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

EVALUATE VEHICLE NAVIGATION AND COMMUNICATION TECHNOLOGIES

Report Number FHWA/CA/TL-93-15
Caltrans Study Number F90TL04

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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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CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quality	English Unit	Multiply By	To Get Metric Equivalent
Length	inches (in) or (")	25.40 .02540	millimetres (mm) metres (m)
	feet (ft) or (')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2) square feet (ft^2) acres	6.432×10^{-4} .09290 .4047	square metres (m^2) square metres (m^2) hectares (ha)
Volume	gallons (gal) cubic feet (ft^3) cubic yards (yd^3)	3.785 .02832 .7646	litre (l) cubic metres (m^3) 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) feet per second (fps)	.4470 .3048	metres per second (m/s) 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) kips (1000 lb)	4.448 4448	newtons (N) newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb) foot-kips (ft-k)	1.356 1356	joules (J) joules (J)
Bending Moment or Torque	inch-pounds (in-lb) foot-pounds (ft-lb)	.1130 1.356	newton-metres (Nm) 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

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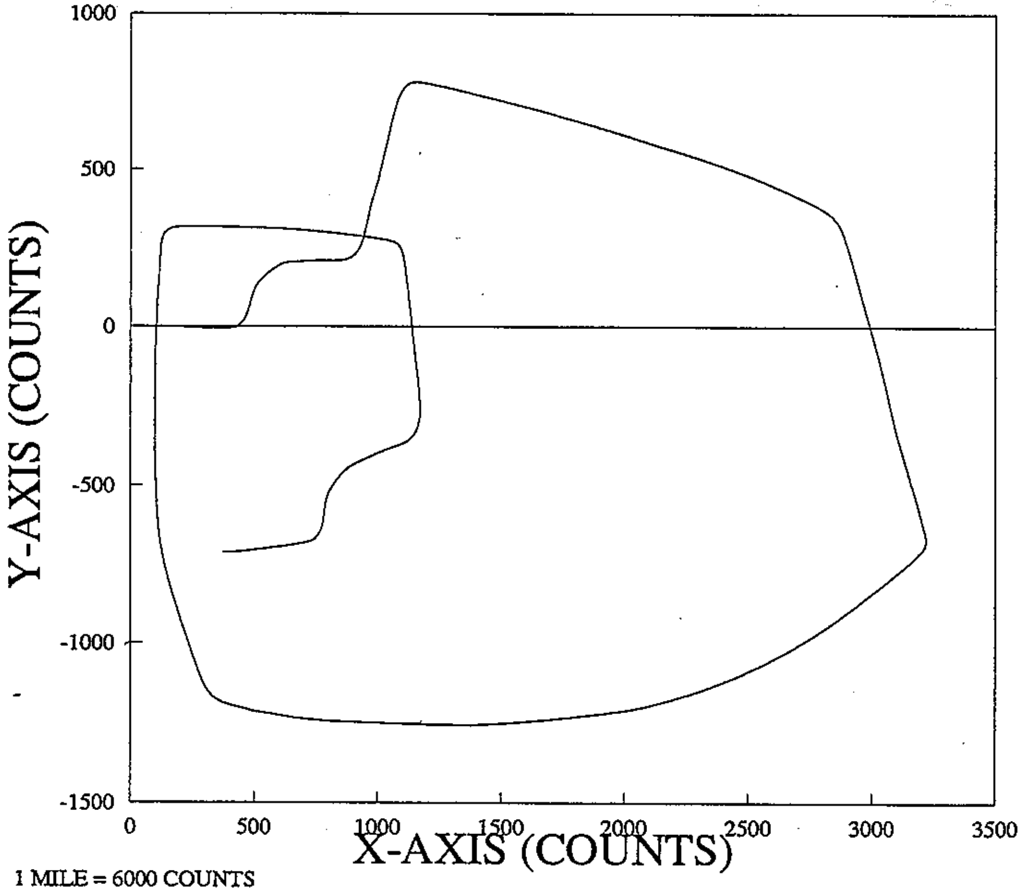


Figure 42

Angular Rate Sensor Path
Route 1 June 1, 1992

TABLES

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)

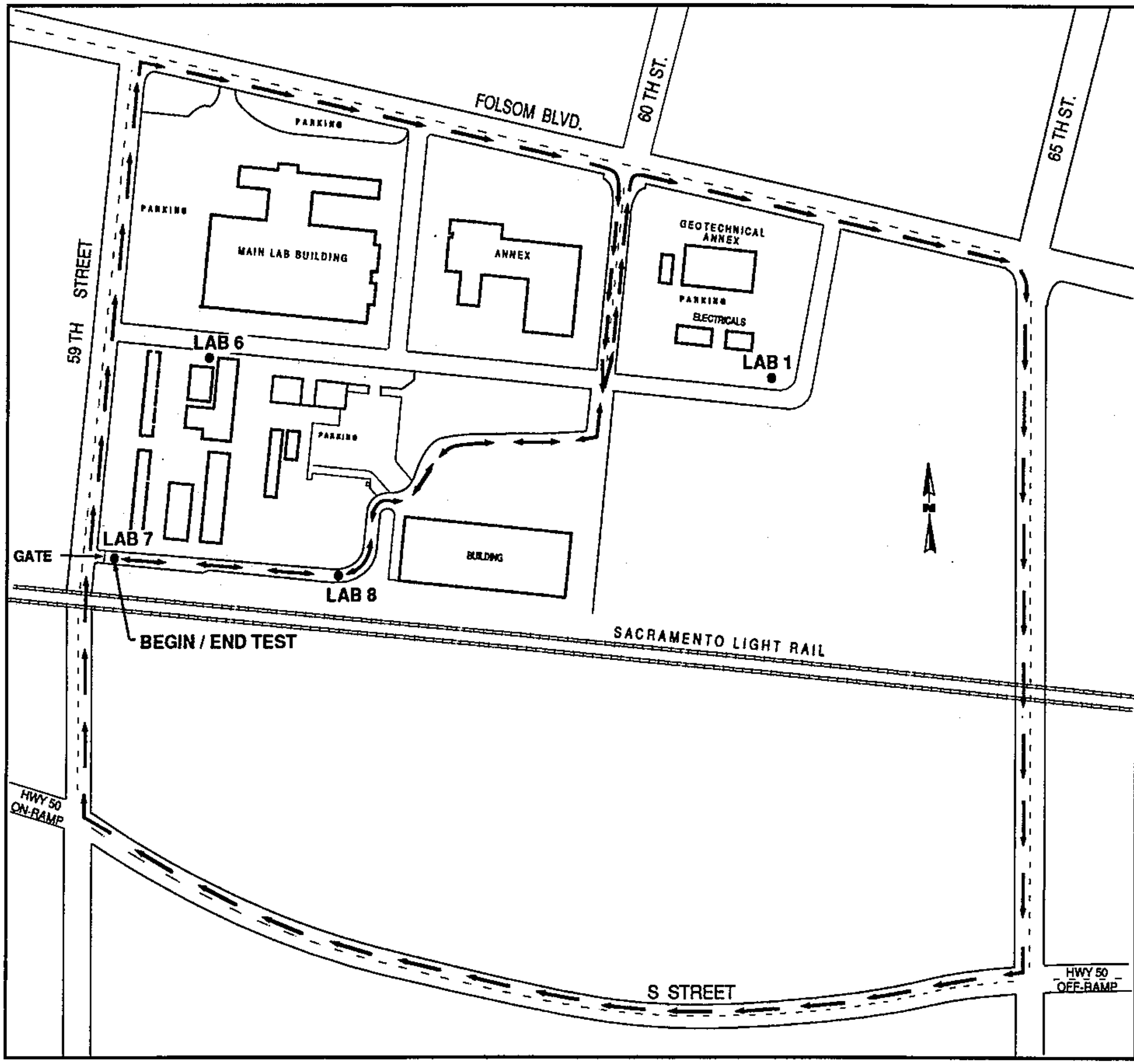
* Begin data logging on Highway 50 in the westbound direction as soon as the vehicle crosses the 10 mile mile marker.
* Exit Highway 50 at the Mather Field Rd. off-ramp.
* South on Mather Field Rd. to eastbound Highway 50 loop ramp.
* East on Highway 50 to Zinfandel Dr. exit.
* North on Zinfandel Dr. 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**

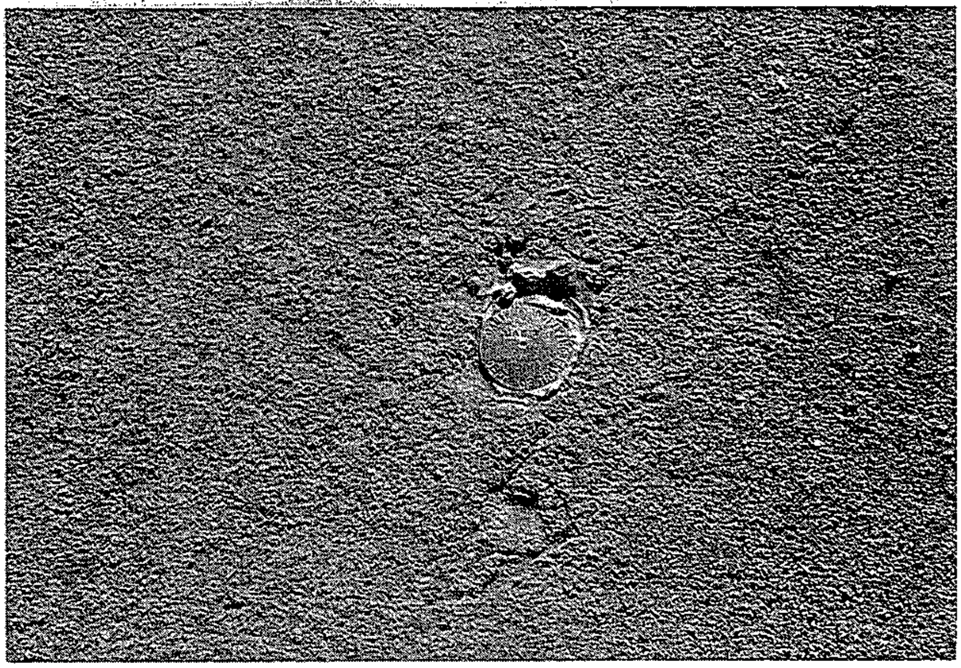


Figure 2

Lab 7 Survey Marker

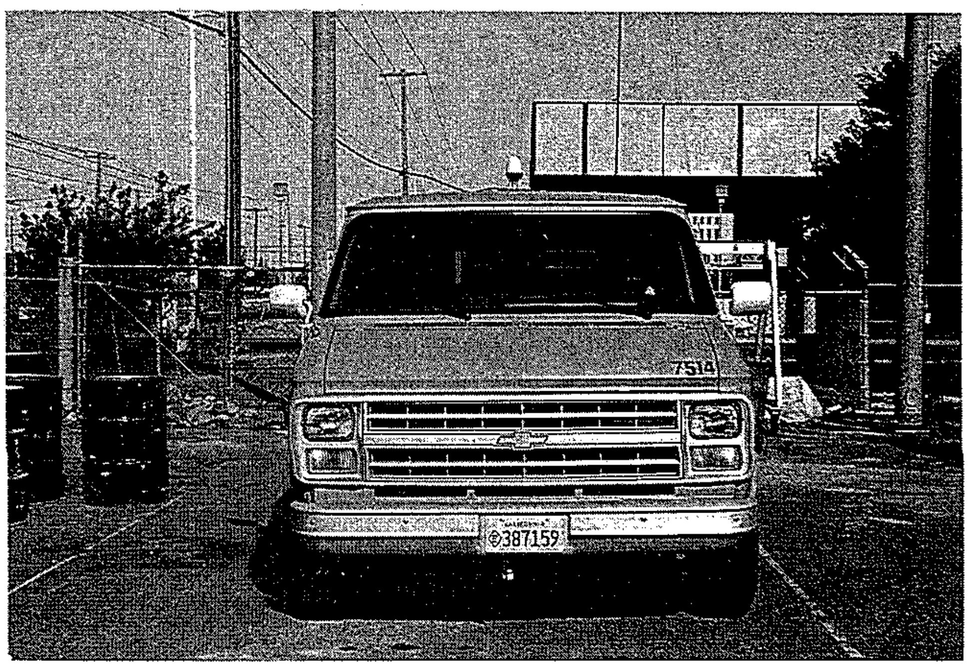


Figure 3

Test Vehicle Parked Over Lab 7 Marker

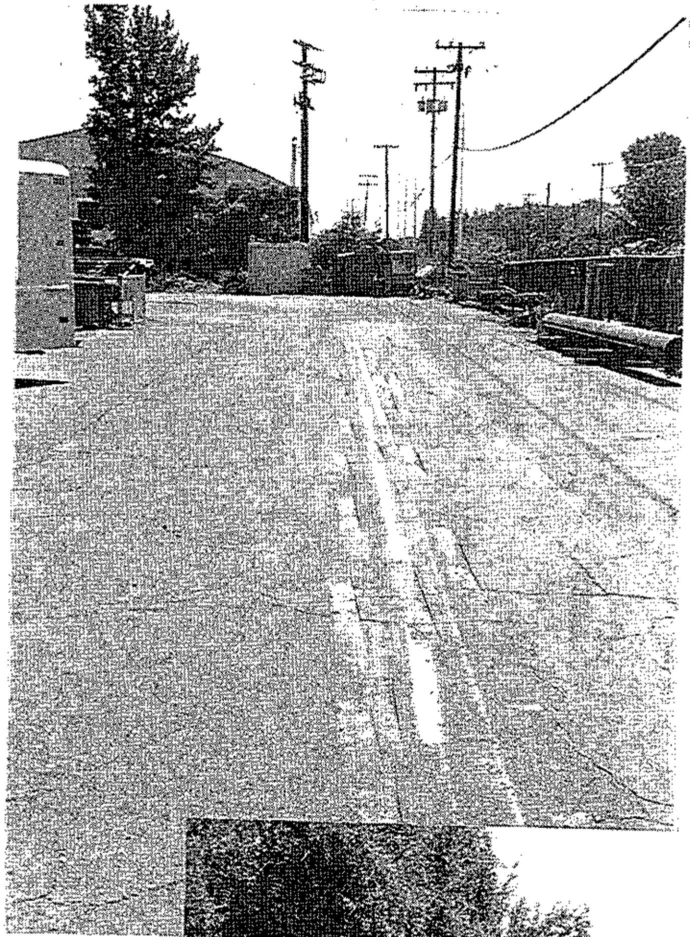


Figure 4

Route 1 Eastbound Approaching Lab 8 Marker

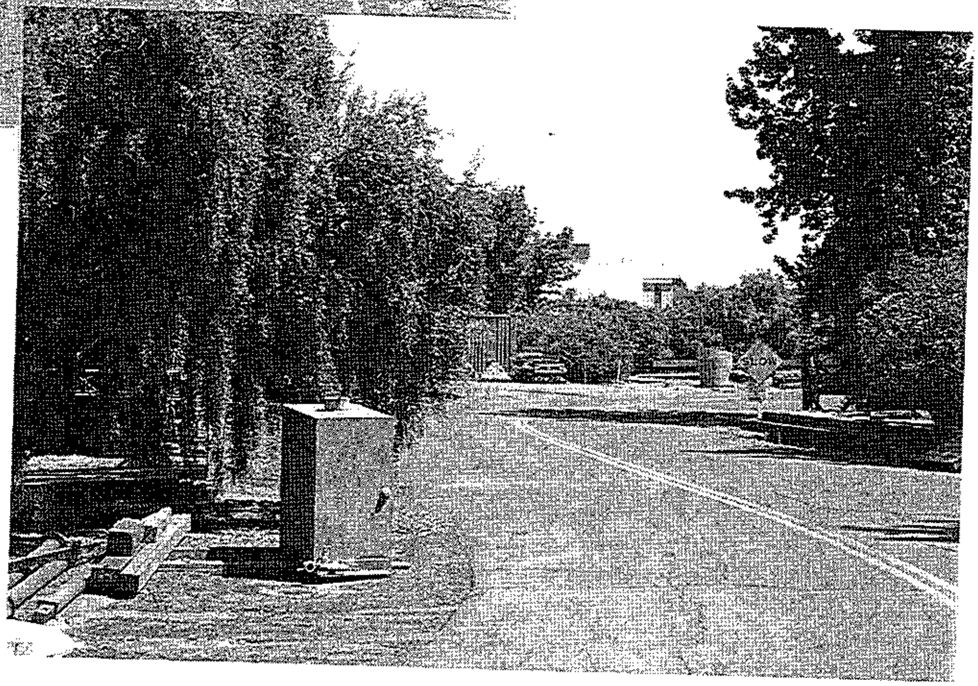


Figure 5

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.

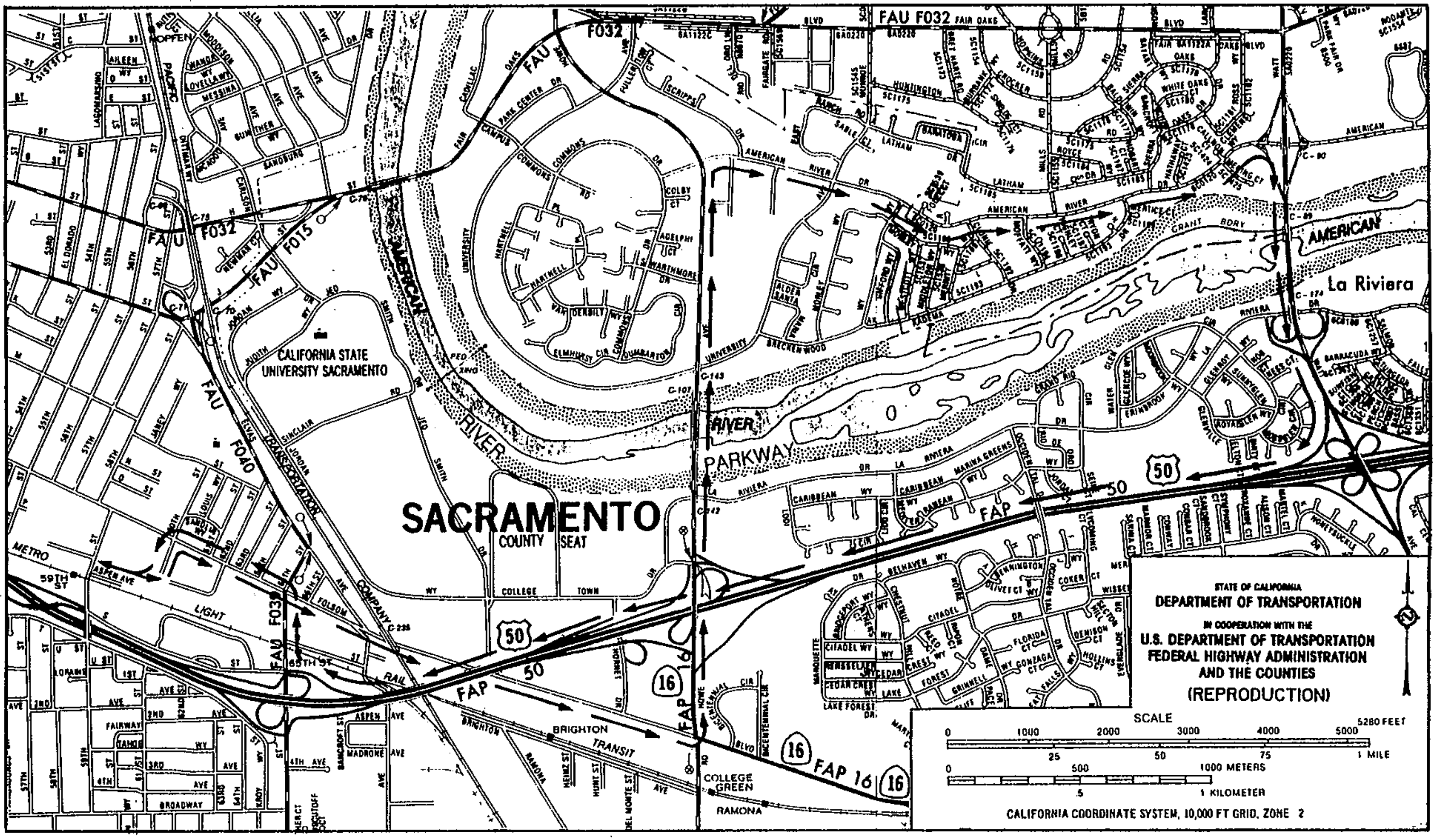


Fig. 8 **ROUTE 2: AMERICAN RIVER DRIVE**

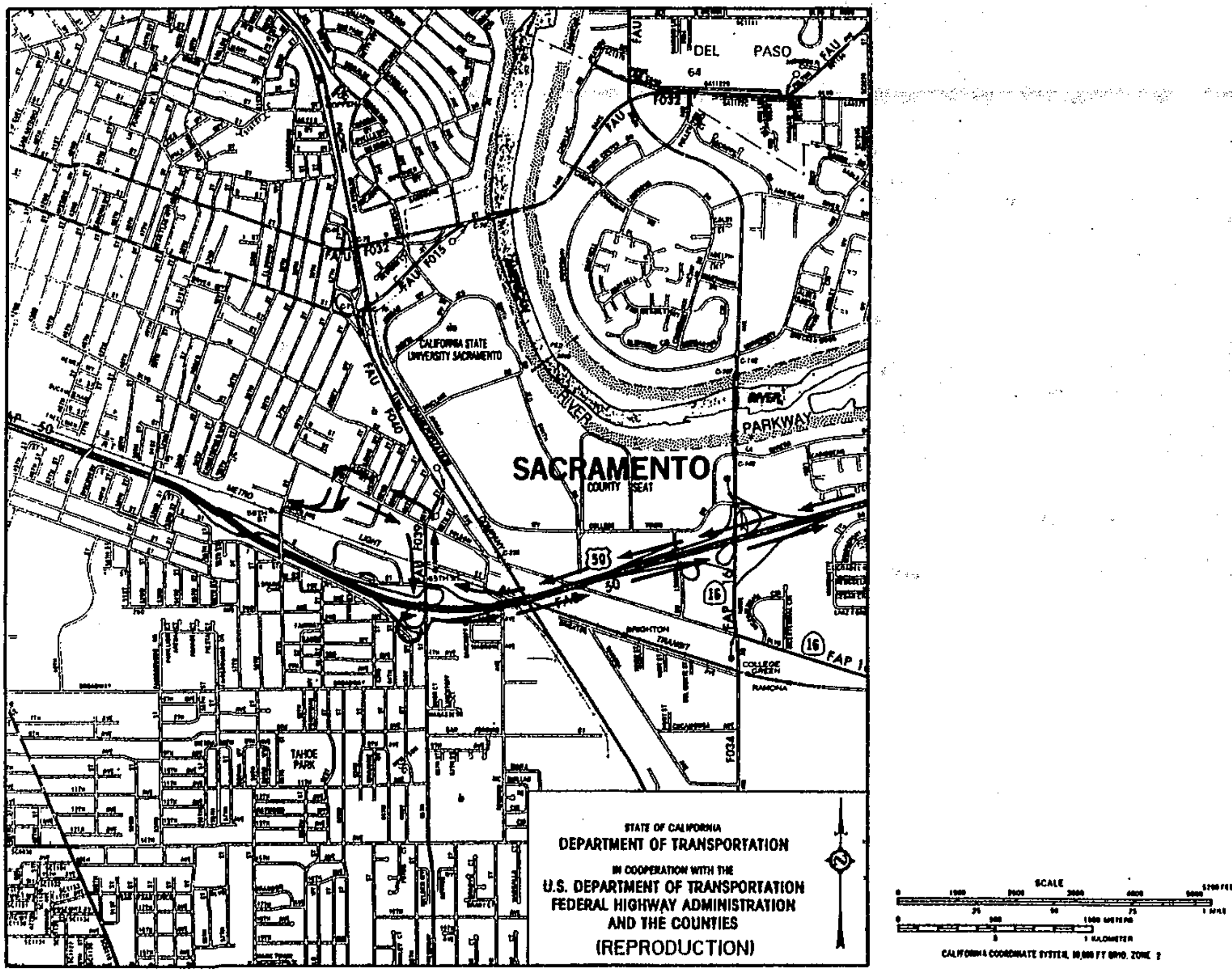


Fig. 9a ROUTE 3: HIGHWAY 50

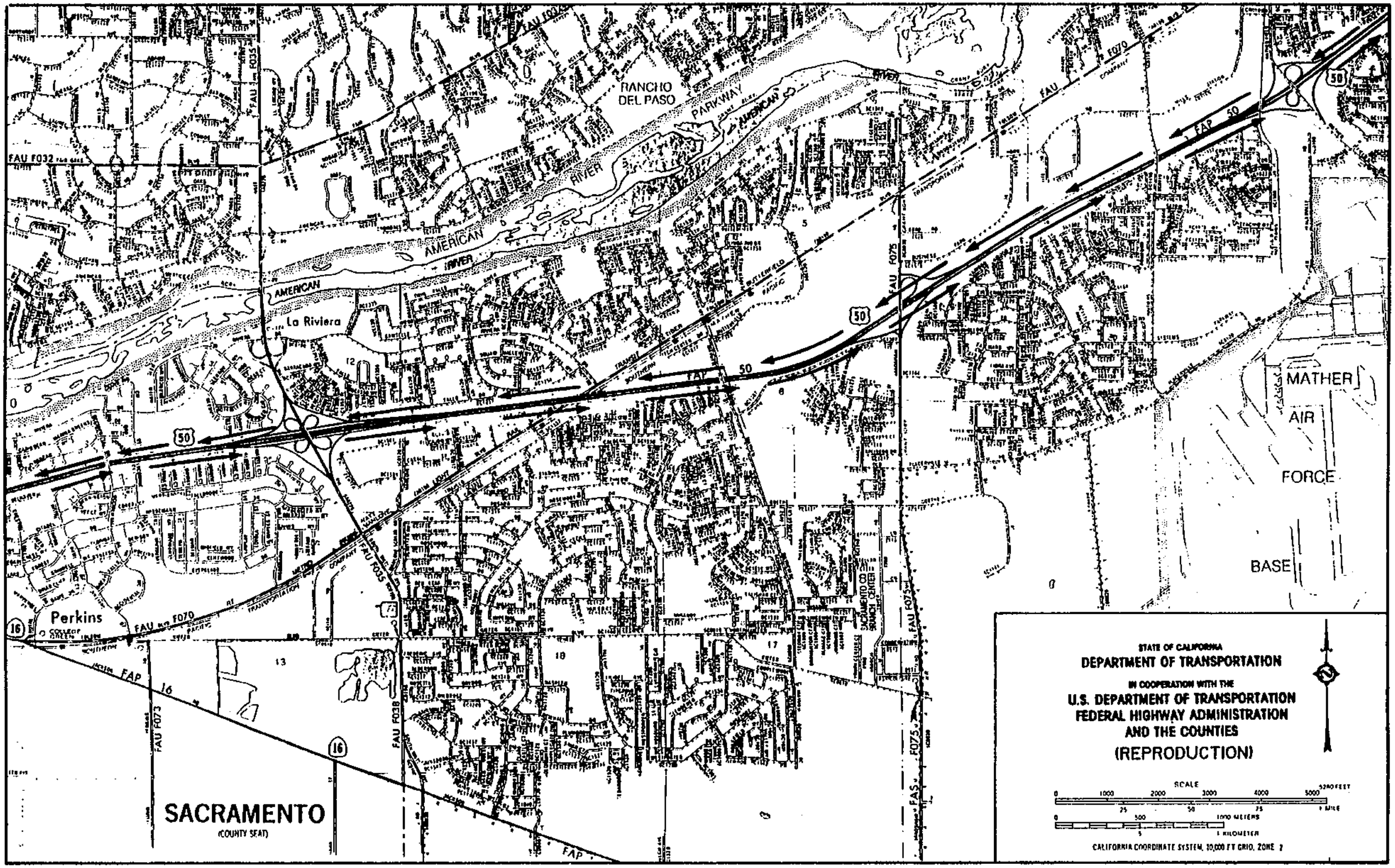


Fig. 9b **ROUTE 3: HIGHWAY 50**

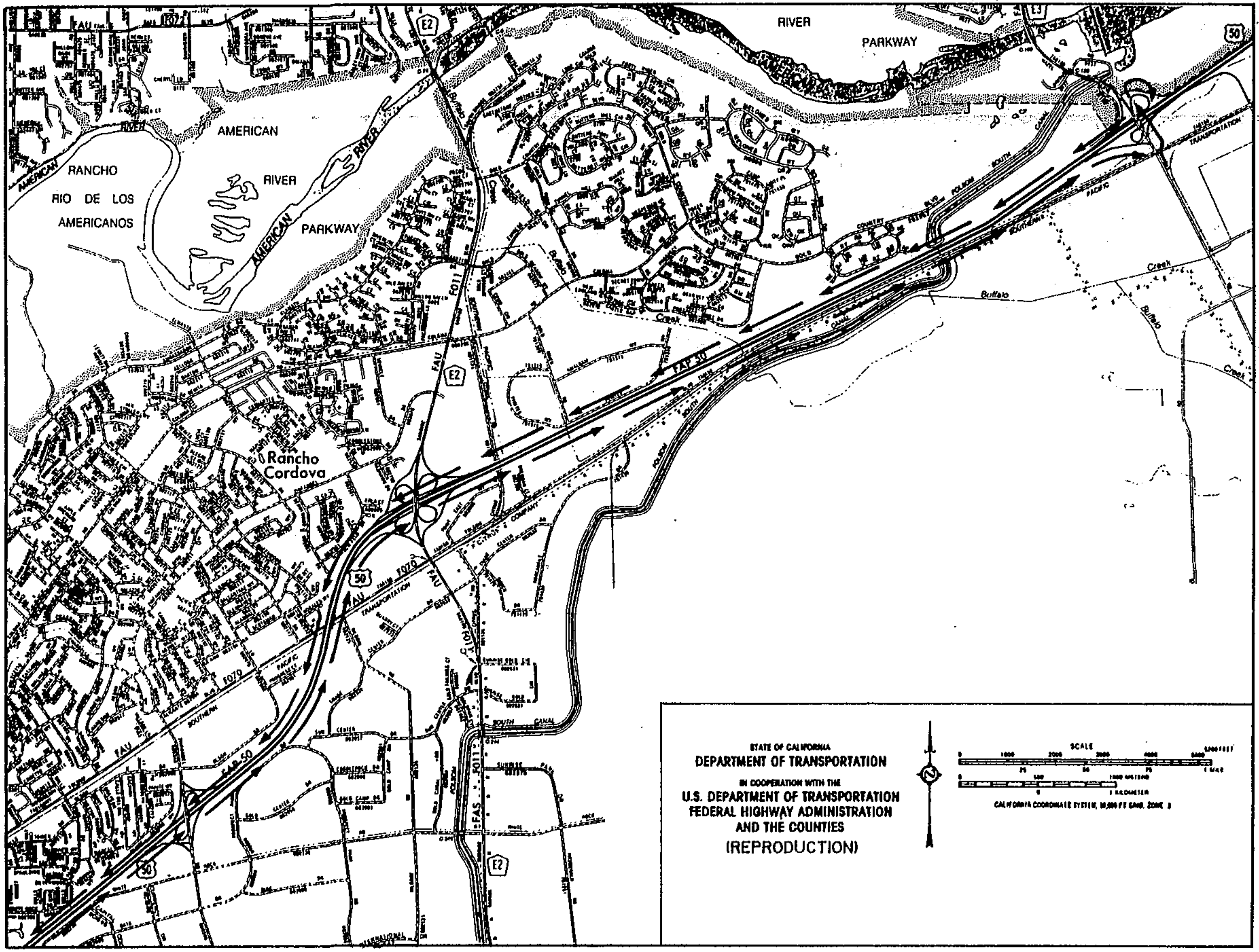


Fig. 9c **ROUTE 3: HIGHWAY 50**

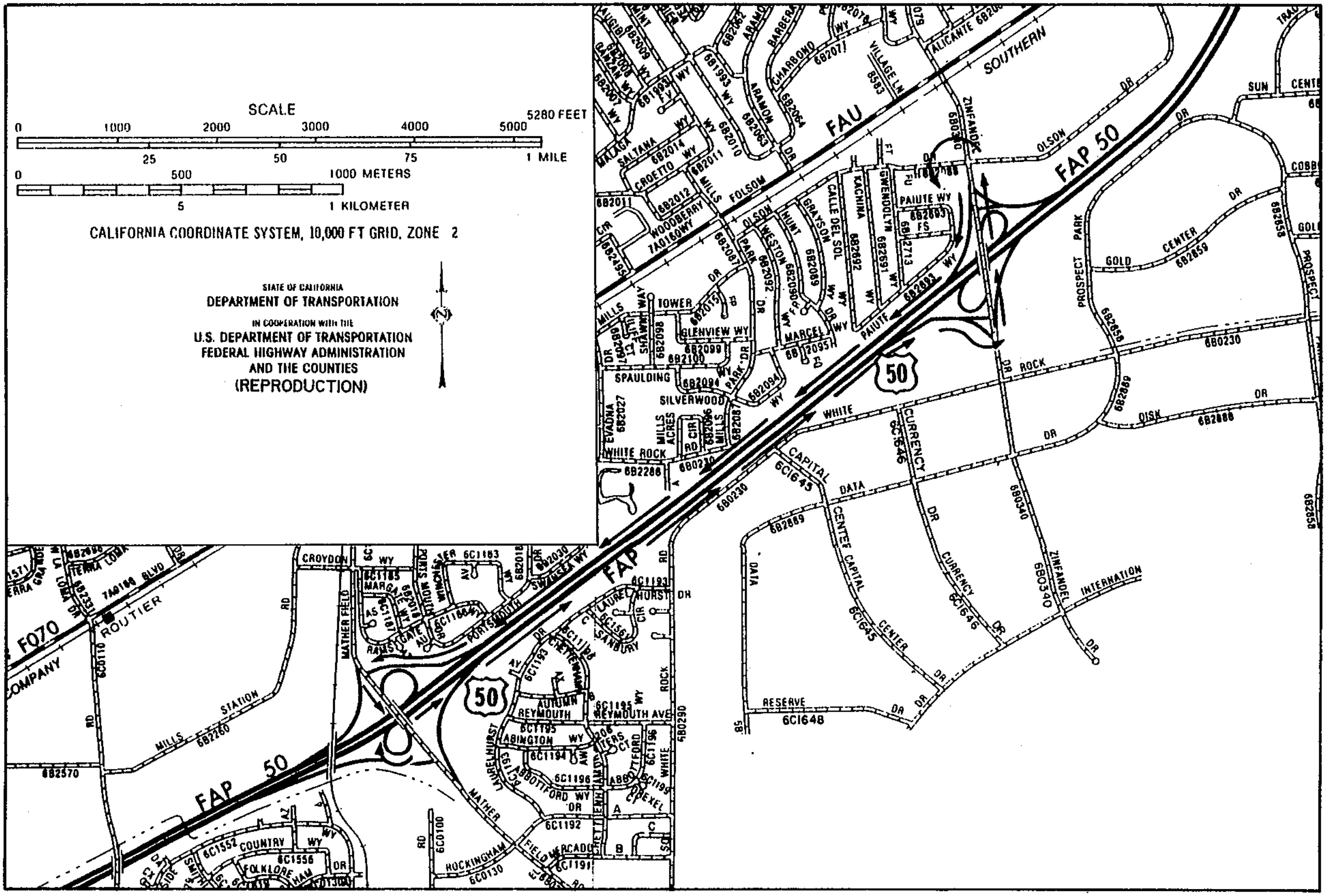


Fig. 10 **ROUTE 4: ZINFANDEL DR. TO MATHER FIELD RD.**

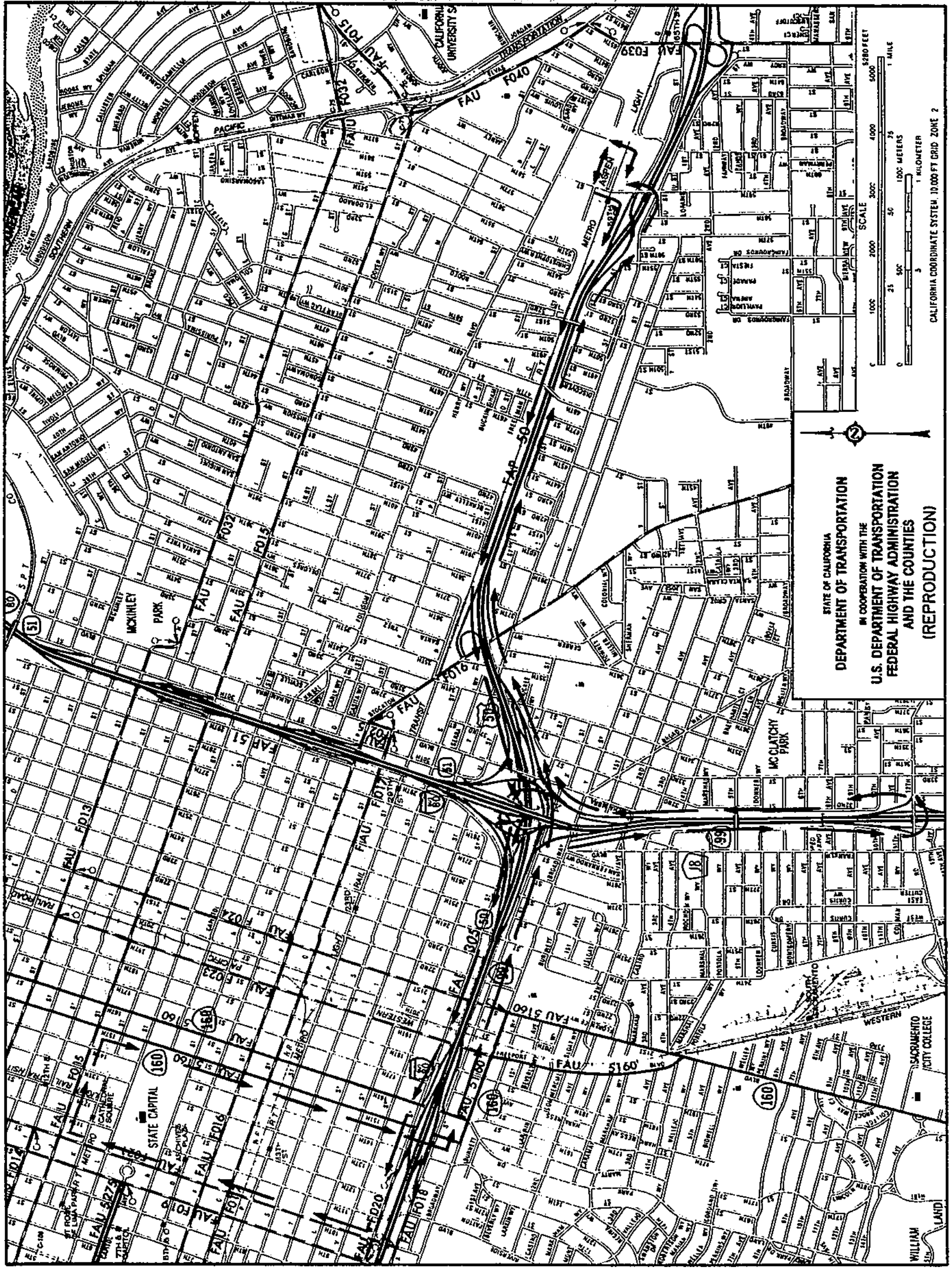


Fig. 11 ROUTE 5: DOWNTOWN

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.

