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DEPARTMENT OF TRANSPORTATION

DIVSION OF NEW TECHNOLOGY, MATERIALS AND RESEARCH
OFFICE OF ELECTRICAL AND ELECTRONICS ENGINEERING

# EVALUATE VEHICLE NAVIGATION AND COMMUNICATION TECHNOLOGIES

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16. Abstract

An automatic vehicle location system incorporated in a vehicle-based data logging system was developed. Navigational inputs from various dead-reckoning sensors and a Global Positioning System (GPS) receiver were used to establish the exact location of logged data. The availability of such a location system eliminates the need for an operator to manually tag logged data, thus increasing productivity, accuracy and enhancing safety. Short-range communication using inductive loops as location beacons was also investigated and reported in this project.

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# NOTICE

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## CONVERSION FACTORS

English to Metric System (SI) of Measurement

| Quality | English Unit | Multiply By | To Get Metric Equivalent |
|---|---|---|---|
| Length | inches (in) or (") | 25.40 | millimetres (mm) |
| | | .02540 | metres (m) |
| | feet (ft) or (') | .3048 | metres (m) |
| | miles (mi) | 1.609 | kilometres (km) |
| Area | square inches ($in^2$) | $6.432 \times 10^{-4}$ | square metres ($m^2$) |
| | square feet ($ft^2$) | .09290 | square metres ($m^2$) |
| | acres | .4047 | hectares (ha) |
| Volume | gallons (gal) | 3.785 | litre (l) |
| | cubic feet ($ft^3$) | .02832 | cubic metres ($m^3$) |
| | cubic yards ($yd^3$) | .7646 | cubic metres ($m^3$) |
| Volume/Time (Flow) | cubic feet per second ($ft^3/s$) | 28.317 | litres per second (l/s) |
| | gallons per minute (gal/min) | .06309 | litres per second (l/s) |
| Mass | pounds (lb) | .4536 | kilograms (kg) |
| Velocity | miles per hour (mph) | .4470 | metres per second (m/s) |
| | feet per second (fps) | .3048 | metres per second (m/s) |
| Acceleration | feet per second squared ($ft/s^2$) | .3048 | metres per second squared ($m/s^2$) |
| | acceleration due to force of gravity (G) | 9.807 | metres per second squared ($m/s^2$) |
| Density | ($lb/ft^3$) | 16.02 | kilograms per cubic metre ($kg/m^3$) |
| Force | pounds (lb) | 4.448 | newtons (N) |
| | kips (1000 lb) | 4448 | newtons (N) |
| Thermal Energy | British thermal unit (BTU) | 1055 | joules (J) |
| Mechanical Energy | foot-pounds (ft-lb) | 1.356 | joules (J) |
| | foot-kips (ft-k) | 1356 | joules (J) |
| Bending Moment or Torque | inch-pounds (in-lb) | .1130 | newton-metres (Nm) |
| | foot-pounds (ft-lb) | 1.356 | newton-metres (Nm) |
| Pressure | pounds per square inch (psi) | 6895 | pascals (Pa) |
| | pounds per square foot (psf) | 47.88 | pascals (Pa) |
| Plane Angle | degrees (°) | 0.0175 | radians (rad) |
| Temperature | degrees fahrenheit (°F) | $\frac{°F - 32}{1.8} = °C$ | degrees celsius (°C) |
| Concentration | parts per million (ppm) | 1 | milligrams per kilogram (mg/kg) |

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## GLOSSARY

A/D ---- Analog-to-Digital
ASCII -- American Standard Code for Information Interchange
AVI ---- Automatic Vehicle Identification
DCE ---- Data Communication Equipment
DGPS --- Differential Global Positioning System
DOS ---- Disk Operating System
DTE ---- Data Terminal Equipment
EPROM -- Erasable Programmable Read-Only Memory
FM ----- Frequency Modulation
FS ------Full Scale
GDOP --- Geometric Dilution of Precision
GPS ---- Global Positioning System
I/O ---- Input/Output
IBM ----. International Business Machines
LCD ---- Liquid Crystal Display
LED ---- Light Emitting Diode
LORAN -- LOng Range Navigation system
LSB ---- Least Significant Bit
NMEA --- National Marine Electronics Association
OEM ---- Original Equipment Manufacturer
PC ----- Personal Computer
R/W ---- Read/Write
RAM ---- Random Access Memory
STD ---- An industrial microcomputer bus standard

## TABLE OF CONTENTS


| | page |
|---|---|
| ACKNOWLEDGEMENTS | ii |
| GLOSSARY | iii |
| 1. INTRODUCTION | 1 |
| 1.1 Problem | 1 |
| 1.2 Objective | 1 |
| 1.3 Background | 1 |
| 1.4 Scope | 2 |
| 2. TECHNOLOGY OPTIONS | 5 |
| 2.1 Dead Reckoning | 5 |
| 2.2 Map Matching | 5 |
| 2.3 Inductive Loops | 6 |
| 2.4 Radio Transponder Tags | 6 |
| 2.5 Radio Beacons | 7 |
| 2.6 Infrared Beacons | 7 |
| 2.7 LORAN | 7 |
| 2.8 Global Positioning System (GPS) | 8 |
| 3. CONCURRENT PROJECTS | 9 |
| 4. NEW PRODUCTS | 11 |
| 4.1 Compass | 11 |
| 4.2 Gyroscope | 11 |
| 4.3 Angular Rate Sensor | 12 |
| 4.4 GPS | 12 |
| 5. CONCLUSIONS | 13 |
| 6. RECOMMENDATIONS | 15 |
| 7. IMPLEMENTATION | 17 |

8. TECHNICAL DISCUSSION 19

8.1 Test Conditions 19

8.1.1 Test Routes 19

8.1.2 Test Vehicle 31

8.1.3 Test Equipment 31

8.1.4 Test Procedures 31

8.1.4.1 Calibration 31

8.1.4.2 Data Collection 35

8.1.4.3 Data Reduction 35

8.1.4.3.1 Compass 35

8.1.4.3.2 Angular Rate Sensor 37

8.1.4.3.3 GPS 39

8.2 Discussion of Results 40

8.2.1 Compass 40

8.2.2 Angular Rate Sensor 41

8.2.3 GPS 41

8.2.4 Feature Logging 43

8.2.5 Loop Excitation Monitor 43

9. REFERENCES 93

APPENDICES

A. Record Formats A-1

A.1 Navigation Files (Dead Reckoning) A-1

A.2 Navigation Files (GPS) A-2

A.3 Loop Files A-4

A.4 Attribute Files A-5

A.5 Summary A-5

B. Hardware Description B-1

B.1 General B-1

B.2 Functional Description B-1

B.2.1 Sensing Devices B-1

B.2.1.1 Inductive Radio Communications System B-1

B.2.1.2 Angular Rate Sensor B-1

B.2.1.3 Transmission Sensor (Odometer) B-2

B.2.1.4 Fluxgate Compass B-2

B.2.1.5 Loop Excitation Monitor B-2

B.2.1.6 Global Positioning System B-2

B.2.2 Computer System B-3

B.2.2.1 Power Supply B-3

B.2.2.2 Signal Conditioning Board B-3

B.2.2.3 Multichannel Serial Board B-4

B.2.2.4 A/D Converter B-4

B.2.2.5 CPU Board B-4

B.2.2.6 Memory Cassette B-5

B.2.2.7 Memory Board B-5

B.2.2.8 Front Panel Display B-5

B.2.2.9 Laptop Computer B-6

C. Software Description C-1

C.1 Data Collection Routines C-1

C.1.1 ISR.ASM C-1

C.1.2 NAV.C C-2

C.2 CONVERSION ROUTINES C-3

C.2.1 CNVNAV.C C-3

C.2.2 CNVLOOP.C C-3

C.2.3 CNVGPS.C C-4

D. Software Listings D-1

D.1 ISR.ASM D-2

D.2 NAV.C D-7

D.3 CNVNAV.C D-25

D.4 CNVLOOP.C D-28

D.5 CNVGPS.C D-32

E. Computer System Configuration E-1

E.1 System Addressing E-2

E.2 Matrix ADC-12M Jumper Configuration and Switch Settings E-3

E.3 Enlode 334C-1M Jumper Configuration E-5

E.4 Caltrans Signal Conditioning Board 631150-300 Jumper Configuration E-6

E.5 Ziatech ZT8809 CPU Jumper Configuration E-7

E.6 Ziatech ZT8840 Jumper Configuration E-12

E.7 Ziatech ZT8825 Memory Jumper Configuration E-14

F. Computer System Schematics F-1

Wiring Interconnect F-3

Wiring Interconnect Bill of Materials F-4

Cable Details F-7

Cable Details Bill of Materials F-8

Operator Interface Interconnect F-11

Operator Interface Interconnect Bill of Materials F-12

| | | |
|---|---|---|
| | Display Interface Board | F-13 |
| | Display Interface Board Bill of Materials | F-14 |
| | Power Supply Board | F-17 |
| | Power Supply Board Bill of Materials | F-18 |
| | Loop Excitation Antenna | F-21 |
| | Loop Excitation Antenna Bill of Materials | F-22 |
| | Signal Conditioning Board | F-23 |
| | Signal Conditioning Board Bill of Materials | F-24 |
| | Backup Light Monitor | F-29 |
| | Signal Conditioning Board to CPU Interconnect | F-31 |
| | In-Vehicle CPU Wirewrap/Jumper Assignments | F-33 |
| | In-Cabinet CPU Wirewrap/Jumper Assignments | F-35 |
| | GPS Connections | F-37 |
| | GPS Connections Bill of Materials | F-38 |
| G. | Sample Data -- BLOCK.WK3 | G-1 |
| | G.1 Compass and ARS | G-2 |
| | G.2 GPS | G-9 |
| H. | Attribute Log/Inductive Loop Summary and Plots for Route 3 | H-1 |
| I. | INRAD | I-1 |
| J. | Loop Excitation Monitor Calibration | J-1 |

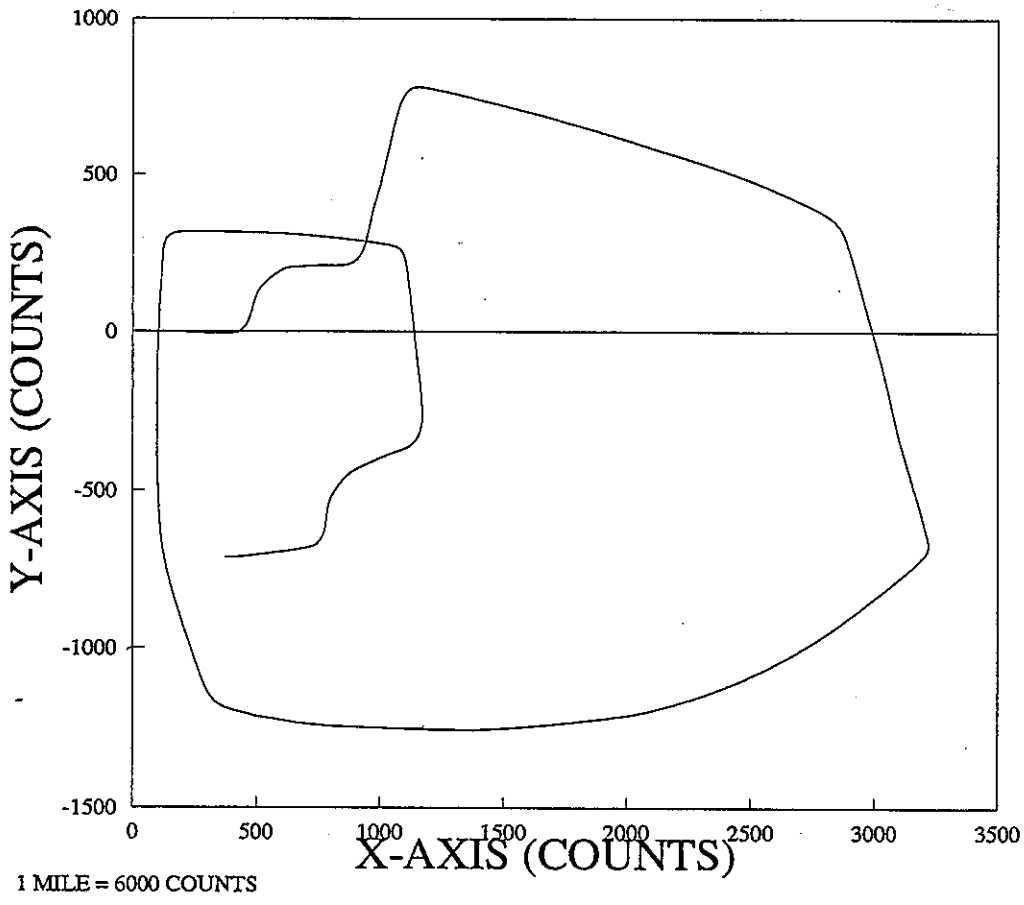



Figure 42

Angular Rate Sensor Path
Route 1 June 1, 1992

| | | |
|---|---|---|
| 18 | Compass Magnetization Circle<br>Route 2<br>May 28, 1992 | 47 |
| 19 | Compass Magnetization Circle<br>Route 3<br>June 12, 1992 | 48 |
| 20 | Compass Magnetization Circle<br>Route 4<br>June 15, 1992 | 49 |
| 21 | Compass Magnetization Circle<br>Route 5<br>August 4, 1992 | 50 |
| 22 | Compass Magnetization Circle<br>Route 5A<br>August 5, 1992 | 51 |
| 23 | Compass Path<br>Route 1<br>June 1, 1992 | 52 |
| 24 | Compass Path<br>Route 1<br>June 12, 1992 | 53 |
| 25 | Compass Path<br>Route 2<br>May 28, 1992 | 54 |
| 26 | Compass Path<br>Route 3<br>June 12, 1992 | 55 |
| 27 | Compass Path<br>Route 4<br>June 15, 1992 | 56 |
| 28 | Compass Path<br>Route 5<br>August 4, 1992 | 57 |
| 29 | Compass Path<br>Route 5A<br>August 5, 1992 | 58 |
| 30 | Angular Rate vs. Time<br>Route 1<br>June 1, 1992 | 59 |

| | | |
|---|---|---|
| 31 | Corrected Angular Rate vs. Time<br>Route 1<br>June 1, 1992 | 59 |
| 32 | Angular Rate vs. Time<br>Route 1<br>June 12, 1992 | 60 |
| 33 | Corrected Angular Rate vs. Time<br>Route 1<br>June 12, 1992 | 60 |
| 34 | Angular Rate vs. Time<br>Route 2<br>May 28, 1992 | 61 |
| 35 | Corrected Angular Rate vs. Time<br>Route 2<br>May 28, 1992 | 61 |
| 36 | Angular Rate vs. Time<br>Route 3<br>June 12, 1992 | 62 |
| 37 | Corrected Angular Rate vs. Time<br>Route 3<br>June 12, 1992 | 62 |
| 38 | Angular Rate vs. Time<br>Route 5<br>August 4, 1992 | 63 |
| 39 | Corrected Angular Rate vs. Time<br>Route 5<br>August 4, 1992 | 63 |
| 40 | Angular Rate vs. Time<br>Route 5A<br>August 5, 1992 | 64 |
| 41 | Corrected Angular Rate vs. Time<br>Route 5A<br>August 5, 1992 | 64 |
| 42 | Angular Rate Sensor Path<br>Route 1<br>June 1, 1992 | 65 |
| 43 | Angular Rate Sensor Path<br>Route 1<br>June 12, 1992 | 66 |

44 Angular Rate Sensor Path
Route 2
May 28, 1992 67

45 Angular Rate Sensor Path
Route 3
June 12, 1992 68

46 Angular Rate Sensor Path
(Incrementally Corrected)
Route 4
April 30, 1992 69

47 1-Channel GPS Receiver Path
Route 1
June 1, 1992 71

48 5-Channel GPS Receiver Path
Route 1
June 1, 1992 71

49 1-Channel GPS Receiver Path
Route 1
June 12, 1992 72

50 5-Channel GPS Receiver Path
Route 1
June 12, 1992 72

51 1-Channel GPS Receiver Path
Route 2
May 28, 1992 73

52 5-Channel GPS Receiver Path
Route 2
May 28, 1992 73

53 1-Channel GPS Receiver Path
Route 3
June 12, 1992 74

54 5-Channel GPS Receiver Path
Route 3
June 12, 1992 74

55 1-Channel GPS Receiver Path (Lab7 to Watt Ave.)
Route 3
June 12, 1992 75

56 5-Channel GPS Receiver Path (Lab7 to Watt Ave.)
Route 3
June 12, 1992 75

57 1-Channel GPS Receiver Path (Hazel Ave. Ramps)
Route 3
June 12, 1992 76

58 5-Channel GPS Receiver Path (Hazel Ave. Ramps)
Route 3
June 12, 1992 76

59 1-Channel GPS Receiver Path
Route 4
June 15, 1992 77

60 5-Channel GPS Receiver Path
Route 4
June 15, 1992 77

61 1-Channel GPS Receiver Path
Route 5
August 4, 1992 78

62 5-Channel GPS Receiver Path
Route 5
August 4, 1992 78

63 1-Channel GPS Receiver Path
Route 5A
August 4, 1992 79

64 5-Channel GPS Receiver Path
Route 5A
August 4, 1992 79

65 1-Channel GPS Receiver Path
Route 2
September 17, 1992 80

66 5-Channel GPS Receiver Path
Route 2
September 17, 1992 80

67 Inductive Loop 1
Route 1
June 12, 1992 84

68 Inductive Loop 5
Route 1
June 12, 1992 85

69 Light Rail Crossing
"Loop 10"
Route 1
June 12, 1992 86

| | | |
|---|---|---|
| 70 | Inductive Loop 14<br>Route 4<br>April 30, 1992 | 87 |
| 71 | Folsom Blvd. Undercrossing<br>View from Westbound Highway 50 | 88 |
| 72 | Folsom Blvd. Undercrossing<br>View from Folsom Blvd. | 88 |
| 73 | Stockton Blvd. Undercrossing<br>View from Stockton Blvd. | 89 |
| 74 | Stockton Blvd. Undercrossing<br>View from Westbound Highway 50 | 89 |
| 75 | Interchange: Highway 50, Business 80, Highway 99<br>View from Westbound Highway 50 | 90 |
| 76 | 26th St. Undercrossing<br>View from 26th St. | 91 |
| 77 | 26th St. Undercrossing<br>View from Westbound Highway 50 | 91 |
| B1 | Computer System | B-7 |
| B2 | INRAD Operator Interface | B-8 |
| B3 | Inductive Radio Communications System | B-8 |
| B4 | Angular Rate Sensor | B-9 |
| B5 | Odometer | B-9 |
| B6 | Fluxgate Compass | B-10 |
| B7 | Loop Excitation Antenna | B-10 |
| B8 | 5-Channel GPS Receiver with Antenna | B-11 |
| B9 | Power Supply | B-12 |
| B10 | Signal Conditioning Board | B-12 |
| B11 | Multichannel Serial Board | B-13 |
| B12 | A/D Converter | B-13 |
| B13 | CPU Board | B-14 |
| B14 | Cassette Memory Board | B-14 |

| | | |
|---|---|---|
| B15 | Memory Board | B-15 |
| B16 | Navigation Equipment Installation | B-16 |
| B17 | Odometer Installation | B-17 |
| B18 | Loop Excitation Antenna and Modem Installation | B-18 |
| H1 | Inductive Loop 6 Route 3 | H-7 |
| H2 | Inductive Loop 7 Route 3 | H-8 |
| H3 | Inductive Loop 13 Route 3 | H-9 |
| H4 | Inductive Loop 15 Route 3 | H-10 |
| J1 | Loop Excitation Monitor Calibration Plot | J-3 |

## TABLES


| Table | | Page |
|---|---|---|
| 1 | A Comparison of GPS Positions Against Surveyed Monuments | 70 |
| 2 | Feature Log for Route 5A | 81 |
| 3 | Loops Detected Along Route 1 | 82 |
| H1 | Feature Log for Route 3 | H-2 |
| H2 | Loops Detected Along Route 3 | H-3 |
| J1 | Loop Excitation Monitor Calibration | J-2 |

# 1. INTRODUCTION

## 1.1 Problem

The efficient flow of people, goods, and services on tomorrow's highways will be expedited by the navigation technologies being developed today. Transportation agencies also have internal needs for navigation systems that differ significantly from the highway user's needs. Vehicle position information is essential to automating many highway maintenance and inventory operations such as highway sign logging, pavement striping, pavement marker installation, and pavement evaluation testing.

## 1.2 Objective

The objective of this project was to develop a practical in-vehicle navigator with data logging capability for use by Caltrans. The research focused on dead reckoning navigation and absolute position sensing methods. Roadway-to-vehicle communications was evaluated as an absolute position determination technology.

## 1.3 Background

The usefulness of vehicle navigation systems is shown by the emergence of systems targeted at a wide variety of users. Navigation systems are important elements of Intelligent Vehicle/Highway System (IVHS) research such as Pathfinder in California and TravTek in Florida. A satellite-based vehicle tracking system is being marketed to interstate trucking firms. Radio-based automatic vehicle location (AVL) systems are currently available in some major urban areas which may prove invaluable to emergency vehicle fleet managers (1).

In order to navigate, one needs to know present location, destination, and desired path. This project deals only with the position sensing element of navigation. There are, in turn, two aspects of position fixing. For many applications, the present position is passed to the vehicle operator in real time. Other position fixing applications only need vehicle position after the fact to establish the positions of tests, anomalous conditions, or inventory items.

The precision requirements for real-time position sensing are normally less than the requirements for recording test and inventory locations. This is fortunate because real-time navigators only have information received prior to the instant of use. Test and inventory logging systems, however, can use "postprocessing" to determine positions after the fact. Postprocessing can use navigation information taken both before and after the instant of test

and also can use any number of techniques to adjust out errors and fit recorded navigational data to known control.

There is no one technology that can stand alone as an economically feasible, full feature navigator for highway use. There appears to be a consensus in the literature that, unless a breakthrough emerges, a vehicle navigation system should use more than one technology (2,3,4,5).

Any practical navigator probably will use an odometer and direction sensor (dead reckoning) as its basic element. It will then require an absolute positioning technology to establish initial position and correct accumulated errors or "cage" the system.

Three groups of currently popular caging technologies are long-range radio, map matching, and location beacons. The satellite-based Global Positioning System (GPS) is emerging as the method of choice for long-range radio-based systems. Sophisticated map-matching systems are now commercially available. There is not yet, however, a consensus on the most appropriate location beacon technology. Europe is evaluating infrared and microwave beacons while Japan is using microwave and inductive radio (6). The highway systems in those areas are significantly different than in the United States, so solutions that may be optimum in Europe or Japan may not be appropriate here.

This project investigated both GPS and location beacons as caging technologies. Location beacons are essentially a short-range communication technology. Beacons need only transmit location codes from the roadway to the vehicle. There are also, however, many uses for vehicle-to-roadway communication. Two-way, short-range communication was examined in a closely related, State-funded project called INductive RADio (INRAD). The INRAD project is reported in Appendix I and reference 7.

A side issue to inductive radio communication is service diagnostics for the pavement loops that INRAD uses as antennas. A method of sensing the loops was developed which may have application not only as a diagnostic tool but as an additional navigator caging technology.

## 1.4 Scope

This project was initially conceptualized to produce an odometer that would read directly in post-miles. Initial investigation showed that this goal could not be realized within the time and funding constraints of the project. California has a post mile system with many equation points and with discontinuities at county lines and there are many other technical issues that have not yet been adequately

resolved that stand in the way of a robust post-mile based odometer.

It was decided that the main use that Caltrans had for a navigation system was to determine the position of infrastructure features. These features may be roadway inventory, anomalous features, or test locations. In most cases, a post-mission determination of position was most important so features could be logged into appropriate data bases.

It was realized, however, that developing post-mission software to automatically adjust out errors and integrate navigation and logged data into appropriate data bases was beyond the scope of the project. The project scope was limited to evaluating needs and making appropriate recommendations.

This project focused on methods of post-mission position determination. The immediate effort was to evaluate navigation sensors and conceptualize the appropriate navigation technology. It became apparent that dead reckoning was needed as one of the navigation elements. It was also apparent that dead reckoning needed an additional technology for initialization and correction.

All of the technology considered would have to be appropriate to internal Caltrans use. Systems must be cost effective, physically robust, and usable in routine Caltrans operations.

The previously mentioned INRAD project was a State-funded effort commissioned by the Caltrans Director to evaluate roadway-to-vehicle communications. INRAD shared many elements with this project which allowed slight expansion of the scope of both projects.

# 2. TECHNOLOGY OPTIONS

## 2.1 Dead Reckoning

Dead reckoning is a vehicle positioning technique which uses heading and distance senors to compute a vehicle's relative movement. Distance can be measured using wheel or transmission-mounted odometers. Heading may be determined from geomagnetic sensors, gyroscopes, differential odometers or a combination of sensors.

Dead reckoning systems are inexpensive and do not require support from the road infrastructure. They are one of the most accurate navigation devices for short distances. However, because this technique is a cumulative process, sensor errors will tend to accumulate. This causes increasing error in calculated position. Sources of error include magnetic anomalies, vehicle tilt, changes in tire dimensions, and imperfect calibration.

Caging techniques should be used to periodically correct errors and update calibrations. Map matching is a commonly used caging technology that requires no infrastructure support. Other caging techniques include long-range radio-based navigators and short-range beacons.

Dead reckoning is an insufficient stand alone vehicle navigator but is an almost indispensable element in a vehicle navigation system.

## 2.2 Map Matching

Map matching is a navigator caging technique that is currently used extensively with dead reckoning. An electronic map is a valuable element in any navigation system, so map matching is a logical element to include in a navigator.

The initial map matching systems were limited to dead reckoning inputs. The map matcher detects turns and matches the turns to the most logical position on the map where that turn is possible. On a trip with many turns, the map matcher can dead reckon between turns and maintain position very accurately.

The initial position needed to be manually entered on these systems. They tended to accumulate errors on long tangents, and they sometimes got lost. These problems are eliminated with the addition of an absolute position finder. Long-range radio navigators (GPS) are beginning to be used, and beacons would add similar functionality.

Post-mission map matching presents quite a different set of technical challenges. Much more information is available to the software. Navigation data will normally have periodic closures against known points. The analysis process becomes more like a surveying traverse closure exercise. The outputs from the traverse closure calculations would then be "rubber banded" onto an electronic map. The result would be a very precise determination of the traveled path and all data points along that path.

## 2.3 Inductive Loops

Inductive loops can be used as position location beacons. Loops are currently used to monitor traffic on the freeway system and to detect vehicles at signalized intersections. These loops can also be used as antennas to broadcast location identification codes and roadway status to vehicles that pass over them. This can be done without degrading their performance as traffic detectors. The loops can also be used as receiving antennas to gather information from the vehicles passing over them.

The loops use inductive coupling which limits the effective transmission pattern to within the confines of the loop. This has the benefit of precise location, lack of regulatory problems, and the ability to use a single frequency on adjacent loops. The carrier frequency must be below one megahertz which limits the data rates. The small size of the antenna pattern limits the exposure time of a vehicle at freeway speed to about 50 milliseconds. These factors limit amount of information that can be transmitted during the brief time a vehicle is within range.

### The Inductive Radio Project (INRAD)

INRAD was a Caltrans sponsored project to demonstrate the use of short-range, two-way communication between vehicles and the roadway. INductive RADio (INRAD) was the technology chosen for the demonstration. The INRAD project shared equipment and software with this project. INRAD dealt with communications and this project focused on navigation issues. There is considerable overlap in these functions.

A summary of the INRAD project is included in Appendix I. The INRAD final report is cited under REFERENCES (7).

## 2.4 Radio Transponder Tags

Radio transponder tag systems are now extensively used for tracking cargo in the railroad and shipping industries. They are also extensively used in manufacturing and inventory control. Radio transponder tag-based Automatic Toll Collection (ATC) facilities have been implemented in numerous locations throughout the world. Caltrans is

currently implementing a transponder-based automatic toll collection system on the toll facilities under its jurisdiction.

There are two ways of implementing transponder tags for vehicle navigation and communication. The normal operation is to have a fixed site reader which reads vehicle-mounted tags. The vehicle tag can be intelligent enough to know when it is poled and by whom. This can serve a position fixing function for the vehicle. Another approach is to have a vehicle-mounted reader which poles for infrastructure-mounted tags. If the location of the tags is known, vehicle position can be inferred.

The navigational element of the infrastructure-mounted reader will probably always be secondary to its primary use of collecting tolls, tracking fleet vehicles, et cetera. When enough of these readers are installed, however, navigation will be a low cost spin-off.

Vehicle-mounted readers were successfully demonstrated. Microwave frequency radio backscatter tags were placed on structures adjacent to the traveled way and a vehicle-mounted reader automatically determined its position by reading those tags. The practicality of implementing this on a massive scale, however, may be somewhat questionable.

## 2.5 Radio Beacons

Radio beacons are used to transmit information to vehicles. If the antennas are configured properly, they may also be used to give precise location. The Japanese have developed an inverted phase microwave transmission scheme where vehicles pass through a null point when exactly perpendicular to the transmitter (8).

## 2.6 Infrared Beacons

Infrared beacons are currently used in Europe for a traffic information and guidance system (9). The beacon heads are mounted on signs or signal light posts. Infrared transceivers are mounted in vehicles behind the windshield in front of the rear view mirror. It receives data transmitted by the beacon and transmits vehicle information back.

The Europeans have chosen this technology for a number of reasons. Advantages include insusceptibility to interference among nearby infrared transmitters and by electromagnetic waves, low cost and no frequency band allocation requirements (9).

## 2.7 LORAN

LORAN (LOng Range Navigation system) is a radio beacon-based system used for maritime navigation. It is, however, losing ground to the satellite-based Global Positioning System (GPS). The receiver computes position based on the arrival differences of two transmitters. LORAN has been used as the positioning element on dispatch systems marketed by Motorola.

LORAN has the disadvantage of being confused by reflective and shielded paths, relatively poor resolution, and limited coverage.

## 2.8 Global Positioning System (GPS)

GPS is a radionavigation system whereby the position of any receiver on earth can be determine by ranging to a constellation of 24 high-orbit satellites (21 satellites plus 3 spares).

The advantages are that the system is available on a 24-hour, all-weather basis. The disadvantages are that it is susceptible to shielding and reflections and its accuracy is purposely degraded by the Department of Defense. Due to its passive nature, it has little value as an element in roadway-to-vehicle communications or vehicle-to-roadway communications. GPS receivers are currently installed in many vehicle navigation and location systems under development.

## 3. CONCURRENT PROJECTS

During the course of this study, we became aware of similar projects that researchers in other parts of the country were working on.

The Ohio State University, The Center for Mapping, developed the GPSVan which collects road mapping data to locate transportation features. The system is comprised of an inertial system (wheel sensors and gyroscope), a GPS receiver operated in differential mode, and a stereo vision system. The system was operated through an 80386 personal computer with a touch screen monitor for operator interface. Captured data could be integrated into a GIS (Geographic Information System) (10).

The Virginia Department of Transportation demonstrated a GPS-based "road track" and feature inventory data collection system. The GPS data was supplemented with data from an altimeter, gyroscope, and a distance measurement instrument (wheel sensors). Equipment was installed in a station wagon and operated from three laptop computers (11).

The Tennessee Department of Transportation sponsored a project to develop a road inventory and mapping system. It was also vehicle-based and used GPS as its primary means of vehicle location (12,13).

# 4. NEW PRODUCTS

Many new products and services were introduced during the time of this research project which are applicable to vehicle navigation and may improve system performance. Many of these new products were announced in trade journals. All of the products had in common low cost and compactness. Specifications and applications literature were requested from the manufacturer, but no attempt was made to procure a sample for testing due to the lack of time and funds remaining on the project. Any future improvement to the navigation system would take these products into account. The following list is intended to be a sample of the new products found and not intended to be a complete list of all of the products introduced during the time of this study.

## 4.1 Compass

KVH Industries, Inc.
Model KVH C100 Compass Engine
Reference 14

This is a microprocessor-controlled fluxgate compass subsystem consisting of a detachable toroidal fluxgate sensor and a small electronics board. The sensor element is a saturable ring core which floats freely in an inert fluid within a cylindrical housing. The floating ring core keeps the sensing element horizontal with respect to the earth. According to the manufacturer's literature, this will reduce the compass error due to vehicle tilt. The Compass Engine is automatically compensated when the vehicle is driven in a circle.

## 4.2 Gyroscope

Gyration, Inc.
GyroEngine
Reference 15

According to the manufacturer's literature, the GyroEngine offers many features which make it useful as a dead-reckoning device in ground navigation. Low cost, reduced weight, low power consumption, reduced drift, and ease of system integration are its advantages. It features optical (rather than physical) sensing elements, integrated (instead of external) motor control electronics and direct digital (rather than analog) output.

## 4.3 Angular Rate Sensor

Systron Donner Inertial Division
GyroChip
Reference 16

The GyroChip operates on the same principle as the Watson angular rate sensor used in this project. It has a vibrating quartz tuning fork to sense angular rate by responding to Coriolis forces. According to Systron Donner, the GyroChip tuning forks, support fixtures and frame are all fabricated from a wafer of a single-crystal piezoelectric quartz. This and the fact that it operates at a higher frequency (10 kHz versus 360 Hz) will supposedly eliminate the drift problem we were having with the Watson unit.

## 4.4 GPS

Magnavox and CUE Network
Reference 17

The November 1992 issue of GPS World announce that Magnavox and CUE Network planned to launch a nationwide low-cost, real-time differential GPS (DGPS) service. Magnavox would transmit DGPS data to subscribers through CUE's paging network using subcarriers from commercial FM radio stations.

## 5. CONCLUSIONS

The vehicle navigation method chosen for this research comprised of dead reckoning sensors (fluxgate compass, angular rate sensor and electronic odometer), GPS, and an inductive loop monitor. Based on performance tests described later in this report, the following conclusions were made:

1. Dead reckoning techniques are accurate over short distances. Because the technique is a cumulative process, it needs to know initial position and errors in calculated positions accumulate. Dead reckoning works best when combined with another technique.

2. The fluxgate compass, odometer combination mirrored the actual travelled path quite well. The compasses were affected by short-term transients but offered good long-term stability.

3. The angular rate sensor was very susceptible to drift. Extensive corrections were required in post-processing to produce meaningful path plots. The drift problem greatly reduced its usefulness as a navigational element.

   Other angular rate sensors are reportedly available with superior drift specifications.

4. Global Positioning System (GPS) receivers provide excellent positioning particularly over long distances. Differential correction methods are available to provide accuracies in the sub ten-meter range.

   These systems require clear paths to a constellation of satellites. They will not work in tunnels and will be confused by multipath in many urban and rural environments. It is advisable to incorporate dead reckoning to bridge these gaps in coverage.

5. The ability to record comments and landmarks along with their respective elapsed time and distance information is useful for post-processing to locate the source of anomalies in recorded data. The accuracy of this feature is limited by the operator's attentiveness and quickness.

6. By sensing inductive loop signal amplitude and frequency, the inductive loop monitor could provide an accurate method by which dead reckoning positions could be compensated for drift.

   The loop sensor also proved to be a quick and safe method for locating inductive loops in the road.

The state-of-the-art in vehicle navigation systems is rapidly evolving. Some day a purely inertial guidance system may be cost effective for private vehicles. Until that day arrives, however, the navigation system of choice will probably use a mixture of technologies.

Dead reckoning will probably be the element that guides the vehicle from minute to minute. The dead reckoning sensors will include an odometer and either a compass, an angular rate sensor, or both. Dead reckoning requires a method of initial and periodic absolute position fixing.

Automation will replace the historical method of manual position fixing. GPS is becoming the obvious choice for open terrain and rural applications. Some form of positioning beacons may supplement or replace GPS in urban and high traffic volume environments.

## 6. RECOMMENDATIONS

Many of the components of the prototype navigation system hardware are functional as they are currently available. For future implementation, the following upgrades should be considered:

1. Test new hardware as it becomes available.

2. Find a low drift angular rate sensor.

3. Investigate the option of using differential corrections for GPS to improve the accuracy of the position fixes.

4. Investigate why the inductive loop monitor is not sensitive for certain loops. Is there a problem with the loop monitor sensitivity or is there a problem with the loop?

This project has progressed in parallel with a plethora of related research and product announcements. There are now a number of solutions to any given problem. Technology that was once manufactured and priced for limited aerospace application is now being targeted to the consumer market.

Making long term commitments to a particular hardware configuration in this environment is, at best, dangerous. It should be practical, however, to define the function of navigation system components and to also define the logical interfaces between these components. Standards should then be established to define these interfaces. The goal should be the establishment of national standards for the flow of information between navigation system components, test transducers, and related data handling software.

The developed navigation system is now being implemented on a profile measuring device that will be collecting highway profiles for hundreds of miles at a time. The processing and storage of this information is expected to be a major challenge. Serious thought and perhaps some research must be given to the following issues:

- Post-mission processing of navigation and test data to close transducer readings with positional control.

- Post-mission processing to summarize adjusted test data into appropriate sections for incorporation into the target data bases.

- Establishment of standardized methods of handling data with geographical relationships.

## 7. IMPLEMENTATION

A modified version of the navigation system used in this project was built and installed in five test vehicles for the Interstate 880 Freeway Service Patrol evaluation project south of Oakland, California. Hardware consisted of the dead reckoning sensors (compass and odometer), GPS, inductive radio communications, and an STD Bus data collection computer. Data collected were used to determine vehicle travel times and location. Inductive loop monitors were used during the setup period to troubleshoot inductive loops. Equipment was installed in November 1992. The first phase of data collection was completed in March 1993. The second phase is scheduled to begin in October 1993.

The navigation equipment will be used to support the data collection efforts in the Federal Highway Administration sponsored research project "Develop an Improved Winter Weather and Traffic Information Gathering and Distribution System for the Interstate 80 Corridor." In addition to gathering information on vehicle travel times, an infrared temperature sensor will be mounted on the test vehicles to collect data on road temperatures during the winter months in the Sierra Nevada mountains.

A navigation element is being installed in a pavement profile measuring vehicle which is being built as part of the Federal Highway Administration sponsored research project "High Speed Profiling Device." The navigation equipment will include the fluxgate compass, the GPS, and the loop excitation monitor. A precise odometer with turn indication is an integral part of the profile gathering instrumentation. An angular rate sensor with lower drift is being purchased.

This profile measuring device will collect significant quantities of data which will become a challenge to the implementors. This issue is discussed under RECOMMENDATIONS.

# 8. TECHNICAL DISCUSSION

## 8.1 Test Conditions

### 8.1.1 Test Routes

Navigation system tests were conducted within the Divison of New Technology Materials and Research laboratory facilities, on city streets, and on the state highway. Five test routes were used to test the navigation system. Criteria for selecting these routes included distance, variation in elevation, the availablity of inductive loops, and availability of possible interference sources on the navigation components. All of the courses started and ended at survey marker Lab 7 (Figure 2) on the grounds of the laboratory facilities. The three courses are described below:

I. Route 1: Around the Block (Figure 1)

* Start from Lab 7 with the vehicle facing east.
* Follow the route depicted in Figure 1 and exit the facility at 60th St. and Folsom Blvd.
* East on Folsom Blvd. to 65th St.
* South on 65th St. to S St.
* West on S St. to 59th St.
* North on 59th St. to Folsom Blvd.
* East on Folsom Blvd. to 60th St.
* Enter the facility at the 60th St. entrance.
* Retrace the exit route back to Lab 7 with the vehicle facing west.

II. Route 2: American River Drive (Figure 8)

* Start from Lab 7 with the vehicle facing east.
* Follow the route depicted in Figure 8 and exit the facility at 60th St. and Folsom Blvd.
* East on Folsom Blvd. to Howe Ave.
* North on Howe Ave. to American River Dr.
* East on American River Dr. to Watt Ave.
* South on Watt Ave. to the Highway 50 on-ramp.
* West on Highway 50 to the 65th St off-ramp.
* North on 65th St. to Folsom Blvd.
* West on Folsom Blvd. to 60th St.
* Enter the facility at the 60th St. entrance.
* Retrace the exit route back to Lab 7 with the vehicle facing west.

III. Route 3: Highway 50 (Figures 9a, 9b, 9c)

* Start from Lab 7 with the vehicle facing east.
* Follow the route depicted in Figures 9a, 9b, and 9c and exit the facility at 60th St. and Folsom Blvd.

* East on Folsom Blvd. to 65th St.
* South on 65th St. to the Highway 50 on-ramp.
* East on Highway 50 to the Hazel Ave. off-ramp.
* North on Hazel Ave. to the westbound Highway 50 loop ramp.
* West on Highway 50 to the 65th St off-ramp.
* North on 65th St. to Folsom Blvd.
* West on Folsom Blvd. to 60th St.
* Enter the facility at the 60th St. entrance.
* Retrace the exit route back to Lab 7 with the vehicle facing west.

IV. Route 4: Highway 50 from Zinfandel Dr. to Mather Field Rd. (Figure 10)

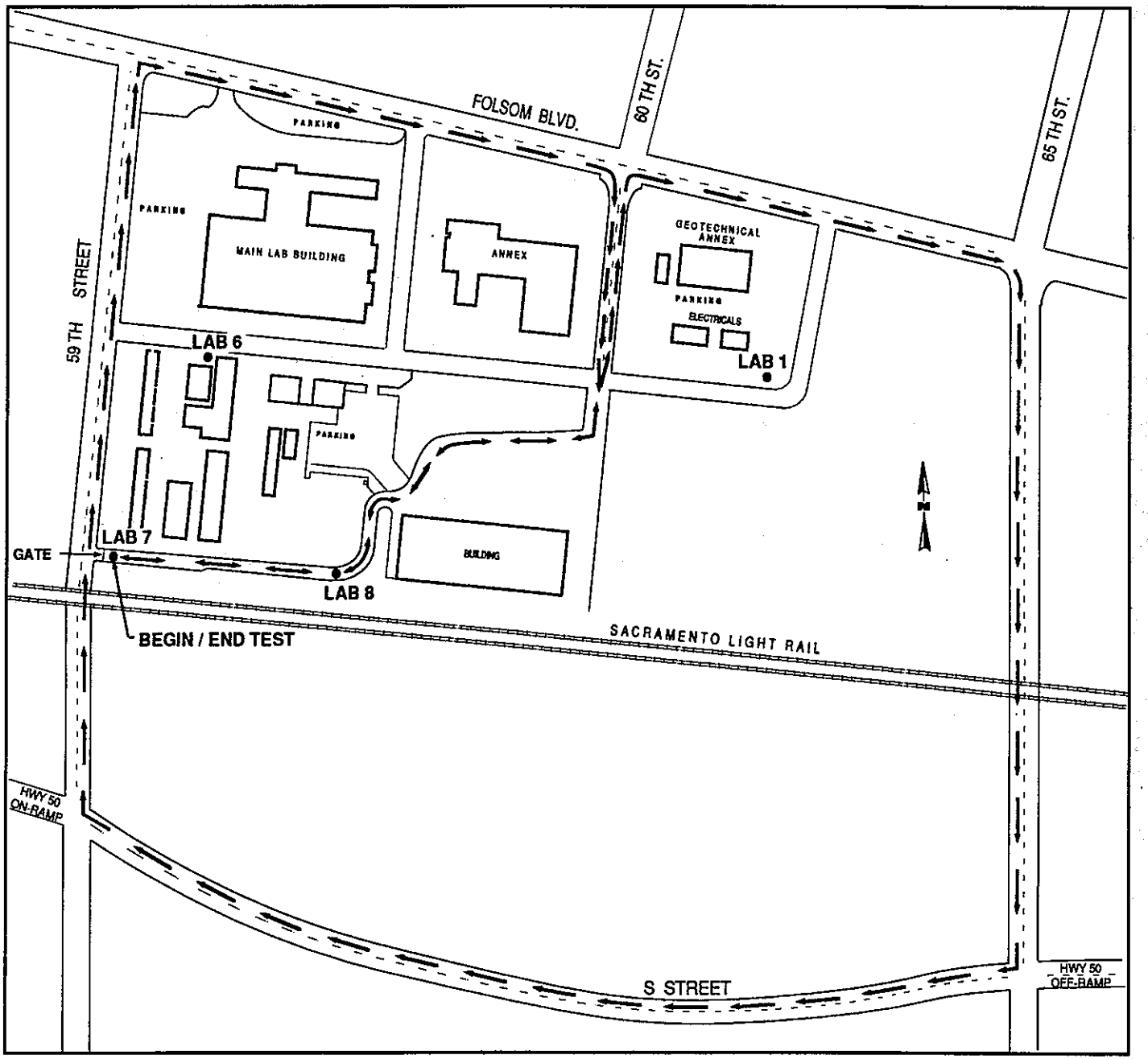
* Begin data logging on Highway 50 in the westbound direction as soon as the vehicle crosses the 10 mile mile marker.
* Exit Highway 50 at the Mather Field Rd. off-ramp.
* South on Mather Field Rd. to eastbound Highway 50 loop ramp.
* East on Highway 50 to Zinfandel Dr. exit.
* North on Zinfandel Dr. to Olson Dr.
* West on Olson Dr, then south into the motel parking lot.
* U turn back to Olson Dr.
* East on Olson Dr.
* South on Zinfandel Dr. to the westbound Highway 50 on-ramp.
* West on Highway 50.
* Exit Highway 50 at the Mather Field Rd. off-ramp.
* End data logging at the Mather Field stoplight.

V. Route 5: Downtown (Figure 11)

* Start from Lab 7 with the vehicle facing east.
* Follow the route depicted in Figure 11 and exit the facility onto 59th St.
* South on 59th St. to S St.
* West onto the Highway 50 on-ramp and proceed westbound.
* Exit Highway 50 at the 10th St. off-ramp.
* West on W St. to 10th St.
* North on 10th Street to J St.
* East on J St. to 15th St.
* South on 15th St. to X St.

Alternative 1:

* East on X St. to the Highway 50 26th St. on-ramp.
* East on Highway 50 to 59th St.
* North on 59th St. to the lab facility.
* Enter the facility at the 59th St. entrance and return to Lab 7.




NOT TO SCALE

Fig. 1 **ROUTE 1: AROUND THE BLOCK**

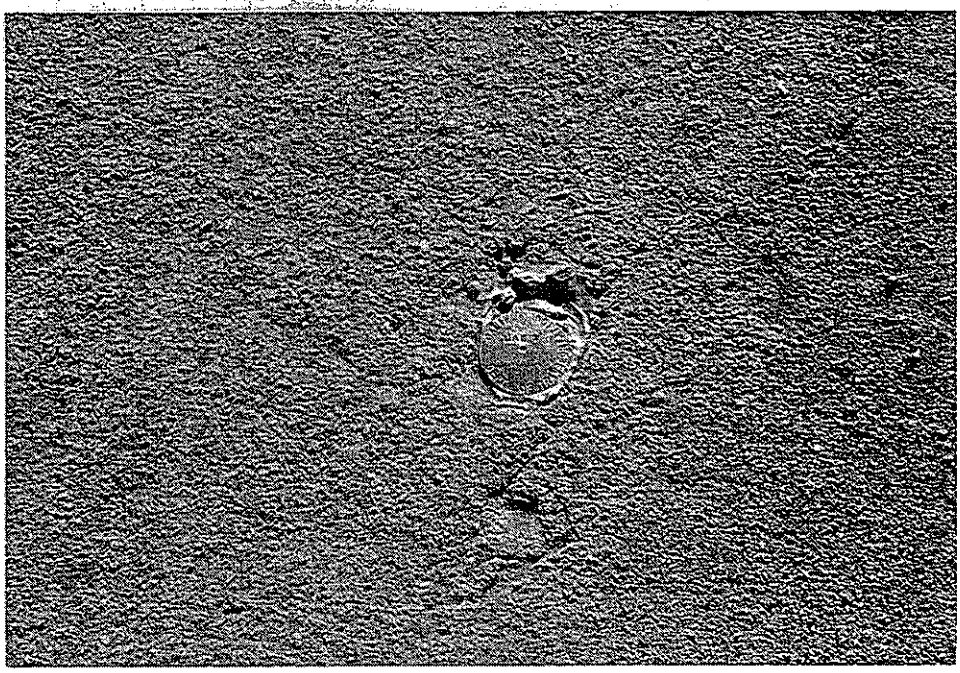


Figure 2

Lab 7 Survey Marker

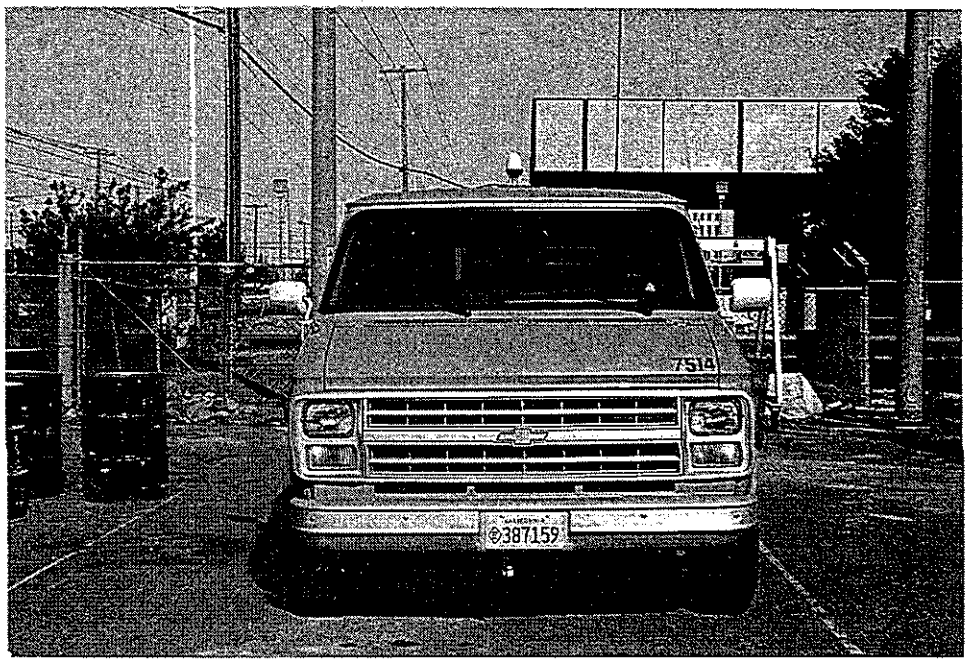



Figure 3

Test Vehicle Parked Over Lab 7 Marker

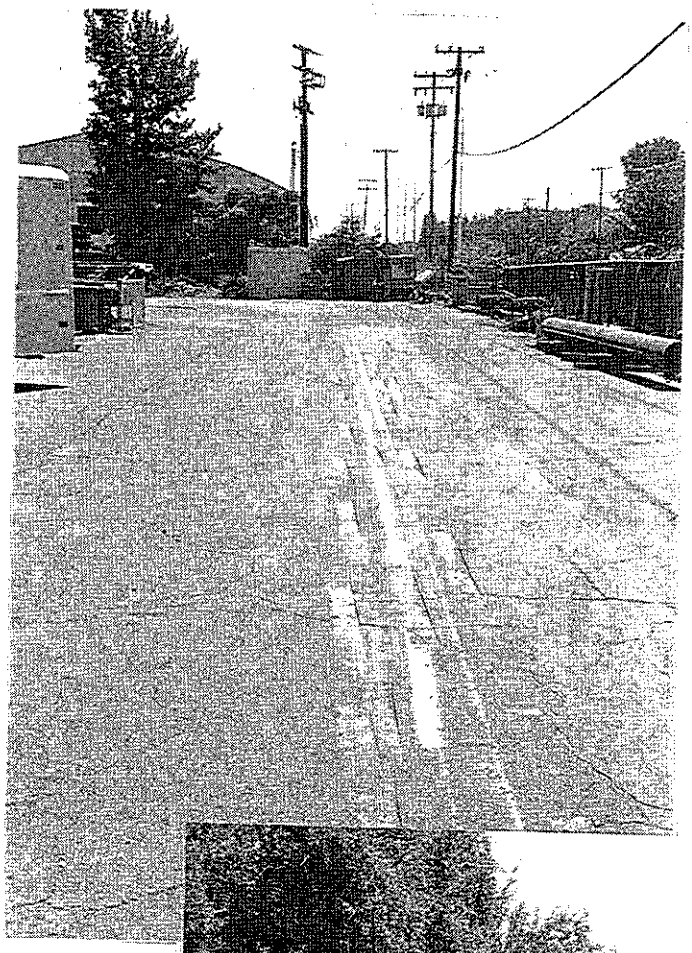


Figure 4

Route 1 Eastbound Approaching Lab 8 Marker

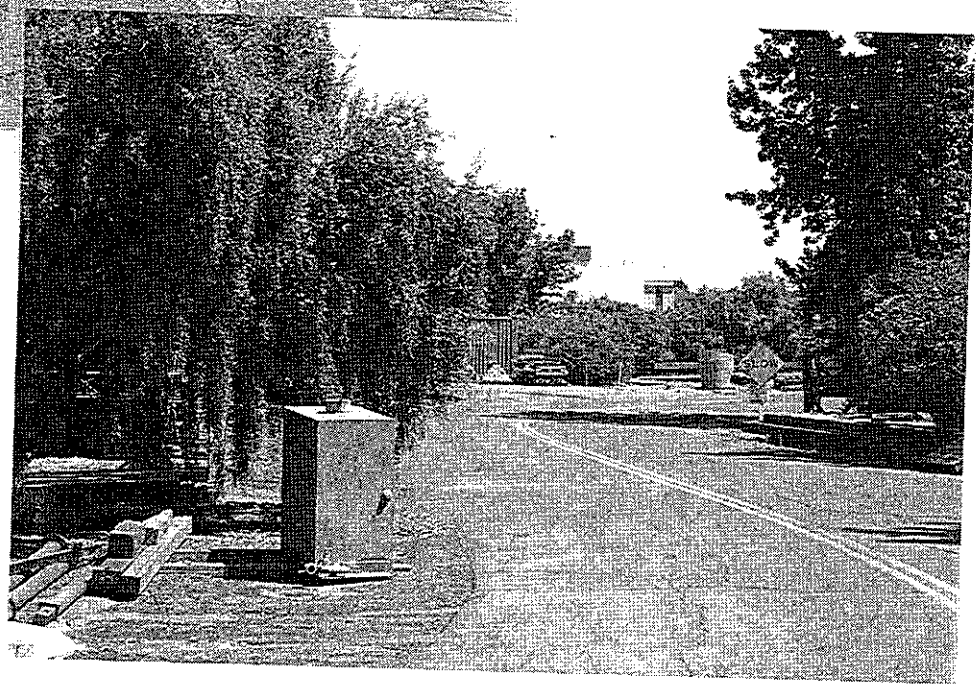


Figure 5

Route 1 Curve in the Road After Lab 8

Figure 6

Route 1 Northbound Approaching
Folsom Blvd.and 60th St.

Figure 7

Route 1 Southbound
Entering the Lab from Folsom Blvd. and 60th St.

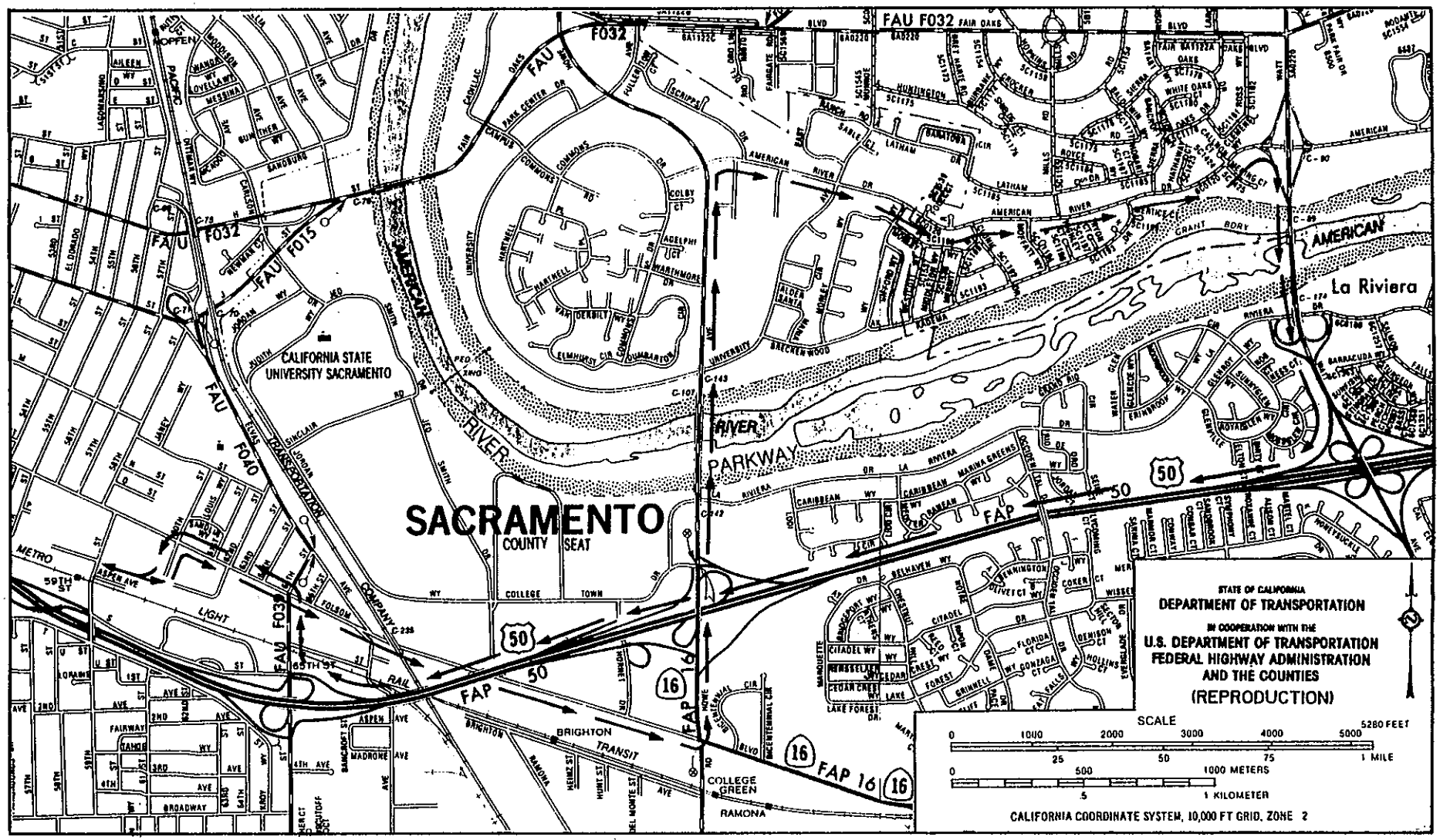
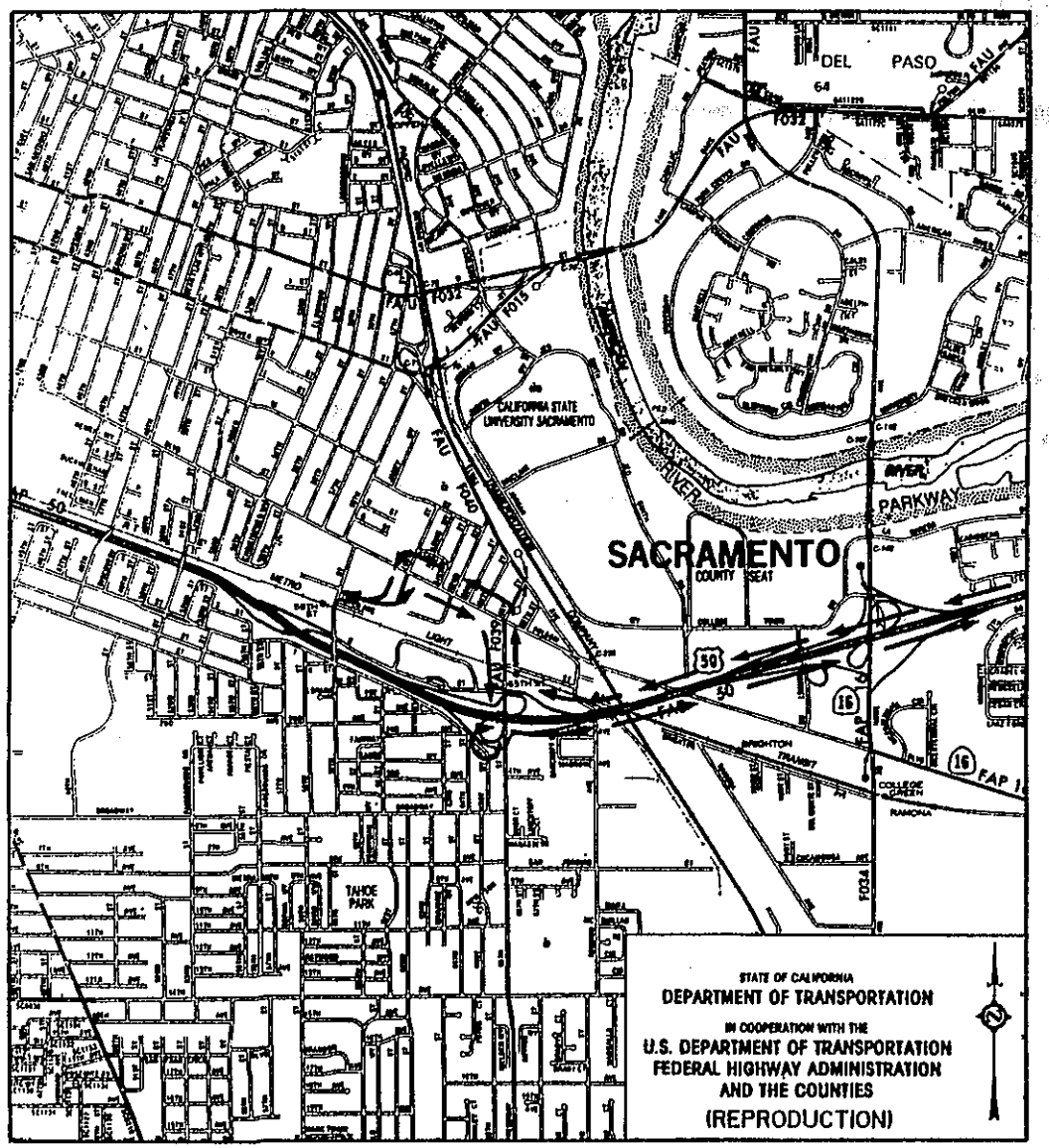



Fig. 8 **ROUTE 2: AMERICAN RIVER DRIVE**



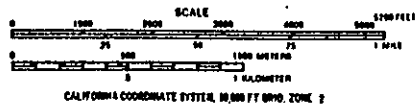




Fig. 9a **ROUTE 3: HIGHWAY 50**

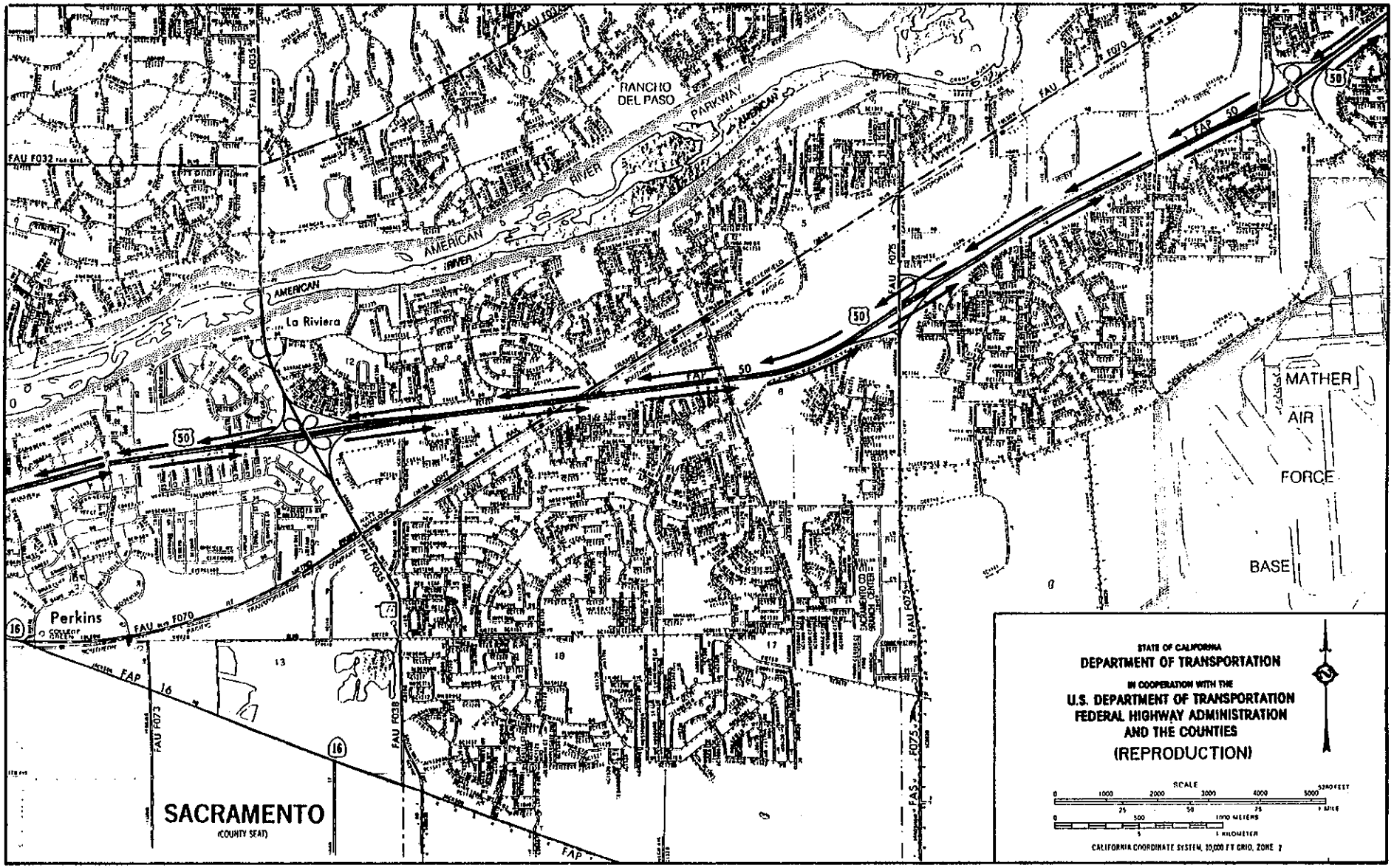



Fig. 9b **ROUTE 3: HIGHWAY 50**

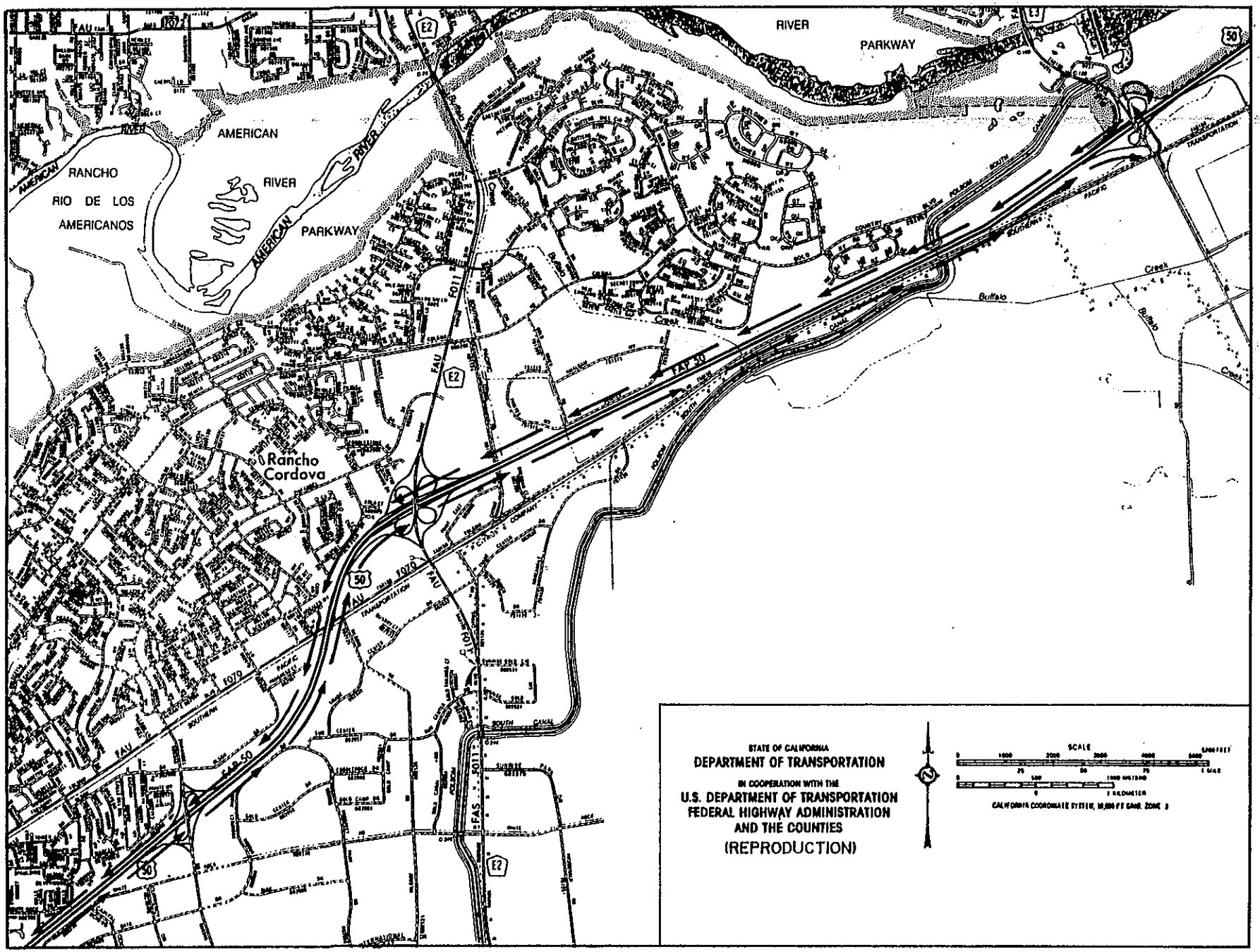



Fig. 9c **ROUTE 3: HIGHWAY 50**

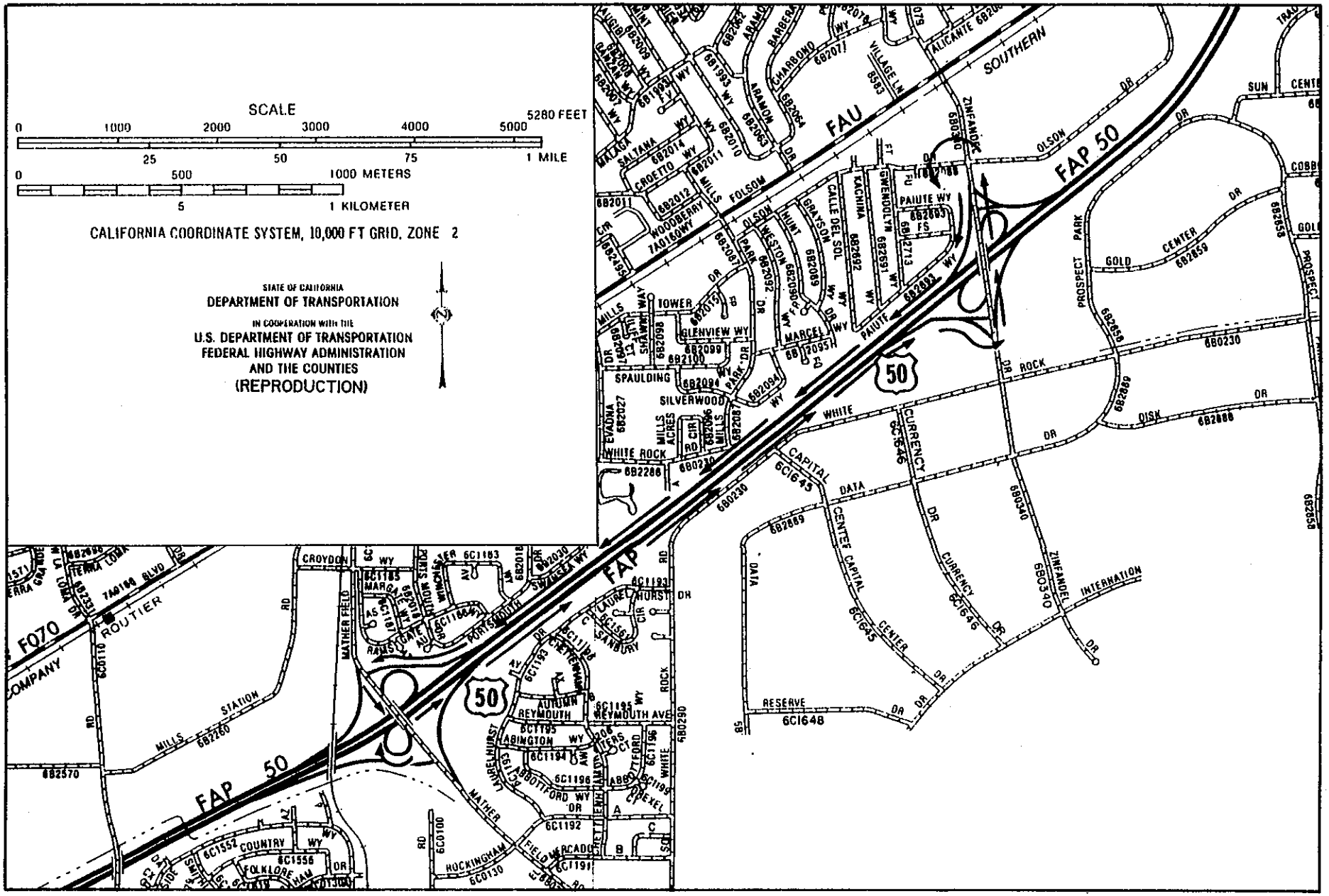



Fig. 10 **ROUTE 4: ZINFANDEL DR. TO MATHER FIELD RD.**

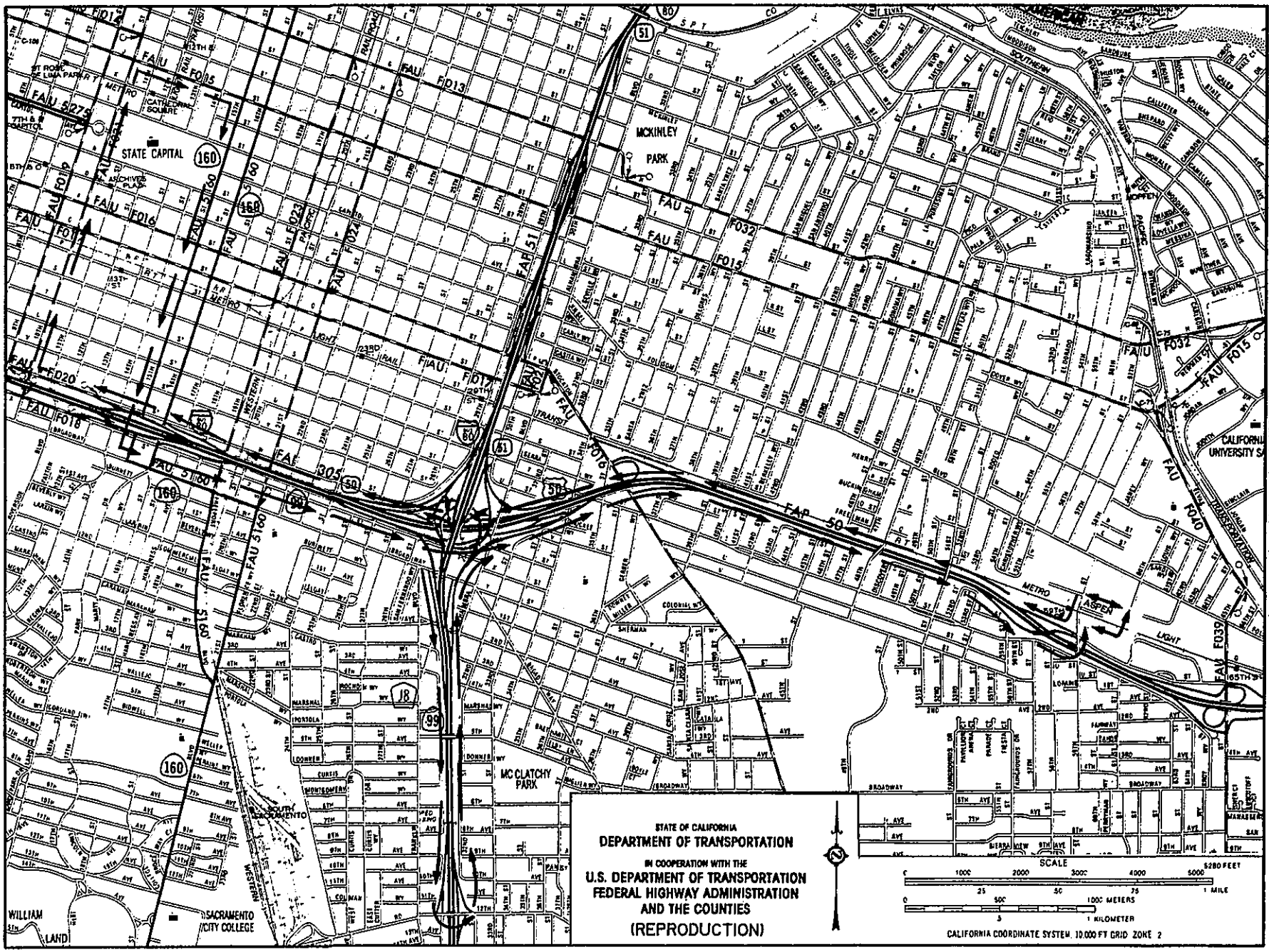



Fig. 11 **ROUTE 5: DOWNTOWN**

Alternative 2:

* East on X St. to the Business 80 16th St. on-ramp.
* East on Business 80 to eastbound Highway 50.
* East on Highway 50 to the 59th St. off-ramp.
* North on 59th St. to the lab facility.
* Enter the facility at the 59th St. entrance and return to Lab 7.

