1983

Prepared for
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Systems Engineering Service
Washington, D.C.
under Contract DTFA01-80-C-10030

Technical Report Documentation Page

1. Report No. DOT/FAA/ES-83-1	2. Government Accession No. AD-A127 157	3. Recipient's Catalog No.
4. Title and Subtitle Cost Development of the Dual-Channel GPS Navigator for General Aviation Application		5. Report Date March 1983
		6. Performing Organization Code
7. Author(s) K. Markin and D. Swann		8. Performing Organization Report No. 1378-51-6-2939
9. Performing Organization Name and Address ARINC Research Corporation 2551 Riva Road Annapolis, Maryland 21401		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DTFA01-80-C-10030
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Aviation Administration Systems Engineering Service Washington, D.C.		13. Type of Report and Period Covered Final Report
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

This report presents the methodology used and the results obtained in the avionics cost development of a dual-channel Global Positioning System (GPS) navigation set. The avionics design considered is currently undergoing technical evaluation at MIT Lincoln Laboratory.

The cost of the navigation set was developed using an industry-accepted accounting method of cost estimating.

17. Key Words GPS Cost LSI	18. Distribution Statement Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	76	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGEMENT

The Federal Aviation Administration provided the overall guidance in this study. Several avionics manufacturers cooperated in supplying the necessary technical material and economic data. We received valuable data and technical support from Dr. Raymond LaFrey and Dr. Steven Campbell of the Lincoln Laboratory of the Massachusetts Institute of Technology.

A

SUMMARY

This development of the costs of avionics for the dual-channel Global Positioning System (GPS) navigation set was based on an industry-accepted accounting method of cost estimation. ARINC Research Corporation performed the evaluation for the Federal Aviation Administration (FAA) Systems Engineering Service. A design currently undergoing technical evaluation under FAA sponsorship provided the basis for the evaluation. Typical general aviation packaging practices were applied to this design to develop the production model navigation set evaluated in this study.

The dual-channel GPS navigation set comprises a receiver/processor, a control/display unit, and an antenna with a built-in preamplifier. Three versions of the navigation set were evaluated. The first version used discrete logic integrated circuits (ICs) throughout the design, whereas the second version replaced many of the ICs with custom large scale integration (LSI) components. The third version incorporated advanced digital memory components in the design and used material costs for microprocessors and memory components estimated for the year 1990.

The expected costs of each of these versions are presented in Table S-1. The results are given in 1982 constant dollars with no escalation during the manufacturing period. Application of custom LSI technology is shown to reduce the price of the discrete logic version by $1584 (or 13 percent). The effect of incorporating advanced memory components and applying the expected cost reductions in microprocessors and memory reduces the retail price by a further $2130 (or 19 percent).

Table S-1. ACQUISITION COST OF THE DUAL-CHANNEL GPS NAVIGATION SET

Equipment	Cost (1982 Constant Dollars)		
	Discrete Logic Version	Custom LSI Version	Projected Memory and Microprocessor Cost Version
Receiver/Processor	11,351	10,017	7,887
Control/Display	960	710	710
Antenna/Preamplifier	250	250	250
Total Cost	12,561	10,977	8,847

CONTENTS

	Page
ACKNOWLEDGEMENT	iii
SUMMARY	v
CHAPTER ONE: INTRODUCTION	1-1
1.1 Background	1-1
1.2 Purpose	1-1
1.3 Scope	1-2
1.4 Technical Approach	1-2
1.5 Report Organization	1-2
CHAPTER TWO: GLOBAL POSITIONING SYSTEM DUAL-CHANNEL NAVIGATOR	2-1
2.1 Remote Navigator Unit	2-1
2.2 Control/Display Unit	2-4
2.3 Antenna/Preamplifier	2-4
CHAPTER THREE: COST ESTIMATING METHODOLOGY	3-1
3.1 Input Data	3-1
3.2 Output Data	3-2
3.3 Application of Custom Large Scale Integration	3-2
3.4 Cost Projections for Digital Memory and for Microprocessors	3-3
CHAPTER FOUR: COST DEVELOPMENT RESULTS	4-1
4.1 Discrete Logic Version	4-1
4.1.1 GPS Navigator Unit	4-1
4.1.2 GPS Control and Display Unit	4-1
4.1.3 Total Equipment Set Cost	4-3
4.2 Custom LSI Version	4-4
4.2.1 GPS Navigator Unit	4-4
4.2.2 GPS Control and Display Unit	4-4
4.2.3 Total Equipment Set Cost	4-4

CONTENTS (continued)

	Page
4.3 Cost Development of the Projected Microprocessor and Digital Memory Cost Version	4-7
4.3.1 GPS Navigator Unit	4-7
4.3.2 GPS Control and Display Unit	4-7
4.3.3 Total Equipment Set Cost	4-7
4.3.4 Application-Unique Components	4-7
4.4 Cost Development Summary	4-7
APPENDIX A: DISCRETE VERSICN WORKSHEETS	A-1
APPENDIX B: LSI VERSION WORKSHEETS	B-1
APPENDIX C: PROJECTED-COST VERSION WORKSHEETS	C-1
APPENDIX D: REFERENCES	D-1

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

The NAVSTAR Global Positioning System (GPS) is a proposed space-based radionavigation system that is intended, when fully operational, to provide accurate worldwide navigation and position information to properly equipped users. Although GPS is a military system, its potential use for civil navigation is a major topic of discussion and study.

The Federal Aviation Administration (FAA) has sponsored the design, development, and evaluation of a dual-channel GPS navigator suitable for use in the civil aviation community. The navigator was to be designed to the specification presented in Reference 16 of Appendix D, which satisfies the requirements for 2D area navigation as defined in FAA Advisory Circular AC 90-45A. Currently, the proof-of-concept model is undergoing technical evaluation at the Lincoln Laboratory of the Massachusetts Institute of Technology.

The Systems Engineering Service of the FAA contracted with ARINC Research Corporation to use the proof-of-concept design as a basis for development of the engineering, manufacturing, distribution, and support costs in order to estimate the retail selling price of the GPS navigator. Appropriate design and packaging modifications have been made to reflect the practices of general aviation avionics manufacturers and the needs of the general aviation community.

1.2 PURPOSE

The Federal Radionavigation Plan directs the Departments of Transportation and Defense to select a suitable mix of radionavigation systems that can meet the diverse technical, operational, and economic requirements imposed by users, manufacturers, and the Air Traffic Control System. GPS is one of the candidate navigation systems for meeting these requirements. The dual-channel GPS navigator is being developed as a low-cost civil aviation navigator. The purpose of this study is to project the cost of the dual-channel GPS navigator as an economic input to the selection process.

1.3 SCOPE

The retail cost of the dual-channel GPS navigator has been determined by an industry-accepted accounting method. Cost estimates were developed for three separate designs. The first design uses all discrete digital logic components. The second design uses custom large scale integration (LSI) components. Whereas these first two designs assume 1982 technology and costs, the third design derives expected cost reductions in microprocessors and memory components. The cost of those components is projected for the year 1990 on the basis of historical price data.

1.4 TECHNICAL APPROACH

In preparation for applying the cost evaluation techniques, three separate production designs of the dual-channel GPS navigator were developed. Discrete logic components were used throughout the first design. That design was then modified to use custom LSI devices to replace many of the discrete logic components. Finally, the design was further modified to include advanced digital memory components projected to be used in 1990.

Complete parts lists were prepared for each of the three designs. Material and labor costs were then developed from the parts lists. Material costs were obtained from original equipment manufacturer (OEM) price lists, assuming purchase quantities of 1000 or more of each component. Material costs for microprocessors and memory components estimated for the year 1990 were extrapolated from OEM price trends. Manufacturing and assembly labor estimates were based on historical data provided by avionics manufacturers. Labor rates were developed from data obtained from the U.S. Department of Labor.

The retail cost for each of the three designs was developed from the material and labor costs. Also included in the retail cost are factory overhead charges, quality control costs, general and administrative (G&A) expenses, profit, and distribution costs. The rates used for these expenses in this evaluation represent industry averages.

1.5 REPORT ORGANIZATION

Chapter Two identifies the GPS concept and defines the avionics considered in the evaluation.

Chapter Three describes the methodology used in estimating avionics retail costs.

Chapter Four presents the results of the evaluation for each of the three different designs.

Appendixes A, B, and C contain the cost estimating worksheets used in the evaluations of the three designs.

A list of references is provided in Appendix D.

CHAPTER TWO

GLOBAL POSITIONING SYSTEM DUAL-CHANNEL NAVIGATOR

NAVSTAR GPS is a proposed space-based radionavigation system that is intended to provide accurate navigation and position information to all properly equipped users. The fully operational system will enable continuous worldwide navigation, regardless of weather conditions. Using signals from four satellites, a user can obtain three position dimensions (latitude, longitude, and altitude), determine time, and derive velocity.

The avionics required by low-performance aircraft using GPS as the navigation system consist of an antenna with built-in preamplifier, a remotely mounted receiver/processor (navigator unit), and a console-mounted control/display unit (CDU). The design of the dual-channel GPS navigator production model was based on the Lincoln Laboratory proof-of-concept design and on existing area navigation (RNAV) unit designs. The packaging, quality, and functional features of the production model are consistent with the practices of general aviation manufacturers and with the needs of the general aviation community.

This chapter describes the design and packaging of the complete GPS navigation set. A functional block diagram of the set is presented in Figure 2-1. Typical general aviation packaging of a navigation set is illustrated in Figure 2-2.

2.1 REMOTE NAVIGATOR UNIT

The navigator unit comprises a down coverter, a synthesizer and timer circuit, two distinct receiver channels, a position and navigation processor (PNP), and a power supply. Each receiver channel includes a dual numerically controlled oscillator (NCO), a coder circuit, a correlator circuit, and a digital processor. The synthesizer/timer uses a temperature-controlled crystal oscillator, a voltage-controlled crystal oscillator, and various frequency-divider, frequency-multiplier, and mixer circuits to synthesize several local oscillator frequencies and basic timing pulses required by the other receiver circuits. The down converter translates the 1575 MHz GPS signal from the preamplifier to a 156.86 MHz signal. The coder circuit generates the pseudorandom noise code corresponding to the satellite signal being acquired or tracked. The code phase and frequency of the generated code is adjusted so that maximum correlation is achieved