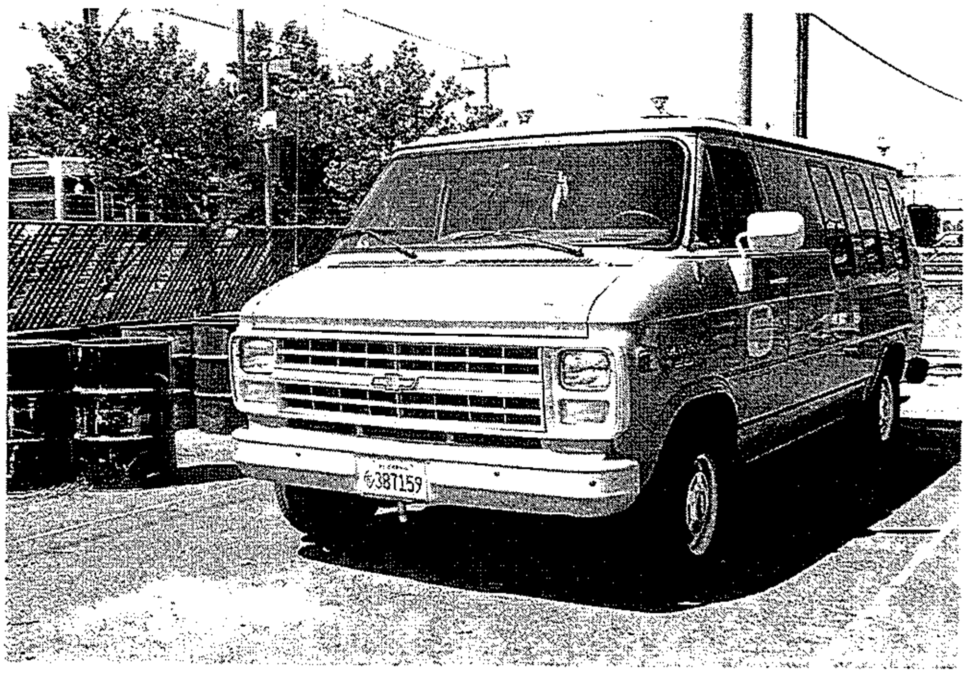


Figure 12

Test Vehicle

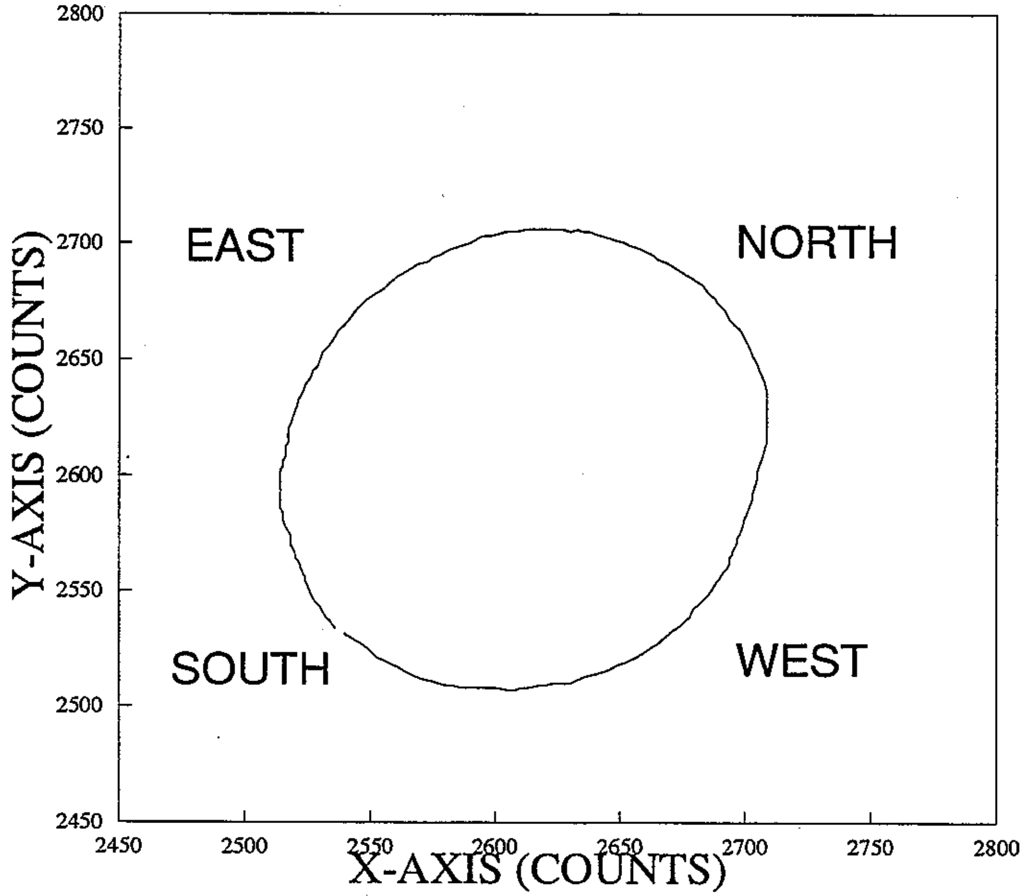


Figure 13

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

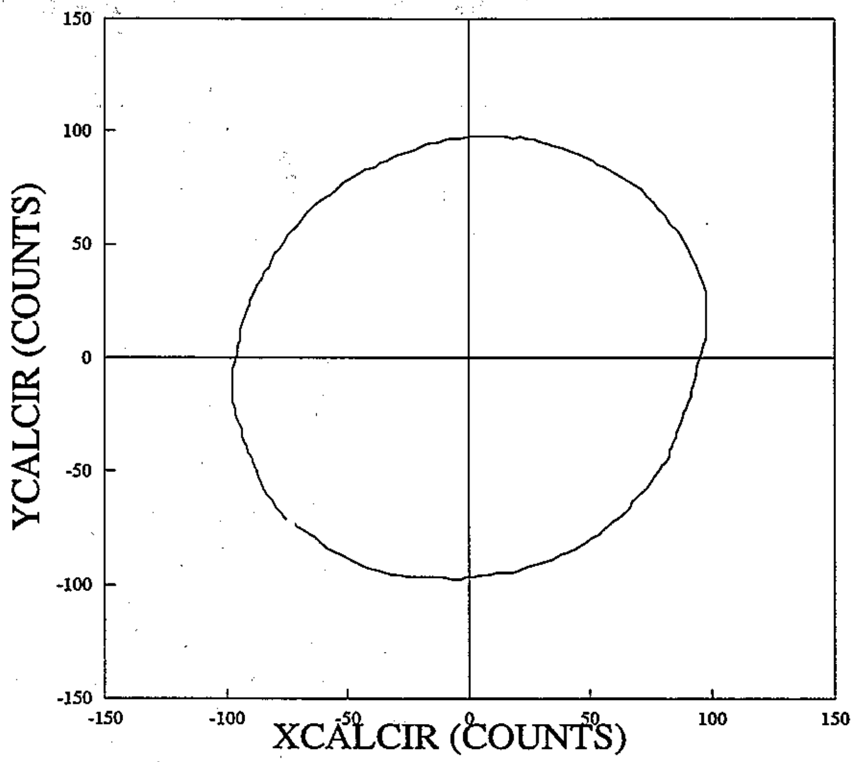


Figure 14

Compass Magnetization Circle Translated to the Origin

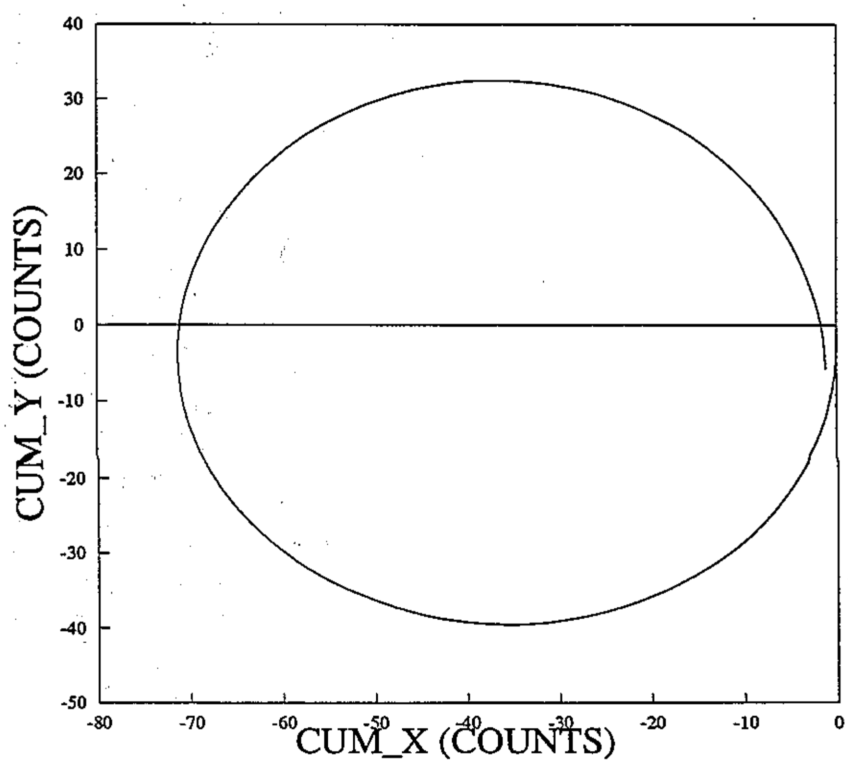


Figure 15

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 <u>COMPASS</u>

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 ANGULAR RATE SENSOR

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

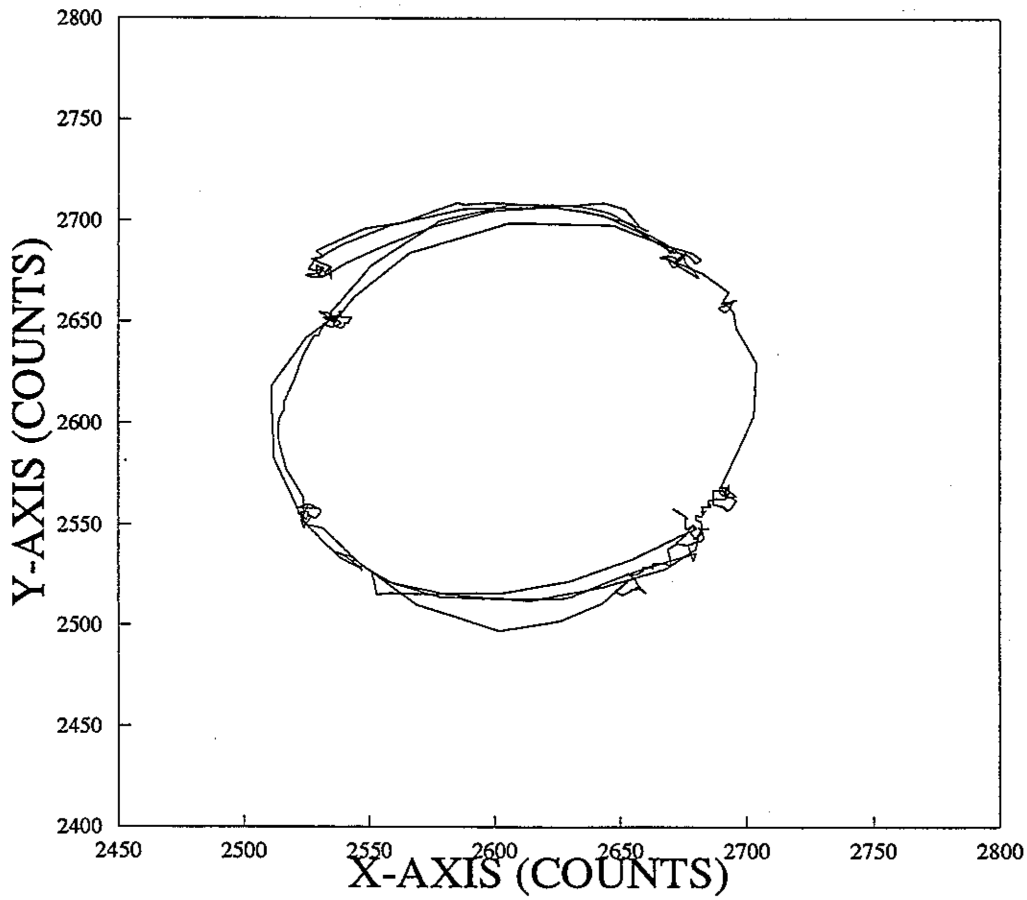

Figure 16

Compass Magnetization Circle
Route 1 June 1, 1992

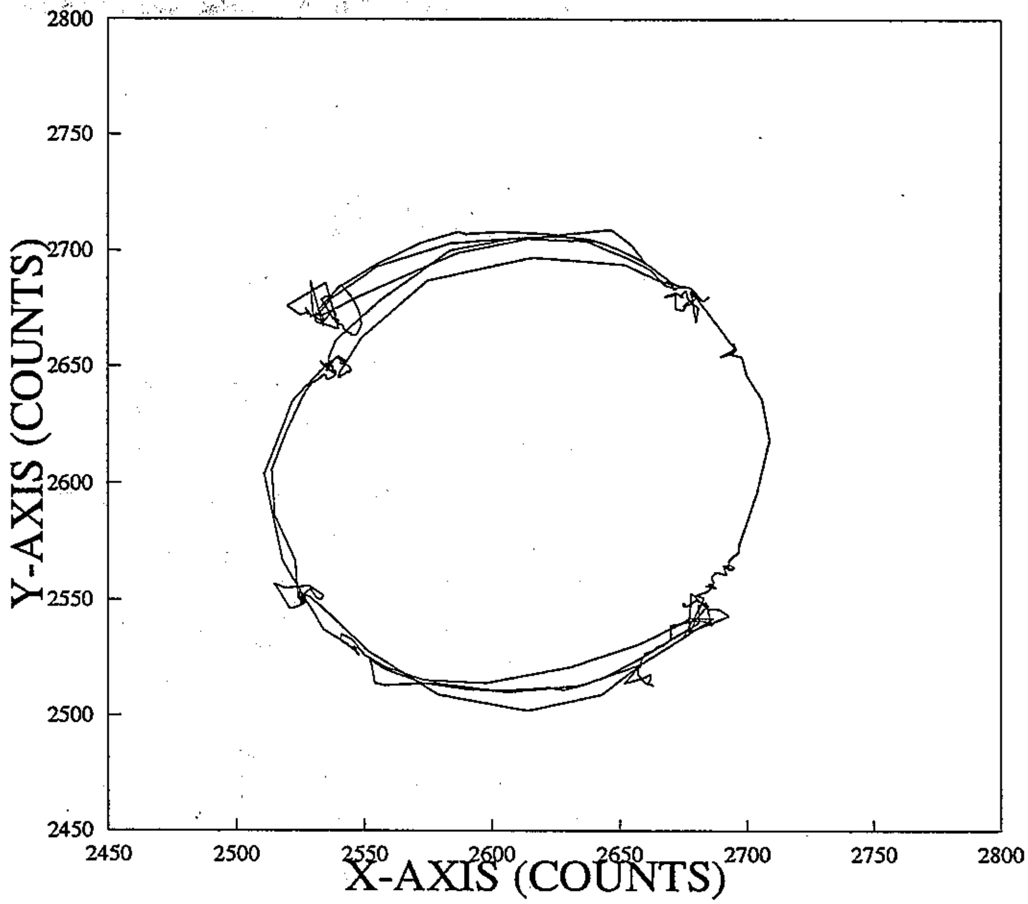

Figure 17

Compass Magnetization Circle
Route 1 June 12, 1992

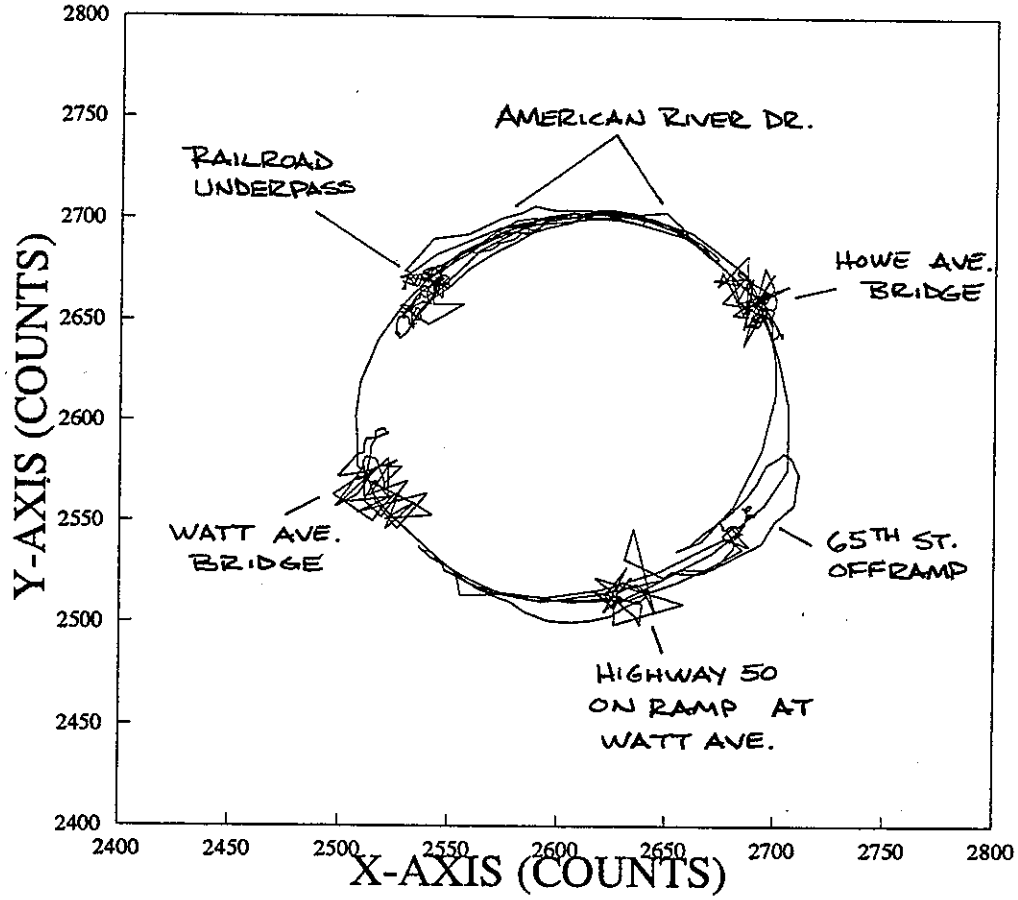

Figure 18

Compass Magnetization Circle
Route 2 May 28, 1992

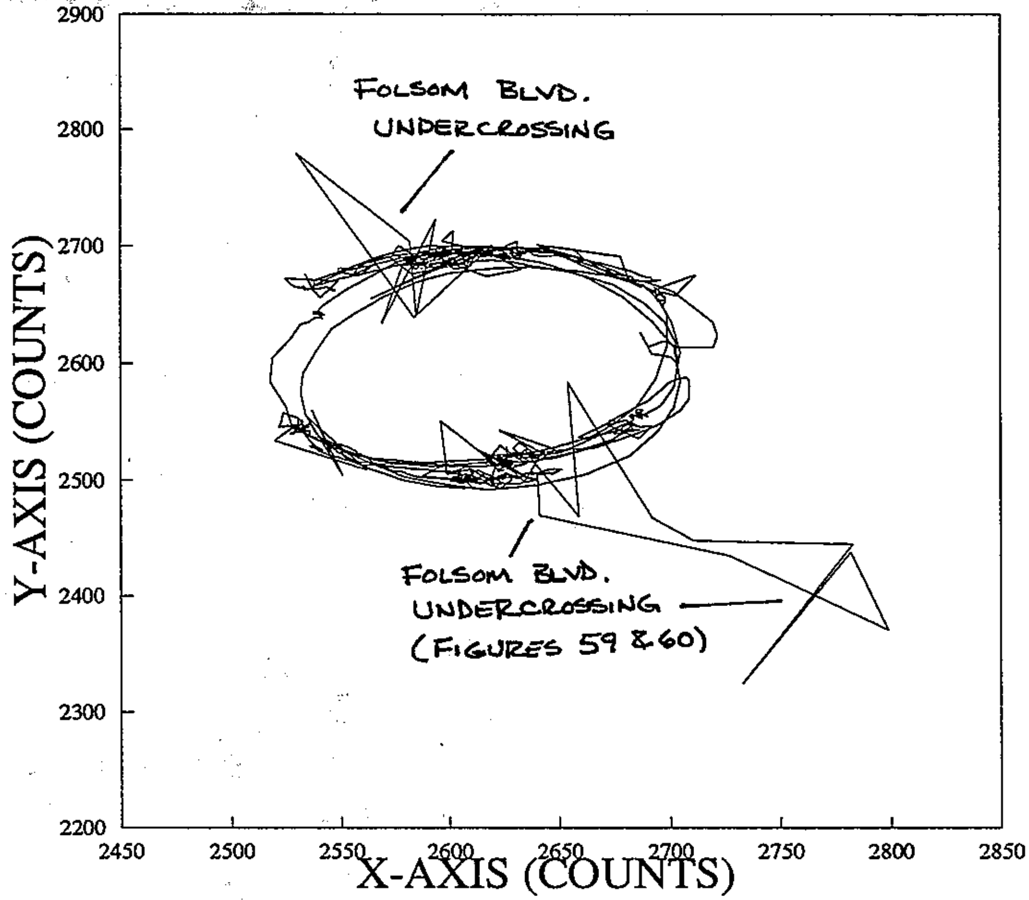

Figure 19

Compass Magnetization Circle
Route 3 June 12, 1992

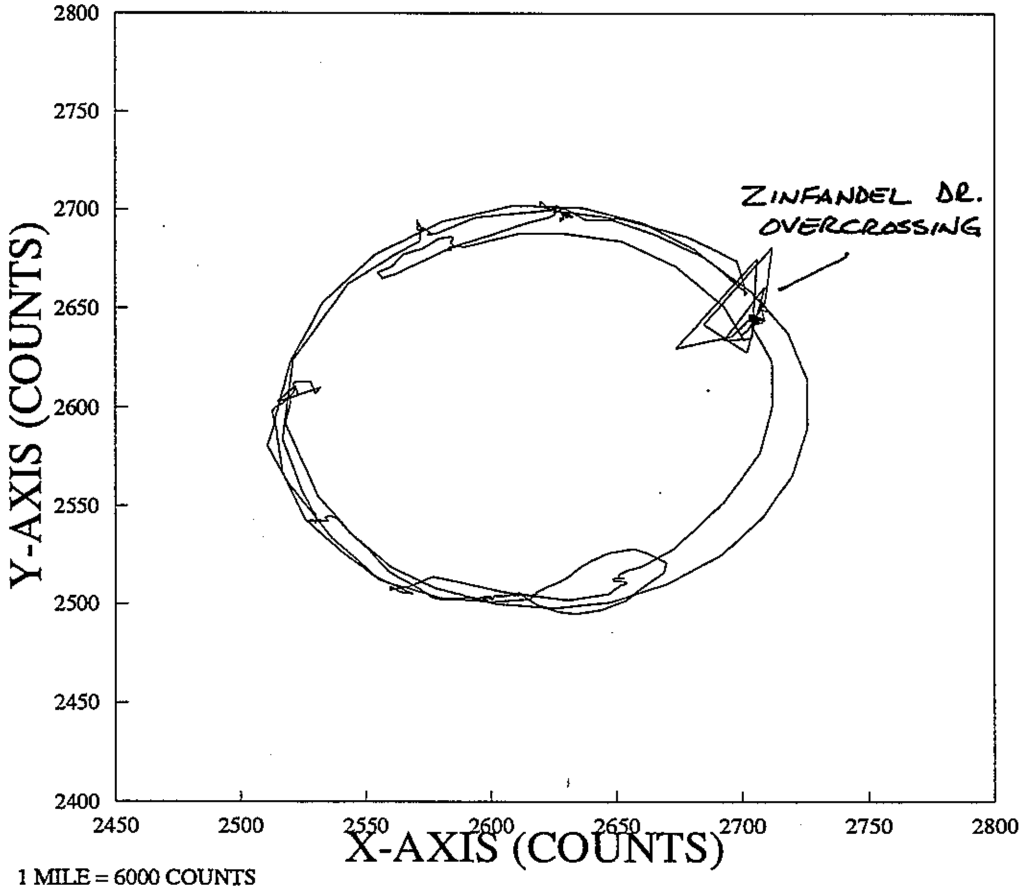

Figure 20

Compass Magnetization Circle
Route 4 June 15, 1992

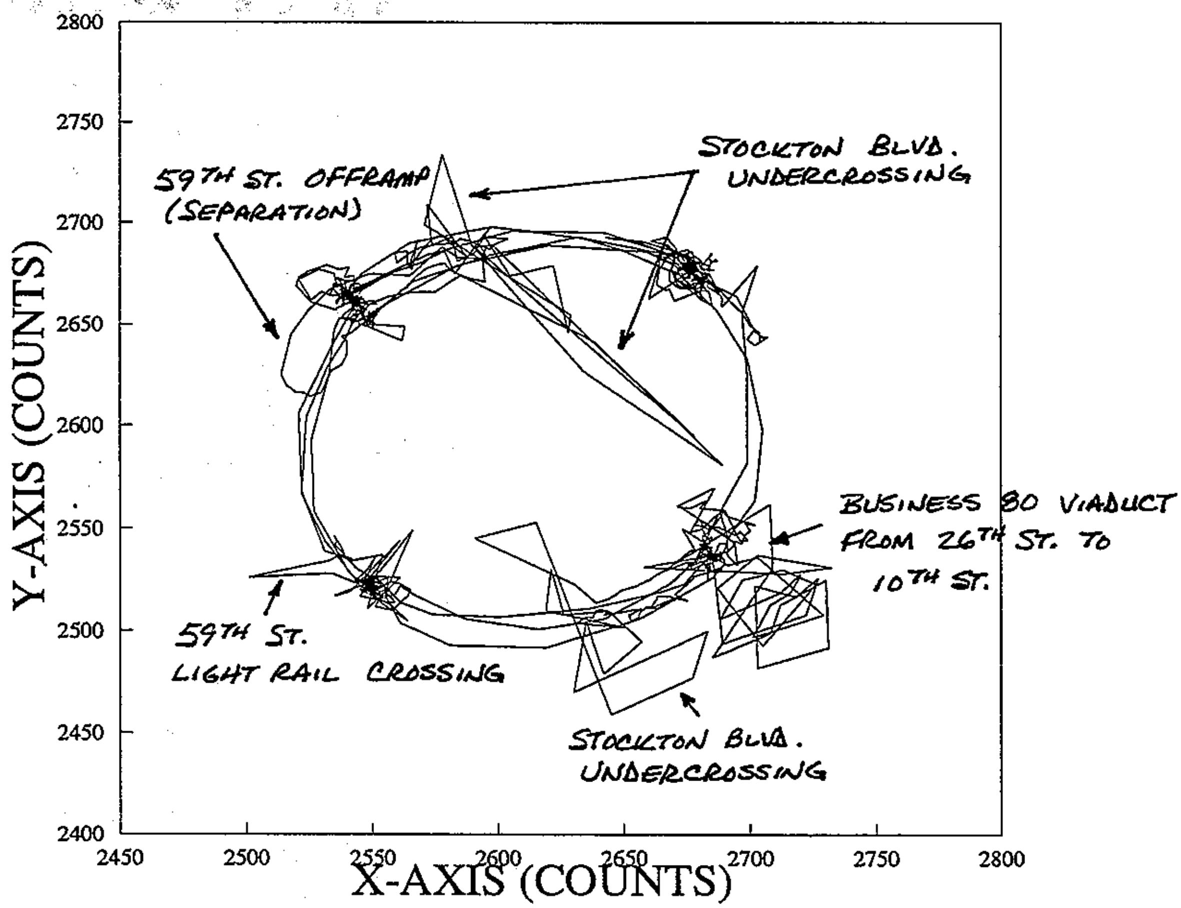

Figure 21

Compass Magnetization Circle
Route 5 August 4, 1992

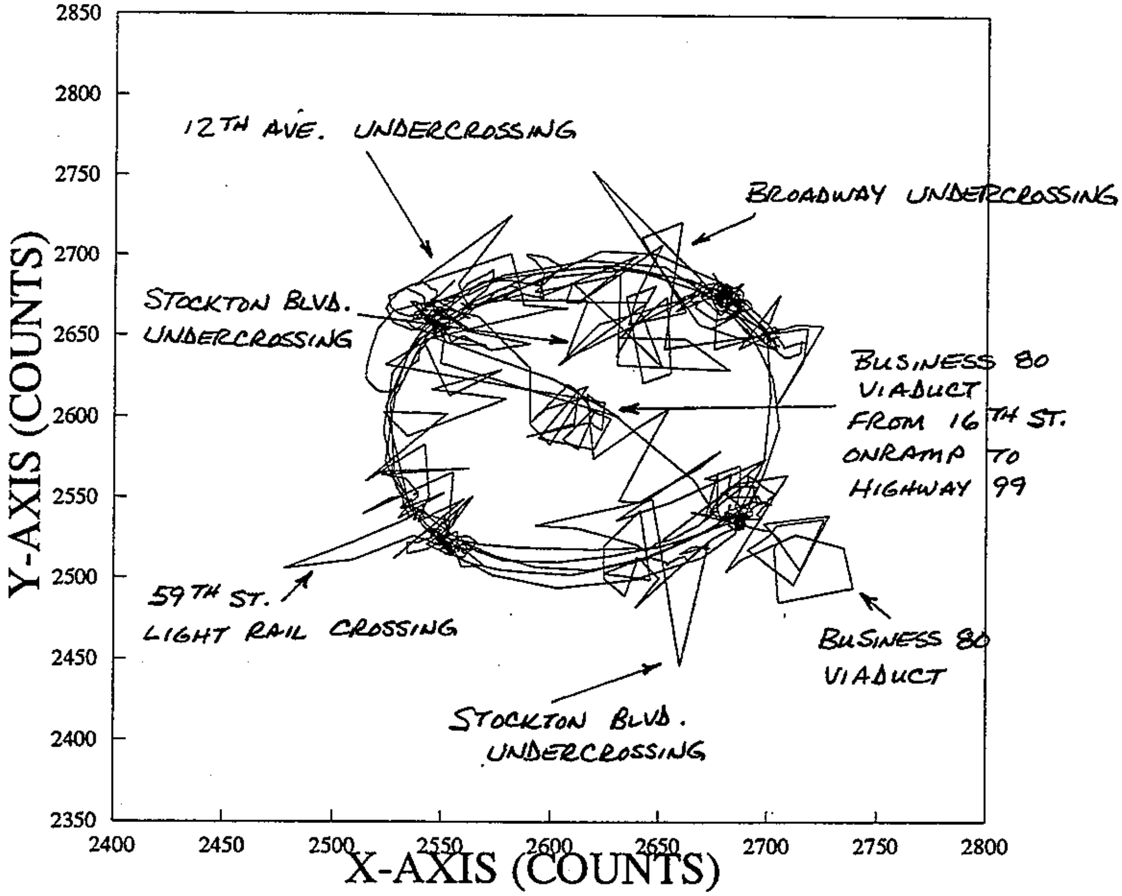

Figure 22

Compass Magnetization Circle
Route 5A August 5, 1992

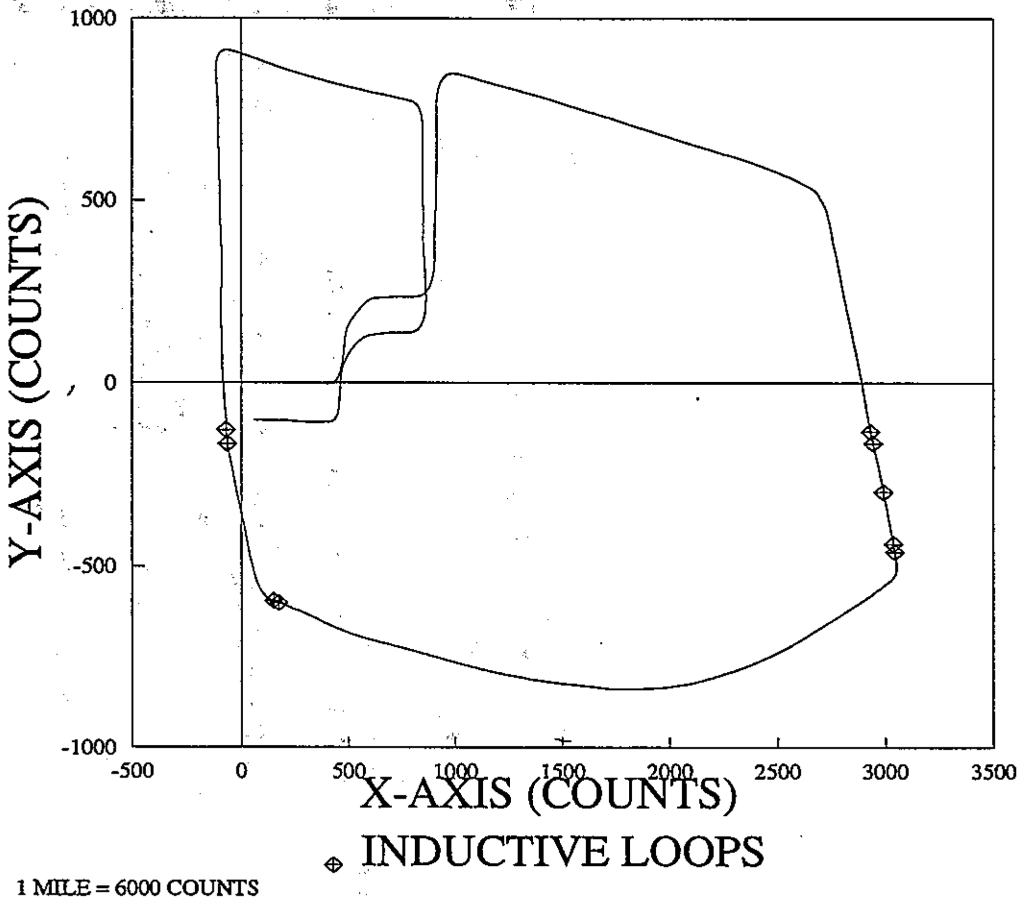

Figure 23

Compass Path
Route 1 June 1, 1992

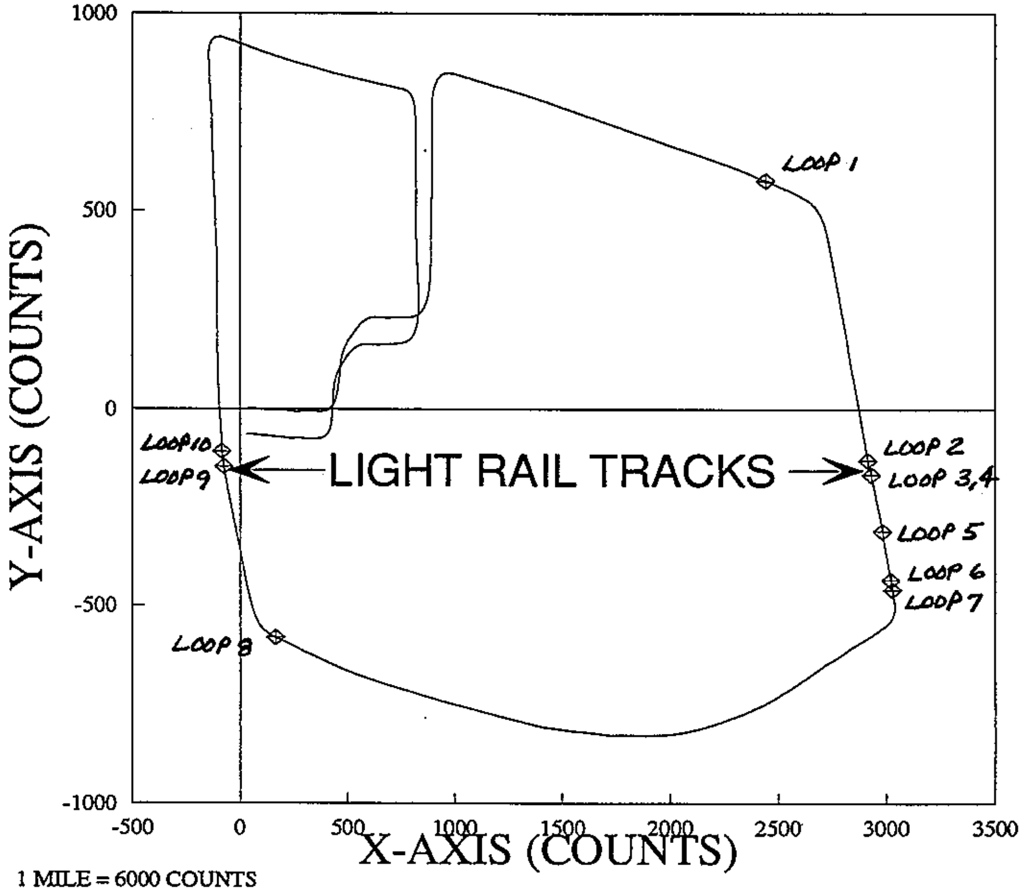

Figure 24

Compass Path
Route 1 June 12, 1992

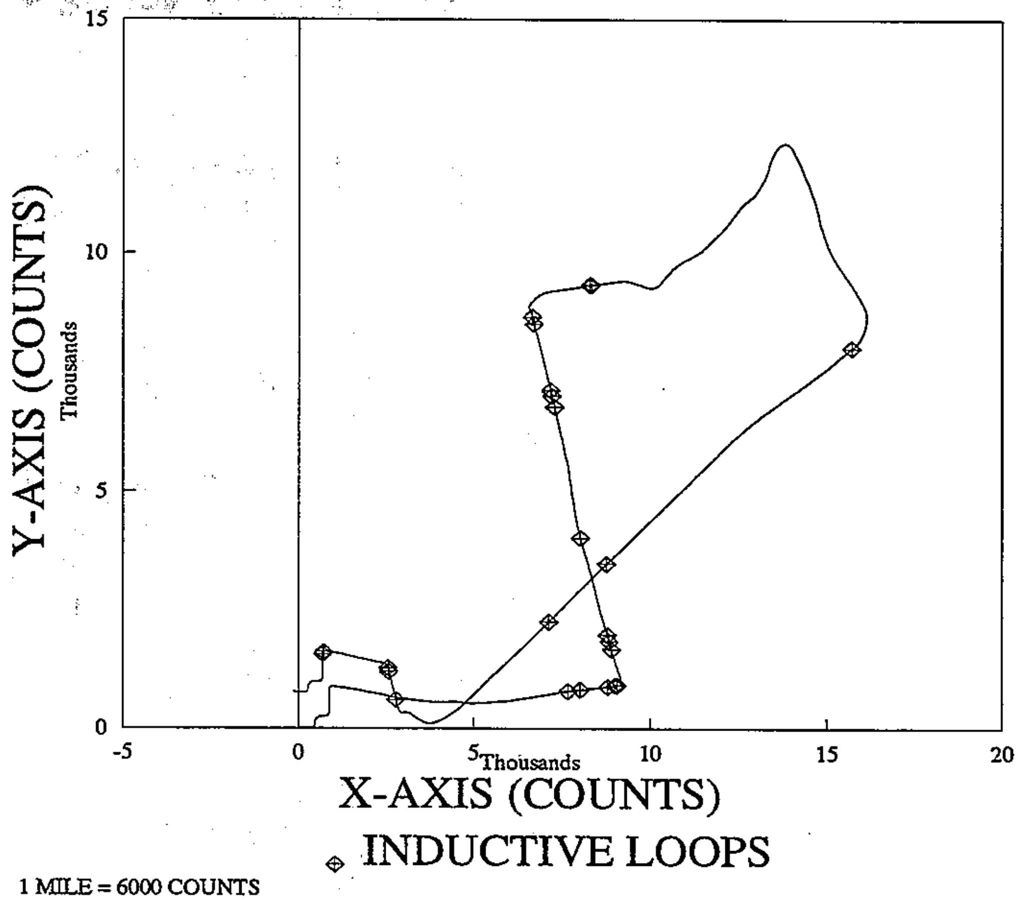

Figure 25

Compass Path
Route 2 May 28, 1992

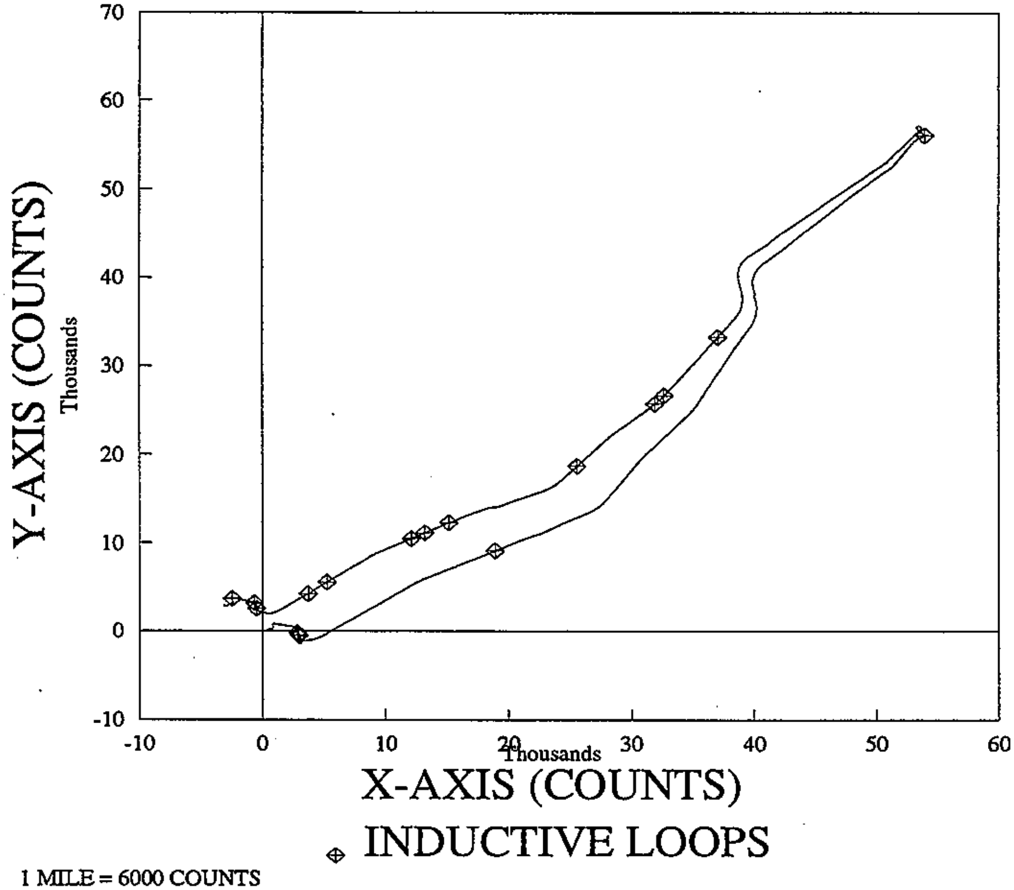

Figure 26

Compass Path
Route 3 June 12, 1992

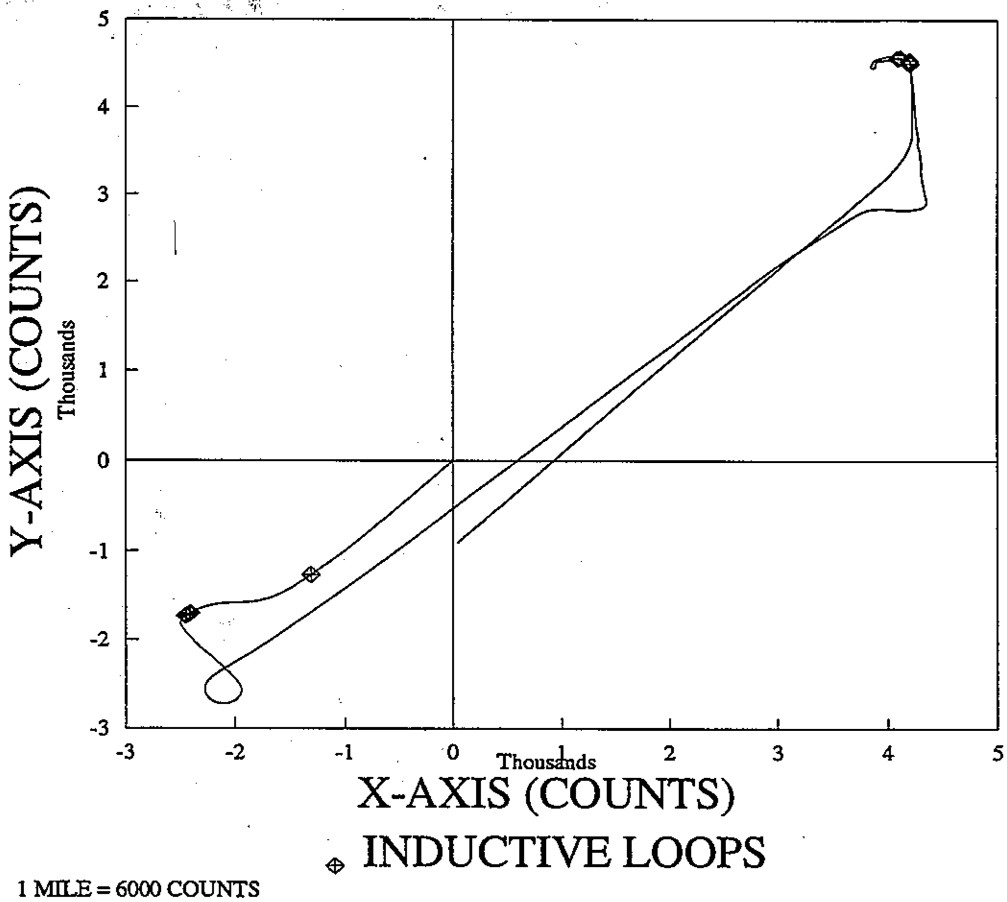

Figure 27

Compass Path
Route 4 June 15, 1992

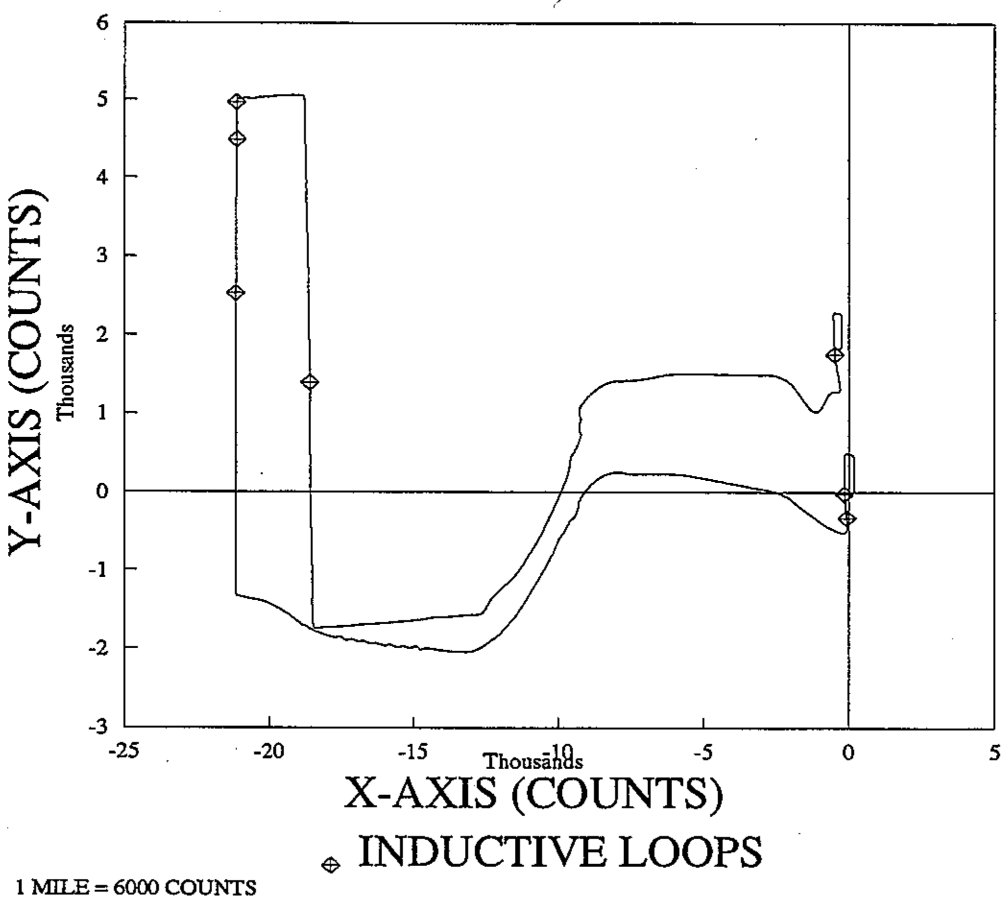

Figure 28

Compass Path
Route 5 August 4, 1992

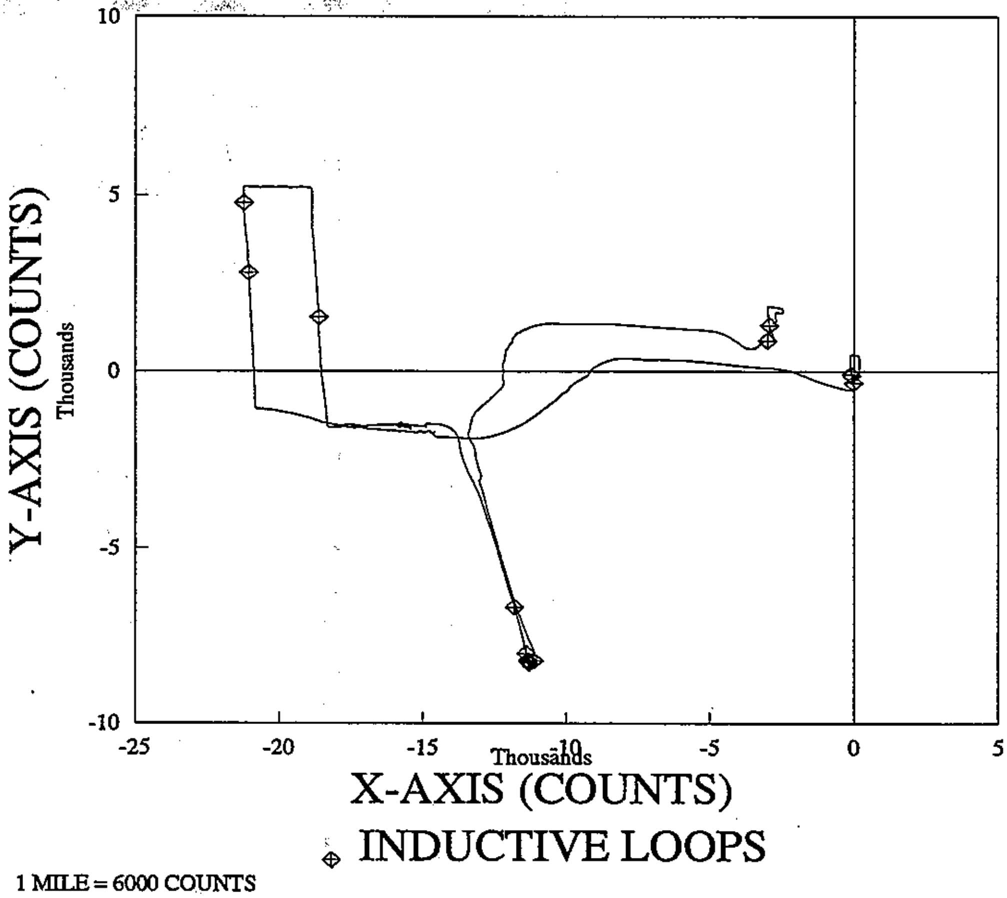

Figure 29

Compass Path
Route 5A August 5, 1992

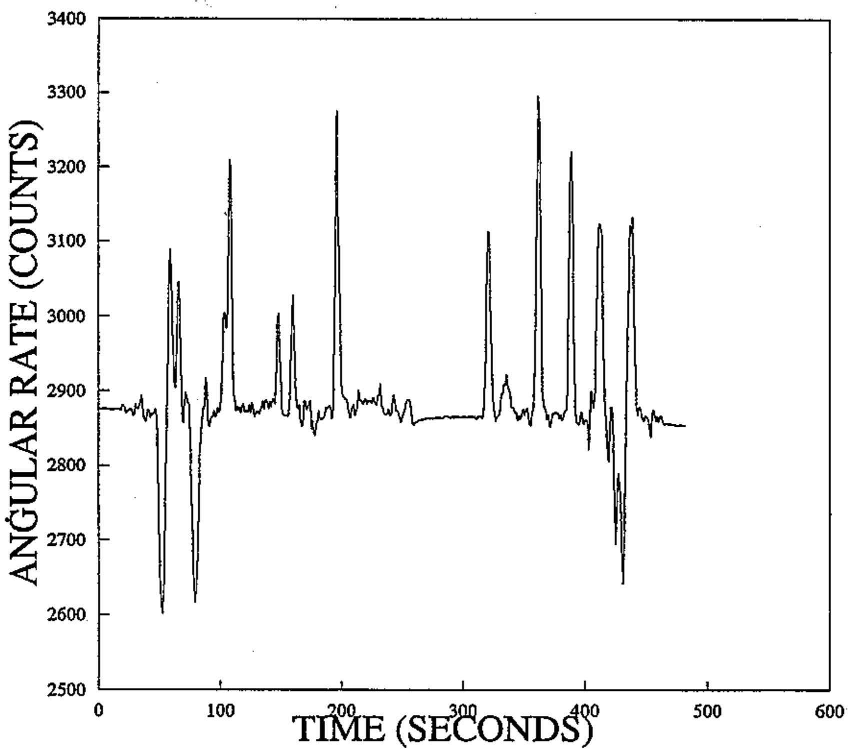

Figure 30 Angular Rate vs. Time
Route 1 June 1, 1992

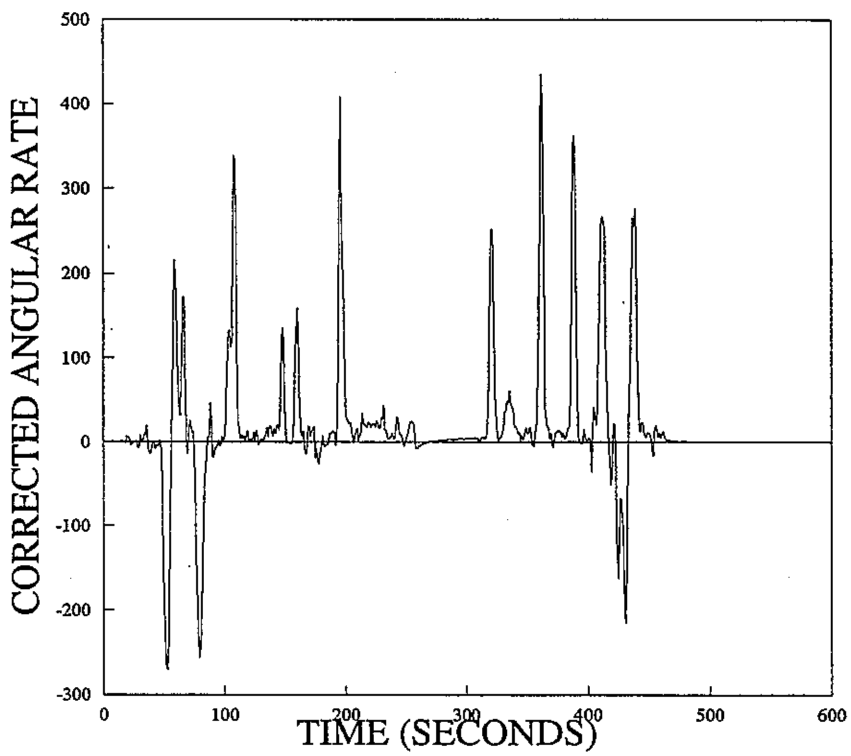

Figure 31 Corrected Angular Rate vs. Time