### 8.1.2 TEST VEHICLE

Navigation and data collection equipment were installed in a 1989 Chevrolet van, model Chevy Van 20. See Figure 12.

### 8.1.3 TEST EQUIPMENT

The navigation system consisted of a fluxgate compass, an angular rate sensor, an odometer, a loop excitation monitor, and a GPS unit. The data acquisition system was comprised of a STD Bus DOS-compatible computer system. A laptop computer was used as the operator interface to the data acquisition system. Details and schematics of the navigation and test hardware may be found in Appendix B.

### 8.1.4 TEST PROCEDURES

Each data collection session was comprised of three steps:

1. Calibration
2. Data collection
3. Data reduction

#### 8.1.4.1 CALIBRATION

As mentioned in Kao and Peters (3,18) fluxgate compasses are affected by earth magnetic field distortion due to vehicle geometry, permeability, and residual magnetism and by magnetic anomalies. In order to compensate for field distortion, the compass was calibrated before each run. An X-Y plot of the compass coil output voltages was plotted to create what is called a magnetization circle (Figure 13). The greater the degree of vehicle body magnetization, the greater the circle drifts from the origin. To calibrate for this magnetization effect, the vehicle was driven in a large (about 50-foot diameter) circle. The output voltages were plotted, the maxima and minima were determined to identify the center of the circle. The ratio of the minimum diameter to the maximum diameter was determined to correct the "circle's" elliptical shape.

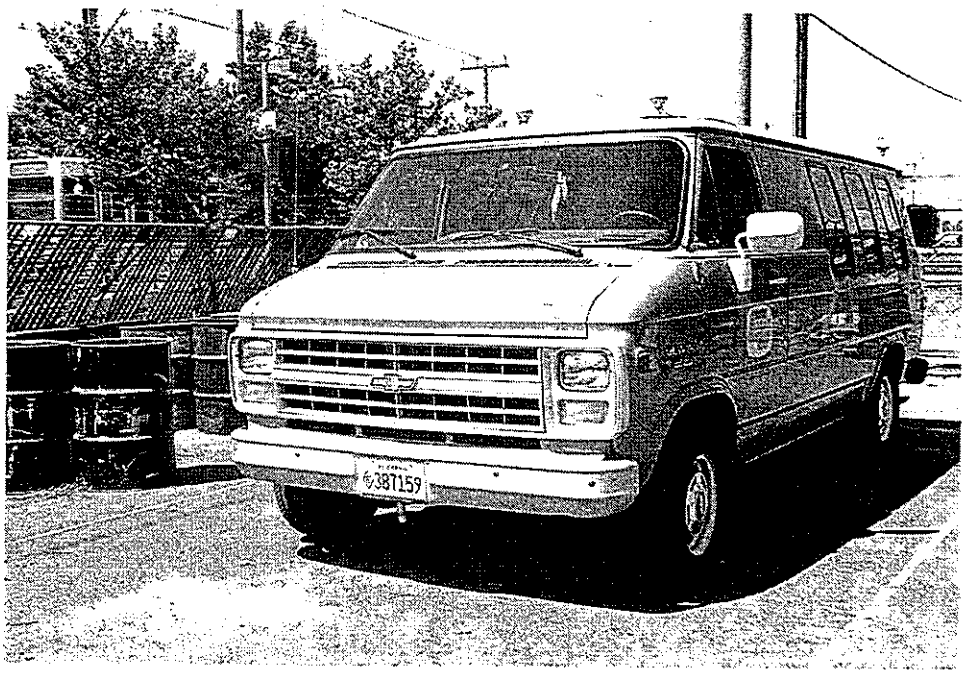



Figure 12

Test Vehicle

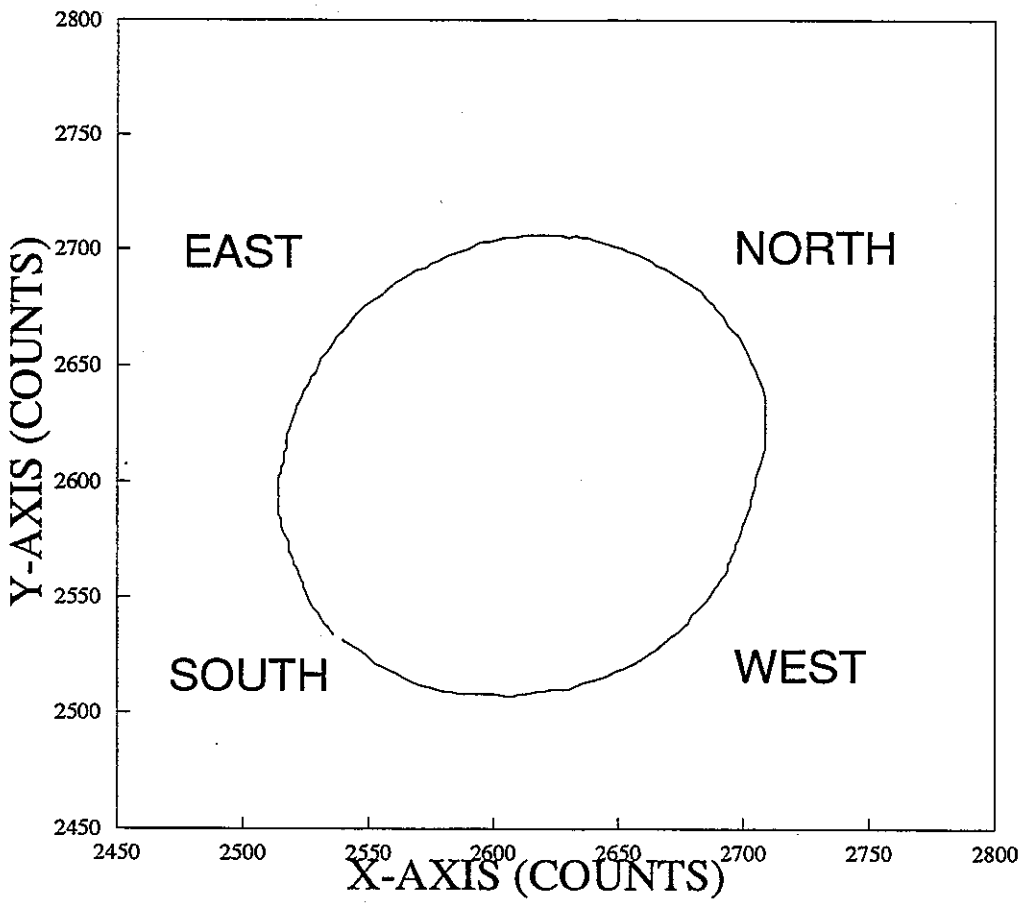



Figure 13

Compass Magnetization Circle
Calibration (Clockwise Direction) May 7, 1992

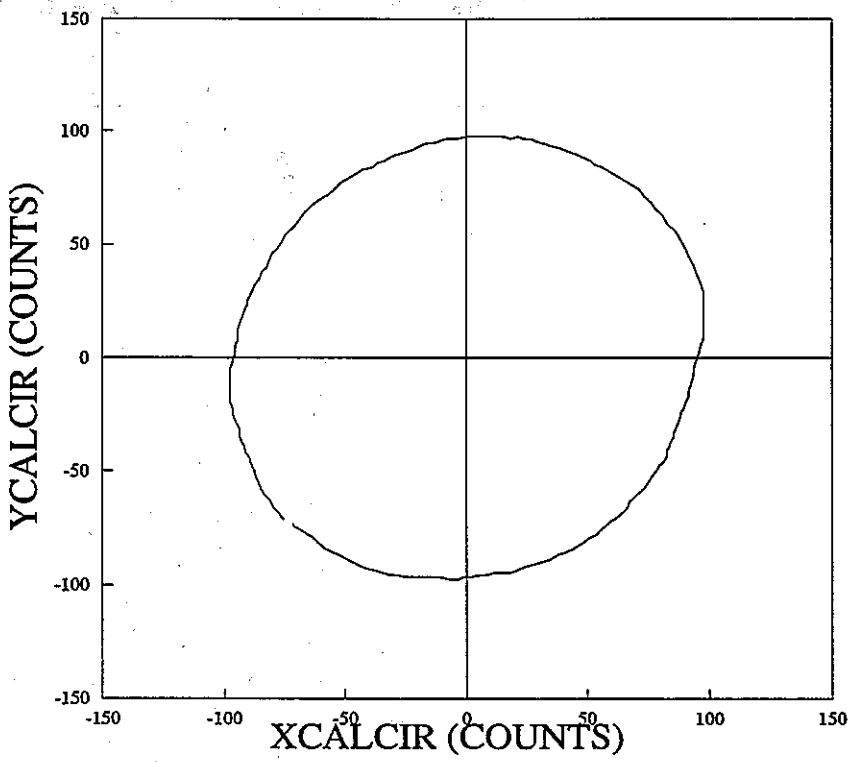



Figure 14

Compass Magnetization Circle Translated to the Origin

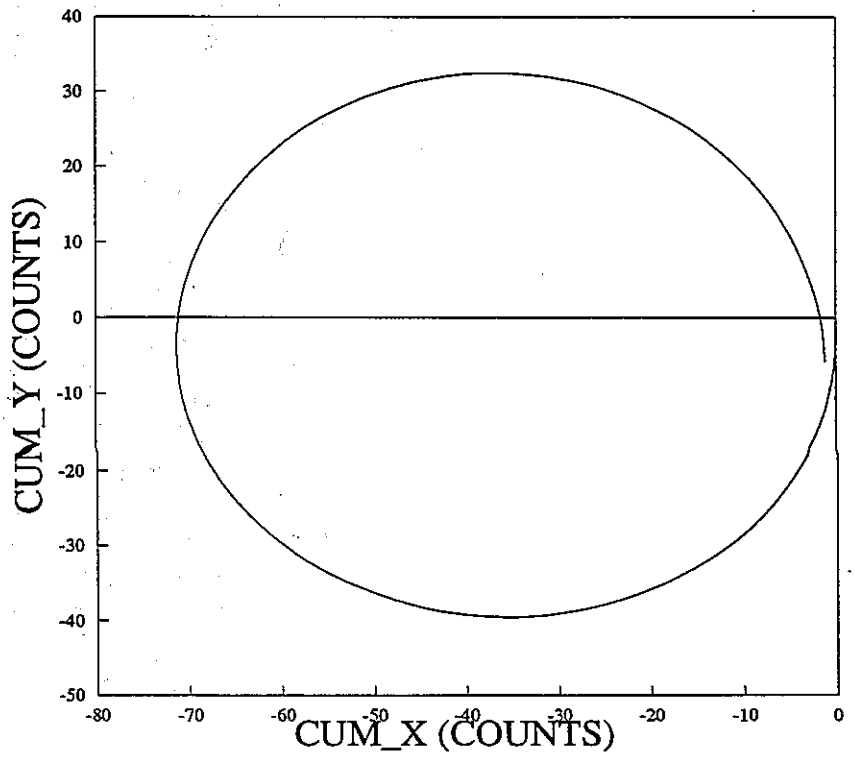



Figure 15

Plot of Vehicle Travel in the Clockwise Direction

8.1.4.2 DATA COLLECTION

For each data collection session, a team consisting of a driver and an operator to tend to the data collection system was used. The driver drove the prescribed test route while the operator started the data collection process, entered attribute information and terminated the process when the route was completed. Data were collected and stored in four files: navigation (dead reckoning), navigation (GPS), inductive loops and attributes.

8.1.4.3 DATA REDUCTION

After each session, the data were downloaded from the data acquisition systems memory onto floppy diskettes. Data were reduced and converted according to the procedure outined in below using the Lotus 1-2-3 spreadsheet program. The following discussion uses results from the compass calibration run as an example.

8.1.4.3.1 COMPASS

| Data | Variable |
|---|---|
| Odometer counts | ODM |
| X-axis counts | X |
| Y-axis counts | Y |

1. Plot Y against X to examine the shape of the magnetization circle. See Figure 13. Look for any extreme deviations from the circle which would indicate interference with the compass. If the plot is extremely noisy, step 2 must be included in the data reduction process. Otherwise, step 2 may be used to verify the calculations of step 1.

   a. Find X-axis maxima. Assign it the variable XMAX.
   b. Find X-axis minima. Assign it the variable XMIN.
   c. Find Y-axis maxima. Assign it the variable YMAX.
   d. Find Y-axis minima. Assign it the variable YMIN.
   e. Find the X offset from the center of the magnetization circle. Assign it the variable XCEN, where

      XCEN = (XMAX + XMIN)/2

   f. Find the Y offset from the center of the magnetization circle. Assign it the variable YCEN, where

      YCEN = (YMAX + YMIN)/2

   g. Normalize X to Y. Calculate the multiplication factor to convert the ellipse to a circle. Assign this factor the variable YCOR, where

$$YCOR = (XMAX-XMIN)/(YMAX-YMIN)$$

The average YCOR for six calibration runs (three clockwise and three counterclockwise) is 0.973254. This multiplication factor is assigned the variable YCORR.

2. Plot Y against X and manually determine the center of the magnetization circle. Assign the coordinates the variables XCEN1 and YCEN1.

   a. From the plot, find X-axis maxima. Assign it the variable XMAX1.
   b. From the plot, find X-axis minima. Assign it the variable XMIN1.
   c. From the plot, find Y-axis maxima. Assign it the variable YMAX1.
   d. From the plot, find Y-axis minima. Assign it the variable YMIN1.
   e. Calculate the multiplication factor to convert the ellipse to a circle. Assign this factor the variable YCOR1, where

$$YCOR1 = (XMAX1-XMIN1)/(YMAX1-YMIN1)$$

3. Translate the circle to a circle centered on the origin by removing the X and Y offsets.

$$XCALCIR = X - XCEN1$$

Multiply the Y translation by YCORR to convert the ellipse to a circle.

$$YCALCIR = (Y - YCEN1)(YCORR)$$

The plot of the resulting calculations is shown in Figure 14.

4. Measure the angle of declination and assign it the variable DECLIN. For the test sessions in this report, the angle is 50 degrees.

5. Determine the azimuth in radians for each sample point and assign it the variable AZIM.

$$AZIM = ARCTAN(YCALCIR/XCALCIR) - (DECLIN \times \pi/180)$$

6. Calculate the X-component of the displacement vector and assign it the variable INC_X.

$$INC\_X = SIN(AZIM) \times (ODM_{CURRENT} - ODM_{PREVIOUS})$$

7. Locate the current vehicle position (in the x-direction) with respect to the starting point located at the origin.

$$CUM\_Xcurrent = CUM\_X_{PREVIOUS} + INC\_X_{CURRENT}$$

8. Calculate the Y-component of the displacement vector and assign it the variable INC_Y.

$$INC\_Y = COS(AZIM) \times (ODM_{CURRENT} - ODM_{PREVIOUS})$$

9. Locate the current vehicle position (in the y-direction) with respect to the starting point located at the origin.

$$CUM\_Ycurrent = CUM\_Y_{PREVIOUS} + INC\_Y_{CURRENT}$$

10. For each sample point where a loop had been detected, copy CUM_Y into a column labeled LOOP.

11. Plot CUM_Y and LOOP against CUM_X. Figure 15 shows the resulting plot. Loops are not plotted since there are no loops in the calibration test course.

8.1.4.3.2 <u>ANGULAR RATE SENSOR</u>

| Data | Variable |
|---|---|
| Time | TIME |
| Angular rate sensor counts | RATE |

1. Plot RATE against TIME. Examine the graph for any drift.

2. Draw a horizontal line through the quiescent level of the graph to establish the zero level. Assign it the variable ARS_ZERO.

3. Calculate the slope of the drift and assign it the variable DRIFT.

$$DRIFT = (ARS_{BEGIN} - ARS_{END})/(TIME_{END} - TIME_{BEGIN})$$

4. Adjust each ARS reading by the drift and assign it the variable ADJ_RATE.

$$ADJ\_RATE = (TIME \times DRIFT) + ARS$$

5. Subtract the ARS_ZERO from ADJ_RATE to remove the offset from zero. Assign it the variable CORR_RATE.

6. Plot CORR_RATE against TIME. Adjust for the drift further if necessary.

7. Add the CORR_RATEs and assign the result to a variable named SUM_TURN.

$$SUM\_TURN = \Sigma CORR\_RATE$$

8. From the compass plot, manually sum the turns made in a test run. Right turns (right angle) are +90 degrees and left turns are -90 degrees. It is 540 degrees around the block.

9. From steps 7 and 8, calculate the gain and assign it the variable GAIN_FAC.

$$GAIN\_FAC = (SUM\_TURN)/(CUM\_HEAD)$$

10. Assign an initial azimuth of 50 degrees to AZIM_INIT.

11. Add the current azimuth to the previous azimuth where

$$CUM\_RATE = CUM\_RATE_{PREVIOUS} + CORR\_RATE_{CURRENT}$$

12. Calculate the azimuth in radians.

$$AZIM = ((CUM\_RATE_{CURRENT}/GAIN\_FAC) + AZIM\_INIT) \times \pi/180$$

13. Calculate the X-component of the displacement vector and assign it the variable INC_X.

$$INC\_X = SIN(AZIM) \times (ODM_{CURRENT} - ODM_{PREVIOUS})$$

14. Locate the current vehicle position (in the x-direction) with respect to the starting point located at the origin.

$$CUM\_Xcurrent = CUM\_X_{PREVIOUS} + INC\_X_{CURRENT}$$

15. Calculate the Y-component of the displacement vector and assign it the variable INC_Y.

$$INC\_Y = COS(AZIM) \times (ODM_{CURRENT} - ODM_{PREVIOUS})$$

16. Locate the current vehicle position (in the x-direction) with respect to the starting point located at the origin.

$$CUM\_Ycurrent = CUM\_Y_{PREVIOUS} + INC\_Y_{CURRENT}$$

8.1.4.3.3 GPS

NOTE: Latitude and longitude are in the format "degrees, minutes.fractions." For example, 121 degrees 26.15 minutes is stored as 12126.15.

1. Convert west longitudes to negative values.

2. Plot latitude against longitude.

## 8.2 Discussion of Results

### 8.2.1 COMPASS

The fluxgate compass was tested under each of the test conditions described previously. Each test route was driven at least twice on different days. The results of each test was consistent and repeatable. Figures 16 and 17 show compass plots taken during two different test runs. They show identical anomalies in the same locations. The remaining compass X-Y plots are shown in Figures 18 through 22.

Two of the test routes, Highway 50 and Downtown, showed extreme interference to the compass. Using the attribute and odometer data, the noise spikes on the plots could be located along the route.

The plot for the Highway 50 test run (Figure 19) showed interference occurring on the east and westbound directions at the Folsom Blvd. undercrossing near Mayhew Rd. An investigation of the location indicated that there were three possible sources of interference. Two of the sources are power lines running diagonally across the freeway. Sacramento Regional Light Rail power lines run diagonally within about a foot beneath the freeway structure (Figure 72). Overhead electrical power distribution lines run almost parallel to the light rail lines above the freeway (Figures 71 and 72). Another possible interference source is the freeway bridge structure. Of these possibilities, the most likely interference source is the bridge stucture. The effect of overhead power lines could be discounted since they occur at numerous locations along this and other test routes with no affect on the compass. The light rail lines may have had a compounding effect on the compass readings but could not have been the sole source of interference since these lines also run under the 65th St. section of the freeway and did not have a great effect on the compass. Figure 21 shows that the light rail lines affected the compass in the Route 5 test run. This is the only situation where the light rail lines had any great effect on the compass.

The effect of bridge structures can be seen in the Downtown test run (Figures 21 and 22). Figure 21 shows the compass was affected by the Stockton Blvd. undercrossing (Figure 73 and 74) and the Business 80 viaduct (Figure 76 and 77). The Highway 99 and Business 80 interchange shown in Figure 75 did not have an effect on the compass. Figure 18 shows the effect of the Folsom Blvd. railroad undercrossing and Figure 20 shows the effect of the Zinfandel Dr. overcrossing.

Other anomalies could be found on the compass X-Y plot. Figure 21 shows interference on J St. Also, there was

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interference on the approach to the Q St. intersection which is not shown clearly in this figure. There were no obvious physical features at these locations which could explain such noise. It is possible that there are underground utilities beneath these streets.

Figures 23 through 29 show the resulting plot of the x- and y-component of the azimuth. Inductive loops detected by the inductive loop monitor were superimposed onto these plots. In each case, the sensor plot mirrored the actual path quite well. Also in each case, the compass path drifted, resulting in the path not closing. Isolated magnetic anomalies like the ones shown in the Highway 50 runs did not affect the plot. Thus, the compass was affected by short-term transients but offered good long-term directions.

ANGULAR RATE SENSOR

Plots of the angular rate sensor output versus time (Figures 30 through 41) show that the sensor was capable of reacting to changes as the vehicle turned. Positive excursions above the zero baseline indicate right turns; negative excursions indicate left turns. However, the angular rate sensor was subject to short-term drift. The most graphic example is the American River test run shown in Figures 34 and 35. As a result, the angular rate sensor exhibited serious cummulative azimuth errors. The angular rate sensor path plot Around-the-Block test run is shown in Figure 43. Test runs at greater distances where the drift was excessive could not be plotted without laboriously correcting data points for drift. Figure 44 and 45 illustrate the drift problem. Figure 46 shows an angular rate sensor path plot for the Mather-to-Zinfandel test run. It was created by incrementally correcting the angular output versus time plot for drift.

GPS

Two GPS units were used in this study. Initial system development and testing was done using a Magellan 1-channel OEM GPS unit. A 5-channel unit was purchased later in the project as soon as it became available. Both units were used in tests and compared. The 5-channel GPS was connected to the data logging system with its position coordinates stored in the logging systems memory. The 1-channel unit was run as a stand-alone unit with its positions stored in a laptop computer using OEM software.

Table 1 shows a comparison of GPS positions against surveyed monument positions. The location of monuments Lab 7 and Lab 8 is shown in Figure 1. Their latitude, longitude and equivalent state plane coordinates are shown at the top of Table 1. The distance between monuments is 302.82 feet (92.299 meters). Data for the 1-channel GPS is shown on the

lefthand portion of the table and data for the 5-channel GPS is shown on the righthand portion. For each test run, the first Lab 7 position is the static measurement (vehicle stationary) at the beginning of the test and the first Lab 8 position is the dynamic measurement (vehicle moving), also at the beginning of the test. The second Lab 8 position is the dynamic reading on the return trip and the second Lab 7 position is the static reading at the end of the test run. The non-differentially corrected 1-channel GPS positions had an error of 5.351 to 68.888 meters (17.6 to 224.3 feet) when compared to the monuments actual state plane coordinates. 5-channel GPS positions had an error of 9.032 to 81.928 meters (29.6 to 268.8 ft). Because of this inaccuracy, the GPS was useful only at distances which were much greater than the error of the GPS position. At distances over 8 miles, the inaccuracy became insignificant and thus, a smooth plot of the path could be drawn.

Figures 46 through 66 show the plots of the paths logged by the GPS units. A comparision of plotted paths using the 5-channel unit and the 1-channel unit yielded mixed results. The 5-channel unit was expected to plot out a smoother path and be more accurate than shown in Table 1 because the satellites could be continuously tracked instead of sequentially tracked. On some test runs it did (see Figures 56, 60, 64). However, on test Route 5 (Figure 61), the 1-channel unit plotted out a smoother, more precise path than the 5-channel unit (Figure 62). A review of the raw position data indicated that the 5-channel unit had more instances of losing satellite lock than the 1-channel unit. It was also observed that sometimes the 1-channel unit was locked onto 4 satellites while the 5-channel unit was locked onto 3. The Magellan technical representative informed us that the 5-channel unit had stricter limits on acceptable signal quality. Thus, the 1-channel unit was more likely to keep acquiring position fixes from satellites whose positions in the sky were less than desirable. Toward the end of this project, new firmware was installed in the 5-channel unit to improve the satellite re-acquisition time should the receiver momentarily lose sight of a satellite. The unit was tested along Route 2 along with a 1-channel unit. As shown in Figure 66, the new firmware improved the performance of the 5-channel unit. The sharp discontinuity shown in Figure 52 had disappeared in Figure 66. Also, the 1-channel unit lost lock on the satellite during the test run (see Figure 65). The 5-channel unit continued to track during this time and the resulting path was plotted in Figure ___. Table 1 shows that the amount of error for the 5-channel unit was less when compared to previous test runs and to the 1-channel unit positions collected at the same time. The 5-channel unit with the new firmware should greatly improve the accuracy of the plots in future runs.

Because of the inaccuracies of uncorrected GPS positions, GPS is useful only for providing an overall picture of the paths taken and not for accurate vehicle location. Should GPS locations be differentially corrected, accurate vehicle locations using GPS as a stand-alone navigation element can be achieved. This will be investigated as an option for future applications.

The state-of-the-art in GPS receivers has grown enormously in the past year since we first began searching for a receiver. Technological improvements are expected to continue. We have concluded from our experiments with GPS in this project that performance is dependent on receiver and firmware design. Navigation solutions may vary between different receivers of the same manufacturer. Performance must be judged from testing and not solely on published specifications.

Feature Logging

Landmark features, their respective elapsed times and odometer counts, were recorded periodically during the test runs. This feature was intended only to be used in this research project for testing purposes and not as a part of any eventual vehicle navigation application. However, the attribute recording feature was quite useful whenever the source of the anomalies in the recorded data, such as compass noise, needed to be located. Its accuracy, however, was limited to the quickness and attentiveness of the operator recording the features in a speeding vehicle and the frequency at which he was recording them.

Table 2 shows a sample printout of t he attributes identified along Route 5A.

Loop Excitation Monitor

The loop excitation monitor probe, mounted at the rear of the test vehicle, sensed the vertical component of the inductive loop field as the vehicle traveled over the loop. An asterisk (*) appeared on the laptop display each time the preset loop signal amplitude threshold was crossed. The signal amplitude and a signal proportional to the loop frequency was stored in memory.

Figures 67 through 70 show a sample of the loops detected during two test runs. Table 3 is the output from test Route 1, which summarizes the characteristics of the loops encountered during the test. Figure 24 shows the plot of the test route along with the loops (represented by the squares) encountered. Overall, the loop monitor worked quite well. Occasionally, on Route 1, the loop on Folsom Blvd. (Inductive Loop 1) on the approach to 65th St. was not detected. See Figure 23 for its location.

The loop monitor was used on Route 4 to determine the location of newly installed loops on a newly paved surface (loop sawcuts not visible). District traffic operations personnel had problems on the Zinfandel ramp because some of the cars entering the freeway missed the ramp metering demand loops (they drove too far to the right as they rounded the slip ramp). Also, the location of the queue loop was not documented and needed to be located. The queue loop was readily detected as we entered the ramp. See Figure 70. The demand loop, however, could not be detected in three attempts at different lateral offsets. The loop detector was working at the time, so the loop monitor was not sufficiently sensitive to detect the loop field.

The loop monitor was also used to locate loops covered by pavement overlay in another research project on Interstate 880 in San Leandro, California. In this project, the loop monitor successfully detected and located all of the loops in question.

The loop monitor also detected the low frequency signal (700 to 7000 Hz) which is a part of the light rail crossing gate activation circuit. The loop monitor activated when the vehicle crossed over each rail. No signal was detected at crossings where there was no crossing gate. A plot of the signal is shown in Figure 69. The calculated frequency shown in the loop summary table for these signals is inaccurate due to the number of harmonics present in the signal. The fact that the signal plots and the calculated frequencies do not match those found in normal detectors would provide a hint these are not loop detectors.

Additional loop plots are included in Appendix H.