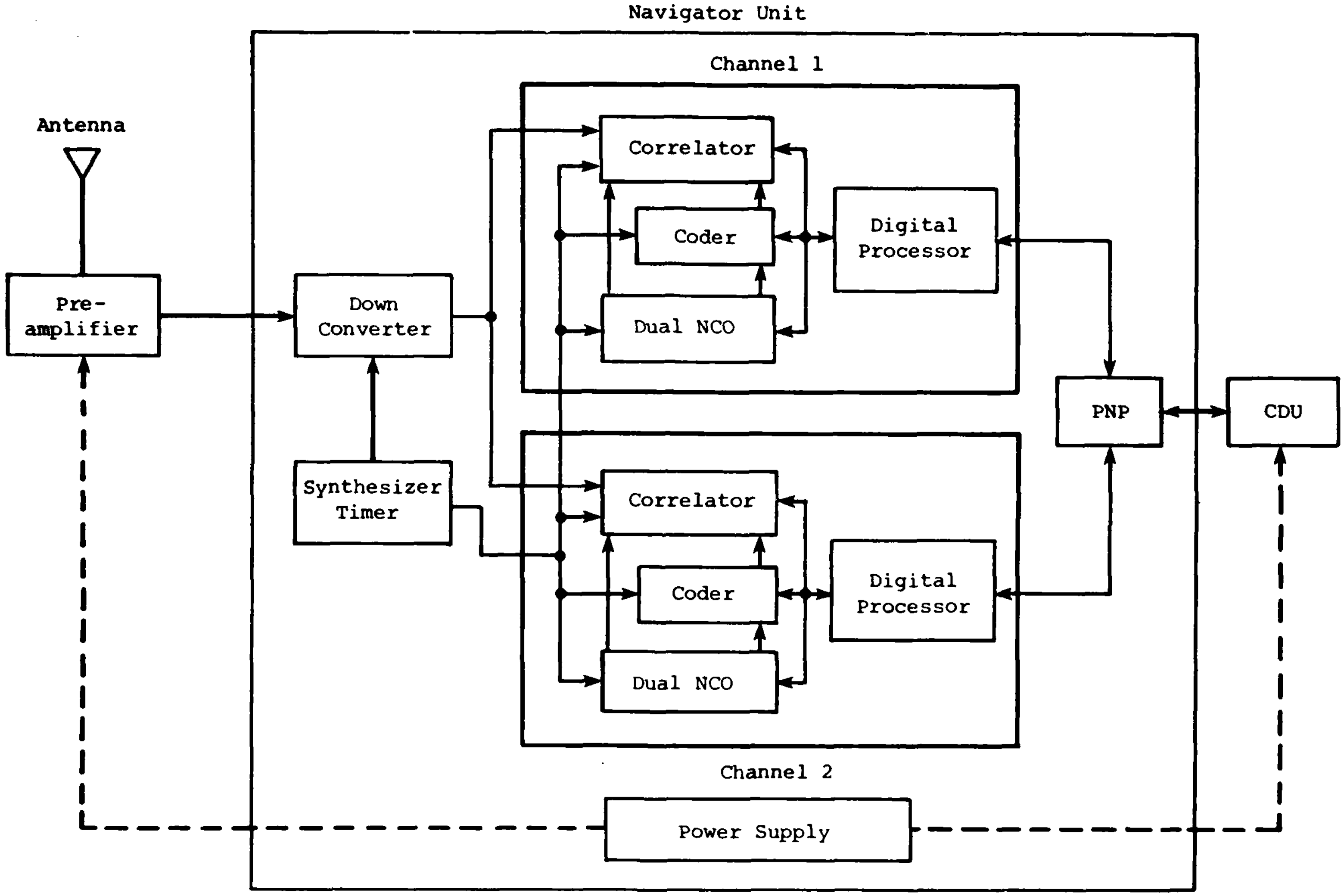


Figure 2-1. DUAL-CHANNEL GPS FUNCTIONAL DIAGRAM

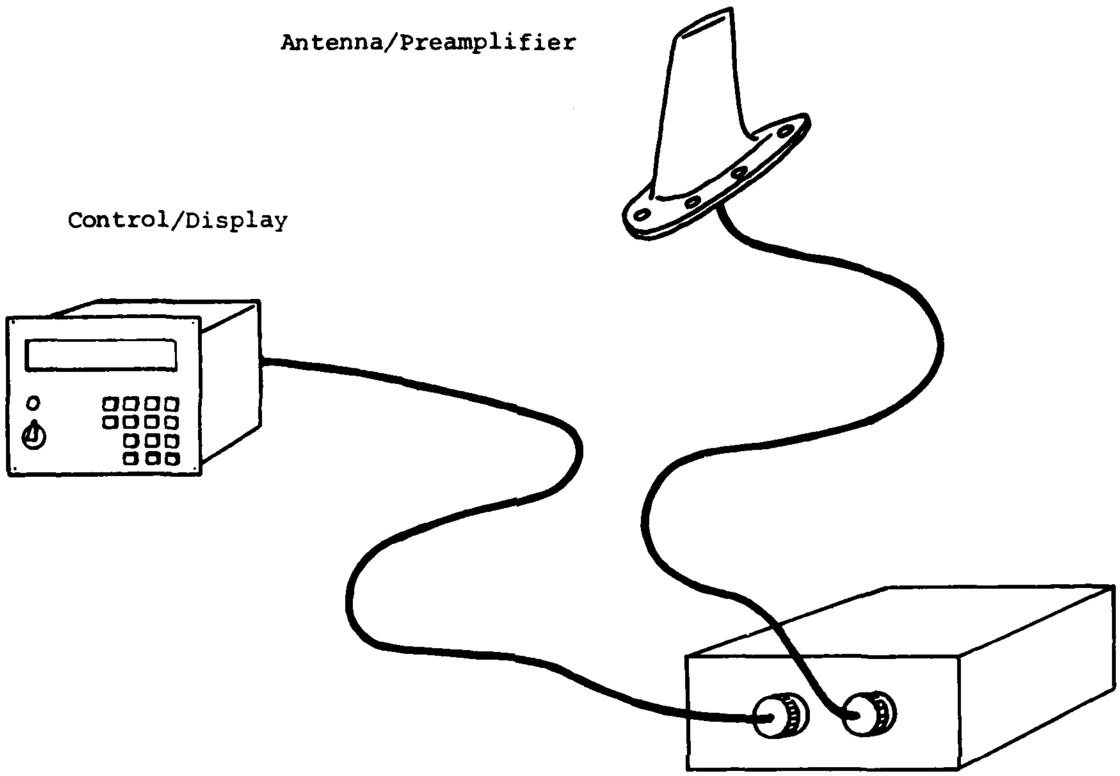


Figure 2-2. GPS AVIONICS FOR GENERAL AVIATION AIRCRAFT

between the generated and received signals. The correlation is determined by the correlator circuit and by the digital processor, which then adjusts the frequency and code phase as needed by means of an automatic frequency control (AFC) loop and a delay lock loop (DLL), respectively. The feedback function of the AFC and DLL circuits is provided by the dual NCO. The digital processor in each channel determines the pseudo-range by observing the delay relative to the system clock required for maximum correlation. The digital processor in each channel also decodes the navigation message from the incoming GPS signal and transmits those data and the pseudo-range measurements to the PNP over a serial data bus. The PNP dictates which satellites each receiver channel is to acquire and track, then computes user position from the resulting pseudo-range measurements. The PNP also generates the desired course, compares present position with the course, then computes cross-track deviation and track angle error. The PNP also provides an estimation of range, bearing, and time from present position to the next waypoint; computation of groundspeed; and an estimation of magnetic variation (from a look-up table). Those data are transmitted to the CDU over a serial data bus. The PNP accepts waypoint data from the CDU, by which it defines the desired course.

The discrete logic component version of the navigator unit houses its printed circuit boards (PCBs) in an enclosure measuring 6-1/4 by 4-1/2 by 12 inches. The total number of integrated circuits (ICs) is reduced from the 334 used in the discrete version to 166 required in the custom LSI design. The 166 remaining ICs include the custom LSI chips, microprocessors, memory components, bus driver circuits, special registers, and other logic circuits not suitable for customizing. The custom LSI version of the navigator houses its PCBs in an enclosure measuring 6-1/4 by 3-1/2 by 12 inches. The total number of memory ICs is reduced from the 100 used in the discrete and custom LSI versions to 29 in the 1990 version. The 1990 version of the navigator houses its PCBs in a enclosure measuring 6-1/4 by 3 by 12 inches. Each version of the navigator unit includes a power supply and provides connectors for the antenna/preamplifier input and for the CDU interface cable.

2.2 CONTROL/DISPLAY UNIT

The CDU cost analysis was based on designs of CDUs currently used in general aviation RNAV systems. The CDU allows entry and display of up to nine waypoints (used to define flight path); entry and display of present position and GPS time; entry and display of track offset distance; and display of the various navigation parameters provided by the PNP.

The packaging and quality of the CDU components used in the cost analysis are consistent with the practice of the general aviation manufacturers. The unit is designed for installation in the flight console of aircraft for easy access and readability. Electronics required for lamp drivers, displays, input data processing, power regulation, and interface with the receiver are mounted on printed circuit cards housed in the unit. The total number of ICs is reduced from 58 used in the discrete version to 18 in the custom LSI version. Since the CDU contains no memory components, the 1990 version of the CDU is identical to the custom LSI version.

2.3 ANTENNA/PREAMPLIFIER

The antenna, with a built-in preamplifier, is assumed to be similar in complexity, and therefore in cost, to a unit recently developed for general aviation application (Reference 12).

CHAPTER THREE

COST ESTIMATING METHODOLOGY

The technique chosen for the cost evaluation is an industry-accepted accounting method of estimating production costs based on estimates of the numbers and types of piece parts. The method requires detailed bills of material and associated labor units, schematic diagrams, mechanical and electronic module layouts, and total quantity of units to be manufactured. Material costs are then determined on the basis of original equipment manufacturer price lists for quantities of 1,000 or greater.

The final retail price also includes material handling costs, labor charges, factory overhead charges, quality control costs, general and administrative (G&A) expenses, profit, and distribution costs. The accounting structures of potential manufacturers were considered in determining the factors used to project those costs.

3.1 INPUT DATA

The data necessary for the preparation of the cost-estimating worksheets are usually taken directly from engineering bills of material. The component part numbers are identified and quantities entered on the worksheets. Procurement costs of the components are obtained either from OEM price lists or, for unique or high-cost components, from direct quotes provided by OEM distributors. Labor required for fabrication or assembly of components is estimated in terms of hours per 1,000 units in a mass production assembly line. Historical data maintained by most manufacturers provide the average labor estimates for both manual and automatic insertion processes. These data provide the average labor associated with assembly of components configured in a module (e.g., printed circuit card or subassembly).

The total labor hours are subjected to a comparative evaluation to determine the relative complexity of the assembly in comparison with the historical data. If the module is complex (has high component density or requires printed circuit boards with multiple layers), a compensating complexity factor is applied to the labor estimate. The resultant material costs and labor estimates provide the data necessary for development of the cost-estimating output sheets.

3.2 OUTPUT DATA

The worksheets used in developing total equipment costs are structured to provide cost information on individual modules and total avionics units. Total avionics unit costs include unit assembly, test, and integration costs incurred when the avionics package is completed.

Costs are developed by considering the expense of materials, material handling charges, labor at either known or estimated hourly rates, average overhead obtained from a sampling of avionics manufacturers, and factory inspection costs during production. The addition of G&A costs, together with a reasonable profit, yields the selling price of the unit. This is the cost distributors expect to pay when buying the product at quantity prices. In this study, the G&A costs are assumed to include a six percent markup for engineering development costs such as software development, EPROM programming, and custom LSI development costs. Private general aviation aircraft owners usually purchase avionics from distributors and pay an additional distributor handling markup of 100 percent.

The output data sheets are structured to permit easy reevaluation of the expected costs of avionics by substituting different labor, overhead, G&A, profit, and markup rates if there is sufficient concern over the data used or if a manufacturer prefers to use the exact factory rates rather than the average of the industry.

3.3 APPLICATION OF CUSTOM LARGE SCALE INTEGRATION

Present trends in avionics designs indicate that many manufacturers are taking advantage of the benefits in packaging and cost associated with the use of custom large scale integration. Where there is a large enough market for a particular type of avionics, the manufacturers are developing LSI chips to reduce assembly labor costs and packaging size, and to improve the reliability of the avionics. Two of the GPS configurations considered in this study have been adapted to incorporate custom LSI devices.

A custom LSI can be used to replace many small scale integration (SSI) and medium scale integration (MSI) components in an existing design. The number of devices that can be replaced is limited by the number of pins on the LSI and by the maximum number of components (i.e., transistors) that can be implemented by use of a given LSI technology. The number of pins required (pinout) depends on the application. The number of transistors to be implemented is dependent on the number of SSI and MSI functions to be incorporated and on the complexity of each function.