Route 1 June 1, 1992

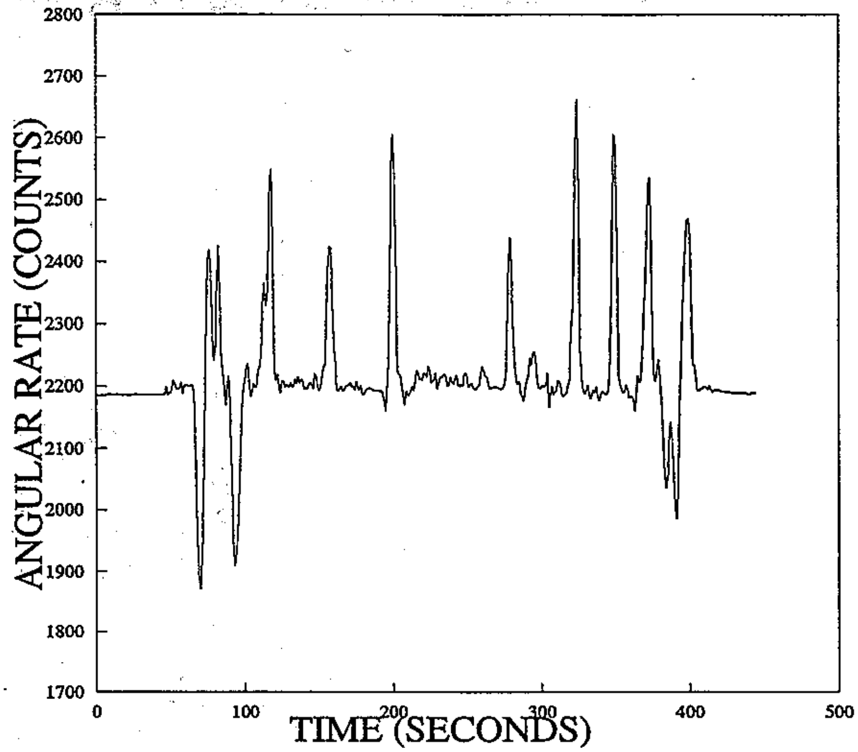

Figure 32 Angular Rate vs. Time
Route 1 June 12, 1992

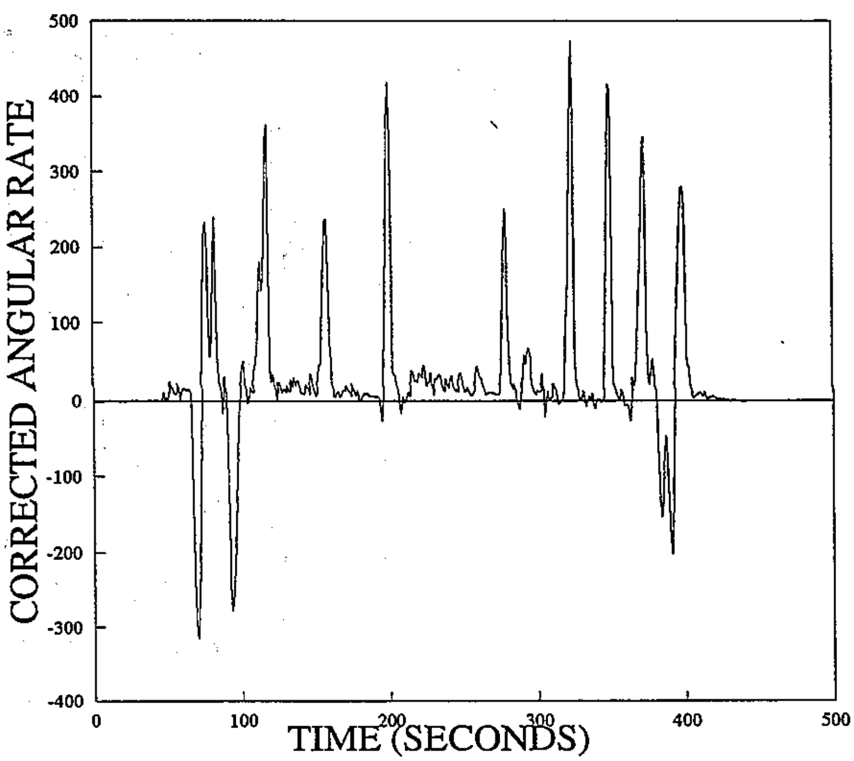

Figure 33 Corrected Angular Rate vs. Time
Route 1 June 12, 1992

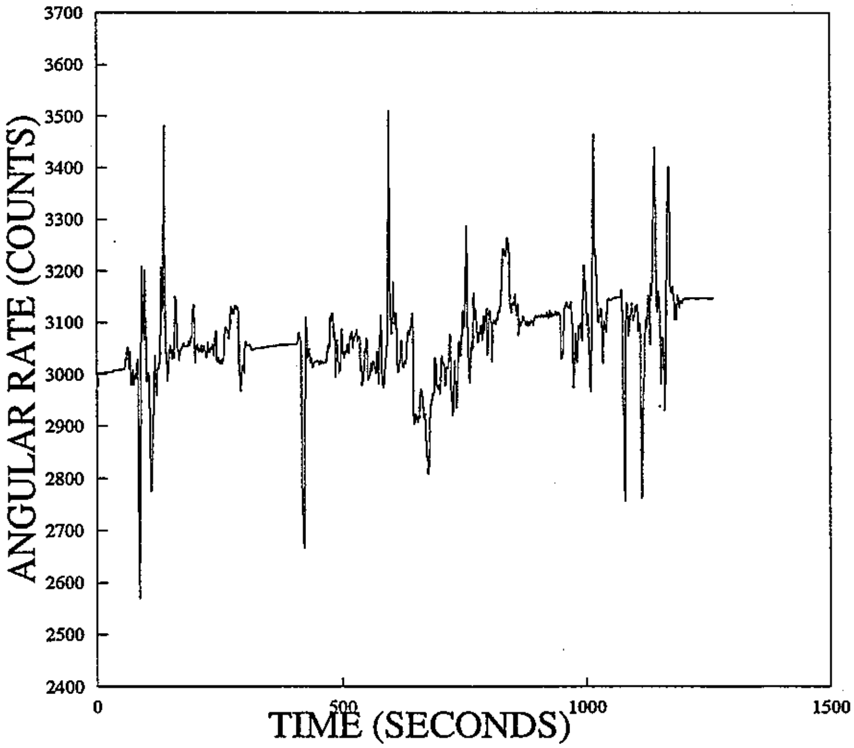

Figure 34 Angular Rate vs. Time
Route 2 May 28, 1992

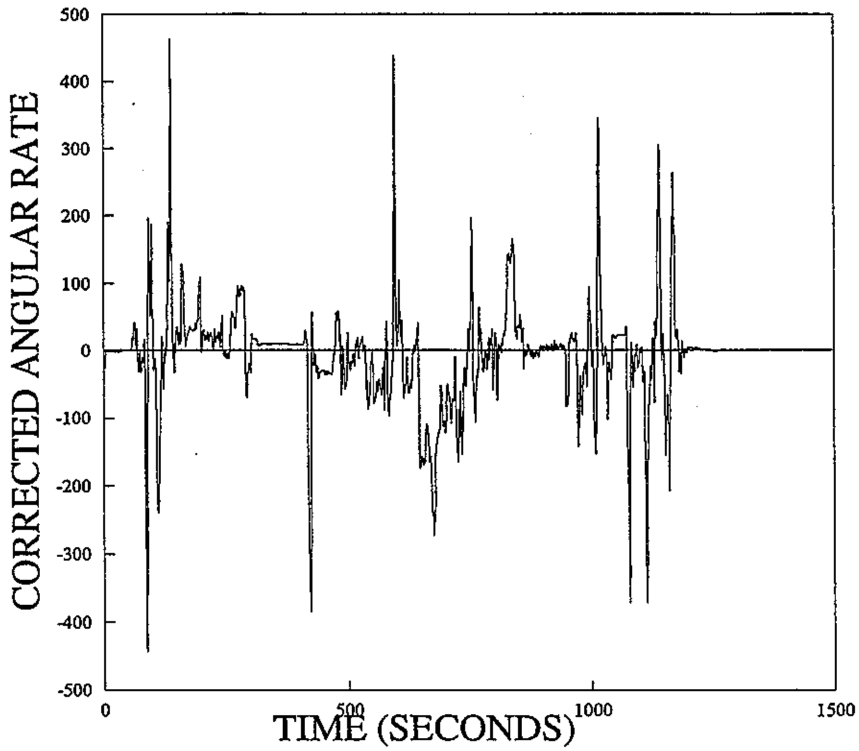

Figure 35 Corrected Angular Rate vs. Time
Route 2 May 28, 1992

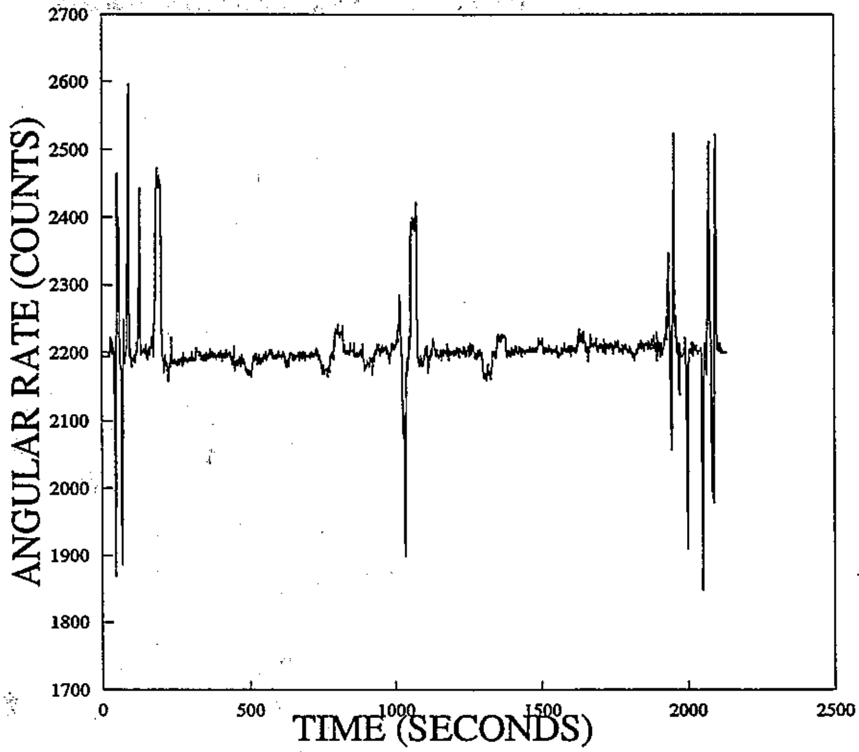

Figure 36 Angular Rate vs. Time
Route 3 June 12, 1992

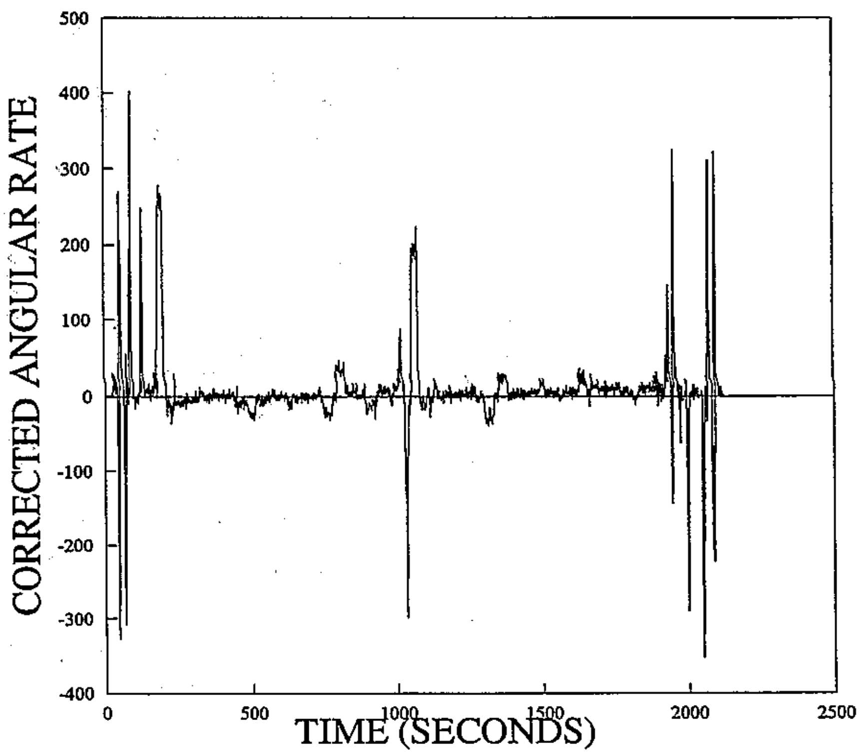

Figure 37 Corrected Angular Rate vs. Time
Route 3 June 12, 1992

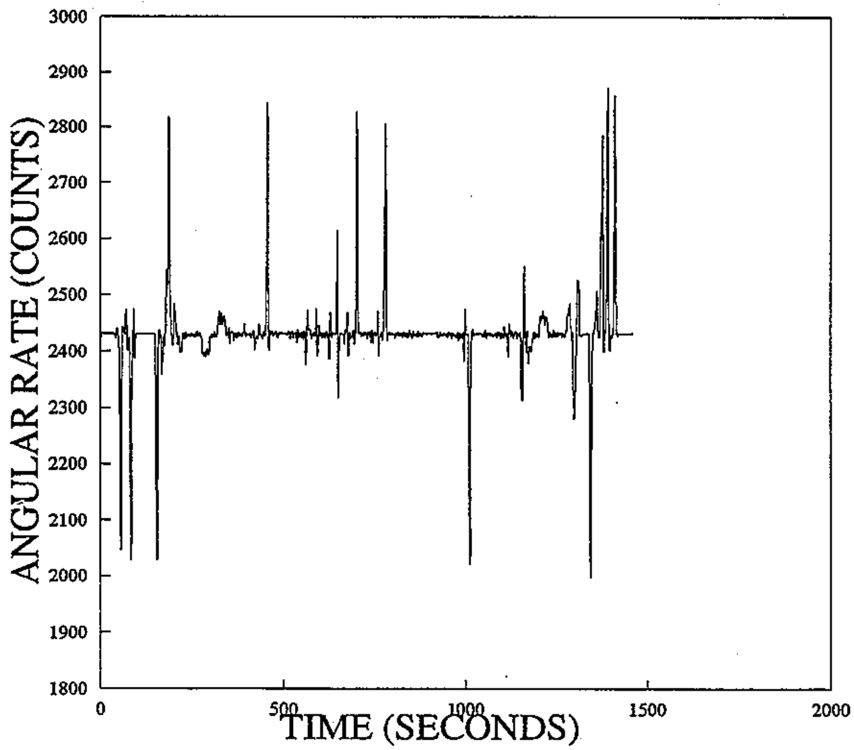

Figure 38 Angular Rate vs. Time
Route 5 August 4, 1992

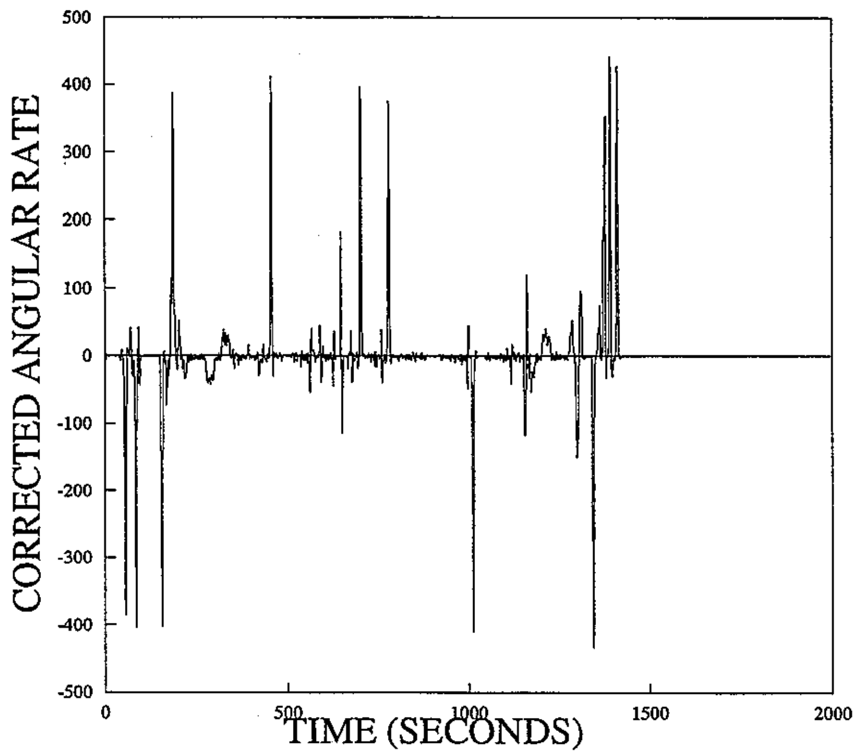

Figure 39 Corrected Angular Rate vs. Time
Route 5 August 4, 1992

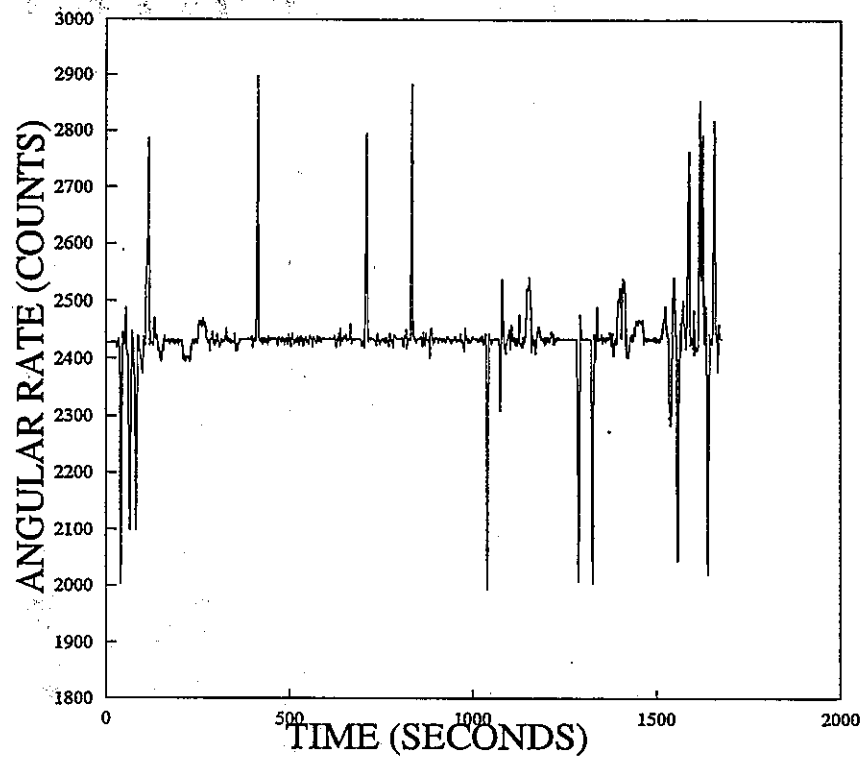

Figure 40 Angular Rate vs. Time

Route 5A August 5, 1992

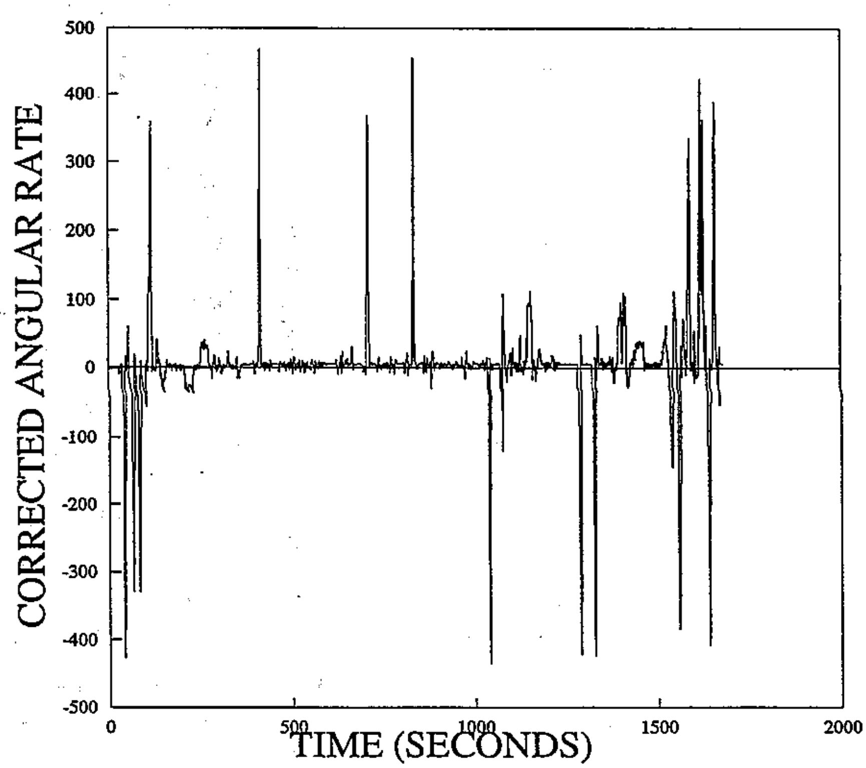

Figure 41 Corrected Angular Rate vs. Time
Route 5A August 5, 1992

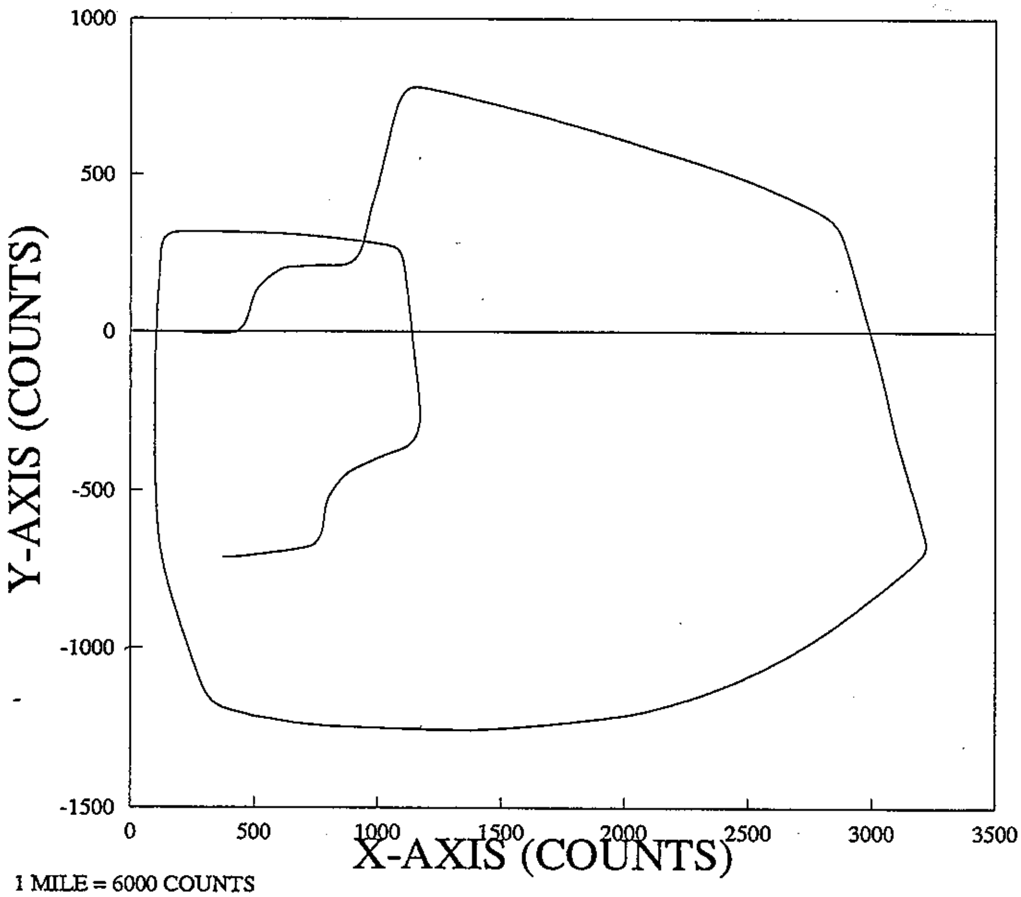

Figure 42

Angular Rate Sensor Path
Route 1 June 1, 1992

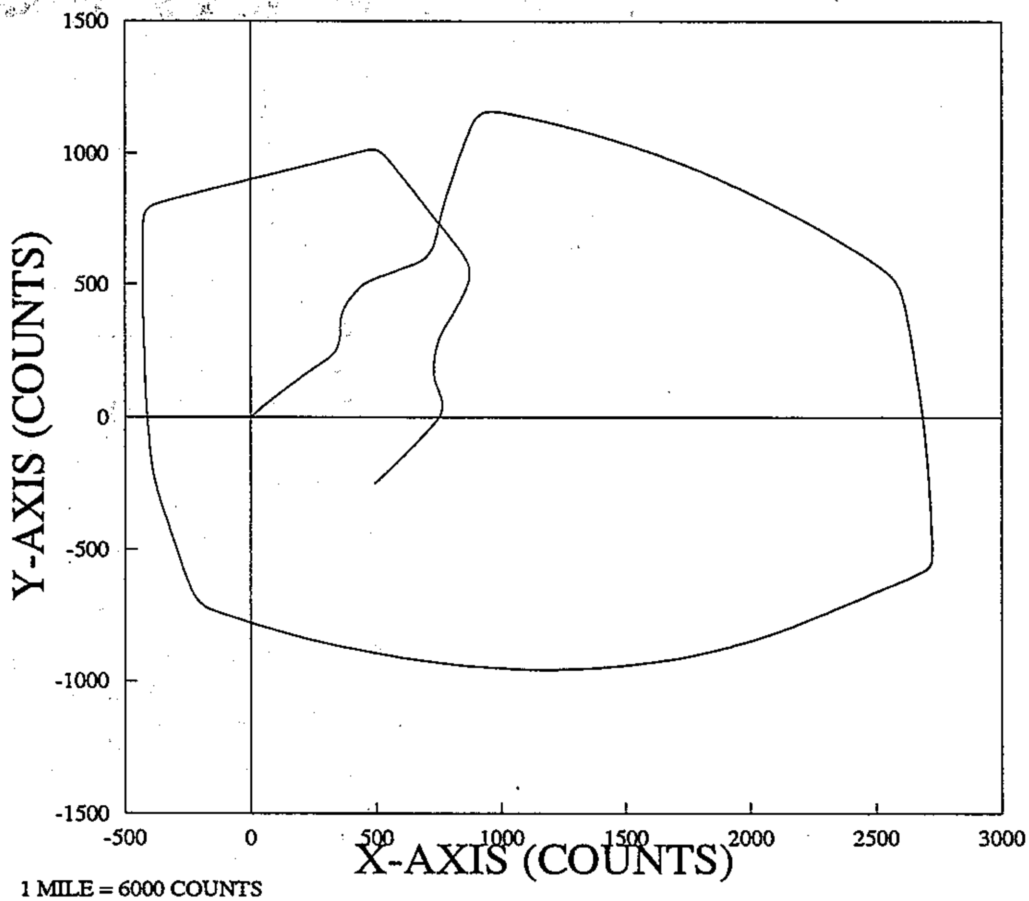

Figure 43

Angular Rate Sensor Path
Route 1 June 12, 1992

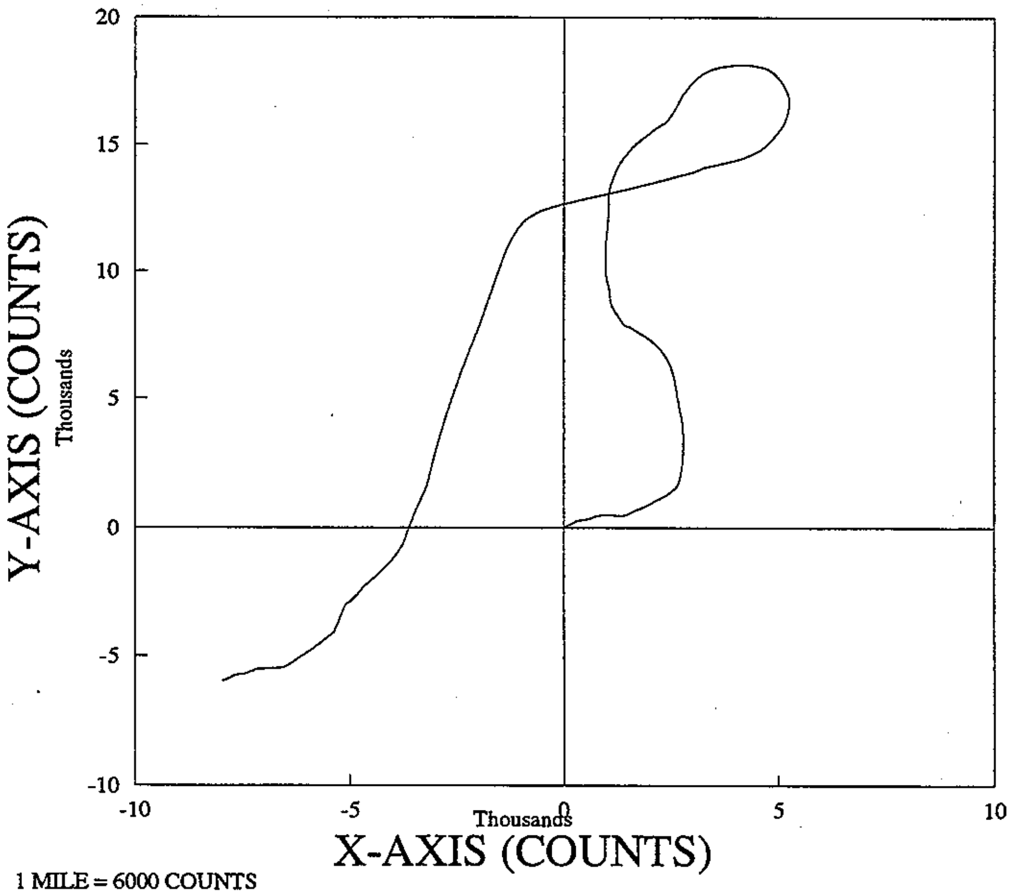

Figure 44

Angular Rate Sensor Path
Route 2 May 28, 1992

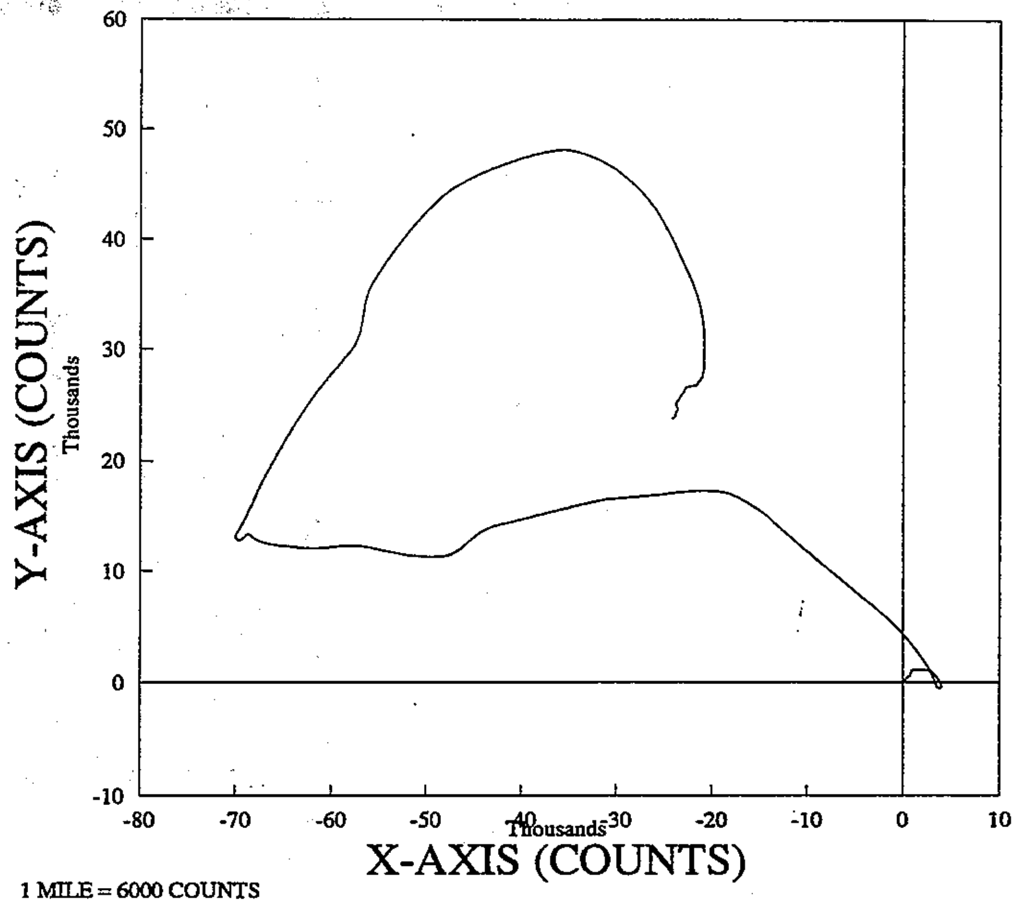

Figure 45

Angular Rate Sensor Path
Route 3 June 12, 1992

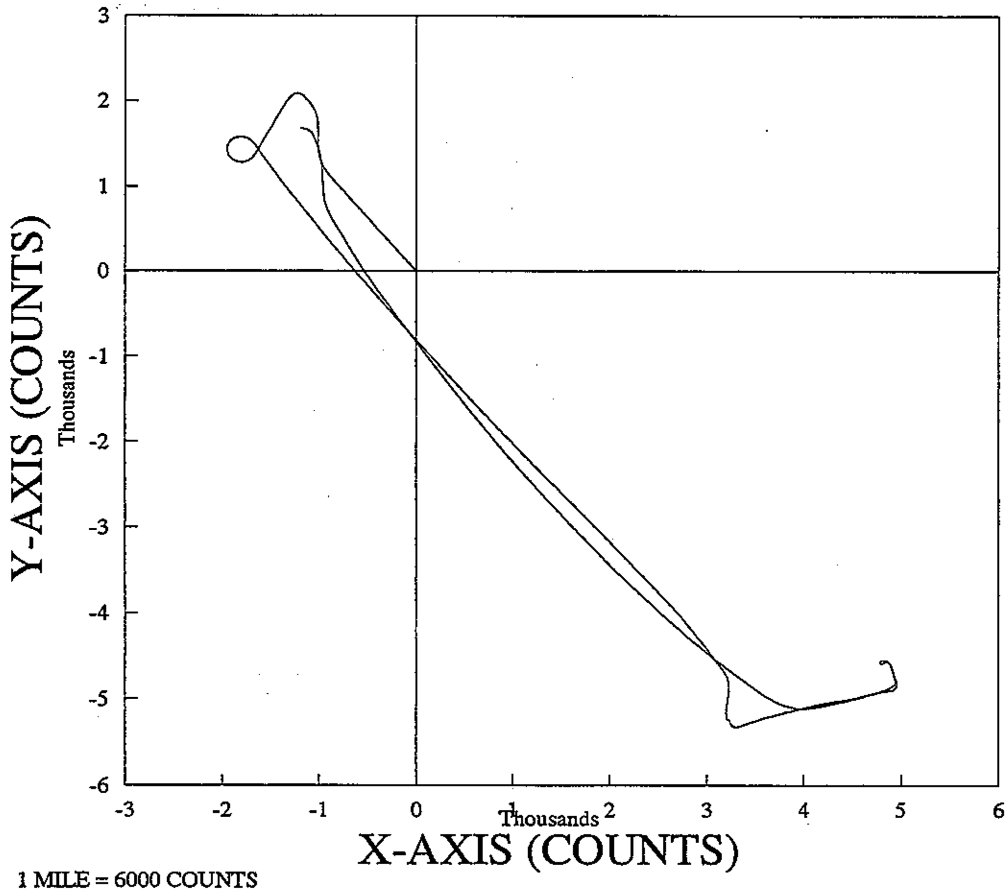

Figure 46

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)	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	598743.8125	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)	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)	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
		LAB7	3833.31	12126.17	598781.371	2049144.780	9.032			3833.31	12126.17	598781.371	2049144.780	9.032			UPDATED
		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	FIRMWARE VER 2.5
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	0.886	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	