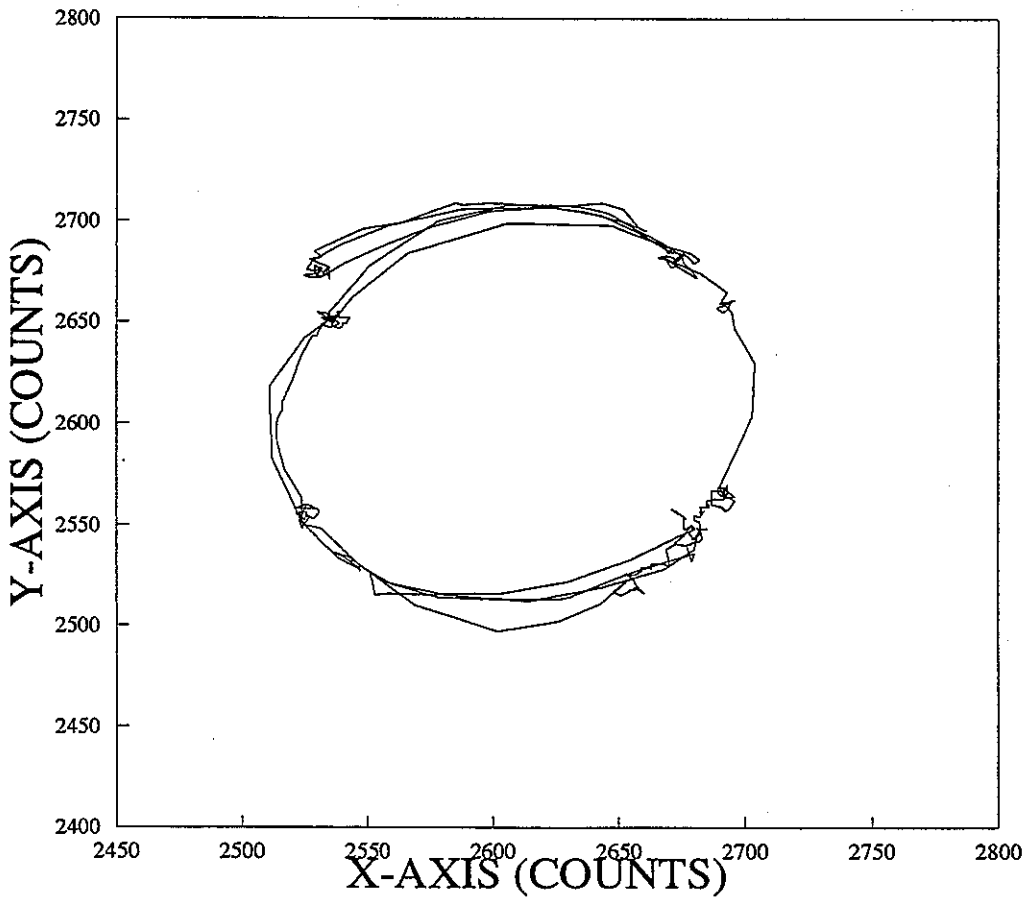


Figure 16

Compass Magnetization Circle
Route 1 June 1, 1992

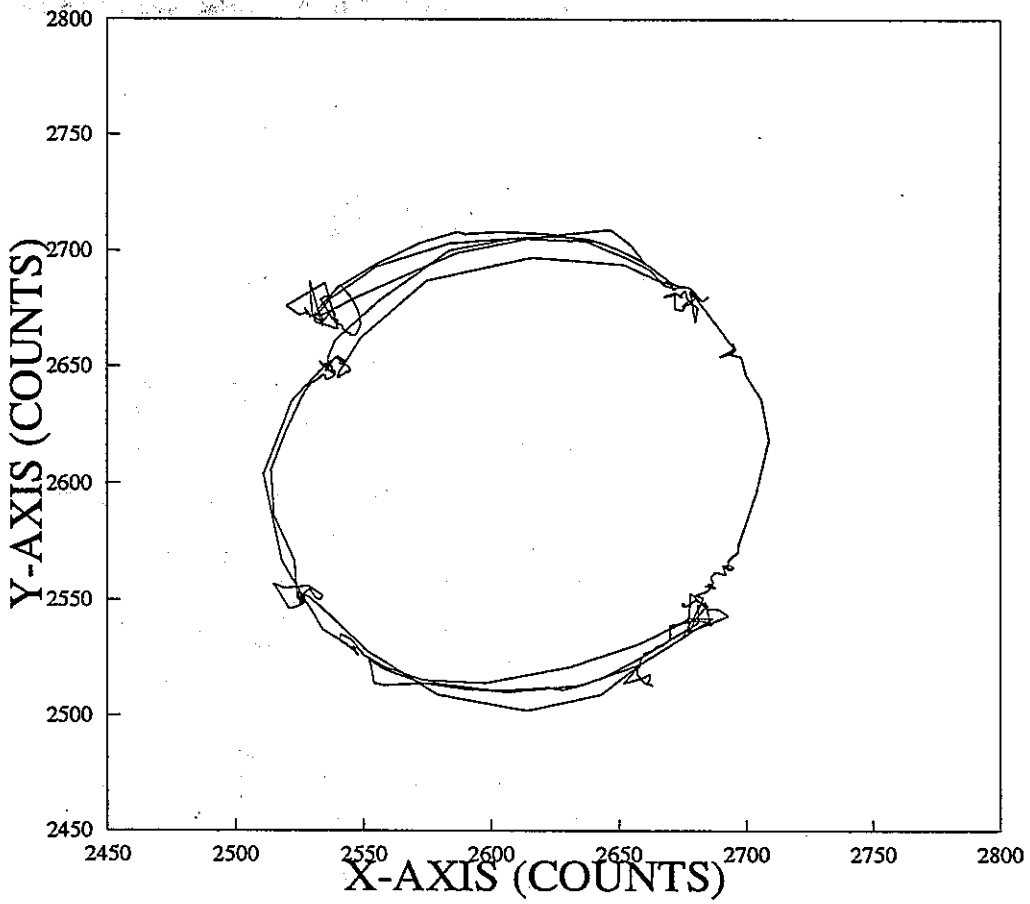


Figure 17

Compass Magnetization Circle
Route 1 June 12, 1992

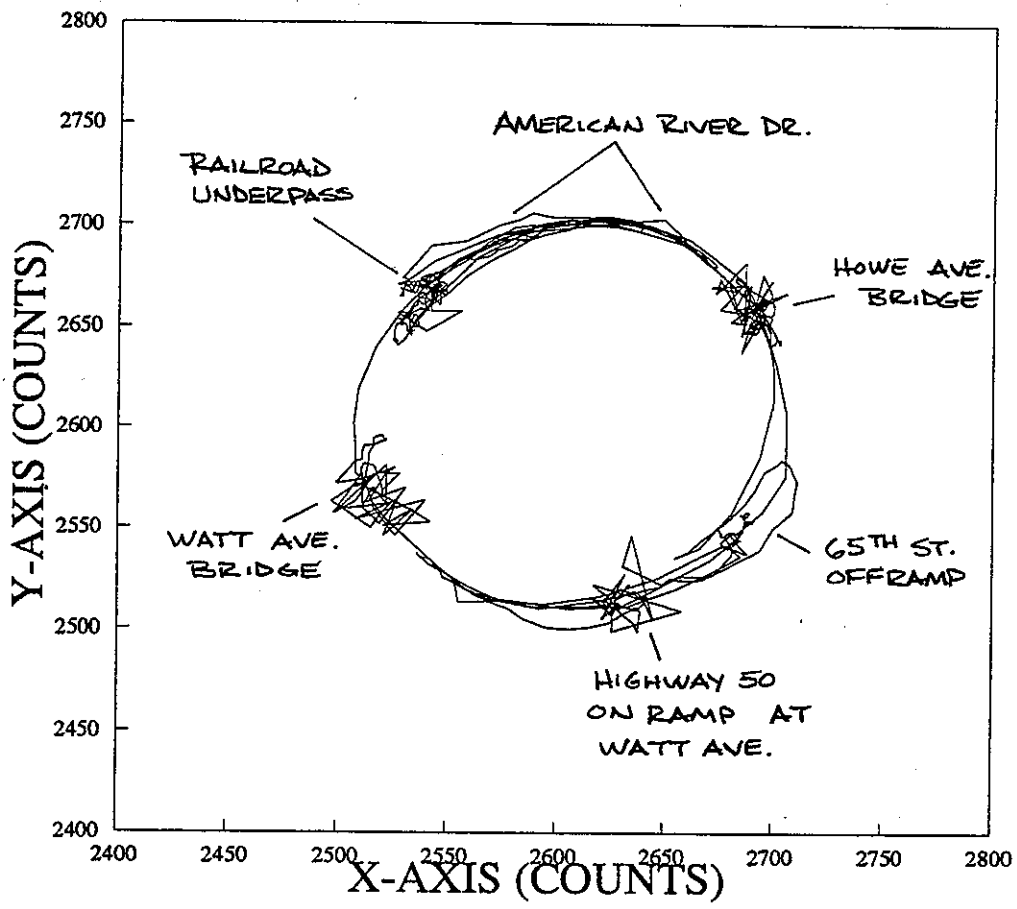


Figure 18

Compass Magnetization Circle
Route 2 May 28, 1992

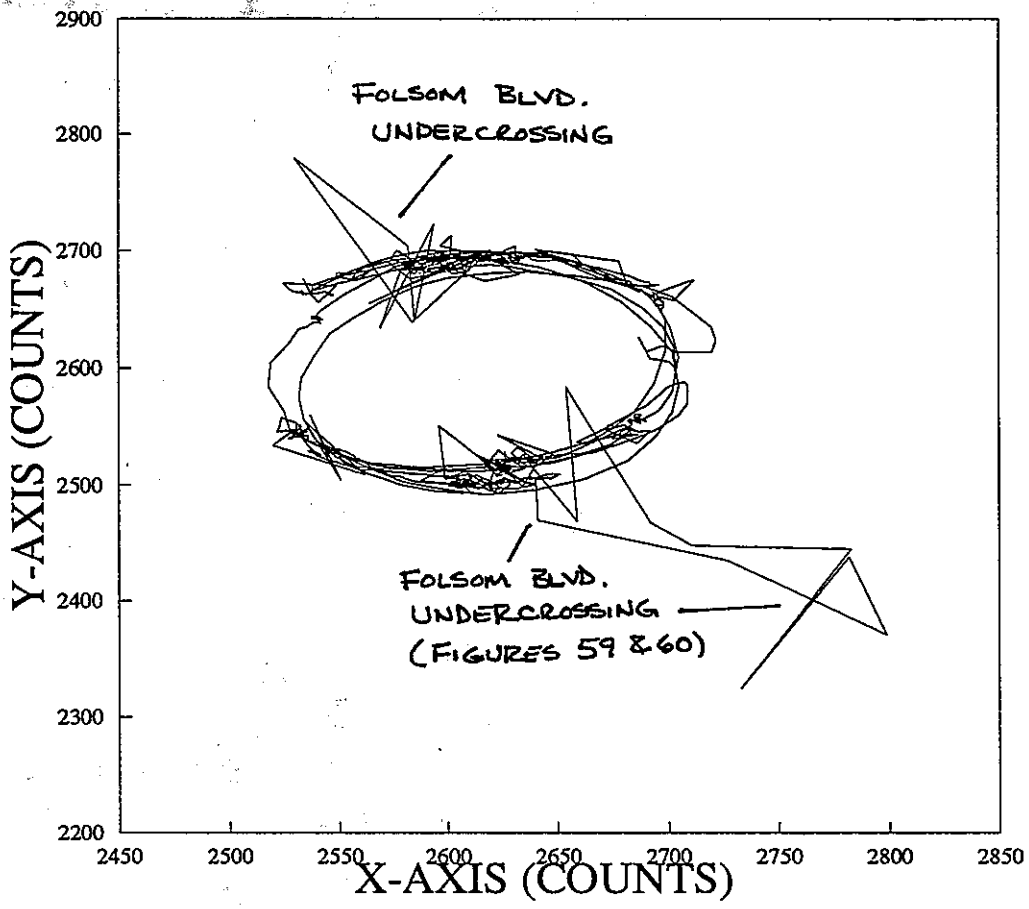


Figure 19

Compass Magnetization Circle
Route 3 June 12, 1992

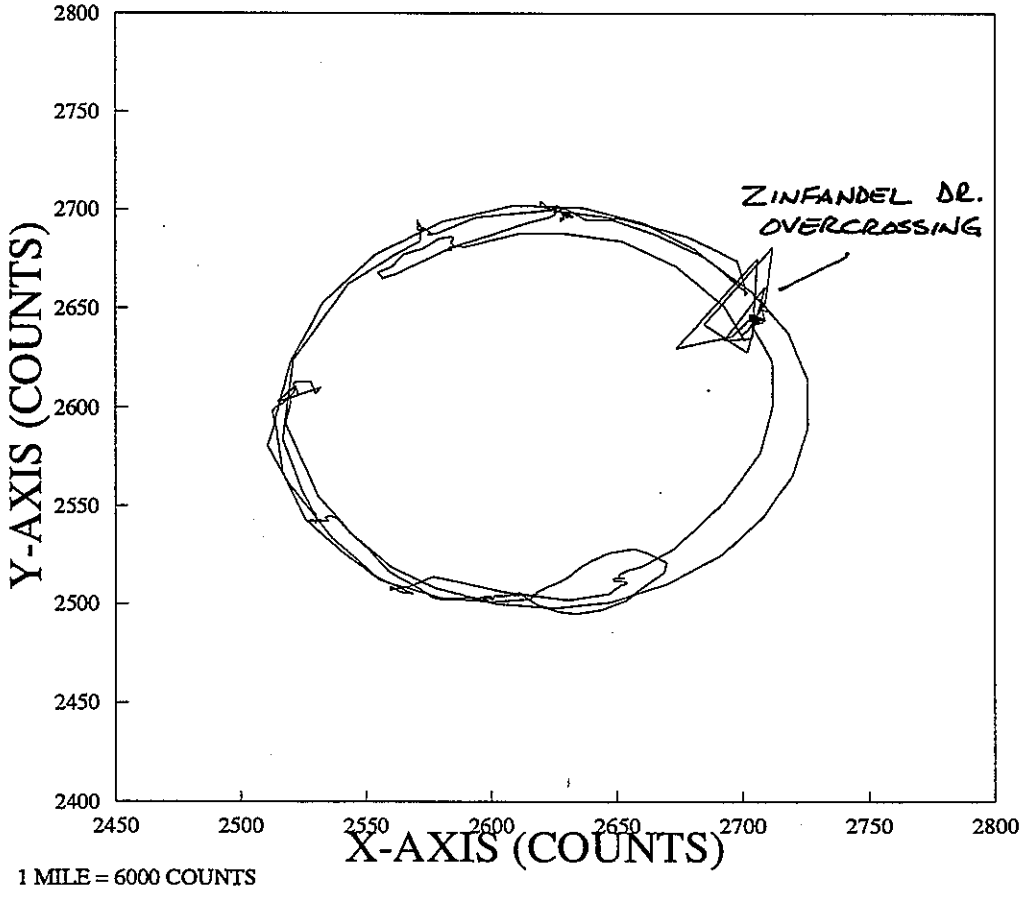


Figure 20

Compass Magnetization Circle
Route 4 June 15, 1992

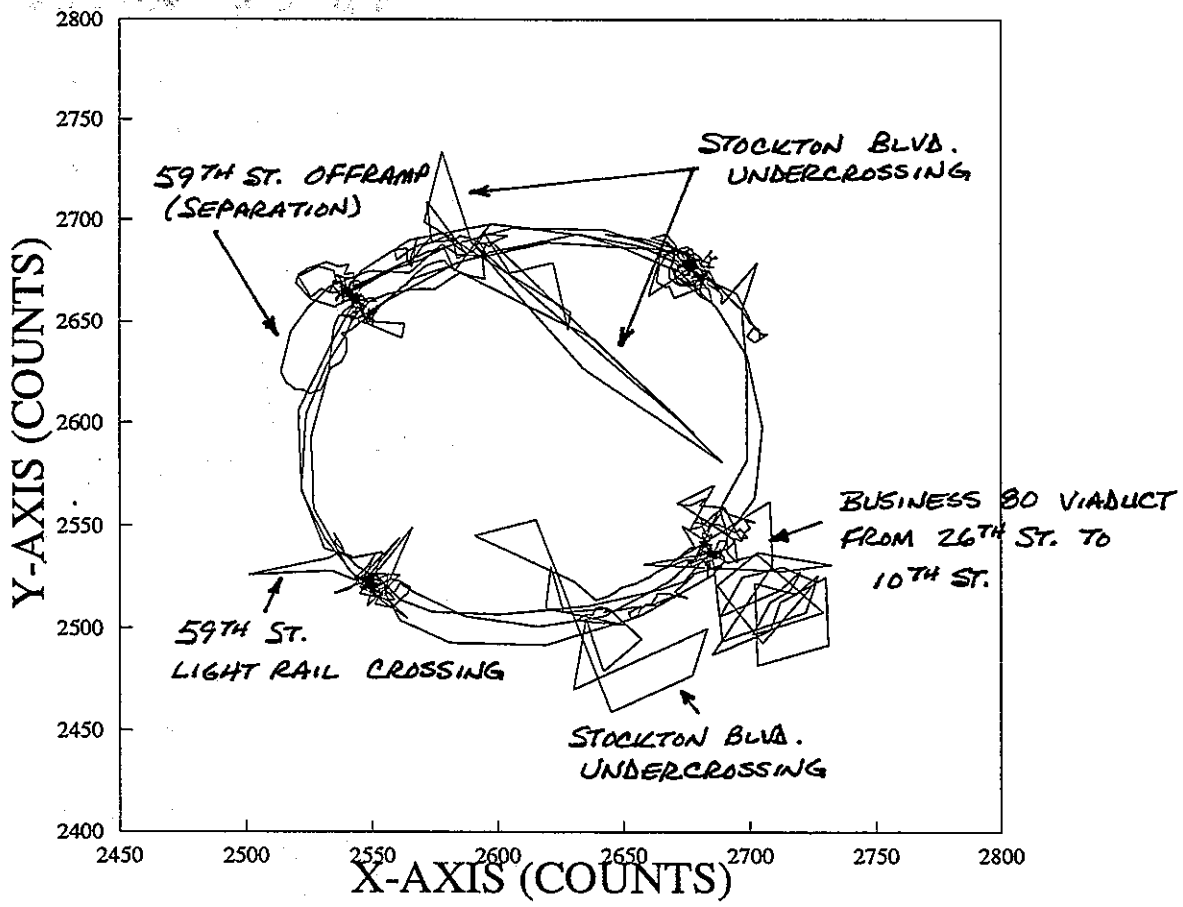


Figure 21

Compass Magnetization Circle
Route 5 August 4, 1992

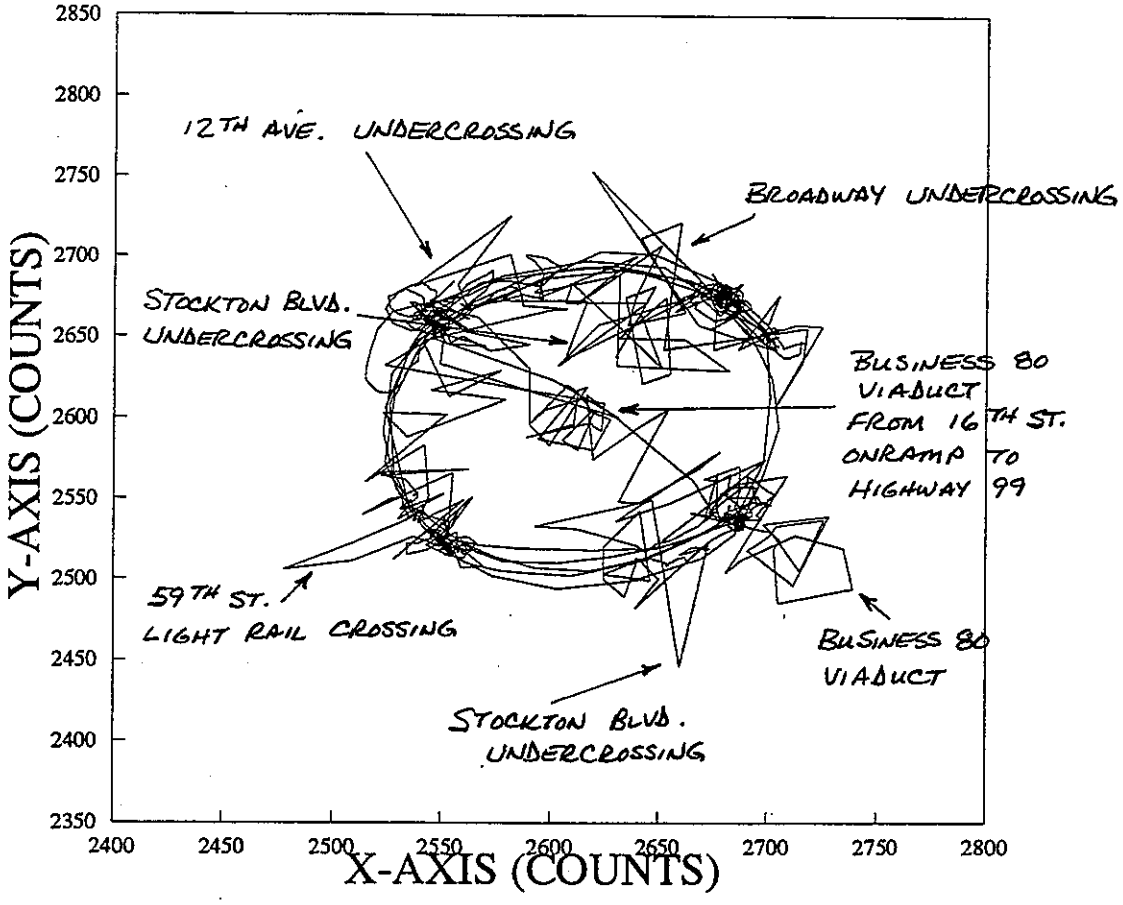


Figure 22

Compass Magnetization Circle
Route 5A August 5, 1992

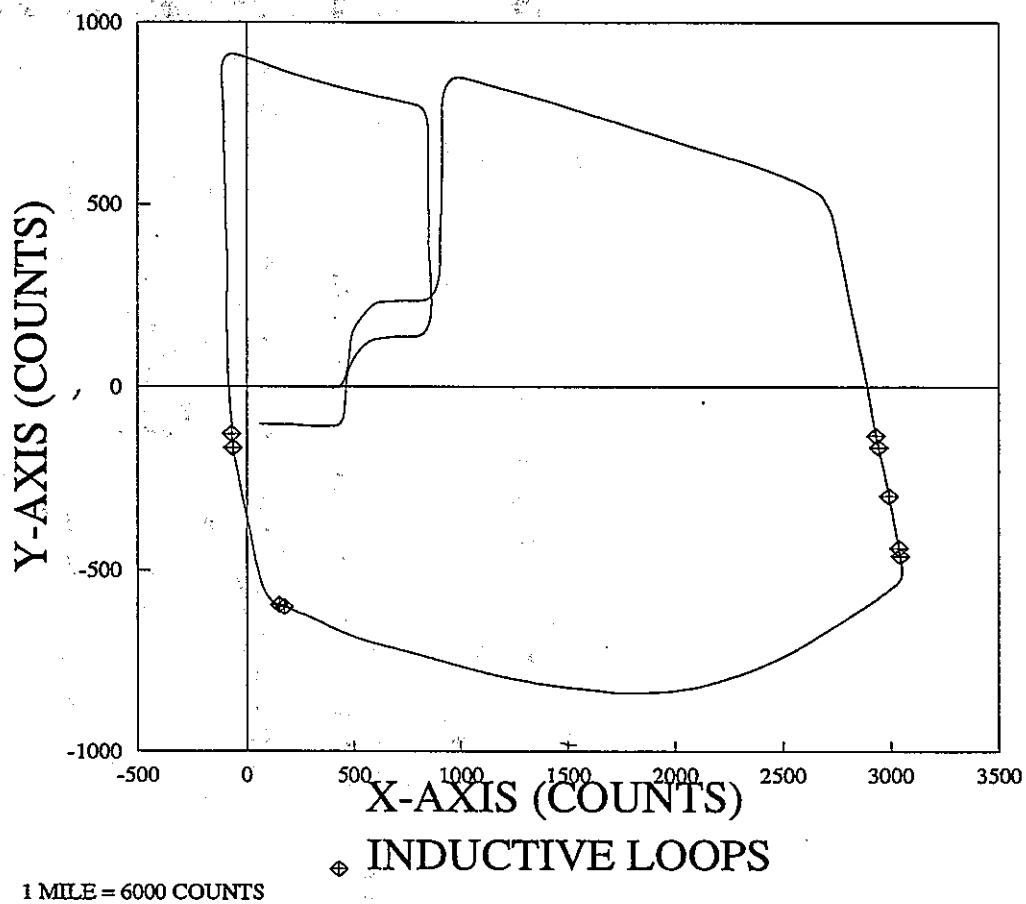


Figure 23

Compass Path
Route 1 June 1, 1992

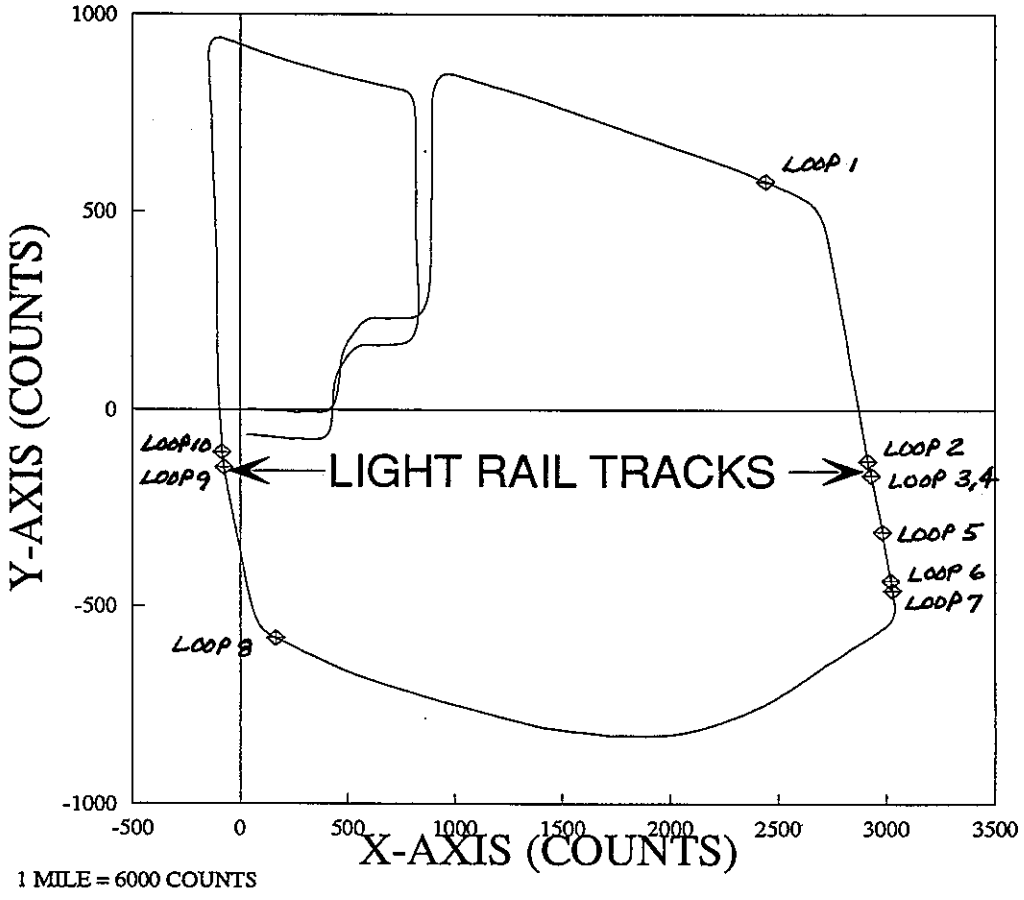


Figure 24

Compass Path
Route 1 June 12, 1992

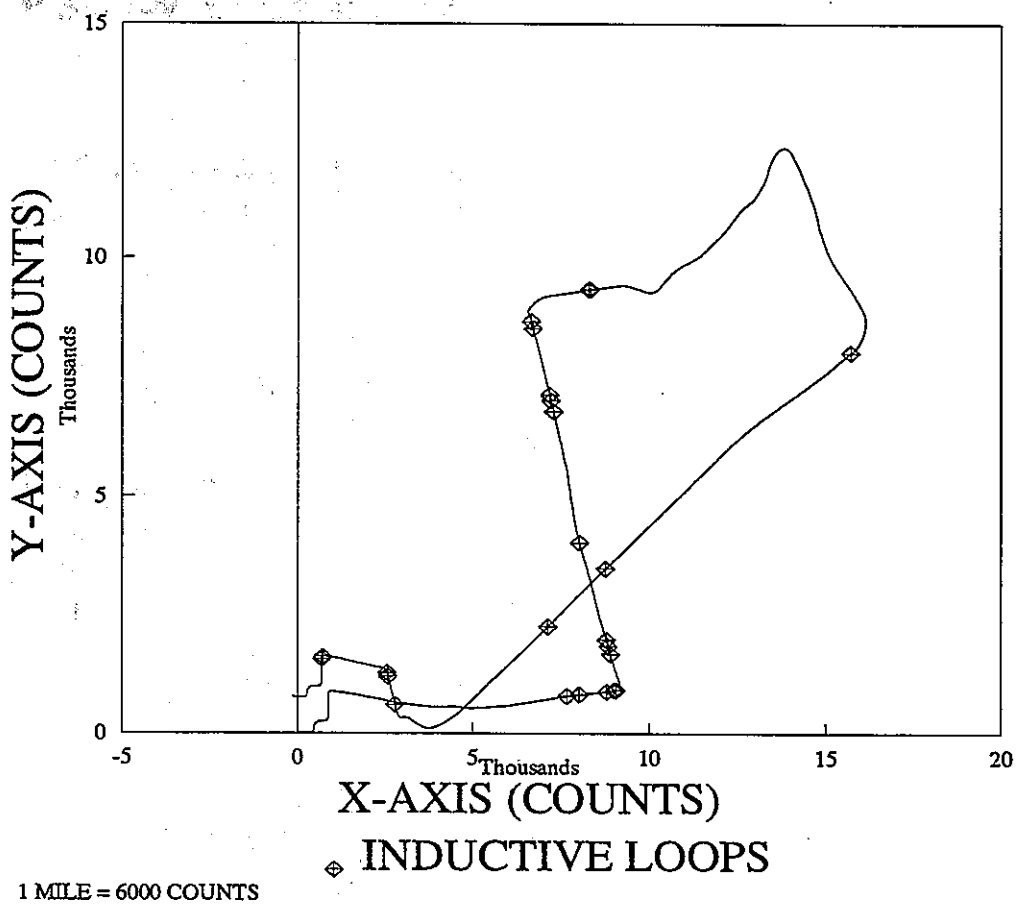


Figure 25

Compass Path
Route 2 May 28, 1992

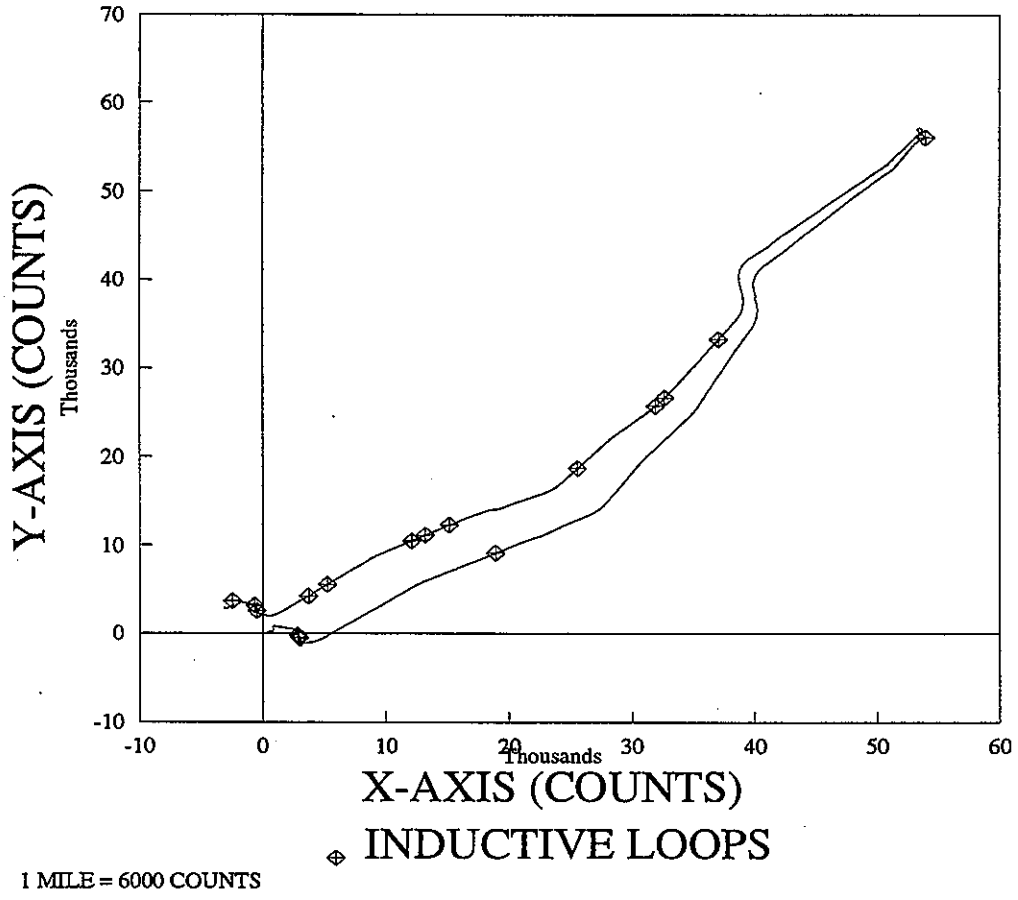


Figure 26

Compass Path
Route 3 June 12, 1992

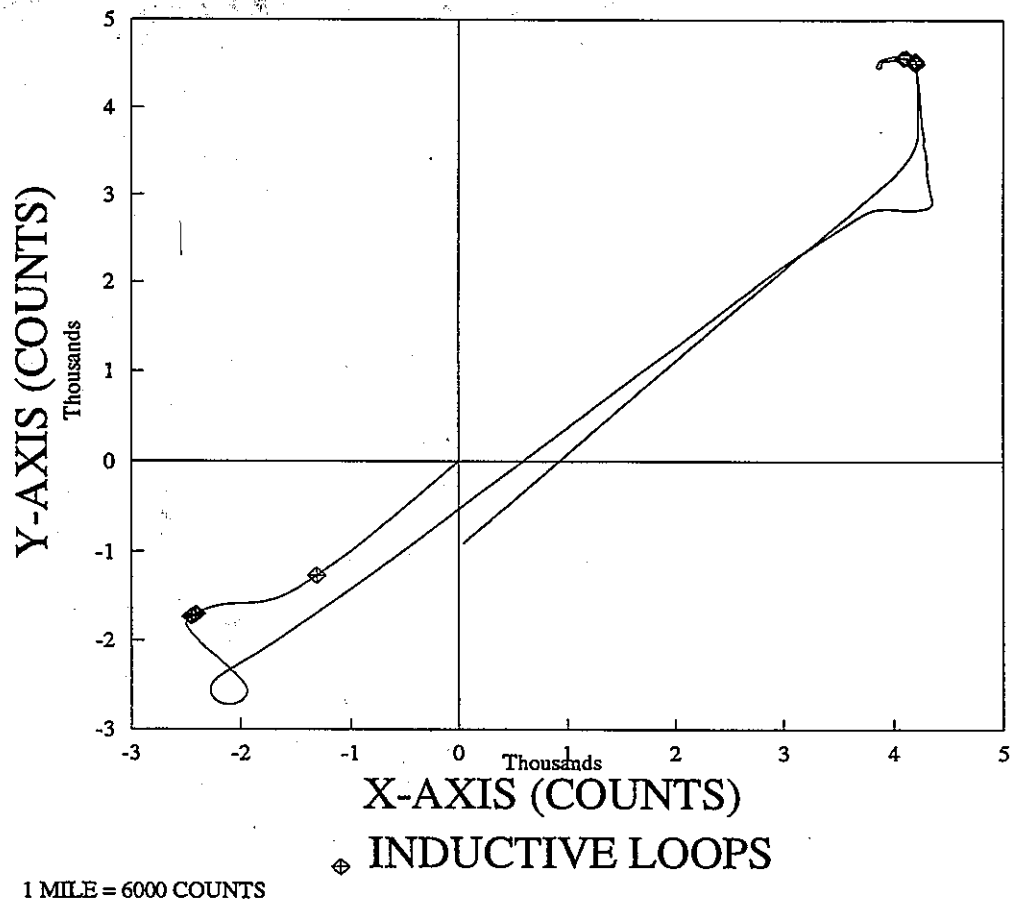


Figure 27

Compass Path
Route 4 June 15, 1992

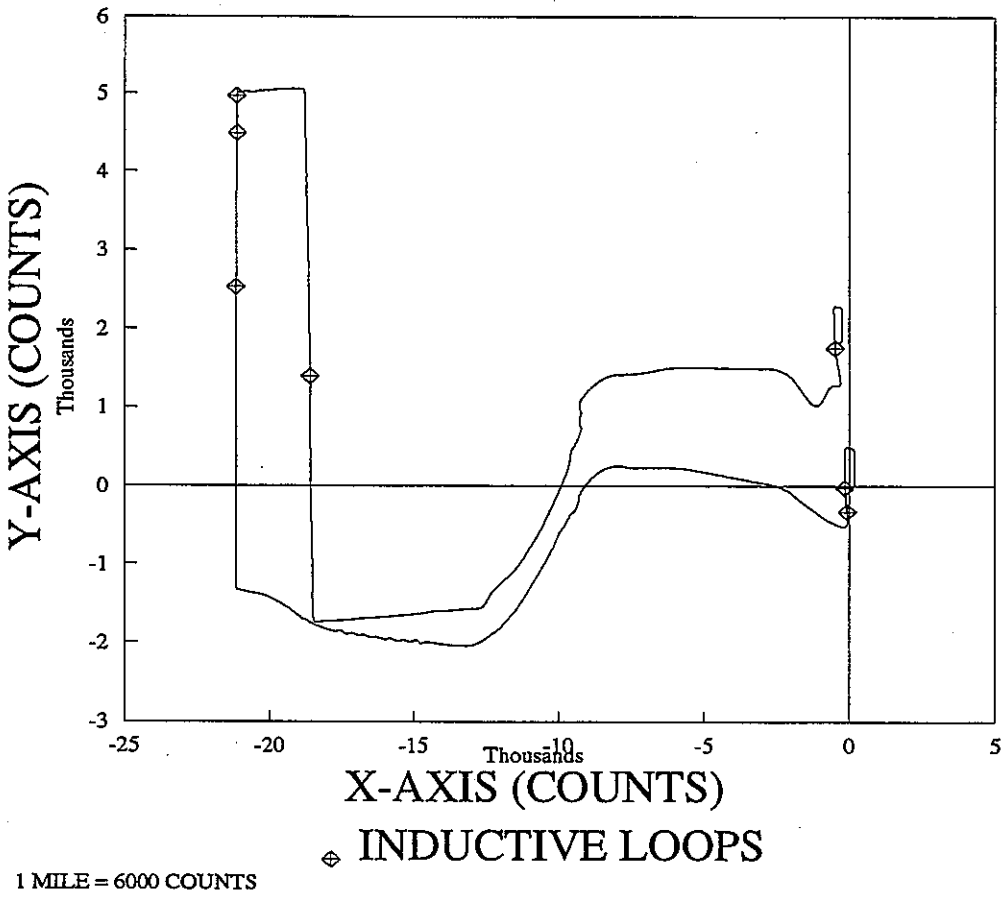


Figure 28

Compass Path
Route 5 August 4, 1992

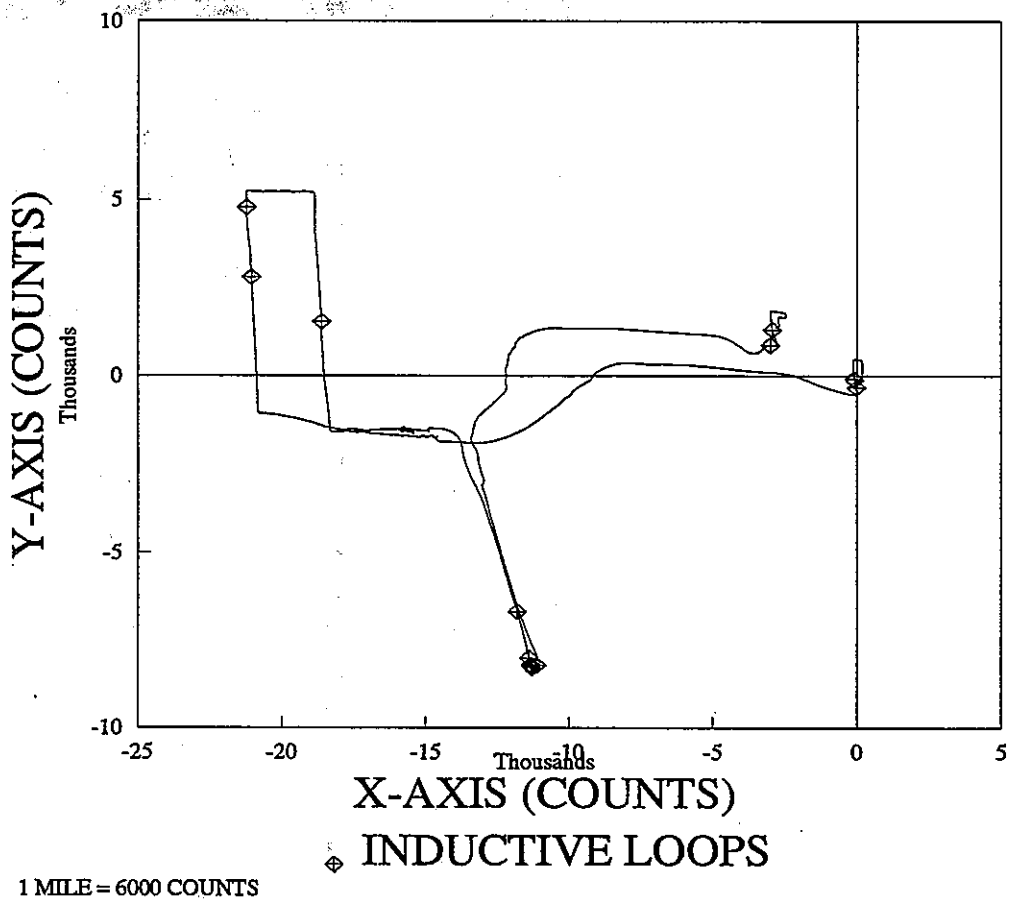


Figure 29

Compass Path
Route 5A August 5, 1992

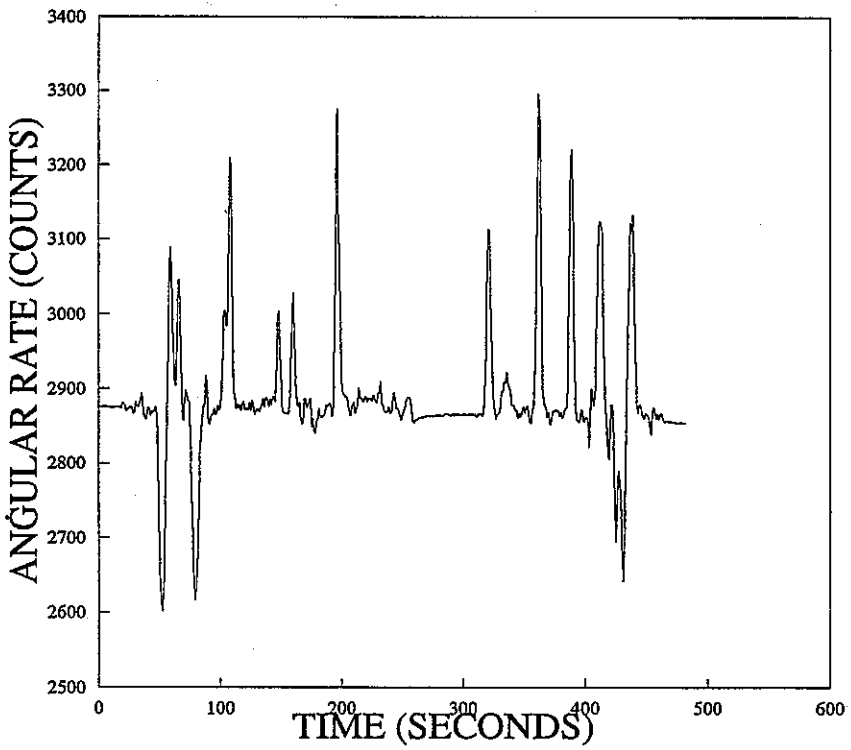


Figure 30 Angular Rate vs. Time
Route 1 June 1, 1992

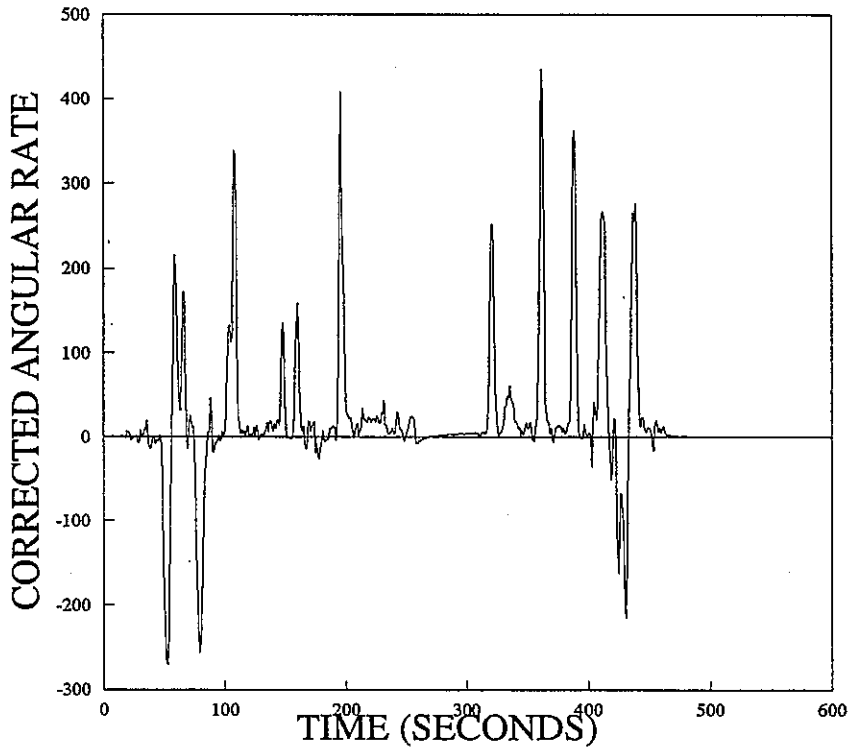


Figure 31 Corrected Angular Rate vs. Time
Route 1 June 1, 1992

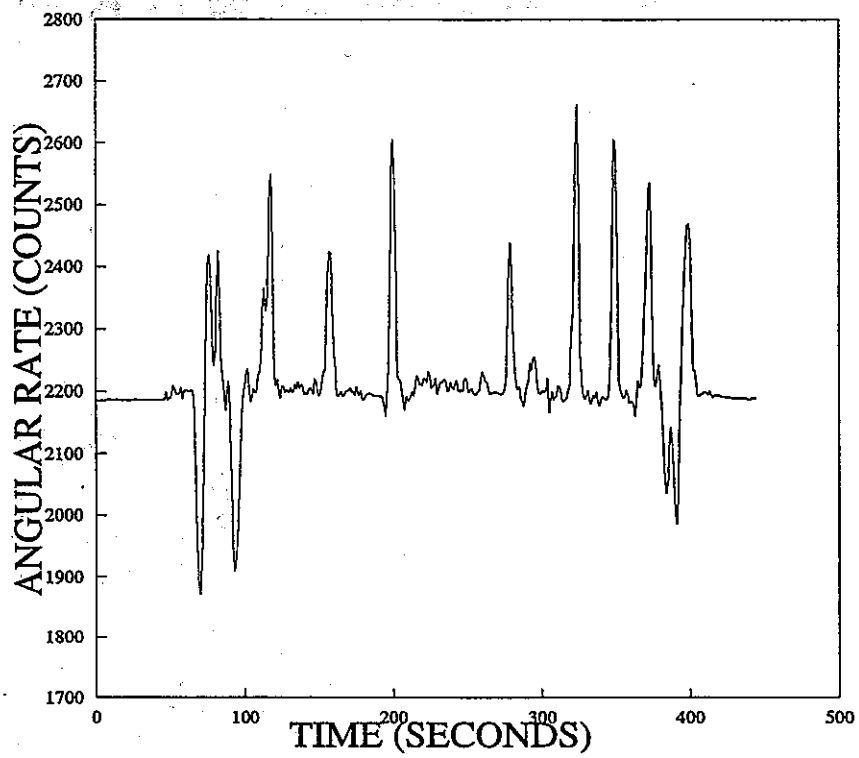


Figure 32 Angular Rate vs. Time
Route 1 June 12, 1992

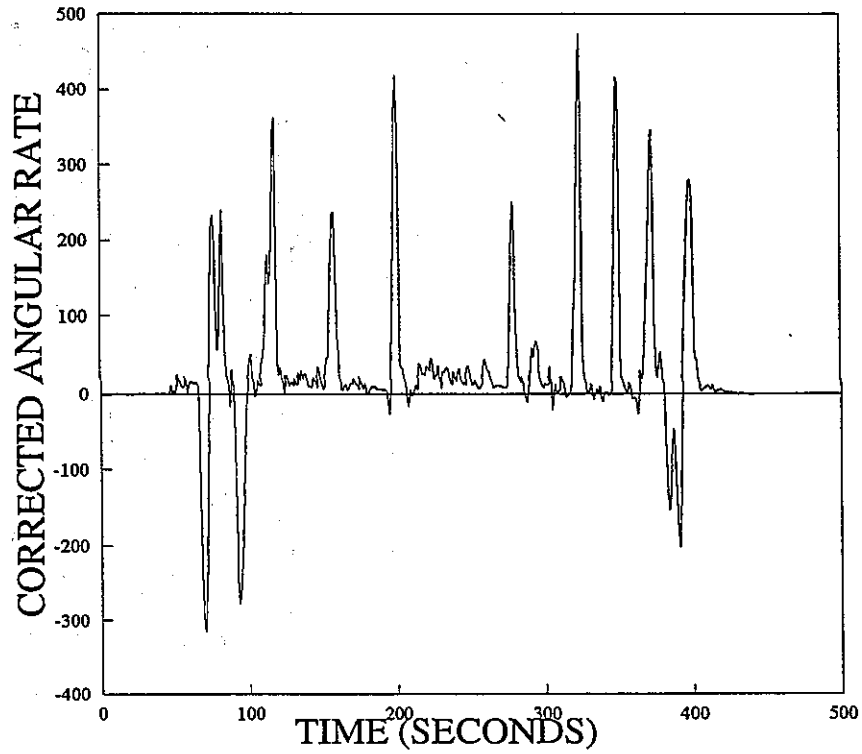


Figure 33 Corrected Angular Rate vs. Time
Route 1 June 12, 1992

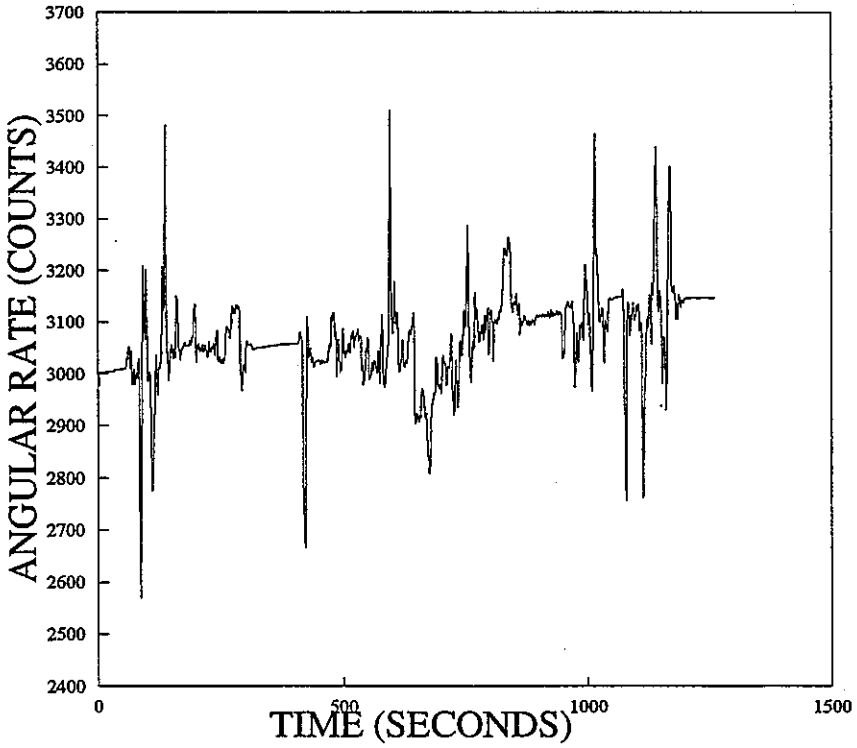


Figure 34 Angular Rate vs. Time
Route 2 May 28, 1992

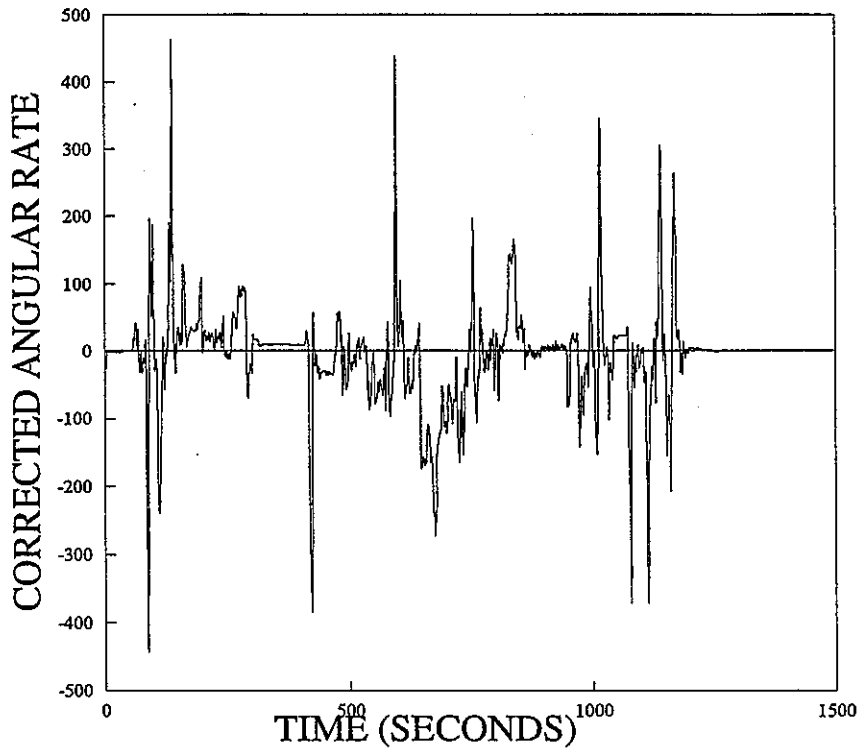


Figure 35 Corrected Angular Rate vs. Time
Route 2 May 28, 1992

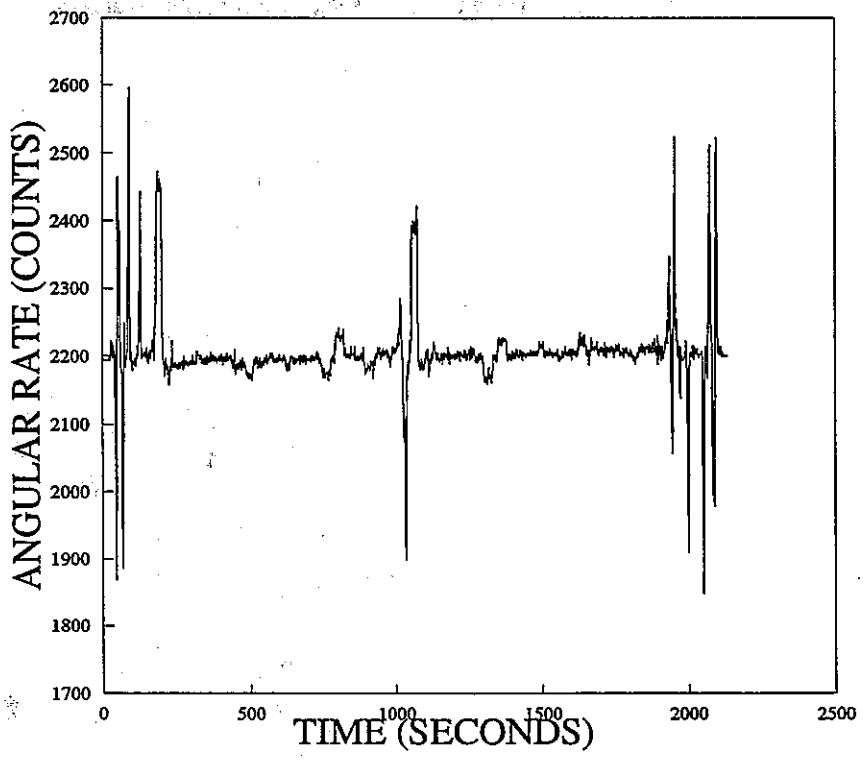


Figure 36 Angular Rate vs. Time
Route 3 June 12, 1992

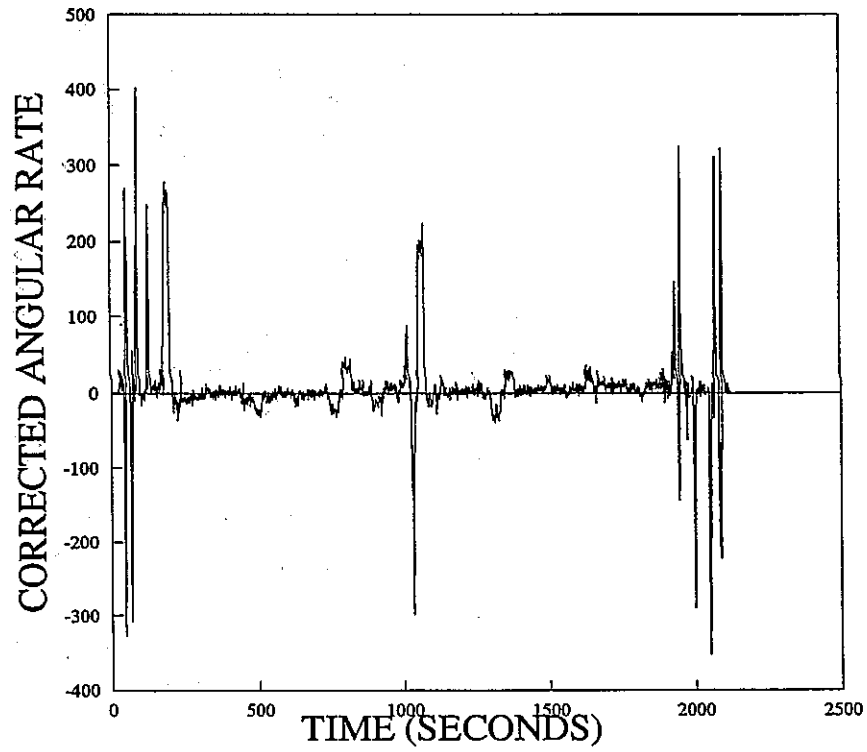


Figure 37 Corrected Angular Rate vs. Time
Route 3 June 12, 1992

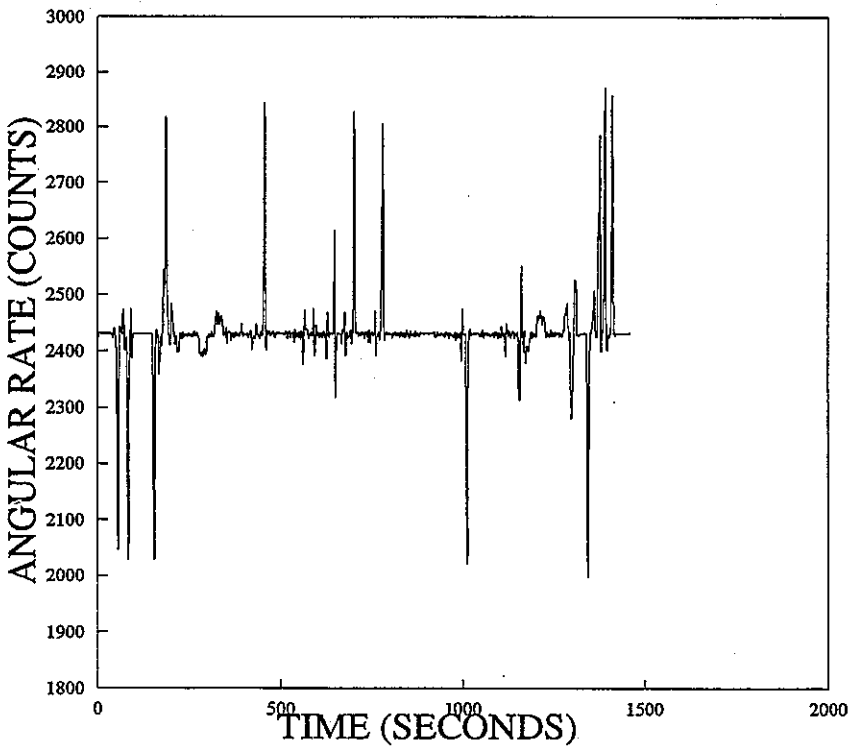


Figure 38 Angular Rate vs. Time
Route 5 August 4, 1992

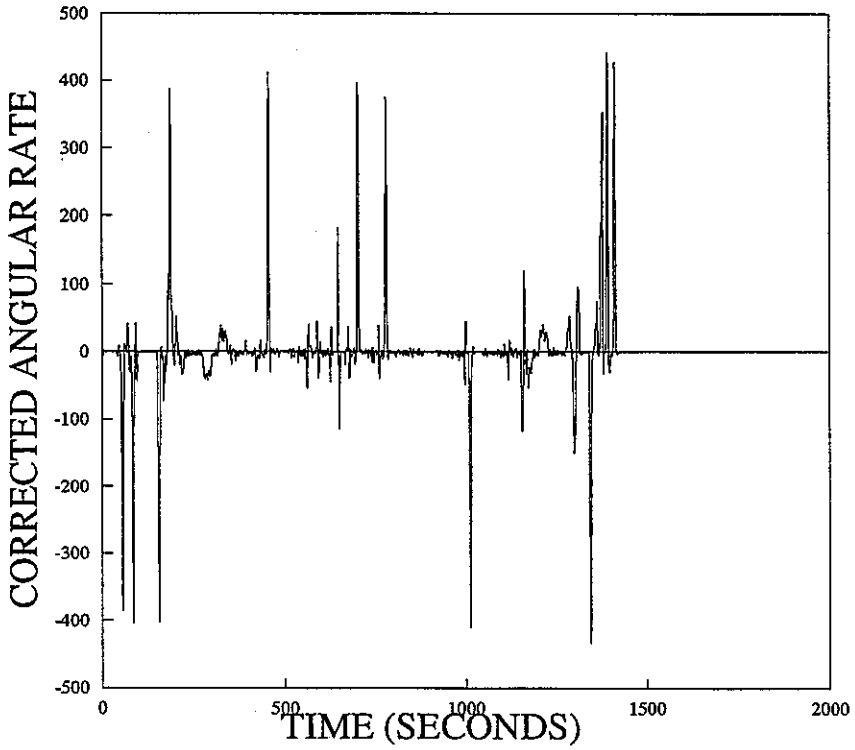


Figure 39 Corrected Angular Rate vs. Time
Route 5 August 4, 1992

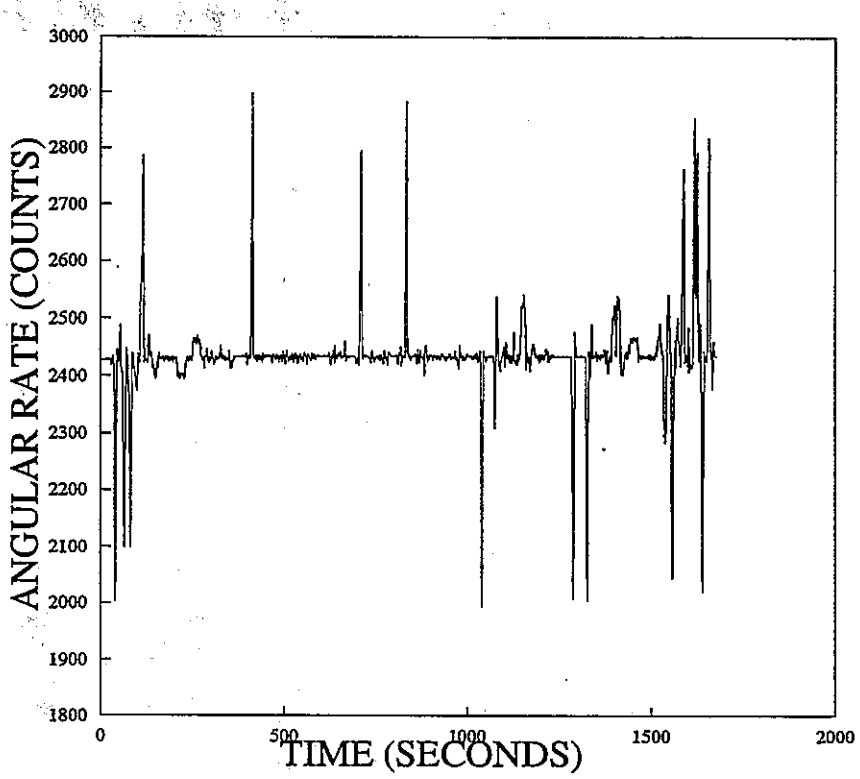


Figure 40 Angular Rate vs. Time

Route 5A August 5, 1992

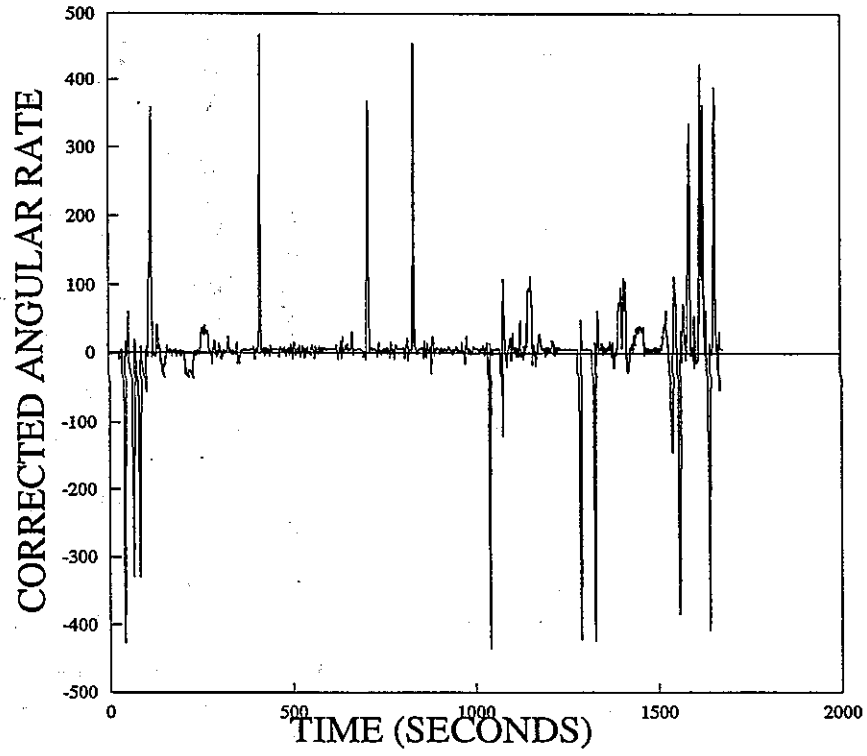


Figure 41 Corrected Angular Rate vs. Time
Route 5A August 5, 1992

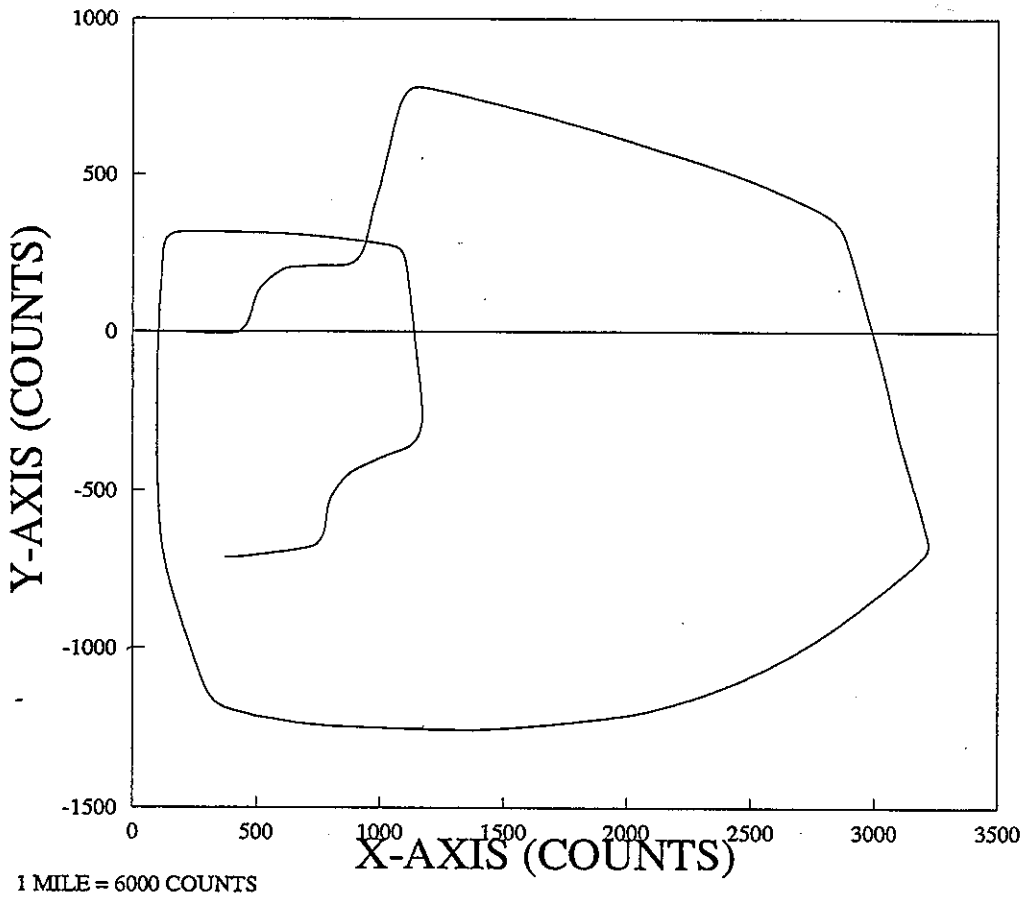


Figure 42

Angular Rate Sensor Path
Route 1 June 1, 1992

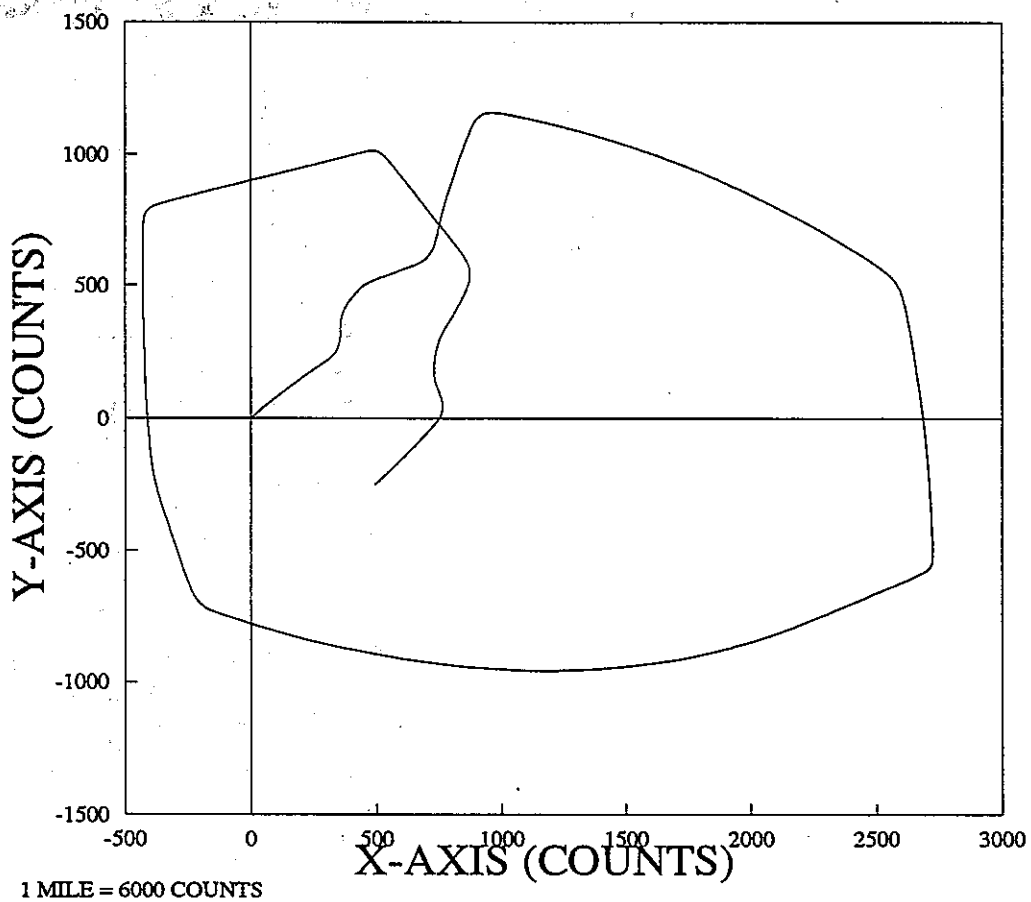


Figure 43

Angular Rate Sensor Path
Route 1 June 12, 1992

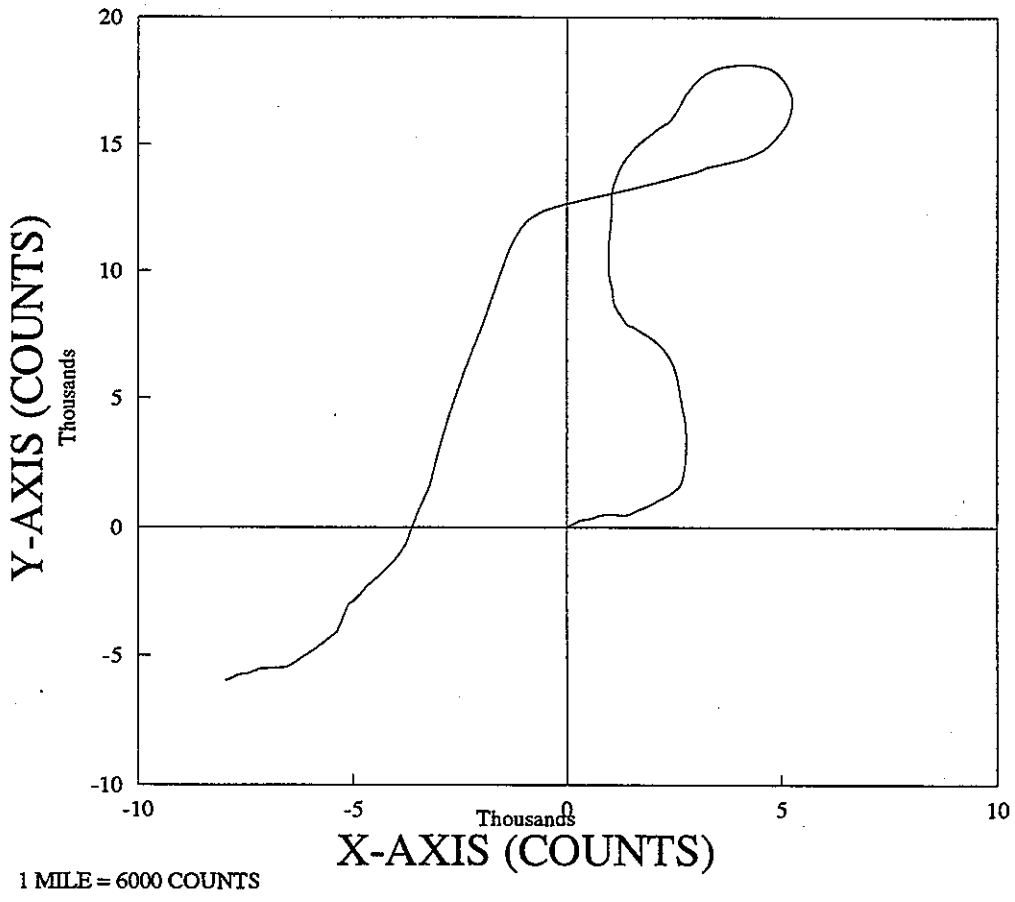


Figure 44

Angular Rate Sensor Path
Route 2 May 28, 1992

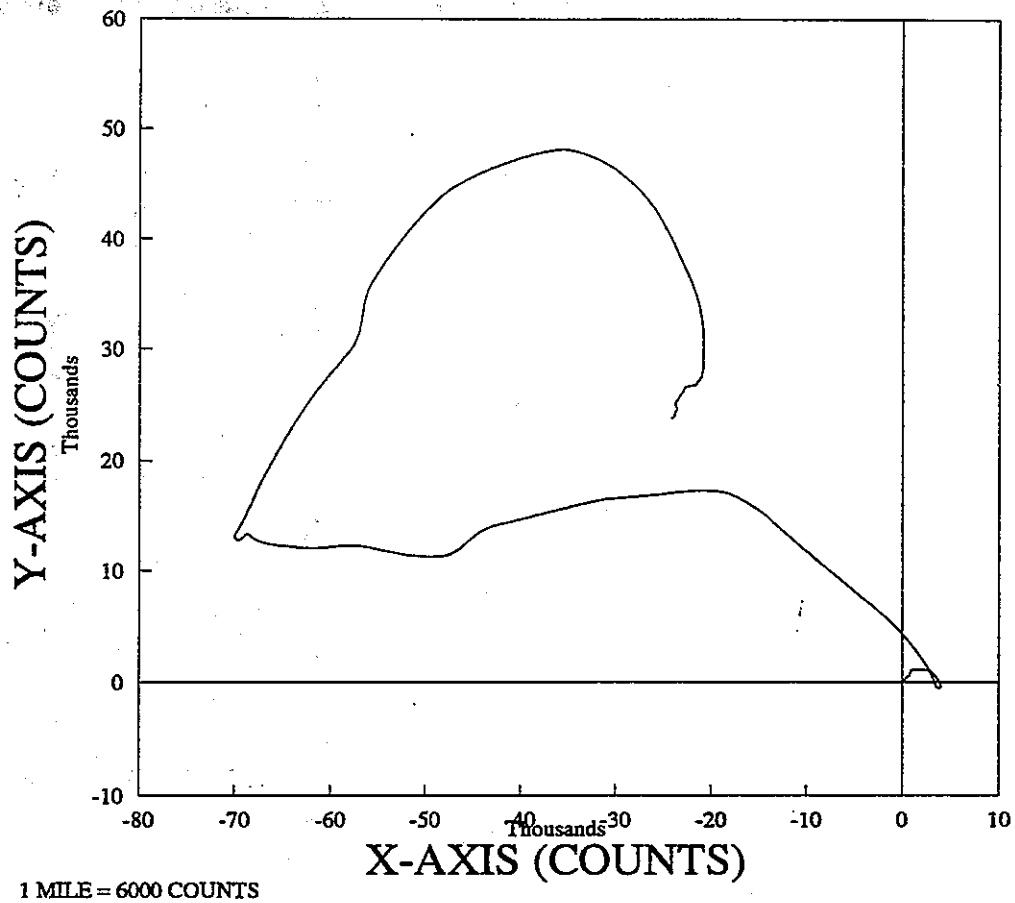


Figure 45

Angular Rate Sensor Path
Route 3 June 12, 1992

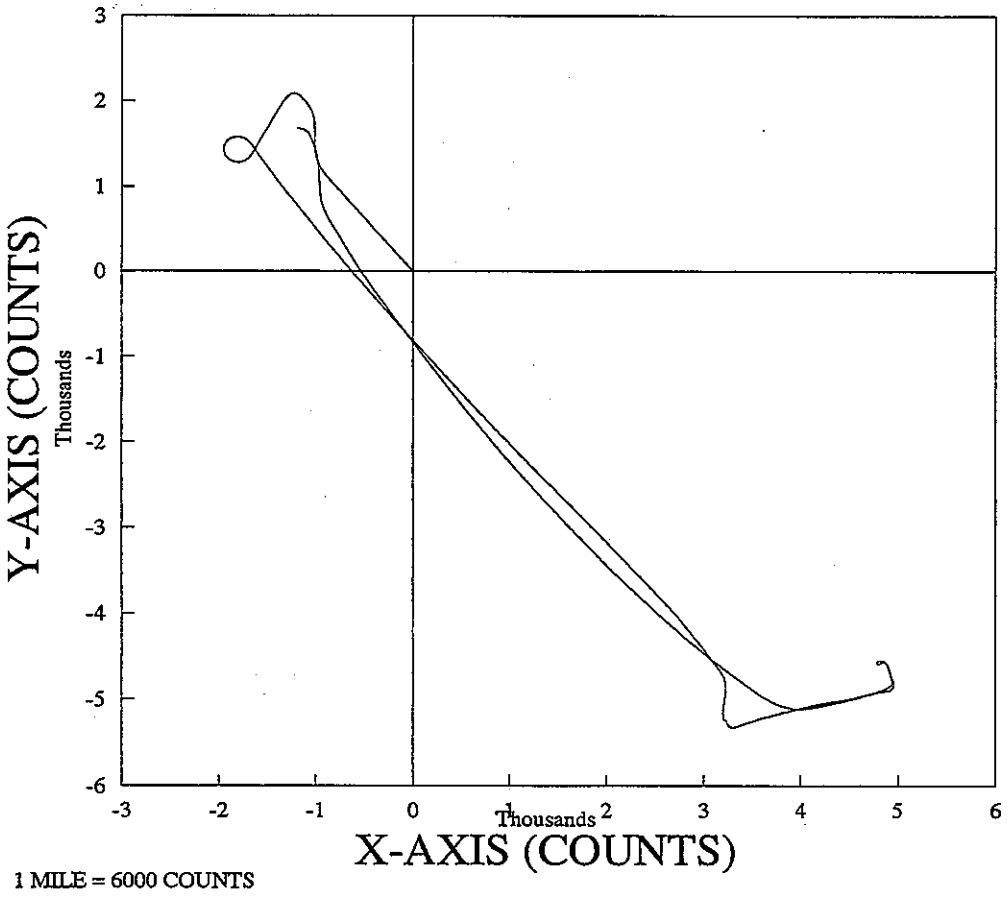


Figure 46

Angular Rate Sensor Path
(Incrementally Corrected)
Route 4 April 30, 1992

TABLE 1: A COMPARISON OF GPS POSITIONS AGAINST SURVEYED MONUMENTS

NOTE: STATE PLANE COORDINATES BASED ON NAD83, ZONE 2, CALIFORNIA

FILE: LAB7LAB8.WK3

| | ACTUAL LAT (deg/min) | ACTUAL LONG (deg/min) | STATE PLANE COORDINATES NORTHING (meters) | STATE PLANE COORDINATES EASTING (meters) | MARKER ERROR (meters) | DISTANCE LAB7 TO LAB8 (meters) | ERROR (meters) |
|---|---|---|---|---|---|---|---|
| LAB7 | 3833.22 | 12126.24 | 598773.9157 | 2049139.6823 | 0 | | |
| LAB8 | 3833.32 | 12126.12 | 598743.6125 | 2049226.9346 | 0 | 92.299 | 0 |

| DATE | ROUTE | MARKER | 1-CH GPS LAT (deg/min) | 1-CH GPS LONG (deg/min) | STATE PLANE COORDINATES NORTHING (meters) | STATE PLANE COORDINATES EASTING (meters) | MARKER ERROR (meters) | DISTANCE LAB7 TO LAB8 (meters) | ERROR (meters) | 5-CH GPS LAT (deg/min) | 5-CH GPS LONG (deg/min) | STATE PLANE COORDINATES NORTHING (meters) | STATE PLANE COORDINATES EASTING (meters) | MARKER ERROR (meters) | DISTANCE LAB7 TO LAB8 (meters) | ERROR (meters) | COMMENT |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6-1-92 | 1 | LAB7 | 3833.33 | 12126.20 | 598818.101 | 2049100.970 | 58.745 | | | 3833.31 | 12126.22 | 598780.921 | 2049072.146 | 67.899 | | | |
| | | LAB8 | 3833.32 | 12126.14 | 598800.142 | 2049188.245 | 68.337 | 89.104 | 3.196 | 3833.29 | 12126.17 | 598744.371 | 2049145.009 | 81.928 | 81.516 | 10.783 | |
| | | LAB7 | 3833.33 | 12126.17 | 598818.371 | 2049144.550 | 44.721 | | | 3833.30 | 12126.21 | 598762.511 | 2049086.787 | 54.111 | | | |
| | | LAB8 | 3833.31 | 12126.10 | 598782.003 | 2049246.467 | 42.896 | 108.211 | -15.912 | 3833.31 | 12126.13 | 598781.732 | 2049202.887 | 44.902 | 117.680 | -25.381 | |
| 6-12-92 | 1 | LAB7 | 3833.33 | 12126.14 | 598818.642 | 2049188.131 | 65.937 | | | 3833.32 | 12126.15 | 598800.051 | 2049173.719 | 42.913 | | | |
| | | LAB8 | 3833.31 | 12126.10 | 598782.003 | 2049246.467 | 42.896 | 68.888 | 23.412 | 3833.3 | 12126.09 | 598763.593 | 2049261.109 | 39.486 | 94.690 | -2.391 | |
| | | LAB7 | 3833.32 | 12126.13 | 598800.232 | 2049202.772 | 68.358 | | | 3833.32 | 12126.15 | 598800.051 | 2049173.719 | 42.913 | | | |
| | | LAB8 | 3833.30 | 12126.09 | 598763.593 | 2049261.109 | 39.486 | 68.888 | 23.411 | 3833.3 | 12126.1 | 598763.503 | 2049246.583 | 27.817 | 81.516 | 10.783 | |
| 5-28-92 | 2 | LAB7 | 3833.30 | 12126.17 | 598762.871 | 2049144.895 | 12.213 | | | 3833.3 | 12126.17 | 598762.871 | 2049144.895 | 12.213 | | | |
| | | LAB8 | 3833.30 | 12126.13 | 598763.232 | 2049203.002 | 30.820 | 58.108 | 34.191 | 3833.3 | 12126.13 | 598763.232 | 2049203.002 | 30.820 | 58.108 | 34.191 | |
| | | LAB7 | 3833.31 | 12126.17 | 598781.732 | 2049202.887 | 63.686 | | | 3833.31 | 12126.17 | 598781.371 | 2049144.78 | 9.032 | | | |
| | | LAB8 | 3833.30 | 12126.12 | 598763.232 | 2049203.002 | 30.820 | 18.500 | 73.799 | 3833.3 | 12126.17 | 598763.232 | 2049203.002 | 30.820 | 60.982 | 31.317 | |
| 6-12-92 | 2 | LAB7 | 3833.30 | 12126.15 | 598763.051 | 2049173.948 | 35.947 | | | 3833.3 | 12126.16 | 598762.961 | 2049159.422 | 22.576 | | | |
| | | LAB8 | 3833.30 | 12126.14 | 598763.141 | 2049188.475 | 43.043 | 14.527 | 77.772 | 3833.31 | 12126.11 | 598781.912 | 2049231.941 | 38.427 | 74.954 | 17.345 | |
| | | LAB7 | 3833.33 | 12126.20 | 598818.101 | 2049100.970 | 58.745 | | | 3833.33 | 12126.2 | 598818.101 | 2049100.97 | 58.745 | | | |
| | | LAB8 | 3833.29 | 12126.11 | 598744.912 | 2049232.171 | 5.351 | 150.234 | -57.935 | 3833.31 | 12126.13 | 598781.732 | 2049202.887 | 44.902 | 108.212 | -15.912 | |
| 9-17-92 | 2 | LAB7 | 3833.30 | 12126.17 | 598762.871 | 2049144.895 | 12.213 | | | 3833.31 | 12126.17 | 598781.371 | 2049144.78 | 9.032 | | | |
| | | LAB8 | 3833.28 | 12126.12 | 598726.322 | 2049217.759 | 19.751 | 81.517 | 10.783 | 3833.29 | 12126.11 | 598744.912 | 2049232.171 | 5.351 | 94.691 | -2.392 | 5-CH GPS WITH UPDATED FIRMWARE VER 2.5 |
| | | LAB7 | 3833.31 | 12126.17 | 598781.371 | 2049144.780 | 9.032 | | | 3833.31 | 12126.17 | 598781.371 | 2049144.780 | 9.032 | | | |
| | | LAB8 | 3833.29 | 12126.11 | 598744.912 | 2049232.171 | 5.351 | 94.691 | -2.392 | 3833.29 | 12126.11 | 598744.912 | 2049232.171 | 5.351 | 94.691 | -2.392 | |
| 6-2-92 | 3 | LAB7 | | (NO DATA COLLECTED) | | | | | | 3833.28 | 12126.18 | 598725.781 | 2049130.597 | 46.985 | | | |
| | | LAB8 | | (NO DATA COLLECTED) | | | | | | 3833.29 | 12126.14 | 598744.641 | 2049188.590 | 38.354 | 60.983 | 31.317 | |
| | | LAB7 | | (NO DATA COLLECTED) | | | | | | 3833.31 | 12126.18 | 598781.281 | 2049130.253 | 11.965 | | | |
| | | LAB8 | | (NO DATA COLLECTED) | | | | | | 3833.28 | 12126.12 | 598726.322 | 2049217.759 | 19.751 | 103.333 | -11.034 | |
| 6-12-92 | 3 | LAB7 | 3833.34 | 12126.16 | 598836.961 | 2049158.962 | 65.927 | | | 3833.32 | 12126.18 | 598799.781 | 2049130.138 | 27.570 | | | |
| | | LAB8 | 3833.31 | 12126.11 | 598781.912 | 2049231.941 | 38.427 | 91.413 | 0.686 | 3833.31 | 12126.12 | 598781.822 | 2049217.414 | 39.184 | 89.105 | 3.195 | |
| | | LAB7 | 3833.33 | 12126.14 | 598763.141 | 2049188.475 | 49.968 | | | 3833.32 | 12126.16 | 598799.961 | 2049159.192 | 32.542 | | | |
| | | LAB8 | 3833.30 | 12126.09 | 598763.593 | 2049261.109 | 39.486 | 72.635 | 19.664 | 3833.31 | 12126.1 | 598782.003 | 2049246.467 | 42.896 | 89.103 | 3.196 | |