A circuit design is first partitioned so that each section can be replaced by an LSI. Each section must be carefully defined so that the total number of inputs and outputs to that section does not exceed the number of pins on the LSI. In this study, 48 pins is assumed to be the practical limit. Components that would require an excessive number of

LSI pins -- such as read-only memories (ROMs) -- are generally not included in the LSI. Design changes can sometimes be made to minimize pinout requirements, where that is desirable. For example, parallel data inputs can be serialized for single-pin input with subsequent conversion to parallel form within the LSI.

Assuming pinout requirements can be met, the next step is to determine if the LSI can perform the number of functions required by the design section under consideration. Functions that require significant power dissipation capacity -- such as display driver circuits -- are generally not included on the LSI. The equivalent gates and inverters required to perform the functions of the SSI and MSI components in the original design are first determined. These can be obtained from the appropriate data manuals. The total number of transistors to be implemented in the LSI can then be estimated by means of a set of simple guidelines provided by manufacturers of general aviation avionics:

- An inverter can be implemented with one transistor on an LSI chip.
- Dual input gates can be implemented with three transistors: two for input and one for the output.
- A typical transistor can be implemented with 10 square mils of area. This is an estimate of a reasonably "tight" chip, but the estimate includes allowances for proper heat dissipation, routing paths, and buffer circuits.
- An LSI chip 200 mils on a side was considered acceptable for the purpose of this analysis. The chip size used provides an available area of 40,000 square mils, enough space for a maximum of 4000 transistors.

If more than 4000 transistors are required, the design must be repartitioned to include fewer components. The pinout and LSI transistor density must then be reevaluated for the redefined design section. This procedure is applied to each section of the original design.

3.4 COST PROJECTIONS FOR DIGITAL MEMORY AND FOR MICROPROCESSORS

The third configuration of the GPS Navigation Set considers the effects on the retail price estimate of using advanced memory components and of applying projected cost reductions in memory components and microprocessors. The two other configurations assumed 1982 state-of-the-art technology and associated costs. The projected costs and use of advanced memory components are based on findings in technology forecast studies (references 4 and 9) and on OEM price data.

Reference 9 shows that there is a technology diffusion time delay of about eight years between introduction of a new component technology and incorporation of the component in commercial avionics. Even though 128K EPROM and 16K static random access memory (RAM) components are currently available, they will probably not be found in common use in commercial avionics until around 1990. Prices were projected in this study for a 128K EPROM, 64K EPROM, a 16K static RAM, and a 16-bit microprocessor for the year 1990.

Component price histories were obtained from OEM price lists of major component manufacturers. The price of a given device was traced over several years and then adjusted for inflation. The data were assumed to follow the relationship "Price = $ab^{(time)} + c$" where "a," "b," and "c" are constants determined for each device based on least-squares curve-fitting techniques. Such a relationship provided a curve-fitting confidence of 95 percent or better for the components considered. The constant term "c" was included in the expression to account for such fixed costs as material and handling costs, fabrication costs, testing, quality control, overhead expenses, profit, and distribution costs.

Price data for recently released components such as the 64K EPROM, 128K EPROM, 16K static RAM, and 16-bit microprocessors are insufficient for determining the constant "c" in the equation. The value of "c" was therefore derived from price data of a device similar to the new component of interest. For example, price data of a 16K EPROM were used to derive "c" in the equation for a 64K EPROM which has similar packaging (i.e., 24-pin DIP). Figure 3-1 illustrates the technique used to estimate the price of a 64K EPROM in the year 1990. The prices shown for both the 16K EPROM and the 64K EPROM have been adjusted to constant 1982 dollars. The cost of a 64K EPROM, which is about $25 in 1982, will be about $5 in 1990 (1982 dollars). The cost of a 128K EPROM, which is about $83 in 1982, will be about $6 in 1990 (1982 dollars).

Using similar assumptions and techniques, the cost of a 16K static RAM (NMOS technology), which is about $11 in 1982, will be about $3.70 in 1990 (1982 dollars). Since recent advances in CMOS static RAM technology have allowed the prices of those components to approach those of equivalent size NMOS static RAMs, the price of $3.70 was also assumed for a 16K CMOS static RAM in 1990.

The cost of a 16-bit microprocessor was estimated for the year 1990 using assumptions and techniques similar to those used for the memory cost estimates. Cost data for an 8-bit microprocessor with similar packaging (40-pin DIP) were used to derive the term "c" in the price equation of the 16-bit microprocessor. Adjustments were assumed both for the higher intrinsic value of the 16-bit microprocessor and for the advanced technology (HMOS)* that is used in the 16-bit microprocessor under consideration. A factor of two was applied to account for the higher intrinsic value. On the basis of current prices of similar microprocessors using the two different technologies, an increase of 25 percent was applied to reflect the higher cost of HMOS technology. On the basis of these assumptions and recent price data, the price of a 16-bit microprocessor, which costs about $50 in 1982, will cost about $16 in 1990 (1982 dollars).

*High-performance NMOS technology developed by Intel Corporation.

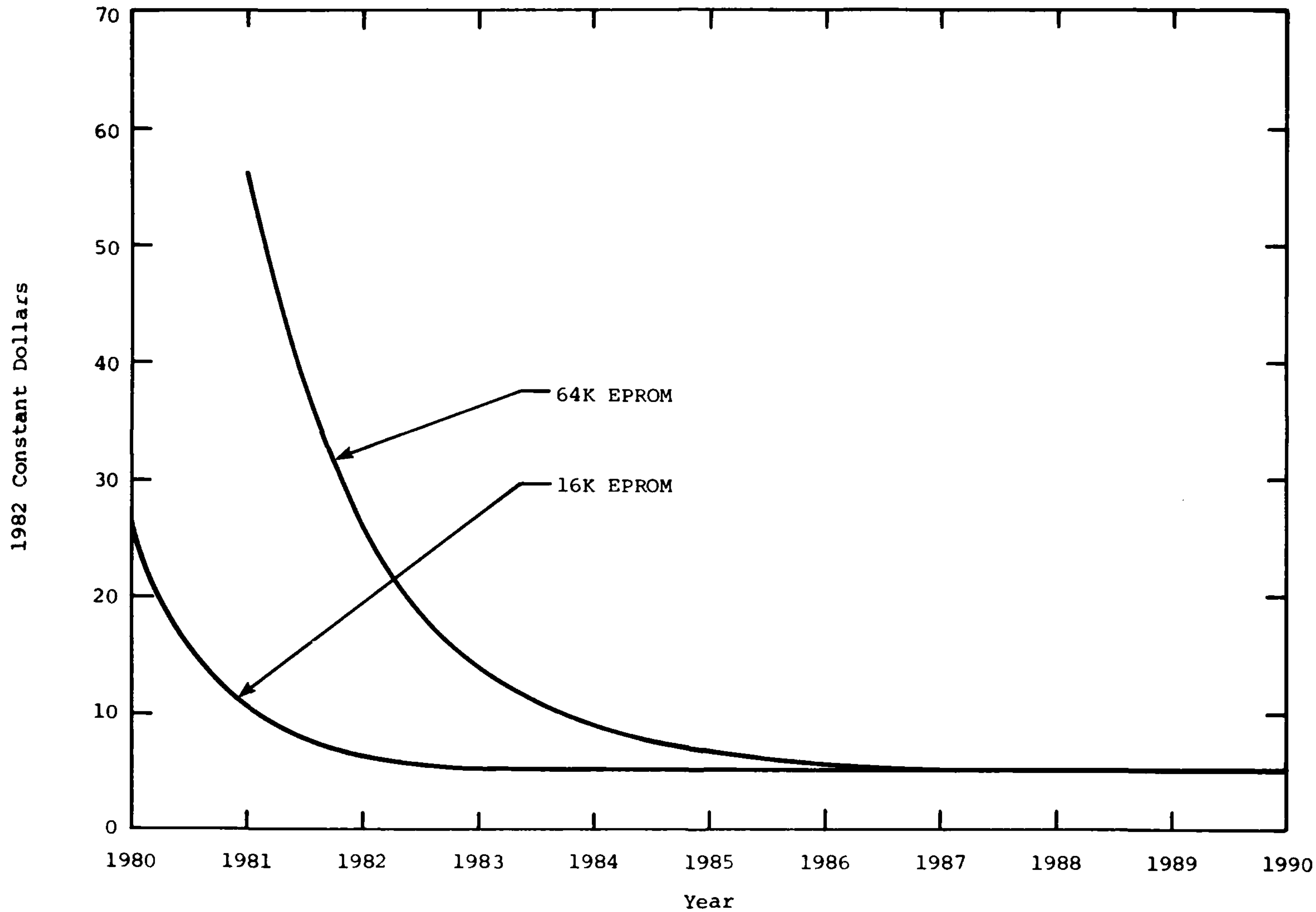


Figure 3-1. ESTIMATION OF 16K AND 64K EPROM OEM COSTS IN 1990

Table 3-1 presents the values for "a," "b," and "c," derived from the data and used in the cost projections.

Table 3-1. CONSTANTS USED IN THE OEM PRICE ESTIMATION EQUATION: PRICE = $c + ab^{time}$

Component	Value of Constant		
	a	b	c
128K EPROM	76.92	0.439	6.08
64K EPROM	50.34	0.408	5.21
16K Static RAM	11.39	0.637	3.50
16-bit Microprocessor	134.04	0.519	16.18

CHAPTER FOUR

COST DEVELOPMENT RESULTS

The cost estimating methodology presented in Chapter Three was used to develop the costs for the three versions of the GPS set. The cost estimating input worksheets are provided in the appendixes. The output worksheets and the results of the evaluation are given in this chapter.

4.1 DISCRETE LOGIC VERSION

The proof-of-concept design was used as a basis in the receiver subassembly design. Redundant and unused developmental circuitry was eliminated. Requirements for the designs of the position and navigation processor, CDU, and power supply subassemblies were based on the proof-of-concept design and on existing Loran-C and VOR/DME RNAV designs. Features unique to Loran-C or VOR/DME were eliminated. Low-cost components consistent with general aviation avionics manufacturing practices were assumed in all subassemblies, but custom LSI technology was not used in this version.

4.1.1 GPS Navigator Unit

The navigator unit consists of six subassemblies housed in an enclosure and chassis. Table 4-1 displays the cost development of each subassembly and the total unit cost, based on material and labor estimates documented in Appendix A. The total cost includes final assembly and functional testing of the unit. The list price of $11,351 is the cost of manufacturing and selling the GPS navigator unit in large quantities. It includes G&A, profit, and distribution costs.

4.1.2 GPS Control and Display Unit

The control and display unit consists of four subassemblies housed in an enclosure designed for mounting in the aircraft control panel. Table 4-2 presents the cost development for the subassemblies and the total cost of the unit, including final assembly and testing. Material and labor estimates used in the cost development are documented in Appendix A. The list price of $960 is the expected cost of the CDU to aircraft owners.