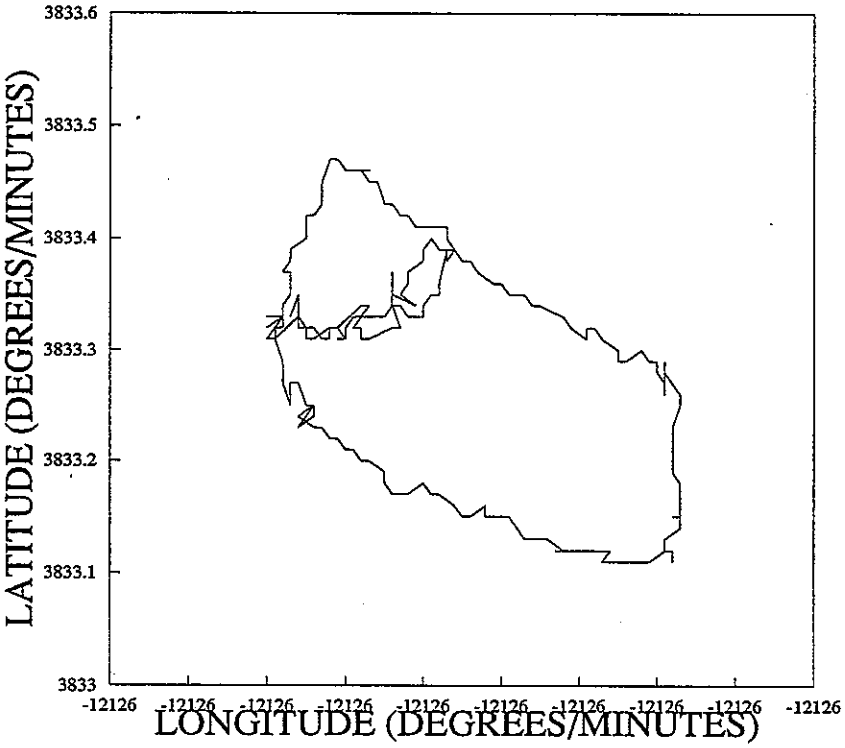

Figure 47 1-Channel GPS Receiver Path
Route 1 June 1, 1992

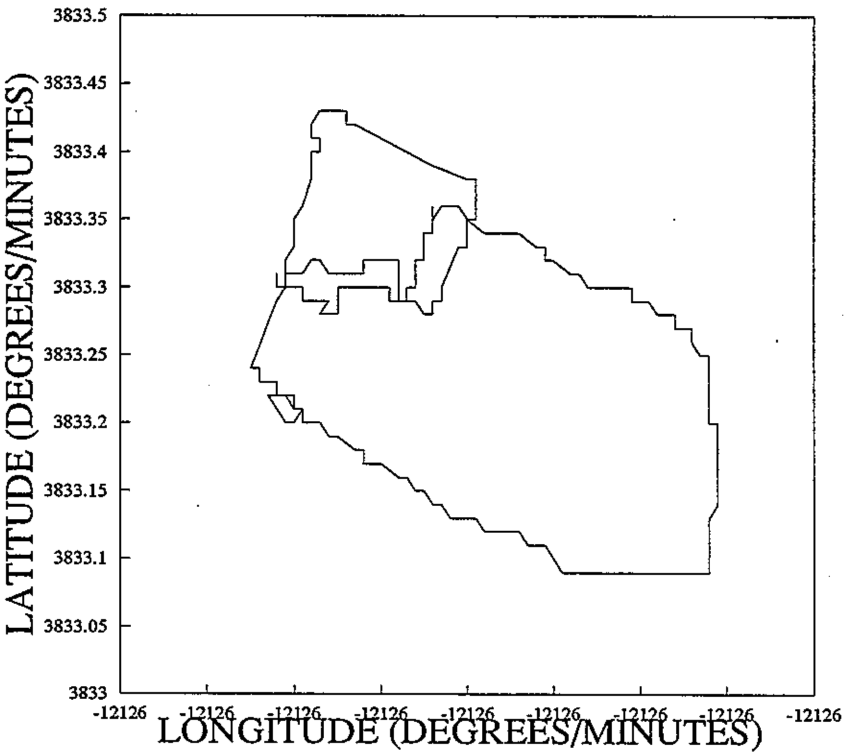

Figure 48 5-Channel GPS Receiver Path
Route 1 June 1, 1992

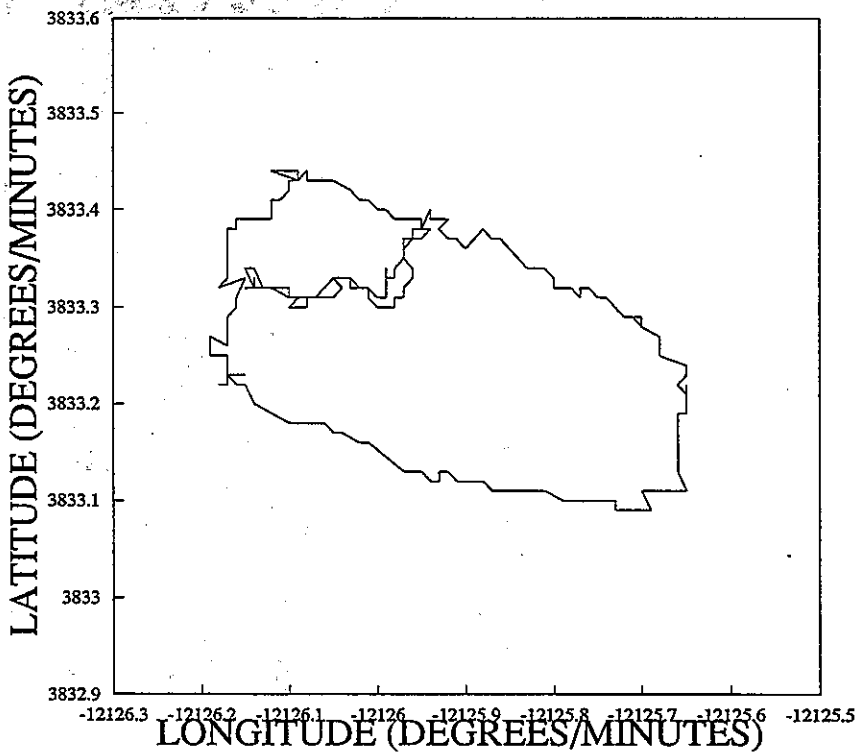

Figure 49 1-Channel GPS Receiver Path
Route 1 June 12, 1992

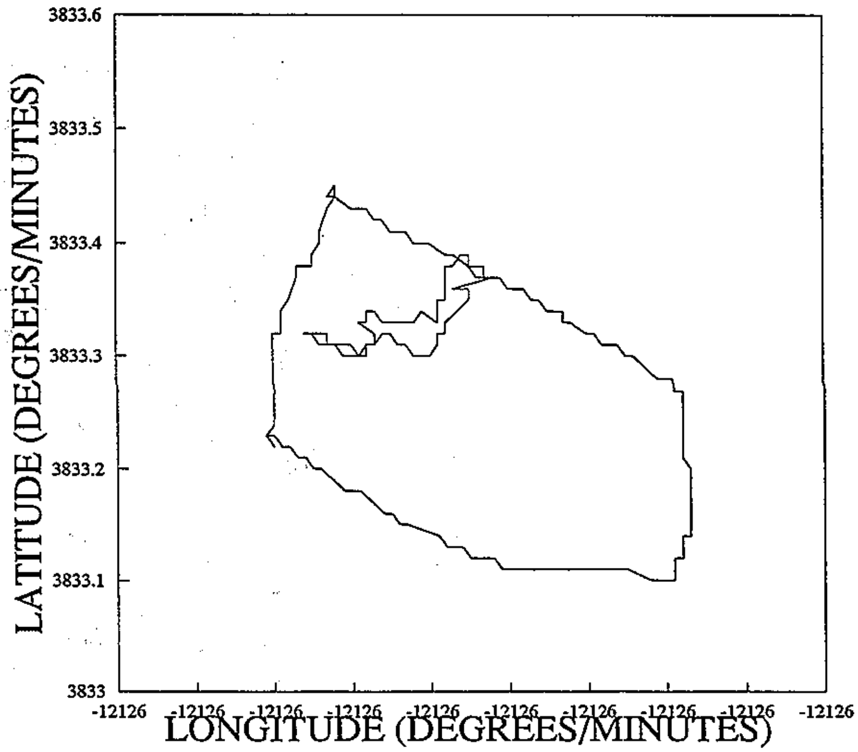

Figure 50 5-Channel GPS Receiver Path
Route 1 June 12, 1992

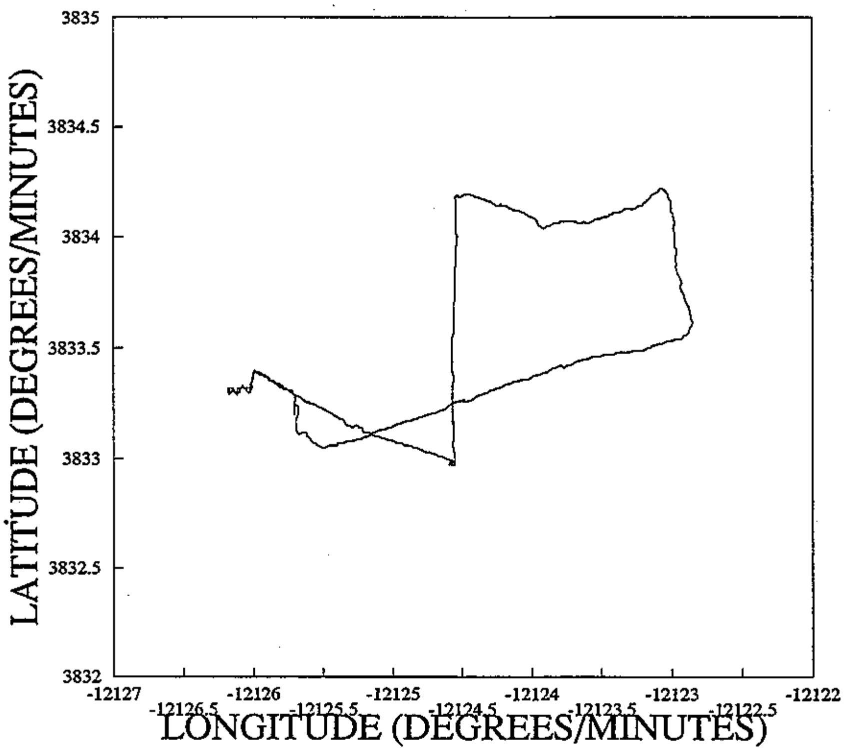

Figure 51 1-Channel GPS Receiver Path
Route 2 May 28, 1992

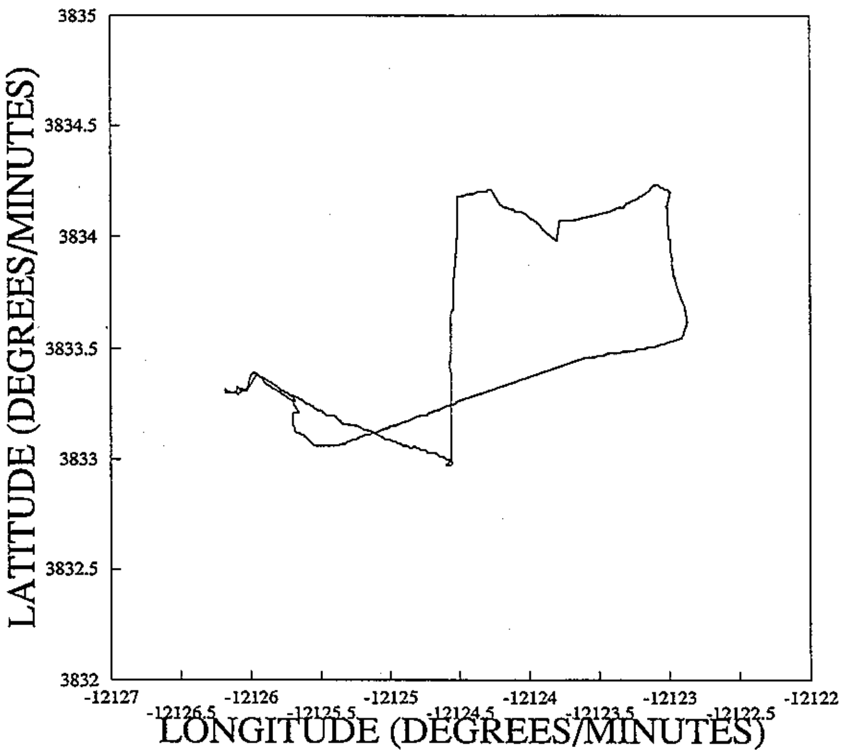

Figure 52 5-Channel GPS Receiver Path
Route 2 May 28, 1992

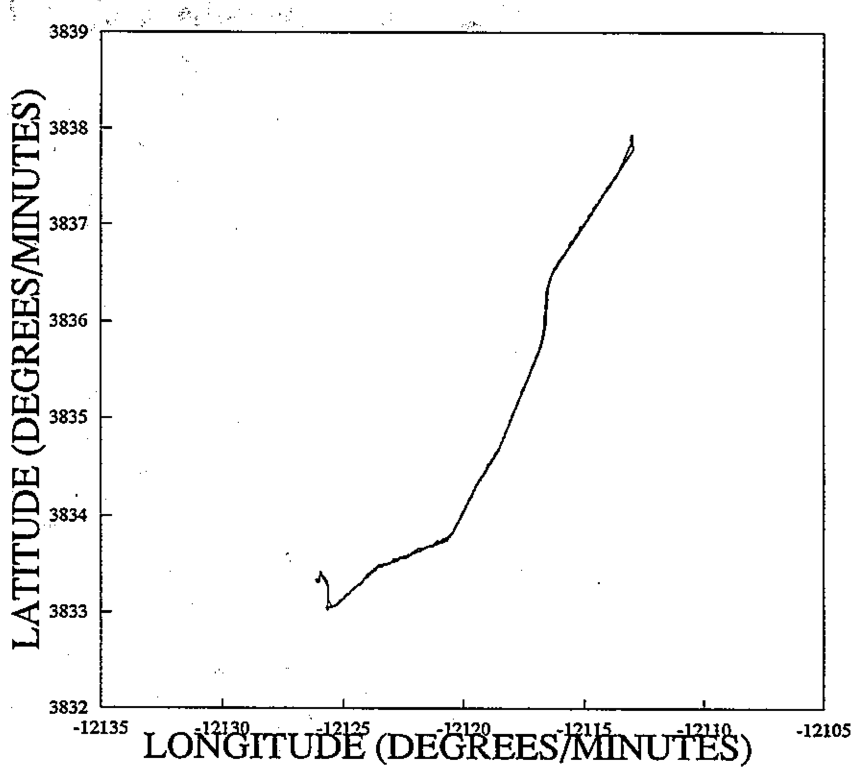

Figure 53 1-Channel GPS Receiver Path
Route 3 June 12, 1992

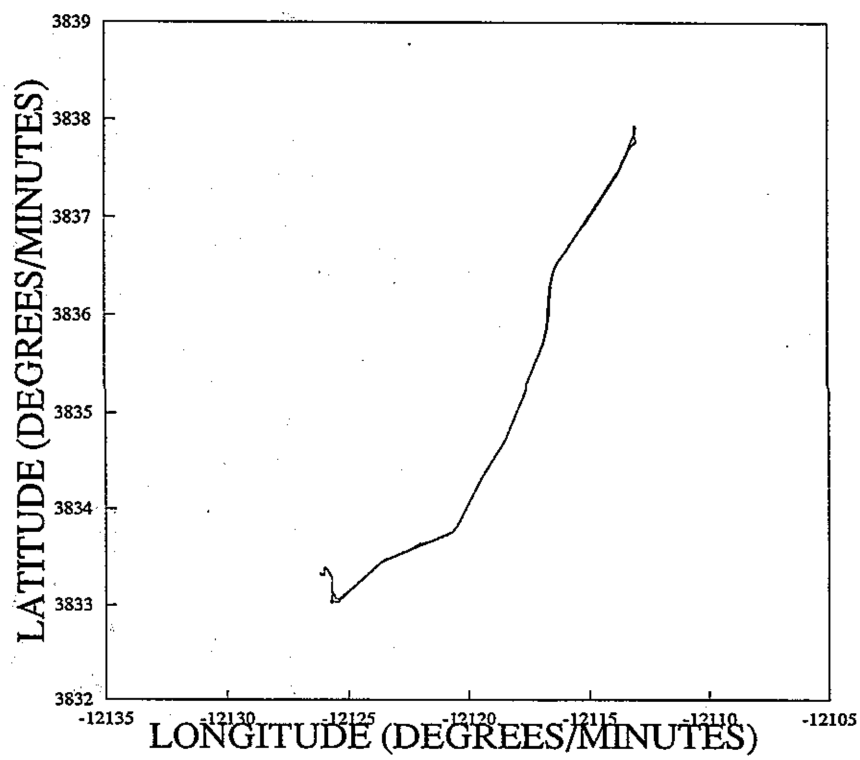

Figure 54 5-Channel GPS Receiver Path
Route 3 June 12, 1992

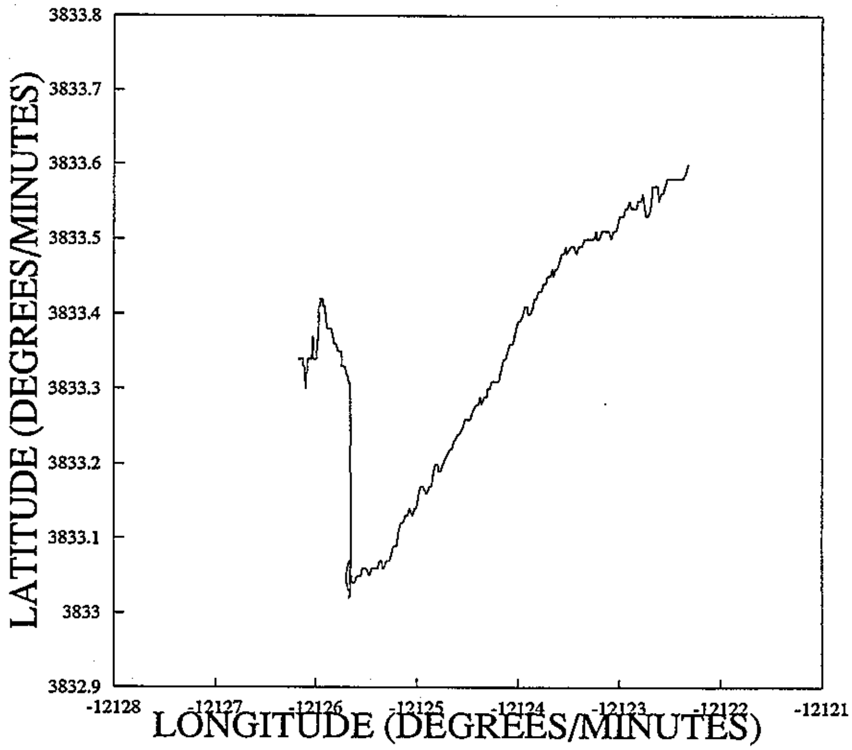

Figure 55 1-Channel GPS Receiver Path (Lab7 to Watt Ave.)
Route 3 June 12, 1992

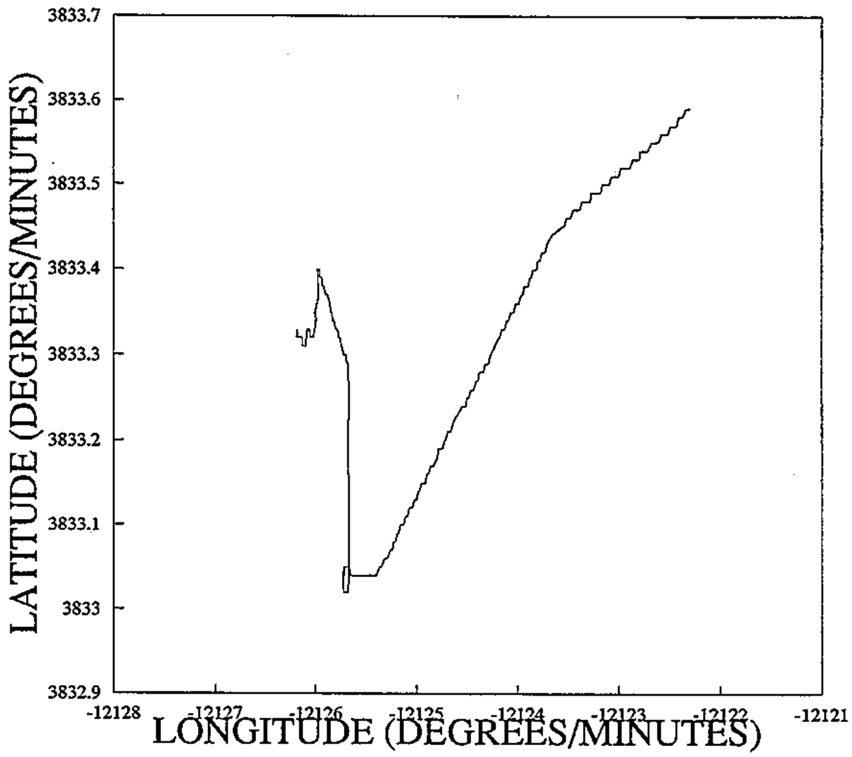

Figure 56 5-Channel GPS Receiver Path (Lab7 to Watt Ave.)
Route 3 June 12, 1992

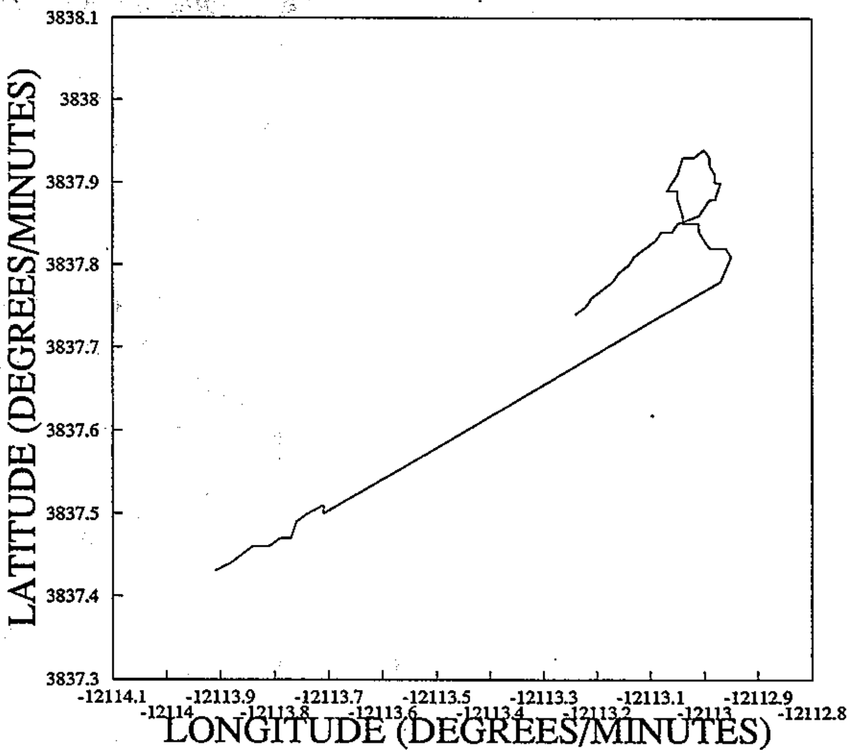

Figure 57 1-Channel GPS Receiver Path (Hazel Ave. Ramps)
Route 3 June 12, 1992

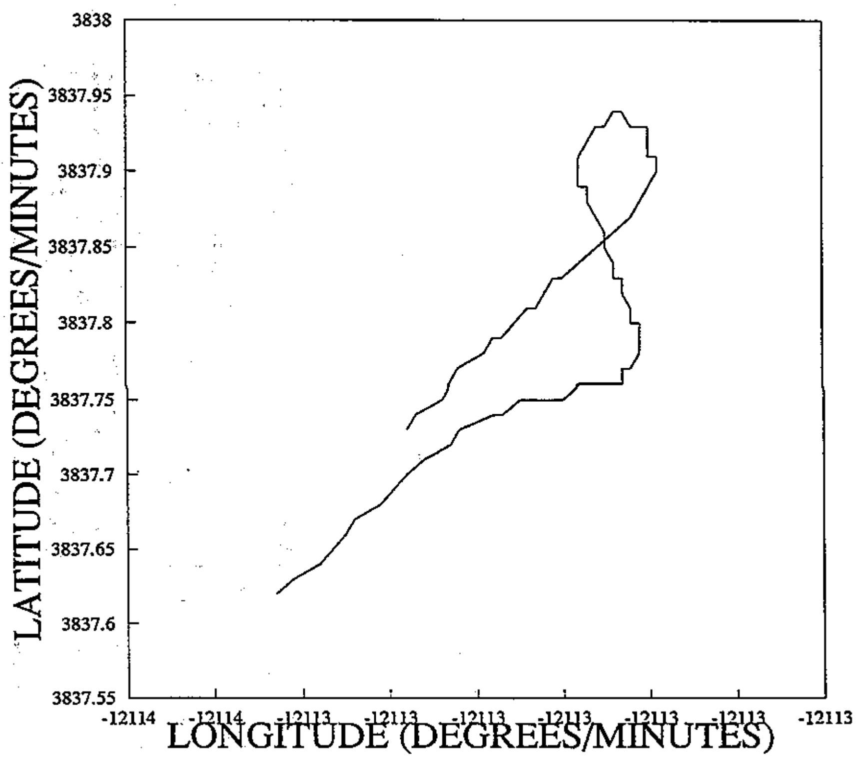

Figure 58 5-Channel GPS Receiver Path (Hazel Ave. Ramps)
Route 3 June 12, 1992

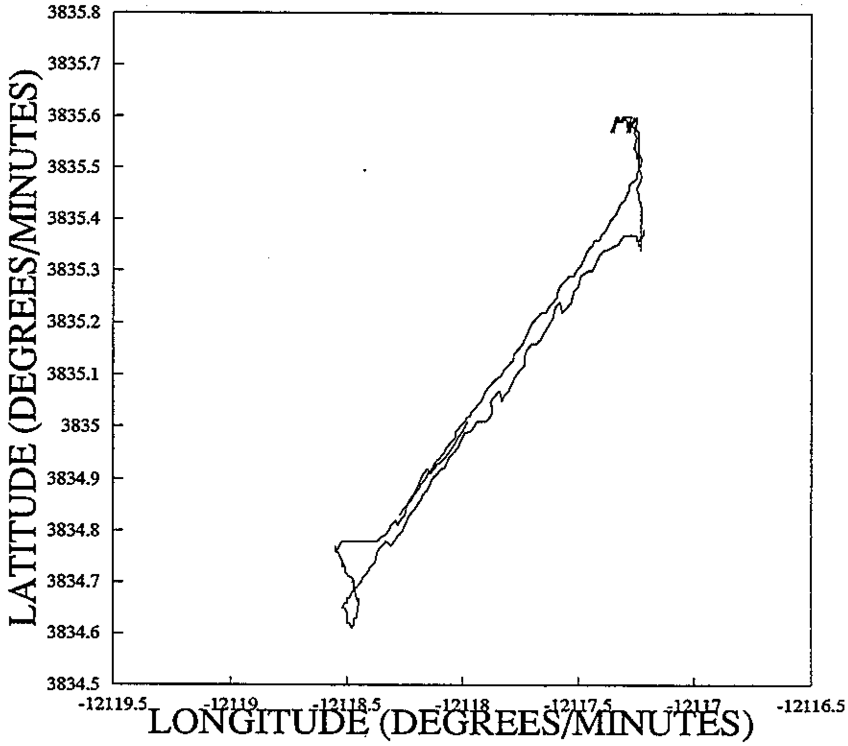

Figure 59 1-Channel GPS Receiver Path
Route 4 June 15, 1992

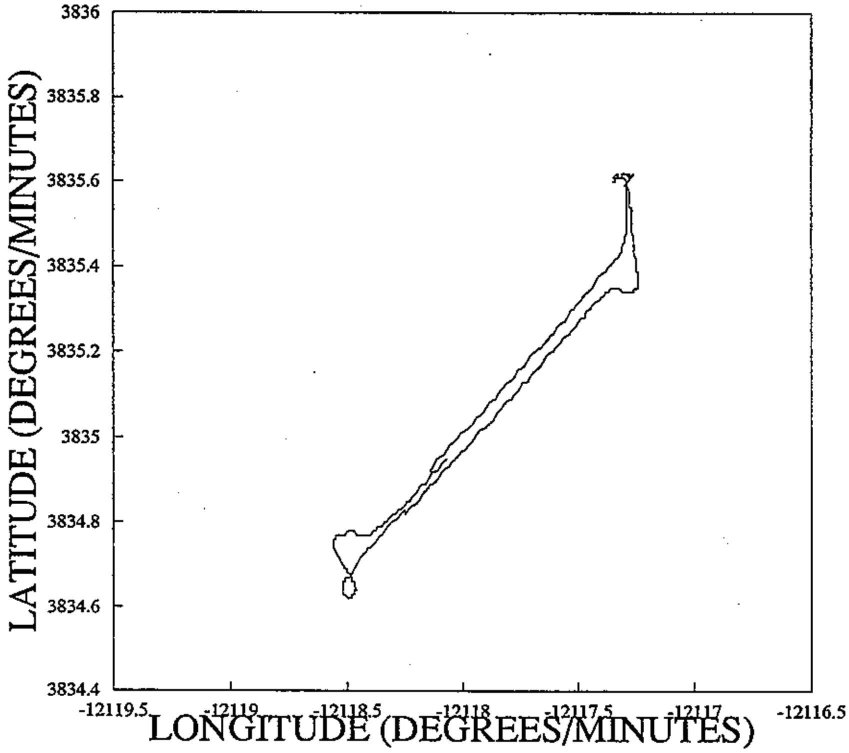

Figure 60 5-Channel GPS Receiver Path
Route 4 June 15, 1992

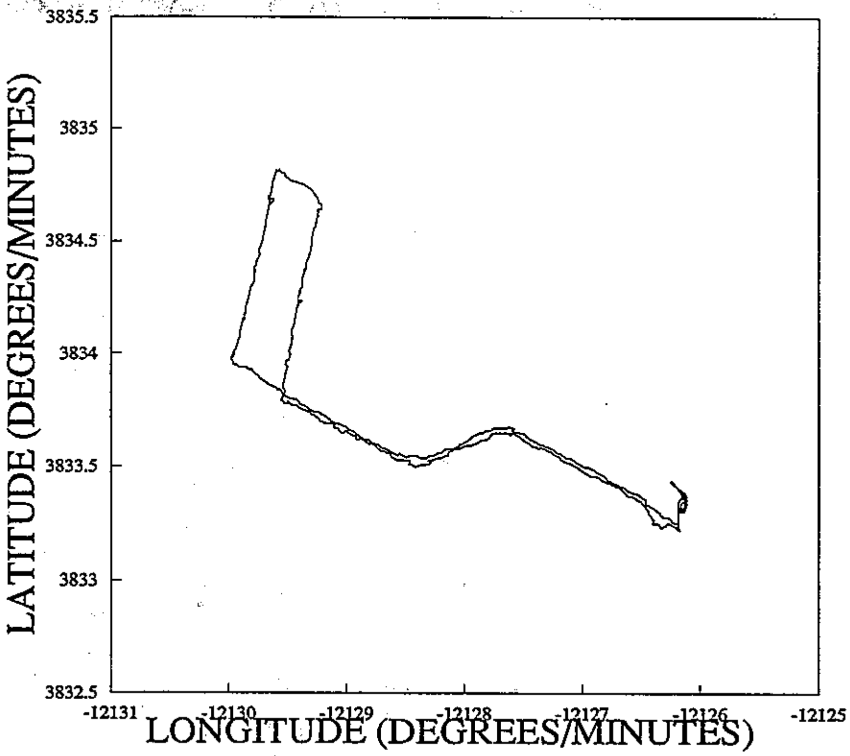

Figure 61 1-Channel GPS Receiver Path
Route 5 August 4, 1992

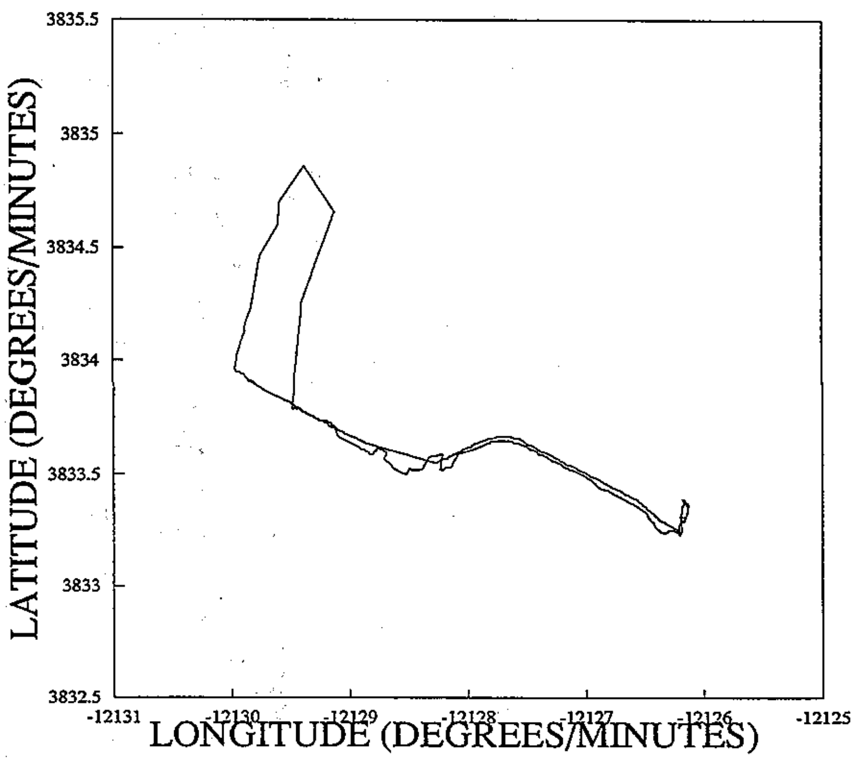

Figure 62 5-Channel GPS Receiver Path
Route 5 August 4, 1992

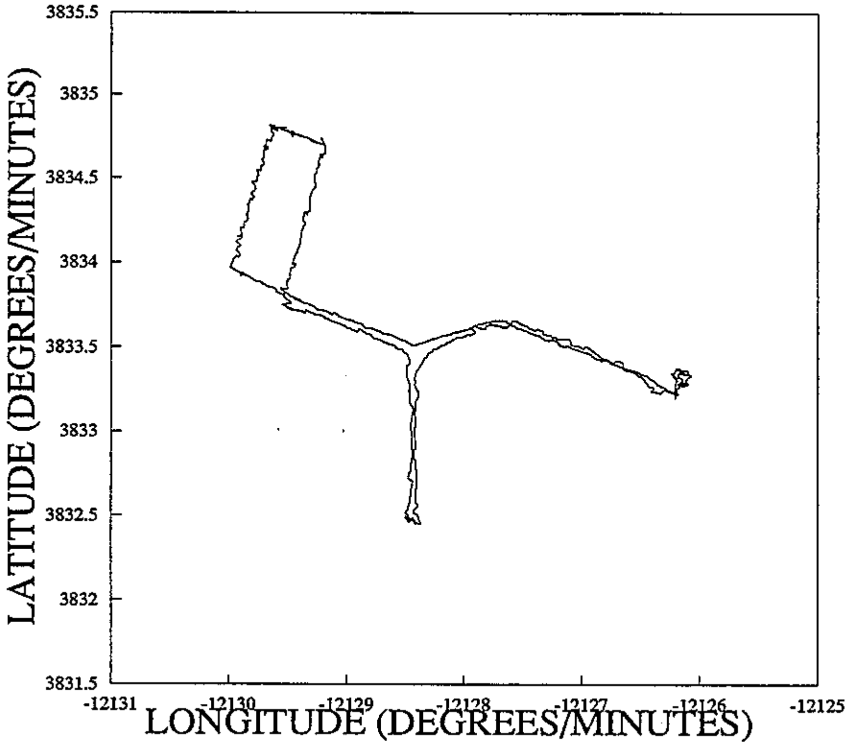

Figure 63 1-Channel GPS Receiver Path
Route 5A August 5, 1992

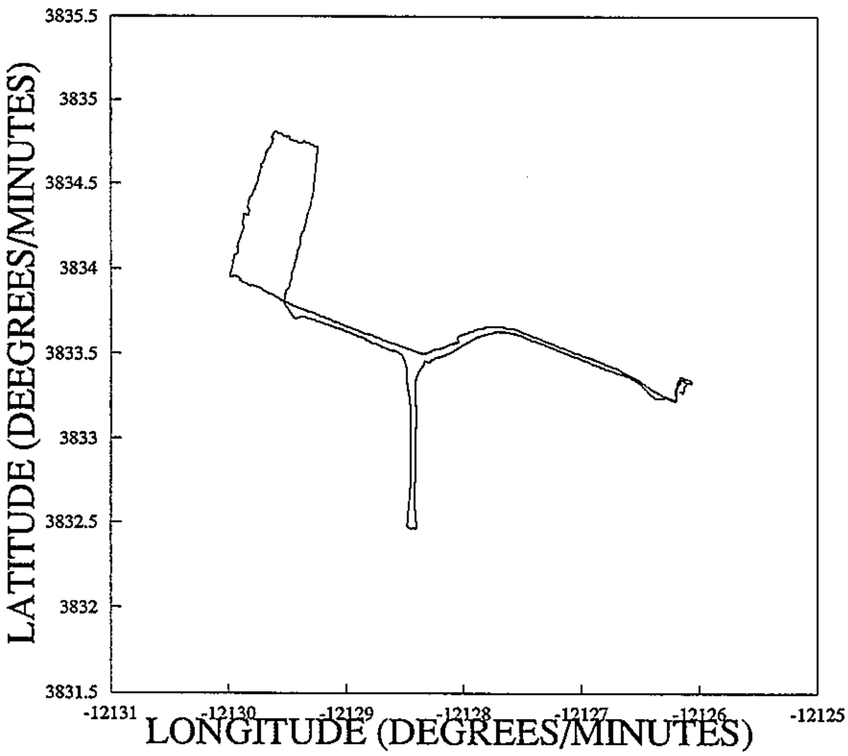

Figure 64 5-Channel GPS Receiver Path
Route 5A August 5, 1992

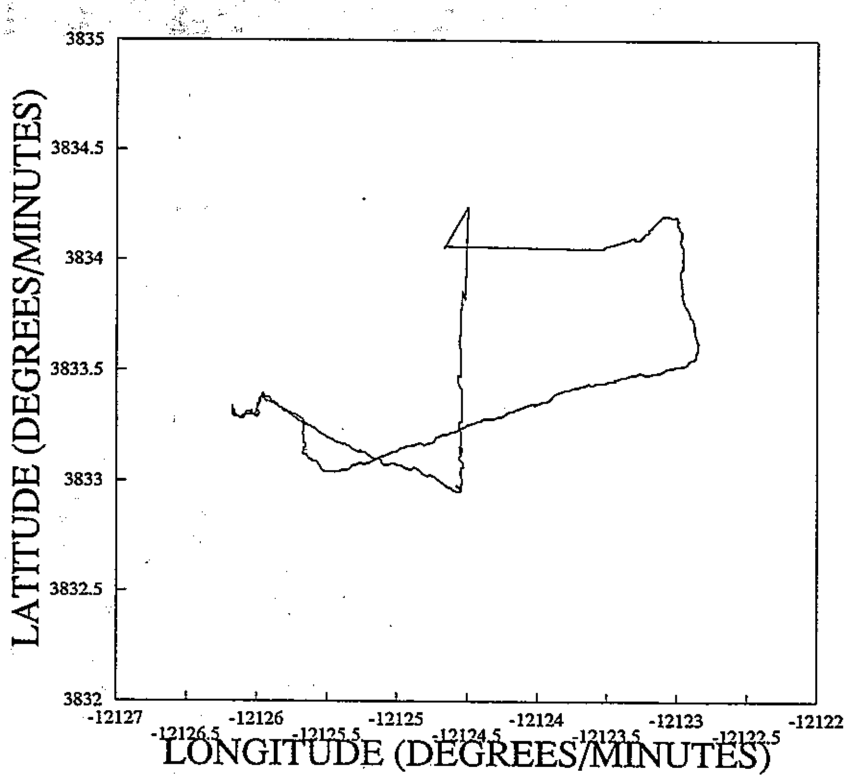

Figure 65 1-Channel GPS Receiver Path
Route 2 September 17, 1992

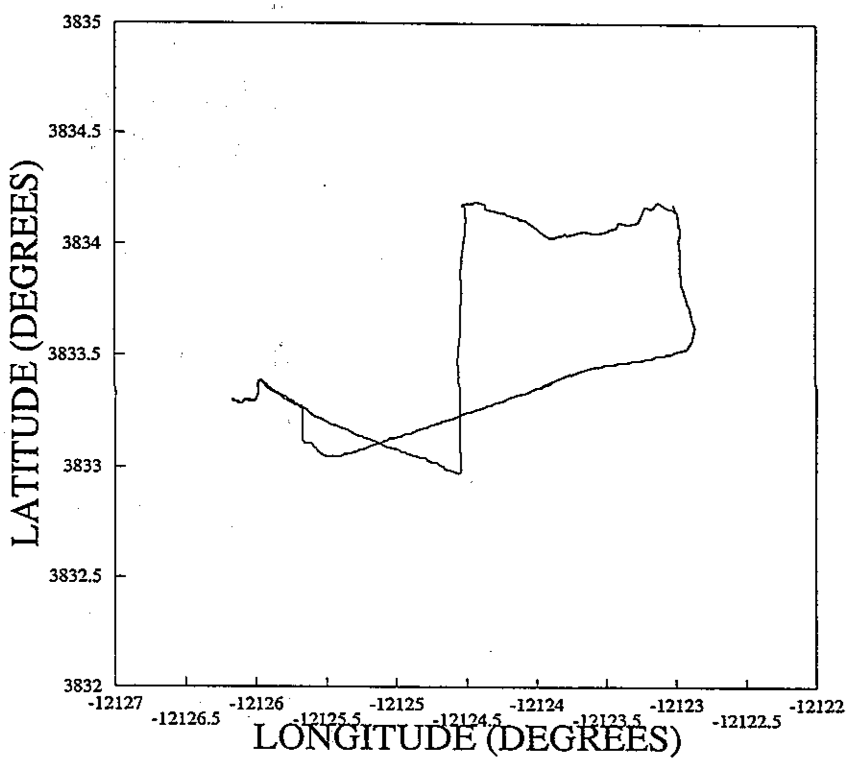

Figure 66 5-Channel GPS Receiver Path
Route 2 September 17, 1992

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
```

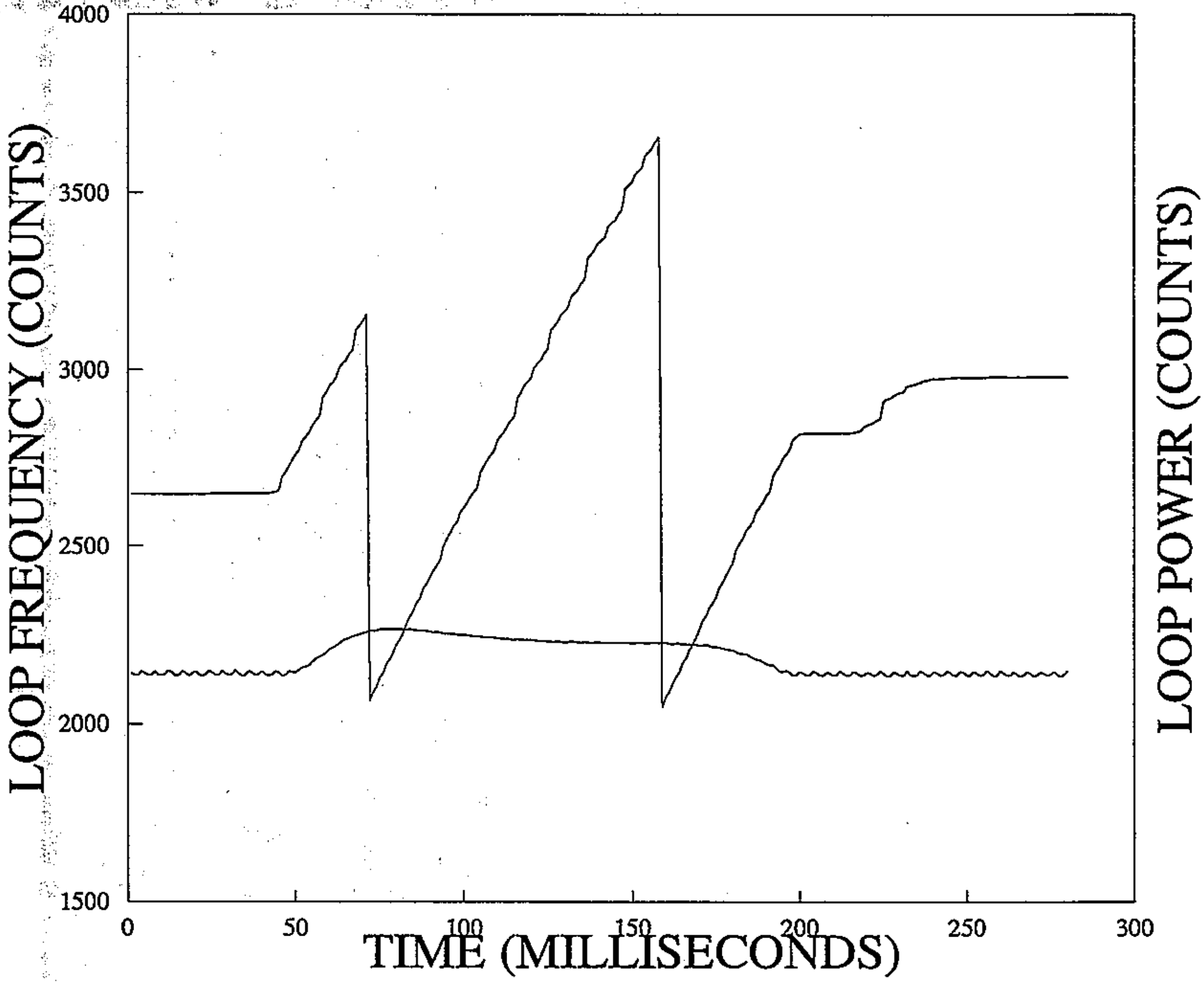

Figure 67 Inductive Loop 1
Route 1 June 12, 1992

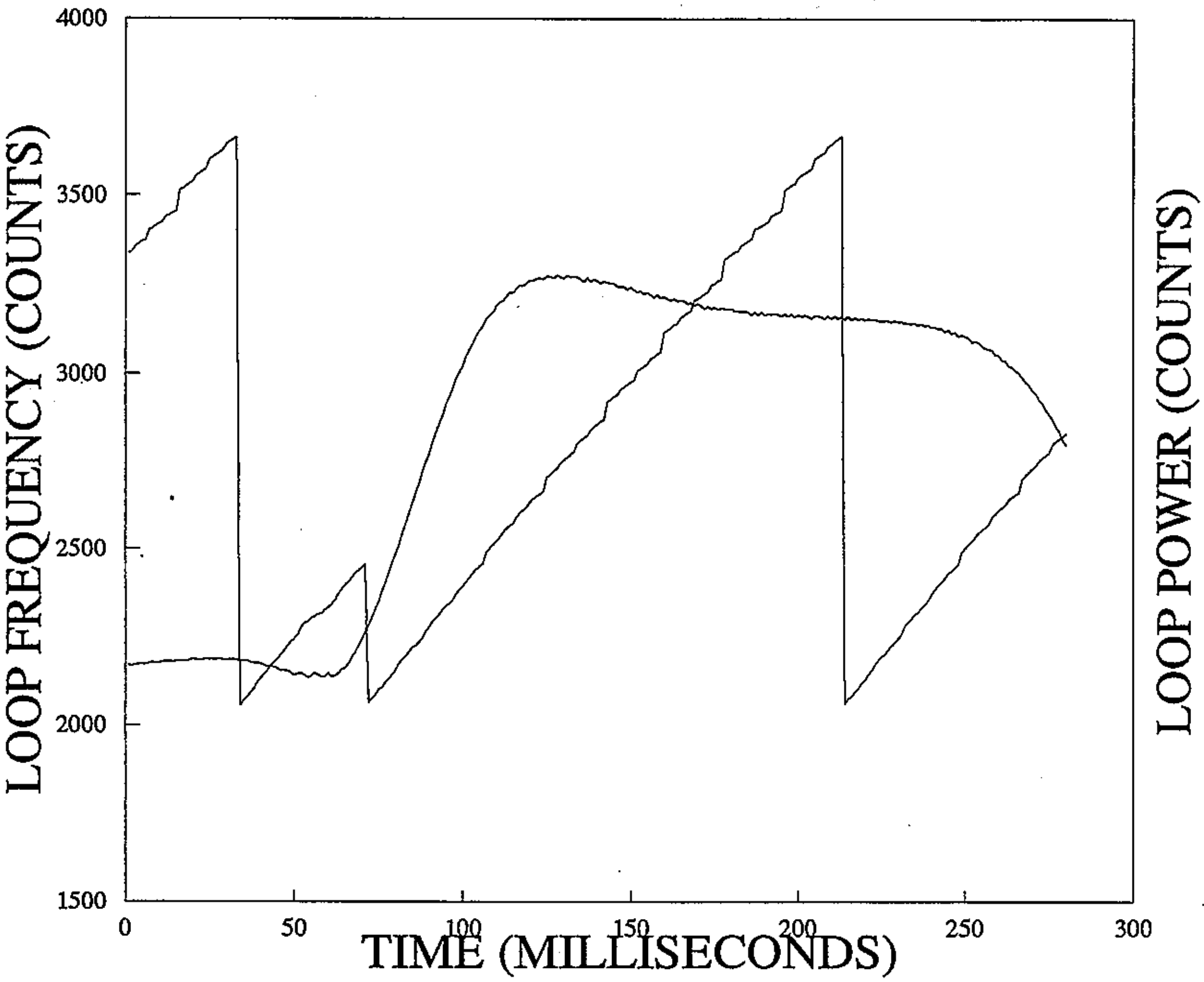

Figure 68 Inductive Loop 5
Route 1 June 12, 1992

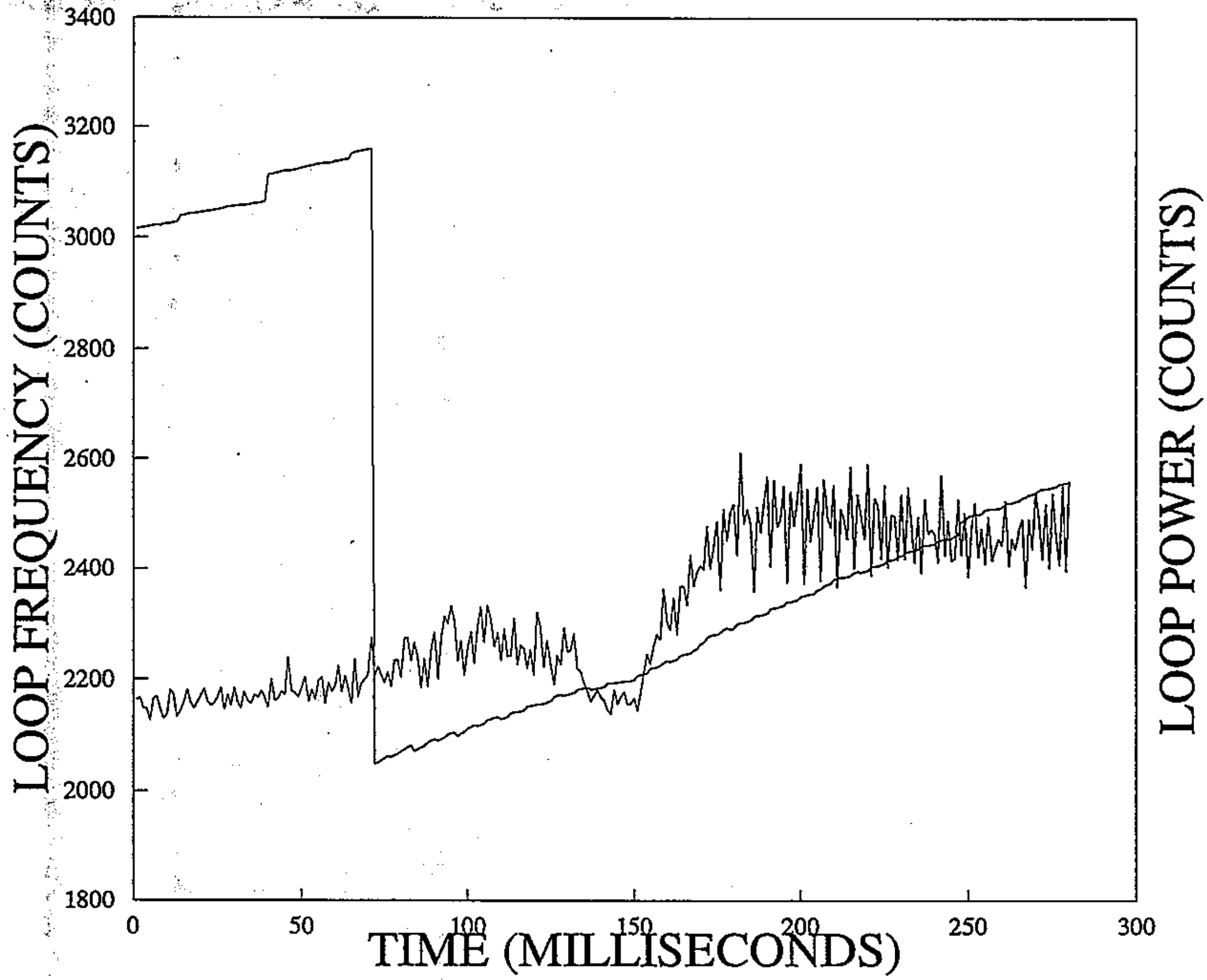

Figure 69 Light Rail Crossing
"Loop 10"
Route 1 June 12, 1992

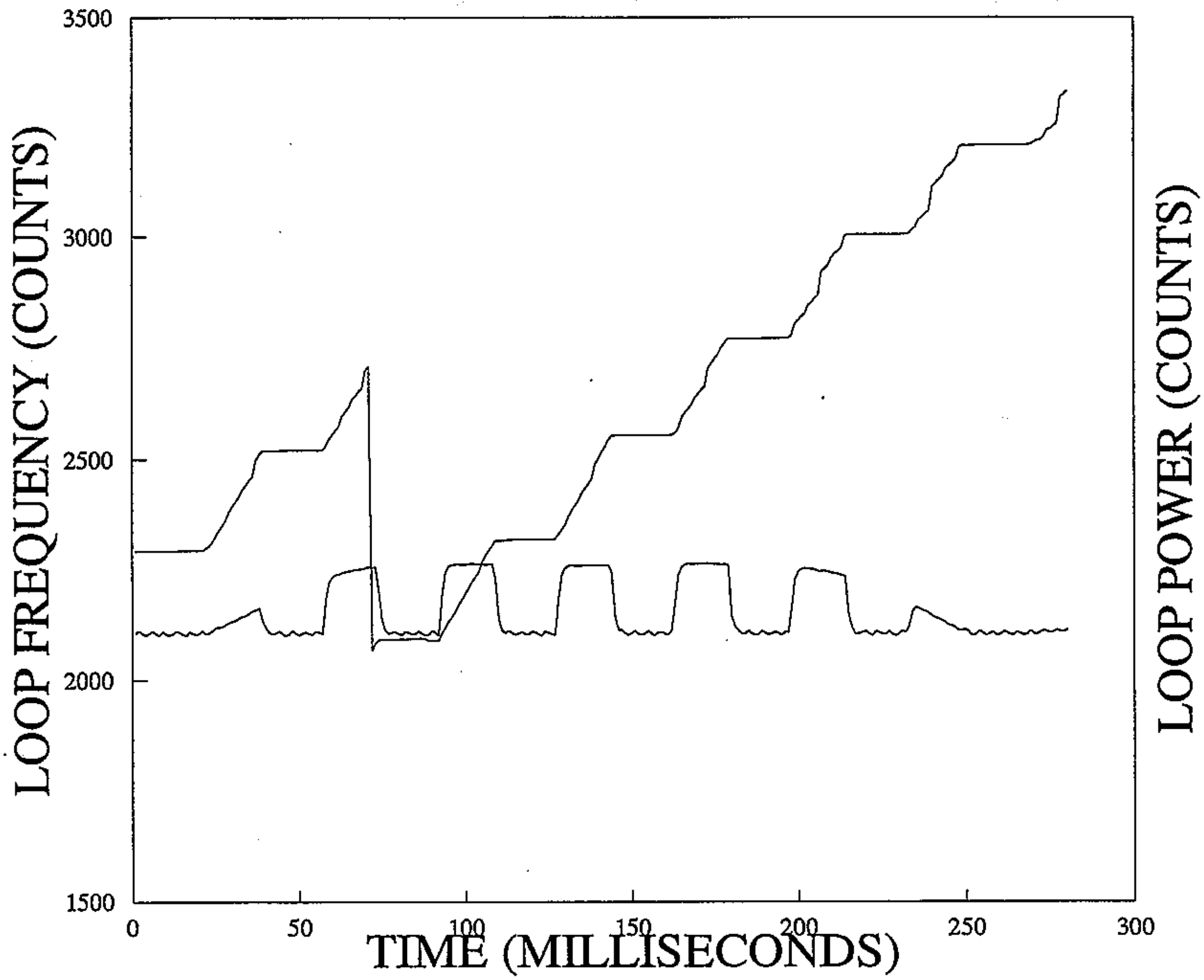

Figure 70 Inductive Loop 14
Route 4 April 30, 1992

Figure 71
Folsom Blvd.
Undercrossing
View from Westbound Highway 50

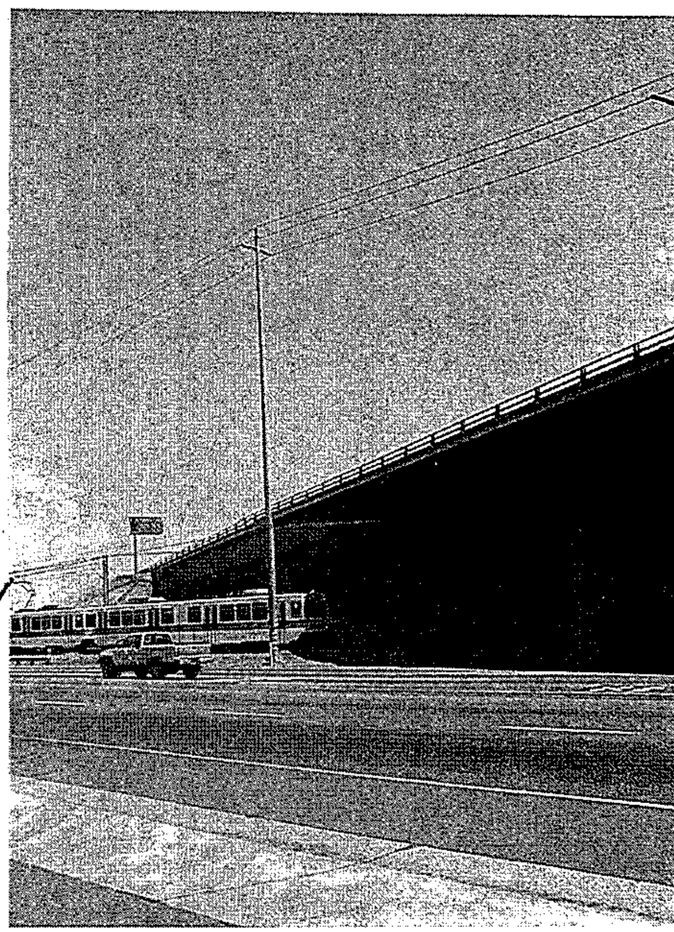

Figure 72
Folsom Blvd.
Undercrossing
View from
Folsom Blvd.

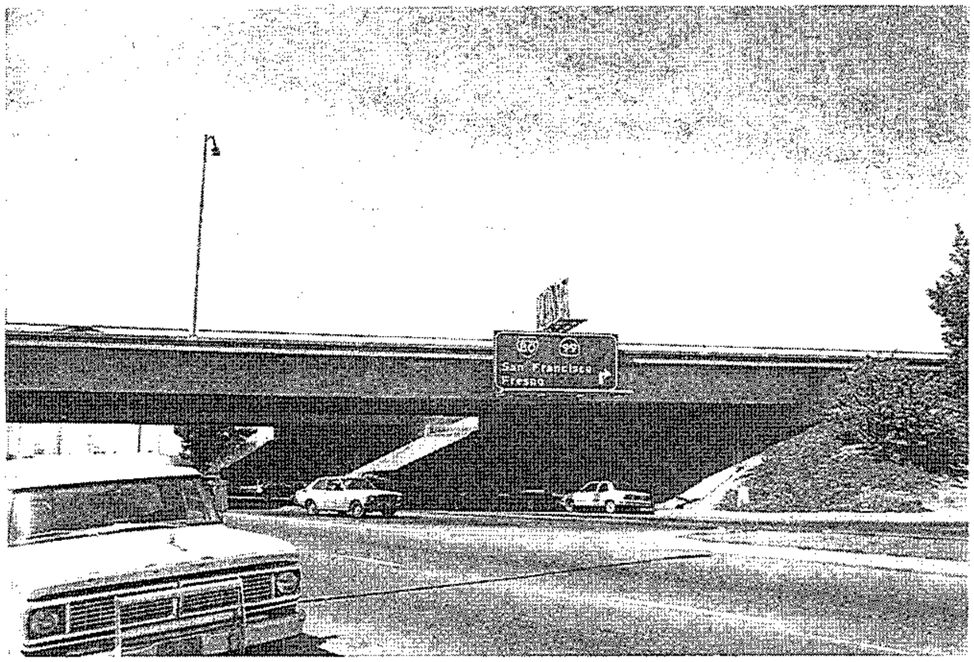

Figure 73

Stockton Blvd. Undercrossing
View from Stockton Blvd.

Figure 74

Stockton Blvd. Undercrossing
View from Westbound Highway 50

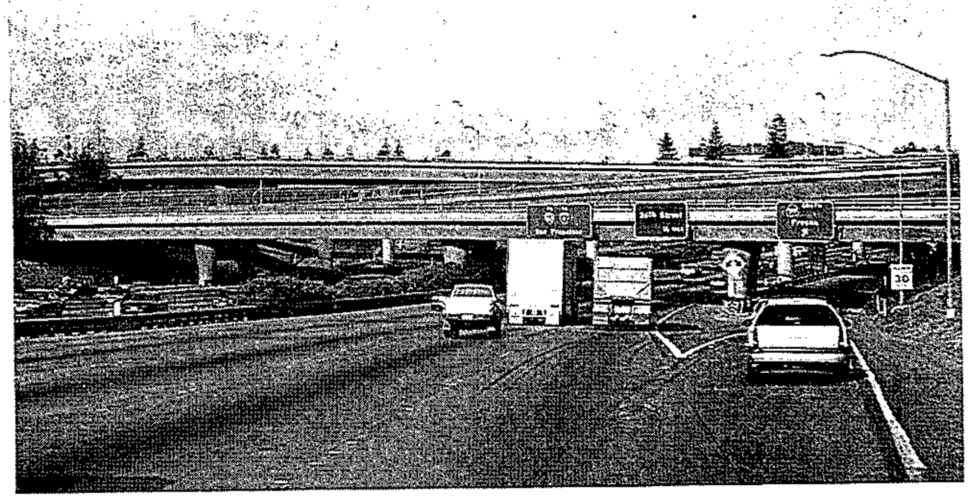

Figure 75

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

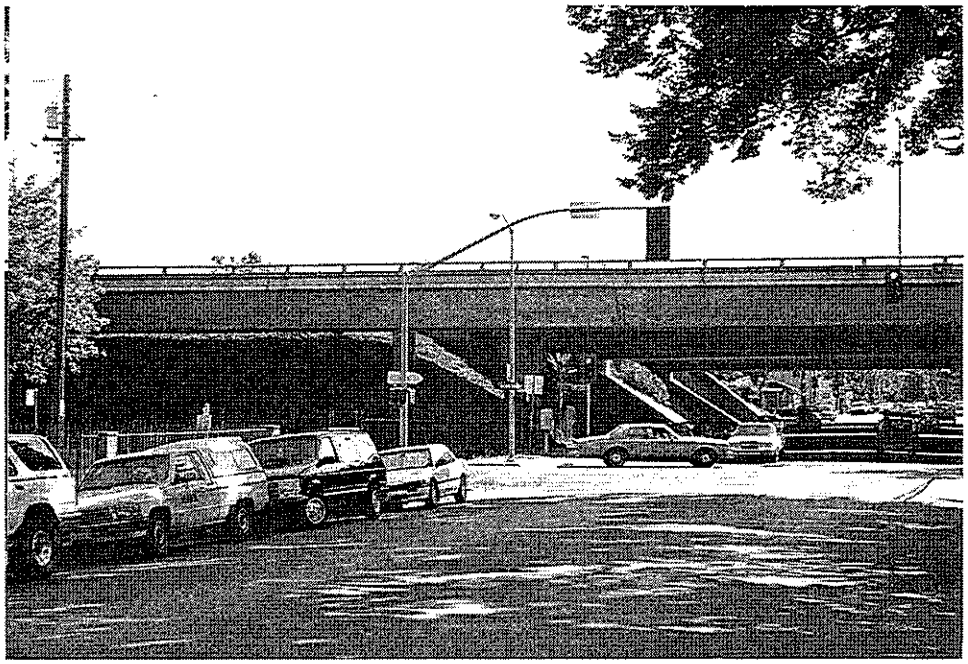

Figure 76

26th St. Undercrossing
View from 26th St.

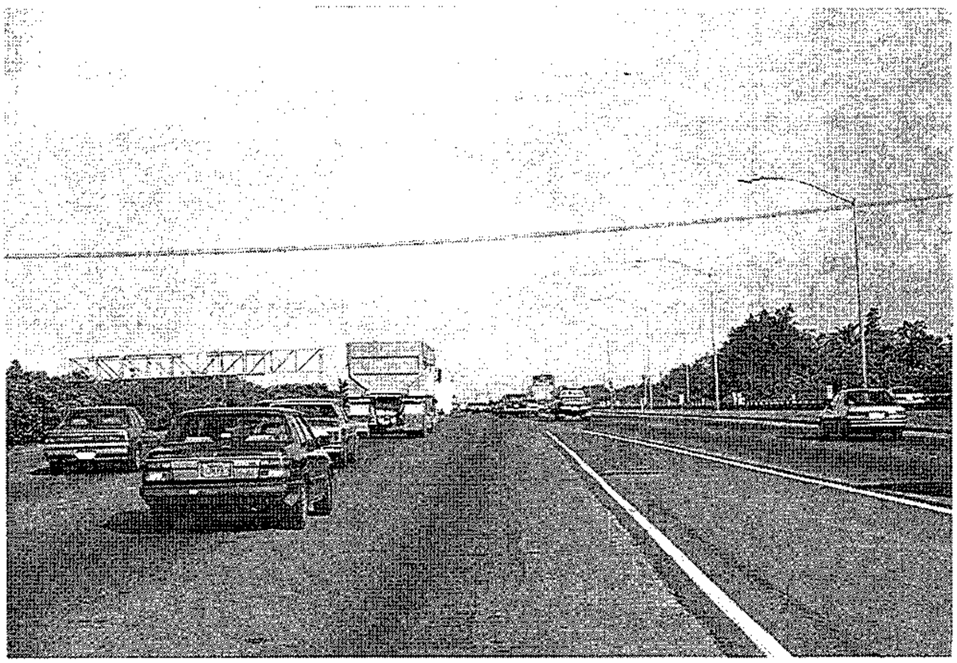

Figure 77

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

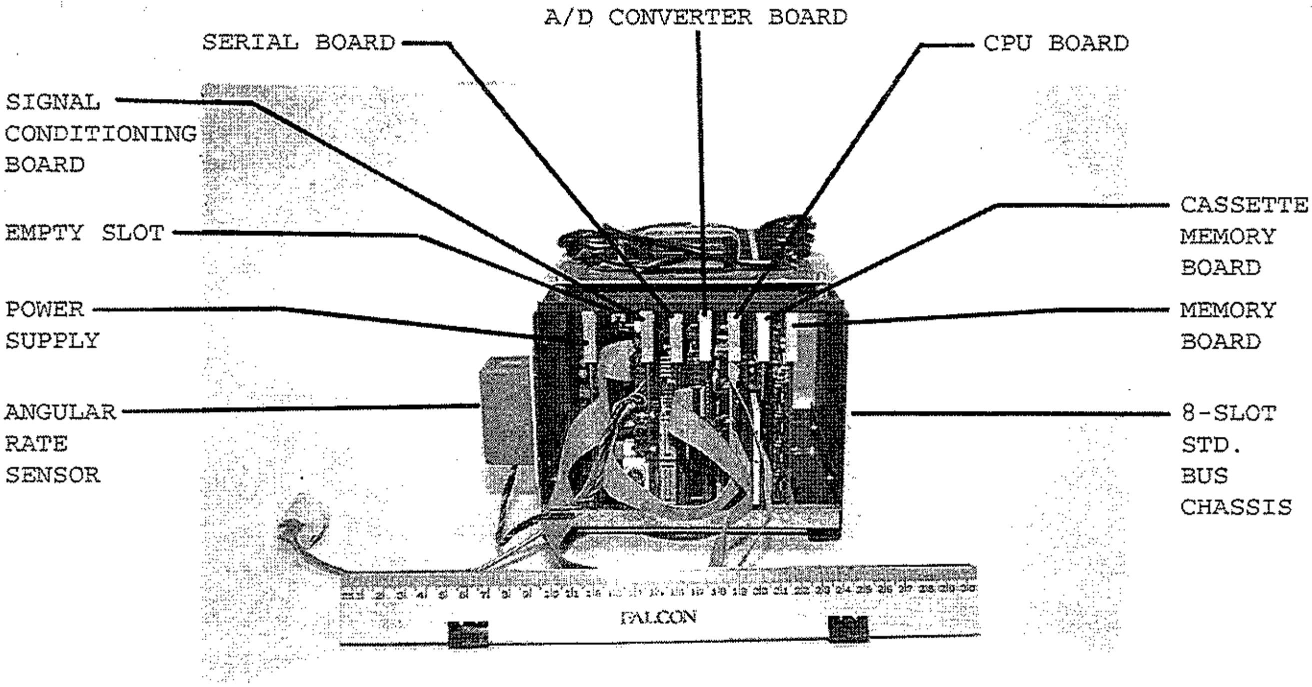
Caltrans Model 631150-100

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.



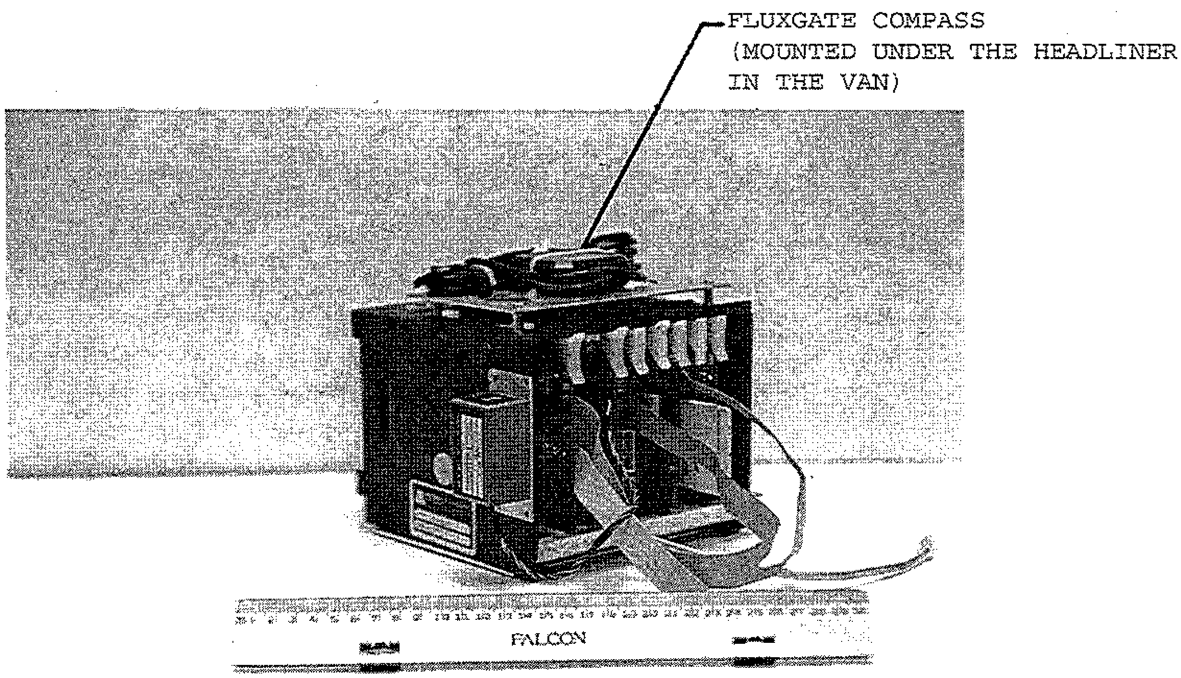


Figure B1
Computer System

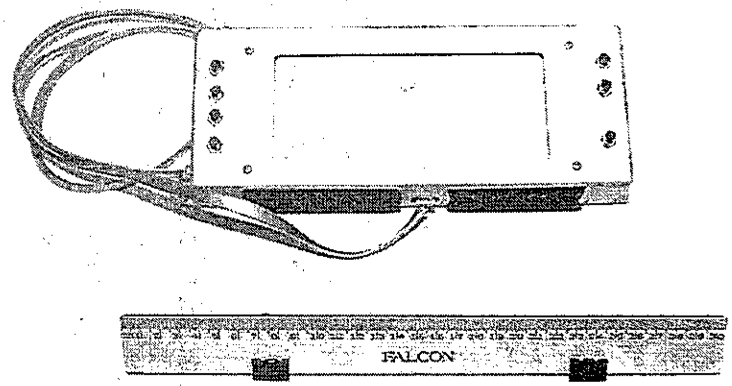


Figure B2

INRAD Operator Interface

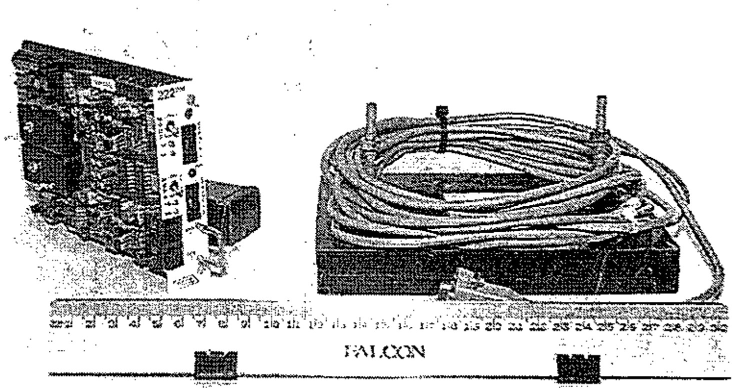


Figure B3

Inductive Radio Communications System

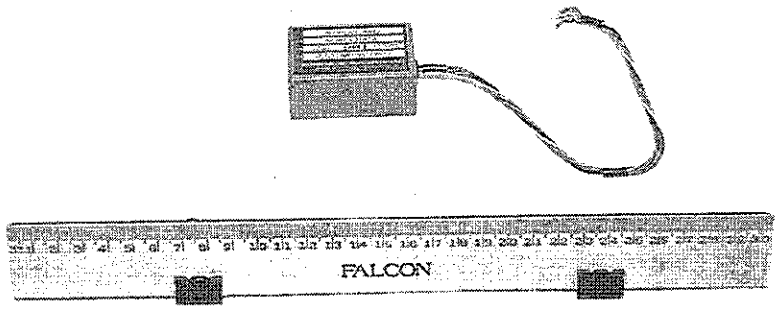


Figure B4

Angular Rate Sensor

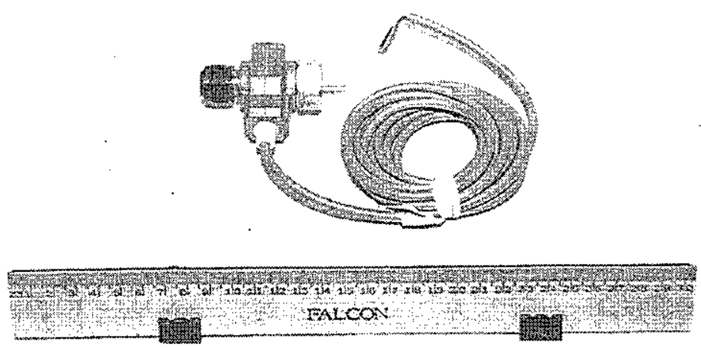


Figure B5

Odometer

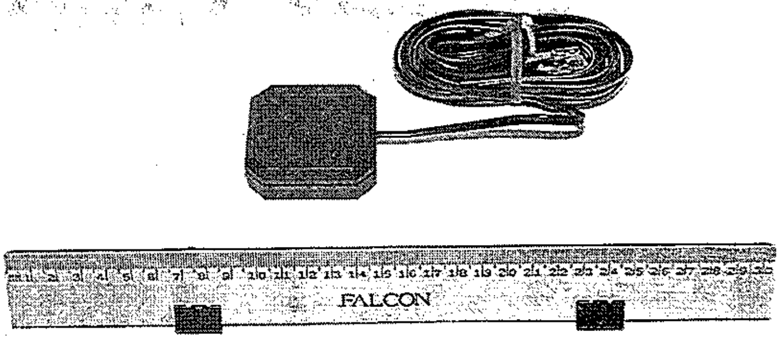


Figure B6

Fluxgate Compass

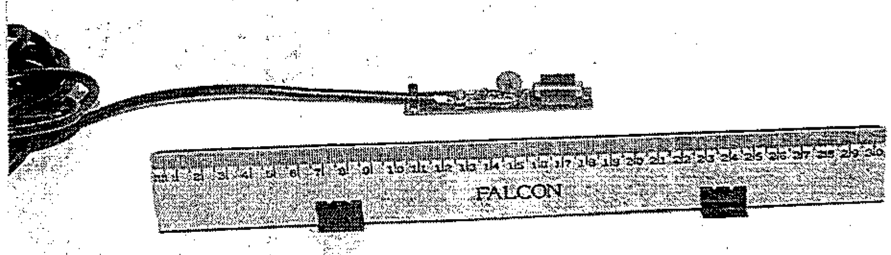


Figure B7

Loop Excitation Antenna

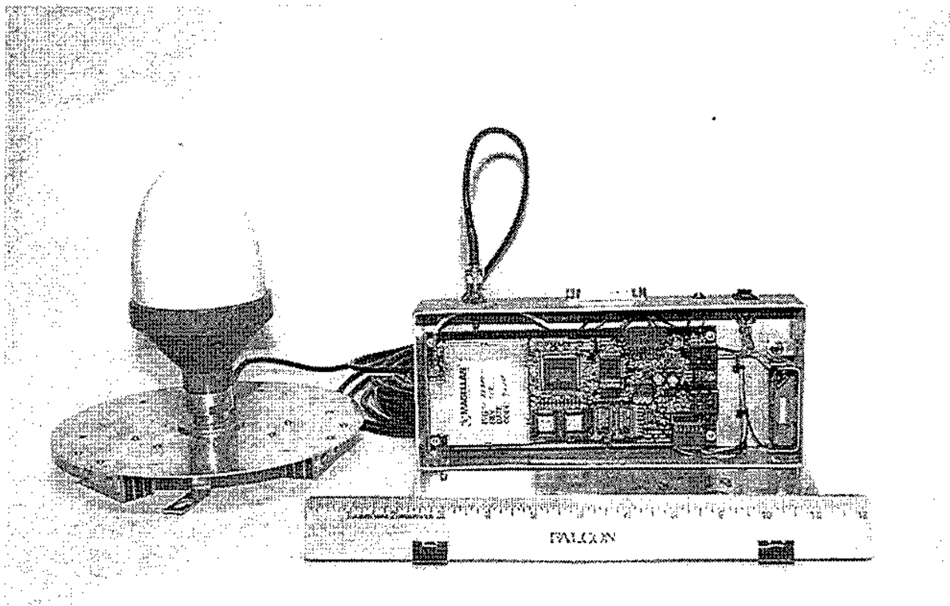


Figure B8

5-Channel GPS Receiver with Antenna

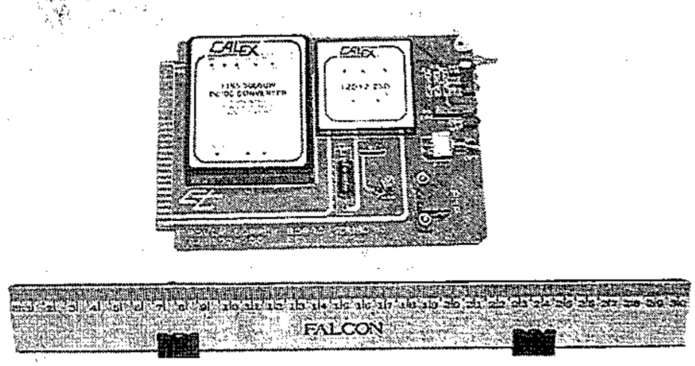


Figure B9

Power Supply

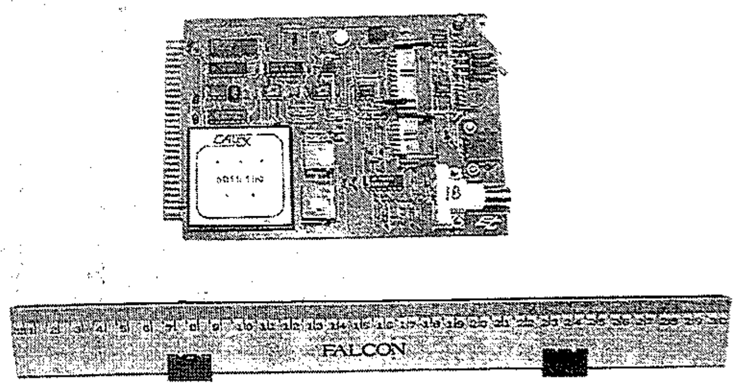


Figure B10

Signal Conditioning Board

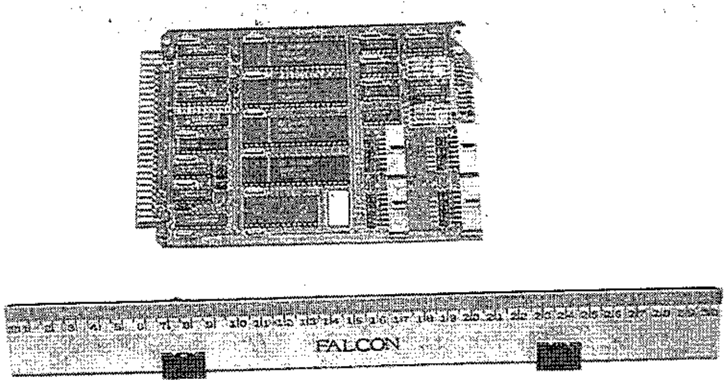


Figure B11

Multichannel Serial Board

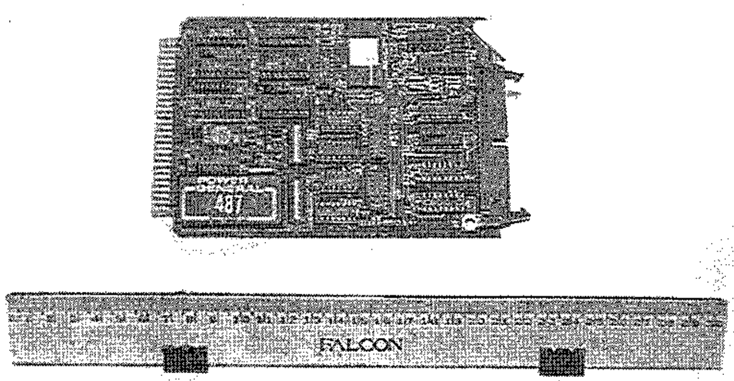


Figure B12

A/D Converter Board

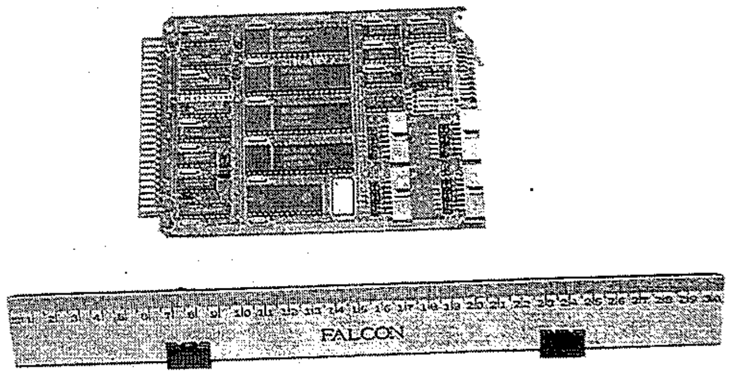


Figure B13

CPU Board

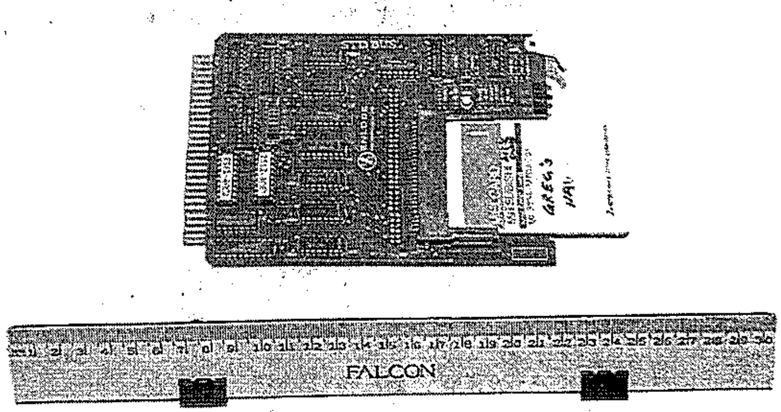


Figure B14

Cassette Memory Board

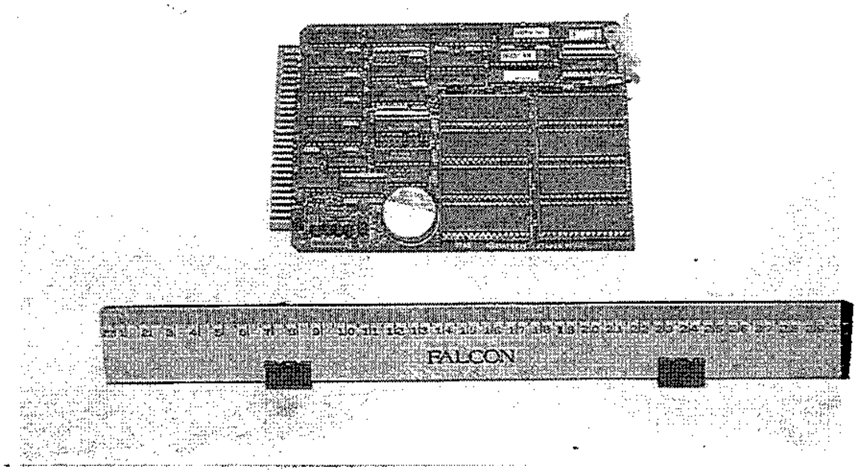


Figure B15

Memory Board

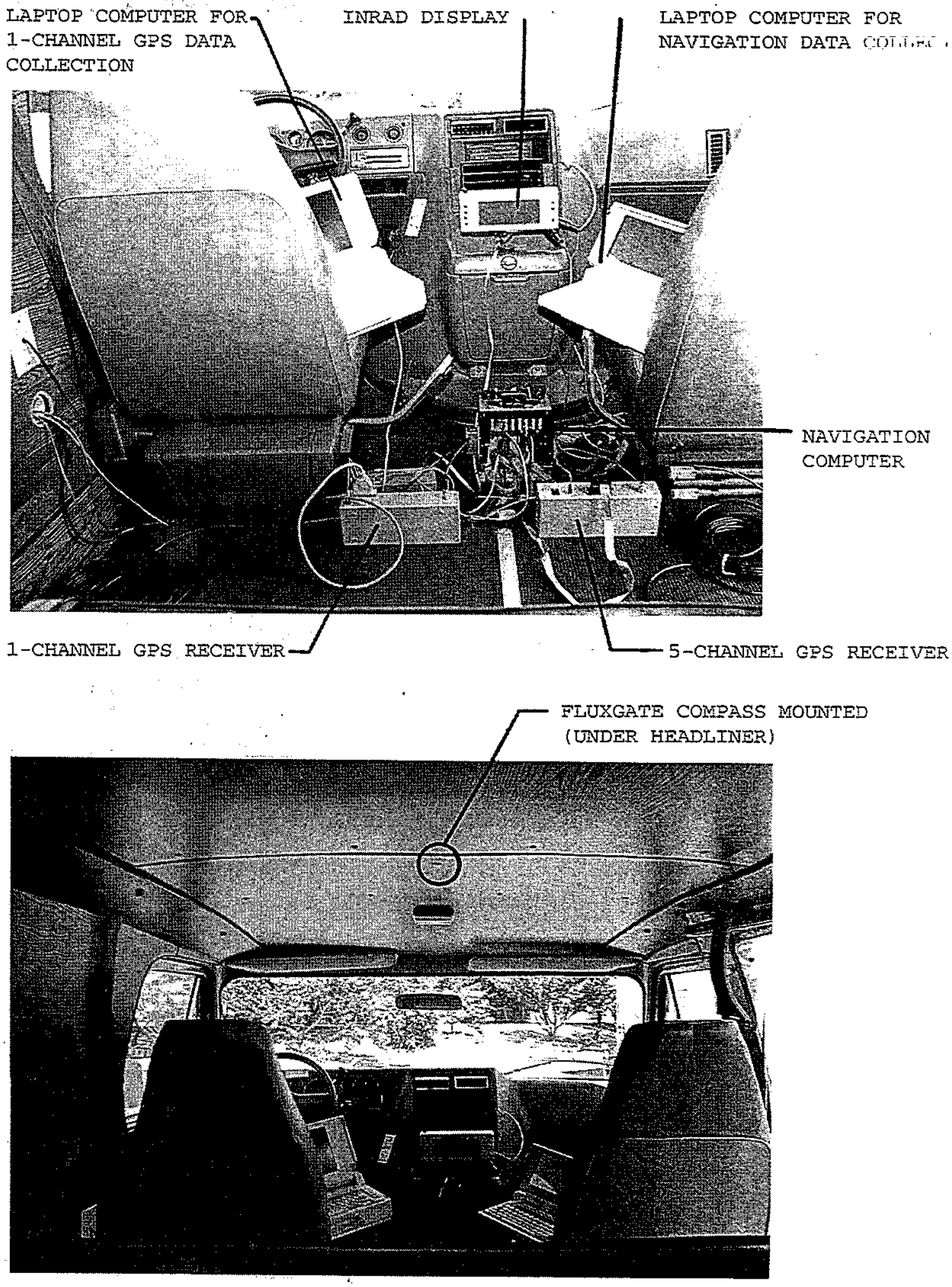


Figure B16

Navigation Equipment

Installation

Figure B17
Odometer
Installation

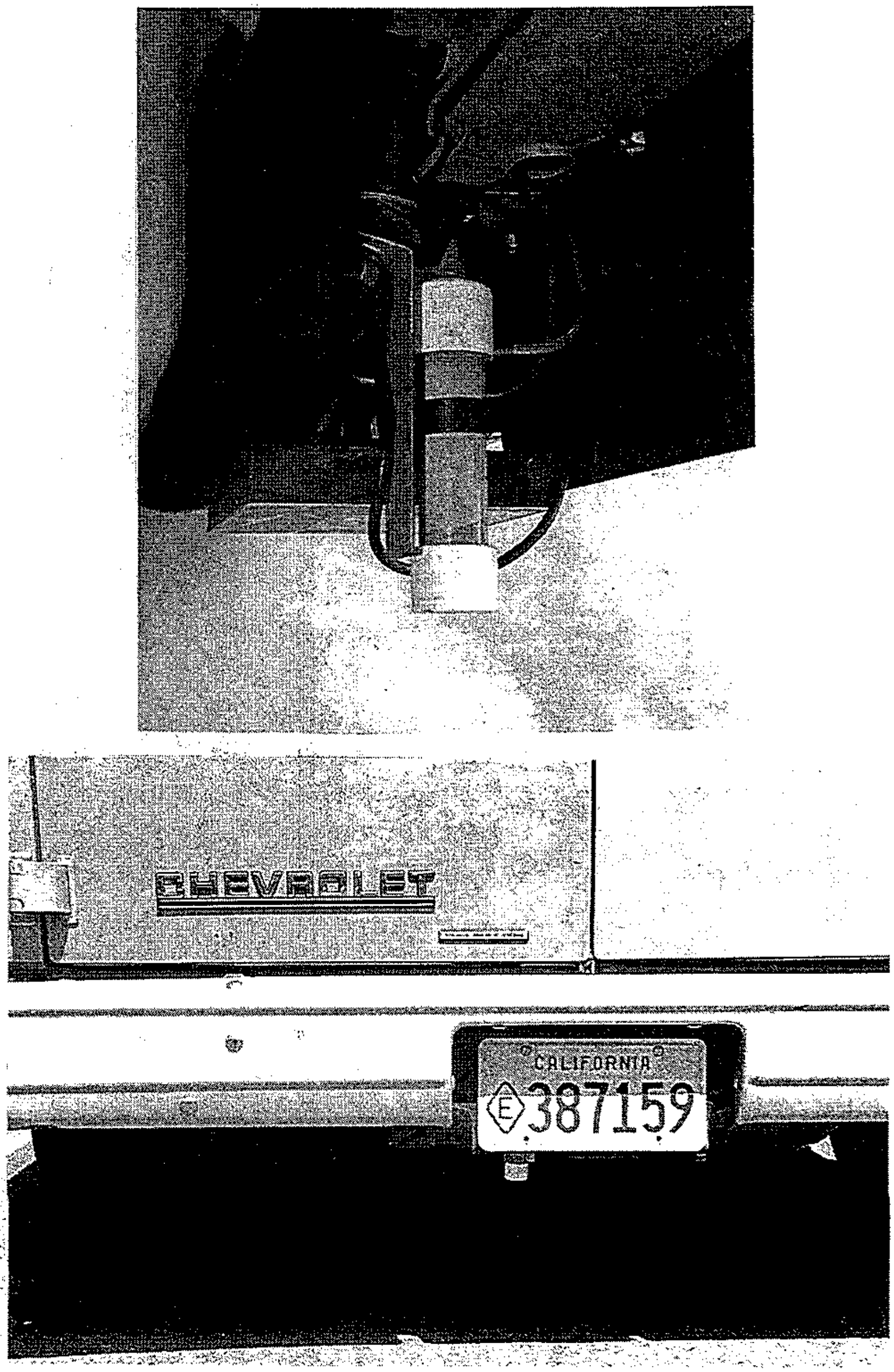


Figure B18

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: %71d\n", odometer);      /* odometer */
    fprintf(sumfile, "Odometer: %71d\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.

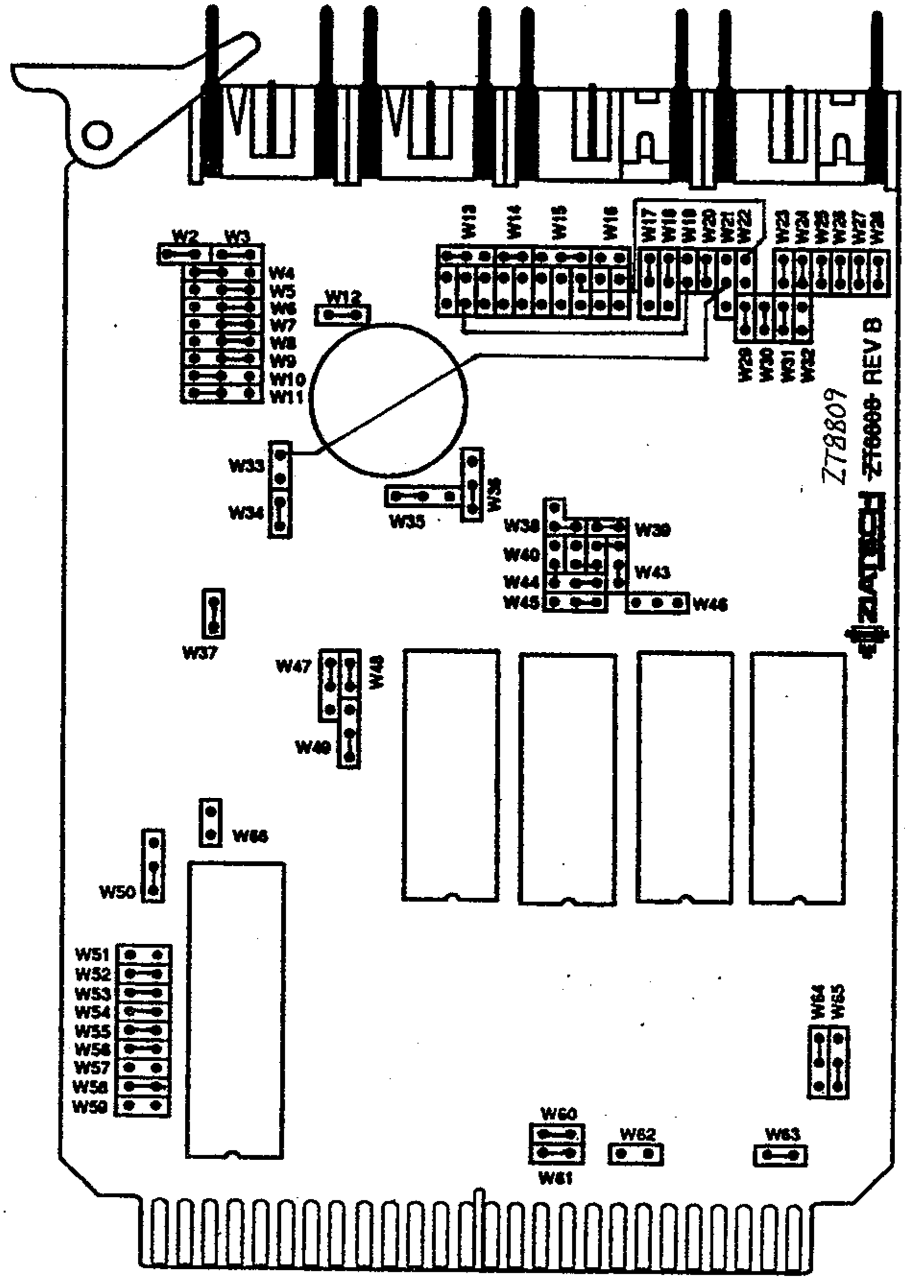


Figure E-1
Ziatech ZT8809 Jumper Configuration

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 for 5MHz 8088 operation
W5	OUT	
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	

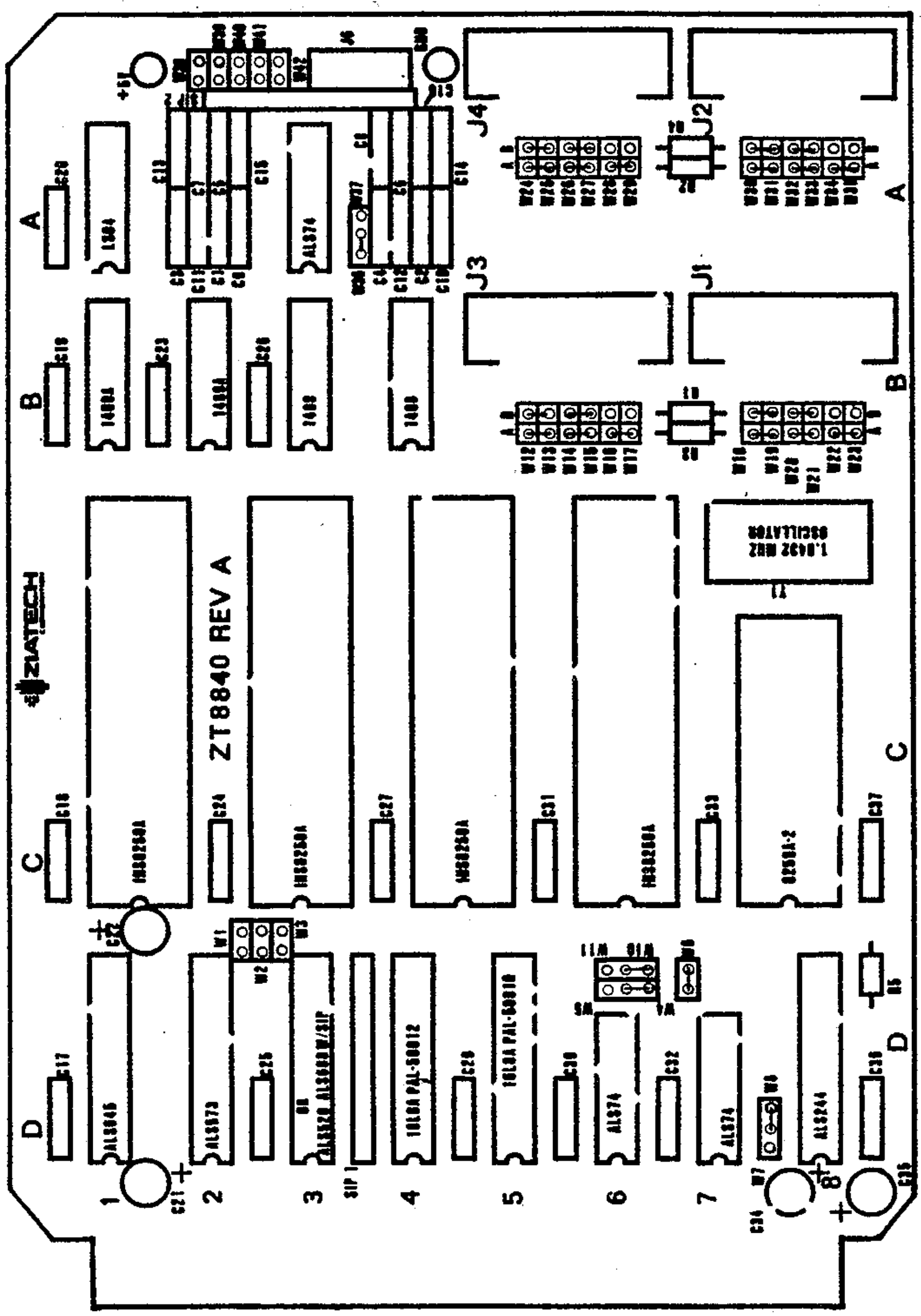


Figure E-2
Ziatech ZT8840 Jumper Configurations

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 W19	IN OUT	Selects battery backup mode for Row B chips
W20 W21	IN OUT	Selects battery backup mode for Row 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

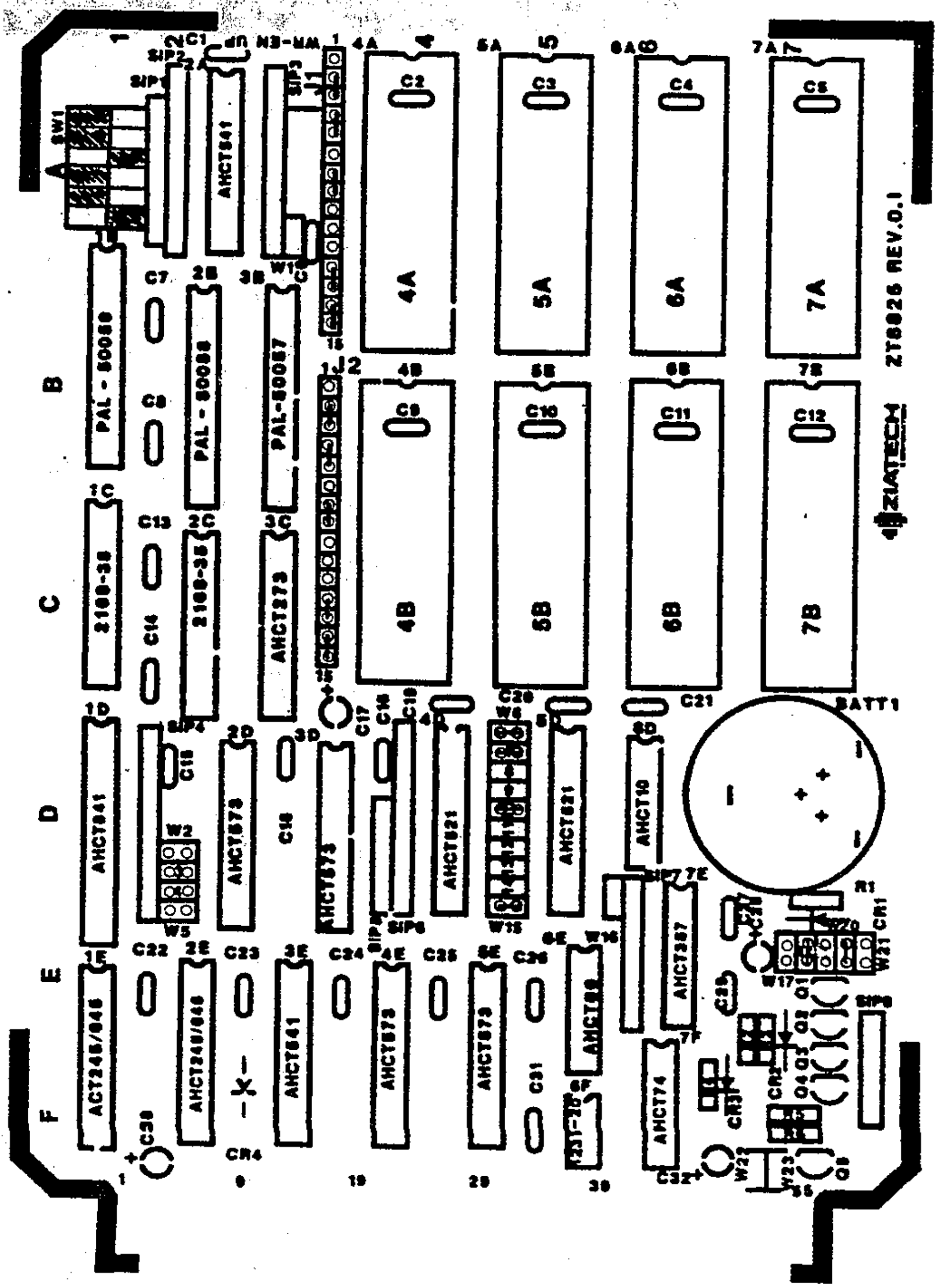


Figure E-3
Ziatech ZT8825 Jumper Configurations

Appendix F

Computer System Schematics

Wiring Interconnect

Cable Details

Operator Interface Interconnect

Display Interface Board

Power Supply Board

Loop Excitation Antenna

Signal Conditioning Board

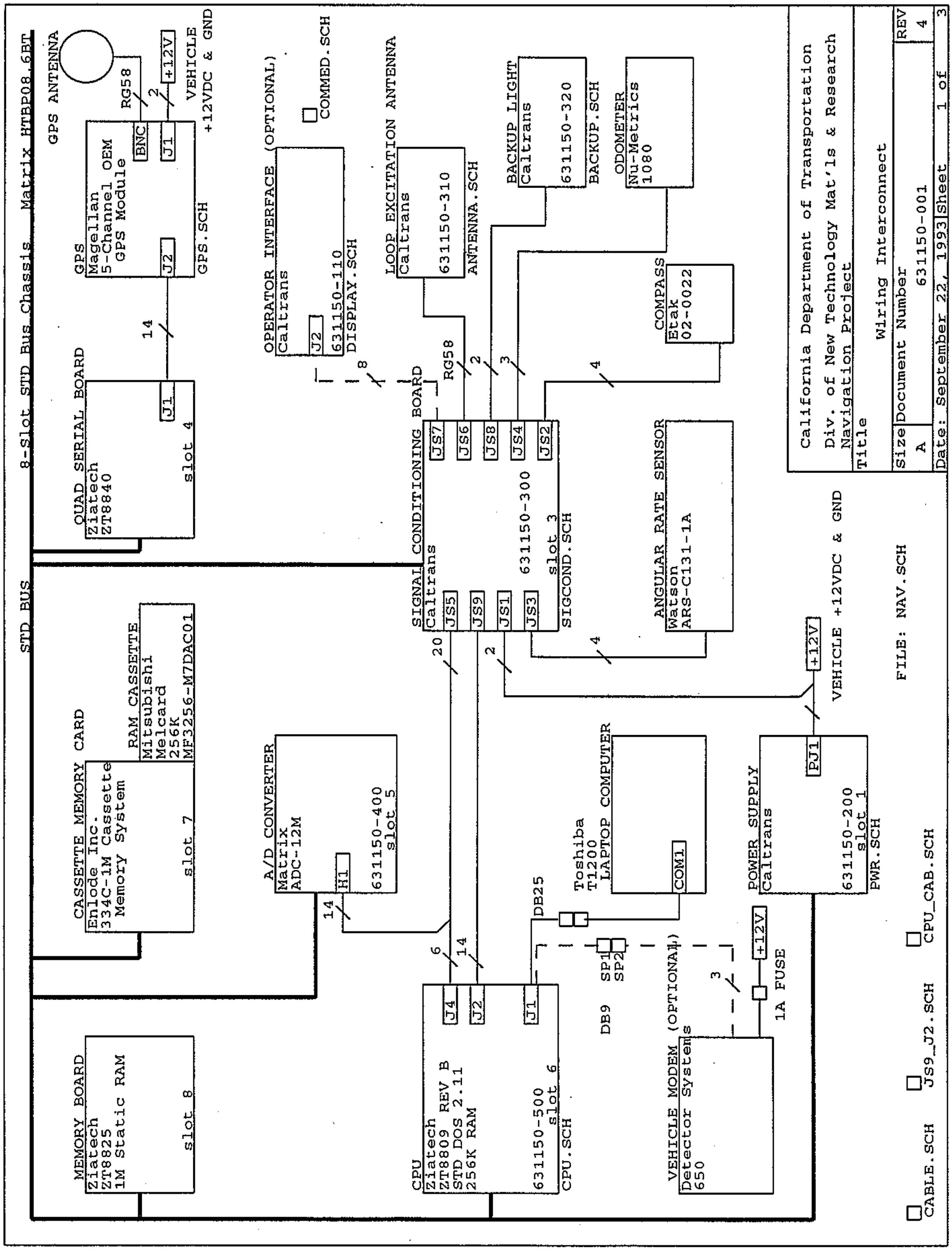
Backup Light Monitor