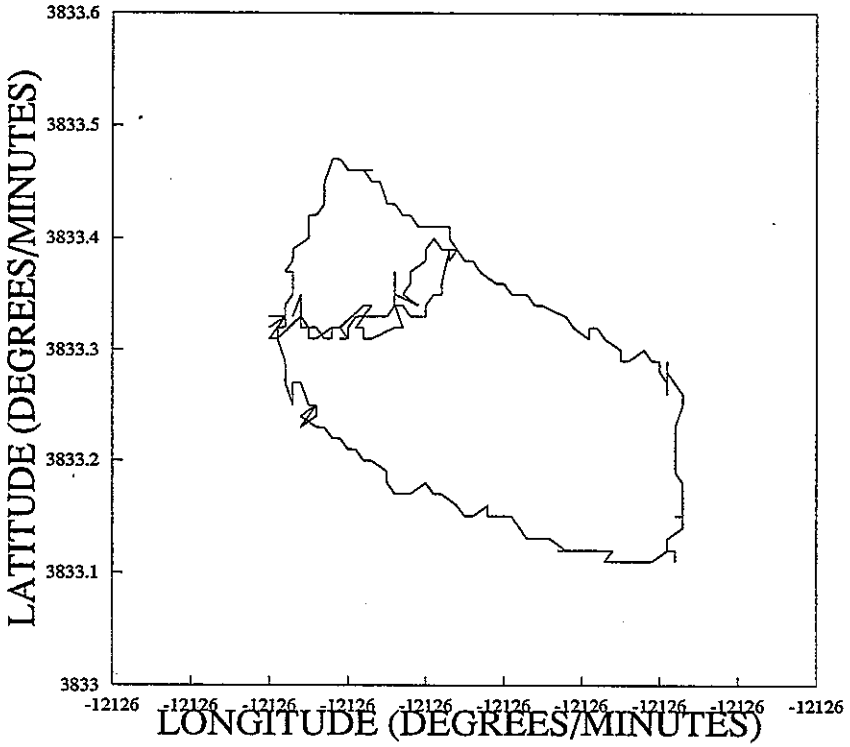


Figure 47 1-Channel GPS Receiver Path
Route 1 June 1, 1992

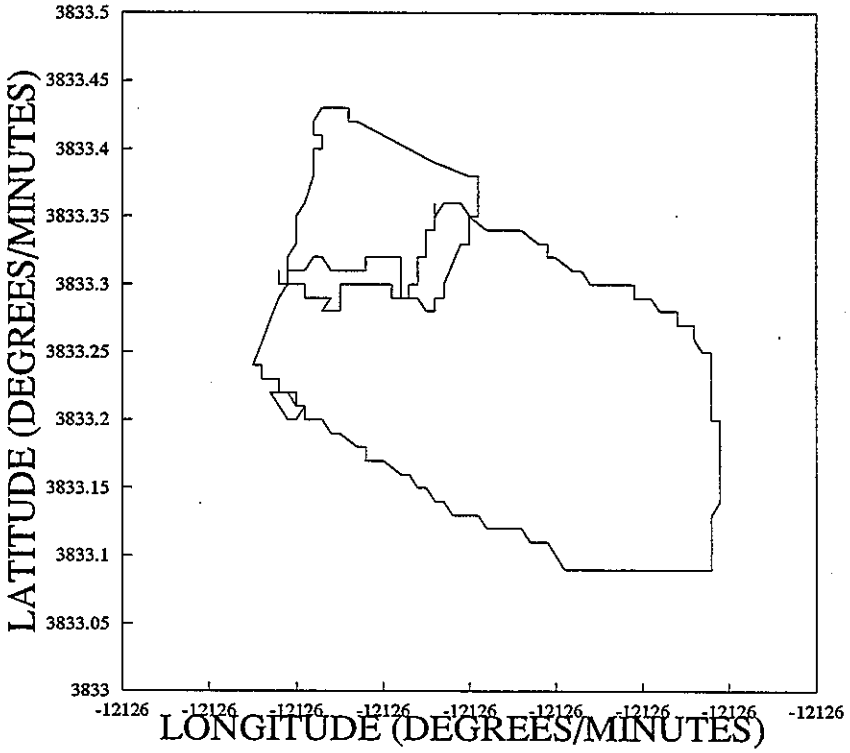


Figure 48 5-Channel GPS Receiver Path
Route 1 June 1, 1992

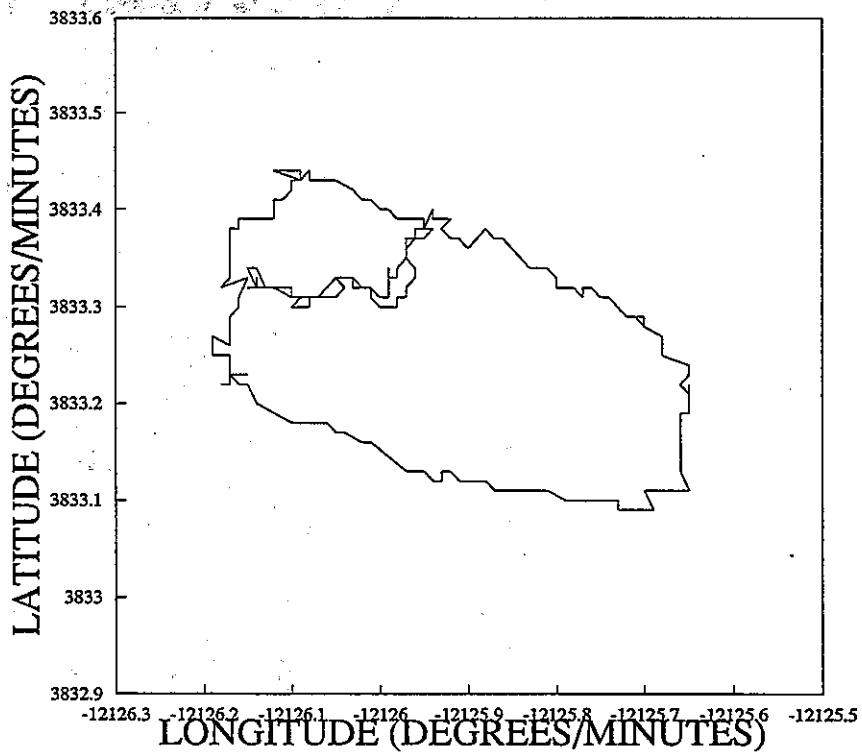


Figure 49 1-Channel GPS Receiver Path
Route 1 June 12, 1992

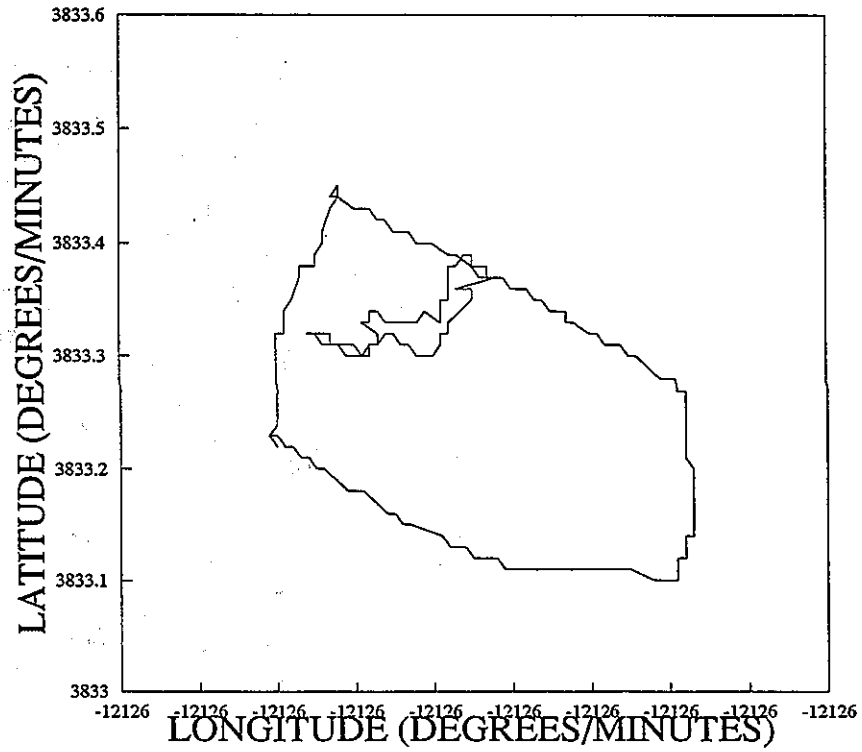


Figure 50 5-Channel GPS Receiver Path
Route 1 June 12, 1992

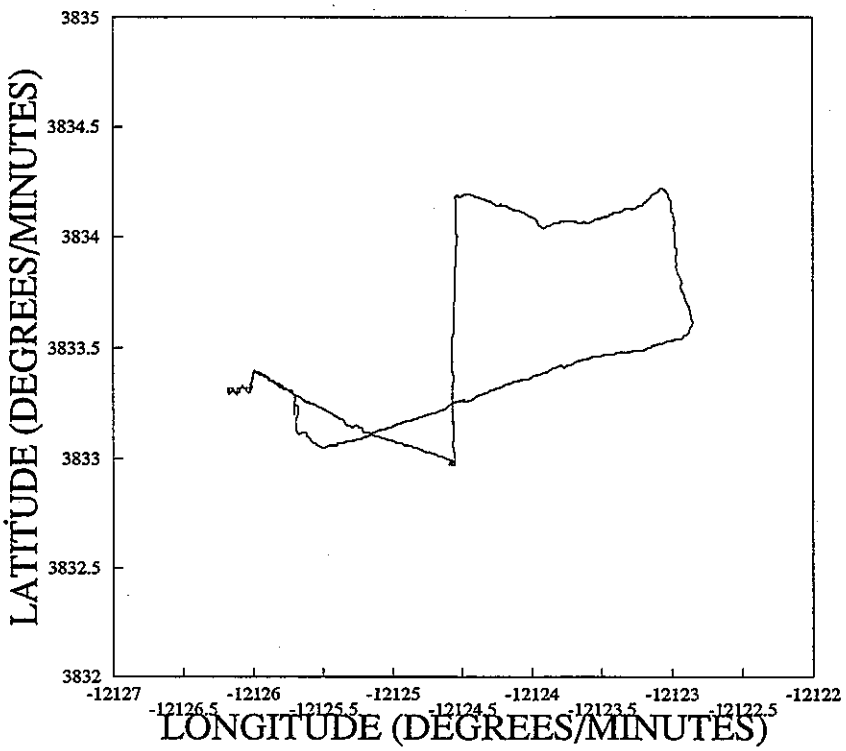


Figure 51 1-Channel GPS Receiver Path
Route 2 May 28, 1992

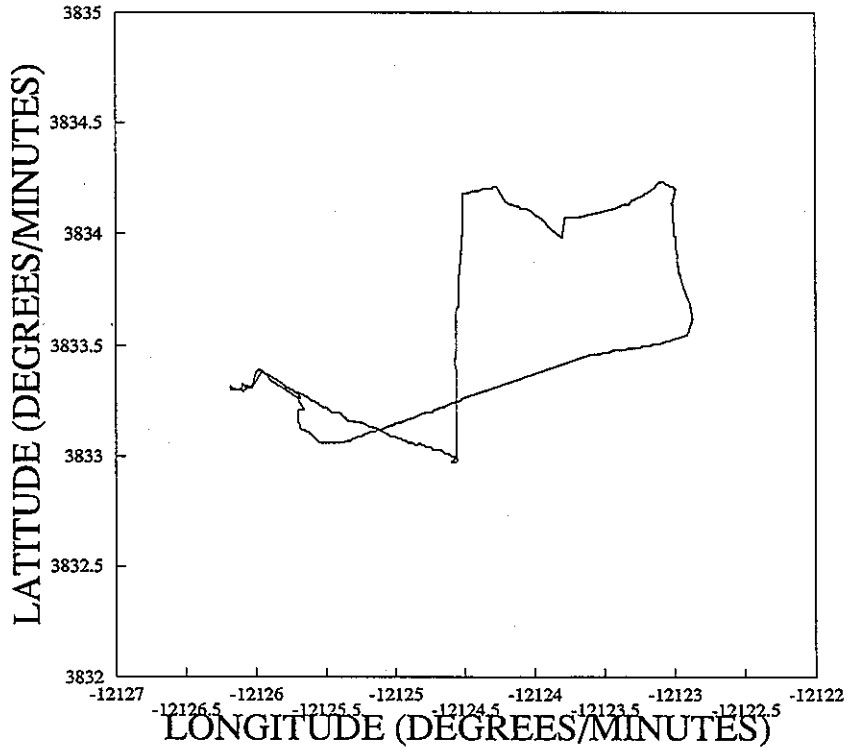


Figure 52 5-Channel GPS Receiver Path
Route 2 May 28, 1992

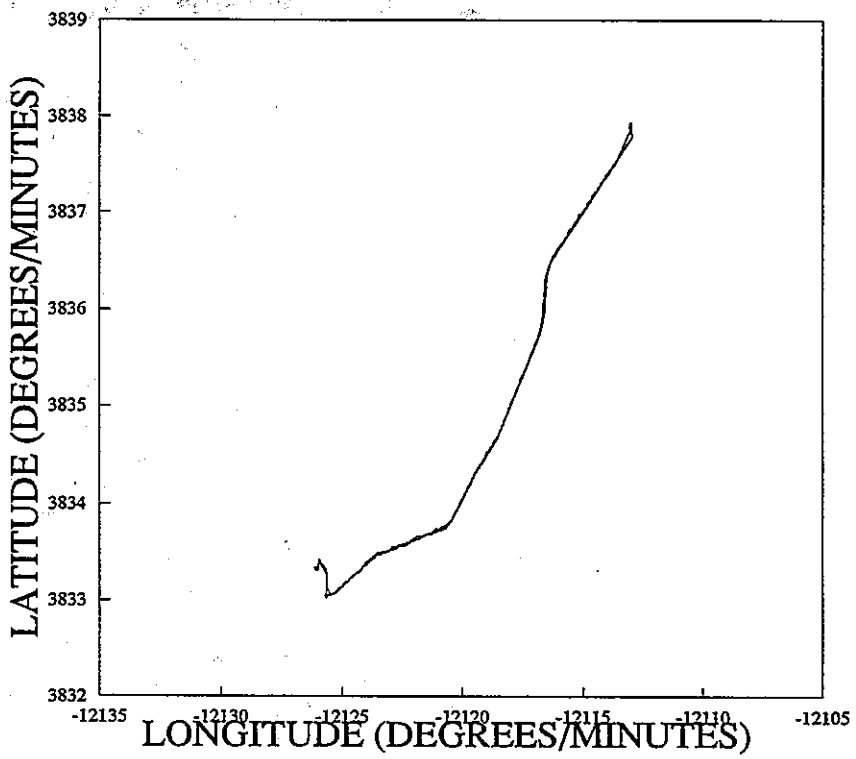


Figure 53 1-Channel GPS Receiver Path
Route 3 June 12, 1992

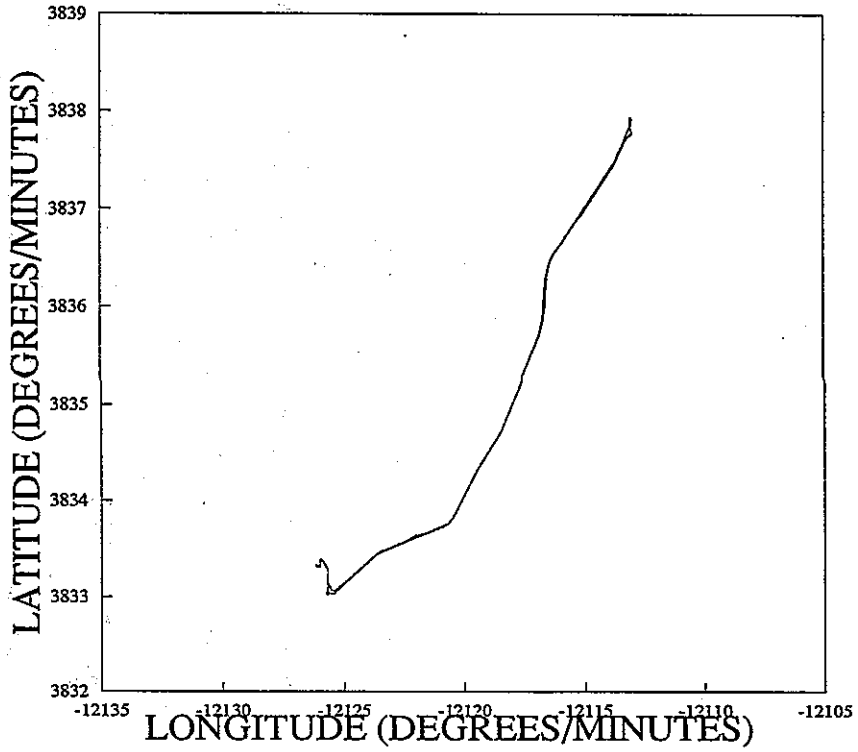


Figure 54 5-Channel GPS Receiver Path
Route 3 June 12, 1992

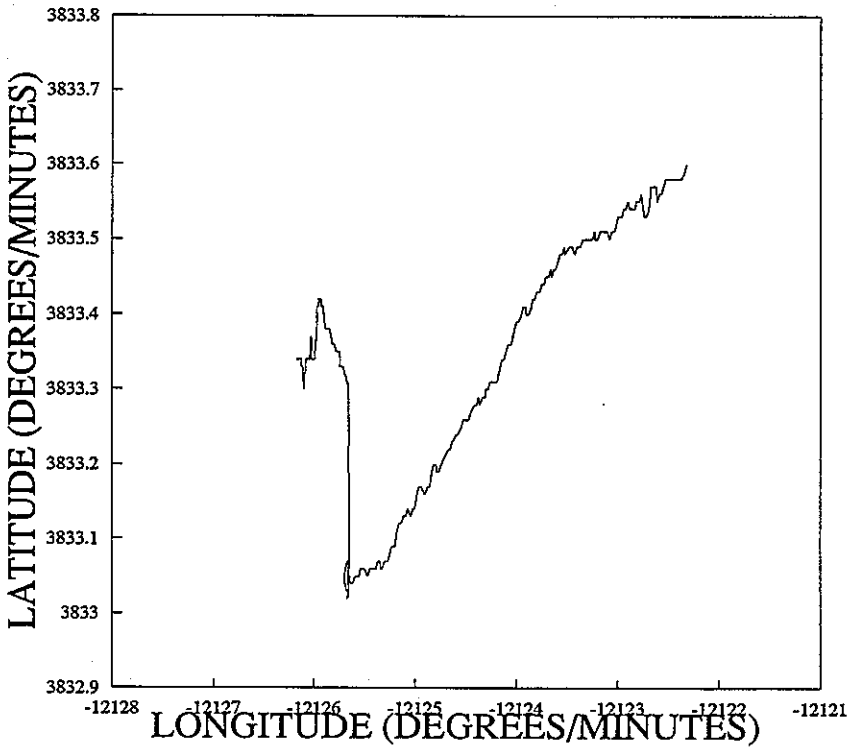


Figure 55 1-Channel GPS Receiver Path (Lab7 to Watt Ave.)
Route 3 June 12, 1992

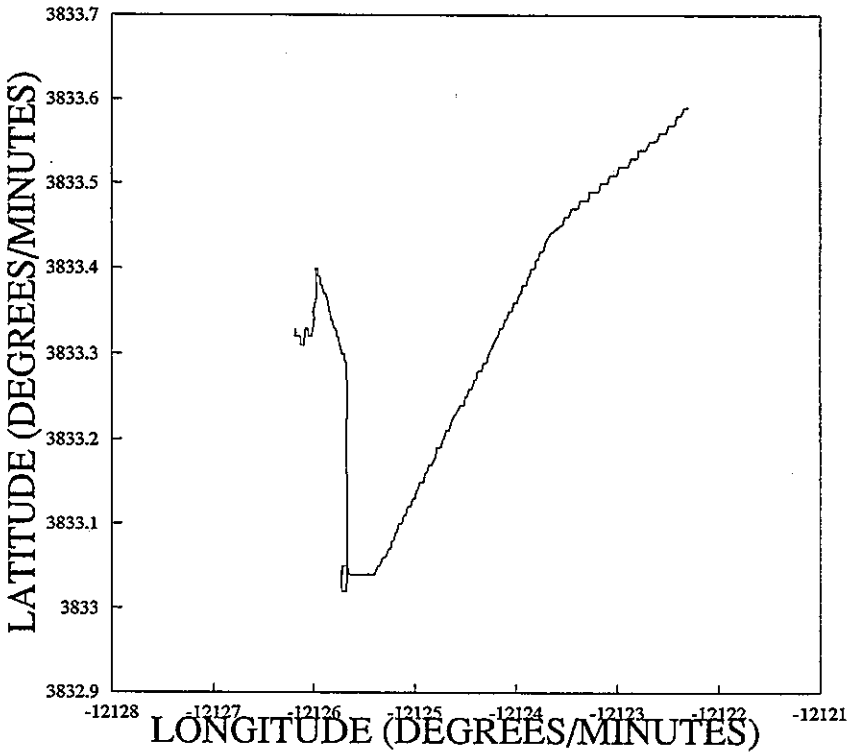


Figure 56 5-Channel GPS Receiver Path (Lab7 to Watt Ave.)
Route 3 June 12, 1992

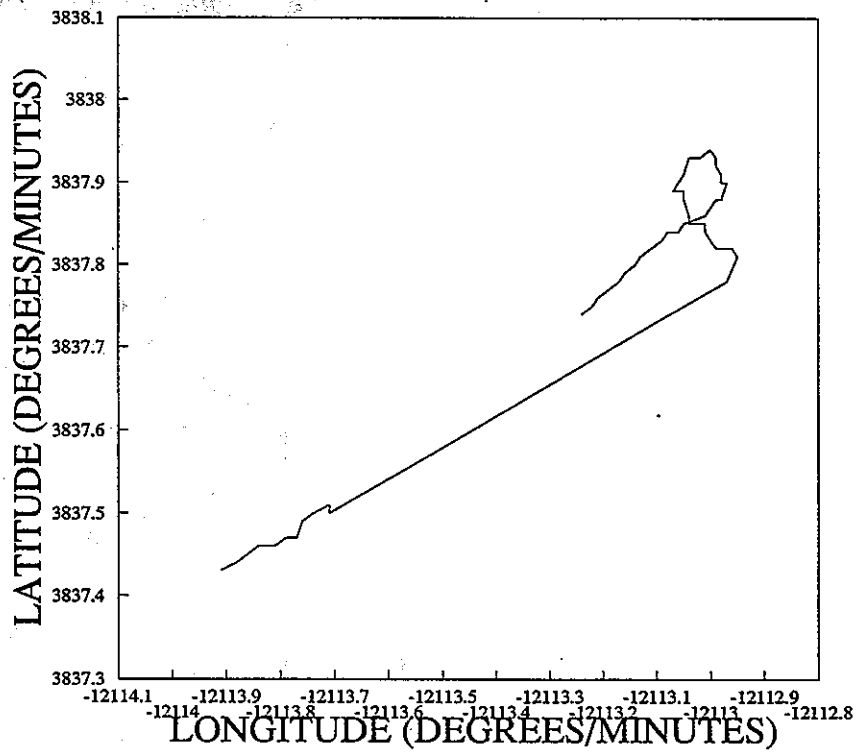


Figure 57 1-Channel GPS Receiver Path (Hazel Ave. Ramps)
Route 3 June 12, 1992

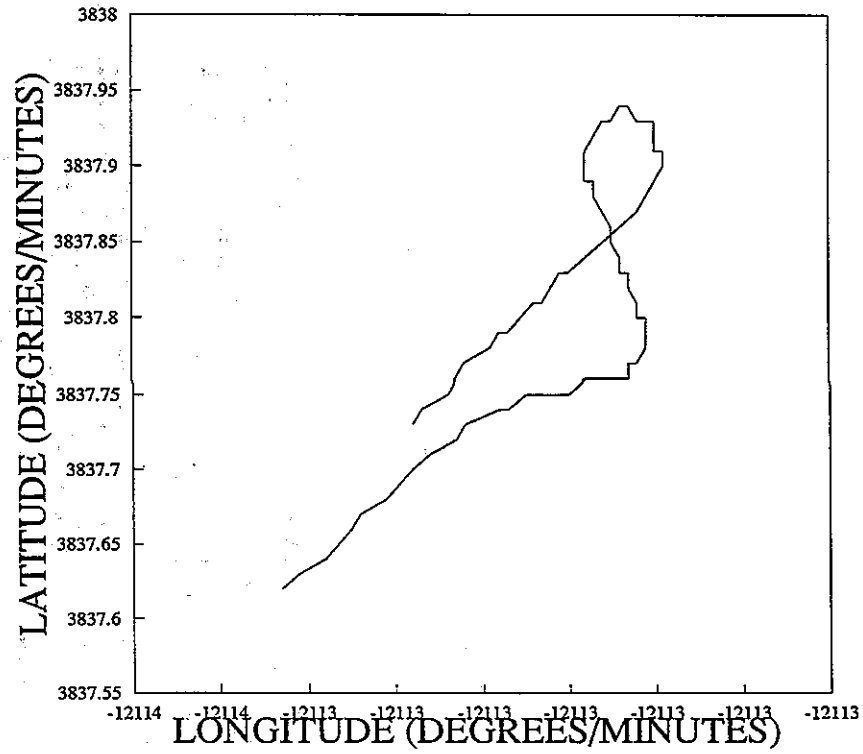


Figure 58 5-Channel GPS Receiver Path (Hazel Ave. Ramps)
Route 3 June 12, 1992

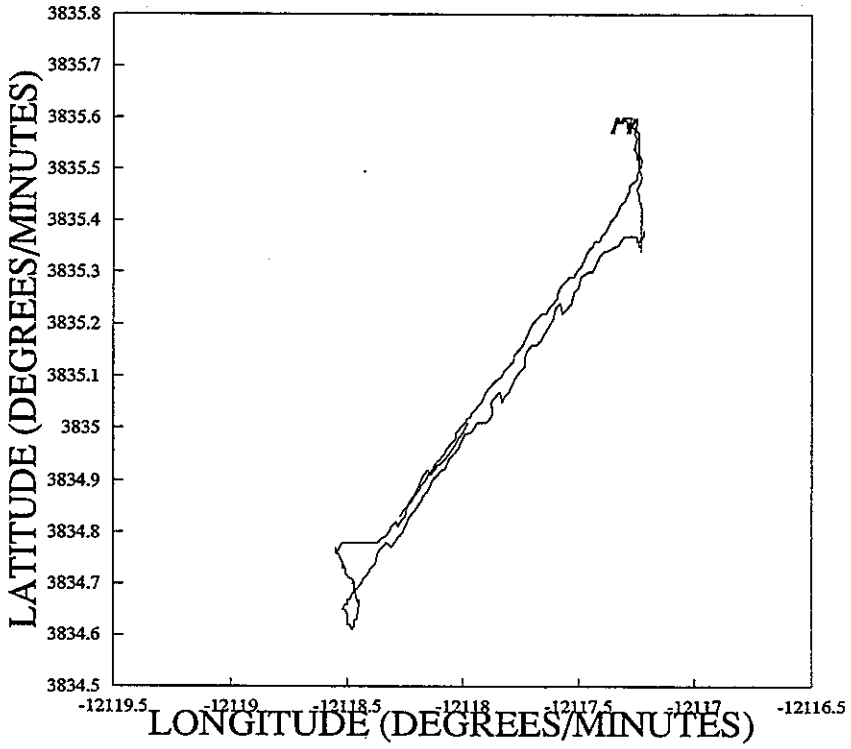


Figure 59 1-Channel GPS Receiver Path
Route 4 June 15, 1992

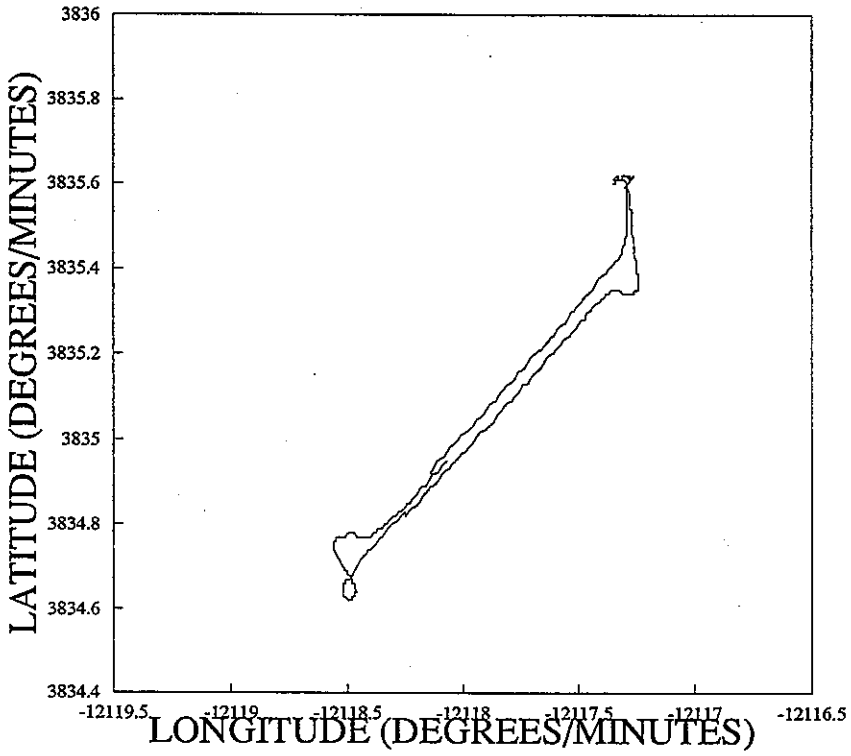


Figure 60 5-Channel GPS Receiver Path
Route 4 June 15, 1992

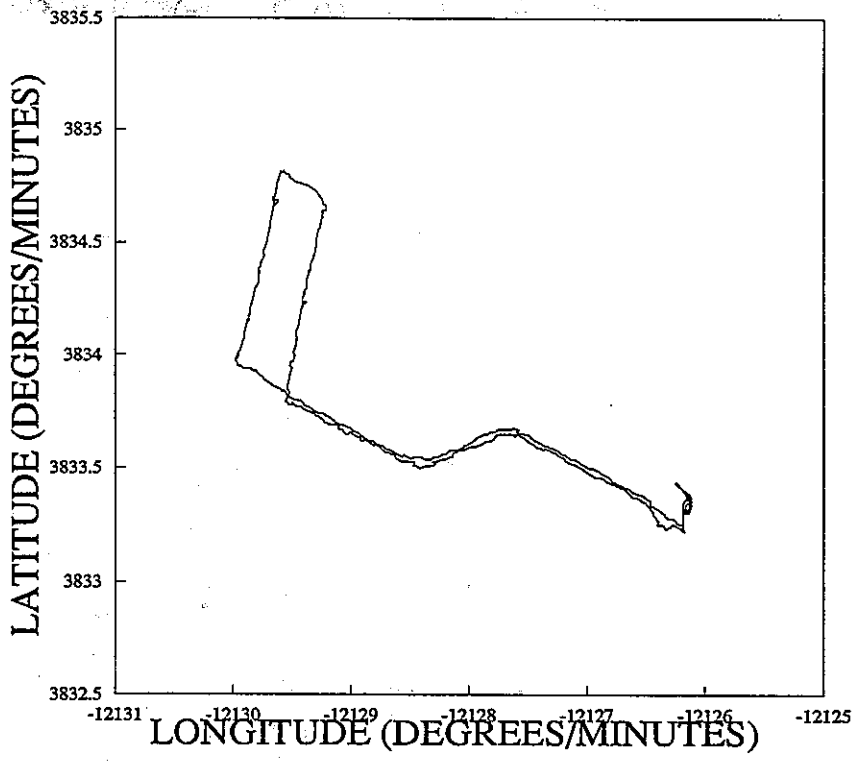


Figure 61 1-Channel GPS Receiver Path
Route 5 August 4, 1992

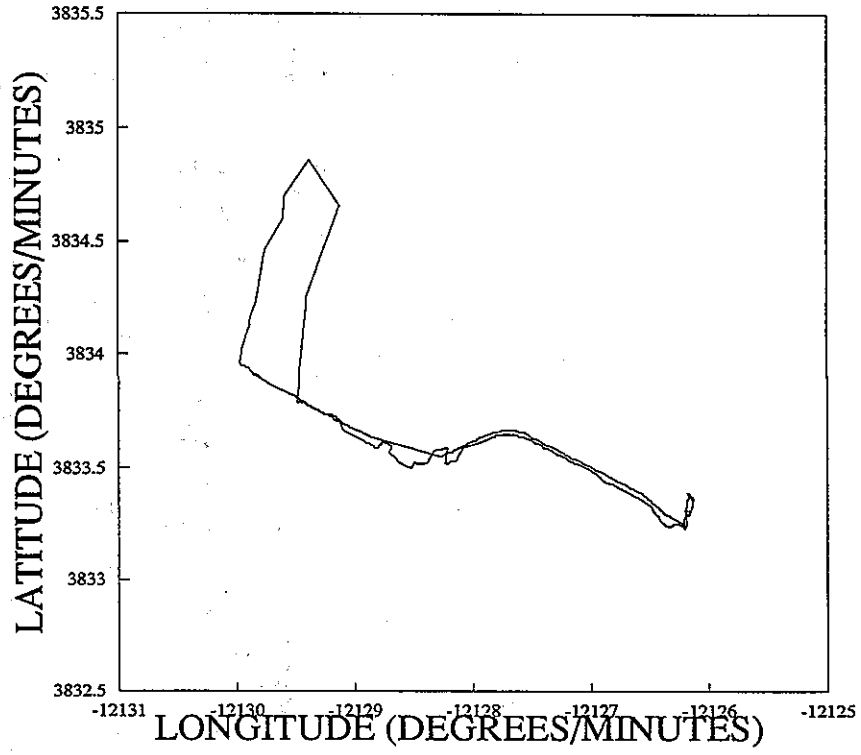


Figure 62 5-Channel GPS Receiver Path
Route 5 August 4, 1992

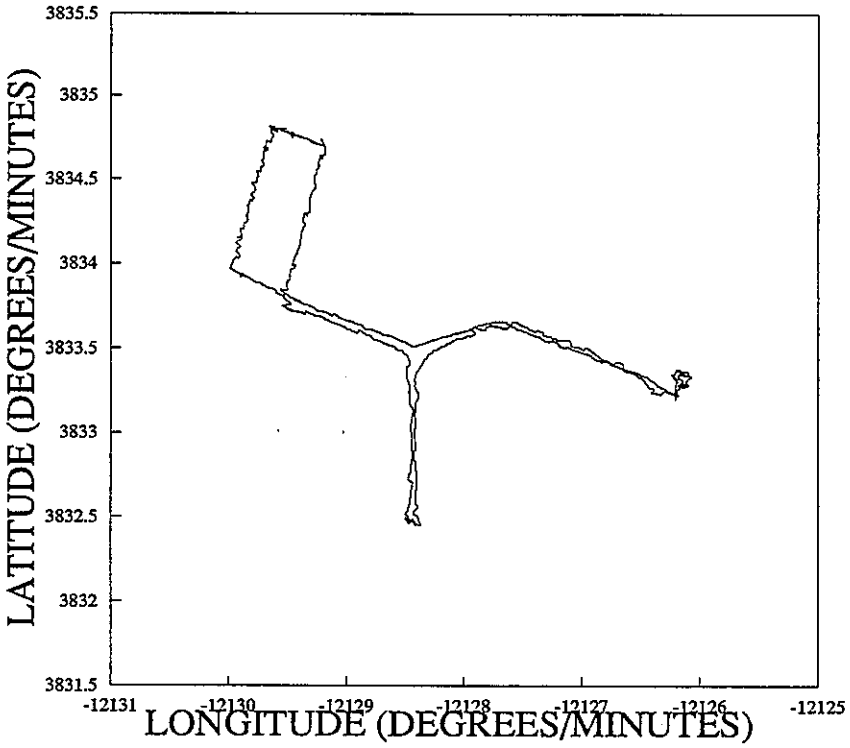


Figure 63 1-Channel GPS Receiver Path
Route 5A August 5, 1992

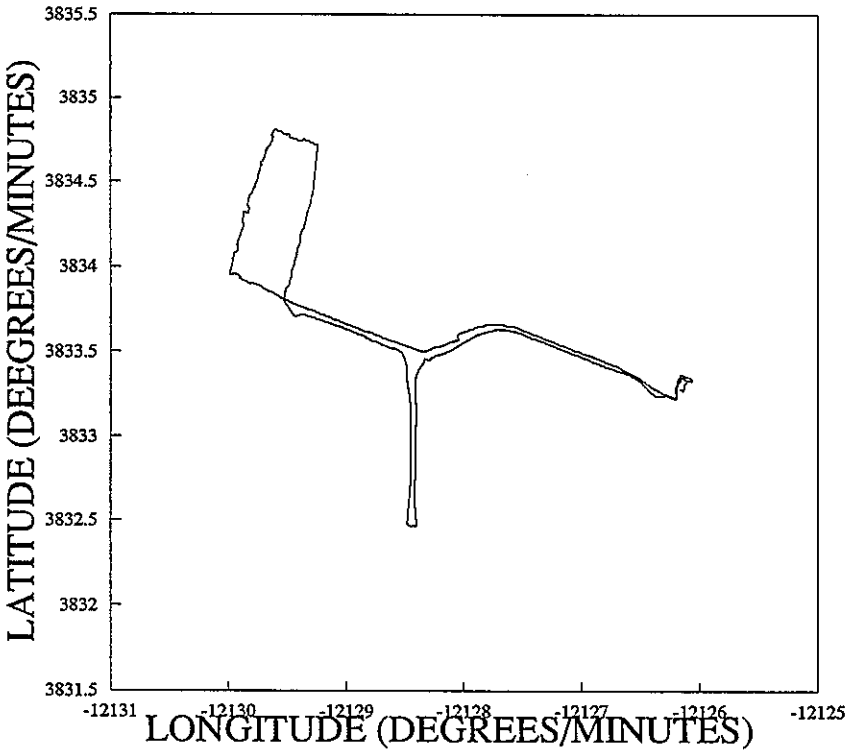


Figure 64 5-Channel GPS Receiver Path
Route 5A August 5, 1992

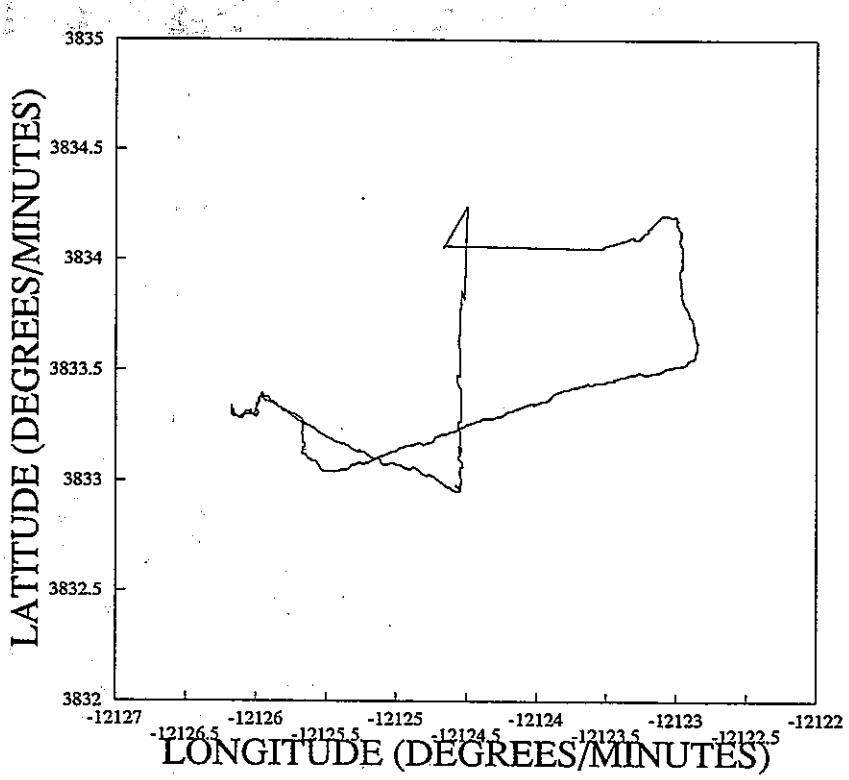


Figure 65 1-Channel GPS Receiver Path
Route 2 September 17, 1992

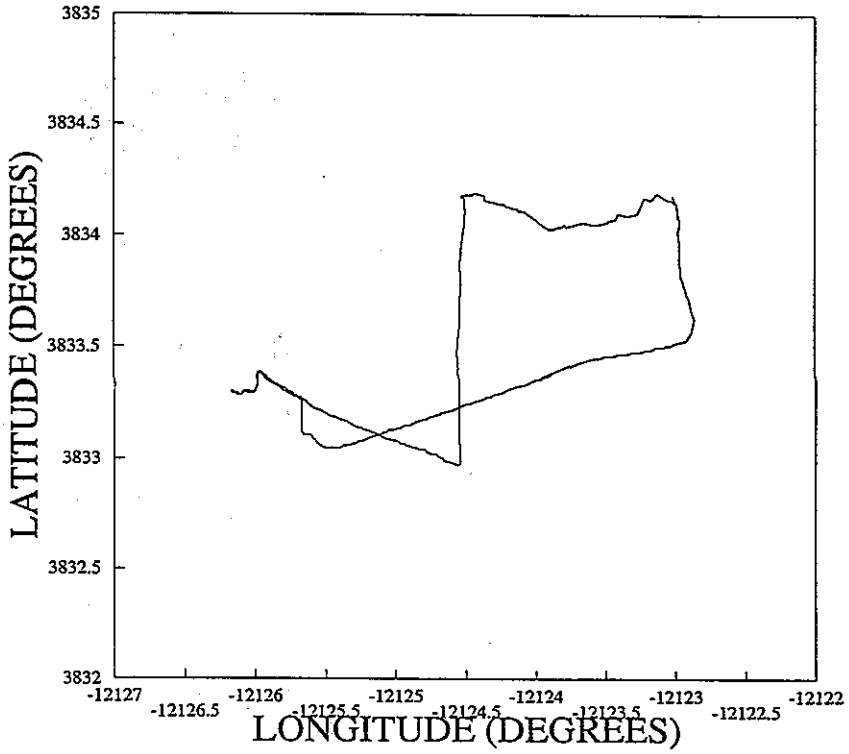


Figure 66 5-Channel GPS Receiver Path
Route 2 September 17, 1992

Table 2

**Feature Log for Route 5A**
(Sample printout)

11:34: 3  8- 5-92

| | | |
|---|---|---|
| 0: 0:24.273 | 3 | start |
| 0: 1:35.887 | 1430 | light rail |
| 0: 1:50.277 | 1838 | right |
| 0: 2:10.319 | 2766 | highway 50 |
| 0: 3:42.848 | 11147 | stockton blvd bridge |
| 0: 4:18.639 | 14574 | hwy 99' |
| 0: 4:53.387 | 17703 | 24th st bridge |
| 0: 5:19.300 | 20049 | 16th st |
| 0: 5:29.447 | 21014 | 10th st sign |
| 0: 6: 7.747 | 23245 | 11th st stoplight |
| 0: 6:50.510 | 23752 | right on 10th |
| 0: 9:22.336 | 28051 | n st |
| 0:11:46.346 | 30033 | right on J |
| 0:12:36.453 | 30937 | 12 th st light rail |
| 0:13:51.982 | 32375 | right on 15th |
| 0:14: 4.139 | 32714 | |
| 0:15:34.361 | 35756 | q st |
| 0:15:40.771 | 36052 | light rail 3 activ |
| 0:17:16.481 | 39124 | left on x |
| 0:17:42.131 | 39519 | 16th light |
| 0:18:18.130 | 40993 | bus 80 ramp |
| 0:19: 5.839 | 45081 | fresno sign |
| 0:19:29.930 | 46900 | hwy99 |
| 0:20:35.859 | 52512 | sutterville stoplight |
| 0:21:24.477 | 52566 | left on 12th |
| 0:22: 1.552 | 52850 | left onto 99 |
| 0:23:18.944 | 59344 | broadway |
| 0:23:32.942 | 60510 | land |
| 0:23:46.386 | 61717 | bridge |
| 0:24: 3.951 | 63166 | stockton blvd |
| 0:25:35.145 | 71651 | 59th bridge |
| 0:25:44.625 | 72196 | land |
| 0:25:52.398 | 72491 | left on 59th |
| 0:26: 8.537 | 73020 | light rail 3 activ |
| 0:26:33.826 | 73692 | lab stop sign |
| 0:27:48.535 | 74852 | stop |
| 0:27:57.131 | 74853 | |

Table 3

**Loops Detected Along Route 1**
(Sample printout)

```
*** LOOP SUMMARY ***

Date:          6-12-92
Start time:   14:17:32
Loop:             1
Frequency:    48211.7
Odometer:     3116
Loop detected at elapsed time  0: 2:27.912

Date:          6-12-92
Start time:   14:17:32
Loop:             2
Frequency:    6398.4
Odometer:     4057
Loop detected at elapsed time  0: 2:51.616

Date:          6-12-92
Start time:   14:17:32
Loop:             3
Frequency:    8707.1
Odometer:     4074
Loop detected at elapsed time  0: 2:52.030

Date:          6-12-92
Start time:   14:17:32
Loop:             4
Frequency:    5885.3
Odometer:     4086
Loop detected at elapsed time  0: 2:52.284

Date:          6-12-92
Start time:   14:17:32
Loop:             5
Frequency:    31024.6
Odometer:     4245
Loop detected at elapsed time  0: 2:56.543

Date:          6-12-92
Start time:   14:17:32
Loop:             6
Frequency:    69759.7
Odometer:     4398
Loop detected at elapsed time  0: 3:12.725

Date:          6-12-92
Start time:   14:17:32
Loop:             7
Frequency:    69759.7
```

```
Odometer:     4418
Loop detected at elapsed time  0: 3:14.157

Date:          6-12-92
Start time:   14:17:32
Loop:            8
Frequency:    56163.9
Odometer:     7419
Loop detected at elapsed time  0: 4:15.702

Date:          6-12-92
Start time:   14:17:32
Loop:            9
Frequency:    7168.0
Odometer:     7961
Loop detected at elapsed time  0: 4:50.353

Date:          6-12-92
Start time:   14:17:32
Loop:           10
Frequency:    7424.5
Odometer:     7976
Loop detected at elapsed time  0: 4:50.780
```

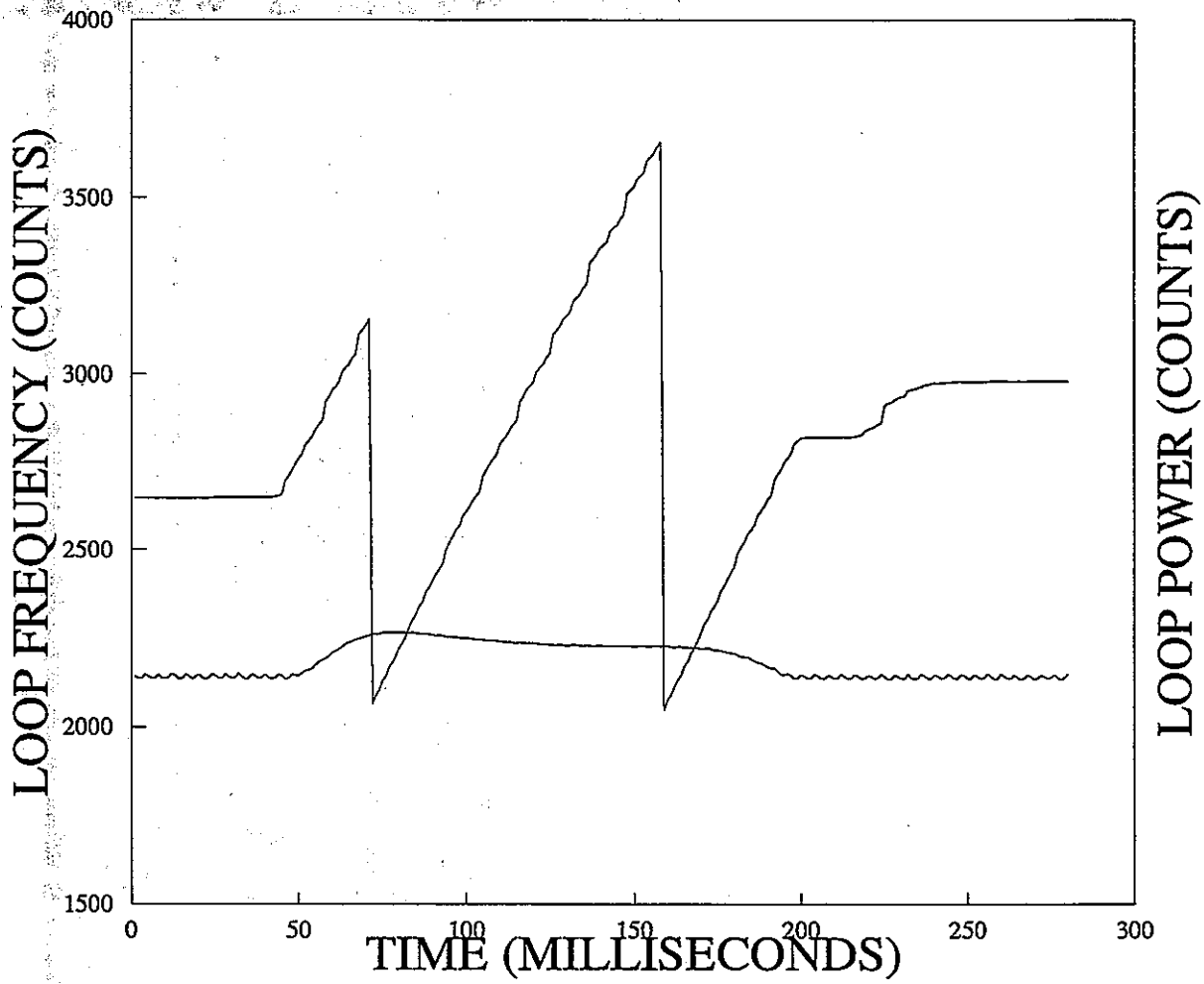


Figure 67 Inductive Loop 1
Route 1 June 12, 1992

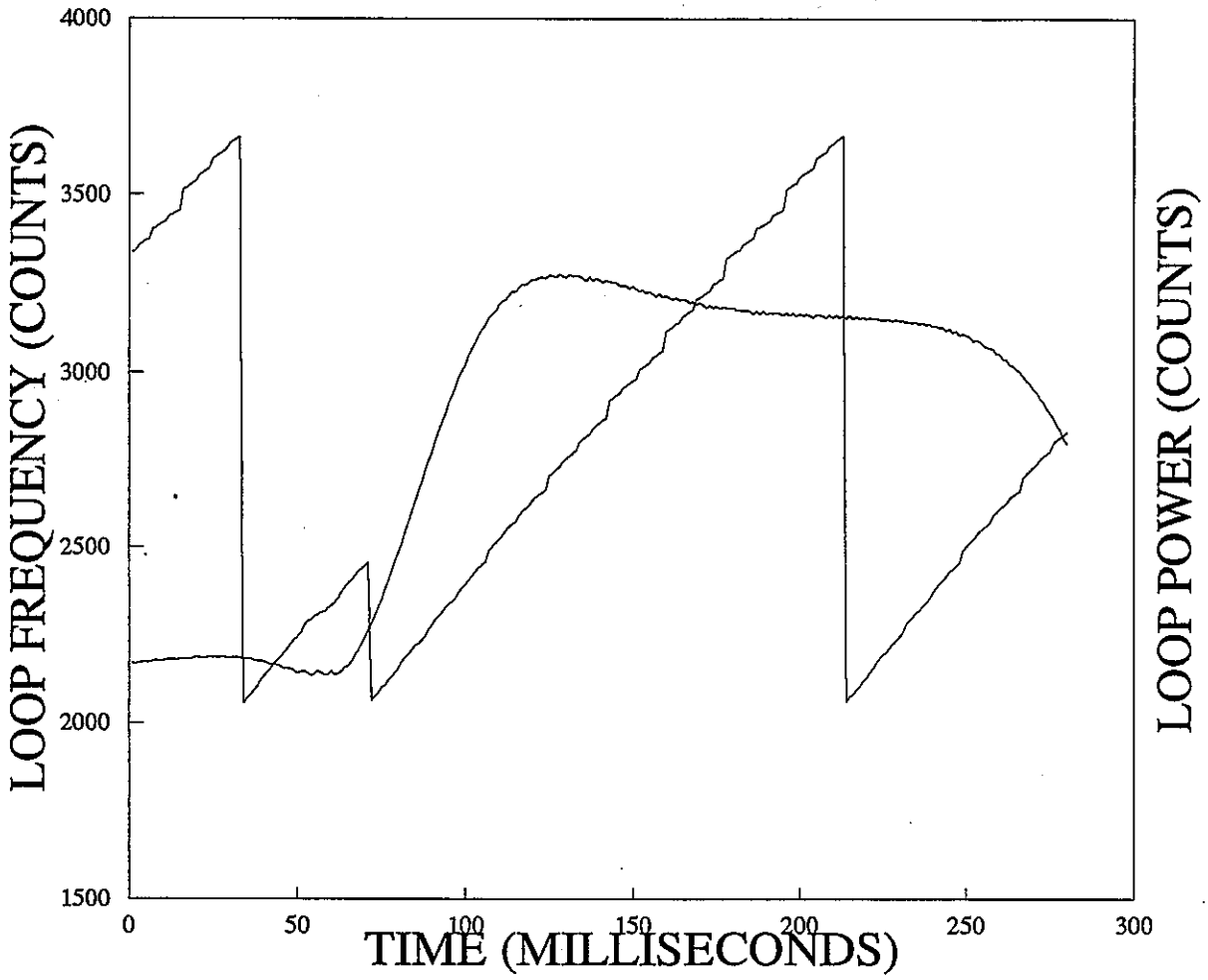


Figure 68 Inductive Loop 5
Route 1 June 12, 1992

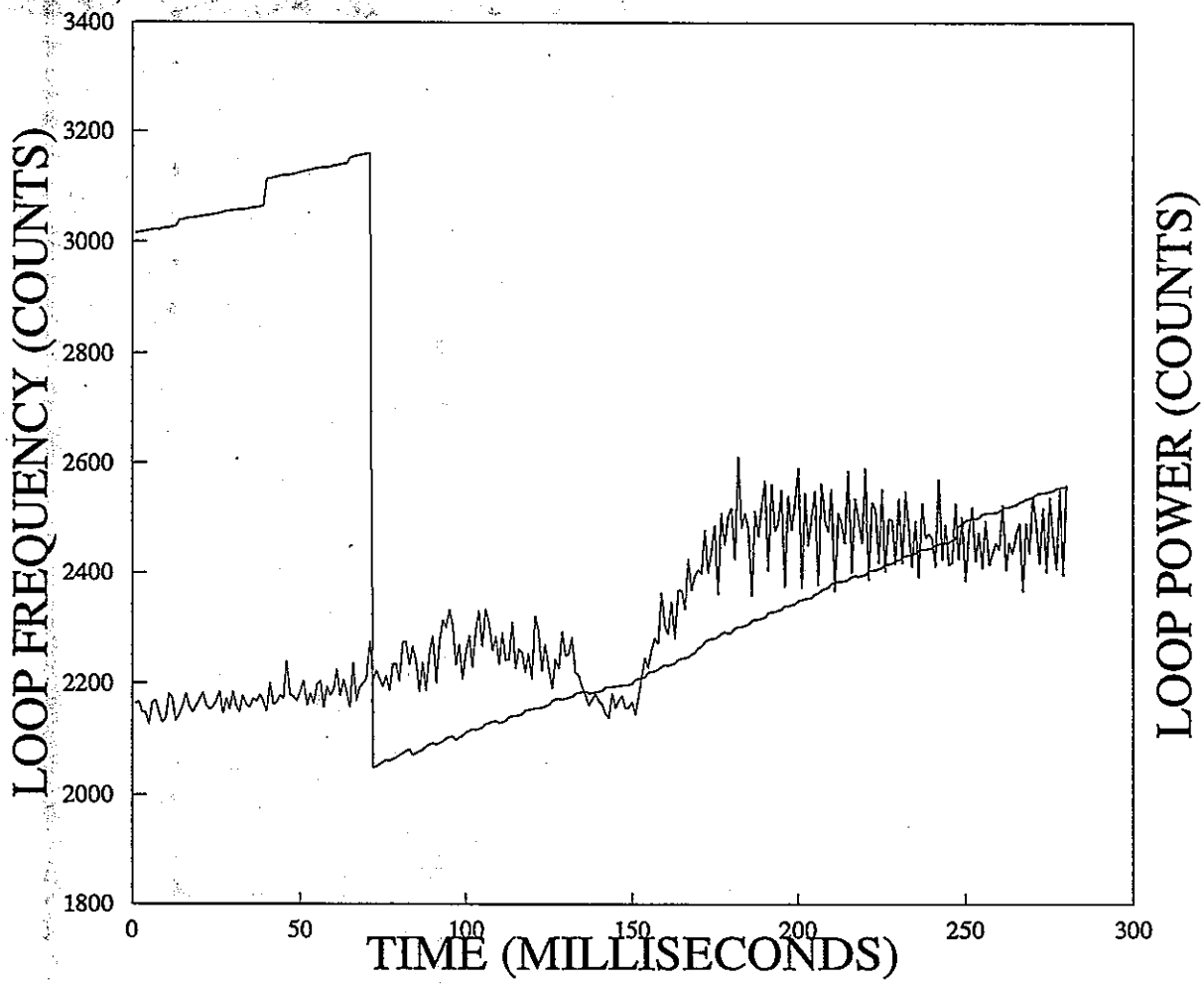


Figure 69 Light Rail Crossing
"Loop 10"
Route 1 June 12, 1992

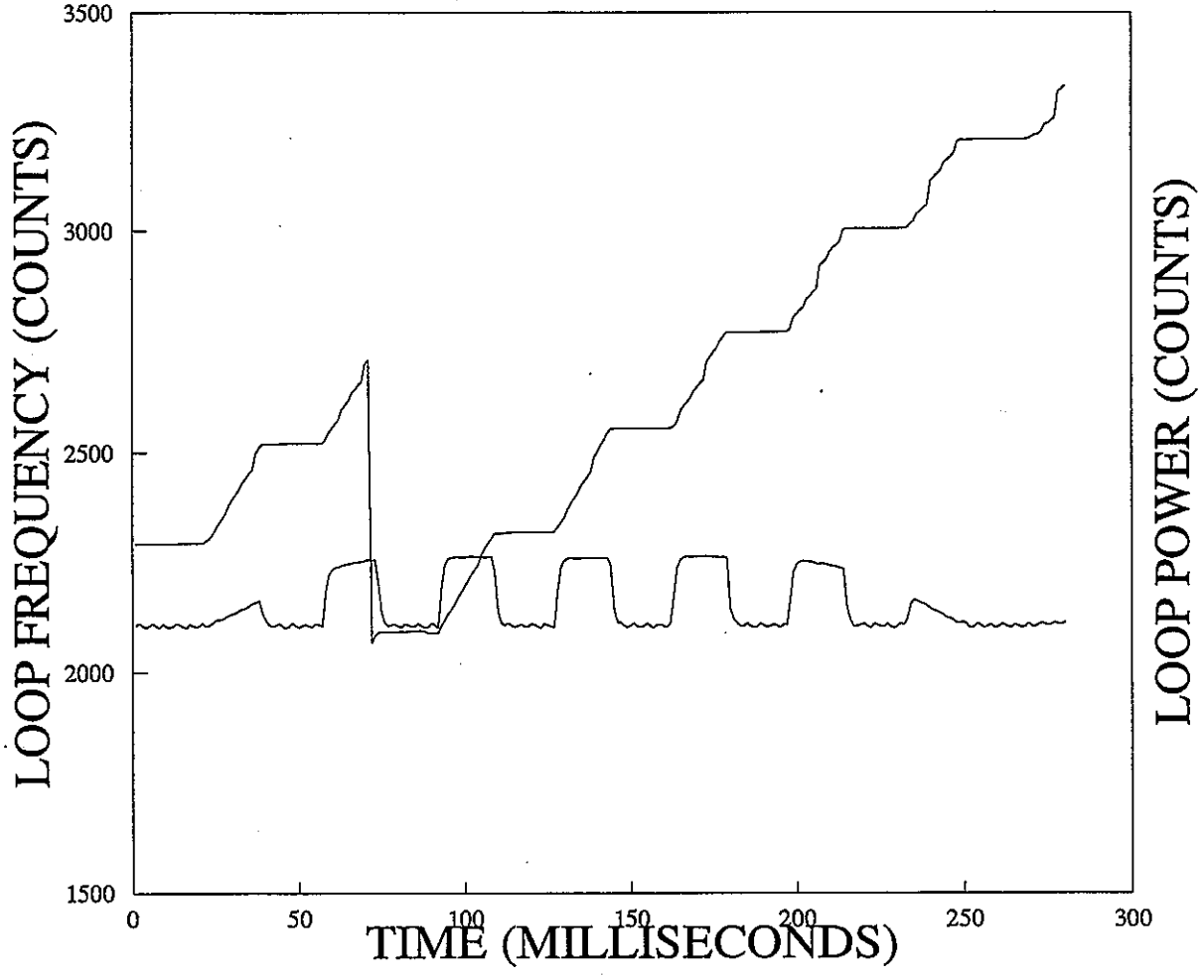


Figure 70 Inductive Loop 14
Route 4 April 30, 1992

Figure 71
Folsom Blvd.
Undercrossing
View from Westbound Highway 50

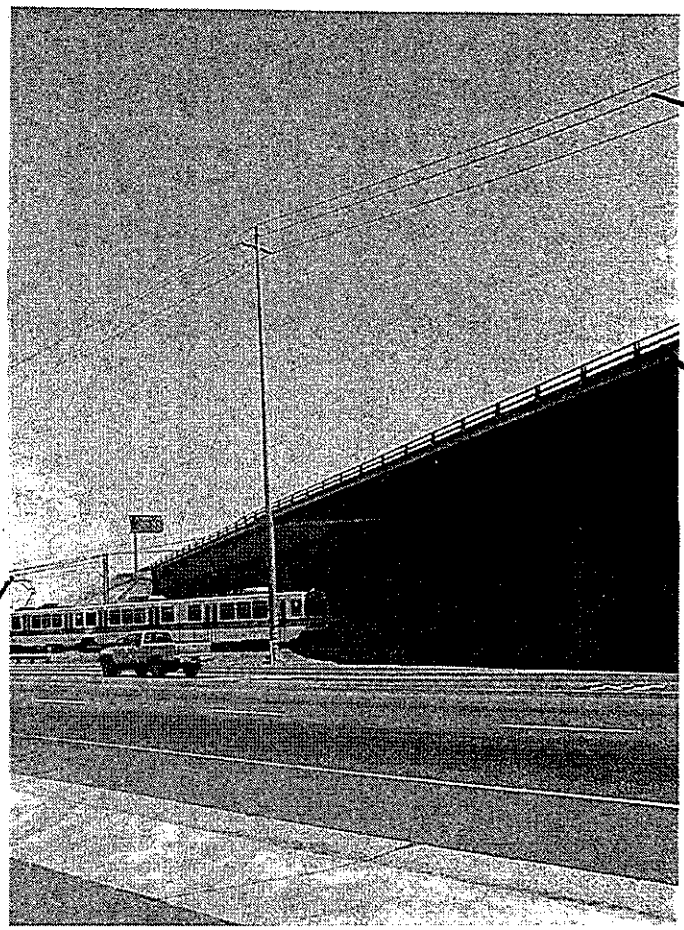


Figure 72
Folsom Blvd.
Undercrossing
View from
Folsom Blvd.

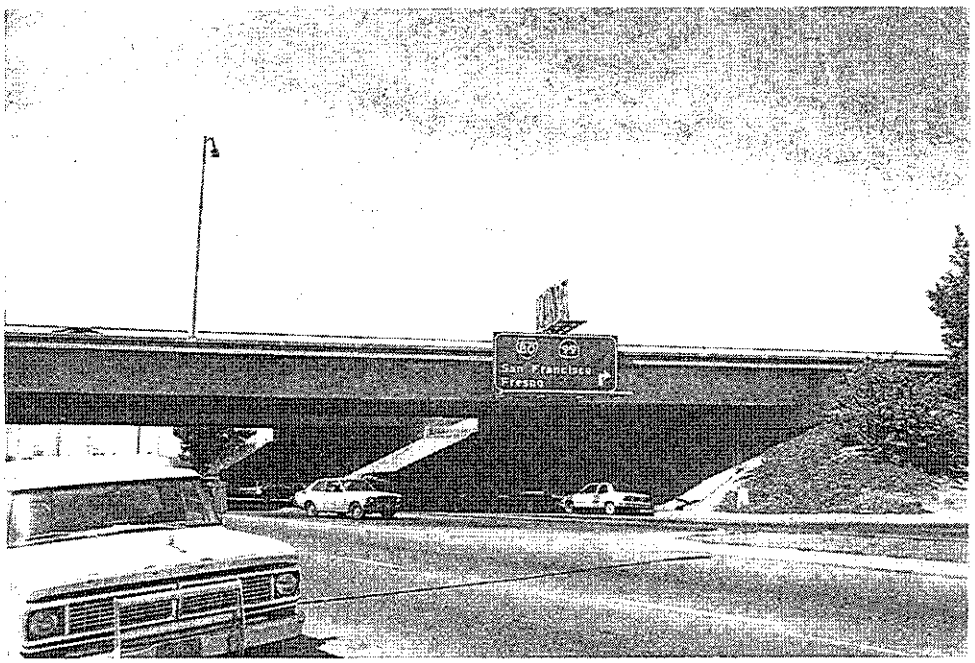


Figure 73

Stockton Blvd. Undercrossing
View from Stockton Blvd.

Figure 74

Stockton Blvd. Undercrossing
View from Westbound Highway 50

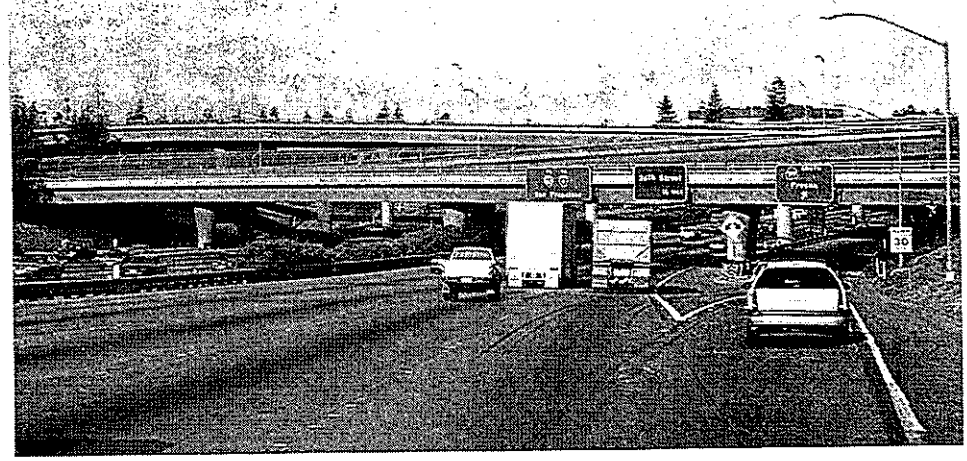

Figure 75

Interchange
Highway 50, Business 80, Highway 99
View from Westbound Highway 50

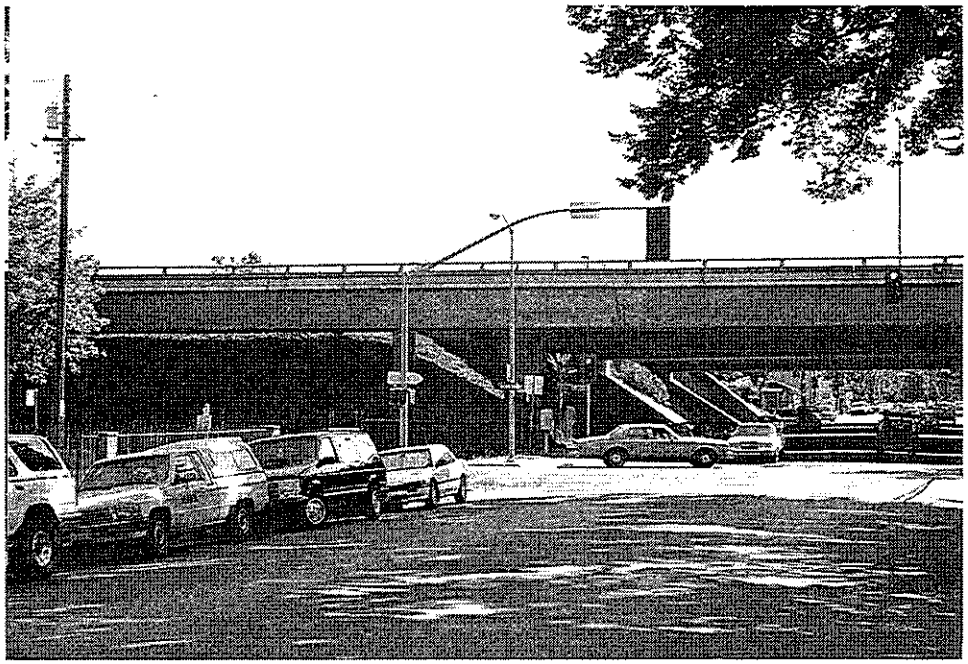

Figure 76

26th St. Undercrossing
View from 26th St.

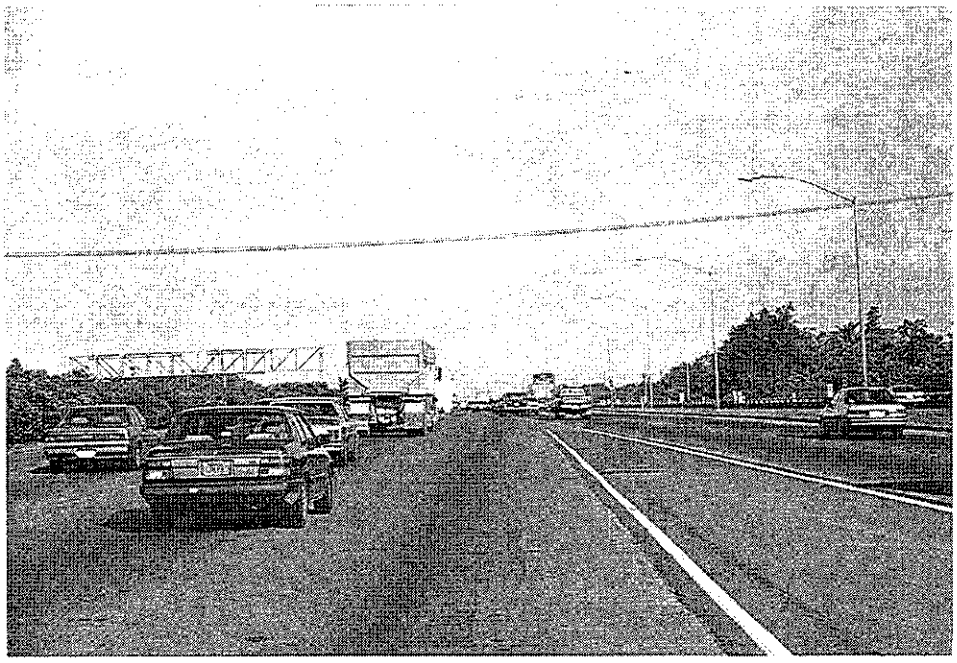

Figure 77

26th St. Undercrossing
View from Westbound Highway 50

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## APPENDIX A

## RECORD FORMATS

Navigation, loop and attribute data are collected and stored on a 1-megabyte static RAM memory board. No attempt is made at real-time navigation. The collected data were retrieved periodically for analysis and storage. The following record types are collected and stored in separate files.

| FILE | FORMAT | UPDATE RATE |
|---|---|---|
| Navigation--Dead Reckoning | binary | once per second |
| Navigation--GPS | text | one message per second |
| Inductive Loops | binary | one block per encounter |
| Attributes | text | as required |

Recorded data is used in the office to plot vehicle path and to fix the location of points logged by the attribute tags. Inputs from coded and uncoded inductive loops may be used in conjunction with map matching to generate useful informaton.

### A.1 NAVIGATION FILES (DEAD RECKONING)

Dead reckoning navigation records contain time counts, odometer counts, average fluxgate compass x-axis values, average fluxgate compass y-axis values, and average angular rate sensor readings for a specific period. Each navigation file is preceded by a header containing the DOS date and time. The sampling period for navigation records is once per millisecond with readings averaged over a one second period and stored in binary format. In the future, the sampling period will probably be variable, since there is little need (or room) for keeping detailed records when the vehicle is not turning or changing speed.

The data records are arranged as follows:

| RECORDS | PARAMETER DERIVED | SIZE (BYTES) |
|---|---|---|
| **FILE HEADER** | | **12** |
| DOS Date | date file opened | |
| Year | | 2 |
| Month | | 2 |
| Day | | 2 |
| DOS Time | time file opened | |
| Hours | | 2 |
| Minutes | | 2 |
| Seconds | | 2 |
| **NAVIGATION DATA** | | **10** |
| Odometer | distance travelled | 4 |

| | | |
|---|---|---|
| X-Axis | heading | 2 |
| Y-Axis | heading | 2 |
| Angular Rate | heading | 2 |

The total number of bytes for the first navigation record is 22 (file header plus data). The total number of bytes for subsequent navigation records is 10. At a storage rate of one record per second, 36,000 bytes of navigation data can be stored each hour.

10 bytes per second x 3600 sec per hour = 36,000 bytes per hour

## A.2 NAVIGATION FILES (GPS)

GPS navigation records are ASCII sentences conforming to the NMEA 0183 sentence format. The first sentence stored is the receiver status in the following format:

```
$PMGLH,00,xx.x,xx,x,x,x,x,x,x,x,x*CKRL
       1  2    3  4 5 6 7 8 91011 1213
```

1: Subindex
2: Firmware version number
3: Customer number
4: Always 0
5: Oscillator
   0 = OK
   1 = out of tune
6: SQ (Signal Quality number)
   range from 0 to 9
   0 = bad
   9 = good
7: GQ (Geometric Quality number)
   range from 0 to 9
   0 = bad
   9 = good
8: Navigation solution
   0 = continuously producing navigation solutions
   1 = continuous update has been interrupted
9: Almanac data
   0 = OK
   1 = no almanac data
   2 = almanac is more than six months old
10: Memory
   0 = memory OK to use
   1 = lost memory data (initial position unavailable)
11: OEM unit status
   1 = IDL
   2 = STS
   3 = ALM
   4 = EPH

5 = ACQ
6 = POS
7 = NAV

12: Checksum
13: Carriage return, line feed

Subsequent sentences describe the vehicle position and altitude in the following format:

```
$GPGGA,xxxxxx,xxxx.xx,N,xxxxx.xx,W,x,x,xxx,uxx,M,uxxx,M*CKRL
       1      2       3 4     5 6 7 8   9  10 11  12 1314
```

1: UTC time tag of position fix (hhmmss)
2: GPS latitude (DDMM.HH)
D = degrees
M = minutes
H = hundredths of minutes
3: Latitude, N or S
4: GPS longitude (DDDMM.HH)
D = degrees
M = minutes
H = hundredths of minutes
5: Longitude, E or W
6: GPS quality indicator
0 = GPS not available
1 = GPS available
7: Number of satellites being used (3 or 4)
8: HDOP
9-10: Antenna height, meters/feet
11-12: Geodial height, meters/feet
13: Checksum
14: Carriage return, line feed

The data records are arranged as follows:

| RECORDS | PARAMETER DERIVED | SIZE (BYTES) |
|---|---|---|
| **FILE HEADER** | | **20** |
| DOS Time | time file opened | |
| Hours | | 2 |
| : | | 1 |
| Minutes | | 2 |
| : | | 1 |
| Seconds | | 2 |
| space | | 1 |
| space | | 1 |
| DOS Date | date file opened | |
| Month | | 2 |
| - | | 1 |
| Day | | 2 |
| - | | 1 |
| Year | | 2 |
| carriage return | | 1 |
| line feed | | 1 |

| | | |
|---|---|---|
| **GPS MESSAGES** | | |
| $PMGLH(once) | receiver status | **38** |
| $GPGGA | position & altitude | **60** |

Each GPS navigation file is preceded by a header containing the DOS date and time. One hour of logging GPS data would require 213,598 bytes.

20 bytes + 38 bytes + (60 bytes per sec x 3559 sec) = 213,598 bytes

## A.3 LOOP FILES

Loop data are collected and stored each time the vehicle crosses an inductive loop. Loop records contain time counts, loop frequency, and loop signal amplitude. Each loop file is preceded by a header containing the DOS date and time; each loop record is preceded by the calculated loop frequency, and the odometer reading at the point of loop detection.

The data records are arranged as follows:

| RECORDS | PARAMETER DERIVED | SIZE (BYTES) |
|---|---|---|
| **FILE HEADER** | | **12** |
| DOS Date | date file opened | |
| Year | | 2 |
| Month | | 2 |
| Day | | 2 |
| DOS Time | time file opened | |
| Hours | | 2 |
| Minutes | | 2 |
| Seconds | | 2 |
| **LOOP RECORD HEADER** | | **12** |
| Loop Frequency | loop frequency | 4 |
| Odometer | distance traveled | 4 |
| Seconds | time loop detected (secs) | 2 |
| Index | time loop detected (ms) | 2 |
| **LOOP DATA** | | **4** |
| Frequency | loop frequency | 2 |
| Power | loop signal amplitude | 2 |

Each loop occupies 1120 bytes of storage space (280 data points per loop x 4 bytes per data point). The total number of bytes per loop record is 1132 (loop record header plus total loop data). Thus, for example, 28,312 bytes of memory are required to record 25 loops (25 loops x 1132 bytes per loop + 12 bytes).

## A.4 ATTRIBUTE FILES

Attributes and comments are entered using a laptop computer keyboard and stored in the attribute file. When the operator passes a landmark which he wishes to record, he presses any key on the keyboard (e.g., the first character of the landmark description), types an attribute description not to exceed 99 characters, and terminates with an ENTER.

The data records are arranged as follows:

| RECORDS | PARAMETER DERIVED | SIZE (BYTES) |
|---|---|---|
| **FILE HEADER** | | **20** |
| DOS Time | time file opened | |
| Hours | | 2 |
| : | | 1 |
| Minutes | | 2 |
| : | | 1 |
| Seconds | | 2 |
| space | | 1 |
| space | | 1 |
| DOS Date | date file opened | |
| Month | | 2 |
| - | | 1 |
| Day | | 2 |
| - | | 1 |
| Year | | 2 |
| carriage return | | 1 |
| line feed | | 1 |
| **ATTRIBUTE DATA** | | **29** |
| Hours | time attribute recorded | 2 |
| Minutes | | 2 |
| Seconds.Milliseconds | | 6 |
| Odometer | position | 7 |
| Attribute | position | 12 (typ) |
| | | 100 (max) |

At a storage rate of one 12-character attribute descripton every minute, 1,740 bytes of memory would be required for each hour of operation.

29 bytes / 1 minute x 60 min per hour = 1,740 bytes per hour

## A.5 SUMMARY

Using the example figures from the data files described above, one hour of data collection would require 279,662 bytes of memory.

| FILE | NUMBER PER HOUR | SIZE (BYTES) |
|---|---|---|
| Navigation--Dead Reckoning | 3600 | 36,012 |
| Navigation--GPS | 3600 | 213,598 |
| Loops | 25 (typ.) | 28,312 |
| Attributes | 60 (typ.) | 1,740 |
| | | 279,662 |

## Appendix B

**HARDWARE DESCRIPTION**
NAVIGATION PROJECT
631150
IN-VEHICLE EQUIPMENT

### B.1 GENERAL

The in-vehicle navigation equipment is controlled by a DOS-compatible computer. Its function is to monitor several sensors, service an inductive radio, interface with the vehicle operator, and store data for later analysis. Below is a functional description of its components:

### B.2 FUNCTIONAL DESCRIPTION

#### B.2.1 Sensing Devices

B.2.1.1 Inductive Radio Communications System
Figures B2 & B3

Detector Systems, Inc. LoopComm system consisting of a Model 222DM Detector/Transceiver & a Model 650 Transceiver

A vehicle detection loop is simultaneously used as an antenna to permit half-duplex two-way serial communication between a transceiver mounted on the underside of a vehicle and a transceiver incorporated in a loop detector in the traffic monitoring and control cabinet. The vehicle-mounted transceiver incorporates a small loop antenna which inductively couples with the roadway loop when it passes directly overhead.

The operating frequency of the communications system is 375 kHz, while the operating frequency of the loop detection system is 20 to 50 kHz. This allows simultaneous operation of the two functions without interference. The transmission data rate is 9600 baud using standard asynchronous protocols of one start bit, eight data bits, and one stop bit.

B.2.1.2 Angular Rate Sensor (Rate-of-Turn Indicator)
Figure B4

Watson Industries, Inc. Model ARS-C131-1A

The angular rate sensor is a solid-state device which responds to the Coriolis forces generated when a pair of resonantly driven piezoelectric bender elements is rotated. It produces an analog output voltage proportional to the angular velocity about its sense axis. The output is nominally zero volts at zero angular rate and +10 or -10 volts at full scale, depending on the direction of rotation.

The Model ARS-C131-1A has a sensitivity of +/- 100 degrees per second at full scale.

Drift in this sensor's quiescent output was a problem that limited its usefulness in detecting gentle turns.

B.2.1.3 Transmission Sensor (Odometer)
Figure B5

Nu-Metrics Instrumentation Model 1080

The sensor is an optical encoder (single phase) which installs in-line with the vehicle's speedometer cable. The sensor provides a pulse output at a rate of 6 pulses per revolution, 1000 revolutions per mile. Thus, the odometer resolution is finer than one foot. Variables which affect the accuracy of distance measurements include tire pressure and wheel vibration.

Because the sensor output does not distinguish between forward and reverse travel, the vehicle backup light must be monitored to infer forward or reverse direction.

B.2.1.4 Fluxgate Compass
Figure B6

Etak, Inc. Model 02-0022

A fluxgate compass responds to the earth's magnetic field electronically rather than by means of rotating parts. It is comprised of a primary winding wound around a saturable core. An excitation voltage is applied to the winding which drives the coil into saturation. Voltages induced into two secondary windings wound perpendicularly around the core are proportional to the earth's magnetic field. Direction is determined from the vector direction of the voltages.

Fluxgate compasses are easily confused in the short term by magnetic anomalies and are sensitive to vehicle tilt.

B.2.1.5 Loop Excitation Monitor
Figure B7

Caltrans Model 631150-300 Signal Conditioning Board and
Model 631150-310 Loop Excitation Antenna Probe

The loop excitation monitor consists of the antenna probe and the signal conditioning circuitry used to measure the amplitude and frequency of inductive loops that may or may not be coded. A sensing probe containing a coil is mounted to the underside of the vehicle, 10 inches above the pavement surface, to sense the excitation fields of loops. Circuitry in the signal conditioning board amplifies the incoming signal from the probe and then creates a ramping

signal output whose slope is proportional to the loop frequency. Other circuitry converts the incoming AC signal to a proportional DC signal, representing the signal amplitude. Information from the two resulting signals allows one to infer the presence of an inductive loop, since their characteristics are known.

B.2.1.6 Global Positioning System
Figure B8

Magellan Systems Corp. Five-Channel GPS Receiver Module

The GPS receiver unit allows receipt of satellite position information from the NAVSTAR GPS satellite-based navigation system developed by the U.S. Department of Defense. The system is based on a constellation of 24 satellites orbiting above the earth. The receiver uses these satellites as precise reference points for triangulating its position. Accurate three-dimensional measurements require four satellites.

The accuracy of GPS measurements is affected by a number of factors, primarily (1) signal obscuration, (2) selective availability, (3) multipath interference, and (4) atmospheric and ionospheric delay, and (5) Geometric Dilution of Precision (GDOP). Various techniques may be applied to minimize these error sources.

**B.2.2 Computer System**

The computer system collects, conditions, and stores data from the sensors. It is based on an 80C88-based DOS compatible computer housed in an 8-slot STD Bus card cage. See Figure B1. Below is a description of its components:

B.2.2.1 Power Supply
Figure B9

Caltrans Model 631150-200

The power supply contains DC-DC converters to convert the vehicle 12 volts to a regulated +5 volts and +12 and -12 volts for use by the navigation system.

B.2.2.2 Signal Conditioning Board
Figure B10

Caltrans Model 631150-300

The signal conditioning board conditions the analog signals from the navigation sensing devices before they are digitized and stored.

Angular rate sensor and compass signals are pulled-up and filtered on the board prior to being routed to the A/D converter. The loop signal output from the loop excitation antenna is amplified and then converted to an amplitude component and a frequency component before being routed to the A/D. See Loop Excitation Monitor description above for further details.

The odometer and backup light signals are routed through circuitry in the signal conditioning board before going to the CPU board. In the CPU board, the odometer signal routes to the CLK1 input (counter 1) of the 8254 counter. The backup light signal routes to the I/O printer port BUSY input where its presence is monitored.

The signal conditioning board provides a path through which the RS-422 signal lines route to the CPU board.

The signal conditioning board also brings in two reset lines from the CPU. Reset 1 comes from the CPU board printer port STB output to provide a reset to the CPU. Reset 2 comes from the CPU board printer port D0 output to reset the loop excitation monitor loop frequency counter and the watchdog timer.

B.2.2.3 Multichannel Serial Board
Figure B11

Ziatech ZT8840

The ZT8840 is a four channel RS-232C communications board. It allows asynchronous data communications via four programmable 8250A universal asynchronous transmitter (UART) chips. Channel 1 has been assigned to the GPS module.

B.2.2.4 A/D Converter Board
Figure B12

Matrix ADC-12M

The A/D converter is used to convert analog input signals from the compass, angular rate sensor, and the loop excitation monitor for processing and storage by the computer.

The ADC-12M is a 12-bit (1 part in 4096) analog-to-digital board. It is configured for 16 single-ended analog input channels with a +/- 10 volt input range. A status bit is monitored to determine whether an A/D conversion cycle has been completed.

B.2.2.5 CPU Board
Figure B13

Ziatech Corp. Model ZT8809

The ZT8809 is a single board STD Bus computer with the following major features:

* NEC V20 microprocessor -- Intel 8088-based CPU operating at 8 MHz
* Three 16-bit counter/timers (8254)
* Interrupt controller (8259A)
* 256K RAM and 256K EPROM
* Two serial ports, one RS-232, one RS-232 or RS-422A/485
* I/O printer port
* STD DOS operating system

B.2.2.6 Memory Cassette
Figure B14

Enlode 334C-1M (CMOS Cassette Memory Card)
Mitsubishi Melcard MF3256-M7DAC01 (Static RAM Cassette)

A removable battery-backed static RAM cassette system is available to provide portable large-capacity storage. The cassettes are "credit card" size with a memory capacity of 256K bytes and are insertable and removable from a receptacle on the cassette memory card which, in turn, plugs into a standard STD bus card slot. A replaceable lithium battery provides memory retention for a minimum of three years on the SRAM cassette. The memory cassette system has been configured as a disk drive from which the navigation data collection program executes. The remainder of its space may be reserved for data storage.

B.2.2.7 Memory Board
Figure B15

Ziatech ZT8825

The Ziatech 8825 memory board, configured as a RAM drive, provides a large-capacity data collection storage for the system. Eight 128K static RAM chips have been installed, providing a total of 1M byte of storage. An on-board 1 Amp-hour lithium battery allows for static RAM memory retention.

B.2.2.8 Front Panel Display
Figure B2

Caltrans Model 631150-100

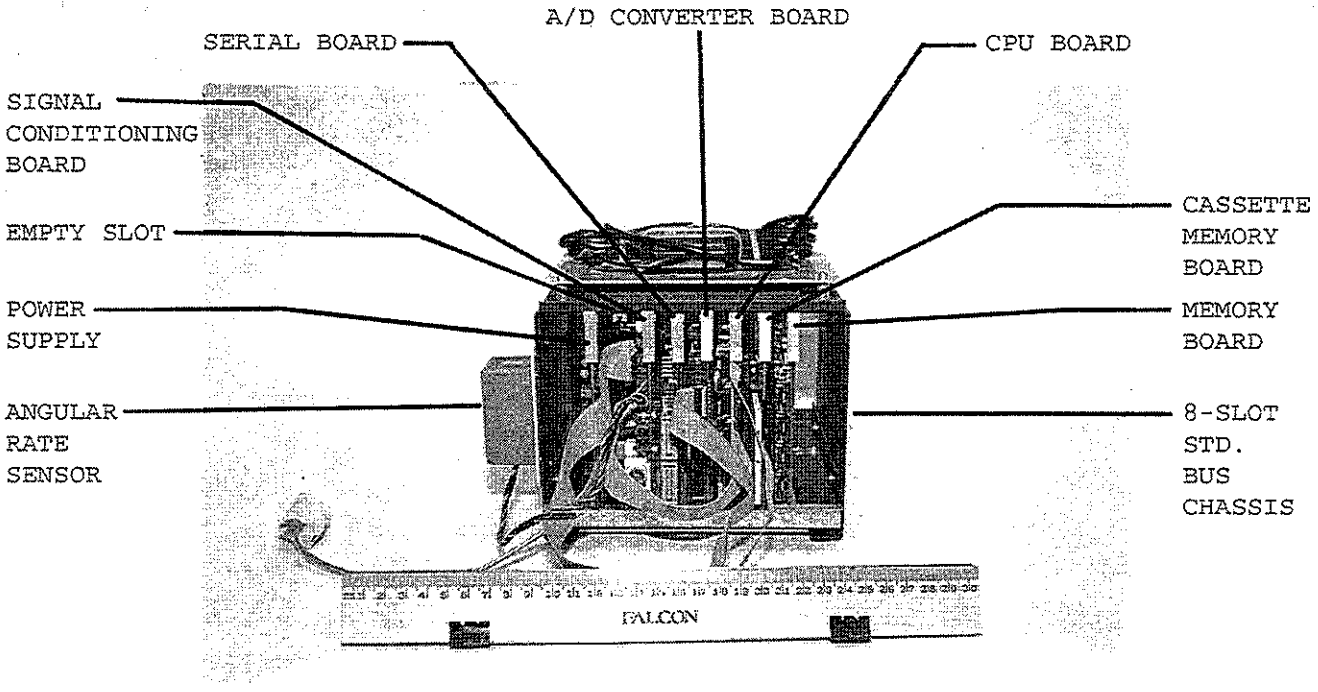
The front panel is a microprocessor controlled operator interface comprised of a digital display, input pushbuttons, and an audible tone generator. The microprocessor is a Motorola MC68HC11. The display is a four-line by 20-character Liquid Crystal Display (LCD). The display features a backlight which can be switched on by the

operator to compensate for poor lighting conditions. Seven pushbuttons are available for operator inputs. A tone generator beeps for a programmed duration. The front panel interfaces to the controlling computer by a RS-422 serial link at 9600 baud.

B.2.2.9 Laptop Computer
Figure B16

Toshiba Model T1200

An IBM PC compatible laptop, connected to the CPU's serial port (J1), is used to communicate with the ZT8809 STD DOS system. The laptop also allows the operator to run the data collection program and to log landmarks from the keyboard.