Table 4-1. GPS NAVIGATOR COST DEVELOPMENT -- DISCRETE VERSION

Cost Element	Module Cost (In Dollars)								
	Down Convertor	Synthesizer/ Timer	Receiver 1	Receiver 2	PNP	Power Supply	Enclosure and Chassis	Assembly and Test	Totals
Material Cost	172.06	270.44	908.08	908.08	552.84	26.73	45.35	--	2,883.58
Material Handling (10 Percent of Material Cost)	17.21	27.04	90.81	90.81	55.28	2.67	4.54	--	288.36
Labor ($7.64/Hour)	8.61	14.59	97.99	97.99	33.75	9.92	18.97	21.97	303.79
Burden (135 Percent of Labor Cost)	11.62	19.70	132.29	132.29	45.56	13.39	25.61	29.66	410.12
Subtotal	209.50	331.77	1,229.17	1,229.17	687.43	52.71	94.47	51.63	3,885.85
G&A (27 Percent of Subtotal)	56.56	89.58	331.88	331.88	185.61	14.23	25.51	13.94	1,049.18
Total Direct Cost	266.06	421.35	1,561.05	1,561.05	873.04	66.94	119.98	65.57	4,935.03
Profit (15 Percent of Total Direct Cost)	39.91	63.20	234.16	234.16	130.96	10.04	18.00	9.84	740.25
Factory Sell Price	305.97	484.55	1,795.21	1,795.21	1,004.00	76.98	137.98	75.41	5,675.28
Distribution (100 Percent of Factory Sell Price)	--	--	--	--	--	--	--	--	5,675.28
List Price	--	--	--	--	--	--	--	--	11,350.56

Table 4-2. CONTROL/DISPLAY COST DEVELOPMENT -- DISCRETE VERSION					
Cost Element	Module Cost (In Dollars)				
	Processor	Front Panel	Enclosure and Chassis	Assembly and Test	Totals
Material Cost	109.66	31.87	10.07	--	151.60
Material Handling (10 Percent of Material Cost)	10.97	3.19	1.01	--	15.16
Labor ($7.64/Hour)	38.51	3.75	9.64	17.00	68.90
Burden (135 Percent of Labor Cost)	51.99	5.06	13.01	22.95	93.02
Subtotal	211.13	43.87	33.73	39.95	328.68
G&A (27 Percent of Subtotal)	57.01	11.84	9.11	10.79	88.74
Total Direct Cost	268.14	55.71	42.84	50.74	417.42
Profit (15 Percent of Total Direct Cost)	40.22	8.36	6.43	7.61	62.61
Factory Sell Price	308.36	64.07	49.27	58.35	480.03
Distribution (100 Percent of Factory Sell Price)	--	--	--	--	480.03
List Price	--	--	--	--	960.07

4.1.3 Total Equipment Set Cost

Table 4-3 presents the cost of the equipment set including the antenna/preamplifier subassembly. The antenna/preamplifier is assumed to be similar in complexity and therefore cost to an antenna/preamplifier recently developed for general aviation application. Development costs are included in the list price.

Table 4-3. TOTAL EQUIPMENT SET COST, DISCRETE VERSION	
Equipment	Cost (In 1982 Dollars)
Receiver/Processor Unit	11,351
Control/Display Unit	960
Antenna/Preamplifier	250
List Price	12,561

4.2 CUSTOM LSI VERSION

The discrete logic designs of the GPS navigator and CDU were used as a basis in the design of the LSI version. Many of the logic functions performed by SSI and MSI components in the discrete version have been replaced by custom LSI devices in this version. The fewer parts associated with LSI technology result in lower material costs, reduced assembly labor, smaller avionics size, and improved reliability.

4.2.1 GPS Navigator Unit

The main improvement over the discrete version is in replacing many SSI and MSI components in each of the two receiver subassemblies with three LSI chips. Table 4-4 presents the cost development of each subassembly and of the total unit cost based on material and labor estimates documented in Appendix B.

4.2.2 GPS Control and Display Unit

The CDU consists of three subassemblies housed in an enclosure designed for mounting in the aircraft control panel. The improvement of this design over the discrete version CDU is in replacing many of the discrete logic components with a single LSI chip. The number of printed circuit boards was thereby reduced from three to two. Table 4-5 presents the cost development of the CDU. The material and labor estimates are documented in Appendix B.

4.2.3 Total Equipment Set Cost

Table 4-6 presents the cost of the total equipment set for the LSI version of the GPS navigator. The antenna/preamplifier is the same unit used in the discrete version. Software development, EPROM programming, and LSI development costs are included in the selling price as part of G&A.

Table 4-4. GPS NAVIGATOR COST DEVELOPMENT-LSI VERSION

Cost Element	Module Cost (In Dollars)								
	Down Convertor	Synthesizer/ Timer	Receiver 1	Receiver 2	PNP	Power Supply	Enclosure and Chassis	Assembly and Test	Totals
Material Cost	172.06	261.33	781.73	781.73	552.84	26.73	44.15	--	2,620.57
Material Handling (10 Percent of Material Cost)	17.21	26.13	78.17	78.17	55.28	2.67	4.42	--	262.06
Labor ($7.64/Hour)	8.61	10.68	64.74	64.74	33.75	9.92	18.59	21.58	232.61
Burden (135 Percent of Labor Cost)	11.62	14.42	87.40	87.40	45.56	13.39	25.10	29.13	314.02
Subtotal	209.50	312.56	1,012.04	1,012.04	687.43	52.71	92.26	50.71	3,429.26
G&A (27 Percent of Subtotal)	56.56	84.39	273.25	273.25	185.61	14.23	24.91	13.69	925.90
Total Direct Cost	266.06	396.95	1,285.29	1,285.29	873.04	66.94	117.17	64.40	4,355.16
Profit (15 Percent of Total Direct Cost)	39.91	59.54	192.79	192.79	130.96	10.04	17.58	9.66	653.27
Factory Sell Price	305.97	456.49	1,478.08	1,478.08	1,004.00	76.98	134.75	74.06	5,008.43
Distribution (100 Percent of Factory Sell Price)	--	--	--	--	--	--	--	--	5,008.43
List Price	--	--	--	--	--	--	--	--	10,071.86

Table 4-5. CONTROL/DISPLAY COST DEVELOPMENT -- LSI VERSION					
Cost Element	Module Cost (In Dollars)				
	Processor	Front Panel	Enclosure and Chassis	Assembly and Test	Totals
Material Cost	81.48	31.87	9.50	--	122.85
Material Handling (10 Percent of Material Cost)	8.15	3.19	0.95	--	12.28
Labor ($7.64/Hour)	15.87	3.75	9.53	16.81	45.96
Burden (135 Percent of Labor Cost)	21.42	5.06	12.87	22.69	62.05
Subtotal	126.92	43.87	32.85	39.50	243.14
G&A (27 Percent of Subtotal)	34.26	11.84	8.87	10.66	65.65
Total Direct Cost	161.19	55.71	41.72	50.16	308.79
Profit (15 Percent of Total Direct Cost)	24.18	8.36	6.26	7.52	46.32
Factory Sell Price	185.37	64.07	47.98	57.68	355.11
Distribution (100 Percent of Factory Sell Price)	--	--	--	--	355.11
List Price	--	--	--	--	710.22

Table 4-6. TOTAL EQUIPMENT SET COST, LSI VERSION	
Equipment	Cost (In 1982 Dollars)
Receiver/Processor Unit	10,017
Control/Display Unit	710
Antenna/Preamplifier	250
List Price	10,977

4.3 COST DEVELOPMENT OF THE PROJECTED MICROPROCESSOR AND DIGITAL MEMORY COST VERSION

The LSI version of the GPS navigator was used as a basis in the development of this version. The only design changes involved the use of more compact digital memory components. Cost projections of microprocessors, EPROM, and static RAM components developed in Chapter Three are used in the cost development of this version. For all discrete components, current prices were used. Significant reductions in the cost of many of these components is not expected.

4.3.1 GPS Navigator Unit

The main design improvement over the LSI version is the reduction in the number of digital memory components used. Table 4-7 presents the cost development of the subassemblies and the total unit cost based on the material and labor estimates documented in Appendix C. The material costs in Appendix C reflect the cost projections developed in Chapter Three.

4.3.2 GPS Control and Display Unit

The control and display unit in this version is unchanged from the one used in the LSI version since no memory is used in the design.

4.3.3 Total Equipment Set Cost

Table 4-8 presents the cost development of this version of the GPS navigator. The same antenna/preamplifier used in the other two versions is also used in this version.

4.3.4 Application-Unique Components

Several components are included in the designs that are unique to this application. Although future increases in sales volumes and improvements in fabrication practices could lower the cost of these devices, there are insufficient data to predict changes in cost. Examples of such components include custom phase comparators and single side-band modulators found in the receiver modules. The total cost of these components represents less than 20 percent of the total material cost. An average reduction of 50 percent in the cost of all these components would produce less than an 8 percent reduction in the list price of $8,847 shown in Table 4-8.

4.4 COST DEVELOPMENT SUMMARY

Three configurations of the dual-channel GPS navigation set were developed to demonstrate the effects of applying LSI technology and of applying expected cost reductions in microprocessor and memory components. Table 4-9 summarizes the results for the three configurations. The effect on retail cost of applying LSI technology is shown to be a reduction of $1,584, or 13 percent of the list price. The effect of applying the expected cost reductions in microprocessors and memory as developed in Section 3.4 of this report is a reduction of $2,130, or 19 percent of the retail cost of the navigation set.

Table 4-7. GPS NAVIGATOR COST DEVELOPMENT -- PROJECTED MICROPROCESSOR AND MEMORY COST VERSION

Cost Element	Module Cost (In Dollars)								
	Down Convertor	Synthesizer/ Timer	Receiver 1	Receiver 2	PNP	Power Supply	Enclosure and Chassis	Assembly and Test	Totals
Material Cost	172.06	261.33	679.84	679.84	163.87	26.73	43.55	--	2,027.22
Material Handling (10 Percent of Material Cost)	17.21	26.13	67.98	67.98	16.39	2.67	4.36	--	202.72
Labor ($7.64/Hour)	8.61	10.68	55.22	55.22	20.66	9.92	18.40	21.39	200.10
Burden (135 Percent of Labor Cost)	11.62	14.42	74.55	74.55	27.89	13.39	24.84	28.88	270.14
Subtotal	209.50	312.56	877.59	877.59	228.81	52.71	91.15	50.27	2,700.18
G&A (27 Percent of Subtotal)	56.56	84.39	236.95	236.95	61.78	14.23	24.61	13.57	729.05
Total Direct Cost	266.06	396.95	1,114.54	1,114.54	290.59	66.94	115.76	63.84	3,429.23
Profit (15 Percent of Total Direct Cost)	39.91	59.54	167.18	167.18	43.59	10.04	17.36	9.58	514.38
Factory Sell Price	305.97	456.49	1,281.72	1,281.72	334.18	76.98	133.12	73.42	3,943.61
Distribution (100 Percent of Factory Sell Price)	--	--	--	--	--	--	--	--	3,943.61
List Price	--	--	--	--	--	--	--	--	7,887.22

Table 4-8. TOTAL EQUIPMENT SET COST, PROJECTED MICROPROCESSOR AND MEMORY COST VERSION

Equipment	Cost (In 1982 Dollars)
Receiver/Processor Unit	7,887
Control/Display Unit	710
Antenna/Preamplifier	250
List Price	8,847

Table 4-9. ACQUISITION COST OF THE DUAL-CHANNEL GPS NAVIGATION SET

Equipment	Cost (1982 Constant Dollars)		
	Discrete Logic Version	Custom LSI Version	Projected Memory and Microprocessor Cost Version
Receiver/Processor	11,351	10,017	7,887
Control/Display	960	710	710
Antenna/Preamplifier	250	250	250
Total Cost	12,561	10,977	8,847