Signal Conditioning Board to CPU Interconnect

In-Vehicle CPU Wirewrap/Jumper Assignments

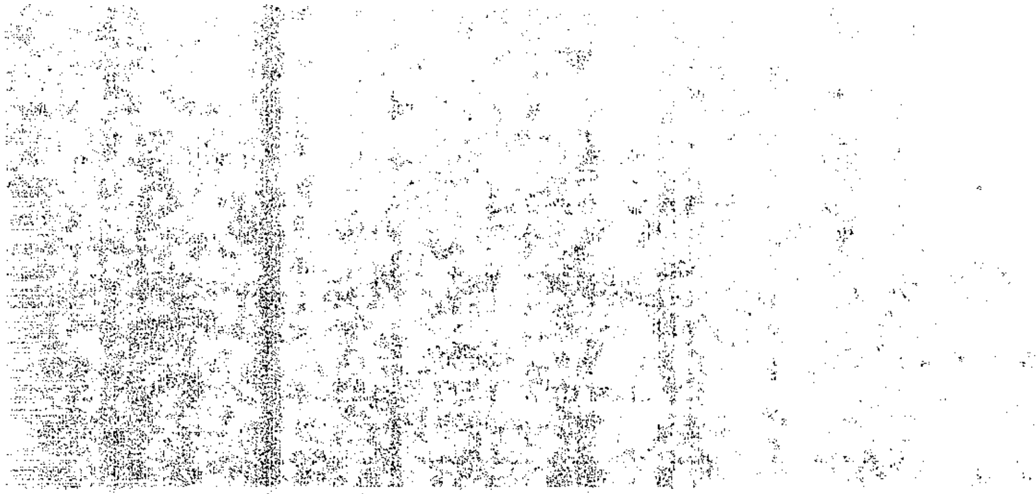
In-Cabinet CPU Wirewrap/Jumper Assignments

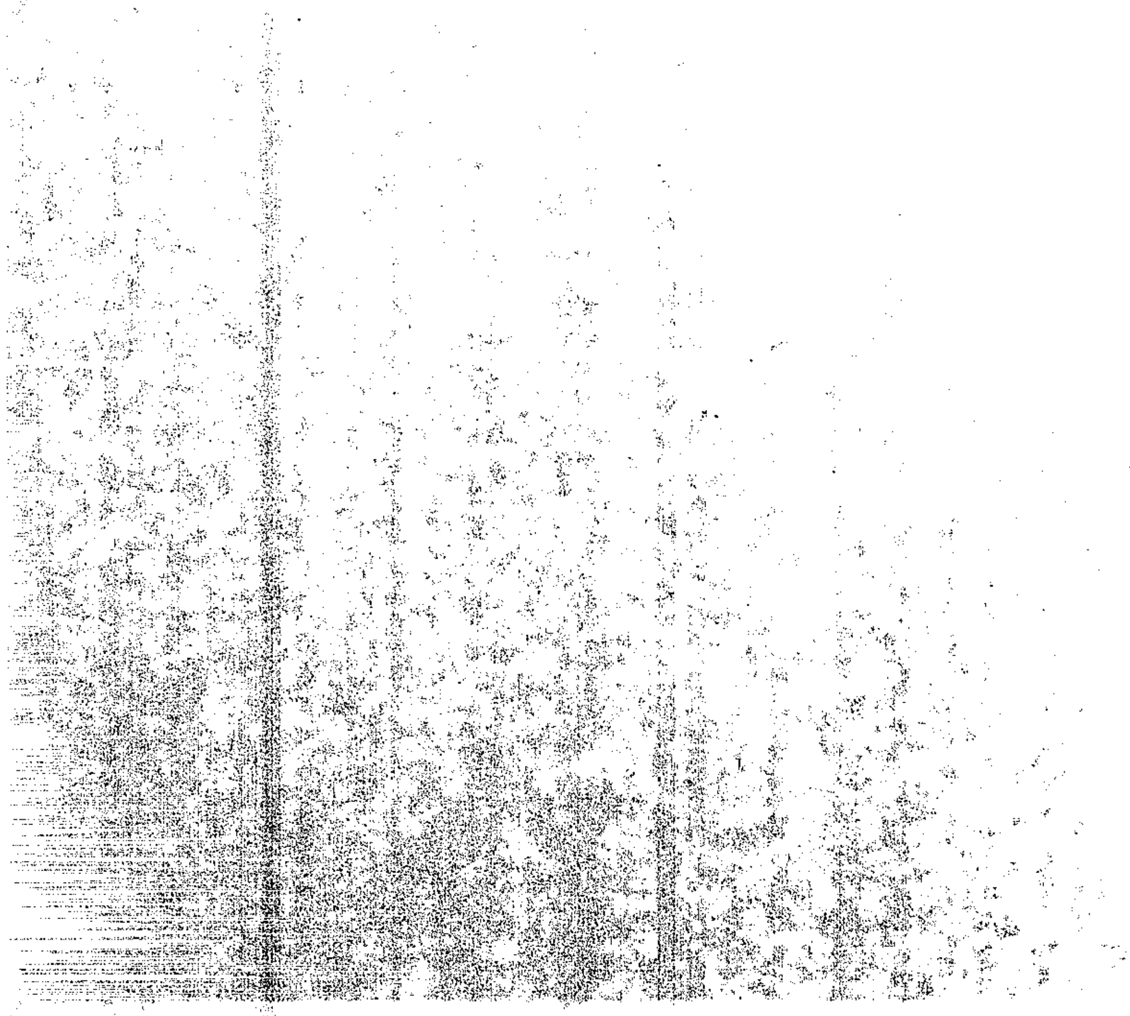
GPS Connections

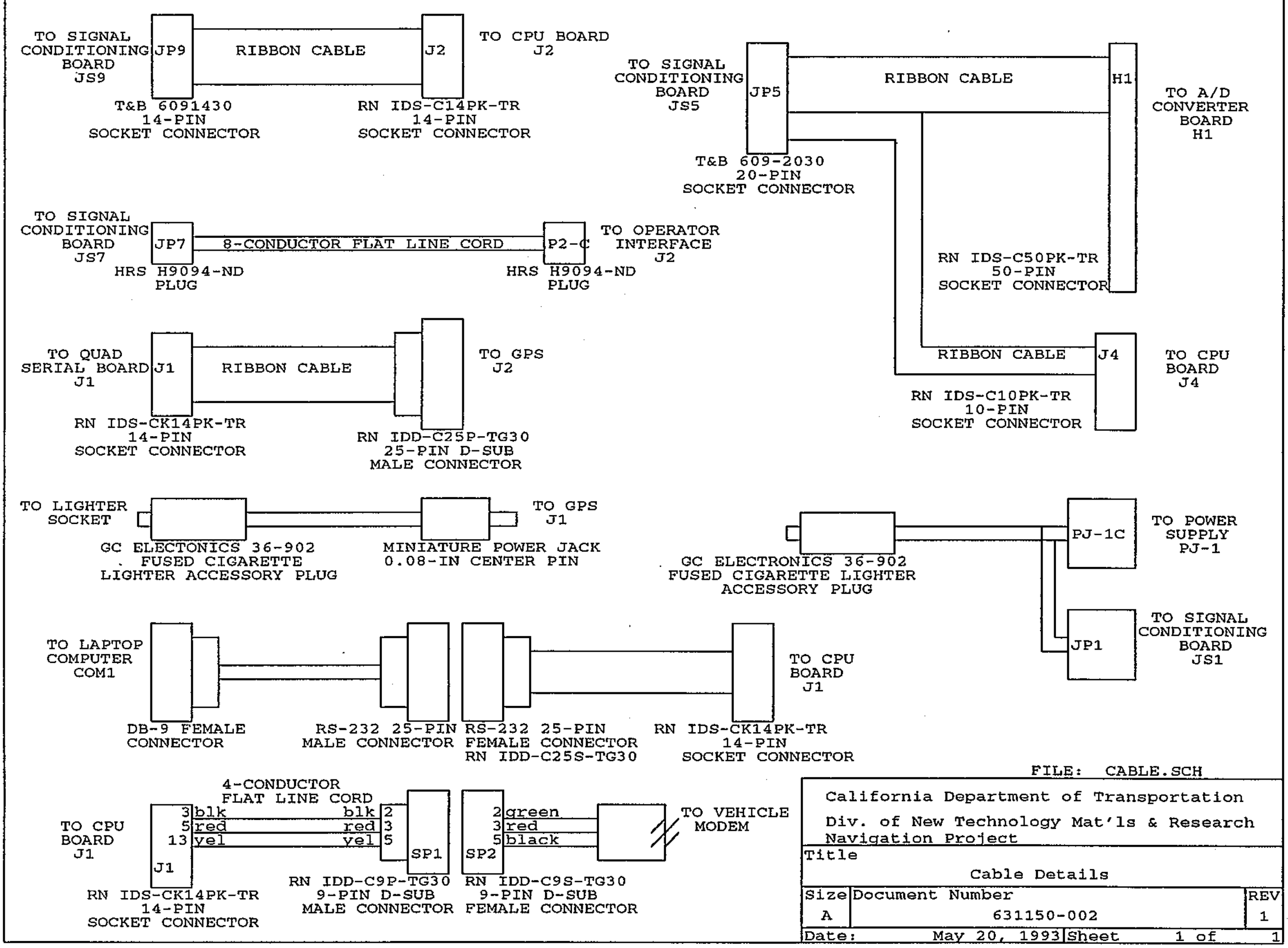

8-Slot STD Bus Chassis Matrix HTBP08.6BT
STD BUS
GPS ANTENNA
RG58
VEHICLE +12VDC & GND
+12V
GPS
Magellan
5-Channel OEM
GPS Module
BNC
J1
J2
GPS.SCH
14
QUAD SERIAL BOARD
Ziatech
ZT8840
slot 4
OPERATOR INTERFACE (OPTIONAL)
Caltrans
631150-110
DISPLAY.SCH
COMMED.SCH
LOOP EXCITATION ANTENNA
Caltrans
631150-310
ANTENNA.SCH
BACKUP LIGHT
Caltrans
631150-320
BACKUP.SCH
ODOMETER
Nu-Metrics
1080
COMPASS
Etak
02-0022
SIGNAL CONDITIONING BOARD
Caltrans
631150-300
slot 3
SIGCOND.SCH
JS7
JS6
JS8
JS4
JS2
JS5
JS9
JS1
JS3
ANGULAR RATE SENSOR
Watson
ARS-C131-1A
CASSETTE MEMORY CARD
Enlode Inc.
334C-1M Cassette
Memory System
slot 7
RAM CASSETTE
Mitsubishi
Melcard
256K
MF3256-M7DAC01
A/D CONVERTER
Matrix
ADC-12M
H1
631150-400
slot 5
Toshiba
T1200
LAPTOP COMPUTER
COM1
DB25
POWER SUPPLY
Caltrans
PJ1
631150-200
slot 1
PWR.SCH
VEHICLE +12VDC & GND
FILE: NAV.SCH
MEMORY BOARD
Ziatech
ZT8825
1M Static RAM
slot 8
CPU
Ziatech
ZT8809 REV B
STD DOS 2.11
256K RAM
J4
J2
J1
631150-500
slot 6
CPU.SCH
SP1
SP2
DB9
VEHICLE MODEM (OPTIONAL)
Detector Systems
650
1A FUSE
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 Matrix HTBP08.6BT
2	1	A/D	A/D Converter Matrix ADC-12M Caltrans 631150-400
3	1	CPU	CPU Ziatech ZT8809 Rev. B
4	1	Card	RAM Card Mitsubishi Melcard 256K MF3256-M7DAC01
5	1	Cassette	Cassette Memory Card Enlode 334C-1M
6	1	GPS	GPS Magellan Systems 5-channel OEM GPS Module 00-85000-000
7	1	GPS Antenna	GPS Antenna Magellan Systems 00-81000-000
8	1	Modem	Vehicle Modem Detector Systems 650
9	1	Operator Interface	Operator Interface Caltrans 631150-110
10	1	Pwr Supply	Power Supply Caltrans 631150-200
11	1	Serial Board	Quad Serial Board Ziatech ZT8840
12	1	Signal Condit.	Signal Conditioning Board Caltrans 631150-300
13	1	Angular Rate Sensor	Angular rate sensor Watson ARS-C131-1A

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







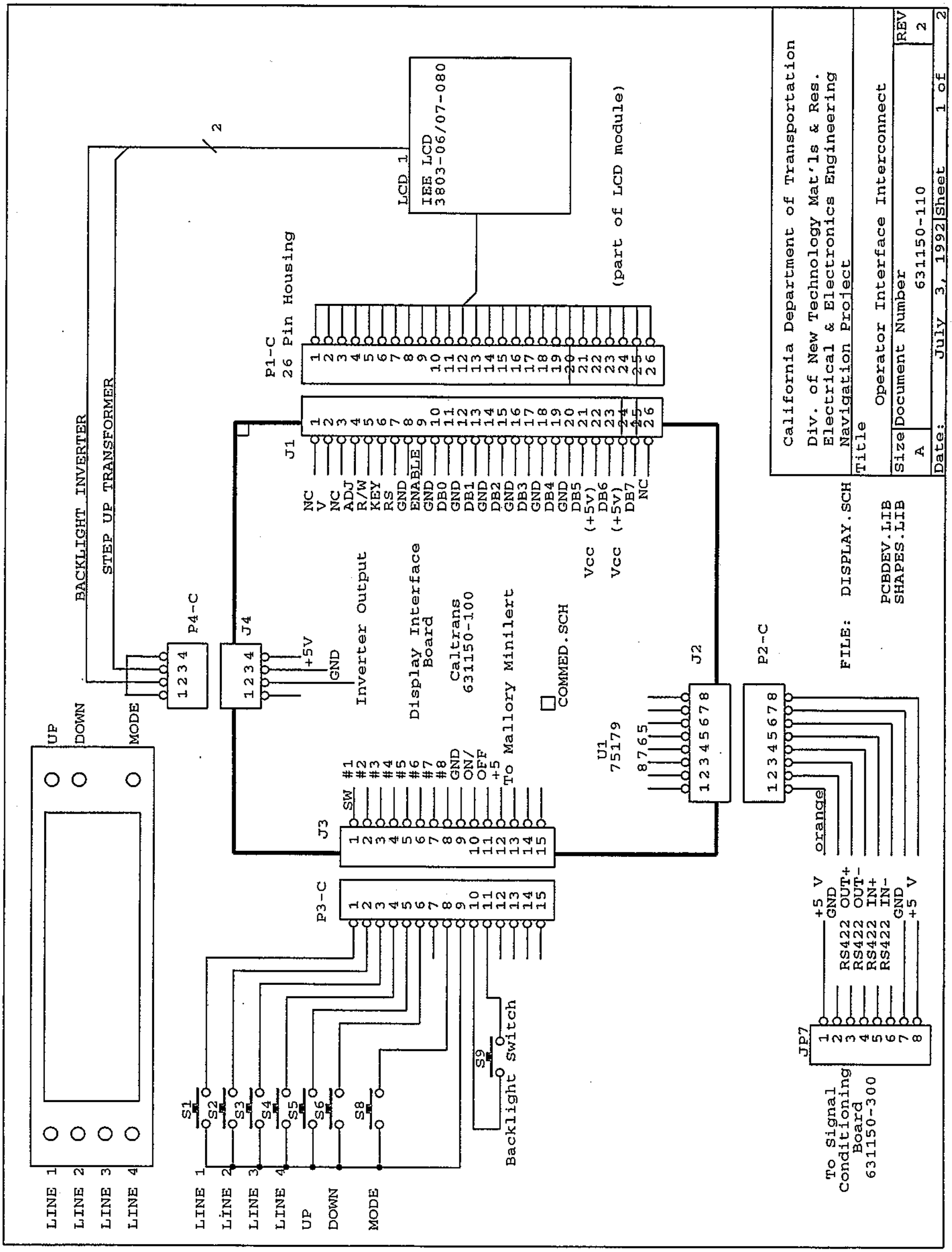
FILE: CABLE.SCH

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

Title		
Cable Details		
Size	Document Number	REV
A	631150-002	1
Date: May 20, 1993	Sheet 1 of 1	

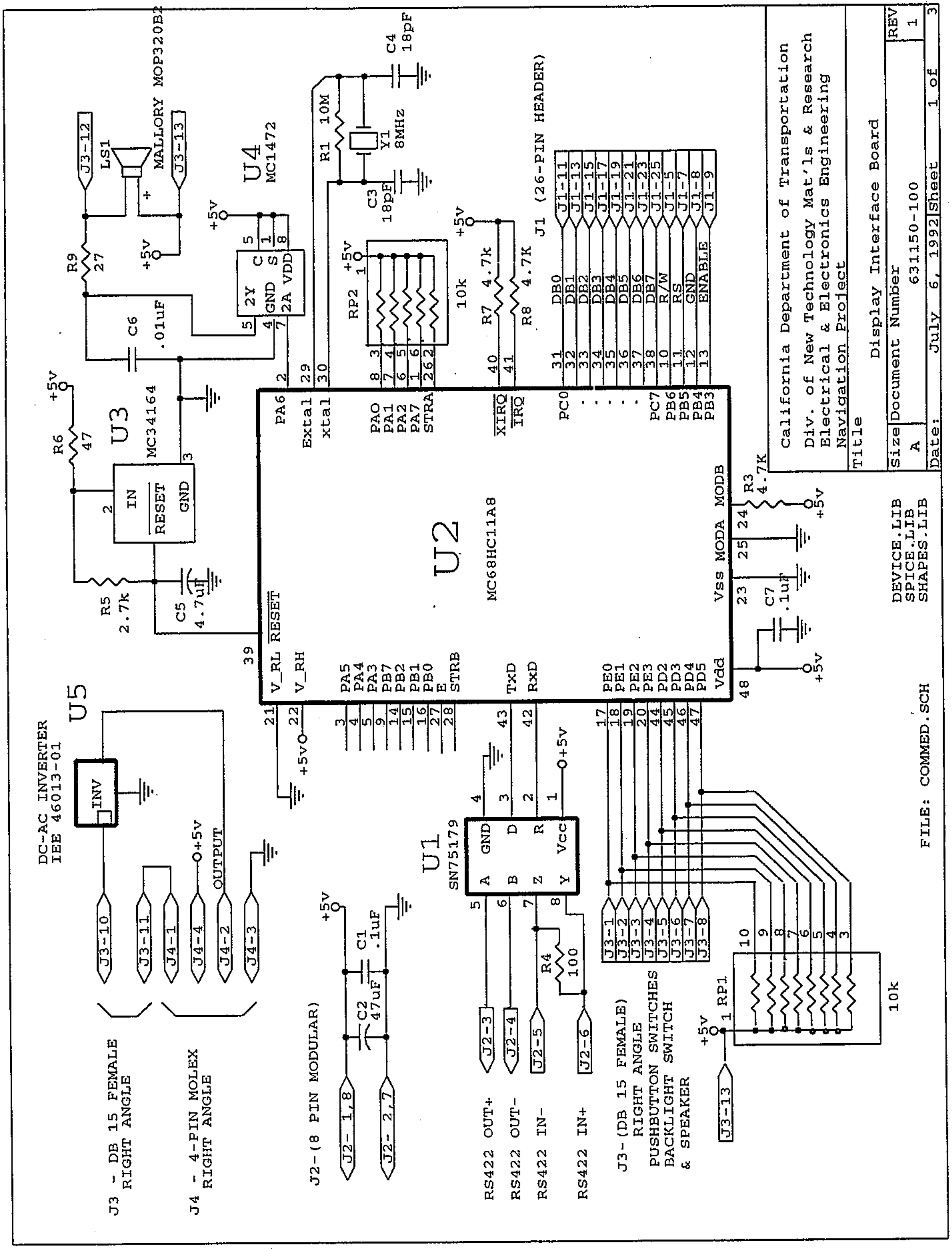
Item	Quantity	Reference	Part
1	1	J1 (Serial Board)	Socket connector for ribbon cable Robinson Nugent IDS-CK14PK-TR
2	1	J2 (GPS)	25-pin D-sub male connector IDD-C25P-TG30
3	1	J1 (GPS)	Miniature power jack 2-conductor 0.08-inch diameter center pin Switchcraft 'Power Jax' 722A S-760 'Power Plug' mating 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 (A/D)	Socket connector for ribbon cable Robinson Nugent IDS-C50PK-TR
12	1	JP5 (Sig. Cond.)	Socket connector for ribbon cable Robinson Nugent IDS-C20PK-TR
13	1	JP1 (Sig. Cond.)	2-circuit plug connector AMP Universal Mate-N-Lok 1-480698-0 AMP socket contacts 350550-1
14	1	PJ-1C (Pwr Supply)	2-circuit plug connector AMP Universal Mate-N-Lok 1-480698-0 AMP socket contacts 350550-1
15	1	P2-C (Oper. Inter.)	Plug, for flat line cord, 8-8 Hirose HRS H9094-ND
16	1	JP7 (Sig. Cond.)	Plug, for flat line cord, 8-8 Hirose HRS H9094-ND
17	1	SP1	9-pin D-sub male connector Robinson Nugent IDD-C9P-TG30
18	1	SP2	9-pin D-sub female connector Robinson Nugent IDD-C9S-TG30


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
LCD 1
IEE LCD
3803-06/07-080
(part of LCD module)
P1-C
26 Pin Housing
J1
NC
V
NC
ADJ
R/W
KEY
RS
GND
ENABLE
GND
DB0
GND
DB1
GND
DB2
GND
DB3
GND
DB4
GND
DB5
DB6
DB7
NC
Vcc (+5v)
Vcc (+5v)
BACKLIGHT INVERTER
STEP UP TRANSFORMER
P4-C
J4
+5V
GND
Inverter Output
Display Interface Board
Caltrans
631150-100
To Mallory Minilert
COMMED.SCH
FILE: DISPLAY.SCH
PCBDEV.LIB
SHAPES.LIB
J2
P2-C
U1
75179
J3
SW #1
#2
#3
#4
#5
#6
#7
#8
GND
ON/OFF
+5
P3-C
UP
DOWN
MODE
LINE 1
LINE 2
LINE 3
LINE 4
S1
S2
S3
S4
S5
S6
S8
S9
Backlight Switch
orange
+5 V
GND
RS422 OUT+
RS422 OUT-
RS422 IN+
RS422 IN-
GND
+5 V
JP7
To Signal Conditioning Board
631150-300

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


California Department of Transportation
Div. of New Technology Mat'ls & Research
Electrical & Electronics Engineering
Navigation Project
Title
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Size A
Document Number
631150-100
REV 1
Date: July 6, 1992
Sheet 1 of 3
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SHAPES.LIB
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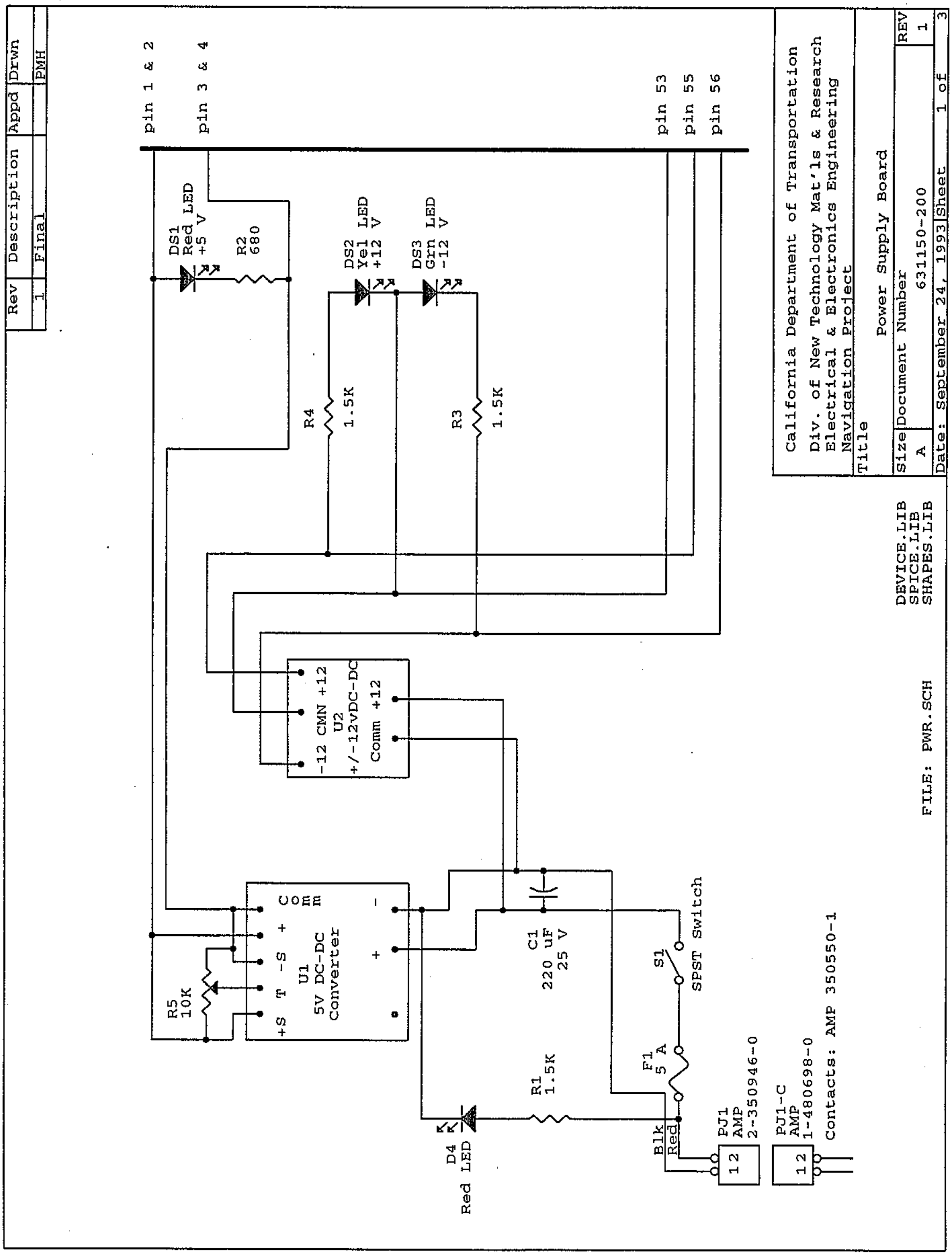
U2
MC68HC11A8
U1
SN75179
U3
MC34164
U4
MC1472
U5
DC-AC INVERTER
IEE 46013-01
LS1
MALLORY MOP320B2
J1 (26-PIN HEADER)
J2-(8 PIN MODULAR)
J3 - DB 15 FEMALE
RIGHT ANGLE
J4 - 4-PIN MOLEX
RIGHT ANGLE
RS422 OUT+
RS422 OUT-
RS422 IN-
RS422 IN+
J3-(DB 15 FEMALE)
RIGHT ANGLE
PUSHBUTTON SWITCHES
BACKLIGHT SWITCH
& SPEAKER

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 Motorola MC1472
18	1	U5	DC-AC Inverter IEE 46013-01
19	1	LS1	Minilert Audible Signal Mallory MCP320B2
20	1	J1	26-pin double row connector Caltrans - SPC Technology FH2-602-72-T female header cut to desired length
21	1	J2	PCB mounted shielded jack, 8-8 Hirose HRS H9200
22	1	J3	DB15 right angle shielded PCB mounted connector Norwesco 315F-ND
23	1	J4	4-pin right angle header Waldom 22-05-3041
24	1		IC socket, 48-pin DIP 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)



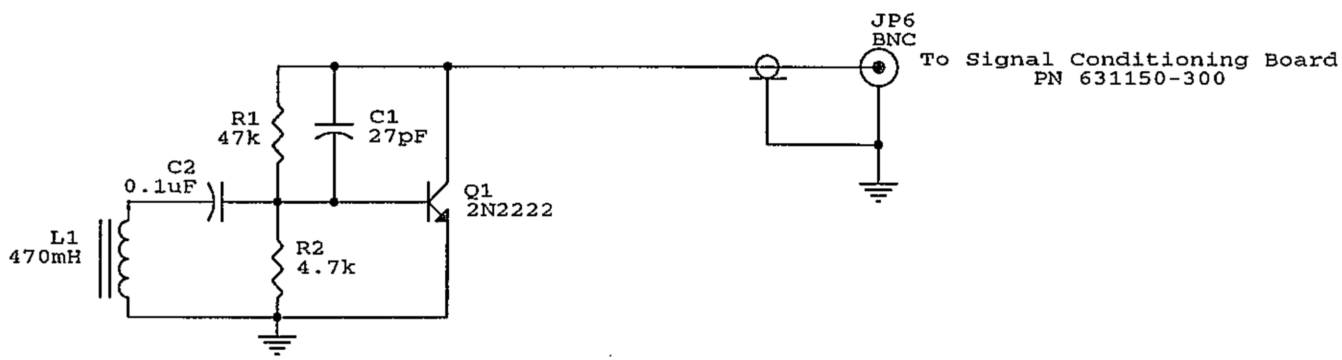
Rev
1
Description
Final
Appd
Drwn
PMH
pin 1 & 2
pin 3 & 4
pin 53
pin 55
pin 56
DS1
Red LED
+5 V
R2
680
DS2
Yel LED
+12 V
DS3
Grn LED
-12 V
R4
1.5K
R3
1.5K
-12 CMN +12
U2
+/-12vDC-DC
Comm +12
C
o
m
m
+S T -S +
U1
5V DC-DC
Converter
R5
10K
C1
220 uF
25 V
S1
SPST Switch
F1
5 A
R1
1.5K
D4
Red LED
Blk
Red
PJ1
AMP
2-350946-0
PJ1-C
AMP