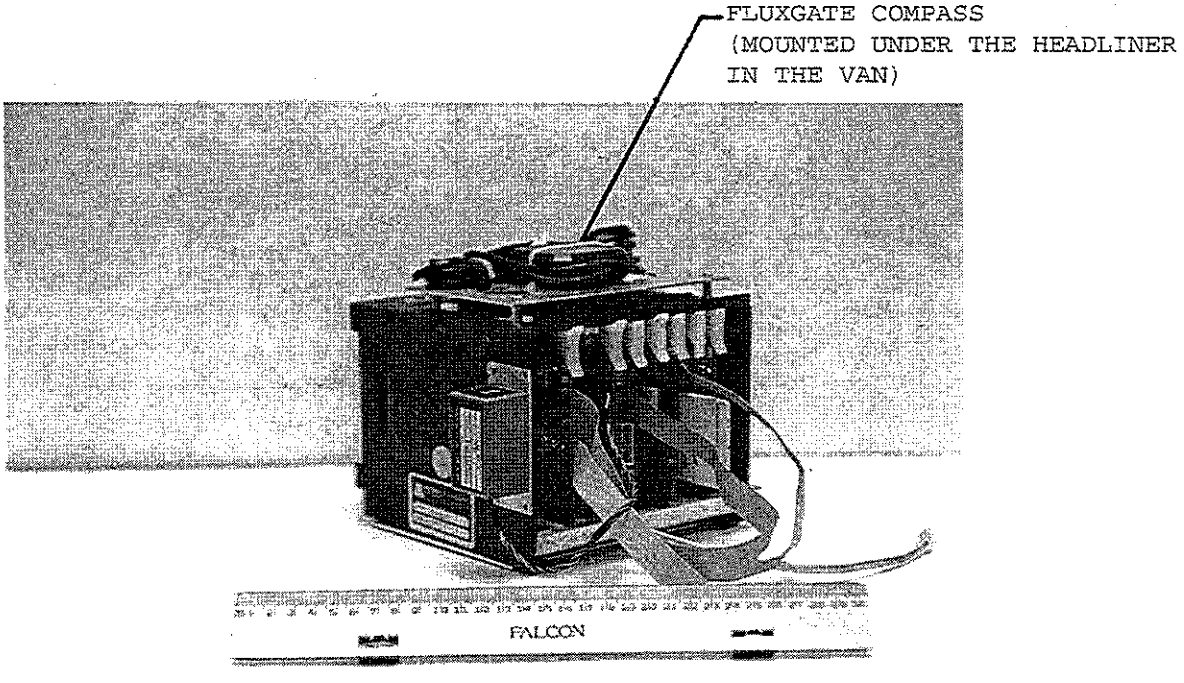




Figure B1

Computer System

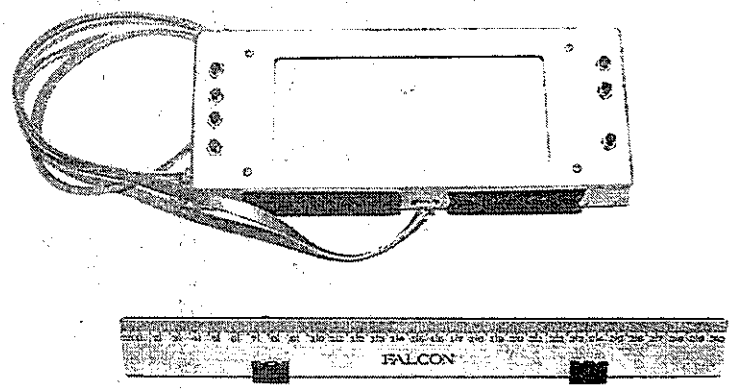



Figure B2

INRAD Operator Interface

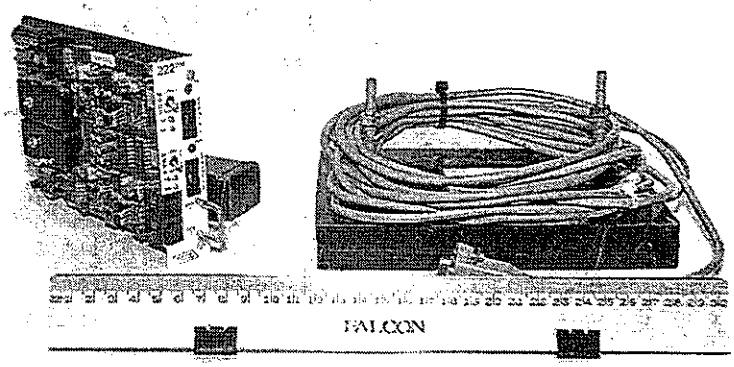



Figure B3

Inductive Radio Communications System

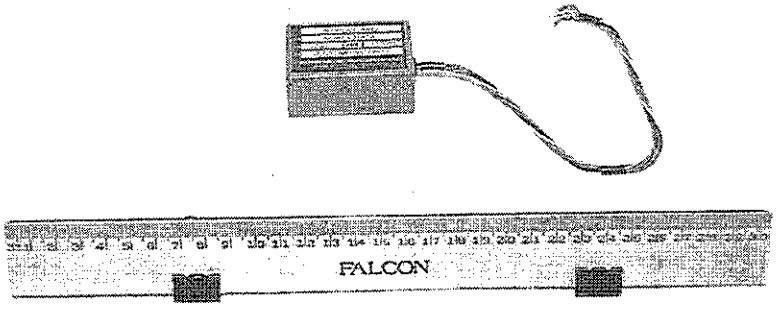



Figure B4

Angular Rate Sensor

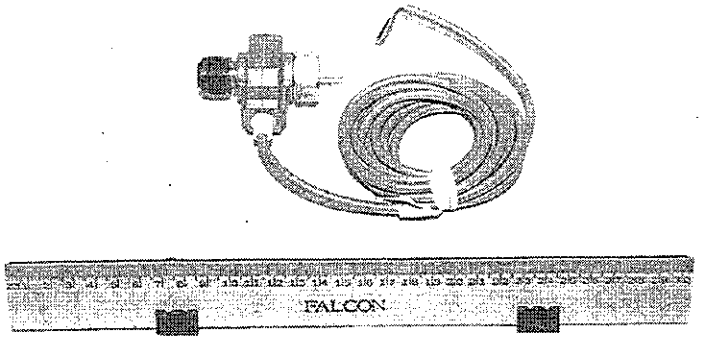



Figure B5

Odometer

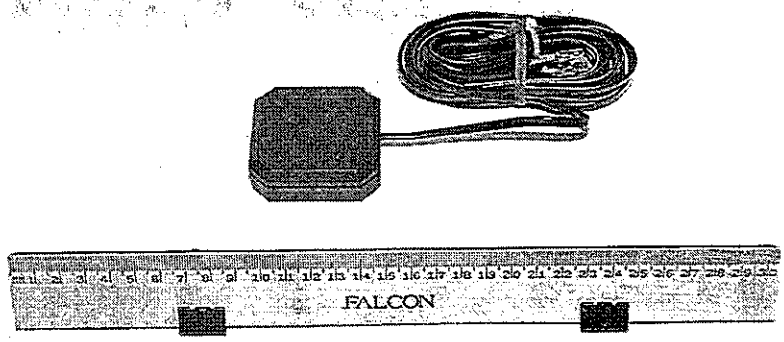



Figure B6

Fluxgate Compass

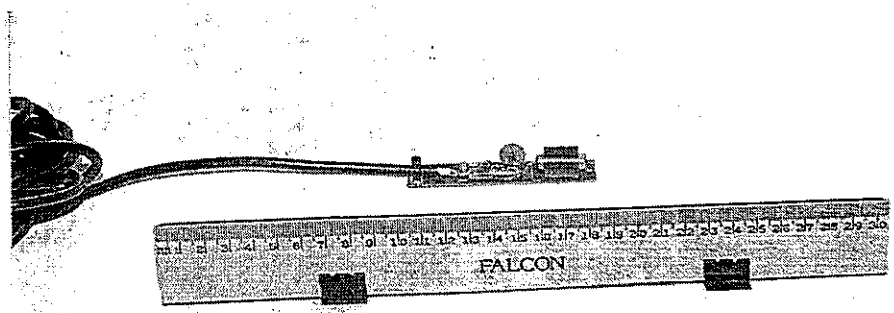



Figure B7

Loop Excitation Antenna

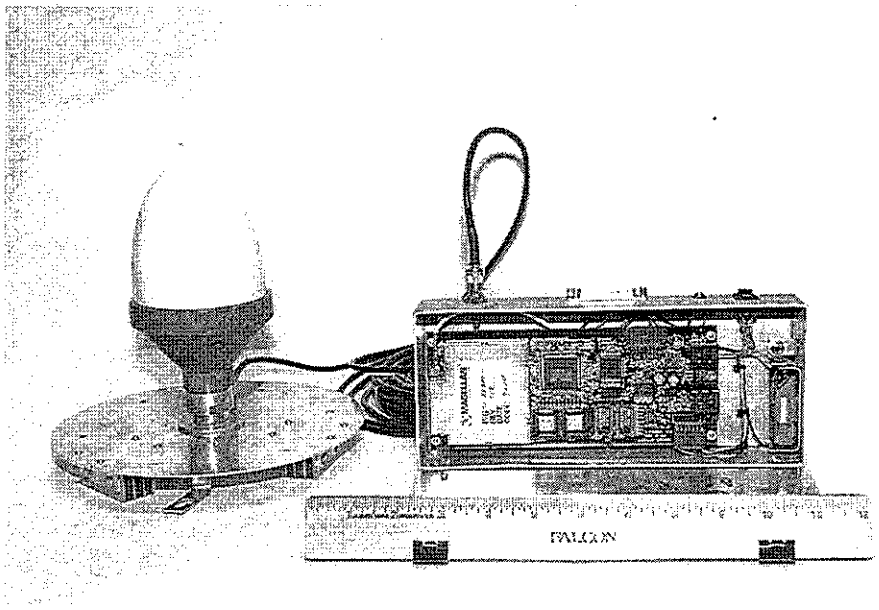


Figure B8

5-Channel GPS Receiver with Antenna

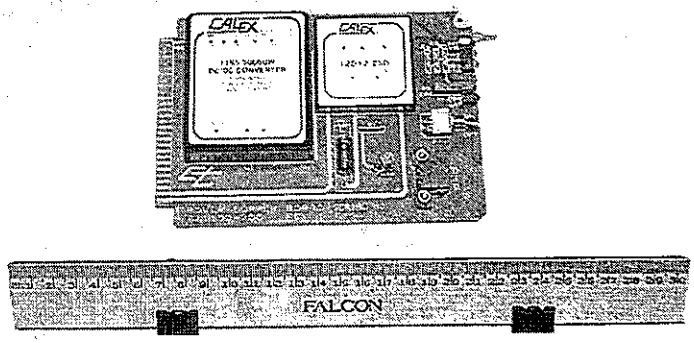



Figure B9

Power Supply

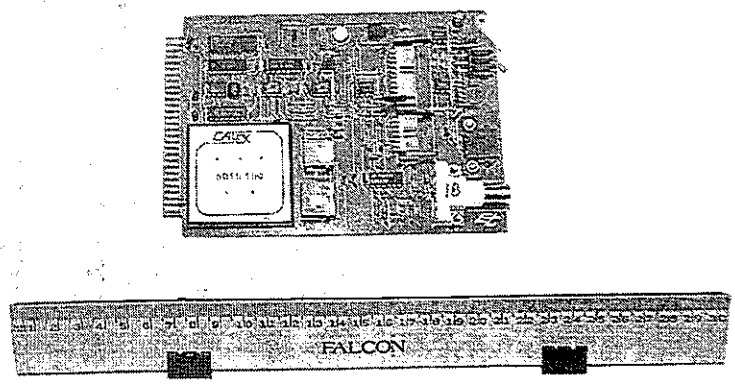



Figure B10

Signal Conditioning Board

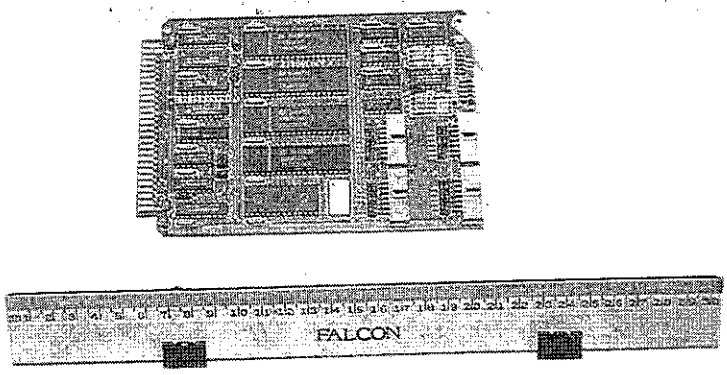



Figure B11

Multichannel Serial Board

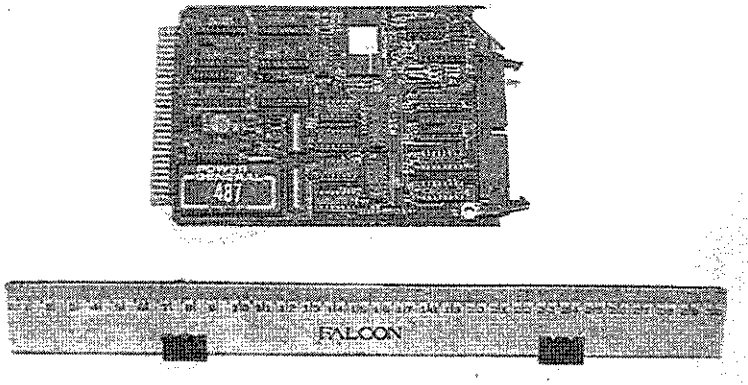



Figure B12

A/D Converter Board

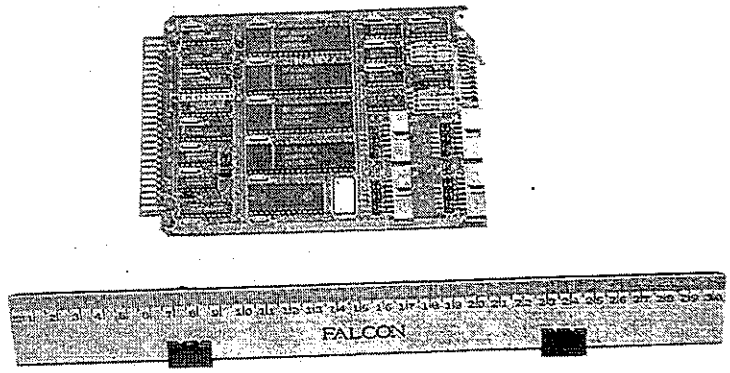



Figure B13

CPU Board

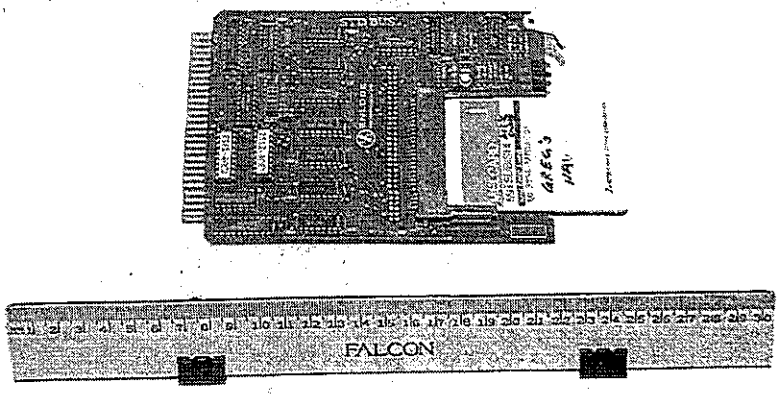



Figure B14

Cassette Memory Board

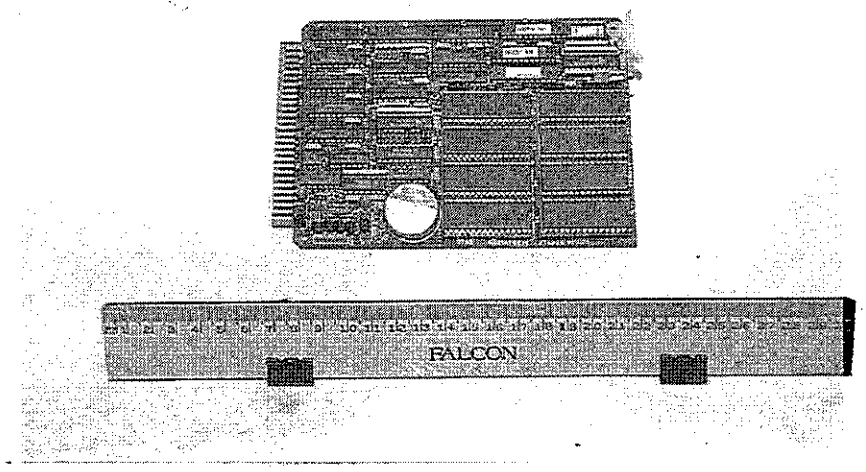
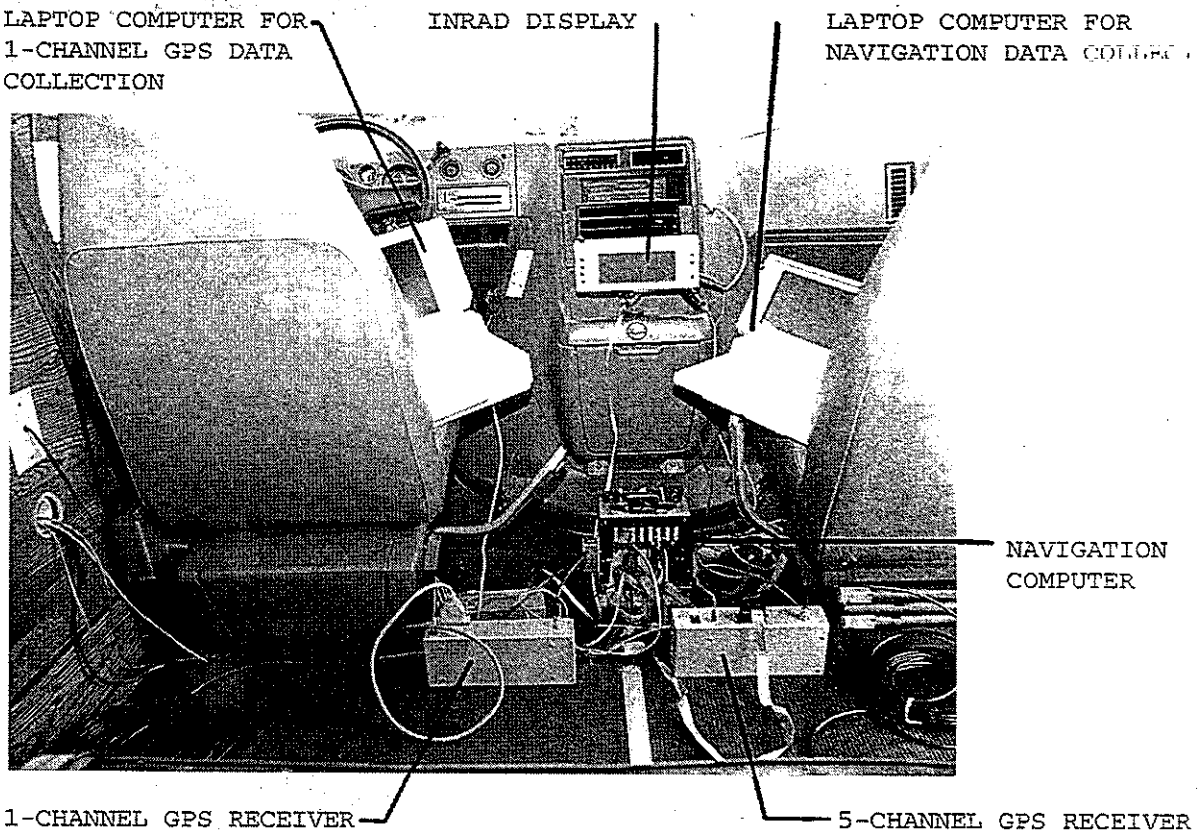



Figure B15

Memory Board



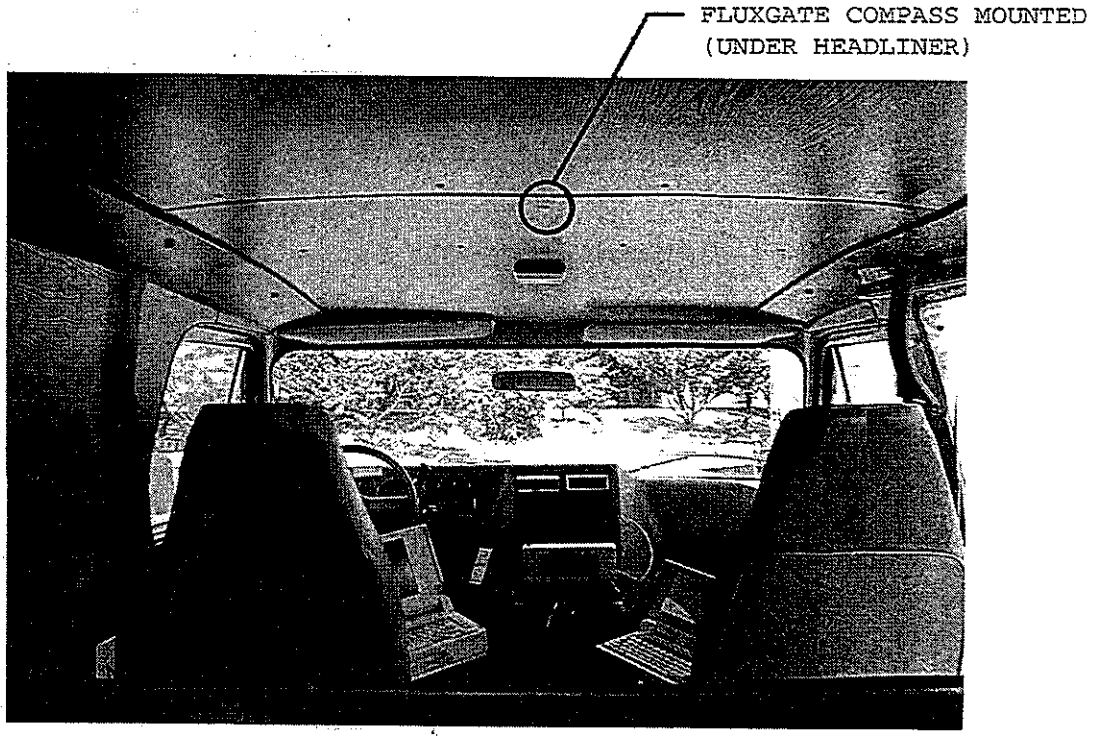




Figure B16

Navigation Equipment

Installation

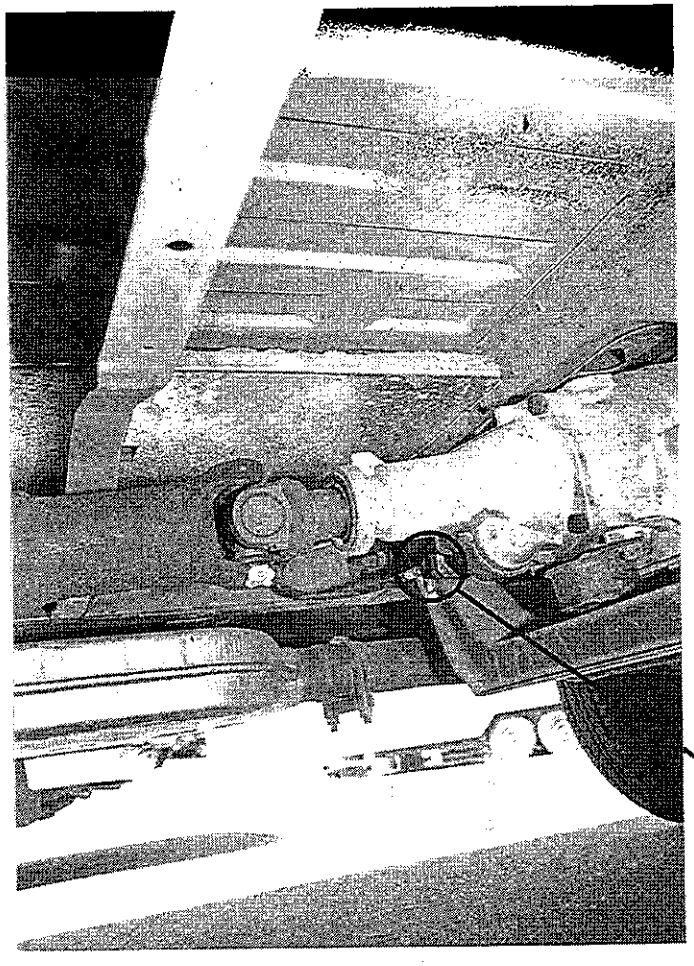



Figure B17
Odometer
Installation

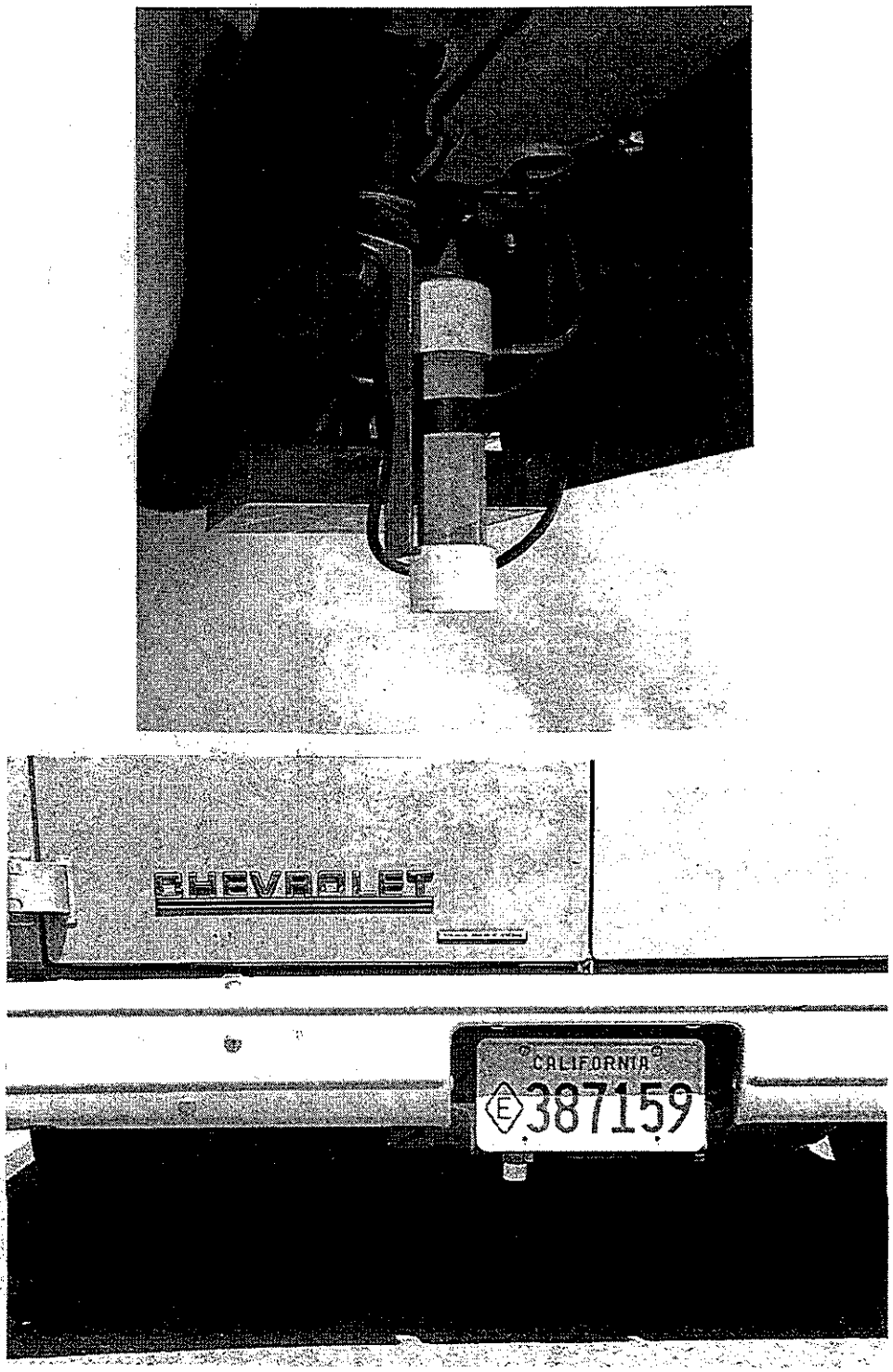



Figure B18

Loop Excitation Antenna and Modem Installation

## Appendix C

**SOFTWARE DESCRIPTION**
NAVIGATION PROJECT
631150

### C.1 DATA COLLECTION ROUTINES

The navigation and loop monitoring software consists of two linked programs. The foreground C program (NAV.C) starts and stops data collection, processes data, and stores data. The background assembly program (ISR.ASM) services interrupts and collects navigation and loop data.

#### C.1.1 ISR.ASM

ISR.ASM is a background interrupt service routine written in assembly to acquire data from the Intel 8254 timer, the odometer counter, and the Matrix analog-to-digital converter (ADC) card and save them in binary files. The 8254 timer is programmed to generate interrupts every millisecond; the interrupts are then processed by the 8259A interrupt controller.

One block of navigation data is collected at each interrupt and stored into one of two 8000-byte circular queue buffers, depending on whether the interrupt occurred on an even seconds count or an odd seconds count. Having two buffers allows processing of data acquired from the previous second while data is collected during the current second. Each block consists of 8 bytes of data comprised of compass x-axis (2 bytes), compass y-axis (2 bytes), angular rate sensor (2 bytes), and a dummy place holder (2 bytes). The dummy place holder ensures the size of each data block is a multiple of two, which facilitates finding the buffer index (bit shift instead of division processing). Since the background program saves 1000 blocks per second, each circular queue contains one second's worth of data that is being continuously updated. The seconds counter is incremented and the navigation flag is set once every 1000 interrupts. The odometer count is also read at each interrupt and updated in memory. It is incremented or decremented depending on whether the vehicle is moving forward or backward.

Loop monitor data are collected at each interrupt and stored in an 8000-byte circular buffer. The data are stored in an 8-byte block comprised of a seconds count (2 bytes), loop frequency (2 bytes), loop power (2 bytes), and a dummy place holder (2 bytes). As each block is collected, the ADC channel that corresponds to the loop power is checked to determine if it crosses a preset voltage threshold. If the threshold is crossed, a flag is set to tell the foreground C program (NAV.C) that a loop has been detected. The buffer

location where this occurs is calculated and stored as a loop index. The frequency counter is then reset at the threshold crossing.

The GPS receiver updates its position as often as once each second. The receiver is polled at each interrupt. Incoming GPS message characters are collected through a UART (Ziatech ZT8840 serial board) and stored in a 1024-byte circular buffer. When a line feed (0AH) is encountered, a flag is set to tell the foreground C program that a complete message has been received. A message tail pointer tracks the next storage location in the buffer.

### C.1.2 NAV.C

NAV.C is the foreground C program that starts and stops data collection and reads GPS, navigation and loop data from their respective buffers and stores them in a 1M byte battery-backed static RAM board. The program contains interactive features which allow the operator to begin data collection by pressing "B," end by pressing "ESC," and change the default loop voltage threshold by entering the desired threshold.

The program checks the loop detected flag and waits until it is set. While waiting for loop data, the program checks the GPS flag to determine whether a complete message is available from the GPS buffer. If a message is available, it is retrieved, its checksum verified, and the message is stored in a file named GPS.DAT. The file header contains the time and date the file was opened.

The program then checks the navigation flag to determine whether navigation data are available. The program retrieves, processes, and stores data from the navigation buffers when the flag is set at one-second intervals. The compass x-axis, compass y-axis, and angular rate sensor readings are averaged over 1000 readings; the resulting values are stored along with the seconds count and odometer count in a file named NAV.DAT file. The file header contains the time and date the file was opened.

When a loop is detected, the program outputs a loop detected message. Seventy counts (70 ms) are subtracted from the loop index to locate the start of the loop signature in the circular queue. From this location, 280 milliseconds of loop data are saved into a buffer in memory. The contents of the buffer are then written into a file named LOOP.DAT file in the RAM card. The file header contains the time and date the file was opened. Each set of loop data includes a header which contains the loop frequency and the odometer reading at the time the loop was detected.

The loop frequency is determined from the slope of the frequency ramp output from the ADC card. The slope is calculated over a 10-millisecond interval starting at the loop index (the point at which the frequency counter was reset) plus one count. Frequency is calculated by substituting the slope into an equation which was previously determined to represent a best fit of a time versus frequency calibration curve (see Appendix J). The frequency is stored and displayed as part of the LOOP.DAT file header.

## C.2 CONVERSION ROUTINES

File conversion routines convert binary navigation and loop data files (.DAT extension) to ASCII formated text files (.PRN). A GPS file conversion routine converts ASCII data from one sentence format to another. Converted data can then be reduced and plotted using commercial software.

### C.2.1 CNVNAV.C

CNVNAV.C converts binary NAV.DAT files to ASCII-formatted text files (NAV.PRN) for use with the Lotus 1-2-3 spreadsheet program.

The program prompts the user for the data source filename (NAV.DAT) and the destination text filename (NAV.PRN). It then determines the amount of data stored in the NAV.DAT file in the RAM board. Data are then transferred from the RAM board to a temporary buffer in memory. From this buffer, data are formatted and written into a file named NAV.PRN. The file contains odometer, compass x-axis, compass y-axis, and angular rate sensor readings updated at one second intervals. Each file contains a file header with the time and date the data were collected.

### C.2.2 CNVLOOP.C

CNVLOOP.C converts binary LOOP.DAT files to ASCII formatted text files (LOOP.PRN) for use with the Lotus 1-2-3 spreadsheet program.

The program prompts the user for the data source filename (LOOP.DAT) and the destination subdirectory. It then determines the amount of data stored in the LOOP.DAT file in the RAM board. Data are then transferred from the RAM board to a temporary buffer in memory. From this buffer, data are formatted and written into files named LOOP___.PRN. Each loop encountered in a data collection session is sequentially numbered and the number is used in creating the .PRN filename. For example, data from the first loop encountered is stored in file LOOP1.PRN, the second loop in LOOP2.PRN, and so forth up to LOOP999.PRN. For each loop detected, the file contains 280 lines showing milliseconds, frequency, and power. Each file contains a file header with

the date and time the data were collected, the loop frequency, the odometer reading, and the time when the loop voltage threshold was reached. The file header information is compiled into a file named LOOP.SUM, a summary of all of the loops encountered in a data collection session.

### C.2.3 CNVGPS.C

CNVGPS.C converts ASCII (Magellan NMEA 0183 format) files to formated GPS.PRN files for use with the Trimble Navigation T-Plane program to convert latitude and longitude coordinates to state plane coordinates.

The GPS.DAT NMEA file format is as follows:

```
xx:xx:xx    xx-xx-xx
$PMGLH,00,xx.x,xx,x,x,x,x,x,x,x,x*CKRL
$GPGGA,xxxxxx,xxxx.xx,N,xxxx.xx,W,x,x,xxx,uxx,M,uxxx,M*CKRL
```

(see GPS files description for a definition of the sentence format)

The GPS.PRN T-plane file format is as follows:

```
z,0402
g,xx.xxxxxxxxx,-xxx.xxxxxxxxx,-xx.x,x.x,"station name"
 1              2               3    4   5
```

| | |
|---|---|
| 1: | Latitude in degrees |
| 2: | Longitude in degrees |
| 3: | Always 0 |
| 4: | Geoid height |
| 5: | Station name (assign time to this field) |

The program prompts the user for the data source filename (GPS.DAT) and the destination filename (GPS.PRN). The file header, "z,0402," is written at the top of the file, signifying that the coordinates are from California, Zone 2. Each GPS sentence is converted until and end-of-file occurs. Latitude and longitude in degrees, minutes and hundredths of minutes are converted to degrees.

# Appendix D

## Software Listings

D.1 ISR.ASM (rev. ISR4.ASM)

D.2 NAV.C (rev. NAV4.C)

D.3 CNVNAV.C (rev. CNV4.C)

D.4 CNVLOOP.C (rev. CNV4LOOP.C)

D.5 CNVGPS.C (rev. CNVGPS.C)

```
;
;       ISR4.ASM
;       1 millisecond interrupt service routine
;       project:    Navigation Project -- 631150
;       version:    01.01
;       created:    08/01/91
;       revised:    5/5/92
;       programmer: Greg Larson
;
        .MODEL   SMALL
        .DATA                       ;start of data segment
;
        EXTRN   _loopque:WORD       ;address of loop data queue
        EXTRN   _qtail:WORD         ;tail of loop, even, and odd data queues
        EXTRN   _gpsque:WORD        ;address of gps data queue
        EXTRN   _gpstail:WORD       ;tail of gps queue
        EXTRN   _threshld:WORD      ;loop power level threshold
        EXTRN   _loopind:WORD       ;index at which a loop is detected
        EXTRN   _loopdet:BYTE       ;loop detected flag
        EXTRN   _loopon:BYTE        ;loop data acquisition enabled flag
        EXTRN   _evnque:WORD        ;nav data buffer for even seconds
        EXTRN   _oddque:WORD        ;nav data buffer for odd seconds
        EXTRN   _odmcount:DWORD     ;odometer count
        EXTRN   _oldcount:WORD      ;last counter output value
        EXTRN   _second:WORD        ;seconds count
        EXTRN   _navflag:BYTE       ;navigation sampling flag
        EXTRN   _gpsflag:BYTE       ;gps sampling flag
;
_DATA   ENDS                        ;end of data segment
;
        .CODE                       ;start of code segment
;
        PUBLIC   _initvec
_initvec PROC   NEAR                ;initialize interrupt vector
        push    ds                  ;save reg
        mov     dx,_TEXT            ;get end of code segment
        mov     ds,dx               ;initialize data segment
        mov     dx,OFFSET intrpt1   ;get offset to interrupt service routine
        mov     ax,0250Ah           ;DOS system call number (25), int number
        int     21h                 ;call DOS
        pop     ds                  ;restore reg
        ret                         ;done
_initvec ENDP                       ;end of initvec procedure
;
intrpt  PROC    FAR                 ;1 millisecond interrupt service routine
intrpt1: sti                        ;enable interrupts
        push    ax                  ;save registers
        push    bx                  ;
        push    cx                  ;
        push    dx                  ;
        push    di                  ;
        push    ds                  ;
;
        mov     dx,DGROUP           ;get data base
```

```
        mov     ds,dx               ;initialize data segment
        mov     bx,OFFSET _loopque  ;point to beginning of queue
        mov     di,_qtail           ;get offset into queue
;
; the following instructions acquire loop data and store them in a circular
; queue, checking for loops as it goes along
;
        mov     ax,_second          ;get seconds count
        call    enque               ;install data in queue
;
        cmp     _loopon,0           ;check for loop data acquisition off
        jz      loopoff             ;branch if loop data acquisition off
        mov     al,3                ;adc channel number (frequency)
        call    inpadc              ;input data from adc
        call    enque               ;install data in queue
        mov     al,4                ;adc channel number (power)
        call    inpadc              ;input data from adc
        call    enque               ;install data in queue
;
        cmp     _loopdet,0FFh       ;check for loop already detected
        je      getdum              ;branch if loop already detected
        cmp     ax,_threshld        ;check for loop detected
        jb      getdum              ;branch if loop not detected
;
        mov     _loopdet,0FFh       ;say loop detected
        mov     ax,di               ;get queue tail
        mov     cl,3                ;get shift count
        shr     ax,cl               ;divide by 8 to get index
        mov     _loopind,ax         ;save index of detected loop
        mov     dx,0378h            ;point to printer port data register
        mov     al,1                ;get reset level
        out     dx,al               ;send reset level to frequency counter
        xor     al,al               ;get un-reset level
        out     dx,al               ;send un-reset level to frequency counter
        jmp     getdum              ;install dummy data
;
loopoff: xor    ax,ax               ;clear register, get dummy data
        call    enque               ;install data in queue (frequency)
        call    enque               ;install data in queue (power)
;
getdum:  xor    ax,ax               ;clear register, get dummy data
        call    enque               ;install data in queue (dummy)
;
; the following instructions acquire navigation data and store them in
; either of two buffers, depending on whether the seconds count is
; even or odd
;
donav:  call    readodm             ;read odometer count
        sub     di,8                ;move tail pointer back by 8 locations
        mov     bx,OFFSET _evnque   ;point to even queue for now
        mov     ax,_second          ;get seconds count
        rcr     al,1                ;check for even number of seconds
        jnb     evensec             ;branch if even number of seconds
        mov     bx,OFFSET _oddque   ;point to odd queue
```

```
evensec: mov    dl,0              ;clear adc channel number
nxtchan: mov    al,dl             ;get channel number
         call   inpadc            ;input data from adc
         call   enque             ;install data in queue
         inc    dx                ;increment channel number
         cmp    dl,3              ;check for more channels
         jb     nxtchan           ;branch if more channels
         xor    ax,ax             ;get dummy data
         call   enque             ;install data in queue
;
         mov    _qtail,di         ;update offset into queue
         cmp    di,01F40h         ;check for space left in queue
         jb     notfull           ;branch if space left in queue
         mov    _qtail,0          ;re-initialize offset into queue
         inc    _second           ;update seconds count
         mov    _navflag,0FFh     ;update nav sampling flag
;
; the following instructions acquire gps data and store them in a circular
; queue
;
notfull: in     al,0E5h           ;get status register
         rcr    al,1              ;check for receive data available
         jnc    nodata            ;branch if no receive data available
         in     al,0E0h           ;get data
         mov    bx,OFFSET _gpsque   ;point to beginning of queue
         mov    di,_gpstail       ;get offset into queue
         mov    [bx][di],al       ;install data in queue
         inc    di                ;update queue tail pointer
         and    di,03FFh          ;check for end of queue
         mov    _gpstail,di       ;update tail pointer
         cmp    al,0Ah            ;check for a LF
         jne    check2            ;jump if not LF
         mov    _gpsflag,0FFh     ;complete message, update gps flag

check2:  in     al,0E5h           ;get status register
         rcr    al,1              ;check for receive data available
         jnc    nodata            ;branch if no receive data available
         in     al,0E0h           ;get data
         mov    [bx][di],al       ;install data in queue
         inc    di                ;update queue tail pointer
         and    di,03FFh          ;check for end of queue
         mov    _gpstail,di       ;update tail pointer
         cmp    al,0Ah            ;check for a LF
         jne    nodata            ;jump if not LF
         mov    _gpsflag,0FFh     ;complete message, update gps flag

;
nodata:  mov    al,020h           ;get end of interrupt command
         cli                      ;disable interrupts
         out    020h,al           ;send end of interrupt to PIC
;
         pop    ds                ;
         pop    di                ;
         pop    dx                ;
```

```
        pop     cx                      ;
        pop     bx                      ;
        pop     ax                      ;
        iret                            ;return from interrupt
intrpt  ENDP                            ;end of intrpt procedure
;
;
;       enque
;       install data in queue
;
;       entries: ax has the data
;                bx points to the beginning of the queue
;                di has the offset into the queue
;
;       exit:   di is updated
;
enque   PROC    NEAR                    ;install data in queue
        mov     [bx][di],ax             ;install data in queue
        inc     di                      ;update queue offset pointer
        inc     di                      ;update queue offset pointer
        ret                             ;done
enque   ENDP                            ;end of enque procedure
;
;
;       inpadc
;       input data from adc
;
;       entry:   al has the channel number
;
;       exit:   ax has the adc data
;
chan    EQU     073h                    ;channel number register
datareg  EQU    074h                    ;data register
status  EQU     075h                    ;status register
;
inpadc  PROC    NEAR                    ;
        out     chan,al                 ;send channel number, start conversion
busy:   in      al,status               ;get adc status
        rcl     al,1                    ;check for adc busy
        jb      busy                    ;branch if adc busy
        in      ax,datareg              ;get adc data
        ret                             ;done
inpadc  ENDP                            ;end of inpadc procedure
;
;
;       readodm
;       read the odometer counter
;
;       entry:   none
;
;       exit:   none
;
datareg1 EQU    041h                    ;data register
control  EQU    043h                    ;control register
```

```
;
readodm  PROC  NEAR                  ;
        mov    al,040h               ;point to counter 1, latch counter data
        out    control,al            ;send control byte
        in     al,datareg1           ;read counter (LSB)
        mov    dl,al                 ;save LSB
        in     al,datareg1           ;read counter (MSB)
        mov    dh,al                 ;save MSB
        cmp    dx,_oldcount          ;check for change from last count
        je     nochng                ;branch if no change from last count
        mov    _oldcount,dx          ;update last count
        mov    dx,0379h              ;point to printer port status register
        in     al,dx                 ;get printer port status register
        rcl    al,1                  ;check for back-up light off
        jnb    forward               ;branch if back-up light off
        sub    WORD PTR _odmcount[0],1  ;decrement odometer count
        sbb    WORD PTR _odmcount[2],0  ;(32 bit variable)
        jmp    nochng                ;skip increment portion
forward: add   WORD PTR _odmcount[0],1  ;increment odometer count
        adc    WORD PTR _odmcount[2],0  ;(32 bit variable)
nochng:  ret                         ;done
readodm  ENDP                        ;end of readodm procedure
;
_TEXT   ENDS                         ;end of code segment
;
        END                          ;end of newisr.asm
;
```

```
/*****************************************************************************
    NAV4.C

    foreground executive for the navigation project

    project: 631150
    version: 04.06
    created: 08/01/91
    revised: 4/22/92
    programmer: Greg Larson / Ed Ung
    compiler: Turbo C++ version 1.0
    linker:  Turbo C++ version 1.0
    background: ISR4.ASM

    This program reads and stores dead-reckoning and GPS navigation data
    every second, loop data when a loop is detected, and landmark descriptions
    as they are entered.  Navigation, loop, and landmark data are stored in
    separate files tagged by time.
*****************************************************************************/
/*** Header files ***/

#include <stdio.h>
#include <conio.h>
#include <io.h>
#include <fcntl.h>
#include <dos.h>
#include <stdlib.h>
#include <time.h>
#include <bios.h>
#include "serial.h"

/*** Definitions ***/

#define S_IWRITE    0000200
#define YES          1
#define NO           0

/*** Serial.C definitions ***/

#define FALSE        0
#define TRUE        (!FALSE)

/*** Function prototypes ***/

int initvec();                          /* initialize interrupt vector */
void GPS_Messages_Off();                /* switch off GPS outputs */
unsigned char Check_GPS();              /* check gps on startup function */
unsigned int Set_Loop_Threshld();       /* set loop voltage threshold */
unsigned char Read_Message();           /* read GPS message */
int Checksum();                         /* calculate checksum */
void No_Message(void);                  /* no message error message */
void PMGLH(unsigned char *);            /* PMGLH message fields */
void Collect_Nav_Data();                /* collect navigation data */
void Collect_Loop_Data();               /* collect loop data */
```

```
void Read_Key();                          /* read keyboard */

/*** Structure declarations ***/

struct loop  {                            /* declare loop structure */
          unsigned int second;
          int frequency;
          int power;
          int dummy;
          };
                                          /* initialize variables */
struct loop loopque[1000];

int qtail = 0, loopind = 0;
unsigned int threshld = 2256;             /* power level threshold, 1.016 V */
unsigned char loopon = 0, loopdet = 0;

struct nav  {                             /* declare nav structure */
         int x_axis;
         int y_axis;
         int rate;
         int dummy;
         };

struct nav evnque[1000], oddque[1000];    /* declare queue structures */
                                          /* initialize variables */
long odmcount = 0, oldodmcount = 0;
unsigned int second = 0, oldcount = 0xFFFF;
unsigned char navflag = 0, gpsflag = 0;

char gpsque[1024];                        /* GPS buffer */
int gpshead = 0;                          /* initialize to top of queue */
int gpstail = 0;

/****************************** MAIN ****************************************/
void
main()                                    /* START OF MAIN */
{

/*** Variable and structure declarations ***/

extern struct loop loopque[];             /* loop */
extern int qtail, loopind;
extern unsigned int threshld;
extern unsigned char loopon, loopdet;

extern struct nav evnque[], oddque[];     /* navigation */
extern long odmcount;
extern unsigned int second, oldcount;
extern unsigned char navflag;

extern unsigned char gpsflag;             /* GPS */
extern char gpsque[1024];
extern int gpshead;
```

```
extern int gpstail;

unsigned char mask;                     /* declare internal variables */
unsigned long xtotal, ytotal, rate_total;

unsigned char gps_command[255], gps_message[255];
unsigned char chksum, checksum1, checksum2;
unsigned char cmdlength;                /* gps command length */
unsigned char msglength;                /* gps message length */
unsigned char escflag = 0;              /* ESC flag */
unsigned char key_ptr = 0;              /* landmark buffer pointer */

char key[100];                          /* landmark buffer */
char tag = 0;                           /* landmark tag flag */

struct date date;
struct time time1;

int todbuf[6];                          /* time of day buffer */

/*** Canned GPS commands ***/

char rcvr_status_cmd[] = {"$PMGLI,00,H00,1,A,00*4B\r\n"}; /*output rcvr status*/
char gps_position_on[] = {"$PMGLI,00,B00,2,A,00*42\r\n"}; /* gps position on */
char gps_position_off[] = {"$PMGLI,00,B00,0,A,00*40\r\n"};/* gps position off */

/*** Data field strings for messages ***/

char bin_prefix[][4] = {                /* sentence prefixes (binary) */
                    "A00",              /* time and date */
                    "B00",              /* position, altitude, etc. */
                    "B01",              /* position (last fix) */
                    "C00",              /* ECEF position */
                    "D00",              /* mode */
                    "E00",              /* ground course and velocity */
                    "F00",              /* sats used */
                    "F01",              /* sats used including status */
                    "G00",              /* PDOP, GDOP, error estimate */
                    "H00",              /* receiver status */
                    "R01",              /* autopilot */
                    "R02",              /* bearing (dest and orig wypts */
                    "R03",              /* bearing and distance to wypt */
                    "R04",              /* magnetic variation */
                    "R05",              /* waypoints */
                    "R06",              /* time to go to waypoint */
                    "R07",              /* ETA to waypoint */
                    "S01",              /* datum, terrain, and units setup*/
                    "T01",              /* almanac data */
                    "T02",              /* ephemeris data */
                    "U01",              /* sat schedule */
                    "U02",              /* sat health (alm, eph, user) */
                    "U03",              /* sat status */
                    "V01"               /* doppler, C/No */
                        };
```

```
/*** File pointers ***/

FILE *fp_loop,                          /* loop file pointer */
     *fp_nav,                           /* nav file pointer */
     *fp_gps,                           /* gps file pointer */
     *fp_key;                           /* landmark file pointer */

/*** Open data files ***/

if ((fp_loop = fopen("J:LOOP.DAT", "wb")) == NULL)          /* loop file */
      {
      printf("Error opening file LOOP.DAT\n");
      exit(1);
      }

if ((fp_nav = fopen("J:NAV.DAT", "wb")) == NULL)            /* nav file */
      {
      printf("Error opening file NAV.DAT\n");
      exit(1);
      }

if ((fp_gps = fopen("J:GPS.DAT", "wt")) == NULL)            /* GPS file */
      {
      printf("Error opening file GPS.DAT\n");
      exit(1);
      }

if ((fp_key = fopen("J:KEY.DAT", "wt")) == NULL)            /* landmark file */
      {
      printf("Error opening file KEY.DAT\n");
      exit(1);
      }

/*** Initialize 8259 interrupt controller ***/

mask = inportb(0x21) | 4;               /* get 8259 interrupt enable mask */
outportb(0x21, mask);                   /* disable timer interrupt */

/*** Initialize 8254 counter ***/

outportb(0x43, 0xB4);                   /* select counter 2, mode 2 */
outportb(0x42, 0xA9);                   /* 0x04A9, pre-load count  */
outportb(0x42, 0x04);                   /* for 1 KHz interrupt     */

/*** Initialize 8840 serial port ***/

outportb(0xE3, 0x83);                   /* 8 bits/channel, 1 stop bit */
outport(0xE0, 0x000C);                  /* 9600 baud */
outportb(0xE3, 0x03);                   /* reset DLAB */
outportb(0xE1, 0x00);                   /* disable receiver interrupts */

initvec();                              /* initialize interrupt vector */
```

```
/*** Greetings ***/

clrscr();                                /* clear screen */
printf("\n\n***** WELCOME TO NAV4 *****\n\n");

/*** Check GPS receiver ***/

outportb(0x21, mask & 0xFB);             /* enable 1 KHz timer interrupt */

GPS_Messages_Off(bin_prefix);            /* switch off all output messages */
SerialString(rcvr_status_cmd);           /* request receiver status */
Check_GPS(gps_message);                  /* check GPS receiver status */

outportb(0x21, mask);                    /* disable timer interrupt */
second = 0;                              /* clear seconds */
loopind = 0;                             /* clear loop index */
qtail = 0;                               /* clear qtail */

/*** Set loop voltage threshold ***/

Set_Loop_Threshld(&threshld);            /* set loop voltage threshold */

/*** ACQUIRE LOOP AND NAVIGATION DATA ***/

printf("\n\nPress \'B\' to begin data acquisition\n\n");
while(getch() != 'b');                   /* wait for a 'B' */

outportb(0x21, mask & 0xFB);             /* enable 1 KHz timer interrupt */

/*** Start odometer log ***/

outportb(0x43, 0x70);                    /* point to counter 1, mode 0  */
outportb(0x41, 0xFF);                    /* initialize counter 1 to the */
outportb(0x41, 0xFF);                    /* maximum count value, 0xFFFF */

getdate(&date);                          /* get current date */
gettime(&time1);                         /* get current time */

todbuf[0] =     date.da_year;            /* initialize time of day buffer */
todbuf[1] = (int) date.da_mon;
todbuf[2] = (int) date.da_day;
todbuf[3] = (int) time1.ti_hour;
todbuf[4] = (int) time1.ti_min;
todbuf[5] = (int) time1.ti_sec;

/*** Write time and date to data files ***/

if(fwrite(todbuf, 2, 6, fp_loop) != 6)  /* loop file */
       {
       perror ("Error writing TOD to LOOP.DAT"); /* print error message */
       exit(1);
       }

if(fwrite(todbuf, 2, 6, fp_nav) != 6)   /* nav file */
```

```
        {
        perror ("Error writing TOD to NAV.DAT");  /* print error message */
        exit(1);
        }

                                                  /* landmark file */
fprintf(fp_key, "%2d:%2d:%2d  ", todbuf[3],todbuf[4],todbuf[5]); /*hr:min:sec*/
fprintf(fp_key, "%2d-%2d-%2d\n", todbuf[1],todbuf[2],todbuf[0]-1900);
/*mo:da:yr*/

                                                  /* GPS file */
fprintf(fp_gps, "%2d:%2d:%2d  ", todbuf[3],todbuf[4],todbuf[5]);  /*hr:min:sec*/
fprintf(fp_gps, "%2d-%2d-%2d\n", todbuf[1],todbuf[2],todbuf[0]-1900);
/*mo:da:yr*/

/*** Prompt user to start acquisition ***/

clrscr();                                         /* clear screen */
printf("\n\nData acquisition started...\n");
printf("\n\nPress ESC to end data acquisition\n");

loopon = 0xFF;                                    /* enable loop data acquisition */

/*** Collect navigation and GPS data while loop is not detected ***/

SerialString(gps_position_on);                    /* request position */

do      {                                         /* collect data ... */
        if(gpsflag != 0)                          /* retrieve GPS message */
                {
                Read_Message(gps_message, fp_gps);
                }
        if(navflag != 0)                          /* collect navigation data */
                {
                Collect_Nav_Data(fp_nav);
                }
        if(loopdet != 0)                          /* collect loop data */
                {
                Collect_Loop_Data(fp_loop);
                }
        if(kbhit())                               /* read keyboard */
                {
                Read_Key(key, fp_key, &key_ptr, &escflag, &tag);
                }

        }  while(escflag == 0);                   /* ... while ESC key is not pressed */

/* Flush buffers and close files */

fclose(fp_loop);                                  /* close loop data file */
fclose(fp_nav);                                   /* close navigation data file */
fclose(fp_gps);                                   /* close GPS data file */
fclose(fp_key);                                   /* close landmark data file */
outportb(0x21, mask);                             /* disable timer interrupt */
```

```
SerialString(gps_position_off);          /* disable gps position output */

printf("\n\nEnd of program\n\n");        /* return to DOS */
}                                        /* end of NAV4.C */

/************************** GPS_MESSAGES_OFF FUNCTION ************************/
/*
 * GPS_Messages_Off()
 *
 * This function individually switches off all GPS output messages.  An array
 * of binary sentence prefixes is substituted individually into message off
 * command string positions 10, 11, and 12.  The checksum is determined and
 * substituted into message off command string positions 21 and 22.
 *
 */

void
GPS_Messages_Off(char bin_prefix[][4])

{
int i;                                   /* string position */
char off_buffer[] = {"$PMGLI,00,___,0,A,00*__\r\n"}; /* message off command */
unsigned char chksum, checksum1, checksum2; /* checksum, MS char, LS char */
unsigned char msglength;                 /* gps message length */


for(i = 0; i < 24; i++)                  /* switch off 24 messages */
      {
      off_buffer[10] = bin_prefix[i][0];     /* prefixes */
      off_buffer[11] = bin_prefix[i][1];
      off_buffer[12] = bin_prefix[i][2];
                                         /* calculate the checksum */
      Checksum(off_buffer, &checksum1, &checksum2, &msglength);

      off_buffer[21] = checksum1;        /* checksum MS char */
      off_buffer[22] = checksum2;        /* checksum LS char */

      SerialString(off_buffer);          /* switch off specified message */
      }

}

/****************************** CHECK_GPS FUNCTION ****************************/
/*
 * Check_GPS()
 *
 * This function requests the GPS status message.  The first message is thrown
 * out.  If a status message is not received in 3 seconds, an error message
 * appears instructing the operator to clear and restart the GPS receiver.
 *
 */

unsigned char
Check_GPS(message)
```

```
char message[];                          /* array pointer */

{
int first_msg  = YES;                    /* first message flag */
int good_msg   = NO;                     /* good message flag  */
time_t last_byte_in;                     /* time of last byte  */
int msg_ptr = 0;                         /* message pointer */
unsigned char chksum, checksum1, checksum2; /* checksum, MS char, LS char */
unsigned char msglength;                 /* gps message length */

char rcvr_status_cmd[] = {"$PMGLI,00,H00,1,A,00*4B\r\n"}; /*output rcvr status*/

last_byte_in = time(NULL);               /* initialize to current time */

do     {                                 /* read incoming message */
       if (gpshead != gpstail)           /* if buffer is not empty, */
              {
              message[msg_ptr++] = gpsque[gpshead]; /* read characters ...*/
              last_byte_in = time(NULL);  /* watchdog timer */
              if (gpsque[gpshead++] == 0x0a)    /* ... until LF occurs */
                     {
                     message[msg_ptr] = 0;   /* install a NUL */
                     msg_ptr = 0;
                     if (first_msg == YES)   /* if first message */
                            {
                            first_msg = NO;
                            SerialString(rcvr_status_cmd);/*request status*/
                            }
                     else                    /* if not first message */
                            {
                            checksum1 = 0;
                            checksum2 = 0;
                            msglength = 0;
                            Checksum(message, &checksum1, &checksum2,
&msglength);
                            if (checksum1 != message[msglength + 1])
                                   printf("checksum1 does not compare\n");
                            if (checksum2 != message[msglength + 2])
                                   printf("checksum2 does not compare\n");
                            good_msg  = YES;    /* reset the flag */
                            }
                     }
              }
       else /* if current time exceeds initial time by 3 seconds output error*/
              {
              if (difftime(time(NULL), last_byte_in) > 3)
                     {
                     No_Message();
                     exit(0);
                     }
              }
       } while (first_msg == YES || good_msg == NO);

PMGLH(message);                          /* interpret status message */
```

```
return (99);
}

/*************************** SET_LOOP_THRESHLD FUNCTION *********************/
/*
 * Set_Loop_Threshld()
 *
 * This function changes the voltage threshold at which a signal is considered a
 * valid inductive loop.
 *
 */

unsigned int
Set_Loop_Threshld(unsigned int *threshld)

{
float threshld_volts;
char chng_threshld;

threshld_volts = (*threshld - 2048) * (float)(10) / 2048; /* convert to volts */
printf("\nThe current power level threshold is %5.3f volts.\n", threshld_volts);
printf("  Do you wish to change it?  (n = NO, y = YES): ");
scanf("%c", &chng_threshld);
if(chng_threshld == 'y'|| chng_threshld == 'Y')
       {
       printf("\nEnter the new threshold and press Enter: ");
       scanf("%f", &threshld_volts);
       }
*threshld = (threshld_volts * 2048 / 10) + 2048;  /* convert to counts */

return(99);

}

/****************************** READ_MESSAGE FUNCTION ************************/
/*
 * Read_Message()
 *
 * This function reads GPS messages.
 *
 */

unsigned char
Read_Message(message, fp_gps)
char message[];
FILE *fp_gps;

{
int msg_ptr = 0;                          /* message pointer */
time_t last_byte_in;                      /* time of last byte */
unsigned char chksum, checksum1, checksum2;  /* checksum, MS char, LS char */
unsigned char msglength;                  /* GPS message length */
```

```
gpsflag = 0;                                /* reset gpsflag */
last_byte_in = time(NULL);                  /* time when character is read */

if (gpshead != gpstail)                     /* if buffer is not empty, */
        {                                   /* read characters until LF occurs */
        do      {
                gpshead = gpshead & 0x3FF; /* resets gpshead at 0x400 */
                message[msg_ptr++] = gpsque[gpshead];
                last_byte_in = time(NULL); /* watchdog timer */
                } while(gpsque[gpshead++] != 0x0A);

        checksum1 = 0;
        checksum2 = 0;
        msglength = 0;
        Checksum(message, &checksum1, &checksum2, &msglength);
        if (checksum1 != message[++msglength])
                {
                printf("checksum1(message) does not compare\n");
                printf("gpshead: %d  gpstail: %d\n", gpshead, gpstail);
                }
        if (checksum2 != message[++msglength])
                {
                printf("checksum2(message) does not compare\n");
                printf("gpshead: %d  gpstail: %d\n", gpshead, gpstail);
                }
        message[++msglength] = '\n';        /* install LF */
        msglength++;                        /* increment msglength */
        }

else    /* if current time exceeds initial time by 3 seconds output error*/
        {
        if (difftime(time(NULL), last_byte_in) > 3)
                {
                No_Message();
                exit(0);
                }
        }

if(fwrite(message, msglength, 1, fp_gps) != 1)   /* write GPS data to file */
        {
        printf("Error writing GPS data to GPS.DAT");
        exit(1);
        }

return (99);

}

/****************************** CHECKSUM FUNCTION ******************************/
/*
 * Checksum()
 *
 * Calculates the checksum of a string by bitwise XOR'ing the bytes
 * between the '$' and the '*.'  The most significant and least
```

```
 * significant digits of checksum and the string length are returned
 * to the main program.
 *
 */

int
Checksum(char_string, chksum1, chksum2, length)
unsigned char char_string[50], *chksum1, *chksum2, *length;

{
unsigned char index = 0;
unsigned char chksum = 0;

for (index = 1; char_string[index] != '*'; index++)
       {
       chksum = chksum ^ char_string[index];
       if (index == 255)
              {
              printf("* cannot be found\n");
              return (99);
              }
       }
*length = index;                        /* message length */

*chksum1 = chksum/16;                   /* 1st digit */
*chksum2 = chksum%16;                   /* 2nd digit */
*chksum1 = *chksum1 + 0x30;             /* ASCII hex code */
if (*chksum1 > 0x39)                    /* digits A-F */
       *chksum1 = *chksum1 + 0x07;
*chksum2 = *chksum2 + 0x30;             /* ASCII hex code */
if (*chksum2 > 0x39)                    /* digits A-F */
       *chksum2 = *chksum2 + 0x07;

return (99);

}

/**************************** NO_MESSAGE FUNCTION ****************************/
/*
 * No_Message()
 *
 */

void
No_Message(void)

{
printf("\n*** *** Messages are not being received *** ***\n\n");
printf("Check cable connections and power to the receiver\n");
printf("If OK, reset the receiver by doing the following:\n");
printf("      1.  Switch off the receiver.\n");
printf("      2.  Remove DC power to the receiver.\n");
printf("      3.  Disconnect the backup battery inside the receiver.\n");
printf("      4.  Reconnect the backup battery.\n");
```

```
printf("      5.  Reapply DC power to the receiver.\n");
printf("      6.  Switch on the receiver.\n");
}

/************************** PMGLH FUNCTION ***********************************/
/*
 * PMGLH()
 *
 * Receiver status messages
 *
 */

void
PMGLH(unsigned char *gps_message)

{
printf("\n*** Receiver Status Message ***\n");

switch (gps_message[18])                /* battery */
      {
      case '0':
            printf("case 0: memory back-up battery ok\n");
            break;
      case '1':
            printf("case 1: memory back-up battery low\n");
            break;
      default:
            printf("default\n");
            break;
      }

switch (gps_message[28])                /* almanac data */
      {
      case '0':
            printf("case 0: almanac ok\n");
            break;
      case '1':
            printf("case 1: no almanac data\n");
            break;
      case '2':
            printf("case 2: almanac is old\n");
            break;
      default:
            printf("default\n");
            break;
      }

switch (gps_message[30])                /* memory */
      {
      case '0':
            printf("case 0: memory ok to use\n");
            break;
      case '1':
            printf("case 1: lost memory data, need re-init\n");
```

```
                break;
        default:
                printf("default\n");
                break;
        }

switch (gps_message[32])                /* OEM unit status */
        {
        case '0':
                printf("case 0: INI\n");
                break;
        case '1':
                printf("case 1: IDL\n");
                break;
        case '2':
                printf("case 2: STS\n");
                break;
        case '3':
                printf("case 3: ALM\n");
                break;
        case '4':
                printf("case 4: EPH\n");
                break;
        case '5':
                printf("case 5: ACQ\n");
                break;
        case '6':
                printf("case 6: POS\n");
                break;
        case '7':
                printf("case 7: NAV\n");
                break;
        default:
                printf("default\n");
                break;
        }

}

/***************************** COLLECT_NAV_DATA FUNCTION *********************/
/*
 * Collect_Nav_Data()
 *
 * This function collects navigation data (odometer, compass, rate of turn)
 * from the navigation buffers.
 *
 */

void
Collect_Nav_Data(FILE *fp_nav)

{
static struct  {                        /* NAVDATA structure */
                long odometer;
```

```
            int x_axis;
            int y_axis;
            int rate;
            }   navdata;

int i;
unsigned long xtotal,                   /* sum of x-axis readings */
            ytotal,                     /* sum of y-axis readings */
            rate_total;                 /* sum of rate readings */

navflag = 0;                            /* reset navflag */
xtotal = 0;                             /* reset xtotal */
ytotal = 0;                             /* reset ytotal */
rate_total = 0;                         /* reset rate_total */

if((second & 0x0001) == 0)              /* if seconds count is even*/
      for (i = 0; i < 1000; i++)
            {
            xtotal = xtotal + evnque[i].x_axis;
            ytotal = ytotal + evnque[i].y_axis;
            rate_total = rate_total + evnque[i].rate;
            }
else                                    /* if seconds count is odd */
      for (i = 0; i < 1000; i++)
            {
            xtotal = xtotal + oddque[i].x_axis;
            ytotal = ytotal + oddque[i].y_axis;
            rate_total = rate_total + oddque[i].rate;
            }

navdata.odometer = odmcount;
navdata.x_axis = (int)(xtotal/1000);    /*average x-axis */
navdata.y_axis = (int)(ytotal/1000);    /*average y-axis */
navdata.rate = (int)(rate_total/1000);  /* average rate of turn */

if (fwrite(&navdata, 10, 1, fp_nav) != 1)
      {
      printf("Error writing nav data to NAV.DAT");
      exit(1);
      }

}

/***************************** COLLECT_LOOP_DATA FUNCTION *********************/
/*
 * Collect_Loop_Data()
 *
 * This function collects loop data (frequency, power) from the loop buffers.
 *
 */

void
Collect_Loop_Data(FILE *fp_loop)
```

```
{
#define ODMTHRESHOLD   10                    /* odometer threshold count */

static struct {                              /* LOOPDATA structure */
             int frequency;                        /* frequency */
             int power;                      /* signal amplitude */
             }   loopdata[280];

struct {                                     /* loopheader stucture */
       float freq;                           /* frequency */
       long odmcount;                              /* odometer count */
       int loopsec;                          /* seconds */
       int index;                            /* mS */
       }   loopheader;

int i, j,                                    /* indices */
    index,                                   /* mS at loop detection */
    loopsec,                                 /* seconds at loop detection */
    freqcnt;                                 /* frequency counts */

float freqcnt_volts,                         /* frequency count (volts) */
            slope,                           /* frequency ramp slope */
            freq;                            /* frequency equivalent of slope */

j = 0;                                       /* reset buffer index */

/* The following if-then-else loop collects the first 70 mS of loop data */

if(loopind >= 70)                            /* normal case */
       {
       index = loopind - 70;
       loopsec = loopque[index].second;
       for(i = loopind - 70; i < loopind; i++, j++)
              {
              loopdata[j].frequency = loopque[i].frequency;
              loopdata[j].power = loopque[i].power;
              }
       }
else   {                                     /* loop detected near start of queue */
       index = loopind + 930;
       loopsec = loopque[index].second;
       for(i = loopind + 930; i < 1000; i++, j++)
              {
              loopdata[j].frequency = loopque[i].frequency;
              loopdata[j].power = loopque[i].power;
              }
       for(i = 0; i < loopind; i++, j++)
              {
              loopdata[j].frequency = loopque[i].frequency;
              loopdata[j].power = loopque[i].power;
              }
       }

/* The following if-then-else loop collects the next 210 mS of data */
```

```
if(loopind < 790)                          /* normal case */
        {
        while(qtail >> 3 < loopind + 210);
        for(i = loopind; i < loopind + 210; i++, j++)
                {
                loopdata[j].frequency = loopque[i].frequency;
                loopdata[j].power = loopque[i].power;
                }
        }
else    {                                  /* loop detected near end of queue */
        while(qtail >> 3 != loopind - 790);
        for(i = loopind; i < 1000; i++, j++)
                {
                loopdata[j].frequency = loopque[i].frequency;
                loopdata[j].power = loopque[i].power;
                }
        for(i = 0; i < loopind - 790; i++, j++)
                {
                loopdata[j].frequency = loopque[i].frequency;
                loopdata[j].power = loopque[i].power;
                }
        }

/*** Calculate loop frequency ***/

j = loopind + 1;                           /* reset buffer index to loopind */

if (j < 990)                               /* check for end of buffer */
        freqcnt = loopque[j + 10].frequency - loopque[j].frequency;
                                           /* frequency counts over a 10 ms period
*/
else
        freqcnt = loopque[j - 990].frequency - loopque[j].frequency;
freqcnt_volts = freqcnt * (float)(10) / 2048; /* convert cnts to volts*/
slope = freqcnt_volts * 100;/* slope of frequency ramp (10 ms period) */
freq = (525.36 * slope) - 14.7;   /* convert slope to frequency */
//printf ("Loop frequency: %.1f Hz\n", freq); /* display loop frequency */

/*** Store loop data ***/

putchar('*');                              /* print * when loop is detected */
if (odmcount > oldodmcount + ODMTHRESHOLD)  /* store only if vehicle moves */
        {
        loopheader.freq = freq;            /* loop header information */
        loopheader.odmcount = odmcount;
        loopheader.loopsec = loopsec;
        loopheader.index = index;

        if (fwrite(&loopheader, 12, 1, fp_loop) != 1)
                {
                printf ("Error writing loopheader to LOOP.DAT");
                exit (1);
                }
```

```
        if (fwrite(loopdata, 4, 280, fp_loop) != 280)
                {
                printf ("Error writing loop data to LOOP.DAT");
                exit (1);
                }
        }

oldodmcount = odmcount;                         /* update old odometer count */
loopdet = 0;                                    /* reset loop detected flag */

}

/**************************** READ_KEY FUNCTION ******************************/
/*
 * Read_Key()
 *
 * This function reads and stores keyboard inputs and stores the resulting
 * character string.  The function tags the odometer reading and the time
 * to the character string.
 *
 */

void
Read_Key(char key[], FILE *fp_key, unsigned char *key_ptr,
        unsigned char *escflag, char *tag)

{
char ch;                                        /* character */
int hr, left, min, sec, millisec;

ch = bioskey(0);                                /* read key */
putchar(ch);

if (*tag == 0)                                  /* if 1st character of landmark ... */
        {                                       /* ... time and odometer tag landmark */
        hr = second / 3600;                     /* hours */
        left = second % 3600;
        min = left / 60;                        /* minutes */
        sec = left % 60;                        /* seconds */
        millisec = qtail >> 3;                  /* milliseconds (divide qtail by 8)*/
        fprintf(fp_key, "%2d:%2d:%2d.%3d  ", hr, min, sec, millisec);
                                                /* time at landmark */
        fprintf(fp_key, "%7ld  ", odmcount);  /* odometer at landmark */
        *tag = 0xFF;                            /* set the flag */
        }

switch(ch) {
        case 0x1B:                              /* if ESC key ... */
                *escflag = 0xFF;                /* ... set ESC flag */
                break;
        case '\b':                              /* if backspace key ... */
                if(*key_ptr > 0)
                        {
                        (*key_ptr)--;           /* ... backup one space */
```

```
                putchar(' ');        /* echo a space */
                putchar('\b');
                }                    /* echo a backspace */
            break;
        case '\r':                   /* if return or enter ... */
            key[(*key_ptr)++] = 0x0A;  /* ... install LF ... */
            putchar(0x0A);           /* echo a LF */
            fwrite(key, *key_ptr, 1, fp_key);   /* ... and write to file */
            *key_ptr = 0;            /* reset the key pointer */
            *tag = 0;                /* reset the flag */
            break;
        default:                     /* otherwise, ... */
            key[(*key_ptr)++] = ch;  /* place character in buffer */

      }

}
```

```
/*************************************************************************
    CNV4NAV.C

    navigation data conversion program for the navigation project

    project:  631150
    version:  04.02
    created:  08/02/91
    revised:  03/02/93
    programmer: Greg Larson / Ed Ung
    compiler: Turbo C++ version 1.0
    linker:   Turbo C++ version 1.0

    This program converts NAV.DAT files in drive J: to formatted NAV.PRN
    files for use in Lotus 1-2-3.

    This program was compiled with a compact memory model to allow code
    to be less than 64K long and data up to 1M.  Huge allows the pointer
    to go beyond 64K.  farmalloc() allows allocation to be greater than
    64K.

*************************************************************************/

#include <stdio.h>
#include <stdlib.h>
#include <io.h>
#include <alloc.h>

#define DATFILENAME  "J:NAV.DAT"
#define NAVFILENAME  "J:NAV.PRN"
#define FileHeaderSize 12

void
main()
{                                        /* START OF MAIN */

unsigned long binlength;

static struct {
             long odometer;
             int x_axis;
             int y_axis;
             int rate;
             }   navdata;

static int todbuf[6];                    /* time and date buffer */
char datfilename[80], prnfilename[80];   /* allot space */
unsigned int huge *navbuf;               /* This line and the next */
unsigned int huge *navptr;               /* must be on separate lines */
unsigned long i;

FILE *binfile, *txtfile;

/*** Open binary file ***/
```

```
if ((binfile = fopen(DATFILENAME, "rb")) == NULL)
    {
    printf("Error opening file %s\n", DATFILENAME);
    exit (1);
    }

/*** Open text file ***/

if ((txtfile = fopen(NAVFILENAME, "w")) == NULL)
    {
    printf("Error opening %s\n", NAVFILENAME);
    exit (1);
    }

/*** File header information ***/

fread(todbuf, 2, 6, binfile);                    /* read TOD buffer */
fprintf(txtfile, "%2d:%2d:%2d    ", todbuf[3], todbuf[4], todbuf[5]);
                                                 /* hours, minutes, seconds */
fprintf(txtfile, "%2d-%2d-%2d\n\n", todbuf[1], todbuf[2], todbuf[0] - 1900);
                                                 /* month, day, year */

binlength = (filelength(fileno(binfile)) - FileHeaderSize)/2;  /* data file
length */
navbuf = (unsigned int huge *)farmalloc(binlength * sizeof(int)); /* allocate
memory block, point to first address */
fread(navbuf, 2, binlength, binfile);            /* read navigation buffer */
navptr = navbuf;                                 /* start of nav data */

/*** Initialize starting location (odometer 0) to first compass and rate reading
***/

navdata.odometer = 0;
navdata.x_axis = *(navptr + 2);
navdata.y_axis = *(navptr + 3);
navdata.rate = *(navptr + 4);

fprintf(txtfile, "%7ld, %4d, %4d, %4d\n",
    navdata.odometer, navdata.x_axis, navdata.y_axis, navdata.rate);

/*** Print formatted data to NAV.PRN ***/

for(i = 0; i < binlength/5; i++, navptr = navptr + 5)
    {
    navdata.odometer = ((long)(*(navptr + 1)) << 16) + (long)(*navptr);
    navdata.x_axis = *(navptr + 2);
    navdata.y_axis = *(navptr + 3);
    navdata.rate = *(navptr + 4);

    fprintf(txtfile, "%7ld, %4d, %4d, %4d\n",
       navdata.odometer, navdata.x_axis, navdata.y_axis, navdata.rate);
    }
```

```
free(navbuf);                          /* release allocated memory */
fclose(binfile);                       /* close binfile */
fclose(txtfile);                       /* close txtfile */

printf("Navigation conversion completed\n");

}                                                /* END OF MAIN */
```

```
/*************************************************************************
   CNV4LOOP.C

   loop data conversion program for the navigation project

   project: 631150
   version: 04.13
   created: 08/06/91
   revised: 04/27/92
   programmer: Greg Larson / Ed Ung
   compiler: Turbo C++ version 1.0
   linker:  Turbo C++ version 1.0

   This program converts LOOP.DAT files to formated LOOP____.PRN files for
   use in Lotus 1-2-3.  Each loop is stored in its own LOOP.PRN file.
   LOOPSUM.PRN is a summary of the loops collected.

*************************************************************************/

#include <stdio.h>
#include <io.h>

#define DATAFILENAME       "J:LOOP.DAT"
#define LOOPSUMMARYFILE "J:LOOPSUM.PRN"

float IntToFloat(long);                        /* function prototype */

void
main()
{                                              /* START OF MAIN */

int i, j, loopcount, FileHeaderSize;
int hour, minute, left;
int frequency, power;
int time = 1;
float second;
long binlength, freq, freqlower, frequpper;
long odometer, odmlower, odmupper;

static int todbuf[6];
static unsigned int loopbuf[566];
char datfilename[80];                          /* allot space */
char base_name[6] = "J:LOOP";
char prnfilename[16];
char loop_number[4];

FILE *binfile, *txtfile, *sumfile;

/*** Set up files ***/

if ((binfile = fopen(DATAFILENAME, "rb")) == NULL)    /* open binary file */
      {
      printf("Error opening file %s\n", DATAFILENAME);
      exit();
```

```
        }

if ((sumfile = fopen(LOOPSUMMARYFILE, "w")) == NULL) /* open loop summary file
*/
        {
        printf("Error opening file %s\n", LOOPSUMMARYFILE);
        exit();
        }

/*** File header information ***/

fread(todbuf, 2, 6, binfile);           /* read TOD buffer */

FileHeaderSize = 12;                    /* file header */
binlength = (filelength(fileno(binfile)) - FileHeaderSize)/2;  /* data file
length */
loopcount = binlength/566;              /* number of loops in the buffer */

fprintf(sumfile, "    *** LOOP SUMMARY ***\n\n"); /* header for loop summary
file */

/*** Print formatted data to LOOP.PRN ***/

for(i = 1; i <= loopcount; i++)
        {
        strcpy(prnfilename, base_name);  /* copy base name to filename */
        itoa(i, loop_number, 10);        /* convert loopcount to ASCII */
        strcat(prnfilename, loop_number); /* add loop number to filename */
        strcat(prnfilename, ".prn");     /* add extension to filename */

        if ((txtfile = fopen(prnfilename, "w")) == NULL)  /* open text file */
                {
                printf("Error opening %s\n", prnfilename);
                exit();
                }

        fread(loopbuf, 2, 566, binfile);

        fprintf(txtfile, "Date:        %2d-%2d-%2d\n", todbuf[1], todbuf[2],
todbuf[0] - 1900);
                                                /* month, day, year */
        fprintf(txtfile, "Start time:  %2d:%2d:%2d\n", todbuf[3], todbuf[4],
todbuf[5]);
                                                /* hours, minutes, seconds */

        fprintf(sumfile, "Date:        %2d-%2d-%2d\n", todbuf[1], todbuf[2],
todbuf[0] - 1900);
                                                /* month, day, year */
        fprintf(sumfile, "Start time:  %2d:%2d:%2d\n", todbuf[3], todbuf[4],
todbuf[5]);
                                                /* hours, minutes, seconds */

        fprintf(txtfile, "Loop:          %4d\n", i);  /* loop number */
```

```
        fprintf(sumfile, "Loop:        %4d\n", i);     /* loop number */

        freqlower = (long)loopbuf[0];           /* lower two bytes of freq */
        frequpper = (long)loopbuf[1] << 16; /* upper two bytes of freq */
        freq = freqlower + frequpper;           /* loop freq in hex */
        fprintf(txtfile, "Frequency:   %.1f\n", IntToFloat(freq)); /* loop
frequency */
        fprintf(sumfile, "Frequency:   %.1f\n", IntToFloat(freq)); /* loop
frequency */

        odmlower = (long)loopbuf[2];            /* lower two bytes of odometer */
        odmupper = (long)loopbuf[3] << 16;      /* upper two bytes of odometer */
        odometer = odmlower + odmupper;  /* odometer in hex */
        fprintf(txtfile, "Odometer: %7ld\n", odometer);       /* odometer */
        fprintf(sumfile, "Odometer: %7ld\n", odometer);       /* odometer */

        hour = loopbuf[4]/3600;                 /* hours */
        left = loopbuf[4]%3600;
        minute = left/60;                       /* minutes */
        second = (float)(left%60) + (float)loopbuf[5]/1000; /* seconds */
        fprintf(txtfile, "Loop detected at elapsed time %2d:%2d:%5.3f\n\n", hour,
minute, second);
        fprintf(sumfile, "Loop detected at elapsed time %2d:%2d:%5.3f\n\n", hour,
minute, second);

        for(j = 6; j < 566; j = j + 2)    /* loop data */
              {
              frequency = loopbuf[j];           /* frequency */
              power = loopbuf[j + 1];           /* power */
              fprintf(txtfile, "%3d, %4d, %4d\n", time, frequency, power);
              time++;                           /* increment ms count */
              }

        fprintf(txtfile, "\n\n");
        fclose(txtfile);                        /* close txtfile */
        time = 1;                               /* reset ms count */
        }

fclose(binfile);                                /* close binfile */
fclose(sumfile);                                /* close sumfile */

printf("Loop conversion completed\n");          /* end of job */

}                                               /* END OF MAIN */

/***************************** INTEGER-TO-FLOAT FUNCTION **********************/
/* IntToFloat()
 *
 * Converts integer input to floating point output
 *
 */

float
IntToFloat(long input)
```

```
{
float mantissa, output;
long exponent, power;

mantissa = 1.0 + (float)(input & 0x007FFFFF)/8388608;
exponent = ((input & 0x7F800000) >> 23) - 127;
for(power = 1; exponent > 0; exponent--, power = power << 1);
output = mantissa * power;              /* floating point value */
return (output);

}
```

```
/*****************************************************************************
   CNVGPS.C

   GPS data conversion program for the navigation project

   project: 631150
   version: 01.02
   created: 04/17/92
   revised: 04/27/92
   programmer:     Ed Ung
   compiler: Turbo C++ version 1.0
   linker:   Turbo C++ version 1.0

   This program converts GPS.DAT ASCII (Magellan NMEA 0183 format) files to
   formated GPS.PRN files for use with the Trimble Navigation T-Plane program
   to convert latitude and longitude coordinates to state plane coordinates.

   GPS.DAT NMEA file format is as follows:
   xx:xx:xx   xx-xx-xx
   $GPGGA,xxxxxx,xxxx.xx,N,xxxxx.xx,W,x,x,xxx,uxx,M,uxxx,M*CKRL

   GPS.PRN T-Plane file format is as follows:
   z,0402
   g,xx.xxxxxxxxx,-xxx.xxxxxxxxx,-xx.x,x.x,"station name"

*****************************************************************************
/
#include <stdio.h>
#include <io.h>
#include <math.h>

#define GPSFILENAME "J:GPS.DAT"
#define TPLANEFILENAME  "J:GPS.PRN"

void
main()
{

char buffer[100];                    /* character buffer */
char trash[20];                      /* trash buffer */
char time[7];                        /* station number */
float lat_deg;                       /* latitude degrees */
float lat_min;                       /* latitude minutes */
char lat_string[6];                  /* latitude in ASCII */
float long_deg;                      /* longitude degrees */
float long_min;                      /* longitude minutes */
char long_string[6];                 /* longitude in ASCII */
int geoid_hgt;                       /* geoidal height */
float lat_decimal_deg;               /* latitude degrees (decimal) */
float long_decimal_deg;              /* longitude degrees (decimal) */
float latitude;                      /* latitude in degrees */
float longitude;                     /* longitude in degrees */

FILE *magellanfile, *tplanefile;
```

```
/*** Open source and destination files ***/

if ((magellanfile = fopen(GPSFILENAME, "r")) == NULL)
        {
        printf("Error opening file %s\n", GPSFILENAME);
        exit(1);
        }

if ((tplanefile = fopen(TPLANEFILENAME, "w")) == NULL)
        {
        printf("Error opening file %s\n", TPLANEFILENAME);
        exit(1);
        }

if (fgets(buffer, 20, magellanfile) == NULL)
        {
        printf("Unable to read file header");
        exit(1);
        }

/*** Convert data until EOF ***/

fprintf(tplanefile, "z,0402\n"); /* file header -- Calif. zone 2 */

while (fgets(buffer, 100, magellanfile) != NULL)
        {
        sscanf(buffer, "%7s%6s%1s%2f%5s%3s%3f%5s%17s%4d%5s",
                &trash, time, &trash, &lat_deg, lat_string, &trash, &long_deg,
                long_string, &trash, &geoid_hgt, &trash);

        lat_min = atof(lat_string);       /* convert to float */
        long_min = atof(long_string); /* convert to float */

        lat_decimal_deg = lat_min/60;     /* convert minutes to degrees */
        long_decimal_deg = long_min/60;   /* convert minutes to degrees */

        latitude = lat_deg + lat_decimal_deg;  /* latitude in degrees */
        longitude = 0 - (long_deg + long_decimal_deg);  /* longitude in degrees*/

        fprintf(tplanefile, "g,%5.3f,%6.3f,0,%d,\"%s\"\n", latitude, longitude,
                geoid_hgt, time);         /* write in tplane format */

        }

fclose(magellanfile);                     /* close magellanfile */
fclose(tplanefile);                       /* close tplanefile */

printf("GPS conversion completed\n");     /* end of job */

}                                         /* END OF MAIN */
```