APPENDIX A

DISCRETE VERSION WORKSHEETS

SYSTEM Dual-Channel GPS Navigator **SHEET** 1 **OF** 1

SUB-ASSEMBLY Down Converter

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
Freq. Doubler	4	9.57	38.28		32	.50	2.00	X16 to L-Band
TFM-15	1	49.95	49.95		7	.50	.50	Mixer (L-Band)
MWA-110	4	6.45	25.80		32	.25	1.00	VHF Amp
Bandpass Filter	1	38.00	38.00		15	.75	.75	156 MHz
PSC-2	1	9.95	9.95		8	.50	.50	VHF Pwr. Split
MPN 3401	1	.30	.30		5	.08	.08	VHF Pin diode
IN 5711	3	.48	1.44		15	.08	.24	
IN 821	1	.50	.50		5	.08	.08	Zener
82P-200	1	.50	.50		15	.30	.30	Trim Pot
Inductor	3	.60	1.80		15	.08	.24	
Capacitor	13	.12	1.56		65	.11	1.43	Ceramic
Resistor	14	.07	.98		70	.08	1.12	Metal Film
PC Board	1	3.00	3.00		25			
Board Process				333	485			
Total Labor				333	794			
PCB Area							8.24	1 - 2" x 6" Card
Complexity				1.0	1.0			
TOTALS			[illegible]	333	794			

SYSTEM Dual-Channel GPS Navigator

SHEET 1 OF 2

SUB-ASSEMBLY Synthesizer/Timer

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
74128	2	.56	1.12		20	.50	1.00	
74LS74	1	.31	.31		10	.50	.50	
74LS90	1	.56	.56		10	.50	.50	
74LS92	1	.72	.72		10	.50	.50	
74LS161	8	.80	6.40		80	.50	4.00	
LM308A	1	.50	.50		8	.25	.25	(OP-05CP)
LM2903	1	.65	.65		8	.50	.50	
LM78L12	1	.25	.25		6	.11	.11	
LM79L12	1	.65	.65		6	.11	.11	
MC10131	1	1.84	1.84		10	.50	.50	ECL
MC10136	2	5.00	10.00		20	.50	1.00	ECL
MC12040	1	6.98	6.98		10	.50	.50	ECL
2N3906	1	.36	.36		6	.11	.11	
2N3933	3	.80	2.40		18	.11	.33	
IN4448	2	.06	.12		10	.08	.16	
IN4001	1	.10	.10		5	.08	.08	
T4-1	1	2.95	2.95		8	.22	.22	Xformer 8 pin DIP
PSC2-1	3	9.95	29.85		24	.50	1.50	Pwr. Split
PSC4-3	1	23.95	23.95		8	.50	.50	Pwr. Split
SRA-1	1	7.95	7.95		8	.50	.50	Mixer
TCXO	1	90.00	90.00		15	4.25	4.25	10.23 MHz
VCXO	1	67.00	67.00		15	2.50	2.50	88.66 MHz
TOTALS								

SYSTEM Dual-Channel GPS Navigator

SUB-ASSEMBLY Synthesizer/Timer

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
Inductor	2	.60	1.20		10	.08	.16	
Capicator	18	.12	2.16		90	.11	1.98	Ceramic
Capacitor	4	.17	.68		20	.11	.44	Mica
Capacitor	6	.33	1.98		30	.11	.66	Tantalum
Resistors	44	.04	1.76		220	.08	3.52	
PC Board	1	8.00	8.00		25			
Board Process				333	485			
Total Labor				333	1195			
PCB Area							24.40	4" x 8" Card
Complexity				1.25	1.[illegible]			
TOTALS			[illegible]0.11	416	1494			

SYSTEM Dual-Channel GPS Navigator

SUB-ASSEMBLY Receiver (1 & 2)

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
26S02	1	1.50	1.50		10	.50	.50	
27S19	1	1.50	1.50		10	.50	.50	
7416	2	.27	.54		16	.50	1.00	
74C00	6	.25	1.50		48	.50	3.00	
74C02	1	.26	.26		8	.50	.50	
74C04	5	.26	1.30		40	.50	2.50	
74C03	2	.26	.52		16	.50	1.00	
74C14	11	.52	5.72		88	.50	5.50	
74C20	2	.26	.52		16	.50	1.00	
74C30	1	.26	.26		8	.50	.50	
74C32	2	.26	.52		16	.50	1.00	
74C42	2	.98	1.96		20	.50	1.00	
74C74	7	.60	4.20		56	.50	3.50	
74C83	12	1.38	16.56		120	.50	6.00	
74C86	5	.68	3.40		40	.50	2.50	
74C151	2	2.54	5.08		24	1.12	2.24	
74C157	1	2.28	2.28		10	.50	.50	
74C162	2	1.18	2.36		20	.50	1.00	
74C163	5	1.18	5.90		50	.50	2.50	
74C174	3	.80	2.40		30	.50	1.50	
74C175	3	.80	2.40		30	.50	1.50	
74C374	27	1.80	48.60		297	.67	18.09	8 bit register
TOTALS								

SYSTEM Dual-Channel GPS Navigator

SUB-ASSEMBLY Receiver (162)

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
74LS00	2	.24	.48		16	.50	1.00	
74LS04	2	.26	.52		16	.50	1.00	
74LS14	8	.64	5.12		64	.50	4.00	
74LS32	3	.26	.78		24	.50	1.50	
74LS42	1	.62	.62		10	.50	.50	
74LS74	5	.31	1.55		40	.50	2.50	
74LS85	3	.73	2.19		30	.50	1.50	
74LS109	1	.31	.31		10	.50	.50	
74LS138	2	.51	1.02		20	.50	1.00	
74LS157	2	.50	1.00		20	.50	1.00	
74LS162	1	.73	.73		10	.50	.50	
74LS163	2	.73	1.46		20	.50	1.00	
74LS241	1	.93	.93		11	.67	.67	
74LS374	1	1.11	1.11		11	.67	.67	
74LS472	4	7.10	23.40		44	.67	2.68	
74S00	4	.30	1.20		32	.50	2.00	
74S02	4	.30	1.20		32	.50	2.00	
74S08	1	.30	.30		8	.50	.50	
74S10	1	[illegible]	.30		8	.50	.50	
74S11	2	[illegible]	.30		8	.50	.50	
74S20	1	[illegible]	[illegible]		8	.50	.50	
74S32	1	.34	[illegible]		[illegible]	.50	.50	
TOTALS								

SYSTEM Dual-Channel GPS Navigator

SUB-ASSEMBLY Receiver (1&2)

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
74S51	2	.30	.60		16	.50	1.00	
74S74	4	.49	1.96		32	.50	2.00	
74S112	3	.49	1.47		30	.50	1.50	
74S139	2	.90	1.80		20	.50	1.00	
74S240	4	1.87	7.48		32	.50	2.00	
74S244	3	2.10	6.30		24	.50	1.50	
74S260	1	.49	.49		8	.50	.50	
74S373	2	2.25	4.50		22	.67	1.34	
74S374	2	2.25	4.50		22	.67	1.34	
74S393	1	.97	.97		8	.50	.50	
8259A	1	5.50	5.50		14	2.00	2.00	
8303	4	2.60	10.40		44	.67	2.68	
8304	2	2.25	4.50		22	.67	1.34	
9513	1	15.65	15.65		20	4.25	4.25	Timer
9551	1	4.25	4.25		20	4.25	4.25	USART
AD570	2	12.60	25.20		22	.62	1.25	A/D Converter
AD583K	2	16.35	32.70		16	.50	1.00	Sample & Hold
AD7524	1	4.50	4.50		10	.50	.50	D/A Converter
AD7525	4	9.60	38.40		44	.62	2.50	Digital Pot
CA3054	1	.73	.73		8	.50	.50	
CA3240E	2	1.34	2.68		16	.50	1.00	
FP8-PC-70	1	75.40	75.40		20	1.50	1.50	Phase Comparitor
TOTALS								

SYSTEM Dual-Channel GPS Navigator

SUB-ASSEMBLY Receiver (1&2)

SHEET 4 OF 5

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
FP8-SSB-1026	1	70.00	70.00		20	1.50	1.50	SSB Modulator
FP8-SSB-1027	1	70.00	70.00		20	1.50	1.50	SSB Modulator
7608	1	.98	.98		6	.19	.19	
7905	1	1.00	1.00		6	.19	.19	
MC34004	2	1.67	3.34		16	.50	1.00	
MWA120	6	6.75	40.50		48	.25	1.50	RF Amplifier
MWA130	3	7.15	21.45		24	.25	.75	RF Amplifier
SL1610C	3	2.03	6.09		24	.50	1.50	
Z8002	1	88.65	88.65		20	4.25	4.25	16 bit CPU
MB7052	2	2.45	4.90		20	.50	1.00	256 x 4 PROM
2716	2	5.10	10.20		24	1.12	2.24	2KX8 EPROM
2732	2	10.75	21.50		24	1.12	2.24	4KX8 EPROM
2114	12	1.90	22.80		132	.62	7.44	1KX4 RAM
Crystal	1	6.84	6.84		15	.60	.60	8.0 MHz
Crystal	1	8.58	8.58		15	.60	.60	19.6608 MHz
2N2222A	3	.18	.54		18	.11	.33	
2N2907	2	.16	.32		12	.11	.22	
2N3546	1	.43	.43		6	.11	.11	
2N3646	1	[illegible]	.20		6	.11	.11	
2N4416	2	.65	1.30		12	.11	.22	
2N5179	1	.77	.77		6	.11	.11	
IN914	1	.13	.13		6	.08	.08	
TOTALS								

SYSTEM Dual-Channel GPS Navigator

SUB-ASSEMBLY Receiver (1&2)

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
IN4001	3	.10	.30		15	.08	.24	
IN4148	6	.06	.36		30	.08	.48	
IN4448	8	.06	.48		40	.08	.64	
IN5711	3	.48	1.44		15	.08	.24	
Capacitor	88	.12	10.56		440	.11	9.68	Ceramic
Capacitor	7	.33	2.31		35	.11	.77	Tantalum
Capacitor	7	.80	5.60		42	.12	.84	Variable
Resistor	2	.12	.24		10	.08	.16	1%,50ppm/°C
Resistor	20	.07	1.40		100	.08	1.60	Metal Film
Resistor	45	.04	1.80		225	.08	3.60	Carbon Comp.
Resistor Pack	4	.06	.24		32	.50	2.00	
T20-10	2	1.24	2.48		500	.75	1.50	Inductor Core
4171F	1	38.00	38.00		10	.50	.50	Bandpass Filter
SBL-1	2	5.95	11.95		16	.50	1.00	Mixer
Ferrite Bead	2	.09	.18		14	.08	.16	
PC Board	3	13.50	40.50		75			
Board Process				999	1455			
Total Labor				999	5414			
PCB Area							170.89	3 - 6" x 9" cards
Complexity				2.0	2.0			
TOTALS			908.08	1998	10828			

SYSTEM Dual-Channel GPS Navigator

SUB-ASSEMBLY PNP

SHEET 1 OF 1

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
8086-2	1	52.30	52.30		20	4.25	4.25	16 bit CPU
Crystal	1	4.10	4.10		15	.60	.60	8.0 MHz
2732	28	10.75	301.00		336	1.12	31.36	4Kx8 EPROM
2114	56	1.90	106.40		616	.62	34.72	1Kx4 RAM
74LS138	3	.61	1.83		30	.50	1.50	
MM5303	3	4.00	12.00		60	4.25	12.75	UART
9101	4	2.80	11.20		44	.70	2.80	256x4 CMOS RAM
8414	4	5.47	21.88		44	.62	2.48	1Kx4 CMOS RAM
8303	2	2.60	5.20		22	.67	1.34	
8304	2	2.25	4.50		22	.67	1.34	
25S373	2	2.05	4.10		22	.67	1.34	
74123	1	.43	.43		10	.50	.50	
4011	1	.42	.42		8	.50	.50	
Capicator	3	.12	.36		5	.08	.24	Ceramic
Resistor	3	.04	.12		5	.08	.24	
P.C. Boards	2	3.50	7.00		50			
Board Process				666	970			
Total Labor				666	2270			
PCB Area				1.5	1.5			
TOTALS			[illegible]	999	[illegible]			