1-480698-0
Contacts: AMP 350550-1
1 2
1 2
DEVICE.LIB
SPICE.LIB
SHAPES.LIB
FILE: PWR.SCH
California Department of Transportation
Div. of New Technology Mat'ls & Research
Electrical & Electronics Engineering
Navigation Project
Title
Power Supply Board
Size
A
Document Number
631150-200
REV
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 Panasonic NHE ECE-B1EGE221
2	1	DS1	Red LED, T-1 3/4 Chicago Miniature Lamp CMI01R White marking--Caltrans reversed
3	1	DS2	Yellow LED, T-1 3/4 Chicago Miniature Lamp CMI01Y
4	1	DS3	Green LED, T-1 3/4 Chicago Miniature Lamp CMI01G
5	1	DS4	Red LED, T-1 3/4 Chicago Miniature Lamp CMI01R
6	1	F1	Fuse, 5 A Littelfuse 273005
7	1		Fuseholder Littelfuse 281005
8	1	PJ1-C	2-circuit plug connector AMP Universal Mate-N-Lok 1-480698-0 AMP socket contacts 350550-1
9	1	PJ1	2-circuit right angle pin header 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 Panasonic EVM-C7GA01B14

15	1	S1	Toggle switch, SPDT Alco AKO MTM-106D-RA
16	1	U1	5 V DC-DC converter Calex 12S5.5000
17	1	U2	+/- 12 V DC-DC converter Calex 12D12.250
18	1		Ejector 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

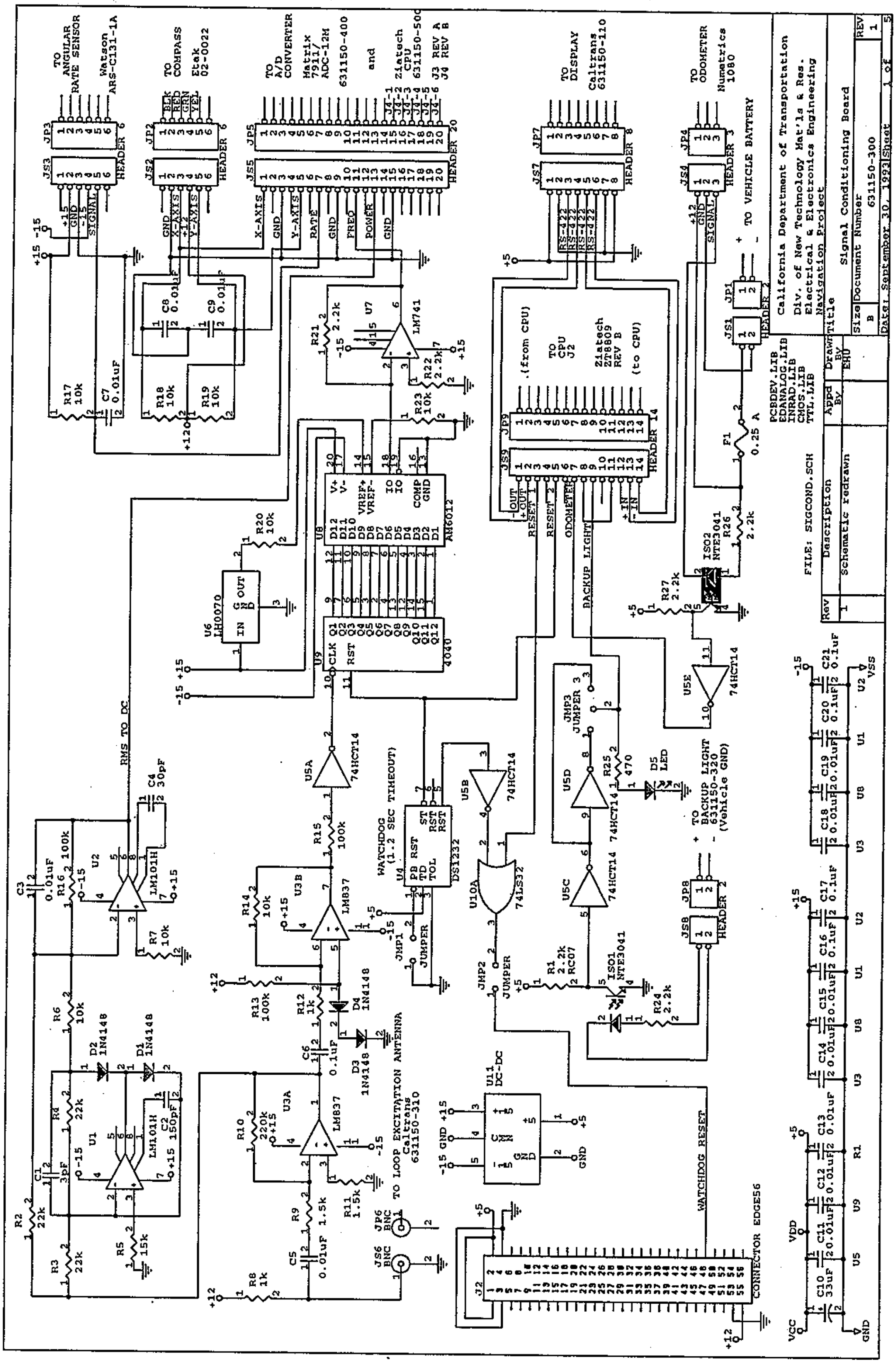
SPICE.LIB
DEVICE.LIB

California Department of Transportation Div. of New Technology Mat'ls & Research Electrical & Electronics Engineering Navigation Project		
Title Loop Excitation Antenna		
Size A	Document Number 631150-310	REV 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 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 Belden 8219
8	1	JP6	BNC connector plug, RG-58 Amp 331350
9	1		Nylon tie


California Department of Transportation
Div. of New Technology Mat'ls & Res.
Electrical & Electronics Engineering
Navigation Project
Signal Conditioning Board
631150-300
Date: September 30, 1993
FILE: SIGCOND.SCH
Schematic Redrawn
TO ANGULAR RATE SENSOR
TO COMPASS
TO A/D CONVERTER
TO DISPLAY
TO ODOMETER
TO VEHICLE BATTERY
TO LOOP EXCITATION ANTENNA
CONNECTOR EDGE56

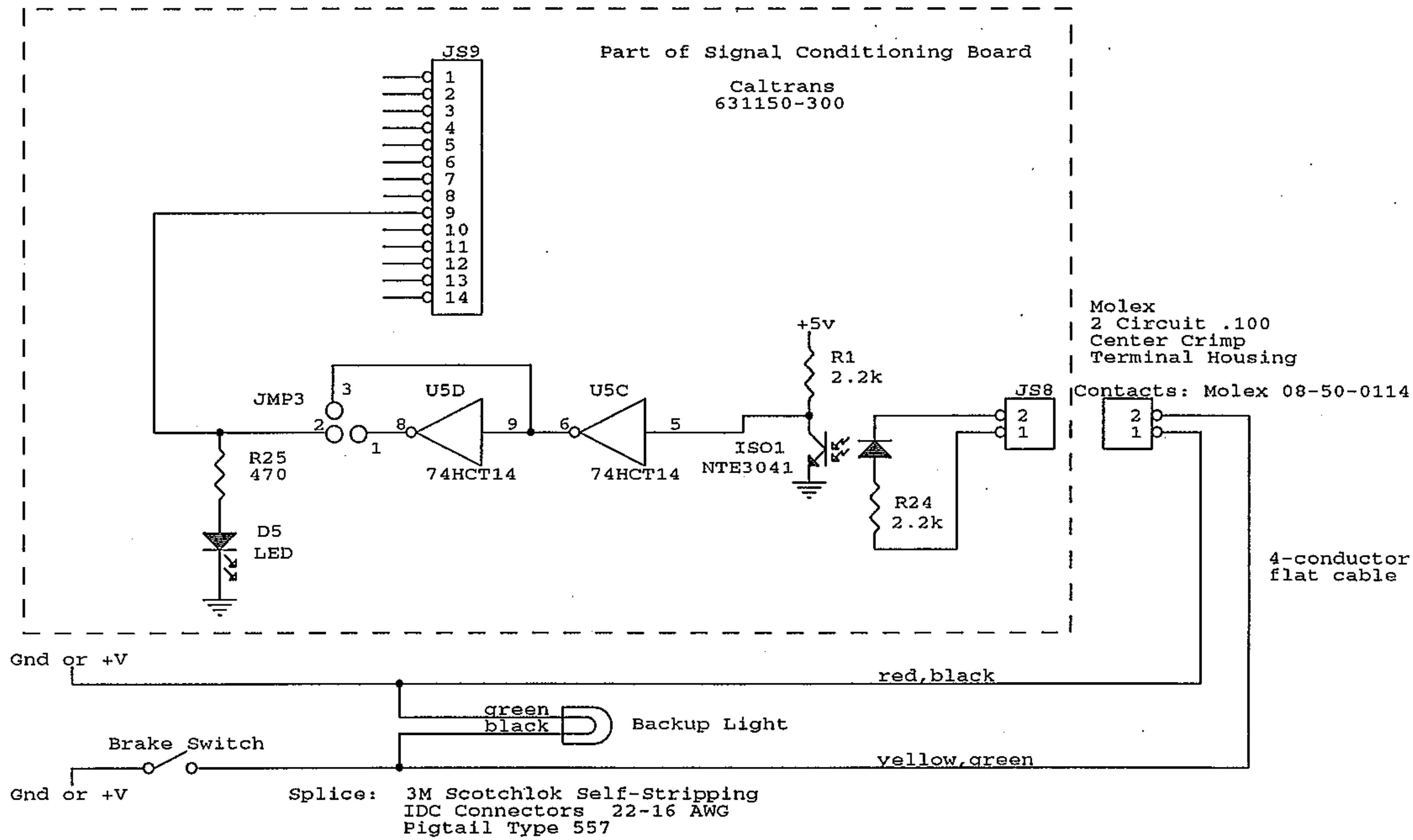
Revised: August 2, 1991
Revision: 1
July 8, 1991 15:08:22

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 Chicago Miniature Lamp CMI01Y
9	1	F1	Fuse, 0.25 AMP Littelfuse 273.250
10	1		Fuseholder Littelfuse 281005
11	2	ISO1,ISO2	Optoisolators NTE NTE3041
12	1	JS6	BNC receptacle, right angle PCB mount AMP 226978-1
13	1	JP6	BNC plug AMP 331350
14	2	JMP1,JMP2	Straight single row male header. .100 spacing, .235 post height. 3M 929834-01-36 or equal. Break to correct length - 2 posts
15	2		Programming jumper 3M 46F4439 or equal.

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

29	1	JP7	Plug, for flat line cord, 8-8 Hirose HRS H9094-ND
30	1	JS8	2-circuit right angle friction lock header, .100 center Molex 22-05-3021
31	1	JP8	2-circuit terminal housing Molex 22-01-3027 Crimp terminals Molex 08-50-0114
32	1	JS9	14-pin right angle header T & B 500-1407E
33	1	JP9	14-pin ribbon cable socket connector 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 Motorola LM101H or LM201AN
44	1	U3	Low Noise Quad Op Amp National Semi. LM837

45	1	U4	Micromonitor (watchdog) Dallas DS1232
46	1	U5	Hex inverting Schmitt trigger CD74HCT14
47	1	U6	BCD buffered voltage reference National Semi. LH0070
48	1	U7	Operational Amplifier Motorola LM741
49	1	U8	12-bit D/A converter Signetics AM6012
50	1	U9	12-stage ripple counter Harris CD4040
51	1	U10	Quad 2-input OR gate Samsung 74HCTLS32
52	1	U11	+/- 15 V DC-DC converter Calex 5D15.150
53	1		Ejector 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

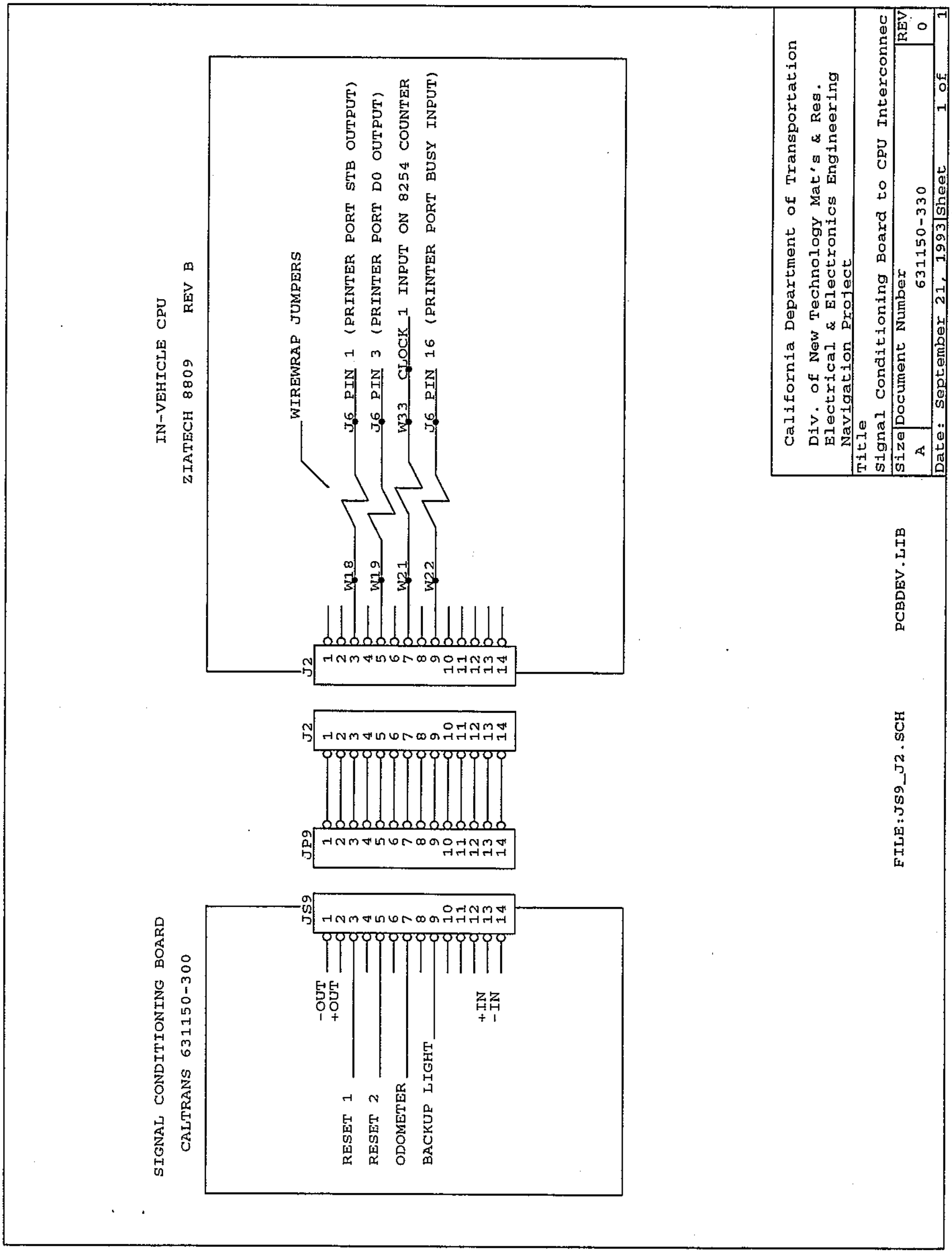
FILE: BACKUP.SCH

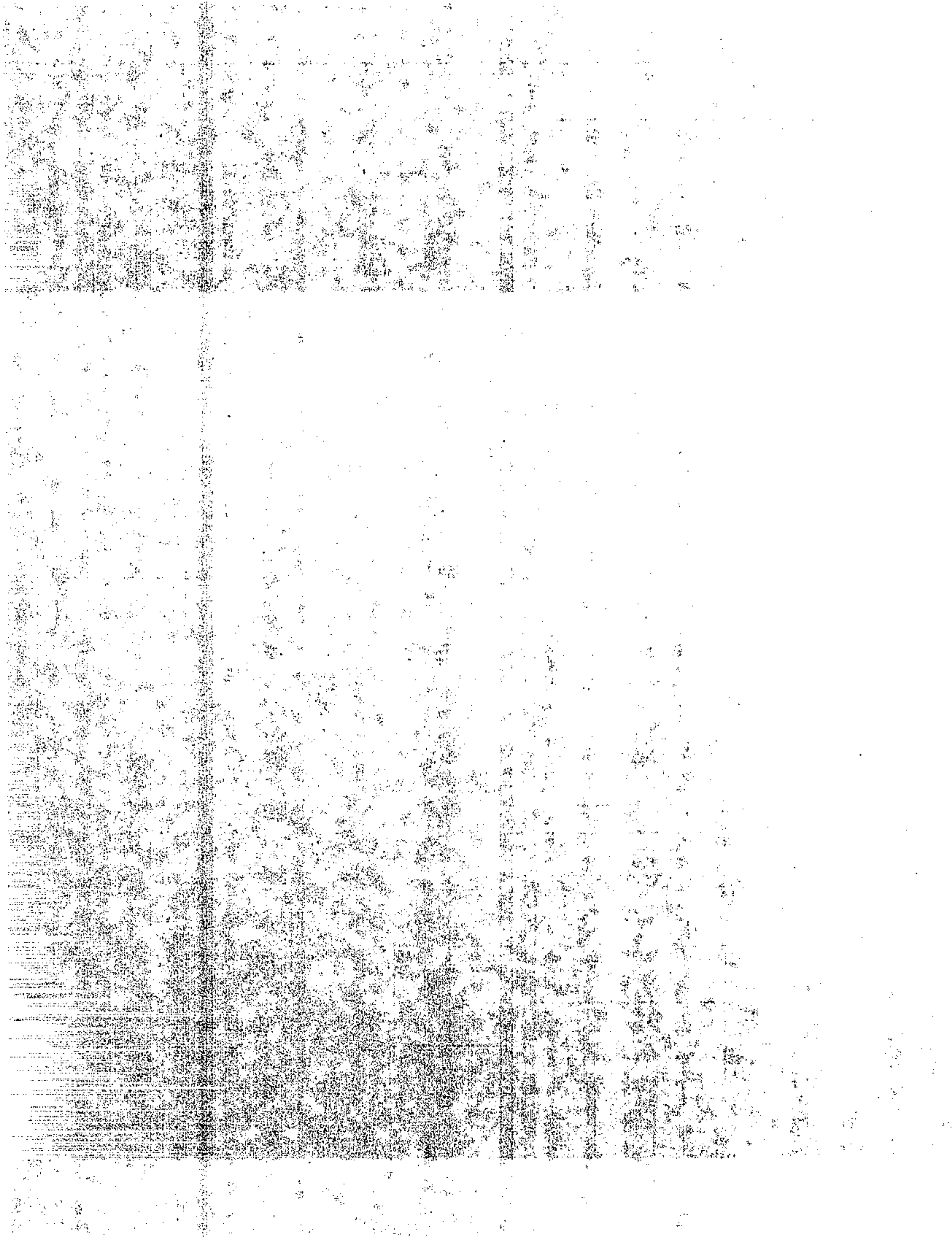
TTL.LIB
DEVICE.LIB
SHAPES.LIB
SPICE.LIB

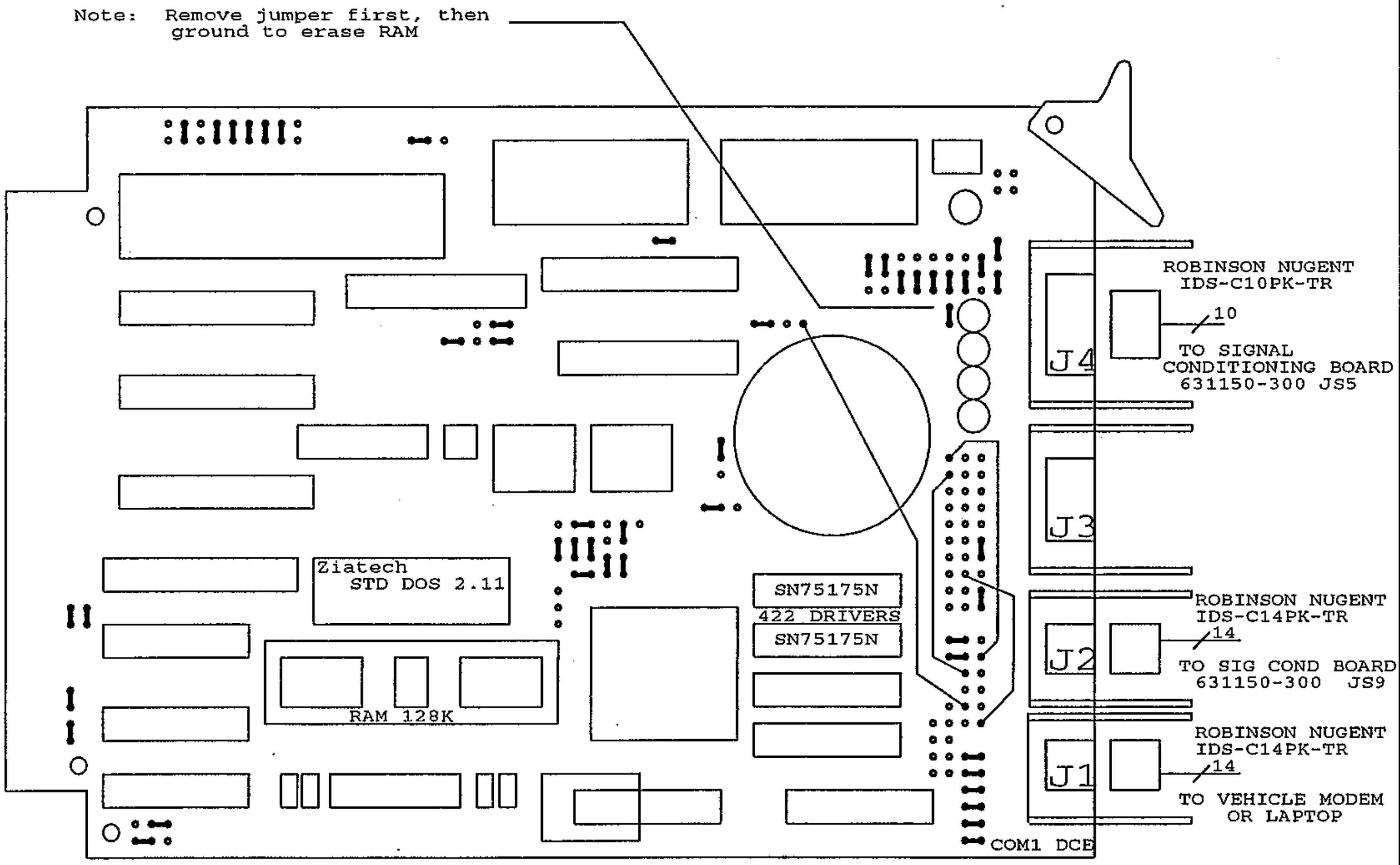
California Department of Transportation

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

Title		
Backup Light Monitor		
Size: A	Document Number: 631150-320	REV: 0
Date: October 7, 1993	Sheet 1 of 1	


IN-VEHICLE CPU
ZIATECH 8809 REV B
WIREWRAP JUMPERS
J6 PIN 1 (PRINTER PORT STB OUTPUT)
J6 PIN 3 (PRINTER PORT D0 OUTPUT)
W33 CLOCK 1 INPUT ON 8254 COUNTER
J6 PIN 16 (PRINTER PORT BUSY INPUT)
W18
W19
W21
W22
J2
JP9
JS9
SIGNAL CONDITIONING BOARD
CALTRANS 631150-300
-OUT
+OUT
RESET 1
RESET 2
ODOMETER
BACKUP LIGHT
+IN
-IN
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 A
Document Number 631150-330
REV 0
Date: September 21, 1993
Sheet 1 of 1

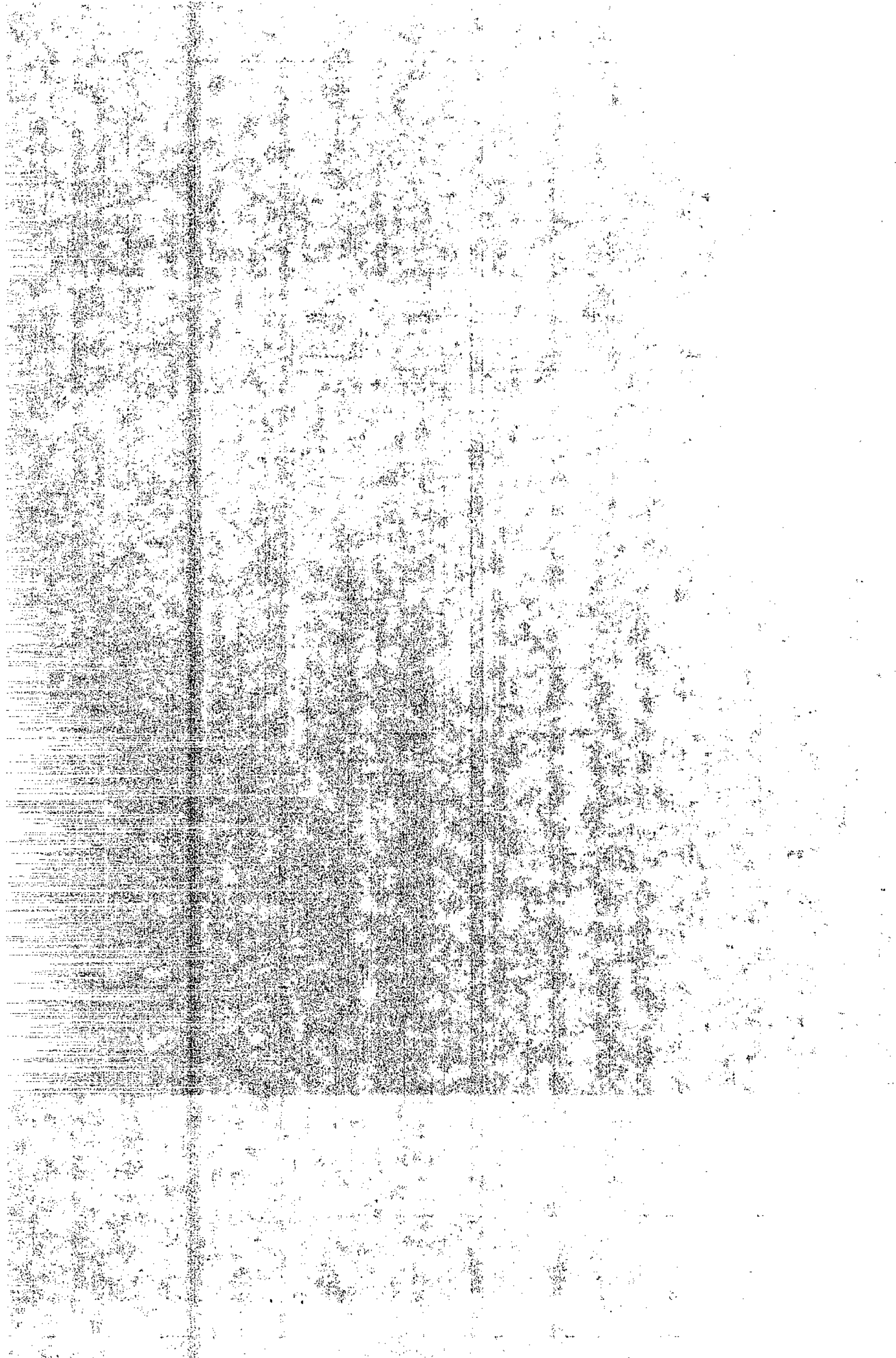


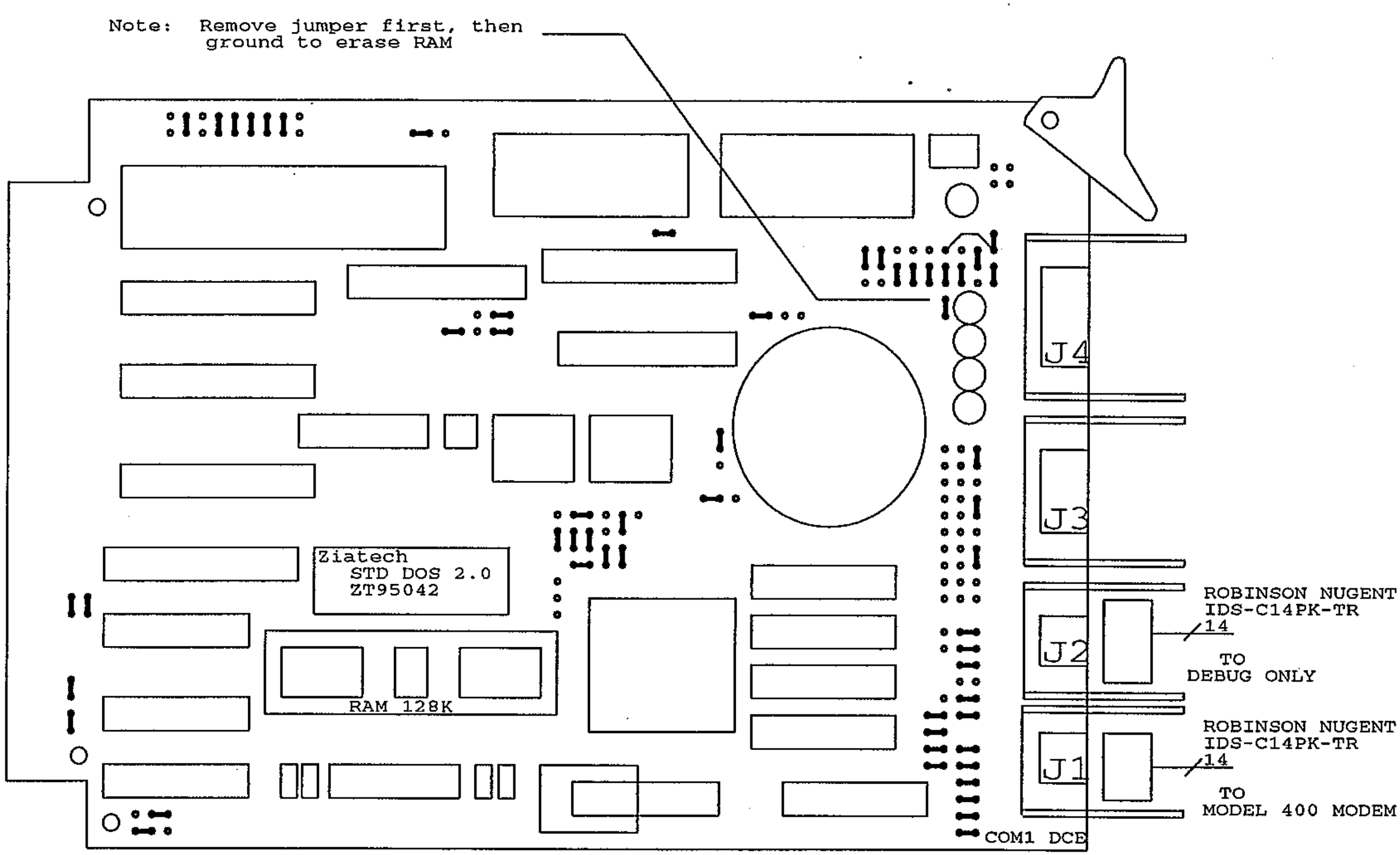


Ziatech ZT8809 REVB

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 A	Document Number 631150-500	REV 0
Date: September 21, 1993	Sheet 1 of 1	



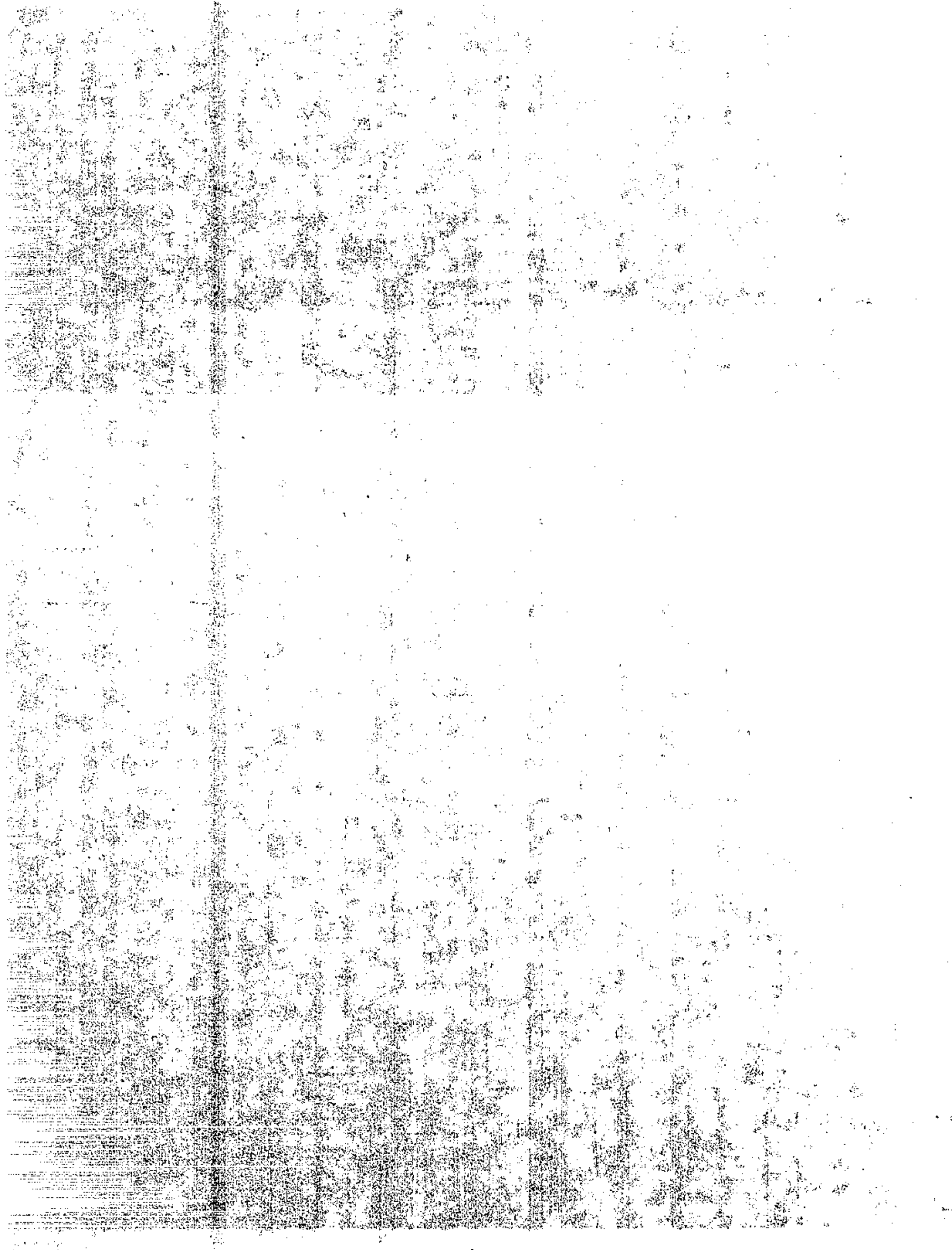


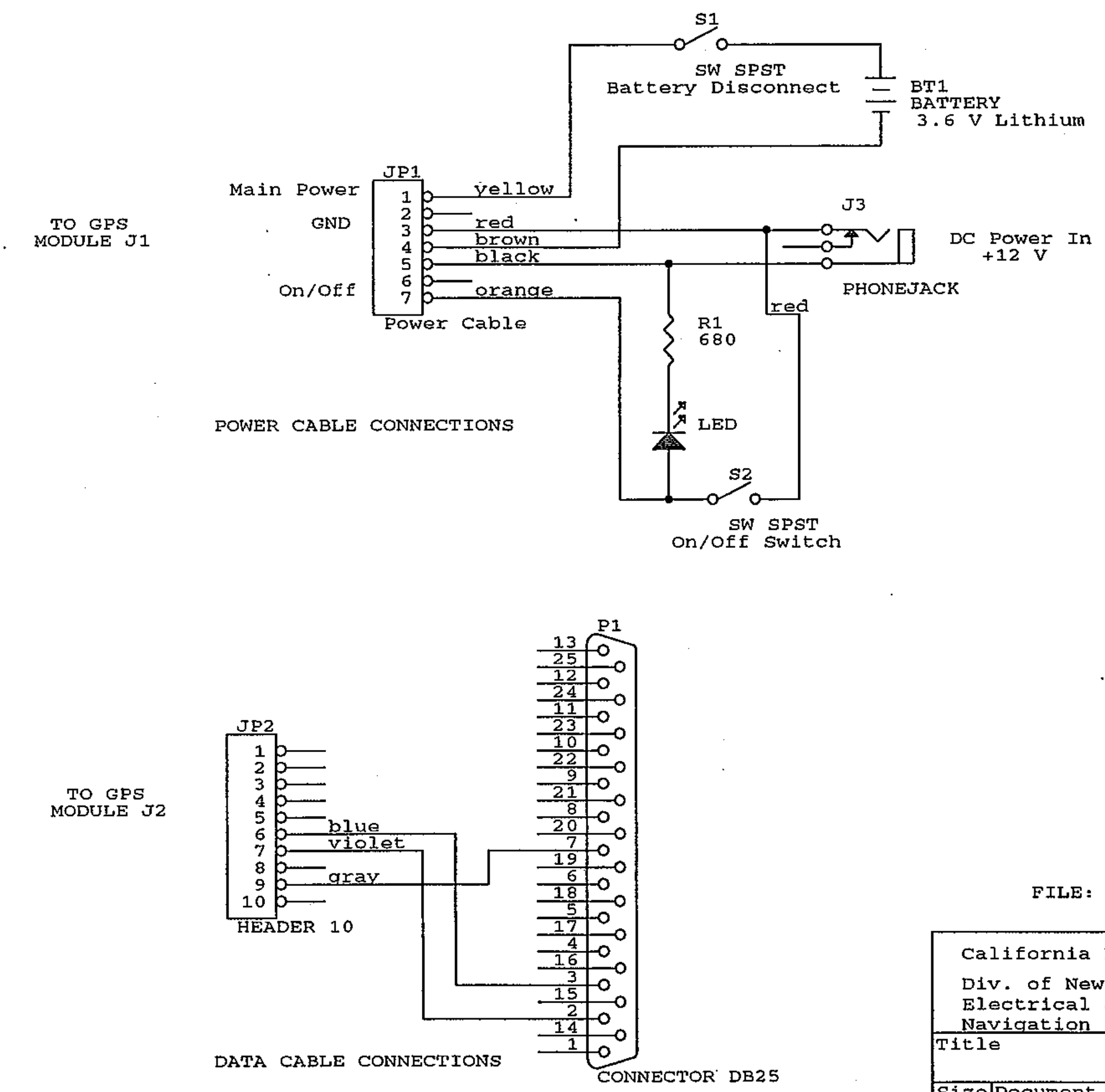
Ziatech ZT88CT08 REV C

FILE: CPU_CAB.SCH SHAPES.LIB

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

Title		
In-Cabinet CPU Wirewrap/Jumper Assignments		
Size: A	Document Number: 631150-610	REV: 0
Date: July 7, 1992	Sheet 1 of 1	





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 A	Document Number 631150-700	REV 1
Date: July 14, 1992	Sheet 1 of	

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

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

APPENDIX G
SAMPLE DATA

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

G.1 COMPASS AND ARS

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	YCOR1	-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	1.546503	0	0.999946	0	0.010345
48	4	2540	2669	2186		-70	60.73915	1.554246	2.999589	3.999536	0.049648	0.059993
49	12	2539	2670	2190		-71	61.69567	1.553533	7.998608	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	1.53098	15.98731	39.98193	0.637205	1.133926
52	59	2538	2674	2209		-72	65.52176	1.530602	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	0.706688
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	315	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