## Appendix E

## Computer System Configuration

E.1 System Addressing

E.2 Matrix ADC-12M Jumper Configuration and Switch Settings

E.3 Enlode 334C-1M Jumper Configuration

E.4 Caltrans Signal Conditioning Board Jumper Configuration

E.5 Ziatech ZT8809 CPU Jumper Configuration

E.6 Ziatech ZT8840 Jumper Configuration

E.7 Ziatech ZT8825 Memory Jumper Configuration

## E.1 SYSTEM ADDRESSING

8259A INTERRUPT CONTROLLER

| Function | Address |
|---|---|
| Interrupt Mask | 0021H |

8254 COUNTER

| Function | Assignment | Address |
|---|---|---|
| Counter 0 | DOS Clock | 0040H |
| Counter 1 | Odometer | 0041H |
| Counter 2 | Interrupt | 0042H |
| Control Word Register | | 0043H |

A/D CONVERTER

| Function | Address |
|---|---|
| Channel Number | 0073H |
| Data Register | 0074H |
| Status Register | 0075H |

PRINTER PORT

| Function | Address |
|---|---|
| Data Port Register (R/W) | 0378H |
| Status Port Register(R only) | 0379H |
| Control Port Register (R/W) | 037AH |

8840 MULTICHANNEL SERIAL BOARD (for GPS)

| Function | Address |
|---|---|
| Data Buffer Channel 1 | 00E0H |
| Interrupt Enable Register | 00E1H |
| Line Control Register | 00E3H |

| 8825 MEMORY BOARD | Address |
|---|---|
| | 0FE68H |

## E.2 MATRIX ADC-12M
## JUMPER CONFIGURATION AND SWITCH SETTINGS

MAPPING

J3: jumper 1 to 2 -- selects STD BUS IOEXP signal line (I/O mapping)
J4: jumper 1 to 2 -- ADC-12M responds to an STD BUS IORQ* (I/O mapping)
J5: OPEN -- selects expanded and nonexpanded mapping

ADDRESSING $XXY0

16-BIT ADDRESS ENABLE
J1: jumper 1 to 2 -- selects 16-bit addressing

HIGH ORDER ADDRESS DECODING
J2: jumper all lines, setting them to "0"
This sets $XX to $00 (address lines A8-A15)

8-BYTE BOUNDARY SELECTION
J9: jumper 2 to 3 -- sets ADC-12M to occupy addresses $XXY0 through $XXY7 and registers at $XXY3, $XXY4, and $XXY5

LOW ORDER ADDRESS DECODING
SW1: set to 7 -- sets next to the most significant nibble of the address to 7 ($XX70)

A/D DATA BYTE LOCATION OPTIONS

J15: jumper 1 to 2 & 3 to 4 -- Intel architecture: the low byte of a 16-bit data value precedes the high value

low byte at $XXY4 or $XXYC
high byte at $XXY5 or $XXYD

STATUS INDICATION MODE

J7: jumper to 1 to 2
J8: OPEN -- selects the polled mode, allowing the user to poll a status bit (data bit 15) to determine whether an A/D conversion cycle has been completed

MULTIPLEXER CONFIGURATION

J11: OPEN

J14: jumper 1 to 2, 3 to 4 -- configures ADC-12M to operate in a single-ended input mode

INPUT RANGE

J12: jumper 1 to 2 -- selects +/-10 volt input range
J13: jumper 2 to 3 -- selects bipolar input mode

A/D OUTPUT CODE FORMAT

J6: jumper 2 to 3
J10: jumper 1 to 2 -- selects offset binary code since the ADC-12M is configured for a bipolar input

0000 = -10.000 V (-FS)
0FFF = +9.9951 V (FS -1 LSB)

## E.3 ENLODE 334C-1M JUMPER CONFIGURATION

BASE PORT ADDRESS (JS1)

JS1 jumper positions correspond to address bit positions A3 through A7 of the base address. A jumper installed corresponds to a "0" bit in the address; an open position (no jumper installed) corresponds to a "1." The base address as shown in the jumper pattern below represents base address 80.

JS1 Position A7 through A3

| | | |
|---|---|---|
| A7 | - Open | (1) |
| A6 | - Jumper | (0) |
| A5 | - Jumper | (0) |
| A4 | - Jumper | (0) |
| A3 | - Jumper | (0) |

I/O PORT ADDRESS ACCESS (JS1 & JS2)

JS1 jumper position EXP and JS2 define whether the 334C-1M is accessed in the expanded or non-expanded I/O map. In the configuration shown below, the 334C-1M is to be used with a processor card which does not actively control the EXP signal.

JS1

EXP - Jumper

JS2

NONEXP - Jumper

## E.4 CALTRANS SIGNAL CONDITIONING BOARD 631150-300 JUMPER CONFIGURATION

PUSHBUTTON RESET OPTION

JMP1: OPEN -- External pushbutton not installed.
JMP2: OPEN -- System reset is disabled.

Note: If the reset feature is desired, install an external pushbutton across the JMP1 terminals and install a jumper on JMP2.

POWER MONITOR/WATCHDOG CIRCUIT ENABLE

JMP2: OPEN -- Disables system reset by the power monitor/watchdog circuit reset.

BACKUP LIGHT POLARITY

JMP3: 1 to 2 (top to center) jumpered.

Note:

Jumpering JMP3 1 to 2 (top to center) causes the program to increment odometer counts when the backup light is on.

Jumpering JMP3 2 to 3 (center to bottom) causes the program to decrement odometer counts when the backup light is on.

## E.5 ZIATECH ZT8809 CPU JUMPER CONFIGURATION

| Position | Jumper | Position | Jumper | Function |
|---|---|---|---|---|
| W1 | OUT | | | Disable AC Power Fail Detect NMI request (PNMI/) |
| W2 | IN | | | FP5/ drives IR5 |
| W3 | IN | | | FP6/ drives IR6 |
| W4A | IN | W4B | OUT | INTRQ1* STD Bus signal drives IR1 |
| W5A | OUT | W5B | IN | Timer 0 output drives IR0 |
| W6A | OUT | W6B | IN | Timer 2 output drives IR2 |
| W7A | OUT | W7B | IN | Serial port 2 (COM2) drives IR3 |
| W8A | OUT | W8B | IN | Serial port 1 (COM1) drives IR4 |
| W9A | OUT | W9B | IN | FP5/ front plane interrupt drives IR5 |
| W10A | IN | W10B | OUT | FP6/ front plane interrupt drives IR6 |
| W11A | IN | W11B | OUT | FP7/ front plane interrupt drives IR7 |
| W12 | IN | | | Tie the battery output to the time-keeper and all battery-backed RAM |
| W13A | OUT | W13B | OUT | Enables RS-422/485 drivers |
| W14 | OUT | | | RS-422/485 at COM2 |
| W15A | IN | W15B | OUT | RS-422/485 at COM2 |

| Postion | Jumper | Position | Jumper | Function |
|---|---|---|---|---|
| W16 | IN | | | RS-422/485 at COM2 |
| W17A | IN | W17B | OUT | RS-422/485 at COM2 |
| W18A* | IN | | | RS-422/485 at COM2 |
| W19 | OUT | | | RS-422/485 at COM2 |
| W20 | OUT | | | |
| W21A* | OUT | W21B | OUT | RS-422/485 at COM2 |
| W22 | OUT | | | RS-422/485 at COM2 |
| W23 | IN | | | COM1 configured DCE |
| W24 | IN | | | COM1 configured DCE |
| W25 | IN | | | COM1 configured DCE |
| W26 | IN | | | COM1 configured DCE |
| W27 | IN | | | COM1 configured DCE |
| W28 | IN | | | COM1 configured DCE |
| W29 | OUT | | | RS-422/485 at COM2 |
| W30 | OUT | | | RS-422/485 at COM2 |
| W31 | OUT | | | RS-422/485 at COM2 |
| W32 | OUT | | | RS-422/485 at COM2 |
| W33 | OUT | | | Timer 1 clock input is from J3 pin 4 |
| W34 | IN | | | Timer 2 clock input is 1.19318 MHz |
| W35A | OUT | W35B | IN | Battery back RAM & timekeeper plus sockets 7D1 & 9D1 |
| W36A | IN | W36B | OUT | No wait states inserted |
| W37 | IN | | | LED and write protect of 8k RAM controlled by AFD/ |
| W38A | IN | W38B | OUT | Battery back the RAM |

| Postion | Jumper | Position | Jumper | Function |
|---|---|---|---|---|
| | | | | in socket 3D1 |
| W39 | OUT | | | ERROR/ used at the printer |
| W44A-W40 | | | | 128k or 32k RAM in socket 3D1 |
| W41 | IN | | | 128k or 32k RAM in socket 3D1 |
| W42 | IN | | | 128k or 32k RAM in socket 3D1 |
| W43A | IN | | | 128k or 32k RAM in socket 3D1 |
| W44A | OUT | W44B | IN | 128K EPROM in socket 5D1 |
| W45A | OUT | W45B | IN | 128K EPROM in socket 5D1 |
| W46* | | | | |
| W47A | OUT | W47B | IN | On-board 8259A is single or master |
| W48 | IN | | | On-board 8259A is single or master |
| W49A | IN | W49B | OUT | 128K EPROM in socket 5D1 |
| W50A | IN | W50B | OUT | 8259A drives CPU interrupt input |
| W51 | OUT | | | 8087 NMIRQ* disabled |
| W52 | IN | | | 8087 NMIRQ* disabled |
| W53 | IN | | | AC power fail detect logic drives DCPWRDWN* on STD Bus |
| W54 | IN | | | No zSBC 337 module with 8087 present |
| W55 | IN | | | 128k RAM size for sockets 7D1 & 9D1; 8k RAM in 7D2 enabled |

| Postion | Jumper | Position | Jumper | Function |
|---|---|---|---|---|
| W56 | IN | | | 128k RAM size for sockets 7D1 & 9D1; 8k RAM in 7D2 enabled |
| W57 | OUT | | | RAM3/ROM0 @ 40000-5FFFF |
| W58 | OUT | | | ROM1 @ E0000-FFFFF |
| W59 | IN | | | 8K RAM @ DC000-DFFFF |
| W60 | IN | | | MEMEX tied to Logic Ground |
| W61 | IN | | | IOEXP tied to Logic Ground |
| W62 | OUT | | | CNTRL* not driven by the ZT 8808 |
| W63 | IN | | | Connect Logic Ground to AUX Ground |
| W64A | OUT | W64B | IN | Select Advanced write pulse for memory cycles |
| W65A | IN | W65B | OUT | Select Advanced write pulse for I/O cycles |
| W66(NONE)* | | | | |

* = Note: Jumper configuration differs from the jumper description described in the Ziatech ZT 8808 manual.

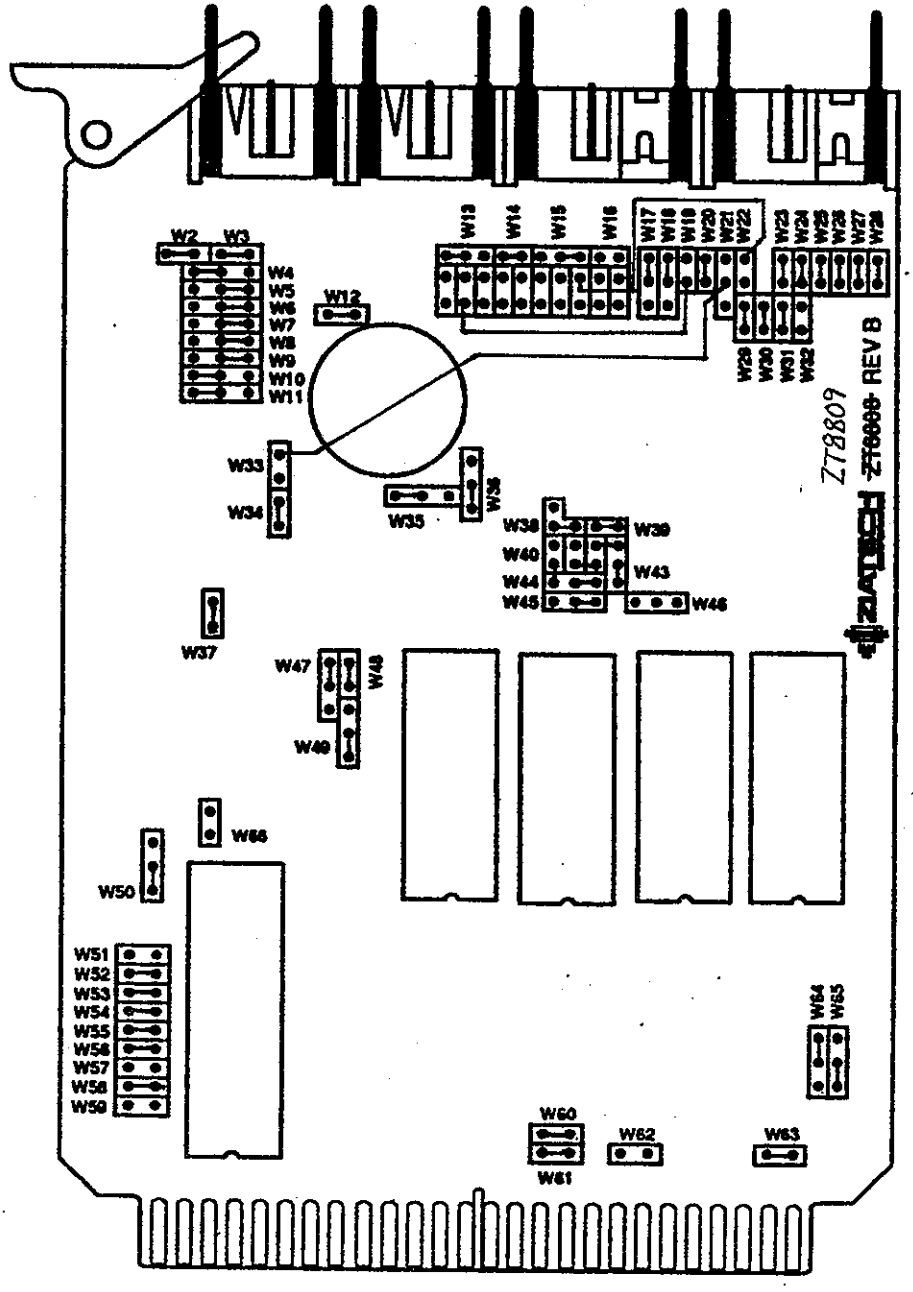



Figure E-1
Ziatech ZT8809 Jumper Configuration

## E.6 ZIATECH ZT8840
## JUMPER CONFIGURATION

| Position | Jumper | Function |
|---|---|---|
| W1 | OUT | Set base address to E0H |
| W2 | OUT | |
| W3 | OUT | |
| W4 | IN | Set wait-states to 1 wait-state |
| W5 | OUT | for 5MHz 8088 operation |
| W6 | IN | Set on-board 8259 to buffered slave |
| W7 | OUT | |
| W8 | IN | |
| W36 | IN | |
| W37 | OUT | |
| W38 | OUT | Front plane interrupt select |
| W39 | OUT | |
| W40 | OUT | |
| W41 | OUT | |
| W10 | IN | IOEXP* not selected |
| W11 | OUT | |
| W12-W35 | | Selects DCE or DTE serial config. |
| W18A,W19A | IN | Set channel 1 to DTE |
| W18B,W19B | IN | |
| W20A,W21A | IN | |
| W20B,W21B | IN | |
| W22A,W23A | IN | |
| W22B,W23B | OUT | |

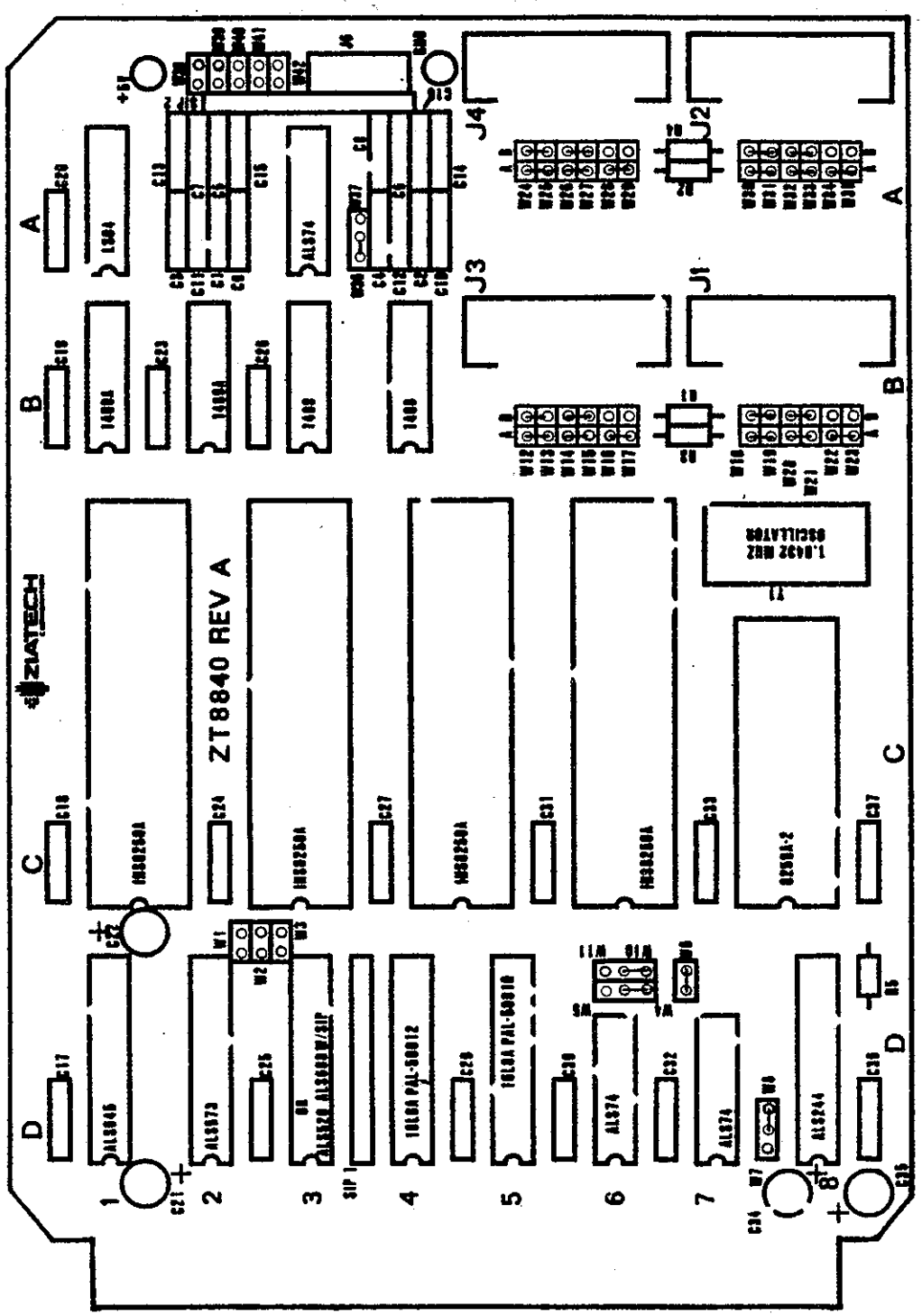



Figure E-2
Ziatech ZT8840 Jumper Configurations

## E.7 ZIATECH ZT8825 MEMORY JUMPER CONFIGURATION

| Position | Jumper | Function |
|---|---|---|
| W1 | OUT | Absolute addressing mode for the board not enabled at power-on or reset time. |
| W2-5 | OUT | 24-bit Memory Addressing mode not enabled. |
| W6 | IN | 16-bit I/O port addressing for the on-board registers enabled. |
| W7 | IN | I/O port address bit A4 set. |
| W8 | OUT | I/O port address bit A5 not set. |
| W9 | OUT | I/O port address bit A6 not set. |
| W10 | IN | I/O port address bit A7 set. |
| W11 | OUT | I/O port address bit A12 not set. |
| W12 | OUT | I/O port address bit A13 not set. |
| W13 | OUT | I/O port address bit A14 not set. |
| W14 | OUT | I/O port address bit A15 not set. |
| W15 | IN | Requires IOEXP to be low for access to registers. |
| W16 | OUT | No Wait State on all memory access. |
| W17 | OUT | Used for Ziatech test only. |
| W18 | IN | Selects battery backup mode for Row |
| W19 | OUT | B chips |
| W20 | IN | Selects battery backup mode for Row |
| W21 | OUT | A chips |
| W22 | OUT | Does not enable board to drive DCLOW when Vcc < 4.5 volts. |
| W23 | OUT | Does not enable board to drive PBRESET when Vcc < 4.5 volts. |
| J1/J2 | | Memory chip type selection |
| 2-3 | IN | 128K byte SRAM |
| 4-5 | IN | |
| 7-8 | IN | |
| 12-13 | IN | |
| 14-15 | IN | |
| SW1 | | Memory chip size selection 128K |
| 1 | OFF | |
| 2 | OFF | |
| 3 | ON | |

| | |
|---|---|
| 4 | OFF |
| 5 | OFF |
| 6 | ON |

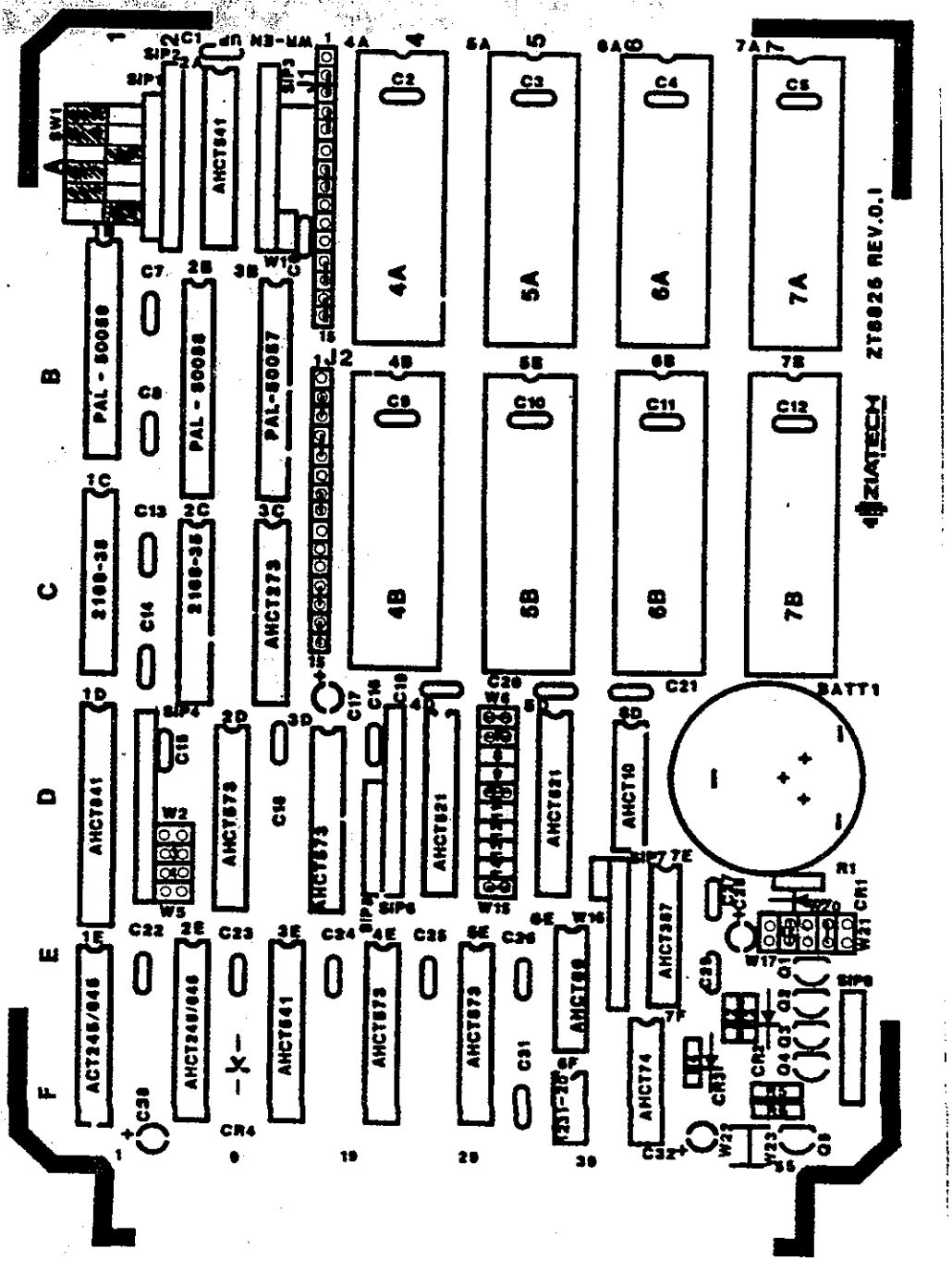



Figure E-3
Ziatech ZT8825 Jumper Configurations

## Appendix F

## Computer System Schematics

Wiring Interconnect

Cable Details

Operator Interface Interconnect

Display Interface Board

Power Supply Board

Loop Excitation Antenna

Signal Conditioning Board

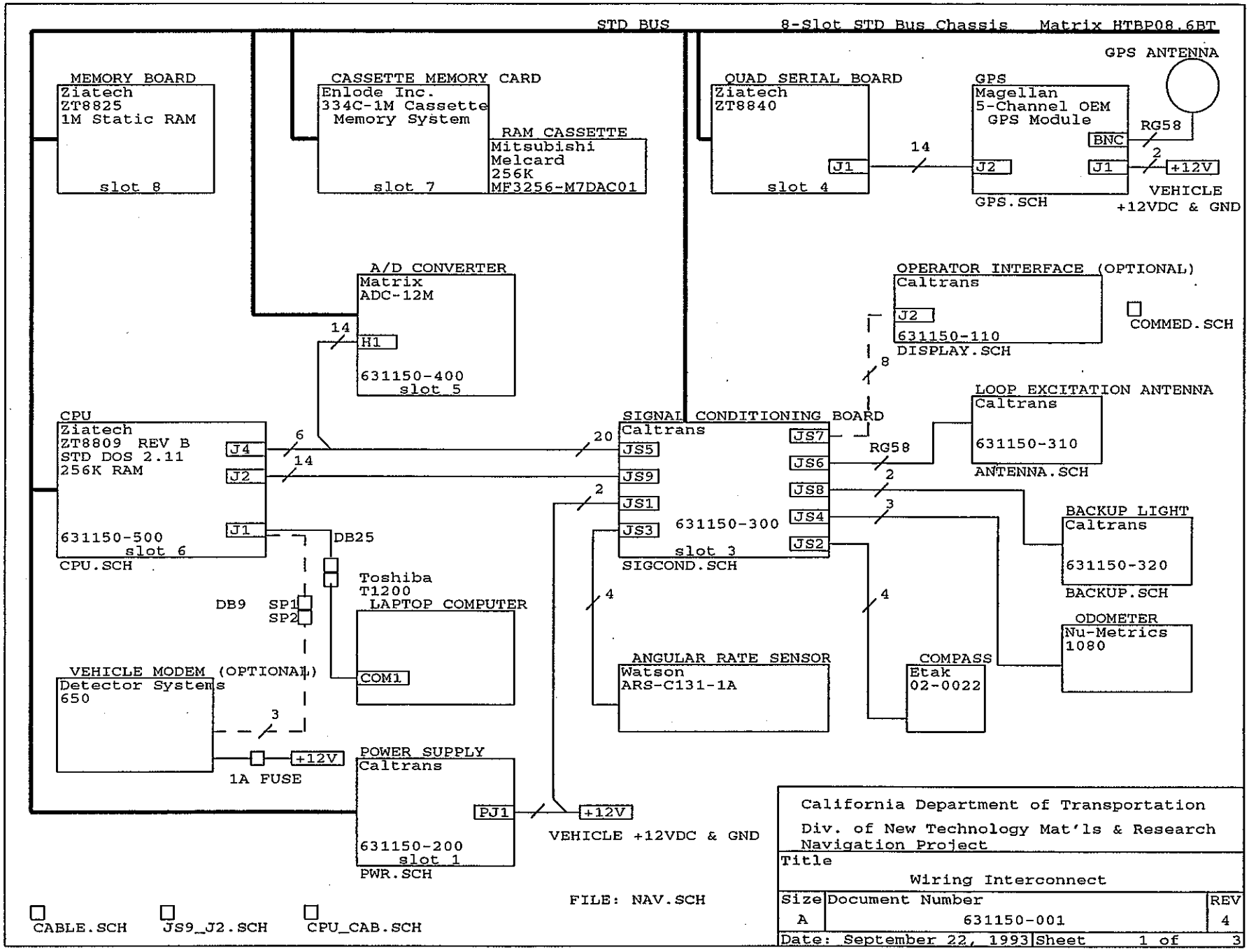
Backup Light Monitor

Signal Conditioning Board to CPU Interconnect

In-Vehicle CPU Wirewrap/Jumper Assignments

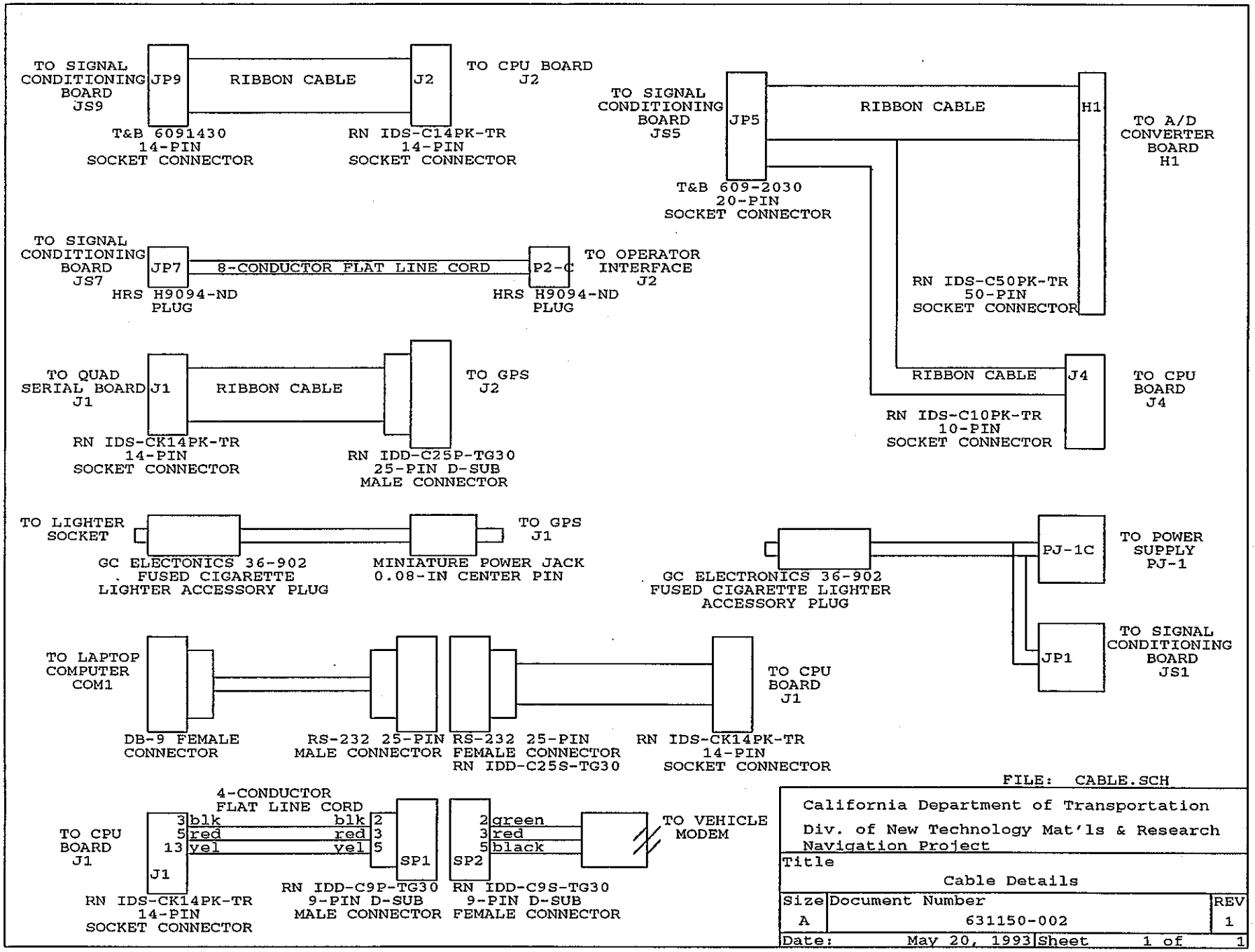
In-Cabinet CPU Wirewrap/Jumper Assignments

GPS Connections


STD BUS
8-Slot STD Bus Chassis Matrix HTBP08.6BT
MEMORY BOARD
Ziatech
ZT8825
1M Static RAM
slot 8
CASSETTE MEMORY CARD
Enlode Inc.
334C-1M Cassette
Memory System
slot 7
RAM CASSETTE
Mitsubishi
Melcard
256K
MF3256-M7DAC01
QUAD SERIAL BOARD
Ziatech
ZT8840
J1
slot 4
14
GPS
Magellan
5-Channel OEM
GPS Module
J2
BNC
J1
GPS.SCH
GPS ANTENNA
RG58
2
+12V
VEHICLE
+12VDC & GND
A/D CONVERTER
Matrix
ADC-12M
14
H1
631150-400
slot 5
OPERATOR INTERFACE (OPTIONAL)
Caltrans
J2
631150-110
DISPLAY.SCH
COMMED.SCH
8
LOOP EXCITATION ANTENNA
Caltrans
631150-310
ANTENNA.SCH
CPU
Ziatech
ZT8809 REV B
STD DOS 2.11
256K RAM
J4
J2
J1
631150-500
slot 6
CPU.SCH
6
14
20
SIGNAL CONDITIONING BOARD
Caltrans
JS5
JS9
JS1
JS3
JS7
JS6
JS8
JS4
JS2
631150-300
slot 3
SIGCOND.SCH
RG58
2
3
2
4
4
DB25
Toshiba
T1200
LAPTOP COMPUTER
COM1
DB9
SP1
SP2
BACKUP LIGHT
Caltrans
631150-320
BACKUP.SCH
ODOMETER
Nu-Metrics
1080
ANGULAR RATE SENSOR
Watson
ARS-C131-1A
COMPASS
Etak
02-0022
VEHICLE MODEM (OPTIONAL)
Detector Systems
650
3
+12V
1A FUSE
POWER SUPPLY
Caltrans
PJ1
631150-200
slot 1
PWR.SCH
+12V
VEHICLE +12VDC & GND
FILE: NAV.SCH
CABLE.SCH
JS9_J2.SCH
CPU_CAB.SCH
California Department of Transportation
Div. of New Technology Mat'ls & Research
Navigation Project
Title
Wiring Interconnect
Size
A
Document Number
631150-001
REV
4
Date: September 22, 1993
Sheet 1 of 3

| Item | Quantity | Reference | Part |
|---|---|---|---|
| 1 | 1 | STD Bus | 8-Slot STD bus chassis<br>Matrix HTBP08.6BT |
| 2 | 1 | A/D | A/D Converter<br>Matrix ADC-12M<br>Caltrans 631150-400 |
| 3 | 1 | CPU | CPU<br>Ziatech ZT8809 Rev. B |
| 4 | 1 | Card | RAM Card<br>Mitsubishi Melcard 256K<br>MF3256-M7DAC01 |
| 5 | 1 | Cassette | Cassette Memory Card<br>Enlode 334C-1M |
| 6 | 1 | GPS | GPS<br>Magellan Systems<br>5-channel OEM GPS Module<br>00-85000-000 |
| 7 | 1 | GPS Antenna | GPS Antenna<br>Magellan Systems<br>00-81000-000 |
| 8 | 1 | Modem | Vehicle Modem<br>Detector Systems 650 |
| 9 | 1 | Operator Interface | Operator Interface<br>Caltrans<br>631150-110 |
| 10 | 1 | Pwr Supply | Power Supply<br>Caltrans<br>631150-200 |
| 11 | 1 | Serial Board | Quad Serial Board<br>Ziatech ZT8840 |
| 12 | 1 | Signal Condit. | Signal Conditioning Board<br>Caltrans 631150-300 |
| 13 | 1 | Angular Rate Sensor | Angular rate sensor<br>Watson ARS-C131-1A |

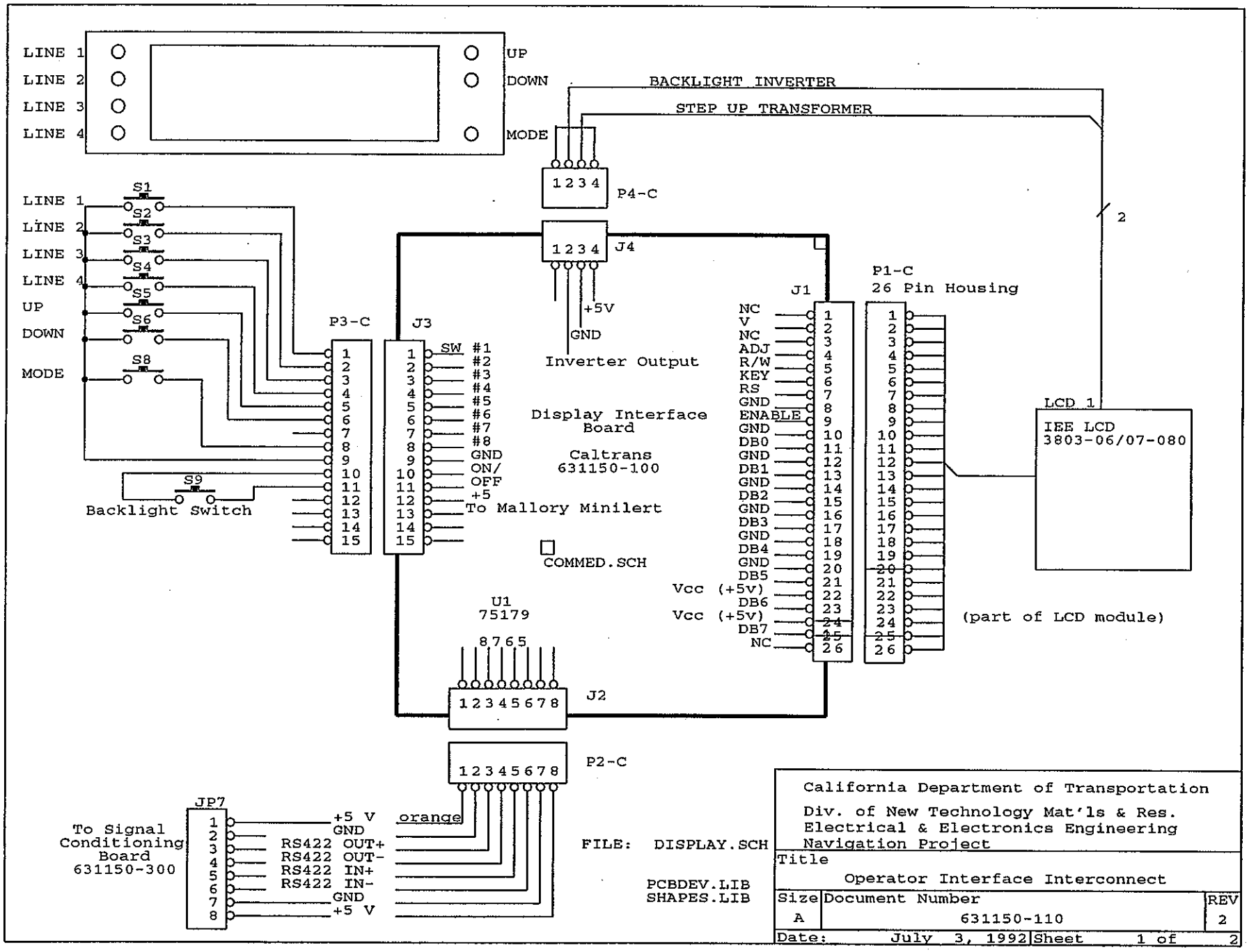
| | | | |
|---|---|---|---|
| 14 | 1 | Compass | Flux gate compass<br>Etak 02-0022 |
| 15 | 1 | Odometer | Odometer sensor<br>Numetrics 1080, Adapters |
| 16 | 1 | Backup Light | Backup Light Monitor<br>Caltrans 631150-320 |
| 17 | 1 | Loop Antenna | Loop Excitation Antenna<br>Caltrans 631150-310 |
| 18 | 1 | Laptop | Laptop computer<br>Toshiba T1200 |
| 19 | 1 | Fuse | Fuse, 1 Amp |
| 20 | 1 | | In-line fuse holder<br>Littelfuse 150145 |
| 21 | 1 | SP1 | 9-pin D-sub male connector<br>Robinson Nugent<br>IDD-C9P-TG30 |
| 22 | 1 | SP2 | 9-pin D-sub female connector<br>Robinson Nugent<br>IDD-C9S-TG30 |


TO SIGNAL CONDITIONING BOARD JS9
JP9
RIBBON CABLE
J2
TO CPU BOARD J2
T&B 6091430 14-PIN SOCKET CONNECTOR
RN IDS-C14PK-TR 14-PIN SOCKET CONNECTOR
TO SIGNAL CONDITIONING BOARD JS5
JP5
RIBBON CABLE
H1
TO A/D CONVERTER BOARD H1
T&B 609-2030 20-PIN SOCKET CONNECTOR
TO SIGNAL CONDITIONING BOARD JS7
JP7
8-CONDUCTOR FLAT LINE CORD
P2-C
TO OPERATOR INTERFACE J2
HRS H9094-ND PLUG
HRS H9094-ND PLUG
RN IDS-C50PK-TR 50-PIN SOCKET CONNECTOR
TO QUAD SERIAL BOARD J1
J1
RIBBON CABLE
TO GPS J2
RIBBON CABLE
J4
TO CPU BOARD J4
RN IDS-C10PK-TR 10-PIN SOCKET CONNECTOR
RN IDS-CK14PK-TR 14-PIN SOCKET CONNECTOR
RN IDD-C25P-TG30 25-PIN D-SUB MALE CONNECTOR
TO LIGHTER SOCKET
TO GPS J1
GC ELECTONICS 36-902 FUSED CIGARETTE LIGHTER ACCESSORY PLUG
MINIATURE POWER JACK 0.08-IN CENTER PIN
GC ELECTRONICS 36-902 FUSED CIGARETTE LIGHTER ACCESSORY PLUG
PJ-1C
TO POWER SUPPLY PJ-1
JP1
TO SIGNAL CONDITIONING BOARD JS1
TO LAPTOP COMPUTER COM1
TO CPU BOARD J1
DB-9 FEMALE CONNECTOR
RS-232 25-PIN MALE CONNECTOR
RS-232 25-PIN FEMALE CONNECTOR RN IDD-C25S-TG30
RN IDS-CK14PK-TR 14-PIN SOCKET CONNECTOR
4-CONDUCTOR FLAT LINE CORD
TO CPU BOARD J1
3 blk blk 2
5 red red 3
13 yel yel 5
J1
SP1
SP2
2 green
3 red
5 black
TO VEHICLE MODEM
RN IDS-CK14PK-TR 14-PIN SOCKET CONNECTOR
RN IDD-C9P-TG30 9-PIN D-SUB MALE CONNECTOR
RN IDD-C9S-TG30 9-PIN D-SUB FEMALE CONNECTOR
FILE: CABLE.SCH
California Department of Transportation
Div. of New Technology Mat'ls & Research
Navigation Project
Title
Cable Details
Size A
Document Number 631150-002
REV 1
Date: May 20, 1993
Sheet 1 of 1

Revised: May 13, 1993
Revision: 4
May 13, 1993 10:45:21

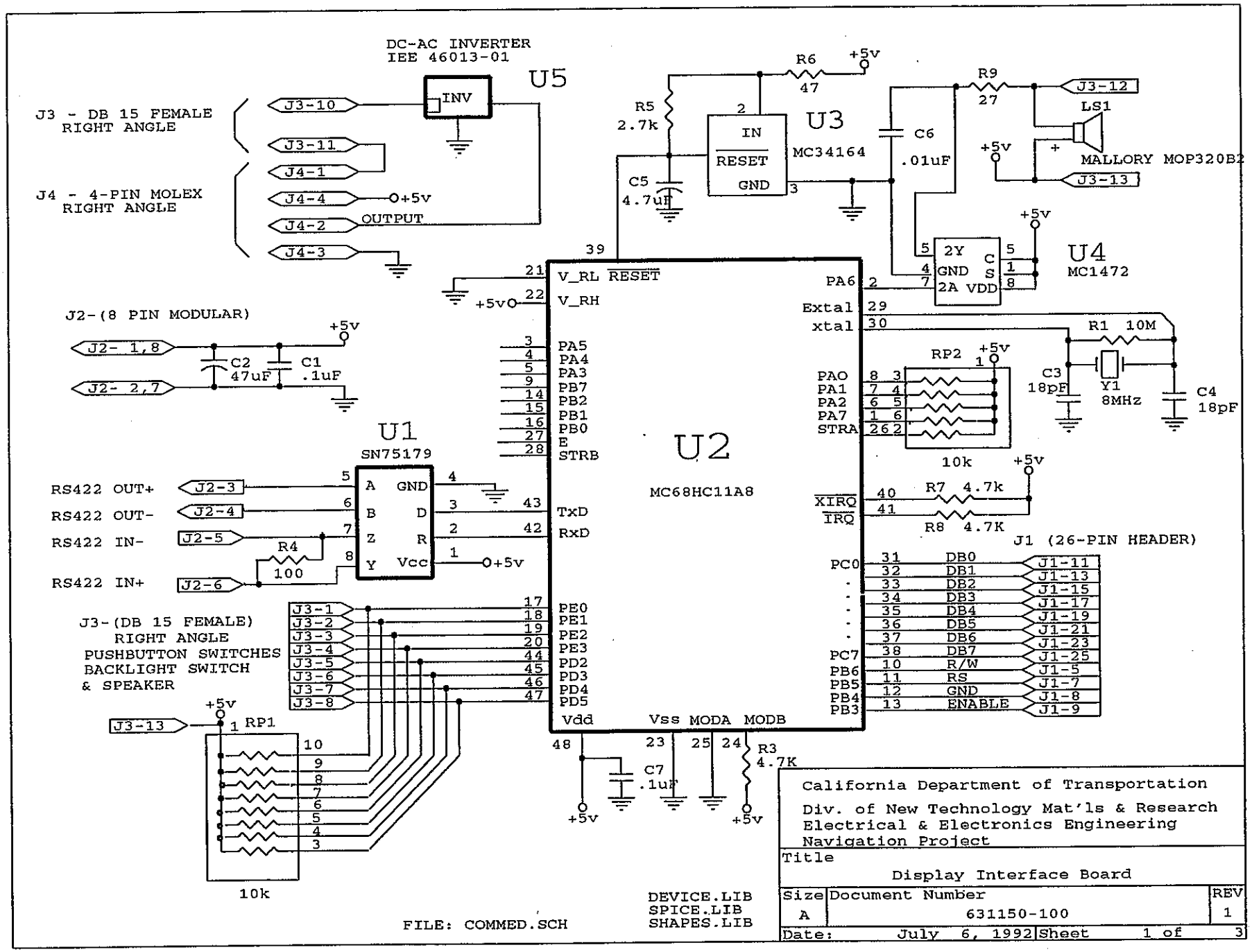
| Item | Quantity | Reference | Part |
|---|---|---|---|
| 1 | 1 | J1 (Serial Board) | Socket connector for ribbon cable Robinson Nugent IDS-CK14PK-TR |
| 2 | 1 | J2 (GPS) | 25-pin D-sub male connector IDD-C25P-TG30 |
| 3 | 1 | J1 (GPS) | Miniature power jack 2-conductor 0.08-inch diameter center pin Switchcraft 'Power Jax' 722A S-760 'Power Plug' mating plug |
| 4 | 2 | Lighter | Fused cigarette lighter accessory plug GC Electronics 36-902 |
| 5 | 1 | J1 (CPU) | Socket connector for ribbon cable Robinson Nugent IDS-CK14PK-TR |
| 6 | 1 | DB25 | 25-pin female connector Robinson Nugent IDD-C25S-TG30 |
| 7 | 1 | | DB-9 to RS-232 cable |
| 8 | 1 | J2 (CPU) | Socket connector for ribbon cable Robinson Nugent IDS-CK14PK-TR |
| 9 | 1 | JP9 (Sig. Cond.) | Socket connector for ribbon cable T&B 6091430 |
| 10 | 1 | J4 (CPU) | Socket connector for ribbon cable Robinson Nugent IDS-C10PK-TR |

| | | | |
|---|---|---|---|
| 11 | 1 | H1<br>(A/D) | Socket connector for ribbon cable<br>Robinson Nugent<br>IDS-C50PK-TR |
| 12 | 1 | JP5<br>(Sig. Cond.) | Socket connector for ribbon cable<br>Robinson Nugent<br>IDS-C20PK-TR |
| 13 | 1 | JP1<br>(Sig. Cond.) | 2-circuit plug connector<br>AMP Universal Mate-N-Lok<br>1-480698-0<br>AMP socket contacts<br>350550-1 |
| 14 | 1 | PJ-1C<br>(Pwr Supply) | 2-circuit plug connector<br>AMP Universal Mate-N-Lok<br>1-480698-0<br>AMP socket contacts<br>350550-1 |
| 15 | 1 | P2-C<br>(Oper. Inter.) | Plug, for flat line cord, 8-8<br>Hirose HRS H9094-ND |
| 16 | 1 | JP7<br>(Sig. Cond.) | Plug, for flat line cord, 8-8<br>Hirose HRS H9094-ND |
| 17 | 1 | SP1 | 9-pin D-sub male connector<br>Robinson Nugent<br>IDD-C9P-TG30 |
| 18 | 1 | SP2 | 9-pin D-sub female connector<br>Robinson Nugent<br>IDD-C9S-TG30 |


LINE 1
LINE 2
LINE 3
LINE 4
UP
DOWN
MODE
BACKLIGHT INVERTER
STEP UP TRANSFORMER
1 2 3 4
P4-C
2
S1
S2
S3
S4
S5
S6
S8
S9
Backlight Switch
P3-C
J3
SW #1
#2
#3
#4
#5
#6
#7
#8
GND
ON/ OFF
+5
To Mallory Minilert
1 2 3 4
J4
+5V
GND
Inverter Output
Display Interface Board
Caltrans 631150-100
COMMED.SCH
J1
NC
V
NC
ADJ
R/W
KEY
RS
GND
ENABLE
GND
DB0
GND
DB1
GND
DB2
GND
DB3
GND
DB4
GND
DB5
Vcc (+5v)
DB6
Vcc (+5v)
DB7
NC
P1-C
26 Pin Housing
LCD 1
IEE LCD
3803-06/07-080
(part of LCD module)
U1
75179
8 7 6 5
1 2 3 4 5 6 7 8
J2
1 2 3 4 5 6 7 8
P2-C
JP7
To Signal Conditioning Board 631150-300
+5 V
GND
RS422 OUT+
RS422 OUT-
RS422 IN+
RS422 IN-
GND
+5 V
orange
FILE: DISPLAY.SCH
PCBDEV.LIB
SHAPES.LIB
California Department of Transportation
Div. of New Technology Mat'ls & Res.
Electrical & Electronics Engineering
Navigation Project
Title
Operator Interface Interconnect
Size A
Document Number 631150-110
REV 2
Date: July 3, 1992
Sheet 1 of 2

Revised: June 28, 1991
Revision: 2
June 28, 1991 10:54:31

| Item | Quantity | Reference | Part |
|---|---|---|---|
| 1 | 1 | Display Interface | Caltrans 631150-100 |
| 2 | 1 | LCD 1 | LCD Display IEE 3803-06/07-080 |
| 3 | 1 | J1 | 26-pin double row connector Caltrans - SPC Technology FH2-602-72-T female header cut to desired length |
| 4 | 1 | J2 | PCB mounted shielded jack, 8-8 Hirose HRS H9200 |
| 5 | 1 | P2-C | Plug, for flat line cord, 8-8 Hirose HRS H9094-ND |
| 6 | 1 | J3 | DB15 right angle shielded PCB mounted connector Norwesco 315F-ND |
| 7 | 1 | P3-C | DB15, D-Sub male connector Norwesco 715M-ND Snap-in crimp socket contacts Norwesco 82S-ND |
| 8 | 1 | J4 | 4-pin right angle header Waldom 22-05-3041 |
| 9 | 1 | P4-C | 4-pin, .100 center crimp terminal housing Waldom 22-01-3037 |
| 10 | 7 | S1,S2,S3,S4, S5,S6,S8 | SPST N.O. pushbutton switch Digi-Key 150C |
| 11 | 1 | S9 | Pushbutton switch, push on - push off Digi-Key 501PB |


DC-AC INVERTER
IEE 46013-01
U5
INV
J3 - DB 15 FEMALE
RIGHT ANGLE
J3-10
J3-11
J4-1
J4-4
+5v
J4-2
OUTPUT
J4-3
J4 - 4-PIN MOLEX
RIGHT ANGLE
R6
47
+5v
R5
2.7k
C5
4.7uF
U3
MC34164
IN
RESET
GND
C6
.01uF
R9
27
J3-12
LS1
MALLORY MOP320B2
J3-13
U4
MC1472
2Y
GND
2A
C
S
VDD
J2-(8 PIN MODULAR)
J2- 1,8
J2- 2,7
C2
47uF
C1
.1uF
U1
SN75179
A
B
Z
Y
GND
D
R
Vcc
RS422 OUT+
RS422 OUT-
RS422 IN-
RS422 IN+
J2-3
J2-4
J2-5
J2-6
R4
100
U2
MC68HC11A8
V_RL
RESET
V_RH
PA5
PA4
PA3
PB7
PB2
PB1
PB0
E
STRB
TxD
RxD
PE0
PE1
PE2
PE3
PD2
PD3
PD4
PD5
Vdd
Vss
MODA
MODB
PA6
Extal
xtal
PAO
PA1
PA2
PA7
STRA
RP2
10k
XIRQ
IRQ
R7 4.7k
R8 4.7K
R1 10M
C3
18pF
Y1
8MHz
C4
18pF
J1 (26-PIN HEADER)
PC0
PC7
PB6
PB5
PB4
PB3
DB0
DB1
DB2
DB3
DB4
DB5
DB6
DB7
R/W
RS
GND
ENABLE
J1-11
J1-13
J1-15
J1-17
J1-19
J1-21
J1-23
J1-25
J1-5
J1-7
J1-8
J1-9
J3-(DB 15 FEMALE)
RIGHT ANGLE
PUSHBUTTON SWITCHES
BACKLIGHT SWITCH
& SPEAKER
J3-1
J3-2
J3-3
J3-4
J3-5
J3-6
J3-7
J3-8
J3-13
RP1
10k
C7
.1uF
R3
4.7K
DEVICE.LIB
SPICE.LIB
SHAPES.LIB
FILE: COMMED.SCH
California Department of Transportation
Div. of New Technology Mat'ls & Research
Electrical & Electronics Engineering
Navigation Project
Title
Display Interface Board
Size
A
Document Number
631150-100
REV
1
Date: July 6, 1992
Sheet 1 of 3

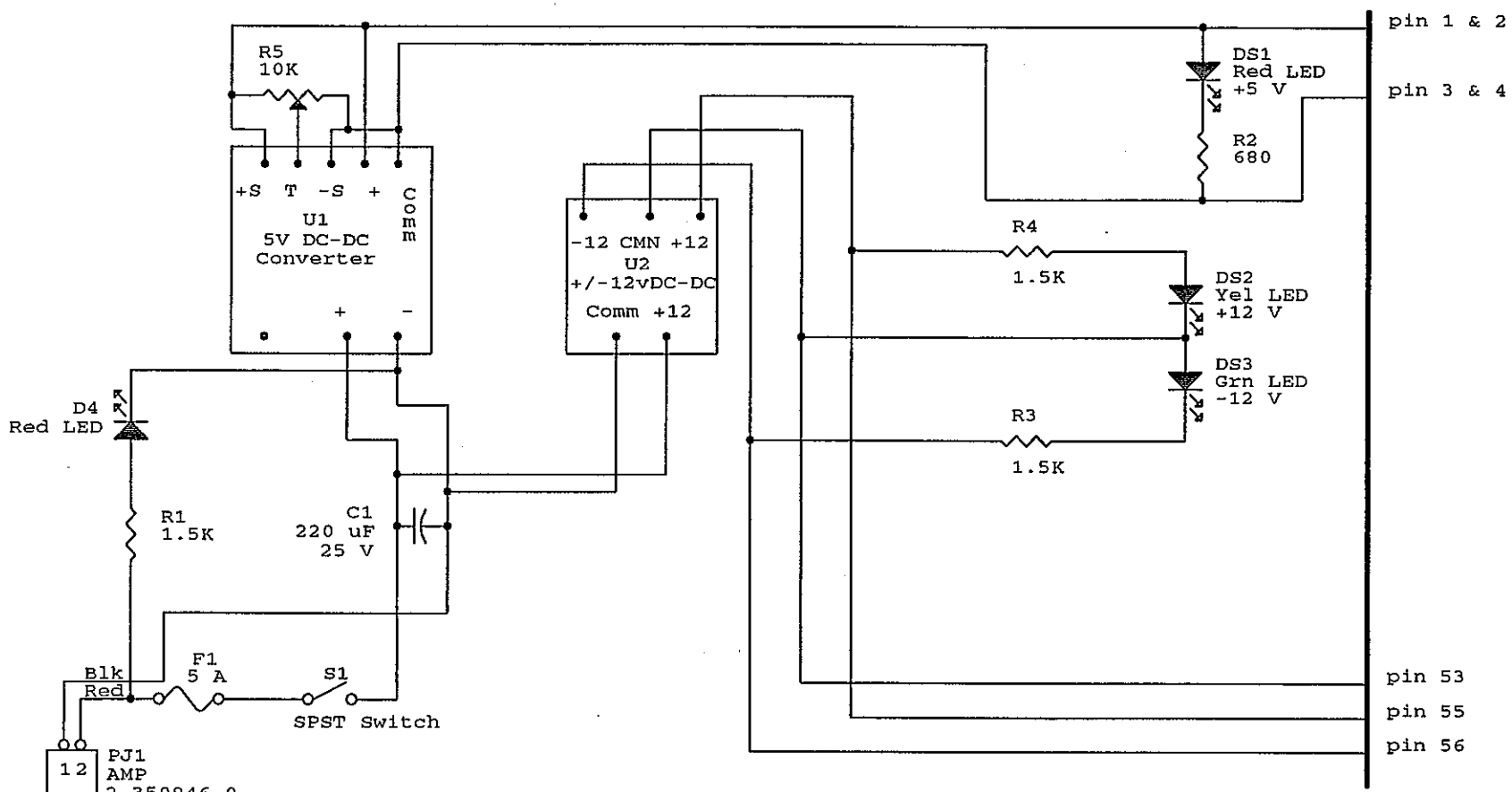
Display Interface Board
631150-100
Bill Of Materials
Page 1

Revised: June 28, 1991
Revision: 1
June 28, 1991 9:46:21

| Item | Quantity | Reference | Part |
|---|---|---|---|
| 1 | 2 | C1, C7 | Capacitor, ceramic disk, 0.1 uF 25 V |
| 2 | 1 | C2 | Capacitor, tantalum, 47 uF, 10 V |
| 3 | 2 | C3, C4 | Capacitor, ceramic disk, 18 pF, 100 V |
| 4 | 1 | C5 | Capacitor, tantalum, 4.7 uF, 10 V |
| 5 | 1 | C6 | Capacitor, monolythic ceramic, 0.01 uF, 50V |
| 6 | 1 | Y1 | Microprocessor crystal, 8 MHz NYMPH NMP080 |
| 7 | 1 | R1 | Resistor, 10M ohm, 1/4 W carbon film, 5% |
| 8 | 3 | R3, R7, R8 | Resistor, 4.7k ohm, 1/4 W carbon film, 5% |
| 9 | 1 | R4 | Resistor, 100 ohm, 1/4 W carbon film, 5% |
| 10 | 1 | R5 | Resistor, 2.7k ohm, 1/4 W carbon film, 5% |
| 11 | 1 | R6 | Resistor, 47 ohm, 1/4 W carbon film, 5% |
| 12 | 1 | R9 | Resistor, 27 ohm, 1/4 W carbon film, 5% |
| 13 | 2 | RP1, RP2 | Resistor Network, SIP, 10k ohm, 2% Panasonic EXB-F10E103G |
| 14 | 1 | U1 | RS-422 Differential Driver & Receiver Pair Texas Instruments SN75179 |
| 15 | 1 | U2 | 8-bit Microcomputer Motorola MC68HC11AB |
| 16 | 1 | U3 | Undervoltage Sensing Circuit |

| | | | |
|---|---|---|---|
| | | | Motorola MC34164 |
| 17 | 1 | U4 | Dual Peripheral-High-Voltage Positive NAND Driver<br>Motorola MC1472 |
| 18 | 1 | U5 | DC-AC Inverter<br>IEE 46013-01 |
| 19 | 1 | LS1 | Minilert Audible Signal<br>Mallory MCP320B2 |
| 20 | 1 | J1 | 26-pin double row connector<br>Caltrans - SPC Technology<br>FH2-602-72-T female header cut to desired length |
| 21 | 1 | J2 | PCB mounted shielded jack, 8-8<br>Hirose HRS H9200 |
| 22 | 1 | J3 | DB15 right angle shielded PCB mounted connector<br>Norwesco 315F-ND |
| 23 | 1 | J4 | 4-pin right angle header<br>Waldom 22-05-3041 |
| 24 | 1 | | IC socket, 48-pin DIP<br>Robinson Nugent ICA486STG |
| 25 | 2 | | Mounting screw, 6-32 x 3/8 |
| 26 | 2 | | Nuts, 6-32 |
| 27 | 2 | | Internal lock washer, #6 |
| 28 | 1 | | Nylon tie |
| 29 | 1 | | Double stick tape (foam) |

| Rev | Description | Appd | Drwn |
|---|---|---|---|
| 1 | Final | | PMH |




FILE: PWR.SCH

DEVICE.LIB
SPICE.LIB
SHAPES.LIB

California Department of Transportation
Div. of New Technology Mat'ls & Research
Electrical & Electronics Engineering
Navigation Project

Title
Power Supply Board

| Size | Document Number | REV |
|---|---|---|
| A | 631150-200 | 1 |

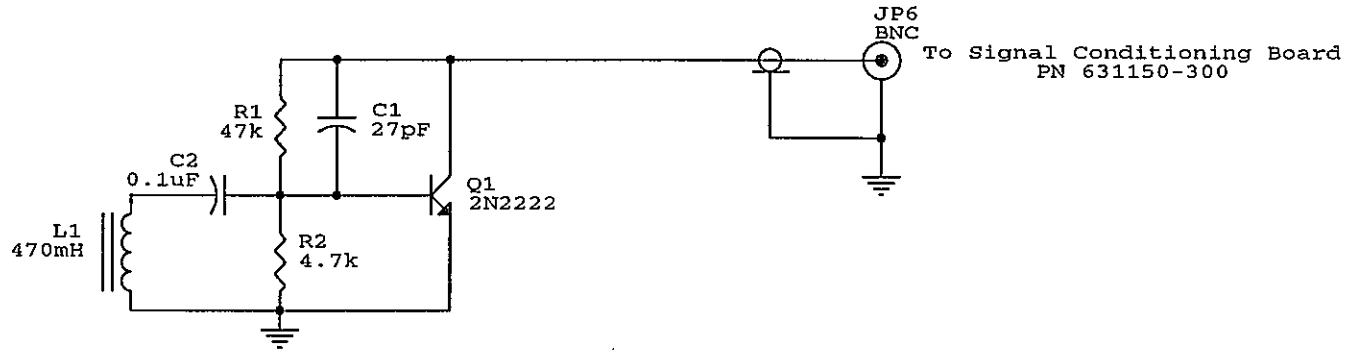
Date: September 24, 1993 Sheet 1 of 3

Power Supply Board
631150-200
Bill Of Materials

Revised: March 13, 1991
Revision: 1
March 13, 1991 10:13:30

| Item | Quantity | Reference | Part |
|---|---|---|---|
| 1 | 1 | C1 | Capacitor, axial, aluminum electolytic, 220 uF, 25 V<br>Panasonic NHE ECE-B1EGE221 |
| 2 | 1 | DS1 | Red LED, T-1 3/4<br>Chicago Miniature Lamp CMI01R<br>White marking--Caltrans reversed |
| 3 | 1 | DS2 | Yellow LED, T-1 3/4<br>Chicago Miniature Lamp CMI01Y |
| 4 | 1 | DS3 | Green LED, T-1 3/4<br>Chicago Miniature Lamp CMI01G |
| 5 | 1 | DS4 | Red LED, T-1 3/4<br>Chicago Miniature Lamp CMI01R |
| 6 | 1 | F1 | Fuse, 5 A<br>Littelfuse 273005 |
| 7 | 1 | | Fuseholder<br>Littelfuse 281005 |
| 8 | 1 | PJ1-C | 2-circuit plug connector<br>AMP Universal Mate-N-Lok<br>1-480698-0<br>AMP socket contacts<br>350550-1 |
| 9 | 1 | PJ1 | 2-circuit right angle pin header<br>AMP 2-350946-0 |
| 10 | 1 | R1 | Resistor, 1.5k ohm, 1/4 W carbon film, 5% |
| 11 | 1 | R3 | Resistor, 1.5k ohm, 1/4 W carbon film, 5% |
| 12 | 1 | R4 | Resistor, 1.5k ohm, 1/4 W carbon film, 5% |
| 13 | 1 | R2 | Resistor, 680 ohm, 1/4 W carbon film, 5% |
| 14 | 1 | R5 | Potentiometer, 10k ohm, 15 turn 3/4" cermet<br>Panasonic EVM-C7GA01B14 |

| | | | |
|---|---|---|---|
| 15 | 1 | S1 | Toggle switch, SPDT<br>Alco AKO MTM-106D-RA |
| 16 | 1 | U1 | 5 V DC-DC converter<br>Calex 12S5.5000 |
| 17 | 1 | U2 | +/- 12 V DC-DC converter<br>Calex 12D12.250 |
| 18 | 1 | | Ejector<br>Scanbe S-202 |
| 19 | 2 | | Mounting screw, 6-32 x 3/8 |
| 20 | 2 | | Nuts, 6-32 |
| 21 | 2 | | Internal lockwasher, #6 |