SYSTEM Dual-Channel GPS Navigator

SUB-ASSEMBLY Power Supply

SHEET 1 OF 1

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
78H05	1	5.05	5.05		6	.11	.11	
7812	1	.25	.25		6	.11	.11	
7912	1	.65	.65		6	.11	.11	
Transistor	2	1.18	2.36		12	.11	.22	
IN4154	2	.06	.12		10	.08	.16	
Inductor	1	.60	.60		5	.08	.08	
Capicators	10	.33	3.30		50	.11	1.10	Tantalum
Resistors	4	.04	.16		20	.08	.32	
Transformer	1	12.09	12.09		315	1.25	1.25	
Heat Sink	1	.15	.15		10	1.00	1.00	
P.C. Borard	1	2.00	2.00		25			
Board Process				333	485			
Total Labor				348	950			
PCB Area							4.46	1 - 2" x 4"
Complexity				1.0	1.0			
TOTALS			26.73	348	950			

SYSTEM Dual-Channel GPS Navigator **SHEET** 1 **OF** 1

SUB-ASSEMBLY Enclosure & Chassis

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
Chassis	1	4.00	4.00	184	44			
Cover L-R	2	.80	1.60	50	22			
Cover F-R	2	2.50	5.00	148	44			
PC. Board Assbly	1	2.00	2.[illegible]	150	75			
Cover T-B	2	.80	1.60	25	22			
Connector RF	1	1.50	1.50	25	15			
Connector Cable	1	1.50	1.50		25			
Connector PCB	10	.60	6.00		250			
Support Bracket	2	1.60	3.20	92	24			
Retaining Strap	2	2.50	5.00	28	10			
Misc. Hardware	Lot	5.75	5.75		250			
Wiring	Lot	8.20	8.[illegible]		1000			
TOTALS			[illegible]	702	[illegible]			

SYSTEM Dual-Channel GPS Navigator

SUB-ASSEMBLY Assembly & Test

SHEET 1 OF 1

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
Down Converter	1				25			
Synthesizer	1				25			
Receiver	2				150			
PNP	1				50			
Power Supply	25				25			
Enclosure/Chassis	1				100			
P.S. Alignment					100			
RCVR Alignment					400			
Burn-In					1000			
Functional Test					1000			
TOTALS					2875			

SYSTEM GPS Control/Display

SUB-ASSEMBLY Processor

SHEET 1 **OF** 2

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
555	1	.30	.30		8	.25	.25	
4001	2	.28	.56		16	.50	1.00	
4020	1	.63	.63		8	.50	.50	
4027	3	.38	1.14		24	.50	1.50	
5303	1	4.00	4.00		20	4.25	4.25	UART
74148	1	1.00	1.00		11	.67	.67	
74C00	1	.32	.32		8	.50	.50	
74C04	1	.32	.32		8	.50	.50	
74C85	2	1.38	2.76		20	.50	1.00	
74C175	20	1.17	23.40		200	.50	10.00	
74C922	1	3.80	3.80		12	1.12	1.12	Keypad Encoder
74L04	1	.51	.51		8	.50	.50	
74L74	2	.74	1.48		16	.50	1.00	
80C97	1	.71	.71		8	.50	.50	
8820	1	1.45	1.45		8	.50	.50	
8830	1	1.45	1.45		8	.50	.50	
8884	14	1.95	27.30		154	.62	8.68	
9667	2	.78	1.56		16	.50	1.00	
314A332	1	.06	.06		8	.50	.50	
DC/DC Converter	1	8.96	8.96		15	1.31	1.31	Display Power
IN3051	1	3.00	3.00		5	.08	.08	
Crystal	1	4.55	1.55		15	.60	.60	1 MHz
TOTALS								

SYSTEM GPS Control Display

SUB-ASSEMBLY Processor

SHEET 2 OF 2

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
Inductor	1	.60	.60		5	.08	.08	
Capicator	8	.33	2.64		40	.11	.88	Tantalum
Capacitor	8	.12	.96		40	.11	.88	Ceramic
Resistor	30	.04	1.20		150	.08	2.40	
P.C. Boards	3	5.00	15.00		75			
Board Process				999	1455			
Total Labor				999	2361			
PCB Area							40.70	3-5" x 3 1/4" cards
Complexity				1.5	1.5			
TOTALS			109.66	1498	3542			

SYSTEM GPS Control/Display

SUB-ASSEMBLY Front Panel

SHEET 1 **OF** 1

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
Panel	1	1.00	1.00	74	22			
Keyboard	1	2.75	2.75		25			
Switch	1	1.64	1.64		[illegible]			DPDT
Switch	1	1.24	1.24		[illegible]			SPDT
Switch	1	2.73	2.73		15			Rotary
Display	1	10.00	10.00		100			Gas Discharge
Potentiometer	1	1.57	1.57		15			
Knob	2	1.10	2.20		10			
1820 lamp	14	.45	6.30		70			
1847 lamp	6	.24	1.44		30			
Misc. Hardware	Lot	1.00	1.00		100			
TOTALS				74	417			

SYSTEM GPS Control/Display

SUB-ASSEMBLY Enclosure & Chassis

SHEET 1 OF 1

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
Chassis	1	2.00	2.00	184	44			
Cover	1	.80	.80	334	5			
PCB Connector	3	.57	1.71		45			
Cable Connector	1	1.56	1.56		25			
Misc. Hardware	Lot	1.50	1.50		125			
Wiring	Lot	2.50	2.50		500			
TOTALS			10.07	518	744			

SYSTEM GPS Control/Display **SHEET** 1 **OF** 1

SUB-ASSEMBLY Assembly and Test

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
PCB 1	1				25			
PCB 2	1				25			
PCB 3	1				25			
Chassis	1				50			
Front Panel	1				100			
Burn-In					1000			
Functional Test					1000			
TOTALS					2225			

APPENDIX B

LSI VERSION WORKSHEETS

SYSTEM Dual-Channel GPS Navigator

SHEET 1 OF 1

SUB-ASSEMBLY Down Converter

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
Freq. Doubler	4	9.57	38.28		32	.50	2.00	X16 to L-Band
TFM-15	1	49.95	49.95		[illegible]	.50	.50	Mixer (L-Band)
MWA-110	4	6.45	[illegible].80		[illegible]	.25	1.00	VHF Amp
Bandpass Filter	1	38.00	38.00		15	.75	.75	156 MHz
PSC-2	1	9.95	9.95		8	.50	.50	VHF Pwr. Split
MPN3401	1	.30	.30		[illegible]	.08	.08	VHF Pin diode
IN5711	3	.48	1.44		15	.08	.24	
IN821	1	.50	.50		5	.08	.08	Zener
82P-200	1	.50	.50		15	.30	.30	Trim Pot
Inductor	3	.60	1.80		15	.08	.24	
Capacitor	13	.12	1.56		65	.11	1.43	Ceramic
Resistor	14	.07	.98		70	.08	1.12	Metal Film
PC Board	1	3.00	3.00		25			
Board Process				333	485			
Total Labor				333	794			
PCB Area							8.24	1-2" x 6" card
Complexity				1.0	1.0			
TOTALS			[illegible]	333	794			

SYSTEM Dual-Channel GPS Navigator **SHEET** 1 **OF** 2

SUB-ASSEMBLY Synthesizer/Timer

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
LM308A	1	.50	.50		8	.25	.25	OP-05CP
LM2903	1	.65	.65		8	.50	.50	
LM78L12	1	.25	.25		6	.11	.11	
LM79L12	1	.65	.65		6	.11	.11	
MC10131	1	1.84	1.84		10	.50	.50	ECL
MC10136	2	5.00	10.00		20	.50	1.00	ECL
MC12040	1	6.98	6.98		10	.50	.50	ECL
2N3906	1	.36	.36		6	.11	.11	
2N3933	3	.80	2.40		18	.11	.33	
1N4448	2	.06	.12		10	.08	.16	
1N4001	1	.10	.10		5	.08	.08	
T4-1	1	2.95	2.95		8	.22	.22	Xformer 8 pin DIP
PSC2-1	3	9.95	29.85		24	.50	1.50	Power Split
PSC4-3	1	23.95	23.95		8	.50	.50	Power Split
SRA-1	1	7.95	7.95		8	.50	.50	Mixer
TCXO	1	90.00	90.00		15	4.25	4.25	10.23 MHz
VCXO	1	67.00	67.00		15	2.50	2.50	88.66 MHz
Inductor	2	.60	1.20		10	.08	.16	
Capacitor	18	.12	2.16		90	.11	1.98	Ceramic
Capacitor	4	.17	.68		30	.11	.66	Tantalum
TOTALS								

SYSTEM Dual-Channel GPS Navigator

SHEET 2 OF 2

SUB-ASSEMBLY Synthesizer/Timer

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
Resistor	44	.04	1.76		220	.08	3.52	
PC Board	1	8.00	8.00		25			
Board Process				333	485			
Total Labor				333	1065			
PCB Area							17.90	4" x 8" card
Complexity				1.0	1.0			
TOTALS			261.33	333	1065			

SYSTEM Dual-Channel GPS Navigator

SUB-ASSEMBLY Receiver (1&2)

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
LSI 1	1	20.00	20.00		24	5.00	5.00	Custom
LSI 2	1	20.00	20.00		24	5.00	5.00	Custom
LSI 3	1	20.00	20.00		24	5.00	5.00	Custom
7416	1	.27	.27		8	.50	.50	
74C374	2	1.80	3.60		22	.67	1.34	
74LS32	1	.26	.26		8	.50	.50	
74S00	2	.30	.60		16	.50	1.00	
74S02	1	.30	.30		8	.50	.50	
74S08	1	.30	.30		8	.50	.50	
74S11	1	.30	.30		8	.50	.50	
74S20	1	.30	.30		8	.50	.50	
74S32	1	.34	.34		8	.50	.50	
74S51	1	.30	.30		8	.50	.50	
74S74	1	.49	.49		8	.50	.50	
74S139	1	.90	.90		10	.50	.50	
74S240	2	1.87	3.74		16	.50	1.00	
74S244	2	2.10	4.20		16	.50	1.00	
74S260	1	.49	.49		8	.50	.50	
74S373	2	2.25	4.50		22	.67	1.34	
74S393	1	.97	.97		8	.50	.50	
8259A	1	5.50	5.50		14	2.00	2.00	
8303	4	2.60	10.40		44	.67	2.68	
8304	2	2.25	4.50		22	.67	1.34	
~~TOTALS~~								

SYSTEM Dual-Channel GPS Navigator — SHEET 2 OF 4

SUB-ASSEMBLY Receiver (1&2)

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
9513	1	15.65	15.65		20	4.25	4.25	Timer
9551	1	4.25	4.25		20	4.25	4.25	USART
AD570	2	12.60	25.20		22	.62	1.25	A/D Converter
AD583K	2	16.35	32.70		16	.50	1.00	Sample & Hold
AD7524	1	4.50	4.50		10	.50	.50	D/A Converter
AD7525	4	9.60	38.40		44	.62	2.48	Digital Pot
CA3054	1	.73	.73		8	.50	.50	
CA3240E	2	1.34	2.68		16	.50	1.00	
FP8-PC-70	1	75.40	75.40		20	1.50	1.50	Phase Comparitor
FP8-SSB-1026	1	70.00	70.00		20	1.50	1.50	SSB Modulator
FP8-SSB-1027	1	70.00	70.00		20	1.50	1.50	SSB Modulator
7808	1	.98	.98		6	.19	.19	
7905	1	1.00	1.00		6	.19	.19	
MC34004	2	1.67	3.34		16	.50	1.00	
MWA120	6	6.75	40.50		48	.25	1.50	RF Amplifier
MWA130	3	7.15	21.45		24	.25	.75	RF Amplifier
SL1610C	3	2.03	6.09		24	.50	1.50	
Z8002	1	88.65	88.65		20	4.25	4.25	16 bit CPU
Crystal	1	6.84	6.84		15	.60	.60	8 MHz
2716	2	5.10	10.20		24	1.12	2.24	2KX8 EPROM
2732	2	10.75	21.50		24	1.12	2.24	4KX8 EPROM
2114	12	1.90	22.80		132	.62	7.44	1KX4 RAM
TOTALS								