TIME	LOOP	ARS ZERO	ADJ_RATE	CORR_RAT	CUM_RATE	AZIM	INC_X	CUM_X	INC_Y	CUM_Y
0		2186	2184	-2	-2	0.87125	0	0	0	0
1			2183.993	-2.00691	-4.00691	0.869831	0.76422	0.76422	0.644955	0.644955
2		DRIFT	2183.986	-2.01382	-6.02074	0.868407	0	0.76422	0	0.644955
3		-0.00691	2183.979	-2.02074	-8.04147	0.866979	0	0.76422	0	0.644955
4			2185.972	-0.02765	-8.06912	0.866959	0	0.76422	0	0.644955
5		SUM_TURN	2183.965	-2.03456	-10.1037	0.865521	0	0.76422	0	0.644955
6		13329.18	2184.959	-1.04147	-11.1452	0.864784	0	0.76422	0	0.644955
7			2185.952	-0.04838	-11.1935	0.86475	0	0.76422	0	0.644955
8		CUM_HEAD	2185.945	-0.0553	-11.2488	0.864711	0	0.76422	0	0.644955
9		540	2185.938	-0.06221	-11.311	0.864667	0	0.76422	0	0.644955
10			2185.931	-0.06912	-11.3802	0.864618	0	0.76422	0	0.644955
11		GAIN_FAC	2186.924	0.923968	-10.4562	0.865271	0	0.76422	0	0.644955
12		24.68367	2186.917	0.917056	-9.53914	0.86592	0	0.76422	0	0.644955
13			2185.91	-0.08986	-9.62899	0.865856	0	0.76422	0	0.644955
14		AZIM_INIT	2185.903	-0.09677	-9.72576	0.865788	0	0.76422	0	0.644955
15		50	2185.896	-0.10368	-9.82944	0.865714	0	0.76422	0	0.644955
16			2185.889	-0.11059	-9.94003	0.865636	0	0.76422	0	0.644955
17			2185.882	-0.1175	-10.0575	0.865553	0	0.76422	0	0.644955
18			2184.876	-1.12442	-11.182	0.864758	0	0.76422	0	0.644955
19			2185.869	-0.13133	-11.3133	0.864665	0	0.76422	0	0.644955
20			2185.862	-0.13824	-11.4515	0.864568	0	0.76422	0	0.644955
21			2184.855	-1.14515	-12.5967	0.863758	0	0.76422	0	0.644955
22			2184.848	-1.15206	-13.7487	0.862943	0	0.76422	0	0.644955
23			2184.841	-1.15898	-14.9077	0.862124	0	0.76422	0	0.644955
24			2185.834	-0.16589	-15.0736	0.862006	0	0.76422	0	0.644955
25			2185.827	-0.1728	-15.2464	0.861884	0	0.76422	0	0.644955
26			2186.82	0.820288	-14.4261	0.862464	0	0.76422	0	0.644955
27			2185.813	-0.18662	-14.6127	0.862332	0	0.76422	0	0.644955
28			2185.806	-0.19354	-14.8063	0.862195	0	0.76422	0	0.644955
29			2186.8	0.799552	-14.0067	0.862761	0	0.76422	0	0.644955
30			2185.793	-0.20736	-14.2141	0.862614	0	0.76422	0	0.644955
31			2185.786	-0.21427	-14.4284	0.862463	0	0.76422	0	0.644955
32			2185.779	-0.22118	-14.6495	0.862306	0	0.76422	0	0.644955
33			2185.772	-0.2281	-14.8776	0.862145	0	0.76422	0	0.644955
34			2185.765	-0.23501	-15.1126	0.861979	0	0.76422	0	0.644955
35			2185.758	-0.24192	-15.3546	0.861808	0	0.76422	0	0.644955
36			2185.751	-0.24883	-15.6034	0.861632	0	0.76422	0	0.644955
37			2185.744	-0.25574	-15.8591	0.861451	0	0.76422	0	0.644955
38			2186.737	0.737344	-15.1218	0.861972	0	0.76422	0	0.644955
39			2185.73	-0.26957	-15.3914	0.861782	0	0.76422	0	0.644955
40			2185.724	-0.27648	-15.6678	0.861586	0	0.76422	0	0.644955
41			2186.717	0.716608	-14.9512	0.862093	0	0.76422	0	0.644955
42			2186.71	0.709696	-14.2415	0.862595	0	0.76422	0	0.644955
43			2185.703	-0.29722	-14.5388	0.862385	0	0.76422	0	0.644955
44			2185.696	-0.30413	-14.8429	0.86217	0	0.76422	0	0.644955
45			2185.689	-0.31104	-15.1539	0.86195	0	0.76422	0	0.644955
46			2186.682	0.682048	-14.4719	0.862432	0	0.76422	0	0.644955
47			2197.675	11.67514	-2.79674	0.870687	0	0.76422	0	0.644955
48			2185.668	-0.33178	-3.12851	0.870453	2.293862	3.058082	1.933442	2.578397
49			2189.661	3.661312	0.5328	0.873041	6.130292	9.188375	5.139992	7.718389
50			2187.654	1.6544	2.1872	0.874211	9.204451	18.39283	7.699228	15.41761
51			2198.647	12.64749	14.83469	0.883154	12.36391	30.75674	10.15547	25.57309
52			2208.641	22.64058	37.47526	0.899163	14.87332	45.63005	11.82305	37.39614
53			2201.634	15.63368	53.10893	0.910217	15.79274	61.42279	12.27149	49.66763
54			2195.627	9.626752	62.73568	0.917024	17.46349	78.88628	13.38008	63.04771
55			2194.62	8.61984	71.35552	0.923119	18.3422	97.22848	13.87673	76.92444
56			2196.613	10.61293	81.96845	0.930623	18.44582	115.6743	13.7387	90.66314
57			2206.606	20.60602	102.5745	0.945193	19.45464	135.1289	14.05408	104.7172
58			2187.599	1.599104	104.1736	0.946324	20.28179	155.4107	14.61674	119.334
59			2199.592	13.59219	117.7658	0.955934	20.42133	175.832	14.42115	133.7551
60			2200.585	14.58528	132.351	0.966247	19.7462	195.5783	13.64139	147.3965
61			2201.578	15.57837	147.9294	0.977262	19.69526	215.4735	13.42306	160.8195
62			2199.571	13.57148	161.5009	0.986858	19.18886	234.6624	12.68021	173.4996
63			2199.565	13.56454	175.0654	0.99645	19.30959	253.972	12.49559	185.9954
64			2201.558	15.55763	190.623	1.00745	19.44588	273.4178	12.28242	198.2778
65			2197.551	11.55072	202.1738	1.015617	17.84593	291.2638	11.069	209.3468

66	380	2532	2672	2170	-78	63.60871	1.584809	20.99794	379.6674	-0.29426	-5.30549	2169.544	-16.4562	185.7176	1.003982	17.71593	308.9797	11.2759	220.6227
67	400	2537	2679	2046	-73	70.30437	1.502338	19.95315	399.6206	1.368094	-3.9374	2045.537	-140.463	45.25446	0.904663	15.72434	324.704	12.35901	232.9817
68	420	2555	2693	1942	-55	83.69568	1.278512	19.15752	418.7781	5.743658	1.806263	1941.53	-244.47	-199.216	0.731804	13.36425	338.0683	14.87841	247.8611
69	440	2584	2703	1883	-26	93.2609	0.970016	16.49789	435.276	11.30573	13.11199	1882.523	-303.477	-502.692	0.517222	9.889342	347.9576	17.38393	265.245
70	461	2621	2706	1871	11	96.13046	0.584199	11.58217	446.8581	17.51723	30.62922	1870.516	-315.484	-816.176	0.29415	6.098453	354.0461	20.09803	285.3431
71	483	2647	2709	1939	37	99.00003	0.340469	7.346433	454.2046	20.73716	51.36638	1938.509	-247.491	-1065.67	0.119154	2.6152	356.6613	21.84401	307.1871
72	506	2655	2702	2060	45	92.30437	0.24452	5.568081	459.7726	22.31583	73.68222	2059.502	-126.498	-1192.16	0.029711	0.683246	357.3445	22.98985	330.1769
73	528	2660	2695	2187	50	85.60872	0.169521	3.711619	463.4843	21.68465	95.36687	2186.495	0.495424	-1191.67	0.030061	0.661243	358.0058	21.99006	352.167
74	550	2657	2697	2334	47	87.52176	0.205317	4.465302	467.9696	21.53792	116.9048	2333.489	147.4885	-1044.18	0.134347	2.94675	360.9525	21.80176	373.9687