FILE: ANTENNA.SCH

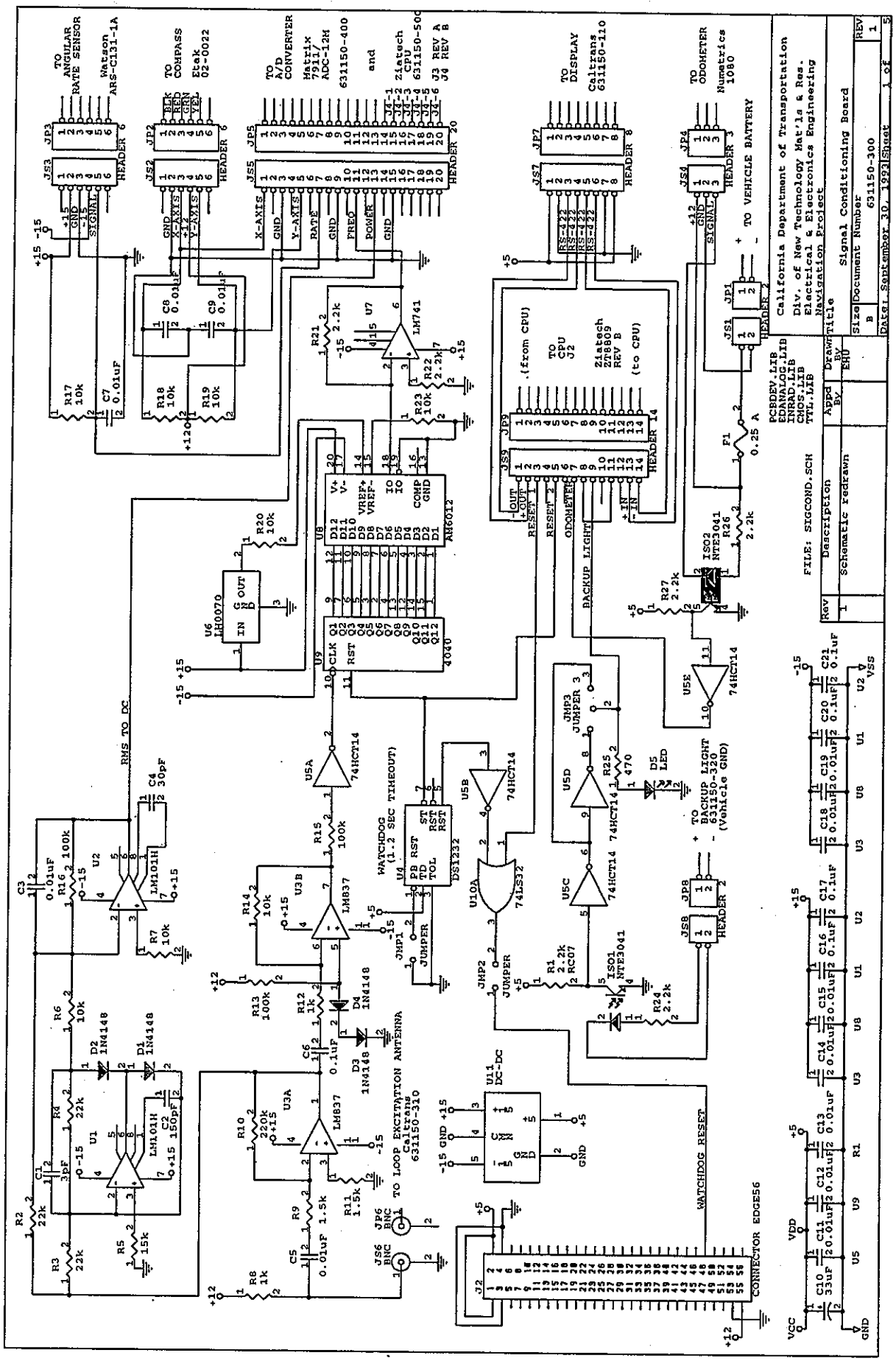
SPICE.LIB
DEVICE.LIB

| | | |
|---|---|---|
| California Department of Transportation<br>Div. of New Technology Mat'ls & Research<br>Electrical & Electronics Engineering<br>Navigation Project | | |
| Title<br>Loop Excitation Antenna | | |
| Size<br>A | Document Number<br>631150-310 | REV<br>0 |
| Date: May 21, 1993 | Sheet 1 of 2 | |

Loop Excitation Antenna
631150-310
Bill Of Materials
Page 1

Revised: July 1, 1991
Revision: 0
July 1, 1991 15:46:19

| Item | Quantity | Reference | Part |
|---|---|---|---|
| 1 | 1 | C1 | Capacitor, ceramic disc, 27pF |
| 2 | 1 | C2 | Capacitor, 0.1uF |
| 3 | 1 | L1 | RF choke, 470 mH<br>J. W. Miller 70F471AF |
| 4 | 1 | Q1 | Transistor, NPN, 2N2222 |
| 5 | 1 | R1 | Resistor, 47k ohm, 1/4 W carbon film, 5% |
| 6 | 1 | R2 | Resistor, 4.7k ohm, 1/4 W carbon film, 5% |
| 7 | 1 | | 50 ohm coax cable, RG-58A/U<br>Belden 8219 |
| 8 | 1 | JP6 | BNC connector plug, RG-58<br>Amp 331350 |
| 9 | 1 | | Nylon tie |



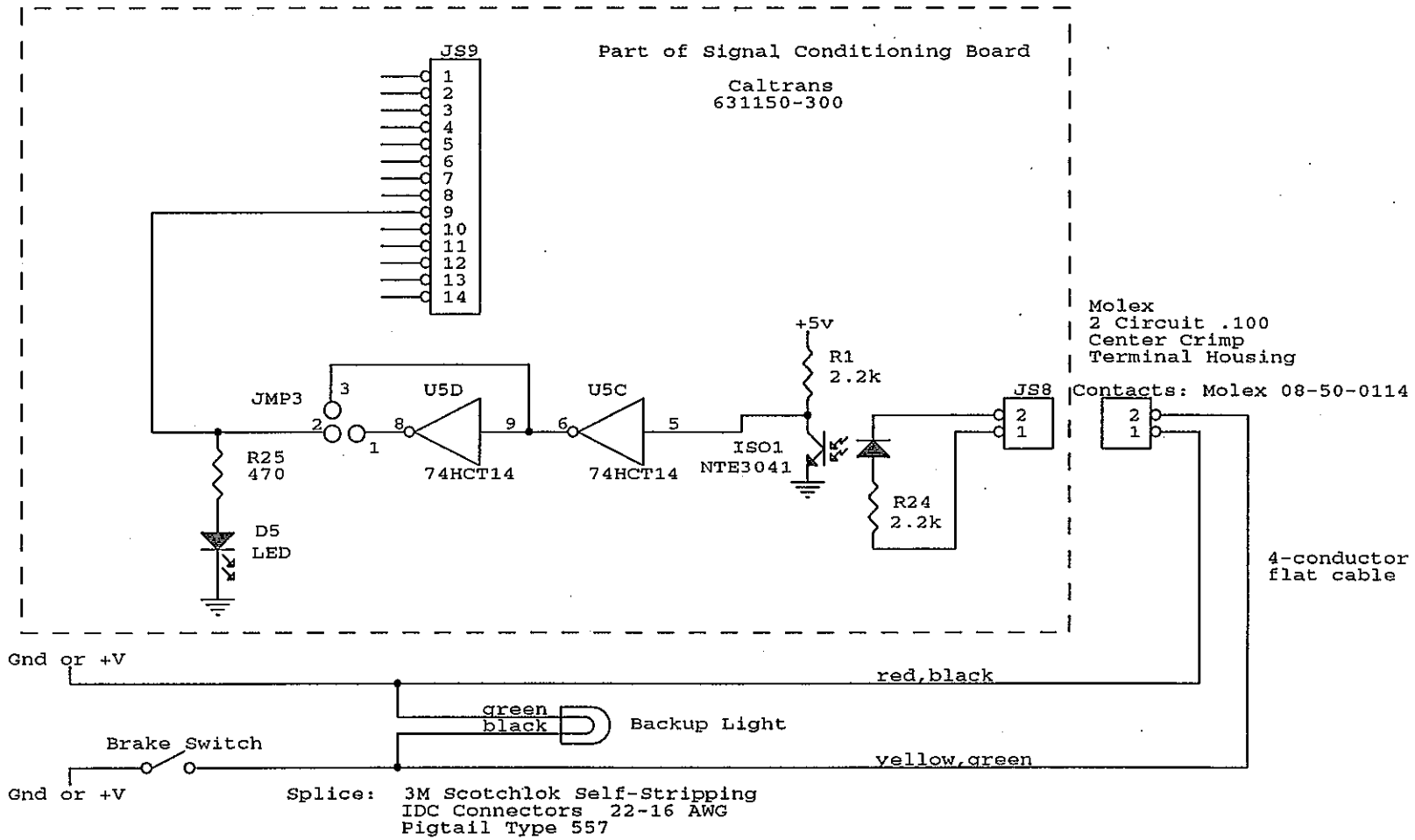
California Department of Transportation
Div. of New Technology Mat'ls & Res.
Electrical & Electronics Engineering
Navigation Project
Title
Signal Conditioning Board
Size
B
Document Number
631150-300
REV
1
Date: September 30, 1993
Sheet 1 of 5
Drawn By
EHU
Appd By
Rev
Description
1
Schematic redrawn
FILE: SIGCOND.SCH
PCBDEV.LIB
EDANA.LIB
INRAD.LIB
CMOS.LIB
TTL.LIB
TO ANGULAR RATE SENSOR
Watson ARS-C131-1A
TO COMPASS
Etak 02-0022
TO A/D CONVERTER
Matrix 7911/ ADC-12M
631150-400
and
Zlatech CPU
631150-500
J3 REV A
J4 REV B
TO DISPLAY
Caltrans 631150-110
TO ODOMETER
Numetrics 1080
TO VEHICLE BATTERY
TO CPU J2
Zlatech ZT8809 REV B
(from CPU)
(to CPU)
TO BACKUP LIGHT 631150-320 (Vehicle GND)
TO LOOP EXCITATION ANTENNA
Caltrans 631150-310
WATCHDOG (1.2 SEC TIMEOUT)
WATCHDOG RESET
CONNECTOR EDGE56
RMS TO DC

| Item | Quantity | Reference | Part |
|---|---|---|---|
| 1 | 1 | C1 | Capacitor, ceramic disk, 3 pF |
| 2 | 1 | C2 | Capacitor, ceramic disk, 150pF |
| 3 | 12 | C3,C5,C7,C8, C9,C11,C12, C13,C14,C15, C18,C19 | Capacitor, monolytic ceramic, 0.01 uF, 50 V |
| 4 | 1 | C4 | Capacitor, 30 pF |
| 5 | 5 | C6,C16,C17, C20,C21 | Capacitor, monolytic ceramic, 0.1 uF, 50 V |
| 6 | 1 | C10 | Capacitor, tantalum, 10uF, 10V |
| 7 | 4 | D1,D2,D3,D4 | Diode, 1N4148 |
| 8 | 1 | D5 | Yellow LED, T-1 3/4<br>Chicago Miniature Lamp CMI01Y |
| 9 | 1 | F1 | Fuse, 0.25 AMP<br>Littelfuse 273.250 |
| 10 | 1 | | Fuseholder<br>Littelfuse 281005 |
| 11 | 2 | ISO1,ISO2 | Optoisolators<br>NTE NTE3041 |
| 12 | 1 | JS6 | BNC receptacle, right angle PCB mount<br>AMP 226978-1 |
| 13 | 1 | JP6 | BNC plug<br>AMP 331350 |
| 14 | 2 | JMP1,JMP2 | Straight single row male header. .100 spacing, .235 post height.<br>3M 929834-01-36 or equal.<br>Break to correct length - 2 posts |
| 15 | 2 | | Programming jumper<br>3M 46F4439 or equal. |

| | | | |
|---|---|---|---|
| 16 | 1 | JMP3 | Straight single row male header. .100 spacing, .235 post height.<br>3M 929834-01-36 or equal.<br>Break to correct length - 3 posts |
| 17 | 1 | | Programming jumper<br>3M 46F4439 or equal. |
| 18 | 1 | JS1 | 2-circuit right angle pin header<br>AMP 2-350946-0 |
| 19 | 1 | JP1 | 2-circuit plug connector<br>AMP Universal Mate-N-Lok<br>1-480698-0<br>AMP socket contacts<br>350550-1 |
| 20 | 1 | JS2 | "TM" modular connector, 6-4<br>Hirose HRS H9082-ND |
| 21 | 1 | JP2 | Plug, for flat line cord, 6-4<br>Hirose HRS H9092-ND |
| 22 | 1 | JS3 | 6-circuit right angle friction lock header, .100 center<br>Molex 22-05-3061 |
| 23 | 1 | JP3 | 6- circuit terminal housing<br>Molex 22-01-3067<br>Crimp terminals<br>Molex 08-50-0114 |
| 24 | 1 | JS4 | 3-circuit right angle friction lock header, .156 center<br>Molex 26-48-1036 |
| 25 | 1 | JP4 | 3-circuit terminal housing<br>Molex 09-50-3031<br>Crimp terminals<br>Molex 08-50-0106 |
| 26 | 1 | JS5 | 20-pin right angle header<br>T & B 500-2007E |
| 27 | 1 | JP5 | 20-pin ribbon cable socket connector<br>T & B 609-2030 |
| 28 | 1 | JS7 | PCB mounted shielded jack, 8-8<br>Hirose HRS H9200 |

| | | | |
|---|---|---|---|
| 29 | 1 | JP7 | Plug, for flat line cord, 8-8<br>Hirose HRS H9094-ND |
| 30 | 1 | JS8 | 2-circuit right angle friction lock header, .100 center<br>Molex 22-05-3021 |
| 31 | 1 | JP8 | 2-circuit terminal housing<br>Molex 22-01-3027<br>Crimp terminals<br>Molex 08-50-0114 |
| 32 | 1 | JS9 | 14-pin right angle header<br>T & B 500-1407E |
| 33 | 1 | JP9 | 14-pin ribbon cable socket connector<br>T & B 609-1430 |
| 34 | 6 | R1,R21,R22, R24,R26,R27 | Resistor, 2.2k ohm, 1/4 W carbon film, 5% |
| 35 | 3 | R2,R3,R4 | Resistor, 22k ohm, 1/4 W carbon film, 5% |
| 36 | 1 | R5 | Resistor, 15k ohm, 1/4 W carbon film, 5% |
| 37 | 8 | R6,R7,R14, R17,R18,R19, R20,R23 | Resistor, 10k ohm, 1/4 W carbon film, 5% |
| 38 | 2 | R8,R12 | Resistor, 1k ohm, 1/4 W carbon film, 5% |
| 39 | 2 | R9,R11 | Resistor, 1.5k ohm, 1/4 W carbon film, 5% |
| 40 | 1 | R10 | Resistor, 220k ohm, 1/4 W carbon film, 5% |
| 41 | 3 | R13,R15,R16 | Resistor, 100k ohm, 1/4 W carbon film, 5% |
| 42 | 1 | R25 | Resistor, 470 ohm, 1/4 W carbon film, 5% |
| 43 | 2 | U1,U2 | Operational Amplifier<br>Motorola LM101H or LM201AN |
| 44 | 1 | U3 | Low Noise Quad Op Amp<br>National Semi. LM837 |

| | | | |
|---|---|---|---|
| 45 | 1 | U4 | Micromonitor (watchdog)<br>Dallas DS1232 |
| 46 | 1 | U5 | Hex inverting Schmitt trigger<br>CD74HCT14 |
| 47 | 1 | U6 | BCD buffered voltage reference<br>National Semi. LH0070 |
| 48 | 1 | U7 | Operational Amplifier<br>Motorola LM741 |
| 49 | 1 | U8 | 12-bit D/A converter<br>Signetics AM6012 |
| 50 | 1 | U9 | 12-stage ripple counter<br>Harris CD4040 |
| 51 | 1 | U10 | Quad 2-input OR gate<br>Samsung 74HCTLS32 |
| 52 | 1 | U11 | +/- 15 V DC-DC converter<br>Calex 5D15.150 |
| 53 | 1 | | Ejector<br>Scanbe S-202 |
| 54 | 4 | | Mounting screw, 6-32 x 3/8 |
| 55 | 4 | | Nuts, 6-32 |
| 56 | 4 | | Internal lockwasher, #6 |




| Vehicle In Reverse LED Lit? | Vehicle Out of Reverse LED Lit? | Action |
|---|---|---|
| N | Y | S/W Jumper to 2 |
| N | N | None |

FILE: BACKUP.SCH

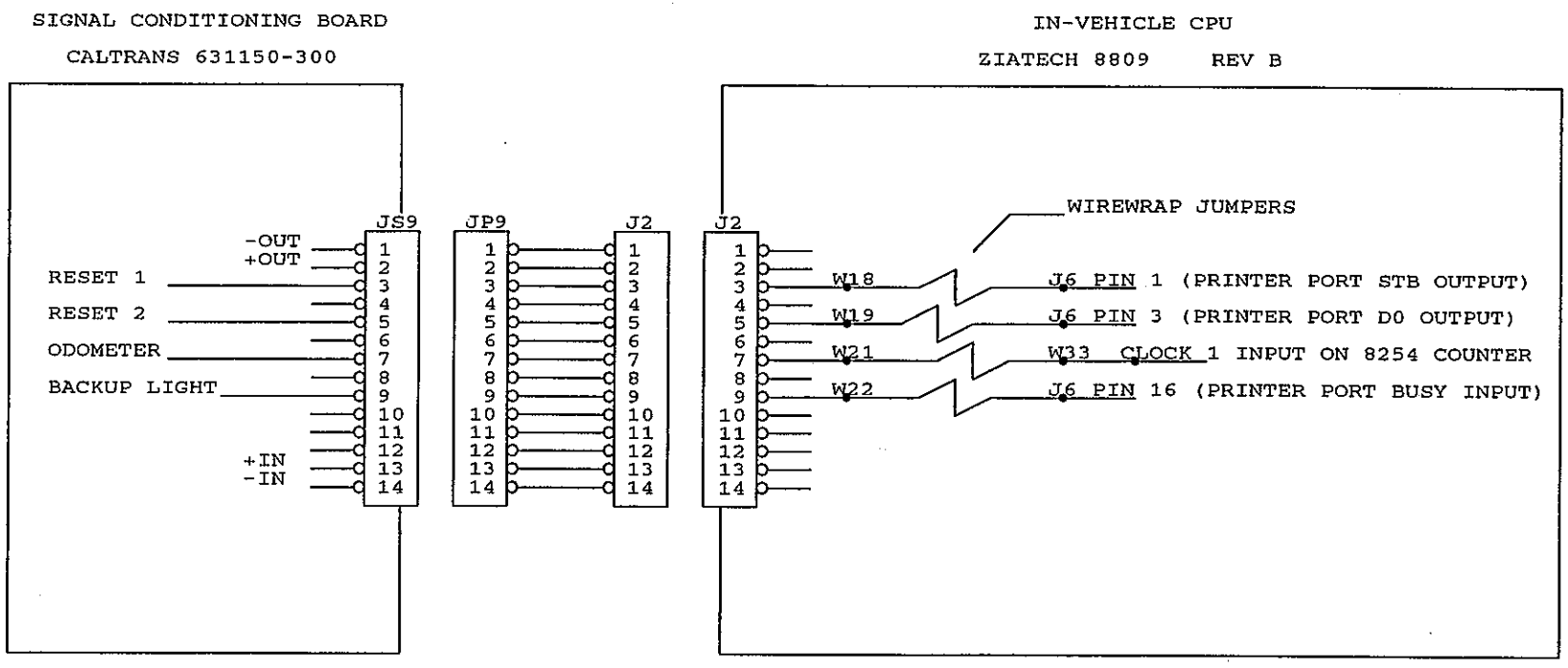
TTL.LIB
DEVICE.LIB
SHAPES.LIB
SPICE.LIB

California Department of Transportation
Div. of New Technology Mat'ls & Research
Electrical & Electronics Engineering
Navigation Project

Title: Backup Light Monitor

| Size | Document Number | REV |
|---|---|---|
| A | 631150-320 | 0 |

Date: October 7, 1993 | Sheet 1 of 1



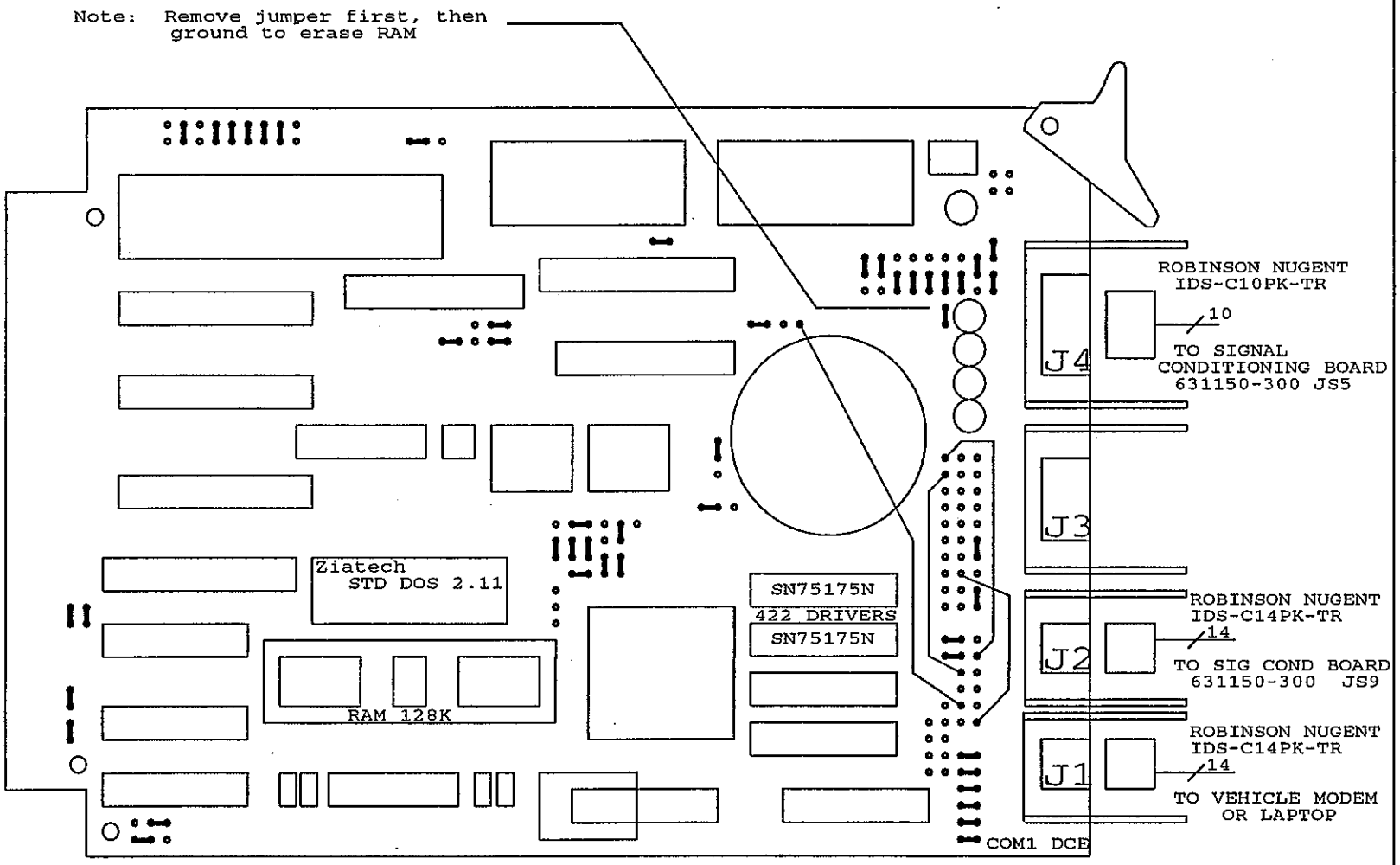

FILE:JS9_J2.SCH PCBDEV.LIB

California Department of Transportation
Div. of New Technology Mat's & Res.
Electrical & Electronics Engineering
Navigation Project

Title
Signal Conditioning Board to CPU Interconnec

| Size | Document Number | REV |
|---|---|---|
| A | 631150-330 | 0 |

Date: September 21, 1993 Sheet 1 of 1

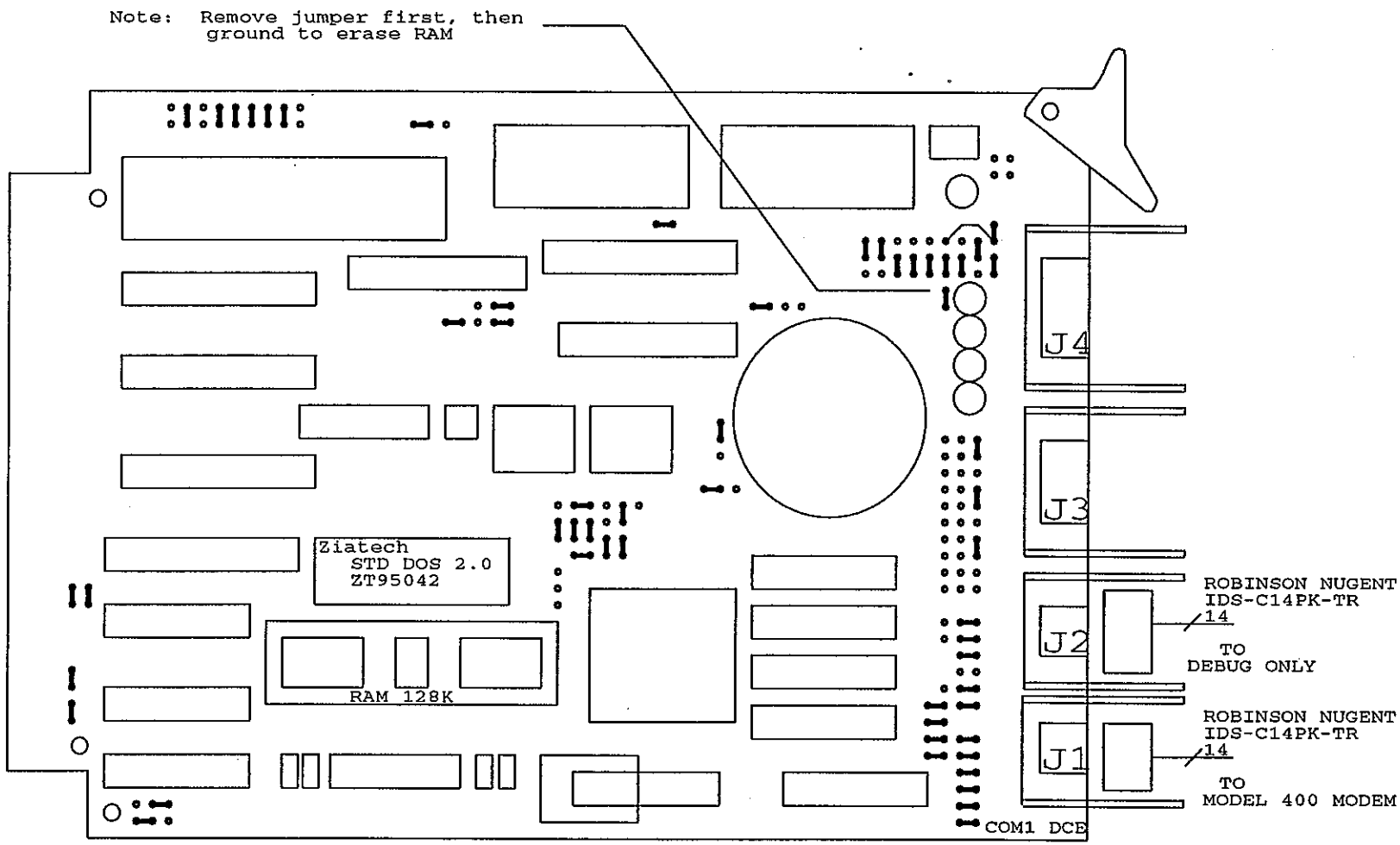



Ziatech ZT8809 REVB

FILE: CPU.SCH SHAPES.LIB

California Department of Transportation
Div. of New Technology Mat'ls & Research
Electrical & Electronics Engineering
Navigation Project

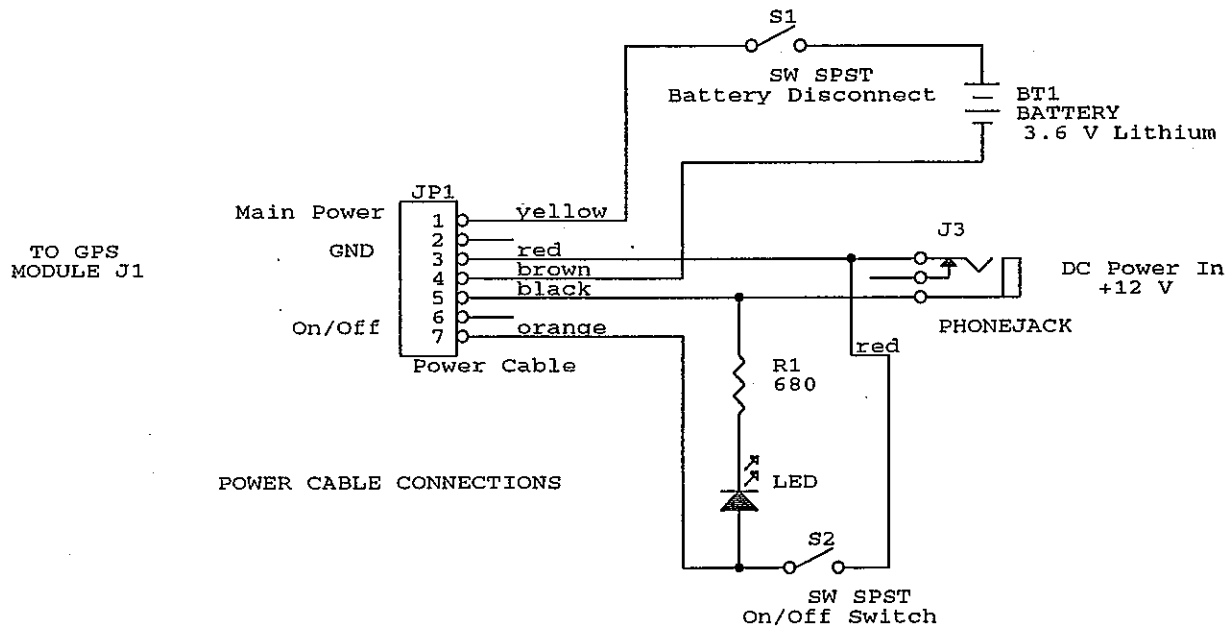
| Title | | |
|---|---|---|
| In-Vehicle CPU Wirewrap/Jumper Assignments | | |
| Size | Document Number | REV |
| A | 631150-500 | 0 |
| Date: September 21, 1993 | Sheet 1 of 1 | |



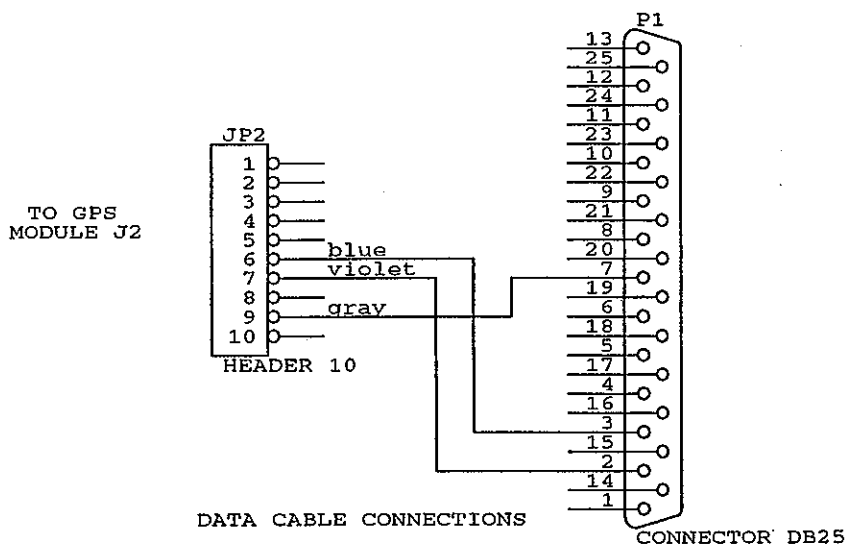

Ziatech ZT88CT08 REV C

FILE: CPU_CAB.SCH SHAPES.LIB

| | | |
|---|---|---|
| California Department of Transportation<br>Div. of New Technology Mat'ls & Research<br>Electrical & Electronics Engineering<br>Navigation Project | | |
| Title<br>In-Cabinet CPU Wirewrap/Jumper Assignments | | |
| Size<br>A | Document Number<br>631150-610 | REV<br>0 |
| Date: July 7, 1992 | Sheet 1 of 1 | |




POWER CABLE CONNECTIONS




DATA CABLE CONNECTIONS

FILE: GPS.SCH DEVICE.LIB

California Department of Transportation
Div. of New Technology Mat'ls & Research
Electrical & Electronics Engineering
Navigation Project

| Title | | |
|---|---|---|
| GPS Connections | | |
| Size | Document Number | REV |
| A | 631150-700 | 1 |
| Date: July 14, 1992 | Sheet 1 of | |

GPS Connections
631150-700
Bill Of Materials
13:51:53 Page 1

Revised: September 23, 1993
Revision: 1
July 14, 1992

| Item | Quantity | Reference | Part |
|---|---|---|---|
| 1 | 1 | BT1 | Lithium battery, 3.6 V<br>Tadiran TL-5104 |
| 2 | 1 | JP1 | 7-circuit terminal housing<br>Molex 22-01-3077<br>Crimp terminals<br>Molex 08-50-0114 |
| 3 | 1 | JP2 | 10-circuit terminal housing<br>Molex 22-01-3107<br>Crimp terminals<br>Molex 08-50-0114 |
| 4 | 1 | J3 | Power jack, miniature 2-conductor power jack to mate with 0.08-inch diameter plugs<br>Switchcraft "Power-Jax" 722A |
| 5 | 1 | P1 | Connector DB-25, female<br>Solder cup type<br>Contact M-D25B |
| 6 | 1 | R1 | Resistor, 680 ohm, 1/4 W carbon film, 5% |
| 7 | 1 | S1 | Switch, SPST momentary<br>Alcoswitch MTA-106F |
| 8 | 1 | S2 | Switch, SPST lighted rocker (green led)<br>GC Electronics 35-681 |
| 9 | 1 | | Battery holder<br>Keystone No. 140 |
| 10 | 1 | | Enclosure<br>Caltrans fabricated |
| 11 | 4 | | Spacers, Hex threaded male/female aluminum spacers. 4-40 thread size, 0.75-inch length.<br>E. F. Johnson 312-7473-024 |
| 12 | 4 | | Hex nuts, 4-40 thread |

| | | |
|---|---|---|
| 13 | 7 | Screws, 4-40 thread, 3/8-inch length |

FILE: BLOCK.WK3

DATA COLLECTION DATE: JUNE 12, 1992

DESCRIPTION: NAVIGATION RUN AROUND THE BLOCK

CONTENTS:

SHEET A: CONTENTS
SHEET B: RAW DATA
SHEET C: COMPASS & ARS
SHEET D: GPS

| TIME | ODM | X | Y | RATE | XMAX | XCALCIR | YCALCIR | AZIM | INC_X | CUM_X | INC_Y | CUM_Y |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 2538 | 2670 | 2184 | 2709 | -72 | 61.69567 | 1.560451 | 0 | 0 | 0 | 0 |
| 1 | 1 | 2538 | 2670 | 2184 | | -72 | 61.69567 | 1.560451 | 0.999946 | 0.999946 | 0.010345 | 0.010345 |
| 2 | 1 | 2538 | 2670 | 2184 | XMIN | -72 | 61.69567 | 1.560451 | 0 | 0.999946 | 0 | 0.010345 |
| 3 | 1 | 2538 | 2670 | 2184 | 2511 | -72 | 61.69567 | 1.560451 | 0 | 0.999946 | 0 | 0.010345 |
| 4 | 1 | 2536 | 2674 | 2186 | | -74 | 65.52176 | 1.544222 | 0 | 0.999946 | 0 | 0.010345 |
| 5 | 1 | 2535 | 2676 | 2184 | YMAX | -75 | 67.4348 | 1.536593 | 0 | 0.999946 | 0 | 0.010345 |
| 6 | 1 | 2533 | 2679 | 2185 | 2709 | -77 | 70.30437 | 1.528953 | 0 | 0.999946 | 0 | 0.010345 |
| 7 | 1 | 2534 | 2679 | 2186 | | -76 | 70.30437 | 1.52244 | 0 | 0.999946 | 0 | 0.010345 |
| 8 | 1 | 2535 | 2680 | 2186 | YMIN | -75 | 71.26089 | 1.509089 | 0 | 0.999946 | 0 | 0.010345 |
| 9 | 1 | 2537 | 2680 | 2186 | 2502 | -73 | 71.26089 | 1.495585 | 0 | 0.999946 | 0 | 0.010345 |
| 10 | 1 | 2541 | 2685 | 2186 | | -69 | 76.0435 | 1.435007 | 0 | 0.999946 | 0 | 0.010345 |
| 11 | 1 | 2545 | 2680 | 2187 | XCEN | -65 | 71.26089 | 1.437614 | 0 | 0.999946 | 0 | 0.010345 |
| 12 | 1 | 2548 | 2674 | 2187 | 2610 | -62 | 65.52176 | 1.45592 | 0 | 0.999946 | 0 | 0.010345 |
| 13 | 1 | 2549 | 2668 | 2186 | | -61 | 59.78263 | 1.493609 | 0 | 0.999946 | 0 | 0.010345 |
| 14 | 1 | 2548 | 2665 | 2186 | YCEN | -62 | 56.91306 | 1.526282 | 0 | 0.999946 | 0 | 0.010345 |
| 15 | 1 | 2547 | 2663 | 2186 | 2605.5 | -63 | 55.00002 | 1.551223 | 0 | 0.999946 | 0 | 0.010345 |
| 16 | 1 | 2546 | 2663 | 2186 | | -64 | 55.00002 | 1.559016 | 0 | 0.999946 | 0 | 0.010345 |
| 17 | 1 | 2546 | 2663 | 2186 | YCOR | -64 | 55.00002 | 1.559016 | 0 | 0.999946 | 0 | 0.010345 |
| 18 | 1 | 2545 | 2663 | 2185 | 0.956522 | -65 | 55.00002 | 1.566671 | 0 | 0.999946 | 0 | 0.010345 |
| 19 | 1 | 2545 | 2664 | 2186 | | -65 | 55.95654 | 1.558157 | 0 | 0.999946 | 0 | 0.010345 |
| 20 | 1 | 2544 | 2664 | 2186 | YCORR | -66 | 55.95654 | 1.565697 | 0 | 0.999946 | 0 | 0.010345 |
| 21 | 1 | 2544 | 2664 | 2185 | 0.973254 | -66 | 55.95654 | 1.565697 | 0 | 0.999946 | 0 | 0.010345 |
| 22 | 1 | 2543 | 2665 | 2185 | | -67 | 56.91306 | 1.564754 | 0 | 0.999946 | 0 | 0.010345 |
| 23 | 1 | 2542 | 2666 | 2185 | XCENI | -68 | 57.86958 | 1.56384 | 0 | 0.999946 | 0 | 0.010345 |
| 24 | 1 | 2542 | 2666 | 2186 | 2610 | -68 | 57.86958 | 1.56384 | 0 | 0.999946 | 0 | 0.010345 |
| 25 | 1 | 2542 | 2666 | 2186 | | -68 | 57.86958 | 1.56384 | 0 | 0.999946 | 0 | 0.010345 |
| 26 | 1 | 2542 | 2667 | 2187 | YCENI | -68 | 58.8261 | 1.555739 | 0 | 0.999946 | 0 | 0.010345 |
| 27 | 1 | 2541 | 2668 | 2186 | 2605.5 | -69 | 59.78263 | 1.554081 | 0 | 0.999946 | 0 | 0.010345 |
| 28 | 1 | 2540 | 2668 | 2186 | | -70 | 59.78263 | 1.562095 | 0 | 0.999946 | 0 | 0.010345 |
| 29 | 1 | 2540 | 2668 | 2187 | YCORI | -70 | 59.78263 | 1.562095 | 0 | 0.999946 | 0 | 0.010345 |
| 30 | 1 | 2540 | 2668 | 2186 | 0.956522 | -70 | 59.78263 | 1.562095 | 0 | 0.999946 | 0 | 0.010345 |
| 31 | 1 | 2540 | 2668 | 2186 | | -70 | 59.78263 | 1.562095 | 0 | 0.999946 | 0 | 0.010345 |
| 32 | 1 | 2540 | 2669 | 2186 | DECLIN | -70 | 60.73915 | 1.554246 | 0 | 0.999946 | 0 | 0.010345 |
| 33 | 1 | 2540 | 2669 | 2186 | 50 | -70 | 60.73915 | 1.554246 | 0 | 0.999946 | 0 | 0.010345 |
| 34 | 1 | 2540 | 2669 | 2186 | | -70 | 60.73915 | 1.554246 | 0 | 0.999946 | 0 | 0.010345 |
| 35 | 1 | 2540 | 2669 | 2186 | | -70 | 60.73915 | 1.554246 | 0 | 0.999946 | 0 | 0.010345 |
| 36 | 1 | 2540 | 2669 | 2186 | | -70 | 60.73915 | 1.554246 | 0 | 0.999946 | 0 | 0.010345 |
| 37 | 1 | 2540 | 2669 | 2186 | | -70 | 60.73915 | 1.554246 | 0 | 0.999946 | 0 | 0.010345 |
| 38 | 1 | 2540 | 2668 | 2187 | | -70 | 59.78263 | 1.562095 | 0 | 0.999946 | 0 | 0.010345 |
| 39 | 1 | 2540 | 2668 | 2186 | | -70 | 59.78263 | 1.562095 | 0 | 0.999946 | 0 | 0.010345 |
| 40 | 1 | 2539 | 2670 | 2186 | | -71 | 61.69567 | 1.553533 | 0 | 0.999946 | 0 | 0.010345 |
| 41 | 1 | 2538 | 2671 | 2187 | | -72 | 62.65219 | 1.552841 | 0 | 0.999946 | 0 | 0.010345 |
| 42 | 1 | 2538 | 2671 | 2187 | | -72 | 62.65219 | 1.552841 | 0 | 0.999946 | 0 | 0.010345 |
| 43 | 1 | 2538 | 2671 | 2186 | | -72 | 62.65219 | 1.552841 | 0 | 0.999946 | 0 | 0.010345 |
| 44 | 1 | 2539 | 2669 | 2186 | | -71 | 60.73915 | 1.561261 | 0 | 0.999946 | 0 | 0.010345 |
| 45 | 1 | 2539 | 2670 | 2186 | | -71 | 61.69567 | 1.553533 | 0 | 0.999946 | 0 | 0.010345 |
| 46 | 1 | 2539 | 2670 | 2187 | | -71 | 61.69567 | 1.553533 | 0 | 0.999946 | 0 | 0.010345 |
| 47 | 1 | 2540 | 2670 | 2198 | | -70 | 61.69567 | 1.548503 | 0 | 0.999946 | 0 | 0.010345 |
| 48 | 4 | 2540 | 2669 | 2186 | | -70 | 60.73915 | 1.554246 | 2.999589 | 3.999536 | 0.049646 | 0.059993 |
| 49 | 12 | 2539 | 2670 | 2190 | | -71 | 61.69567 | 1.553533 | 7.998808 | 11.99834 | 0.138099 | 0.198092 |
| 50 | 24 | 2539 | 2671 | 2188 | | -71 | 62.65219 | 1.545908 | 11.99628 | 23.99463 | 0.298629 | 0.496721 |
| 51 | 40 | 2539 | 2673 | 2199 | | -71 | 64.56524 | 1.53096 | 15.98731 | 39.98193 | 0.637205 | 1.133926 |
| 52 | 59 | 2538 | 2674 | 2209 | | -72 | 65.52176 | 1.530502 | 18.98465 | 58.96659 | 0.763485 | 1.897411 |
| 53 | 79 | 2534 | 2669 | 2202 | | -76 | 60.73915 | 1.594676 | 19.9943 | 78.96089 | -0.47754 | 1.419872 |
| 54 | 101 | 2529 | 2672 | 2196 | | -81 | 63.60871 | 1.603219 | 21.98844 | 100.9493 | -0.71316 | 0.706588 |
| 55 | 124 | 2529 | 2671 | 2195 | | -81 | 62.65219 | 1.610566 | 22.98181 | 123.9311 | -0.91446 | -0.20777 |
| 56 | 147 | 2529 | 2672 | 2197 | | -81 | 63.60871 | 1.603219 | 22.98791 | 146.919 | -0.7456 | -0.95337 |
| 57 | 171 | 2527 | 2675 | 2207 | | -83 | 66.47828 | 1.593612 | 23.99375 | 170.9128 | -0.54754 | -1.50091 |
| 58 | 196 | 2528 | 2672 | 2188 | | -82 | 63.60871 | 1.609171 | 24.98159 | 195.8944 | -0.95913 | -2.46003 |
| 59 | 221 | 2528 | 2673 | 2200 | | -82 | 64.56524 | 1.601929 | 24.98789 | 220.8823 | -0.77819 | -3.23823 |
| 60 | 245 | 2525 | 2672 | 2201 | | -85 | 63.60871 | 1.626492 | 23.96279 | 244.8451 | -1.336 | -4.57422 |
| 61 | 269 | 2520 | 2676 | 2202 | | -90 | 67.4348 | 1.625891 | 23.96358 | 268.8087 | -1.3216 | -5.89582 |
| 62 | 292 | 2535 | 2686 | 2200 | | -75 | 77.00002 | 1.470373 | 22.88412 | 291.6928 | 2.305866 | -3.58995 |
| 63 | 316 | 2540 | 2666 | 2200 | | -70 | 57.86958 | 1.578112 | 22.99038 | 314.6922 | -0.16827 | -3.75822 |
| 64 | 338 | 2531 | 2669 | 2202 | | -79 | 60.73915 | 1.613472 | 22.97906 | 337.6712 | -0.98124 | -4.73946 |
| 65 | 359 | 2531 | 2673 | 2198 | | -79 | 64.56524 | 1.583738 | 20.99824 | 358.6695 | -0.27177 | -5.01123 |

| LOOP | ARS ZERO | ADJ_RATE | CORR_RAT | CUM_RATE | AZIM | INC_X | CUM_X | INC_Y | CUM_Y |
|---|---|---|---|---|---|---|---|---|---|
| | 2186 | 2184 | -2 | -2 | 0.87125 | 0 | 0 | 0 | 0 |
| | | 2183.993 | -2.00691 | -4.00691 | 0.869831 | 0.76422 | 0.76422 | 0.644955 | 0.644955 |
| | DRIFT | 2183.986 | -2.01382 | -6.02074 | 0.868407 | 0 | 0.76422 | 0 | 0.644955 |
| | -0.00691 | 2183.979 | -2.02074 | -8.04147 | 0.866979 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2185.972 | -0.02765 | -8.06912 | 0.866959 | 0 | 0.76422 | 0 | 0.644955 |
| | SUM_TURN | 2183.965 | -2.03456 | -10.1037 | 0.865521 | 0 | 0.76422 | 0 | 0.644955 |
| | 13329.18 | 2184.959 | -1.04147 | -11.1452 | 0.864784 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2185.952 | -0.04838 | -11.1935 | 0.86475 | 0 | 0.76422 | 0 | 0.644955 |
| | CUM_HEAD | 2185.945 | -0.0553 | -11.2488 | 0.864711 | 0 | 0.76422 | 0 | 0.644955 |
| | 540 | 2185.938 | -0.06221 | -11.311 | 0.864667 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2185.931 | -0.06912 | -11.3802 | 0.864618 | 0 | 0.76422 | 0 | 0.644955 |
| | GAIN_FAC | 2186.924 | 0.923968 | -10.4562 | 0.865271 | 0 | 0.76422 | 0 | 0.644955 |
| | 24.68367 | 2186.917 | 0.917056 | -9.53914 | 0.86592 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2185.91 | -0.08986 | -9.62899 | 0.865856 | 0 | 0.76422 | 0 | 0.644955 |
| | AZIM_INIT | 2185.903 | -0.09677 | -9.72576 | 0.865788 | 0 | 0.76422 | 0 | 0.644955 |
| | 50 | 2185.896 | -0.10368 | -9.82944 | 0.865714 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2185.889 | -0.11059 | -9.94003 | 0.865636 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2185.882 | -0.1175 | -10.0575 | 0.865553 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2184.876 | -1.12442 | -11.182 | 0.864758 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2185.869 | -0.13133 | -11.3133 | 0.864665 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2185.862 | -0.13824 | -11.4515 | 0.864568 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2184.855 | -1.14515 | -12.5967 | 0.863758 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2184.848 | -1.15206 | -13.7487 | 0.862943 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2184.841 | -1.15898 | -14.9077 | 0.862124 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2185.834 | -0.16589 | -15.0736 | 0.862006 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2185.827 | -0.1728 | -15.2464 | 0.861884 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2186.82 | 0.820288 | -14.4261 | 0.862464 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2185.813 | -0.18662 | -14.6127 | 0.862332 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2185.806 | -0.19354 | -14.8063 | 0.862195 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2186.8 | 0.799552 | -14.0067 | 0.862761 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2185.793 | -0.20736 | -14.2141 | 0.862614 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2185.786 | -0.21427 | -14.4284 | 0.862463 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2185.779 | -0.22118 | -14.6495 | 0.862306 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2185.772 | -0.2281 | -14.8776 | 0.862145 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2185.765 | -0.23501 | -15.1126 | 0.861979 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2185.758 | -0.24192 | -15.3546 | 0.861808 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2185.751 | -0.24883 | -15.6034 | 0.861632 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2185.744 | -0.25574 | -15.8591 | 0.861451 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2186.737 | 0.737344 | -15.1218 | 0.861972 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2185.73 | -0.26957 | -15.3914 | 0.861782 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2185.724 | -0.27648 | -15.6678 | 0.861586 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2186.717 | 0.716608 | -14.9512 | 0.862093 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2186.71 | 0.709696 | -14.2415 | 0.862595 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2185.703 | -0.29722 | -14.5388 | 0.862385 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2185.696 | -0.30413 | -14.8429 | 0.86217 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2185.689 | -0.31104 | -15.1539 | 0.86195 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2186.682 | 0.682048 | -14.4719 | 0.862432 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2197.675 | 11.67514 | -2.79674 | 0.870687 | 0 | 0.76422 | 0 | 0.644955 |
| | | 2185.668 | -0.33178 | -3.12851 | 0.870453 | 2.293862 | 3.058082 | 1.933442 | 2.578397 |
| | | 2189.661 | 3.661312 | 0.5328 | 0.873041 | 6.130292 | 9.188375 | 5.139992 | 7.718389 |
| | | 2187.654 | 1.6544 | 2.1872 | 0.874211 | 9.204451 | 18.39283 | 7.699226 | 15.41761 |
| | | 2198.647 | 12.64749 | 14.83469 | 0.883154 | 12.36391 | 30.75674 | 10.15547 | 25.57309 |
| | | 2208.641 | 22.64058 | 37.47526 | 0.899163 | 14.87332 | 45.63005 | 11.82305 | 37.39614 |
| | | 2201.634 | 15.63368 | 53.10893 | 0.910217 | 15.79274 | 61.42279 | 12.27149 | 49.66763 |
| | | 2195.627 | 9.626752 | 62.73568 | 0.917024 | 17.46349 | 78.88628 | 13.38008 | 63.04771 |
| | | 2194.62 | 8.61984 | 71.35552 | 0.923119 | 18.3422 | 97.22848 | 13.87673 | 76.92444 |
| | | 2196.613 | 10.61293 | 81.96845 | 0.930623 | 18.44582 | 115.6743 | 13.7387 | 90.66314 |
| | | 2206.606 | 20.60602 | 102.5745 | 0.945193 | 19.45464 | 135.1289 | 14.05408 | 104.7172 |
| | | 2187.599 | 1.599104 | 104.1736 | 0.946324 | 20.28179 | 155.4107 | 14.61674 | 119.334 |
| | | 2199.592 | 13.59219 | 117.7658 | 0.955934 | 20.42133 | 175.832 | 14.42115 | 133.7551 |
| | | 2200.585 | 14.58528 | 132.351 | 0.966247 | 19.7462 | 195.5783 | 13.64139 | 147.3965 |
| | | 2201.578 | 15.57837 | 147.9294 | 0.977262 | 19.89526 | 215.4735 | 13.42306 | 160.8195 |
| | | 2199.571 | 13.57148 | 161.5009 | 0.986658 | 19.18886 | 234.6624 | 12.68021 | 173.4998 |
| | | 2199.565 | 13.56454 | 175.0654 | 0.99645 | 19.30959 | 253.972 | 12.49559 | 185.9954 |
| | | 2201.558 | 15.55763 | 190.623 | 1.00745 | 19.44588 | 273.4178 | 12.28242 | 198.2778 |
| | | 2197.551 | 11.55072 | 202.1738 | 1.015617 | 17.84593 | 291.2638 | 11.069 | 209.3468 |

| | | | | |
|---|---|---|---|---|
| 66 | 380 | 2532 | 2672 | 2170 |
| 67 | 400 | 2537 | 2679 | 2046 |
| 68 | 420 | 2555 | 2693 | 1942 |
| 69 | 440 | 2584 | 2703 | 1883 |
| 70 | 461 | 2621 | 2706 | 1871 |
| 71 | 483 | 2647 | 2709 | 1939 |
| 72 | 506 | 2655 | 2702 | 2060 |
| 73 | 528 | 2660 | 2695 | 2187 |
| 74 | 550 | 2657 | 2697 | 2334 |
| 75 | 572 | 2644 | 2703 | 2408 |
| 76 | 595 | 2624 | 2707 | 2419 |
| 77 | 617 | 2603 | 2708 | 2375 |
| 78 | 640 | 2590 | 2707 | 2293 |
| 79 | 662 | 2587 | 2708 | 2241 |
| 80 | 683 | 2584 | 2707 | 2261 |
| 81 | 704 | 2572 | 2703 | 2365 |
| 82 | 726 | 2555 | 2694 | 2426 |
| 83 | 749 | 2540 | 2684 | 2336 |
| 84 | 774 | 2532 | 2674 | 2243 |
| 85 | 800 | 2534 | 2671 | 2220 |
| 86 | 826 | 2534 | 2667 | 2198 |
| 87 | 853 | 2529 | 2687 | 2170 |
| 88 | 880 | 2530 | 2672 | 2200 |
| 89 | 906 | 2534 | 2672 | 2216 |
| 90 | 930 | 2536 | 2673 | 2163 |
| 91 | 952 | 2546 | 2679 | 2061 |
| 92 | 973 | 2564 | 2688 | 1949 |
| 93 | 993 | 2587 | 2699 | 1909 |
| 94 | 1014 | 2614 | 2705 | 1926 |
| 95 | 1035 | 2637 | 2704 | 1959 |
| 96 | 1058 | 2653 | 2697 | 2020 |
| 97 | 1082 | 2662 | 2692 | 2093 |
| 98 | 1108 | 2668 | 2685 | 2163 |
| 99 | 1134 | 2671 | 2684 | 2195 |
| 100 | 1160 | 2671 | 2685 | 2209 |
| 101 | 1189 | 2671 | 2686 | 2229 |
| 102 | 1220 | 2669 | 2687 | 2236 |
| 103 | 1253 | 2668 | 2687 | 2206 |
| 104 | 1287 | 2670 | 2686 | 2183 |
| 105 | 1324 | 2672 | 2683 | 2190 |
| 106 | 1362 | 2672 | 2683 | 2204 |
| 107 | 1400 | 2671 | 2683 | 2198 |
| 108 | 1437 | 2672 | 2683 | 2198 |
| 109 | 1471 | 2672 | 2684 | 2223 |
| 110 | 1499 | 2675 | 2684 | 2231 |
| 111 | 1521 | 2671 | 2686 | 2252 |
| 112 | 1538 | 2661 | 2694 | 2333 |
| 113 | 1549 | 2649 | 2701 | 2367 |
| 114 | 1558 | 2638 | 2705 | 2329 |
| 115 | 1569 | 2625 | 2706 | 2342 |
| 116 | 1585 | 2608 | 2705 | 2422 |
| 117 | 1605 | 2584 | 2700 | 2534 |
| 118 | 1631 | 2557 | 2679 | 2549 |
| 119 | 1660 | 2539 | 2661 | 2380 |
| 120 | 1694 | 2536 | 2653 | 2226 |
| 121 | 1731 | 2536 | 2651 | 2209 |
| 122 | 1770 | 2535 | 2651 | 2219 |
| 123 | 1811 | 2536 | 2650 | 2203 |
| 124 | 1853 | 2537 | 2650 | 2188 |
| 125 | 1898 | 2538 | 2652 | 2209 |
| 126 | 1946 | 2536 | 2652 | 2209 |
| 127 | 1995 | 2537 | 2650 | 2198 |
| 128 | 2045 | 2538 | 2650 | 2201 |
| 129 | 2096 | 2538 | 2648 | 2202 |
| 130 | 2147 | 2537 | 2648 | 2198 |
| 131 | 2198 | 2537 | 2648 | 2206 |
| 132 | 2250 | 2538 | 2647 | 2199 |

| | | | | | | |
|---|---|---|---|---|---|---|
| -78 | 63.60871 | 1.584809 | 20.99794 | 379.6674 | -0.29426 | -5.30549 |
| -73 | 70.30437 | 1.502338 | 19.95315 | 399.6206 | 1.368094 | -3.9374 |
| -55 | 83.69568 | 1.278512 | 19.15752 | 418.7781 | 5.743658 | 1.806263 |
| -26 | 93.2609 | 0.970016 | 16.49789 | 435.276 | 11.30573 | 13.11199 |
| 11 | 96.13046 | 0.584199 | 11.58217 | 446.8581 | 17.51723 | 30.62922 |
| 37 | 99.00003 | 0.340469 | 7.346433 | 454.2046 | 20.73716 | 51.36638 |
| 45 | 92.30437 | 0.24452 | 5.568081 | 459.7726 | 22.31583 | 73.68222 |
| 50 | 85.60872 | 0.169521 | 3.711619 | 463.4943 | 21.68465 | 95.36687 |
| 47 | 87.52176 | 0.205317 | 4.485302 | 467.9696 | 21.53792 | 116.9048 |
| 34 | 93.2609 | 0.348538 | 7.51352 | 475.4831 | 20.67721 | 137.582 |
| 14 | 97.08698 | 0.554918 | 12.1181 | 487.6012 | 19.5487 | 157.1307 |
| -7 | 98.04351 | 0.769408 | 15.30562 | 502.9068 | 15.8031 | 172.9338 |
| -20 | 97.08698 | 0.901291 | 18.03496 | 520.9418 | 14.27377 | 187.2076 |
| -23 | 96.04351 | 0.928555 | 17.61661 | 538.5584 | 13.17782 | 200.3854 |
| -26 | 97.08698 | 0.959793 | 17.20053 | 555.7589 | 12.04748 | 212.4329 |
| -38 | 93.2609 | 1.085052 | 18.57088 | 574.3298 | 9.804206 | 222.2371 |
| -55 | 84.6522 | 1.274308 | 21.04011 | 595.3699 | 6.427594 | 228.6647 |
| -70 | 75.08698 | 1.448483 | 22.82817 | 618.198 | 2.805205 | 231.4709 |
| -78 | 65.52176 | 1.570255 | 25 | 643.198 | 0.013533 | 231.4844 |
| -76 | 62.65219 | 1.579502 | 25.99901 | 669.1971 | -0.22636 | 231.2581 |
| -76 | 58.8261 | 1.610226 | 25.97979 | 695.1768 | -1.0249 | 230.2332 |
| -81 | 77.95654 | 1.502674 | 26.93738 | 722.1142 | 1.837881 | 232.071 |
| -80 | 63.60871 | 1.597177 | 26.99061 | 749.1048 | -0.71218 | 231.3589 |
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| -74 | 64.56524 | 1.551514 | 23.99554 | 799.1003 | 0.462749 | 231.7889 |
| -64 | 70.30437 | 1.436623 | 21.80227 | 820.9026 | 2.942956 | 234.7318 |
| -46 | 78.91307 | 1.225898 | 19.7633 | 840.6659 | 7.100128 | 241.832 |
| -23 | 89.43481 | 0.949848 | 16.26654 | 856.9325 | 11.63614 | 253.4681 |
| 4 | 95.17394 | 0.656128 | 12.81112 | 869.7436 | 16.63956 | 270.1077 |
| 27 | 94.21742 | 0.41904 | 8.544557 | 878.2881 | 19.18308 | 289.2907 |
| 43 | 87.52176 | 0.241463 | 5.499842 | 883.788 | 22.33275 | 311.6235 |
| 52 | 82.73915 | 0.137033 | 3.278508 | 887.0665 | 23.77502 | 335.3985 |
| 58 | 76.0435 | 0.046539 | 1.209565 | 888.2761 | 25.97185 | 361.3704 |
| 61 | 75.08698 | 0.015881 | 0.41288 | 888.6889 | 25.99672 | 387.3671 |
| 61 | 76.0435 | 0.022067 | 0.573708 | 889.2626 | 25.99367 | 413.3607 |
| 61 | 77.00002 | 0.02816 | 0.816542 | 890.0792 | 28.9885 | 442.3492 |
| 59 | 77.95654 | 0.050272 | 1.557791 | 891.637 | 30.96083 | 473.3101 |
| 58 | 77.95654 | 0.058479 | 1.828705 | 893.5657 | 32.94359 | 506.2537 |
| 60 | 77.00002 | 0.03619 | 1.230198 | 894.7959 | 33.97774 | 540.2314 |
| 62 | 74.13046 | 0.001608 | 0.05949 | 894.8554 | 36.99995 | 577.2314 |
| 62 | 74.13046 | 0.001608 | 0.061098 | 894.9165 | 37.99995 | 615.2313 |
| 61 | 74.13046 | 0.009598 | 0.364725 | 895.2812 | 37.99825 | 653.2296 |
| 62 | 74.13046 | 0.001608 | 0.05949 | 895.3407 | 36.99995 | 690.2295 |
| 62 | 75.08698 | 0.00791 | 0.258933 | 895.6096 | 33.99894 | 724.2284 |
| 65 | 75.08698 | -0.01539 | -0.43077 | 895.1788 | 27.99669 | 752.2251 |
| 61 | 77.00002 | 0.02816 | 0.619445 | 895.7983 | 21.99128 | 774.2164 |
| 51 | 84.6522 | 0.155902 | 2.639603 | 898.4379 | 16.79382 | 791.0102 |
| 39 | 91.34785 | 0.294619 | 3.194133 | 901.632 | 10.52604 | 801.5363 |
| 28 | 95.17394 | 0.412006 | 3.604036 | 905.2361 | 8.246874 | 809.7832 |
| 15 | 96.13046 | 0.543342 | 5.686995 | 910.9231 | 9.415842 | 819.199 |
| -2 | 95.17394 | 0.719143 | 10.53984 | 921.4629 | 12.03793 | 831.2369 |
| -26 | 90.39133 | 0.978209 | 16.58997 | 938.0529 | 11.17018 | 842.4071 |
| -53 | 70.30437 | 1.344102 | 25.33478 | 963.3876 | 5.843704 | 848.2508 |
| -71 | 53.08697 | 1.626898 | 28.95437 | 992.342 | -1.6261 | 846.6247 |
| -74 | 45.4348 | 1.71829 | 33.63085 | 1025.973 | -4.99662 | 841.6281 |
| -74 | 43.52175 | 1.737281 | 36.48842 | 1062.461 | -6.13151 | 835.4966 |
| -75 | 43.52175 | 1.743127 | 38.42232 | 1100.884 | -6.68769 | 828.8089 |
| -74 | 42.56523 | 1.746939 | 40.3656 | 1141.249 | -7.18457 | 821.6243 |
| -73 | 42.56523 | 1.741039 | 41.39284 | 1182.642 | -7.11569 | 814.5086 |
| -72 | 44.47827 | 1.715556 | 44.52932 | 1227.171 | -6.49148 | 808.0172 |
| -74 | 44.47827 | 1.727731 | 47.41013 | 1274.581 | -7.50199 | 800.5152 |
| -73 | 42.56523 | 1.741039 | 48.29164 | 1322.873 | -8.30164 | 792.2135 |
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| -72 | 40.65219 | 1.754934 | 50.13782 | 1422.338 | -9.33806 | 774.7013 |
| -73 | 40.65219 | 1.760819 | 50.082 | 1472.42 | -9.63292 | 765.0684 |
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| -72 | 39.69566 | 1.765065 | 51.02183 | 1573.524 | -10.0386 | 745.3969 |

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|---|---|---|---|---|---|---|---|
| 2169.544 | -16.4562 | 185.7176 | 1.003982 | 17.71593 | 308.9797 | 11.2759 | 220.6227 |
| 2045.537 | -140.463 | 45.25446 | 0.904663 | 15.72434 | 324.704 | 12.35901 | 232.9817 |
| 1941.53 | -244.47 | -199.216 | 0.731804 | 13.36425 | 338.0683 | 14.87941 | 247.8611 |
| 1882.523 | -303.477 | -502.692 | 0.517222 | 9.889342 | 347.9576 | 17.38393 | 265.245 |
| 1870.516 | -315.484 | -818.176 | 0.29415 | 6.088453 | 354.0461 | 20.09803 | 285.3431 |
| 1938.509 | -247.491 | -1065.67 | 0.119154 | 2.6152 | 356.6613 | 21.84401 | 307.1871 |
| 2059.502 | -126.498 | -1192.16 | 0.029711 | 0.683246 | 357.3445 | 22.98985 | 330.1769 |
| 2186.495 | 0.495424 | -1191.67 | 0.030061 | 0.661243 | 358.0058 | 21.99006 | 352.167 |
| 2333.489 | 147.4885 | -1044.18 | 0.134347 | 2.94675 | 360.9525 | 21.80176 | 373.9687 |
| 2407.482 | 221.4816 | -822.699 | 0.280952 | 6.311012 | 367.2635 | 21.07537 | 395.0441 |
| 2418.475 | 232.4747 | -590.225 | 0.45533 | 10.11444 | 377.378 | 20.65667 | 415.7008 |
| 2374.468 | 188.4678 | -401.757 | 0.588591 | 12.21418 | 389.5921 | 18.29792 | 433.9987 |
| 2292.461 | 106.4609 | -295.296 | 0.663867 | 14.17185 | 403.764 | 18.11515 | 452.1138 |
| 2240.454 | 54.45395 | -240.842 | 0.702371 | 14.21264 | 417.9766 | 16.79288 | 468.9067 |
| 2260.447 | 74.44704 | -166.395 | 0.75501 | 14.39122 | 432.3679 | 15.29355 | 484.2003 |
| 2364.44 | 178.4401 | 12.04525 | 0.881182 | 16.20131 | 448.5692 | 13.36104 | 497.5613 |
| 2425.433 | 239.4332 | 251.4785 | 1.05048 | 19.08856 | 467.6577 | 10.93741 | 508.4987 |
| 2335.426 | 149.4263 | 400.9048 | 1.156136 | 21.05082 | 488.7085 | 9.266224 | 517.765 |
| 2242.419 | 56.41939 | 457.3242 | 1.196029 | 23.26482 | 511.9734 | 9.151409 | 526.9164 |
| 2219.412 | 33.41248 | 490.7366 | 1.219654 | 24.41349 | 536.3869 | 8.94324 | 535.8596 |
| 2197.406 | 11.40557 | 502.1422 | 1.227719 | 24.48482 | 560.8717 | 8.746065 | 544.6057 |
| 2169.399 | -16.6013 | 485.5409 | 1.21598 | 25.31818 | 586.1899 | 9.360288 | 553.966 |
| 2199.392 | 13.39174 | 498.9326 | 1.225449 | 25.40586 | 611.5957 | 9.140133 | 563.1261 |
| 2215.385 | 29.38483 | 528.3174 | 1.246226 | 24.64249 | 636.2382 | 8.29143 | 571.4175 |
| 2162.378 | -23.6221 | 504.6954 | 1.229524 | 22.61591 | 658.8541 | 8.032476 | 579.45 |
| 2060.371 | -125.629 | 379.0664 | 1.140694 | 19.99631 | 678.8504 | 9.173199 | 588.6232 |
| 1948.364 | -237.636 | 141.4305 | 0.972667 | 17.3542 | 696.2046 | 11.82505 | 600.4482 |
| 1908.357 | -277.643 | -136.212 | 0.776352 | 14.01362 | 710.2182 | 14.26949 | 614.7177 |
| 1925.35 | -260.65 | -396.862 | 0.592052 | 11.71936 | 721.9376 | 17.42574 | 632.1435 |
| 1958.343 | -227.657 | -624.519 | 0.431081 | 8.774915 | 730.7125 | 19.07881 | 651.2223 |
| 2019.336 | -166.664 | -791.182 | 0.313237 | 7.087208 | 737.7997 | 21.88085 | 673.1031 |
| 2092.33 | -93.6705 | -884.853 | 0.247004 | 5.868009 | 743.6677 | 23.27158 | 696.3747 |
| 2162.323 | -23.6774 | -908.53 | 0.230263 | 5.934064 | 749.6018 | 25.31377 | 721.6885 |
| 2194.316 | 8.315712 | -900.214 | 0.236142 | 6.082802 | 755.6846 | 25.27844 | 746.9669 |
| 2208.309 | 22.3088 | -877.906 | 0.251917 | 6.480773 | 762.1654 | 25.17935 | 772.1463 |
| 2228.302 | 42.30189 | -835.604 | 0.281827 | 8.065229 | 770.2306 | 27.85592 | 800.0022 |
| 2235.295 | 49.29498 | -786.309 | 0.316683 | 9.653895 | 779.8845 | 29.45848 | 829.4607 |
| 2205.288 | 19.28806 | -767.021 | 0.330321 | 10.70344 | 790.5879 | 31.21596 | 860.6766 |
| 2182.281 | -3.71885 | -770.74 | 0.327691 | 10.94318 | 801.5311 | 32.19079 | 892.8674 |
| 2189.274 | 3.27424 | -767.465 | 0.330007 | 11.98862 | 813.5209 | 35.00349 | 927.8709 |
| 2203.267 | 17.26733 | -750.198 | 0.342216 | 12.75186 | 826.2728 | 35.79651 | 963.6674 |
| 2197.26 | 11.26042 | -738.938 | 0.350178 | 13.03647 | 839.3093 | 35.69384 | 999.3613 |
| 2197.254 | 11.2535 | -727.684 | 0.358135 | 12.96954 | 852.2788 | 34.65243 | 1034.014 |
| 2222.247 | 36.24659 | -691.437 | 0.383764 | 12.73006 | 865.0089 | 31.5269 | 1065.541 |
| 2230.24 | 44.23968 | -647.198 | 0.415045 | 11.28047 | 876.2993 | 25.62275 | 1091.163 |
| 2251.233 | 65.23277 | -581.965 | 0.46117 | 9.788911 | 886.0893 | 19.70172 | 1110.865 |
| 2332.226 | 146.2259 | -435.739 | 0.564563 | 9.095792 | 895.185 | 14.36198 | 1125.227 |
| 2366.219 | 180.2189 | -255.52 | 0.691992 | 7.018793 | 902.2038 | 8.469743 | 1133.697 |
| 2328.212 | 142.212 | -113.308 | 0.792547 | 6.409292 | 908.6131 | 6.318305 | 1140.015 |
| 2341.205 | 155.2051 | 41.89696 | 0.902289 | 8.632225 | 917.2454 | 6.817968 | 1146.833 |
| 2421.198 | 235.1982 | 277.0952 | 1.066593 | 14.02438 | 931.2697 | 7.701733 | 1154.535 |
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| 2548.184 | 362.1844 | 986.4708 | 1.570177 | 26 | 976.6143 | 0.016107 | 1159.629 |
| 2379.177 | 193.1775 | 1179.648 | 1.706768 | 28.73233 | 1005.347 | -3.93105 | 1155.698 |
| 2225.171 | 39.17056 | 1218.819 | 1.734465 | 33.54563 | 1038.892 | -5.53993 | 1150.158 |
| 2208.164 | 22.16365 | 1240.983 | 1.750137 | 36.40658 | 1075.299 | -6.60007 | 1143.558 |
| 2218.157 | 32.15674 | 1273.139 | 1.772874 | 38.20642 | 1113.505 | -7.6275 | 1135.73 |
| 2202.15 | 16.14982 | 1289.289 | 1.784293 | 40.06914 | 1153.574 | -8.68702 | 1127.043 |
| 2187.143 | 1.142912 | 1290.432 | 1.785101 | 41.03923 | 1194.614 | -8.93207 | 1118.111 |
| 2208.136 | 22.136 | 1312.568 | 1.800753 | 43.81543 | 1238.429 | -10.2571 | 1107.854 |
| 2208.129 | 22.12909 | 1334.697 | 1.8164 | 46.55955 | 1284.989 | -11.6708 | 1096.183 |
| 2197.122 | 11.12218 | 1345.819 | 1.824264 | 47.43438 | 1332.423 | -12.2874 | 1083.896 |
| 2200.115 | 14.11526 | 1359.935 | 1.834245 | 48.27488 | 1380.698 | -13.0206 | 1070.875 |
| 2201.108 | 15.10835 | 1375.043 | 1.844928 | 49.0957 | 1429.794 | -13.8063 | 1057.069 |
| 2197.101 | 11.10144 | 1386.144 | 1.852777 | 48.98581 | 1478.779 | -14.1912 | 1042.878 |
| 2205.095 | 19.09453 | 1405.239 | 1.866279 | 48.78975 | 1527.569 | -14.8513 | 1028.027 |
| 2198.088 | 12.08762 | 1417.326 | 1.874826 | 49.61518 | 1577.184 | -15.5671 | 1012.46 |