SYSTEM Dual-Channel G S Navigator

SHEET 3 OF 4

SUB-ASSEMBLY Receiver (1&2)

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
Crystal	1	8.58	8.58		15	.60	.60	19.0668 MHz
2N2222A	3	.18	.54		18	.11	.33	
2N2907	2	.16	.32		12	.11	.22	
2N3546	1	.43	.43		6	.11	.11	
2N3646	1	.20	.20		6	.11	.11	
2N4416	2	.65	1.30		12	.11	.22	
2N5179	1	.77	.77		6	.11	.11	
1N914	1	.13	.13		5	.08	.08	
1N4001	3	.10	.30		15	.08	.24	
1N4148	6	.06	.36		30	.08	.48	
1N4448	8	.06	.48		40	.08	.64	
1N5711	3	.48	1.44		15	.08	.24	
Capacitor	88	.12	10.56		440	.11	9.68	Ceramic
Capacitor	7	.33	2.31		35	.11	.77	Tantalum
Capacitor	7	.80	5.60		42	.12	.84	Variable
Resistor	2	.12	.24		10	.08	.16	1%,50ppm/°C
Resistor	20	.07	1.40		100	.08	1.60	Metal Film
Resistor	45	.04	1.80		225	.08	3.60	Carbon Comp.
Resistor Pack	4	.06	.24		32	.50	2.00	
Inductor	2	1.24	2.48		500	.75	1.50	Core,W/#14AWG
Bandpass Filter	1	38.00	38.00		10	.50	.50	
SBL-1	2	5.95	11.95		16	1.00	1.00	Mixer
TOTALS								

SYSTEM Dual-Channel GPS Navigator **SHEET** 4 **OF** 4

SUB-ASSEMBLY Receiver (1&2)

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
Ferrite Bead	2	.09	.18		14	.08	.16	
P.C. Boards	2	13.50	27.00		100			
Board Process				666	970			
Total Labor				666	3571			
PCB Area							99.08	2-6" x 9" cards
Complexity				2.0	2.0			
TOTALS			781.[illegible]	1332	7142			

SYSTEM Dual-Channel GPS Navigator SHEET 1 OF 1

SUB-ASSEMBLY PNP

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
8086-2	1	52.30	52.30		20	4.25	4.25	16 bit CPU
Crystal	1	4.10	4.10		15	.60	.60	8.0 MHz
2732	28	10.75	301.00		336	1.12	31.36	4KX8 EPROM
8114	56	1.90	106.40		616	.62	34.72	1KX4 RAM
74LS138	3	.61	1.83		30	.50	1.50	
MM5303	3	4.00	12.00		60	4.25	12.75	UART
9101	4	2.80	11.20		44	.70	2.80	
8414	4	5.47	21.88		44	.62	2.48	1KX4 CMOS RAM
8303	2	2.60	5.20		22	.67	1.34	
8304	2	2.25	4.50		22	.67	1.34	
25S373	2	2.05	4.10		22	.67	1.34	
74123	1	.43	.43		10	.50	.50	
4011	1	.42	.42		8	.50	.50	
Capacitor	3	.12	.36		5	.08	.08	Ceramic
Resistor	3	.04	.12		5	.08	.24	
P.C. Boards	2	13.50	27.00		50			
Board Process				666	970			
Total Labor				666	2279			
P.C. Area							95.96	2-6" x 9" cards
Complexity					1.5			
TOTALS			552.84	999	3418			

SYSTEM Dual-Channel GPS Navigator **SHEET** 1 **OF** 1

SUB-ASSEMBLY Power Supply

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
78H05	1	5.05	5.05		6	.11	.11	
7812	1	.25	.25		6	.11	.11	
7912	1	.65	.65		6	.11	.11	
Transistor	2	1.18	2.36		12	.11	.22	
IN4154	2	.06	.12		12	.08	.16	
Inductor	1	.60	.60		5	.08	.08	
Capacitors	10	.33	3.30		50	.11	1.10	Tantalum
Resistors	4	.04	.16		20	.08	.32	
Transformer	1	12.09	12.09		315	1.25	1.25	
Heat Sink	1	.15	.15	15	10	1.00	1.00	
P.C. Board	1	2.00	2.00		25			
Board Process				333	485			
Total Labor				348	950			
PCB Area							4.46	1-2" x 3"
Complexity				1.0	1.0			
TOTALS			26.73	348	950			

SYSTEM Dual-Channel GPS Navigator

SUB-ASSEMBLY Assembly & Test

SHEET 1 OF 1

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
Down Converter	1				25			
Synthesizer	1				25			
Receiver	2				100			
PNP	1				50			
Power Supply	1				25			
Enclosure/Chassis	1				100			
P.S. Alignment					100			
RX Alignment					400			
Burn-In					1000			
Functional Test					1000			
TOTALS								

SYSTEM Dual-Channel GPS Navigator

SUB-ASSEMBLY Enclosure & Chassis

SHEET 1 OF 1

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
Chassis	1	4.00	4.00	184	44			
Cover L-R	2	.80	1.60	50	22			
Cover F-R	2	2.50	5.00	148	44			
P.C. Brd. Assbly	1	2.00	2.00	150	75			
Cover TB	2	.80	1.60	25	22			
Connector RF	1	1.50	1.50	25	15			
Connector Cable	1	1.50	1.50		25			
Connector PCB	8	.60	4.80		200			
Support Bracket	2	1.60	3.20	92	24			
Retaining Strap	2	2.50	5.00	28	10			
Misc. Hardware	Lot	5.75	5.75		250			
Wiring	Lot	8.20	8.20		1000			
TOTALS			44.15	702	1731			

SYSTEM GPS Control/Display　　　　SHEET ______ OF ______

SUB-ASSEMBLY Processor

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
Custom LSI	1	20.00	20.00		20	4.25	4.25	40 pin DIP
74C164	1	1.11	1.11		8	.50	.50	
74LS138	1	.63	.63		8	.50	.50	
75584	14	1.95	27.30		154	.62	8.68	Display Driver
9667	2	.78	1.56		16	.50	1.00	
DC/DC Convertor	1	8.96	8.96		15	1.31	1.31	Display Power
IN3051	1	3.00	3.00		5	.10	.10	
Crystal	1	4.55	4.55		15	.60	.60	1 MHz
Inductor	1	.60	.60		5	.08	.08	
Capacitor	9	.33	2.97		45	.11	.99	Tantalum
Resistor	20	.04	.80		100	.08	1.60	
P.C. Board	2	5.00	10.00		50			
Board Process				666	970			
Total Labor				666	1411			
PCB Area						19.61		2-5" x 3" cards
Complexity				1.0	1.0			
TOTALS			81.48	666	1411			

SYSTEM GPS Control/Display

SUB-ASSEMBLY Front Panel

SHEET 1 OF 1

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
Panel	1	1.00	1.00	74	22			
Keyboard	1	2.75	2.75		25			
Switch	1	1,64	1.64		15			DPDT
Switch	1	1.24	1.24		15			SPDT
Switch	1	2.73	2.73		15			Rotary
Display	1	10.00	10.00		100			Gas Discharge
Potentiometer	1	1.57	1.57		15			
Knob	2	1.10	2.20		10			
1820 lamp	14	.45	6.30		70			
1847 lamp	6	.24	1.44		30			
Misc. Hardware	Lot	1.00	1.00		100			
TOTALS			31.87	74	417			

SYSTEM GPS Control/Display

SUB-ASSEMBLY Enclosure & Chassis

SHEET 1 OF 1

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
Chassis	1	2.00	2.00	184	44			
Cover	1	.80	.80	334	5			
PCB Connector	2	.57	1.71		30			
Cable Connector	1	1.56	1.56		25			
Misc. Hardware	Lot	1.50	1.50		125			
Wiring	Lot	2.50	2.50		500			
TOTALS			9.50	518	724			

SYSTEM GPS Control/Display

SUB-ASSEMBLY Assembly & Test

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
Processor PCB	2				50			
Chassis	1				50			
Front Panel	1				100			
Burn-In					1000			
Functional Test					1000			
TOTALS					2200			

APPENDIX C

PROJECTED-COST VERSION WORKSHEETS

SYSTEM Dual-Channel GPS Navigator

SUB-ASSEMBLY Down Converter

SHEET 1 OF 1

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
Freq. Doubler	4	9.57	38.28		32	.50	2.00	X16 to L-Band
TFM-15	1	49.95	49.95		7	.50	.50	Mixer (L-Band)
MWA 110	4	6.45	25.80		32	.25	1.00	VHF Amp
Bandpass Filter	1.	38.00	38.00		15	.75	.75	156 MHz
PSC-2	1	9.95	9.95		8	.50	.50	VHF Pwr. Splitter
MPN3401	1	.30	.30		5	.08	.08	VHF Pin diode
IN5711	3	.48	1.44		15	.08	.24	
IN821	1	.50	.50		5	.08	.08	Zener
BZP-200	1	.50	.50		15	.30	.30	Trim Pot
Inductor	3	.60	1.80		15	.08	.24	
Capacitor	13	.12	1.56		65	.11	1.43	Ceramic
Resistor	14	.07	.98		70	.08	1.12	Metal Film
PC Board	1	3.00	3.00		25			
Board Process				333	485			
Total Labor				333	794			
PCB Area							8.24	1-2" x 6" card
Complexity				1.0	1.0			
TOTALS			172.06	333	794			

SYSTEM Dual-Channel GPS Navigator

SHEET 1 OF 2

SUB-ASSEMBLY Synthesizer/Timer

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
LM308A	1	.50	.50		8	.25	.25	OP-05CP
LM2903	1	.65	.65		8	.50	.50	
LM78L12	1	.25	.25		6	.11	.11	
LM79L12	1	.65	.65		6	.11	.11	
MC10131	1	1.84	1.84		10	.50	.50	ECL
MC10136	2	5.00	10.00		20	.50	1.00	ECL
MC12040	1	6.98	6.98		10	.50	.50	ECL
2N3906	1	.36	.36		6	.11	.11	
2N3933	3	.80	2.40		18	.11	.33	
IN4448	2	.06	.12		10	.08	.16	
IN4001	1	.10	.10		3	.08	.08	
T4-1	1	2.95	2.95		3	.22	.22	Xformer, 8 pin DIP
PSC2-1	3	9.95	29.85		24	.50	1.50	Power Split
PSC4-3	1	23.95	23.95		8	.50	.50	Power Split
SRA-1	1	7.95	7.95		8	.50	.50	Mixer
TCXO	1	90.00	90.00		15	4.25	4.25	10.23 MHz
VCXO	1	67.00	67.00		15	2.50	2.50	88.66 MHz
Inductor	2	.60	1.20		10	.08	.16	
Capacitor	18	.12	2.16		90	.11	1.98	Ceramic
Capacitor	4	.17	.68		20	.11	.44	Mica
Capacitor	6	.33	1.98		30	.11	.66	Tantalum
TOTALS								