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|---|---|---|---|---|
| 133 | 2303 | 2538 | 2648 | 2201 |
| 134 | 2356 | 2539 | 2648 | 2212 |
| 135 | 2409 | 2537 | 2648 | 2204 |
| 136 | 2461 | 2536 | 2648 | 2215 |
| 137 | 2512 | 2535 | 2648 | 2205 |
| 138 | 2562 | 2536 | 2649 | 2211 |
| 139 | 2612 | 2538 | 2647 | 2210 |
| 140 | 2662 | 2539 | 2647 | 2196 |
| 141 | 2713 | 2539 | 2648 | 2197 |
| 142 | 2764 | 2538 | 2648 | 2195 |
| 143 | 2816 | 2537 | 2650 | 2203 |
| 144 | 2867 | 2536 | 2649 | 2206 |
| 145 | 2917 | 2534 | 2650 | 2203 |
| 146 | 2967 | 2533 | 2652 | 2195 |
| 147 | 3016 | 2539 | 2646 | 2220 |
| 148 | 3064 | 2536 | 2644 | 2216 |
| 149 | 3135 | 2535 | 2645 | 2199 |
| 150 | 3159 | 2536 | 2644 | 2193 |
| 151 | 3205 | 2535 | 2646 | 2198 |
| 152 | 3248 | 2534 | 2646 | 2214 |
| 153 | 3283 | 2532 | 2644 | 2231 |
| 154 | 3317 | 2530 | 2643 | 2232 |
| 155 | 3347 | 2527 | 2639 | 2314 |
| 156 | 3376 | 2520 | 2623 | 2382 |
| 157 | 3406 | 2514 | 2606 | 2424 |
| 158 | 3436 | 2515 | 2586 | 2423 |
| 159 | 3470 | 2523 | 2567 | 2341 |
| 160 | 3506 | 2524 | 2553 | 2267 |
| 161 | 3544 | 2525 | 2551 | 2240 |
| 162 | 3583 | 2527 | 2553 | 2195 |
| 163 | 3625 | 2527 | 2549 | 2192 |
| 164 | 3667 | 2524 | 2551 | 2197 |
| 165 | 3711 | 2525 | 2554 | 2200 |
| 166 | 3756 | 2526 | 2550 | 2192 |
| 167 | 3802 | 2527 | 2550 | 2194 |
| 168 | 3849 | 2526 | 2552 | 2200 |
| 169 | 3894 | 2525 | 2550 | 2201 |
| 170 | 3939 | 2527 | 2549 | 2201 |
| 171 | 3983 | 2526 | 2548 | 2206 |
| 172 | 4025 | 2524 | 2547 | 2200 |
| 173 | 4065 | 2521 | 2546 | 2199 |
| 174 | 4105 | 2515 | 2557 | 2194 |
| 175 | 4144 | 2519 | 2555 | 2208 |
| 176 | 4183 | 2529 | 2556 | 2199 |
| 177 | 4220 | 2528 | 2556 | 2194 |
| 178 | 4257 | 2534 | 2552 | 2201 |
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| 180 | 4306 | 2531 | 2551 | 2186 |
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| 184 | 4366 | 2529 | 2555 | 2196 |
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| 188 | 4370 | 2527 | 2551 | 2193 |
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| 190 | 4371 | 2527 | 2551 | 2193 |
| 191 | 4373 | 2526 | 2551 | 2193 |
| 192 | 4378 | 2526 | 2550 | 2192 |
| 193 | 4387 | 2526 | 2549 | 2190 |
| 194 | 4400 | 2525 | 2548 | 2175 |
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| 197 | 4441 | 2529 | 2551 | 2258 |
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| 199 | 4467 | 2551 | 2528 | 2550 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| -72 | 40.65219 | 1.754934 | 52.10401 | 1625.628 | -9.70426 | 735.6927 | |
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| -77 | 44.47827 | 1.745112 | 49.24227 | 2278.19 | -8.67171 | 613.1082 | |
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| -83 | 32.04349 | 1.900491 | 28.38424 | 2647.035 | -9.71263 | 522.569 | |
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| -96 | 0.478261 | 2.263946 | 23.07712 | 2695.362 | -19.1689 | 489.1357 | |
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| -91 | -48.3044 | -3.52626 | 14.63482 | 2944.461 | -36.15 | -202.961 | |
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| 2200.081 | 14.0807 | 1431.407 | 1.884782 | 50.40884 | 1627.593 | -16.3691 | 986.0905 |
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| 2214.06 | 28.05997 | 1501.608 | 1.934419 | 48.59995 | 1776.203 | -18.4944 | 942.4722 |
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| 2210.046 | 24.04614 | 1543.707 | 1.964186 | 46.18074 | 1869.813 | -19.1661 | 904.5603 |
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| 2195.032 | 9.03232 | 1575.779 | 1.986884 | 45.73427 | 1961.41 | -20.2063 | 864.4362 |
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| 2190.853 | 4.852608 | 2981.193 | 2.980602 | 7.213345 | 2667.233 | -44.4181 | 145.0319 |
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| 2195.735 | 9.735104 | 3152.63 | 3.101821 | 0.516898 | 2725.221 | -12.9897 | -452.77 |
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| 2194.645 | 8.645248 | 3182.557 | 3.122982 | 0.260537 | 2726.254 | -13.9976 | -522.757 |
| 2254.638 | 68.63834 | 3251.195 | 3.171514 | -0.41884 | 2725.835 | -13.9937 | -536.751 |
| 2383.631 | 197.6314 | 3448.827 | 3.311255 | -2.19505 | 2723.64 | -12.8133 | -549.564 |
| 2557.625 | 371.6245 | 3820.451 | 3.574023 | -5.44602 | 2718.192 | -11.8033 | -561.367 |

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 200 | 4482 | 2579 | 2509 | 2606 | -31 | -92.3044 | -2.76747 | -5.48183 | 3032.633 | -13.9624 | -525.138 | | 2604.618 | 418.6176 | 4239.069 | 3.870019 | -9.98544 | 2708.207 | -11.1933 | -572.561 |
| 201 | 4500 | 2614 | 2502 | 2533 | 4 | -99 | -2.40308 | -12.1174 | 3020.515 | -13.3105 | -538.448 | | 2531.611 | 345.6107 | 4584.679 | 4.114392 | -14.8764 | 2693.33 | -10.1338 | -582.694 |
| 202 | 4522 | 2643 | 2509 | 2394 | 33 | -92.3044 | -2.10011 | -18.9894 | 3001.526 | -11.1087 | -549.557 | | 2392.604 | 206.6038 | 4791.283 | 4.260477 | -19.7915 | 2673.539 | -9.60709 | -592.301 |
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| 67 | 70.30437 | -0.06321 | -2.71601 | -102.799 | 42.91414 | 88.26936 | |
| 66 | 74.13046 | -0.02931 | -1.26018 | -104.059 | 42.98153 | 131.2509 | |
| 64 | 71.26089 | -0.03364 | -1.4125 | -105.472 | 41.97624 | 173.2271 | |
| 65 | 71.26089 | -0.04135 | -1.73624 | -107.208 | 41.9641 | 215.1912 | |
| 62 | 73.17393 | -0.00479 | -0.19162 | -107.399 | 39.99954 | 255.1908 | |
| 60 | 72.21741 | 0.004876 | 0.185281 | -107.214 | 37.99955 | 293.1903 | |
| 58 | 71.26089 | 0.014966 | 0.508825 | -106.705 | 33.99619 | 327.1865 | |
| 62 | 72.21741 | -0.01129 | -0.38376 | -107.089 | 33.99783 | 361.1843 | |
| 62 | 66.47828 | -0.05242 | -1.88641 | -108.975 | 35.95054 | 397.1349 | |
| 65 | 65.52176 | -0.08327 | -3.32691 | -112.302 | 39.86141 | 436.9963 | |
| 67 | 69.34785 | -0.07005 | -2.93964 | -115.242 | 41.897 | 478.8933 | |
| 65 | 67.4348 | -0.06888 | -3.02848 | -118.271 | 43.89565 | 522.7889 | |
| 68 | 68.39132 | -0.0844 | -3.87767 | -122.148 | 45.83627 | 568.6252 | |
| 70 | 71.26089 | -0.07834 | -3.59999 | -125.748 | 45.85891 | 614.4841 | |
| 68 | 72.21741 | -0.0572 | -2.62967 | -128.378 | 45.92477 | 660.4089 | |
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| 71 | 71.26089 | -0.08543 | -2.84519 | -138.959 | 30.88694 | 808.0095 | |
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| 73 | 69.34785 | -0.11292 | -2.59158 | -143.585 | 22.85353 | 856.7833 | |
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| 58 | 77.00002 | 0.052556 | 0.525318 | -146.59 | 9.986192 | 902.58 | |
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| -70 | 38.73914 | 1.763466 | 34.35238 | -24.4488 | -6.70179 | 928.1212 | |
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| | | | | | | | |
|---|---|---|---|---|---|---|---|
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| 2177.698 | -8.3017 | 9533.617 | 7.613679 | 46.62077 | -43.3881 | 11.42384 | 889.3472 |

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|---|---|---|---|---|
| 334 | 9449 | 2543 | 2647 | 2188 |
| 335 | 9497 | 2544 | 2648 | 2194 |
| 336 | 9545 | 2544 | 2647 | 2190 |
| 337 | 9592 | 2544 | 2647 | 2198 |
| 338 | 9640 | 2545 | 2648 | 2184 |
| 339 | 9687 | 2544 | 2650 | 2177 |
| 340 | 9733 | 2541 | 2651 | 2188 |
| 341 | 9778 | 2541 | 2652 | 2191 |
| 342 | 9819 | 2541 | 2653 | 2191 |
| 343 | 9855 | 2540 | 2653 | 2186 |
| 344 | 9886 | 2543 | 2651 | 2188 |
| 345 | 9909 | 2543 | 2652 | 2191 |
| 346 | 9928 | 2540 | 2654 | 2222 |
| 347 | 9945 | 2535 | 2650 | 2329 |
| 348 | 9963 | 2522 | 2635 | 2491 |
| 349 | 9980 | 2511 | 2604 | 2606 |
| 350 | 10002 | 2518 | 2567 | 2595 |
| 351 | 10027 | 2534 | 2537 | 2413 |
| 352 | 10054 | 2543 | 2531 | 2216 |
| 353 | 10083 | 2545 | 2529 | 2202 |
| 354 | 10112 | 2548 | 2526 | 2195 |
| 355 | 10142 | 2547 | 2527 | 2190 |
| 356 | 10172 | 2547 | 2528 | 2191 |
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| 358 | 10230 | 2546 | 2530 | 2195 |
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| 365 | 10419 | 2540 | 2533 | 2218 |
| 366 | 10446 | 2541 | 2533 | 2207 |
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| 370 | 10542 | 2558 | 2521 | 2368 |
| 371 | 10563 | 2574 | 2515 | 2438 |
| 372 | 10585 | 2598 | 2514 | 2526 |
| 373 | 10608 | 2631 | 2521 | 2536 |
| 374 | 10632 | 2658 | 2531 | 2411 |
| 375 | 10657 | 2671 | 2538 | 2270 |
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| 382 | 10831 | 2681 | 2540 | 2113 |
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| | | | | | |
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| -52 | -88.4783 | -2.9748 | -2.65635 | 425.3764 | -15.778 | -33.357 |
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| -4 | -91.3479 | -2.48722 | -9.1299 | 410.7961 | -11.9015 | -60.3016 |
| 25 | -88.4783 | -2.16808 | -11.5761 | 399.22 | -7.87363 | -68.1752 |
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| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 2185.691 | -0.30861 | 9533.308 | 7.613461 | 45.84706 | 2.258993 | 11.1958 | 900.543 |
| 2191.684 | 5.68448 | 9538.993 | 7.61748 | 46.66385 | 48.92285 | 11.24655 | 911.7895 |
| 2187.678 | 1.677568 | 9540.67 | 7.618666 | 46.67716 | 95.60001 | 11.19119 | 922.9807 |
| 2195.671 | 9.670656 | 9550.341 | 7.625504 | 45.77858 | 141.3786 | 10.64526 | 933.626 |
| 2181.664 | -4.33626 | 9546.005 | 7.622438 | 46.71904 | 188.0976 | 11.01505 | 944.641 |
| 2174.657 | -11.3432 | 9534.661 | 7.614416 | 45.65775 | 233.7554 | 11.15212 | 955.7931 |
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| 2188.643 | 2.643008 | 9536.954 | 7.616039 | 43.73212 | 322.1711 | 10.60667 | 977.3257 |
| 2188.636 | 2.636096 | 9539.59 | 7.617903 | 39.86277 | 362.0339 | 9.589575 | 986.9153 |
| 2183.629 | -2.37082 | 9537.22 | 7.616226 | 34.98729 | 397.0212 | 8.478777 | 995.3941 |
| 2185.622 | -0.37773 | 9536.842 | 7.615959 | 30.12599 | 427.1472 | 7.309216 | 1002.703 |
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| 2213.567 | 27.56698 | 11092.57 | 8.715982 | 17.57485 | 569.8342 | -20.4969 | 952.5801 |
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| 2187.546 | 1.54624 | 11114.23 | 8.731297 | 19.17654 | 626.2372 | -23.0708 | 885.0326 |
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| 2200.532 | 14.53242 | 11131.3 | 8.743368 | 18.26678 | 663.639 | -22.5239 | 839.4036 |
| 2192.526 | 6.525504 | 11137.83 | 8.747882 | 18.16266 | 681.8017 | -22.6079 | 816.7957 |
| 2179.519 | -6.48141 | 11131.35 | 8.743399 | 17.63621 | 699.4379 | -21.7477 | 795.0479 |
| 2180.512 | -5.48832 | 11125.86 | 8.739518 | 17.72047 | 717.1584 | -21.6791 | 773.3688 |
| 2181.505 | -4.49523 | 11121.36 | 8.73634 | 17.15396 | 734.3123 | -20.8505 | 752.5184 |
| 2175.498 | -10.5021 | 11110.86 | 8.728914 | 16.66727 | 750.9796 | -19.955 | 732.5633 |
| 2158.491 | -27.5091 | 11083.35 | 8.709463 | 17.05223 | 768.0318 | -19.6271 | 712.9363 |
| 2182.484 | -3.51597 | 11079.84 | 8.706977 | 17.75871 | 785.7906 | -20.3379 | 692.5984 |
| 2215.477 | 29.47712 | 11109.31 | 8.72782 | 17.33099 | 803.1215 | -20.7035 | 671.8949 |
| 2204.47 | 18.47021 | 11127.78 | 8.740879 | 17.05913 | 820.1807 | -20.9281 | 650.9668 |
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| 2533.422 | 347.4218 | 12455.88 | 9.679949 | -5.80545 | 869.8054 | -22.2553 | 505.4191 |
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| 2228.387 | 42.38726 | 12846.89 | 9.95642 | -13.1807 | 810.9898 | -22.4114 | 392.9691 |
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| 2210.373 | 24.37344 | 12924.64 | 10.0114 | -13.2852 | 784.2267 | -19.9876 | 351.9257 |
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| 2052.353 | -133.647 | 12699.72 | 9.852361 | -9.53748 | 750.156 | -20.9293 | 290.9272 |
| 2032.346 | -153.654 | 12546.06 | 9.743716 | -7.21184 | 742.9442 | -21.8401 | 269.0871 |
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| 2103.318 | -82.6819 | 12220.38 | 9.51343 | -1.68219 | 729.7337 | -18.9254 | 188.2589 |
| 2055.311 | -130.689 | 12089.69 | 9.421023 | 0.075096 | 729.8088 | -19.9999 | 168.2591 |
| 2001.304 | -184.696 | 11904.99 | 9.290429 | 2.544961 | 732.3538 | -18.8288 | 149.4303 |
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| 2046.29 | -139.71 | 11562.58 | 9.048317 | 6.985006 | 744.273 | -17.6695 | 114.4503 |
| 2163.284 | -22.7164 | 11539.87 | 9.032254 | 6.885383 | 751.1584 | -16.631 | 97.81927 |
| 2232.277 | 46.27667 | 11586.14 | 9.064976 | 6.337606 | 757.496 | -16.8474 | 80.97188 |
| 2308.27 | 122.2698 | 11708.41 | 9.15143 | 4.589264 | 762.0852 | -16.3688 | 64.60304 |
| 2377.263 | 191.2628 | 11899.68 | 9.286668 | 2.202745 | 764.288 | -15.8476 | 48.7554 |
| 2430.256 | 244.2559 | 12143.93 | 9.459376 | -0.55346 | 763.7345 | -15.9904 | 32.76497 |
| 2455.249 | 279.249 | 12423.18 | 9.656827 | -3.44958 | 760.285 | -14.588 | 18.16701 |
| 2456.242 | 280.2421 | 12703.42 | 9.85498 | -5.83876 | 754.4462 | -12.7243 | 5.442671 |
| 2439.235 | 253.2352 | 12956.66 | 10.03404 | -9.15616 | 745.29 | -13.1212 | -7.67848 |

| | | | | |
|---|---|---|---|---|
| 401 | 11184 | 2677 | 2535 | 2332 |
| 402 | 11206 | 2680 | 2542 | 2233 |
| 403 | 11229 | 2681 | 2543 | 2234 |
| 404 | 11255 | 2684 | 2547 | 2215 |
| 405 | 11282 | 2678 | 2553 | 2192 |
| 406 | 11310 | 2677 | 2536 | 2192 |
| 407 | 11337 | 2693 | 2543 | 2196 |
| 408 | 11364 | 2689 | 2546 | 2196 |
| 409 | 11391 | 2685 | 2546 | 2198 |
| 410 | 11417 | 2685 | 2546 | 2200 |
| 411 | 11443 | 2685 | 2545 | 2197 |
| 412 | 11465 | 2684 | 2548 | 2194 |
| 413 | 11483 | 2685 | 2547 | 2201 |
| 414 | 11496 | 2680 | 2550 | 2195 |
| 415 | 11504 | 2676 | 2547 | 2190 |
| 416 | 11509 | 2675 | 2547 | 2194 |
| 417 | 11513 | 2675 | 2548 | 2192 |
| 418 | 11515 | 2675 | 2549 | 2194 |
| 419 | 11515 | 2675 | 2549 | 2195 |
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| 435 | 11515 | 2676 | 2548 | 2189 |
| 436 | 11515 | 2675 | 2548 | 2189 |
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| 438 | 11515 | 2675 | 2548 | 2189 |
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| 444 | 11515 | 2675 | 2548 | 2189 |

| | | | | | | |
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| 67 | -67.4348 | -1.6613 | -18.9222 | 365.169 | -1.71717 | -75.1001 |
| 70 | -60.7391 | -1.58735 | -21.997 | 343.172 | -0.36408 | -75.4642 |
| 71 | -59.7826 | -1.5725 | -23 | 320.172 | -0.03921 | -75.5034 |
| 74 | -55.9565 | -1.5201 | -25.9666 | 294.2054 | 1.317475 | -74.1859 |
| 68 | -50.2174 | -1.50876 | -26.9481 | 267.2574 | 1.673924 | -72.512 |
| 67 | -66.4783 | -1.65415 | -27.9028 | 239.3546 | -2.33132 | -74.8433 |
| 63 | -59.7826 | -1.49687 | -26.9262 | 212.4283 | 1.994269 | -72.8491 |
| 79 | -56.9131 | -1.49696 | -26.9264 | 185.5019 | 1.991683 | -70.8574 |
| 75 | -56.9131 | -1.5218 | -26.9676 | 158.5343 | 1.322375 | -69.535 |
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| 75 | -57.8696 | -1.52984 | -25.9782 | 106.5873 | 1.064475 | -67.1971 |
| 74 | -55 | -1.51183 | -21.9618 | 84.62554 | 1.296563 | -65.9006 |
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| 70 | -53.087 | -1.52151 | -12.9842 | 53.6707 | 0.640453 | -64.2322 |
| 66 | -55.9565 | -1.5759 | -7.9999 | 45.67081 | -0.04079 | -64.273 |
| 65 | -55.9565 | -1.58344 | -4.9996 | 40.67121 | -0.06319 | -64.3361 |
| 65 | -55 | -1.57492 | -3.99997 | 36.67124 | -0.0165 | -64.3527 |
| 65 | -54.0435 | -1.56628 | -1.99998 | 34.67126 | 0.009026 | -64.3436 |
| 65 | -54.0435 | -1.56628 | 0 | 34.67126 | 0 | -64.3436 |
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| | | | | | | |
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| 2320.228 | 143.2283 | 13099.89 | 10.13531 | -12.3925 | 732.8975 | -14.4023 | -22.0808 |
| 2230.221 | 44.22138 | 13144.11 | 10.16658 | -14.8636 | 718.034 | -16.2196 | -38.3003 |
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| 2212.208 | 26.20755 | 13215.53 | 10.21708 | -18.5113 | 683.4494 | -18.2574 | -73.0092 |
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| 2191.152 | 5.152256 | 13269.94 | 10.25555 | -16.246 | 531.2196 | -14.8347 | -217.643 |
| 2188.145 | 12.14534 | 13282.09 | 10.26414 | -13.3959 | 517.6237 | -12.0229 | -229.666 |
| 2192.138 | 6.138432 | 13288.22 | 10.26848 | -9.71242 | 508.1113 | -8.64111 | -238.307 |
| 2187.132 | 1.13152 | 13289.36 | 10.26928 | -5.98113 | 502.1302 | -5.31282 | -243.62 |
| 2191.125 | 5.124608 | 13294.48 | 10.2729 | -3.75021 | 498.38 | -3.30695 | -246.927 |
| 2189.118 | 3.117696 | 13297.6 | 10.27511 | -3.006 | 495.374 | -2.63894 | -249.566 |
| 2191.111 | 5.110784 | 13302.71 | 10.27872 | -1.50776 | 493.8662 | -1.31403 | -250.88 |
| 2192.104 | 6.103872 | 13308.81 | 10.28304 | 0 | 493.8662 | 0 | -250.88 |
| 2190.097 | 4.09696 | 13312.91 | 10.28594 | 0 | 493.8662 | 0 | -250.88 |
| 2188.09 | 2.090048 | 13315 | 10.28741 | 0 | 493.8662 | 0 | -250.88 |
| 2188.083 | 2.083136 | 13317.08 | 10.28889 | 0 | 493.8662 | 0 | -250.88 |
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| 2188.069 | 2.069312 | 13321.23 | 10.29182 | 0 | 493.8662 | 0 | -250.88 |
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| 2187.042 | 1.041664 | 13326.44 | 10.2955 | 0 | 493.8662 | 0 | -250.88 |
| 2186.035 | 0.034752 | 13326.47 | 10.29552 | 0 | 493.8662 | 0 | -250.88 |
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| 2185.993 | -0.00672 | 13327.54 | 10.29628 | 0 | 493.8662 | 0 | -250.88 |
| 2185.986 | -0.01363 | 13327.52 | 10.29627 | 0 | 493.8662 | 0 | -250.88 |
| 2185.979 | -0.02054 | 13327.5 | 10.29625 | 0 | 493.8662 | 0 | -250.88 |
| 2185.973 | -0.02746 | 13327.47 | 10.29623 | 0 | 493.8662 | 0 | -250.88 |
| 2185.966 | -2.03437 | 13325.44 | 10.29479 | 0 | 493.8662 | 0 | -250.88 |
| 2185.959 | -2.04128 | 13323.4 | 10.29335 | 0 | 493.8662 | 0 | -250.88 |
| 2185.952 | -0.04819 | 13323.35 | 10.29332 | 0 | 493.8662 | 0 | -250.88 |
| 2185.945 | -0.0551 | 13323.29 | 10.29328 | 0 | 493.8662 | 0 | -250.88 |
| 2185.938 | -0.06202 | 13323.23 | 10.29323 | 0 | 493.8662 | 0 | -250.88 |
| 2185.931 | -0.06893 | 13323.16 | 10.29319 | 0 | 493.8662 | 0 | -250.88 |

## G.2 GPS

| 5-CH GPS | TIME | LAT | LONG | -LONG |
|---|---|---|---|---|
| | 211128 | 3833.32 | 12126.15 | -12126.2 |
| | 211129 | 3833.32 | 12126.15 | -12126.2 |
| | 211130 | 3833.32 | 12126.15 | -12126.2 |
| | 211130 | 3833.32 | 12126.15 | -12126.2 |
| | 211130 | 3833.32 | 12126.15 | -12126.2 |
| | 211133 | 3833.32 | 12126.15 | -12126.2 |
| | 211134 | 3833.32 | 12126.15 | -12126.2 |
| | 211135 | 3833.32 | 12126.15 | -12126.2 |
| | 211136 | 3833.32 | 12126.15 | -12126.2 |
| | 211137 | 3833.32 | 12126.15 | -12126.2 |
| | 211138 | 3833.32 | 12126.15 | -12126.2 |
| | 211139 | 3833.32 | 12126.15 | -12126.2 |
| | 211140 | 3833.32 | 12126.15 | -12126.2 |
| | 211141 | 3833.32 | 12126.15 | -12126.2 |
| | 211141 | 3833.32 | 12126.15 | -12126.2 |
| | 211141 | 3833.32 | 12126.15 | -12126.2 |
| | 211142 | 3833.32 | 12126.15 | -12126.2 |
| | 211144 | 3833.32 | 12126.15 | -12126.2 |
| | 211145 | 3833.32 | 12126.15 | -12126.2 |
| | 211146 | 3833.32 | 12126.15 | -12126.2 |
| | 211147 | 3833.32 | 12126.15 | -12126.2 |
| | 211148 | 3833.32 | 12126.15 | -12126.2 |
| | 211149 | 3833.32 | 12126.15 | -12126.2 |
| | 211150 | 3833.32 | 12126.15 | -12126.2 |
| | 211151 | 3833.32 | 12126.15 | -12126.2 |
| | 211152 | 3833.32 | 12126.15 | -12126.2 |
| | 211152 | 3833.32 | 12126.15 | -12126.2 |
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| 211752 | 3833.33 | 12126.05 | -12126.1 |
| 211752 | 3833.33 | 12126.05 | -12126.1 |
| 211753 | 3833.33 | 12126.05 | -12126.1 |
| 211753 | 3833.33 | 12126.05 | -12126.1 |
| 211754 | 3833.32 | 12126.04 | -12126 |
| 211756 | 3833.31 | 12126.05 | -12126.1 |
| 211758 | 3833.31 | 12126.05 | -12126.1 |
| 211759 | 3833.31 | 12126.05 | -12126.1 |
| 211759 | 3833.31 | 12126.05 | -12126.1 |
| 211800 | 3833.31 | 12126.08 | -12126.1 |
| 211801 | 3833.31 | 12126.08 | -12126.1 |
| 211803 | 3833.3 | 12126.08 | -12126.1 |
| 211804 | 3833.3 | 12126.08 | -12126.1 |
| 211804 | 3833.3 | 12126.08 | -12126.1 |
| 211805 | 3833.3 | 12126.09 | -12126.1 |
| 211806 | 3833.3 | 12126.09 | -12126.1 |
| 211808 | 3833.3 | 12126.09 | -12126.1 |
| 211808 | 3833.3 | 12126.09 | -12126.1 |
| 211809 | 3833.3 | 12126.1 | -12126.1 |
| 211810 | 3833.31 | 12126.09 | -12126.1 |
| 211811 | 3833.31 | 12126.09 | -12126.1 |
| 211811 | 3833.31 | 12126.09 | -12126.1 |
| 211813 | 3833.31 | 12126.1 | -12126.1 |
| 211814 | 3833.32 | 12126.1 | -12126.1 |
| 211815 | 3833.32 | 12126.11 | -12126.1 |
| 211817 | 3833.32 | 12126.11 | -12126.1 |
| 211817 | 3833.32 | 12126.11 | -12126.1 |
| 211818 | 3833.32 | 12126.12 | -12126.1 |
| 211819 | 3833.32 | 12126.12 | -12126.1 |
| 211820 | 3833.32 | 12126.12 | -12126.1 |
| 211820 | 3833.32 | 12126.12 | -12126.1 |
| 211822 | 3833.32 | 12126.13 | -12126.1 |
| 211823 | 3833.32 | 12126.13 | -12126.1 |
| 211824 | 3833.32 | 12126.13 | -12126.1 |
| 211825 | 3833.32 | 12126.13 | -12126.1 |
| 211827 | 3833.32 | 12126.13 | -12126.1 |
| 211828 | 3833.32 | 12126.13 | -12126.1 |
| 211829 | 3833.32 | 12126.13 | -12126.1 |
| 211829 | 3833.32 | 12126.13 | -12126.1 |
| 211830 | 3833.32 | 12126.12 | -12126.1 |
| 211831 | 3833.32 | 12126.12 | -12126.1 |
| 211833 | 3833.32 | 12126.12 | -12126.1 |
| 211833 | 3833.32 | 12126.12 | -12126.1 |
| 211834 | 3833.32 | 12126.12 | -12126.1 |
| 211834 | 3833.32 | 12126.12 | -12126.1 |
| 211834 | 3833.32 | 12126.12 | -12126.1 |
| 211835 | 3833.32 | 12126.14 | -12126.1 |
| 211837 | 3833.32 | 12126.14 | -12126.1 |
| 211840 | 3833.32 | 12126.14 | -12126.1 |
| 211841 | 3833.32 | 12126.14 | -12126.1 |

| | | | |
|---|---|---|---|
| 211808 | 3833.3 | 12126.1 | -12126.1 |
| 211808 | 3833.3 | 12126.1 | -12126.1 |
| 211808 | 3833.3 | 12126.1 | -12126.1 |
| 211812 | 3833.3 | 12126.11 | -12126.1 |
| 211813 | 3833.31 | 12126.12 | -12126.1 |
| 211814 | 3833.31 | 12126.12 | -12126.1 |
| 211815 | 3833.31 | 12126.13 | -12126.1 |
| 211816 | 3833.31 | 12126.13 | -12126.1 |
| 211817 | 3833.31 | 12126.14 | -12126.1 |

| | | | |
|---|---|---|---|
| 211842 | 3833.32 | 12126.13 | -12126.1 |
| 211843 | 3833.32 | 12126.13 | -12126.1 |
| 211845 | 3833.32 | 12126.13 | -12126.1 |
| 211846 | 3833.32 | 12126.13 | -12126.1 |
| 211846 | 3833.32 | 12126.13 | -12126.1 |
| 211847 | 3833.32 | 12126.13 | -12126.1 |
| 211848 | 3833.32 | 12126.13 | -12126.1 |
| 211849 | 3833.32 | 12126.13 | -12126.1 |
| 211850 | 3833.32 | 12126.13 | -12126.1 |

## Appendix H

## Feature Log

## Inductive Loop Summary and Plots


| | |
|---|---|
| Table H-1 | Feature Log for Route 3 |
| Table H-2 | Loops Detected Along Route 3 |
| Figure H1 | Loop 6 Route 3 |
| Figure H2 | Loop 7 Route 3 |
| Figure H3 | Loop 13 Route 3 |
| Figure H4 | Loop 15 Route 3 |

Table H-1

**Feature Log for Route 3**
(Sample Printout)

13:30:28 6-12-92

| | | |
|---|---|---|
| 0: 0:20.302 | 3 | lab7 |
| 0: 0:38.501 | 339 | lab8 |
| 0: 1:25.513 | 1556 | rt on folsom |
| 0: 2:23.141 | 4057 | light rail |
| 0: 2:42.125 | 4464 | s st |
| 0: 4:29.225 | 12367 | howe |
| 0: 5:23.616 | 17681 | occidental |
| 0: 6:12.596 | 22474 | watt |
| 0: 6:38.819 | 25039 | ped |
| 0: 7:19.583 | 28999 | power lines |
| 0: 7:55.206 | 32492 | mayhew |
| 0: 8:12.621 | 34191 | power lines |
| 0: 8:42.689 | 37125 | bradshaw |
| 0: 9:54.798 | 44174 | routiers |
| 0:10:22.730 | 46921 | ped |
| 0:10:32.230 | 47847 | mather |
| 0:11:11.847 | 51702 | ped |
| 0:11:59.620 | 56381 | zinfandel |
| 0:13:40.256 | 66214 | sunrise |
| 0:17: 9.292 | 86050 | lt on hazel |
| 0:17:30.749 | 86933 | hazel loop ramp |
| 0:17:57.381 | 88216 | hazel underpass |
| 0:18:22.390 | 90279 | hwy 50 |
| 0:21:34.329 | 108032 | sunrise |
| 0:23:20.345 | 117866 | zinfandel |
| 0:24:11.357 | 122613 | ped |
| 0:24:52.363 | 126447 | mather |
| 0:25: 1.415 | 127287 | ped |
| 0:25:31.370 | 130054 | routiers |
| 0:26:47.378 | 137131 | bradshaw |
| 0:27:37.436 | 141793 | mayhew |
| 0:28:11.833 | 144950 | power lines |
| 0:28:57.130 | 149188 | ped |
| 0:29:24.929 | 151762 | watt |
| 0:30:16.381 | 156555 | occidental |
| 0:31:13.134 | 161831 | howe |
| 0:32:28.989 | 168150 | rt on 65th |
| 0:32:41.361 | 168539 | light rail |
| 0:33:14.502 | 169222 | lt on folsom |
| 0:34: 7.133 | 171083 | lt into lab |
| 0:34:55.727 | 172338 | lab8 |
| 0:35:14.133 | 172696 | lab7 |
| 0:35:19.382 | 172696 | sunny, scattered clouds |
| 0:35:33.532 | 172696 | |

Table H-2

**Loops Detected Along Route 3**
(Sample Printout)

```
*** LOOP SUMMARY ***

Date:          6-12-92
Start time:   13:30:28
Loop:             1
Frequency:    4859.2
Odometer:     4062
Loop detected at elapsed time  0: 2:23.154

Date:          6-12-92
Start time:   13:30:28
Loop:             2
Frequency:    6911.4
Odometer:     4078
Loop detected at elapsed time  0: 2:24.049

Date:          6-12-92
Start time:   13:30:28
Loop:             3
Frequency:    14.7
Odometer:     4277
Loop detected at elapsed time  0: 2:32.726

Date:          6-12-92
Start time:   13:30:28
Loop:             4
Frequency:    69759.7
Odometer:     4411
Loop detected at elapsed time  0: 2:40.066

Date:          6-12-92
Start time:   13:30:28
Loop:             5
Frequency:    241.8
Odometer:     4463
Loop detected at elapsed time  0: 2:40.798

Date:          6-12-92
Start time:   13:30:28
Loop:             6
Frequency:    19481.1
Odometer:    25037
Loop detected at elapsed time  0: 6:38.489

Date:          6-12-92
Start time:   13:30:28
Loop:             7
Frequency:    24355.0
Odometer:    86036
```

Loop detected at elapsed time 0:17:8.515

Date: 6-12-92
Start time: 13:30:28
Loop: 8
Frequency: 4602.7
Odometer: 118148
Loop detected at elapsed time 0:23:23.025

Date: 6-12-92
Start time: 13:30:28
Loop: 9
Frequency: 19481.1
Odometer: 126022
Loop detected at elapsed time 0:24:47.483

Date: 6-12-92
Start time: 13:30:28
Loop: 10
Frequency: 51546.5
Odometer: 127329
Loop detected at elapsed time 0:25:1.565

Date: 6-12-92
Start time: 13:30:28
Loop: 11
Frequency: 47955.2
Odometer: 136713
Loop detected at elapsed time 0:26:42.590

Date: 6-12-92
Start time: 13:30:28
Loop: 12
Frequency: 26663.7
Odometer: 149305
Loop detected at elapsed time 0:28:58.150

Date: 6-12-92
Start time: 13:30:28
Loop: 13
Frequency: 53855.2
Odometer: 151497
Loop detected at elapsed time 0:29:21.788

Date: 6-12-92
Start time: 13:30:28
Loop: 14
Frequency: 46929.1
Odometer: 152800
Loop detected at elapsed time 0:29:35.764

Date: 6-12-92
Start time: 13:30:28
Loop: 15

Frequency: 54111.7
Odometer: 161226
Loop detected at elapsed time 0:31:6.332

Date: 6-12-92
Start time: 13:30:28
Loop: 16
Frequency: 19994.1
Odometer: 163266
Loop detected at elapsed time 0:31:28.450

Date: 6-12-92
Start time: 13:30:28
Loop: 17
Frequency: 7168.0
Odometer: 168538
Loop detected at elapsed time 0:32:41.033

Date: 6-12-92
Start time: 13:30:28
Loop: 18
Frequency: 5628.8
Odometer: 168554
Loop detected at elapsed time 0:32:41.286

Date: 6-12-92
Start time: 13:30:28
Loop: 19
Frequency: 7168.0
Odometer: 168566
Loop detected at elapsed time 0:32:41.671

Date: 6-12-92
Start time: 13:30:28
Loop: 20
Frequency: 29485.5
Odometer: 169163
Loop detected at elapsed time 0:33:11.669

Date: 6-12-92
Start time: 13:30:28
Loop: 21
Frequency: 28972.4
Odometer: 169189
Loop detected at elapsed time 0:33:12.798

Date: 6-12-92
Start time: 13:30:28
Loop: 22
Frequency: 29229.0
Odometer: 169228
Loop detected at elapsed time 0:33:14.476

Date: 6-12-92

Start time: 13:30:28
Loop: 23
Frequency: 45389.9
Odometer: 171162
Loop detected at elapsed time 0:34:11.272

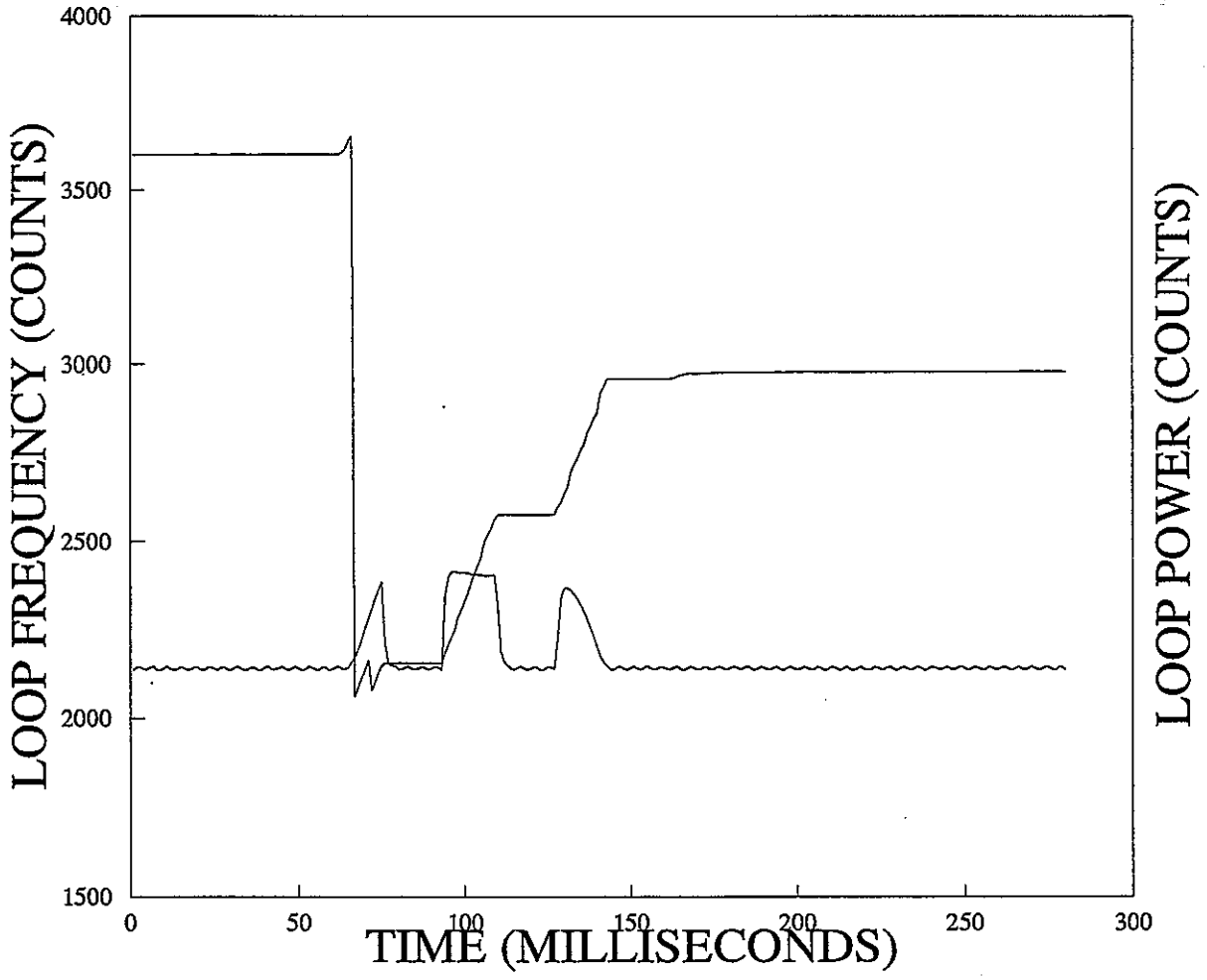


Figure H1 Inductive Loop 6
Route 3 June 12, 1992

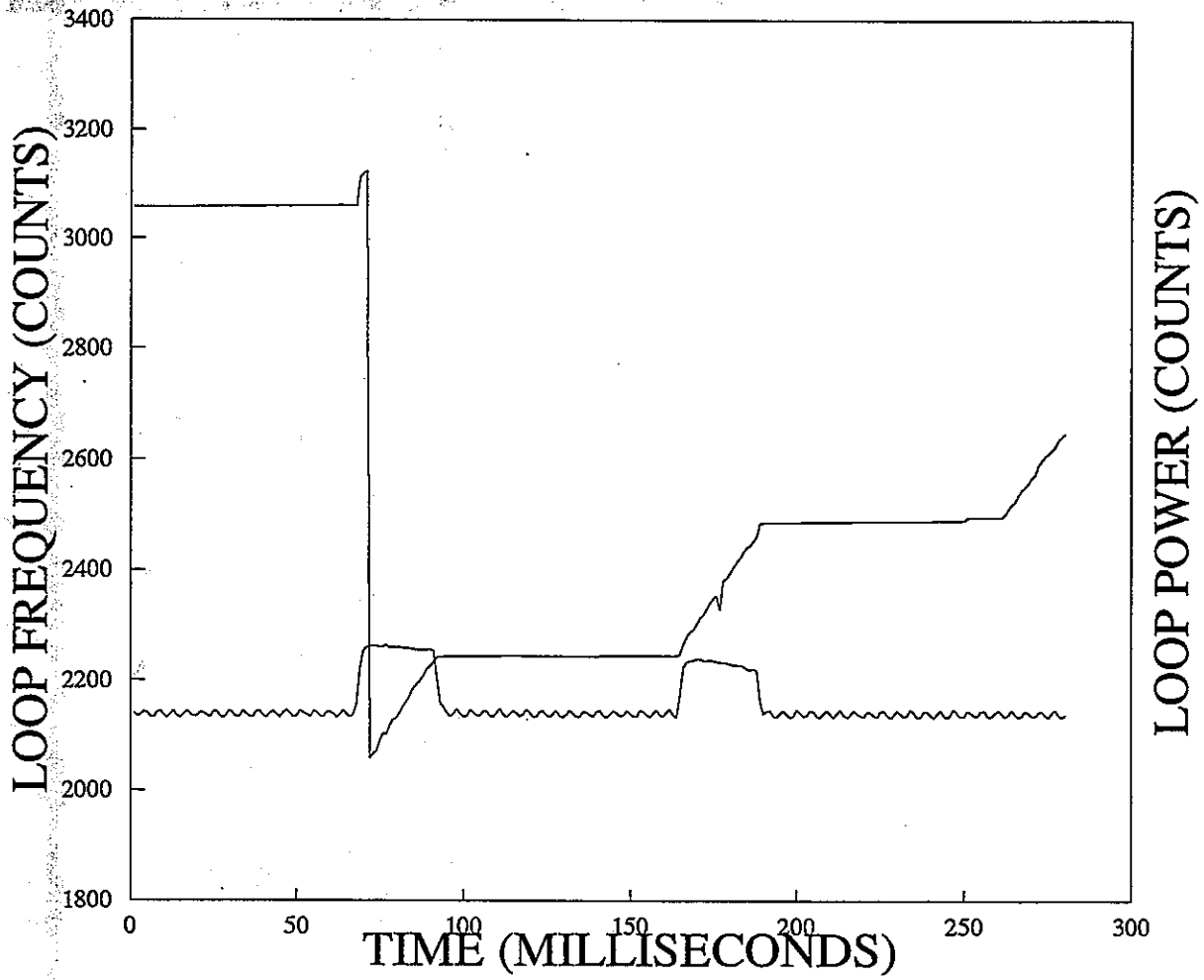


Figure H2 Inductive Loop 7
Route 3 June 12, 1992

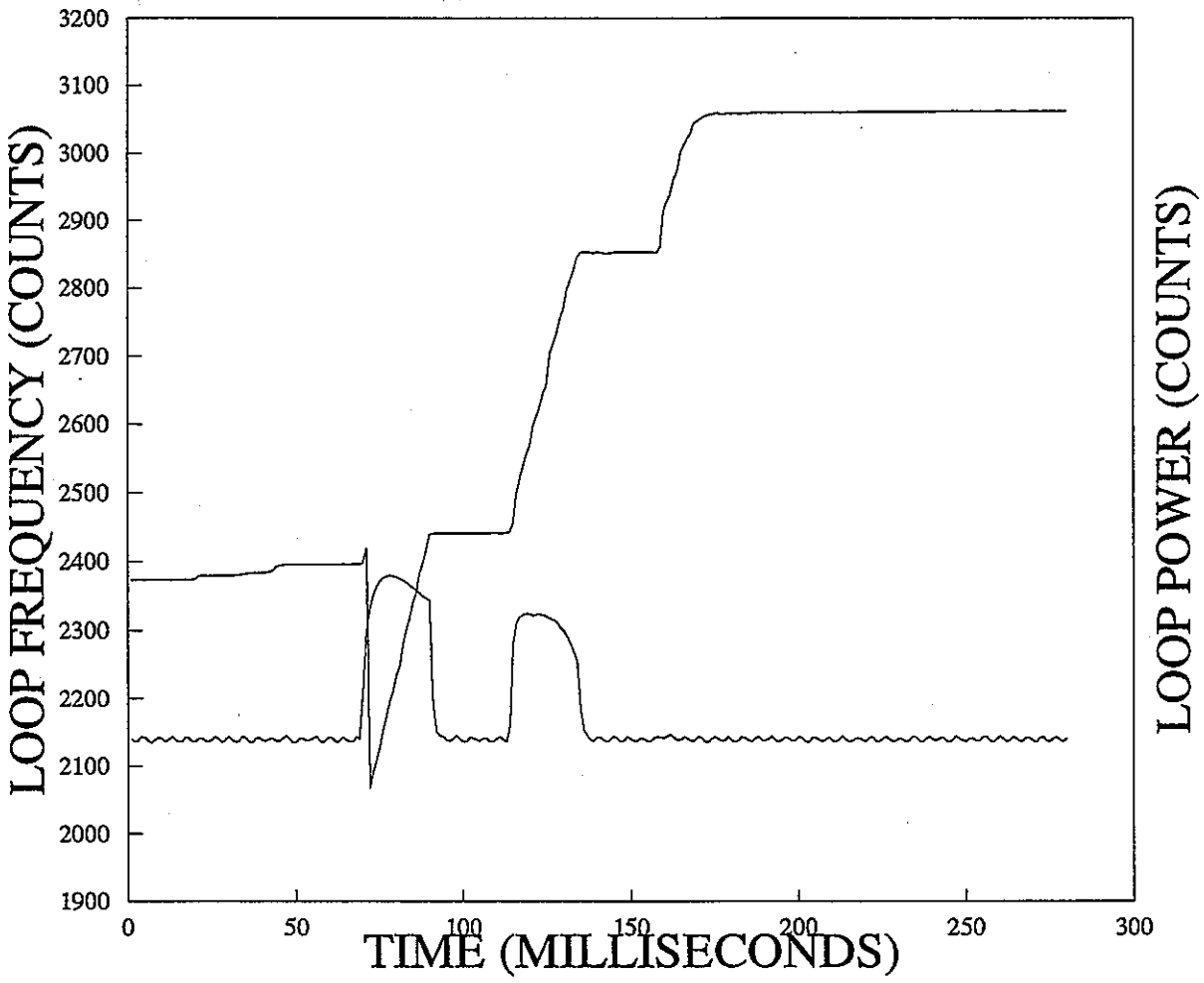


Figure H3 Inductive Loop 13
Route 3 June 12, 1992

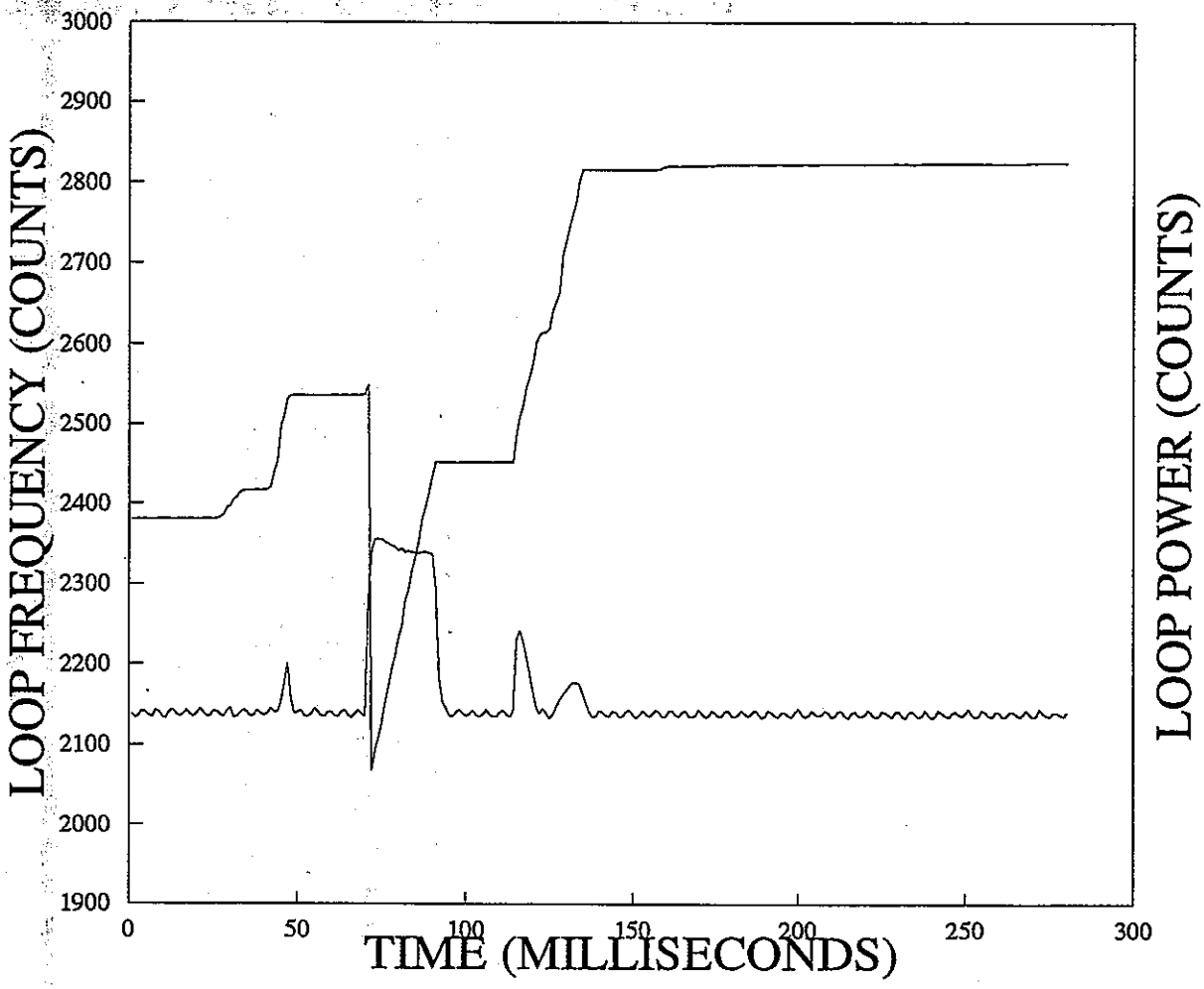


Figure H4 Inductive Loop 15
Route 3 June 12, 1992

## APPENDIX I

## INRAD

### A Short Range Roadway/Vehicle Communication System

INRAD was a Caltrans sponsored project to demonstrate the use of short range, two-way communication between vehicles and the roadway. INductive RADio (INRAD) was the technology chosen for the demonstration. This is a summary of the project.

California has led the world in the development of its highway system. The system now is reaching saturation in many areas. Although some increases in traffic capacity will be gained by constructing new facilities, this response is both temporary and insufficient. Programs and technologies must be implemented that emphasize alternative modes of transportation, increase the use of electronic communications as an alternative to transportation, and optimize the use of existing facilities.

Many innovative ways of optimizing highway operation and of assisting the growth of mixed and alternative transportation modes are based upon some communication of intelligence between vehicles and their roadways. Short range communication is perceived to have some unique capabilities, and its short range aspect strongly implies transportation agency involvement. The INRAD project examined potential applications of one short range communication technology.

WHAT IS INDUCTIVE RADIO?

Inductive radio is an inherently short range radio technique that uses relatively low frequency radio. It can be thought of as two halves of an electrical transformer. One half is fixed in the infrastructure and the other is mounted on the vehicle. Communication only occurs when the two halves are very close to each other.

The INRAD project utilized existing pavement mounted inductive loops as antennas to communicate with smaller antennas mounted on vehicles that passed overhead. Inductive loops are currently used to sense vehicle presence at traffic lights and to monitor traffic on highways.

A normal vehicle detector may employ a 20 kilohertz signal impressed on wire loops cut into the pavement. INRAD communications was done at 360 kilohertz on the same wire loops. The two functions did not interfere with each other. Inductive radio was installed by replacing standard loop controller cards with modified cards within the roadside controller cabinets. For the demonstration, an additional

computer was installed in each cabinet to handle INRAD related functions.

The in-vehicle INRAD transponder electronics and antenna were fabricated on a single printed circuit board and molded into a tabular package measuring about 5.5 by 6.5 by 1 inches. This was mounted beneath the rear of the INRAD demonstration vehicles.

Inductive radio was chosen for the project for a number of reasons. It is well within the state-of-the-art. Inductive radio communication technology could be installed with only minor modifications to the existing infrastructure. Traffic disruptions during implementation were minimal.

The INRAD project emphasized the use of low-cost, straightforward technology that is suitable for rapid implementation. Equipment selection relied heavily on off-the-shelf components.

INRAD Project Goals

The goals of the INRAD project were to identify those transportation users who can benefit from short range communication, to identify specific application for these users, and to demonstrate those applications having significant positive impact. The INRAD project was not focused on proving that inductive radio is the optimum technology for short range communication.

The Demonstration

Caltrans with the help of the Caltrans Los Angeles District Office, California Polytechnic State University, San Luis Obispo, and IBI Group of Newport Beach staged the INRAD demonstration during May of 1992. An attempt was made to demonstrate or simulate specific applications for a wide variety of users. Representatives from specific application areas were asked to comment on how their organizations could benefit from short range communication.

SYSTEM CONSTRAINTS

The project addressed applications that would make sense if implemented on a regional scale. Many of these would require roadway installations spaced at intervals on the order of one mile. Potential applications involved a broad spectrum of private vehicle, private sector, and public sector users.

Design Must Scale to Full Implementation

It was required that all demonstrated applications must be able to coexist in a full scale implementation. It was also

required that the vehicle/roadway communication link must be able to handle a full implementation where virtually all vehicles are instrumented.

No attempt was made to install the roadway controller to control center communication and computational bandwidth necessary for full implementation. However, the existing four wire telephone company service which is shared by 16 cabinets should be adequate for implementation with 100 percent vehicle instrumentation. The computational capabilities at the Traffic Operations Center would require major additions if hundreds of such lines were to be serviced simultaneously. It would also be advisable to redesign the communication protocols.

Navigational Element

One of the most useful features of short range communication is its navigational element. If the roadway transmitter identifies itself, the vehicle knows its location within the maximum range of that specific roadway transmitter.

The navigation element is particularly precise with INRAD because communication only occurs when the vehicle antenna is within the confines of an inductive loop. On California highways, this is approximately five feet. This resolution is potentially valuable to automated roadway measurement equipment, highway inventory loggers, and automated maintenance equipment. INRAD class resolution would also give meaning to lane specific information.

INRAD's superior position fixing resolution may well be its most important feature. INRAD could be used as positioning beacons that could economically fix vehicle position without the multi-pathing and shadowing problems associated with both ground and satellite based microwave systems.

Simple Outbound Message

The message that is passed from the roadway to the vehicle is called the outbound message. Implementation is vastly simplified by limiting the outbound message to location and generic status. Attempting to send specific messages to specific vehicles increases complexity and data bandwidth by orders of magnitude. A message that has no application specific information may be less functional for any given use but has infinite ability to service varied applications. A priori knowledge of future applications also becomes unnecessary.

It was rationalized that the subset of vehicles that needed to be individually accessed could be more cost effectively contacted through alternative technology. Pager systems and cellular telephones are currently available possibilities.

The passing of real time traffic information to vehicles was included in the INRAD demonstration message. Following this functionality through to its logical conclusion, however, left considerable question if this is an appropriate function for short range communication. Alternatives are discussed below under Advanced Travel Information Systems.

### Inbound Messages

Messages from the vehicle to the roadway were called inbound messages. The inbound INRAD message gave identification and status. The identification codes define specific vehicles, and it is expected that each vehicle message will be routed to the appropriate fleet management center. The vehicle status codes may then have meaning specific to that fleet or even an individual vehicle.

Even though it is more practical for the system to specify a fixed meaning for outbound status codes, there is no reason that inbound message status codes cannot be individually defined.

## INRAD DEMONSTRATION DESIGN SPECIFICS

The project demonstrated concepts as opposed to specific technology solutions. The hardware and software used in the demonstration were chosen for ease of prototyping and to inexpensively evaluate these concepts. This was an exercise in market analysis as opposed to product development.

### In-Vehicle Equipment

Beyond the INRAD transponder, the in-vehicle equipment was selected to reduce prototyping costs and was not an attempt to develop potential products. The operator interface was a four line by 20 character alphanumeric display with seven buttons for operator inputs. A beeper was incorporated to annunciate button pushes and the arrival of messages. Voice synthesis would probably have been used if the expected development effort had been less threatening.

A MS-DOS based computer was used within the vehicle because it afforded a familiar platform for software development. The 20 dollar microcontroller used to run the operator interface probably had adequate capacity to handle the whole application but would have required more development effort.

### In-Cabinet Equipment

The in-cabinet installation involved removing the existing vehicle detector cards and replacing them with cards containing the radio element. These cards continued to provide all of the original functionality. The radio was

accessed by separate connectors included on the face of the cards.

A MS-DOS computer similar to the in-vehicle computer was installed in each controller cabinet. This computer performed two way communication through each of the modified detector cards. It also had a modem which was used to communicate to an INRAD Project communications processor through previously existing phone lines. The cabinet's DOS computer collected vehicle counts and occupancies as well as controlling the roadway to vehicle communications.

The phone lines connecting each cabinet and the central communications processor were the same lines used by the District Traffic Operations Center (TOC) computer to monitor the in-cabinet type 170 controller. To save development time and cost, the in-cabinet controller was not communicated with when the INRAD DOS system was active.

Communication Link

Controller cabinets communicated to the District TOC through four wire telephone company lines using 1200 BAUD modems. The sixteen cabinets used for this project were daisy chained to one phone line using active bridges. Passive bridges were installed in each cabinet so that either the in-cabinet type 170 controller or the INRAD DOS computer could be accessed. Coded polling messages were used to select specific DOS computers or type 170 controllers.

Communication Processor

The communications Processor (CP) was located in the District office. It was a Motorola 68030 based VME chassis computer running under the OS-9 operating system. Processor and operating system selection was strongly affected by the Caltrans effort to develop an advanced transportation controller of similar configuration.

The CP polled the cabinets at 30 second intervals and logged those transactions to disk. The CP also allowed access to this information by phone from remote stations. Two such ports were available. One was dedicated to local terminal interaction and the other attached to a dial up line.

Basic Command Computer

A Basic Command Computer (BCC) was implemented on a MS-DOS computer. This could communicate with the PC to send and receive information to the cabinet computers. It acted as a character based control work station.

Graphic Command Computer

A Graphic Command Computer (GCC) was implemented on a Sun graphics workstation. This graphics workstation was programmed to display maps of the test area with icons that moved through the map in response to actual vehicle reports. Pop up dialog boxes were also implemented to allow monitoring detailed information on specific vehicles or cabinets within the test section.

USAGE EXAMPLES

There were a number of usages considered during the demonstration project. They fell into a couple of basic categories. INRAD could track vehicles and monitor their status. It could also tell vehicles where they are and pass them information.

Advanced Traveler Information Systems

Advanced Traveler Information Systems (ATIS) were a target application for INRAD. Initial thought was that information regarding the roadway ahead should be passed to vehicles as they pass over INRAD loops.

There are a number of reasons why it is expensive and difficult to pass large quantities of information to vehicles through short range radio. The real issue, however, is the advisability of using short range methods even if they were cost effective.

Information is only of benefit if it is used to make a decision. A driver has limited ability to make a productive travel decision when already in the trouble area. The more time the driver has to react, the greater are his/her options. The most productive decision point is before even entering a vehicle to become a driver.

Fleet dispatch centers have need for traffic information so they can guide their fleets to avoid congestion. All of this implies that a long rang technology is more appropriate for disseminating traffic information.

Once a vehicle is committed to a path, the in-vehicle system needs to warn the driver of changing conditions that affect its route. This can best be done by a computer onboard the vehicle that listens to all of the available traffic data and passes only appropriate information to the driver. Such a computer needs to know vehicle position.

The INRAD navigation element, Global Positioning System (GPS), dead reckoning navigation, and map matching are some of the competing technologies for a position sensor. Each has its advantages but each also has its failings. A combination of position sensing technologies is almost mandatory for superior performance under all conditions, but

a single technology may be quite adequate for some less demanding applications. The in-vehicle requirements of INRAD would be significantly less expensive than for any of the other technologies, and would out perform all of them in some scenarios.

Advanced Traffic Management Systems

Some Advanced Traffic Management Systems (ATMS) can also be assisted by short range communication systems. The "vehicles as probes" concept is currently getting a lot of attention. Vehicles are tracked as they progress through traffic and highly accurate link times can be determined. There is also potential to pass emergency status messages to vehicles and for vehicles to report incidents to transportation authorities.

Fleet Management

INRAD is particularly well suited to tracking busses and other fleet vehicles that operate within the instrumented area.

It is not necessary for the fleet vehicle to have either a navigator or a radio. Fleet management does not need to obtain a FCC frequency allocation. Fleet management can get location every time one of its fleet vehicles crosses an instrumented loop. Vehicles could keep management informed of payload and vehicle operation status. Fleet management could use a paging service to send messages to the vehicles that INRAD was monitoring.

RESULTS

Quite a bit of media interest was shown at the INRAD demonstration. However, the main targets of the demonstration were public transit and fleet management. These sectors showed little interest in the concepts. They saw INRAD as strictly a freeway system and their operations extended to surface streets.

Interest was shown by Caltrans managers who had specific applications for portions of the INRAD technology. One immediate application is tracking Freeway Service Patrols (FSP). These are tow trucks hired by Caltrans to cruise congestion hot-spots and quickly remove disabled vehicles. Caltrans is currently using INRAD technology and equipment to assist in evaluating the effectiveness of these patrols.

ALTERNATIVES TO INRAD

As stated above, the INRAD project was not intended to sell inductive radio as the short range communication technology of choice. California has recently developed an Automatic

Vehicle Identification (AVI) specification for use in Automatic Toll Collection (ETC). A form of two way microwave communication was selected for this application. The new standard serves many of the same functions as INRAD and is virtually assured of implementation on the State's toll facilities.

CONCLUSIONS

Short range communication is an excellent solution to a number of advanced traffic information and control applications. Large scale implementation, however, is necessary to get maximum benefit. Two way communication implies communications channels linking fleet managers with the infrastructure and the addition of significant computational power.

On the other hand, the advent of automatic toll collection is, essentially, an implementation of short range communication. Uses may well grow into other application areas as the benefits become evident and infrastructure investment is amortized against toll collection.

Near term implementations of a fully two way INRAD type system will probably be limited to special purpose applications in well defined corridors.

RECOMMENDATIONS

Full function INRAD should only be implemented where it is the most cost effective solution to a given application. It should compete with microwave AVI technology for these projects.

A one way, fixed message implementation would cost orders of magnitude less than a two way system. Retrofitting existing controllers may cost several hundred dollars per instrumented loop, but the incremental cost of INRAD in new systems should be well under a hundred dollars per loop. In either case, operating costs would be minimal because no communications are needed to or from the controller cabinets. Traffic light control loops at signalized intersections could easily be included in the project.

If a percentage of the inductive loops in a significant area were instrumented to transmit codes that indicated location (latitude and longitude), centerline azimuth, and some other fixed information (lane, speed limit, etc). A highly accurate and reliable navigator could be added to a vehicle for well under one hundred dollars.

## Appendix J

## Loop Excitation Monitor Calibration

The loop excitation monitor was calibrated by using a signal generator, frequency counter and an oscilloscope. A sine wave signal was applied to the loop excitation input (JS 6) of the signal conditioning board. The frequency of the signal was varied from 10 kHz to 100 kHz in approximately 10-kHz increments. The ramping output signal at U7 pin 6 was monitored with an oscilloscope. The slope of the ramp is proportional to the frequency of input signal. The input frequency, measured with a frequency counter, and the corresponding time required for the output to ramp from 0 to 7.8 volts was recorded (see Table J-1). The slope of the ramp was calculated from the equation

$$\text{slope (V/s)} = 7800 \text{ mV} / \text{time (ms)} \qquad (1)$$

A plot of frequency against time is shown in Figure J-1. Linear regression was performed on the variables. A best fit curve and equation were determined and are shown in the figure. Solving equation 1 for time yields

$$\text{time (ms)} = 7800 \text{ mv} / \text{slope (V/s)} \qquad (2)$$

Substituting equation 2 into the best fit equation yields

$$y = -14.7266 + 4097819 / 7800 / \text{slope} \qquad (3)$$

or

$$y = -14.7216 + (525.3614 \text{ X slope}) \qquad (4)$$

where $y$ = frequency

Substituting the slopes calculated in Table J-1 yields the calculated frequencies shown in the fourth column (CALFREQ). The error between the calculated and measured frequencies is tabulated in the %ERR column.

Equation 4 was used in the NAV.C routine to calculate the loop frequency. The voltage attained at the end of a 10-ms interval was used to calculate the slope of the ramp.

TABLE J-1

LOOP EXCITATION MONITOR CALIBRATION

| FREQ | TIME | SLOPE | CALFREQ | %ERR |
|---|---|---|---|---|
| 10080 | 406.5 | 19.18819 | 10066.00 | 0.138800 |
| 10768 | 379.5 | 20.55335 | 10783.21 | -0.14130 |
| 11026 | 371 | 21.02425 | 11030.60 | -0.04178 |
| 12016 | 341 | 22.87390 | 12002.33 | 0.113699 |
| 13075 | 312.5 | 24.96 | 13098.29 | -0.17815 |
| 13985 | 293.5 | 26.57580 | 13947.17 | 0.270446 |
| 14980 | 273 | 28.57142 | 14995.59 | -0.10413 |
| 15025 | 272.5 | 28.62385 | 15023.14 | 0.012370 |
| 16403 | 249.5 | 31.26252 | 16409.39 | -0.03900 |
| 18245 | 223.5 | 34.89932 | 18320.03 | -0.41125 |
| 19849 | 207 | 37.68115 | 19781.50 | 0.340065 |
| 19970 | 204 | 38.23529 | 20072.62 | -0.51387 |
| 22522 | 182 | 42.85714 | 22500.76 | 0.094297 |
| 24940 | 164 | 47.56097 | 24971.97 | -0.12820 |
| 27280 | 150.5 | 51.82724 | 27213.30 | 0.244477 |
| 29830 | 137.2 | 56.85131 | 29852.75 | -0.07629 |
| 34900 | 117.4 | 66.43952 | 34890.03 | 0.028553 |
| 40360 | 101.6 | 76.77165 | 40318.13 | 0.103722 |
| 45230 | 90.6 | 86.09271 | 45215.06 | 0.033023 |
| 50000 | 82.1 | 95.00609 | 49897.80 | 0.204386 |
| 55080 | 74.4 | 104.8387 | 55063.48 | 0.029982 |
| 60450 | 67.8 | 115.0442 | 60425.08 | 0.041221 |
| 70010 | 58.4 | 133.5616 | 70153.40 | -0.20483 |
| 80300 | 51 | 152.9411 | 80334.66 | -0.04317 |
| 90280 | 45.4 | 171.8061 | 90245.60 | 0.038099 |
| 99940 | 41 | 190.2439 | 99932.07 | 0.007926 |

Figure J1
Loop Excitation Monitor Calibration Plot

HYPERBOLIC 1 Y = A + (B/X)

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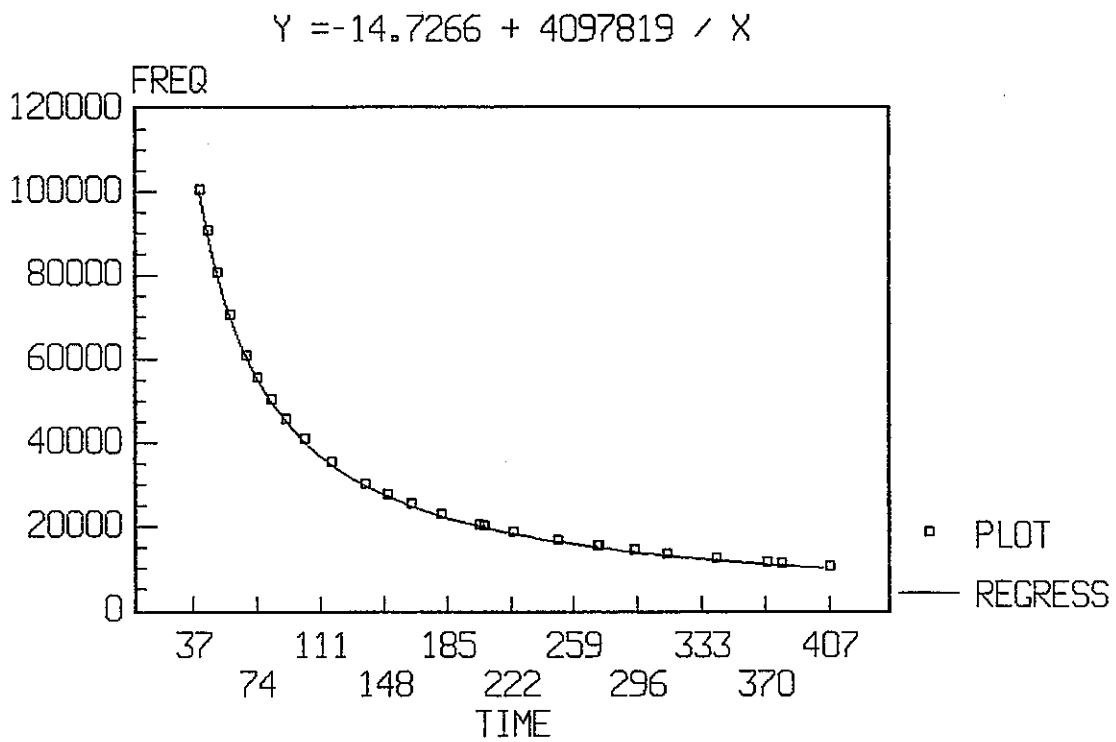
Y = -14.7266 + 4097819 / X

UNADJUSTED R^2 = 1
CORRELATION COEFFICIENT = 1

ANOVA FOR PREDICTION F = 6288437
CHANCE PROBABILITY P = <.0001

STD ERROR OF ESTIMATE = 51.4328
VARIANCE OF ESTIMATE = 2645.333

DEGREES OF FREEDOM = 1 AND 24

WITH X = TIME AND Y = FREQ

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