SYSTEM Dual-Channel GPS Navigator

SUB-ASSEMBLY Synthesizer/Timer

SHEET 2 OF 2

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
Resistor	44	.04	1.76		220	.08	3.52	
PC Board	1	8.00	8.00		25			
Board Process				333	485			
Total Labor				333	1065			
PCB Area							17.90	4" x 8" cards
Complexity				1.0	1.0			
TOTALS			261.33	333	1065			

SYSTEM Dual-Channel GPS Navigator

SUB-ASSEMBLY Receiver (1&2)

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
LSI 1	1	20.00	20.00		24	5.00	5.00	Custom
LSI 2	1	20.00	20.00		24	5.00	5.00	Custom
LSI 3	1	20.00	20.00		24	5.00	5.00	Custom
7416	1	.27	.27		8	.50	.50	
74C374	2	1.80	3.60		22	.67	1.34	
74LS32	1	.26	.26		8	.50	.50	
74S00	2	.30	.60		16	.50	1.00	
74S02	1	.30	.30		8	.50	.50	
74S08	1	.30	.30		8	.50	.50	
74SL	1	.30	.30		8	.50	.50	
74S20	1	.30	.30		8	.50	.50	
74S32	1	.34	.34		8	.50	.50	
74S51	1	.30	.30		8	.50	.50	
74S74	1	.49	.49		8	.50	.50	
74S139	1	.90	.90		10	.50	.50	
74S240	2	1.87	3.74		16	.50	1.00	
74S244	2	2.10	4.20		16	.50	1.00	
74S260	1	.49	.49		8	.50	.50	
74S373	2	2.25	4.50		22	.67	1.34	
74S393	1	.97	.97		8	.50	.50	
8259A	1	5.50	5.50		4	2.00	2.00	
8303	4	2.60	10.40		44	.67	2.68	
8304	2	2.25	4.50		22	.67	1.34	
TOTALS								

SYSTEM Dual-Channel GPS Navigator

SUB-ASSEMBLY Receiver (1&2)

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
9513	1	15.65	15.65		20	4.25	4.25	Timer
9551	1	4.25	4.25		20	4.25	4.25	USART
AD570	2	12.60	25.20		22	.62	1.25	A/D Convertor
AD583K	2	16.35	32.70		16	.50	1.00	Sample & Hold
AD7524	1	4.50	4.50		10	.50	.50	D/A Converter
AD7525	4	9.60	38.40		44	.62	2.48	Digital Pot
CA3054	1	.73	.73		8	.50	.50	
CA3240E	2	1.34	2.68		16	.50	1.00	
FP8-PC-70	1	75.40	75.40		20	1.50	1.50	Phase Comparitor
FP8-SSB-1026	1	70.00	70.00		20	1.50	1.50	SSB Modulator
FP8-SSB-1027	1	70.00	70.00		20	1.50	1.50	SSB Modulator
7808	1	.98	.98		6	.19	.19	
7905	1	1.00	1.00		6	.19	.19	
MC34004	2	1.67	3.34		16	.50	1.00	
MWA120	6	6.75	40.50		48	.25	1.50	RF Amplifier
MWA130	3	7.15	21.45		24	.25	.75	RF Amplifier
SL1610C	3	2.03	6.09		24	.50	1.50	RF Amplifier
16bit CPU	1	16.00	16.00		20	4.25	4.25	
Crystal	1	6.84	6.84		15	.60	.60	8 MHz
64K EPROM	2	5.23	10.46		28	2.00	4.00	8KX8
16K RAM	4	3.70	14.80		48	1.12	4.48	2KX8
TOTALS								

SYSTEM Dual-Channel GPS Navigator | SHEET 3 OF 4

SUB-ASSEMBLY Receiver (1&2)

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENT
				MANUFACTURING	ASSEMBLY			
Crystal	1	8.58	8.58		15	.60	.60	19.0668 MHz
2N2222A	3	.18	.54		18	.11	.33	
2N2907	2	.16	.32		12	.11	.22	
2N3546	1	.43	.43		6	.11	.11	
2N3646	1	.20	.20		6	.11	.11	
2N4416	2	.65	1.30		12	.11	.22	
2N5179	1	.77	.77		6	.11	.11	
1N914	1	.13	.13		5	.08	.08	
1N4001	3	.10	.30		15	.08	.24	
1N4148	6	.06	.36		30	.08	.48	
1N4448	8	.06	.48		40	.08	.64	
1N5711	3	.48	1.44		15	.08	.24	
Capacitor	88	.12	10.56		440	.11	9.68	Ceramic
Capacitor	7	.33	2.31		35	.11	.77	Tantalum
Capacitor	7	.80	5.60		42	.12	.84	Variable
Resistor	2	.12	.24		10	.08	.16	1%,50ppm/°C
Resistor	20	.07	1.40		100	.08	1.60	Metal Film
Resistor	45	.04	1.80		225	.08	3.60	Carbon Comp.
Resistor Pack	4	.06	.24		32	.50	2.00	
Inductor	2	1.24	2.48		500	.75	.50	Core, W/#14AWG
Bandpass Filter	1	38.00	38.00		10	.50	.50	
SBL-1	2	5.95	11.95		16	1.00	1.00	Mixer
TOTALS								

SYSTEM Dual-Channel GPS Navigator

SUB-ASSEMBLY Receiver (1&2)

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
Ferrite Bead	2	.09	.18		14	.08	.16	
P.C. Board	2	13.50	27.00		100			
Board Process				666	970			
Total Labor				666	3464			
PCB Area							95.64	2-6" x 9" cards
Complexity				1.75	1.75			
TOTALS			679.84	1166	6062			

SYSTEM Dual-Channel GPS Navigator SHEET 1 OF 1

SUB-ASSEMBLY PNP

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
16bit CPU	1	16.00	16.00		20	4.25	4.25	
Crystal	1	4.10	4.10		15	.60	.60	8.0 MHz
128K EPROM	7	6.19	43.33		98	1.75	12.25	16KX8
16K RAM	14	3.70	51.80		168	1.12	8.96	2KX8
74LS138	1	.61	.61		10	.50	.50	
MM5303	3	4.00	12.00		60	4.25	12.75	UART
16K CMOS RAM	2	3.70	7.40		24	1.12	2.24	2KX8
8303	2	2.60	5.20		22	.67	1.34	
8304	2	2.25	4.50		22	.67	1.34	
25S373	2	2.05	4.10		22	.67	1.34	
74123	1	.43	.43		10	.50	.50	
4011	1	.42	.42		8	.50	.50	
Capacitor	3	.12	.36		15	.08	.24	Ceramic
Resistor	3	.04	.12		15	.08	.24	
PCBoard	1	13.50	13.50		25			
Board Process				333	485			
Total Labor				333	1019			
PCB Area							53.77	6" x 9" card
Complexity				2.0	2.0			
TOTALS			163.87	666	2038			

SYSTEM Dual-Channel GPS Navigator

SHEET 1 OF 1

SUB-ASSEMBLY Power Supply

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
78H05	1	5.05	5.05		6	.11	.11	
7812	1	.25	.25		6	.11	.11	
7912	1	.65	.65		6	.11	.11	
Transistor	2	1.18	2.36		12	.11	.22	
IN4154	2	.06	.12		10	.08	.16	
Inductor	1	.60	.60		5	.08	.08	
Capacitors	10	.33	3.30		50	.11	1.10	Tantalum
Resistors	4	.04	.16		20	.08	.32	
Transformer	1	12.09	12.09		315	1.25	1.25	
Heat Sink	1	.15	.15		10	1.00	1.00	
PC Board	1	2.00	2.00		25			
Board Process				333	485			
Total Labor				348	950			
PCB Area							4.46	1-2" x 3" card
Complexity				1.0	1.0			
TOTALS			26.73	348	950			

SYSTEM Dual-Channel GPS Navigator

SUB-ASSEMBLY Enclosure & Chassis

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
Chassis	1	4.00	4.00	184	44			
Cover L-R	2	.80	1.60	50	22			
Cover F-R	2	2.50	5.00	148	44			
PC Brd. Assbly.	1	2.00	2.00	150	75			
Cover T-B	2	.80	1.60	25	22			
Connector RF	1	1.50	1.50	25	15			
Connector Cable	1	1.50	1.50		25			
Connector PCB	7	.60	4.20		175			
Support Bracket	2	1.60	3.20	92	24			
Retaining Strap	2	2.50	5.00	28	10			
Misc. Hardware	Lot	5.75	5.75		250			
Wiring	Lot	8.20	8.20		1000			
TOTALS			43.55	702	1706			

SYSTEM Dual-Channel GPS Navigator

SUB-ASSEMBLY Assembly & Test

SHEET 1 OF 1

ITEM NAME OR CATEGORY	QTY	UNIT COST	TOTAL COST	LABOR HOURS PER 1000 UNITS		UNIT PCB AREA	TOTAL PCB AREA	COMMENTS
				MANUFACTURING	ASSEMBLY			
Down Converter	1				25			
Synthesizer	1				25			
Receiver	2				100			
PNP	1				25			
Power Supply	1				25			
Enclosure/Chassis	1				100			
P.S. Alignment					100			
RCVR Alignment					400			
Burn-In					1000			
Functional Test					1000			
TOTALS					2800			

APPENDIX D

REFERENCES

1. Kowalski, S., *Avionics Cost Development for Civil Application of Global Positioning System,* FAA Report FAA-EM-79-1, April 1979.

2. Kowalski, S., et al, *Cost Analysis of the Discrete Address Beacon System for the Low-Performance General Aviation Aircraft Community,* FAA Report FAA-RD-81-61, September 1981.

3. "GPS Navigation Receiver for Civil Aviation," MIT Lincoln Laboratory Quarterly Technical Letters for periods 1 October 1979 through 31 December 1981.

4. *Future Information Processing Technology,* Defense Intelligence Agency Report C-81117, November 1980.

5. Campbell, S., "GPS Navigation Software Design," MIT Lincoln Laboratory Internal Memorandum, 10 July 1981.

6. "GPS Test and Evaluation System PNP External/Software Interfaces," MIT Lincoln Laboratory Interface Control Document, February 16, 1981.

7. Grundy, P., *GPS Test and Evaluation System Receiver/Navigation Processor,* Intermetrics, Inc., Interface Control Document IR-675, 25 February 1981.

8. *GPS Test and Evaluation System Position and Navigation Software,* Intermetrics, Inc., Critical Design Review, March 1981.

9. Toth, S., Lovelace, W., Markin, K., *Impact of Technology on Avionics Cost Trends,* FAA Report FAA-EM-82-6, November 1981.

10. "Experimental Dual Channel Receiver," STI Critical Design Review, STI-TR-9021, 27 February 1981.

11. *PRICE 84 Reference Manual,* Edition 2, Manual for the RCA PRICE Computer Costing Model, January 1981.

12. Schust, A., Young, P., Peter, K., *Life-Cycle-Cost Analysis of the Microwave Landing System Ground and Airborne Systems,* FAA Report FAA-RD-81-96.

13. "Monthly Labor Review," U.S. Department of Labor, Volume 103, No. 11, November 1980.

14. Kowalski, S., *Avionics Cost Development for Use of Loran-C-Navigation Systems by Low-Performance General-Aviation Aircraft*, ARINC Research Publication 1326-01-8-1906, April 1979.

15. Preston, G., "Large Scale Integrated Circuits for Military Applications," IDA Paper P-1244, May 1977.

16. "GPS Test and Evaluation Equipment Specification," MIT Lincoln Laboratory, RFI 033483, October 19, 1979.

END

DATE
FILMED

5 – 83

DTIC