75	572	2644	2703	2408	34	93.2609	0.348538	7.51352	475.4831	20.67721	137.582	2407.482	221.4816	-822.699	0.290952	6.311012	367.2635	21.07537	395.0441
76	595	2624	2707	2419	14	97.08698	0.554818	12.1181	487.6012	19.5487	157.1307	2418.475	232.4747	-590.225	0.45533	10.11444	377.378	20.65667	415.7008
77	617	2603	2708	2375	-7	98.04351	0.769408	15.30562	502.9068	15.8031	172.9338	2374.468	188.4678	-401.757	0.588591	12.21418	389.5921	18.29792	433.9987
78	640	2590	2707	2293	-20	97.08698	0.901291	18.03496	520.9418	14.27377	187.2076	2292.461	106.4609	-295.296	0.663867	14.17185	403.764	18.11515	452.1138
79	662	2587	2708	2241	-23	98.04351	0.928555	17.61661	538.5584	13.17782	200.3854	2240.454	54.45395	-240.842	0.702371	14.21264	417.9766	16.79288	468.9067
80	683	2584	2707	2261	-26	97.08698	0.959793	17.20053	555.7589	12.04748	212.4329	2260.447	74.44704	-166.395	0.75501	14.39122	432.3679	15.29355	484.2003
81	704	2572	2703	2365	-38	93.2609	1.085052	18.57088	574.3298	9.604206	222.2371	2364.44	178.4401	12.04525	0.881182	16.20131	448.5692	13.36104	497.5613
82	726	2555	2694	2426	-55	84.6522	1.274308	21.04011	595.3699	6.427594	228.6647	2425.433	239.4332	251.4785	1.05048	19.08856	467.6577	10.93741	508.4987
83	749	2540	2684	2336	-70	75.08698	1.448483	22.82817	618.198	2.806205	231.4709	2335.426	149.4263	400.9048	1.156136	21.05082	488.7085	9.266224	517.765
84	774	2532	2674	2243	-78	65.52176	1.570255	25	643.198	0.013533	231.4844	2242.419	56.41939	457.3242	1.196029	23.26482	511.9734	9.151409	526.9164
85	800	2534	2671	2220	-76	62.65219	1.579502	25.99901	669.1971	-0.22636	231.2581	2219.412	33.41248	490.7366	1.219654	24.41349	536.3869	8.94324	535.8596
86	826	2534	2667	2198	-76	58.8261	1.610226	25.97979	695.1768	-1.0249	230.2332	2197.406	11.40557	502.1422	1.227719	24.48482	560.8717	8.746065	544.6057
87	853	2529	2687	2170	-81	77.95654	1.502674	26.93738	722.1142	1.837881	232.071	2169.399	-16.6013	485.5409	1.21598	25.31818	586.1899	9.380288	553.986
88	880	2530	2672	2200	-80	63.60871	1.597177	26.99061	749.1048	-0.71218	231.3589	2199.392	13.39174	498.9326	1.225449	25.40586	611.5957	9.140133	563.1261
89	906	2534	2672	2216	-76	63.60871	1.572055	25.99998	775.1048	-0.03273	231.3261	2215.385	29.38483	528.3174	1.246226	24.64249	636.2382	8.29143	571.4175
90	930	2536	2673	2163	-74	64.56524	1.551514	23.99554	799.1003	0.462749	231.7889	2162.378	-23.6221	504.6954	1.229524	22.61591	658.8541	8.032476	579.45
91	952	2546	2679	2061	-64	70.30437	1.436623	21.80227	820.9026	2.942956	234.7318	2060.371	-125.629	379.0664	1.140694	19.99631	678.8504	9.173199	588.6232
92	973	2564	2688	1949	-46	78.91307	1.225898	19.7633	840.6659	7.100128	241.832	1948.364	-237.636	141.4305	0.972667	17.3542	696.2046	11.82505	600.4482
93	993	2587	2699	1909	-23	89.43481	0.949848	16.26654	856.9325	11.63614	253.4681	1908.357	-277.643	-136.212	0.776352	14.01362	710.2182	14.26949	614.7177
94	1014	2614	2705	1926	4	95.17394	0.656128	12.81112	869.7436	16.63956	270.1077	1925.35	-260.65	-396.862	0.592052	11.71936	721.9376	17.42574	632.1435
95	1035	2637	2704	1959	27	94.21742	0.41904	8.544557	878.2881	19.18308	289.2907	1958.343	-227.657	-624.519	0.431081	8.774915	730.7125	19.07881	651.2223
96	1058	2653	2697	2020	43	87.52176	0.241463	5.499842	883.788	22.33275	311.6235	2019.336	-166.664	-791.182	0.313237	7.087208	737.7997	21.88085	673.1031
97	1082	2662	2692	2093	52	82.73915	0.137033	3.278508	887.0665	23.77502	335.3985	2092.33	-93.6705	-884.653	0.247004	5.868009	743.6677	23.27158	696.3747
98	1108	2668	2685	2163	58	76.0435	0.046539	1.209565	888.2761	25.97185	361.3704	2162.323	-23.6774	-908.53	0.230263	5.934064	749.6018	25.31377	721.6885
99	1134	2671	2684	2195	61	75.08698	0.015881	0.41288	888.6889	25.99672	387.3671	2194.316	8.315712	-900.214	0.236142	6.082802	755.6846	25.27844	746.9569
100	1160	2671	2685	2209	61	76.0435	0.022067	0.573708	889.2626	25.99367	413.3607	2208.309	22.3088	-877.906	0.251917	6.480773	762.1654	25.17935	772.1463
101	1189	2671	2686	2229	61	77.00002	0.02816	0.816542	890.0792	28.9885	442.3492	2228.302	42.30169	-835.604	0.281827	8.065229	770.2306	27.85592	800.0022
102	1220	2669	2687	2236	59	77.95654	0.050272	1.557791	891.637	30.96083	473.3101	2235.295	49.29498	-786.309	0.316683	9.653895	779.8845	29.45848	829.4607
103	1253	2668	2687	2206	58	77.95654	0.058479	1.928705	893.5657	32.94359	506.2537	2205.288	19.28606	-767.021	0.330321	10.70344	790.5879	31.21596	860.6766
104	1287	2670	2686	2183	60	77.00002	0.03619	1.230198	894.7959	33.97774	540.2314	2182.281	-3.71885	-770.74	0.327691	10.94318	801.5311	32.19079	892.8674
105	1324	2672	2683	2190	62	74.13046	0.001608	0.05949	894.8554	36.99995	577.2314	2189.274	3.27424	-767.465	0.330007	11.98982	813.5209	35.00349	927.8709
106	1362	2672	2683	2204	62	74.13046	0.001608	0.061098	894.9165	37.99995	615.2313	2203.267	17.26733	-750.198	0.342216	12.75186	826.2728	35.79651	963.6674
107	1400	2671	2683	2198	61	74.13046	0.009598	0.364725	895.2812	37.99825	653.2296	2197.26	11.26042	-738.938	0.350178	13.03647	839.3093	35.69384	999.3613
108	1437	2672	2683	2198	62	74.13046	0.001608	0.05949	895.3407	36.99995	690.2295	2197.254	11.2535	-727.684	0.358135	12.96954	852.2788	34.65243	1034.014
109	1471	2672	2684	2223	62	75.08698	0.00791	0.268933	895.6096	33.99894	724.2284	2222.247	36.24659	-691.437	0.383764	12.73006	865.0089	31.5269	1065.541
110	1499	2675	2684	2231	65	75.08698	-0.01539	-0.43077	895.1788	27.99669	752.2251	2230.24	44.23968	-647.198	0.415045	11.28047	876.2993	25.62275	1091.163
111	1521	2671	2686	2252	61	77.00002	0.02816	0.619445	895.7983	21.99128	774.2164	2251.233	65.23277	-581.965	0.46117	9.789911	886.0893	19.70172	1110.865
112	1538	2661	2694	2333	51	84.6522	0.155902	2.639603	898.4379	16.79382	791.0102	2332.226	146.2259	-435.739	0.564563	9.095792	895.185	14.36198	1125.227
113	1549	2649	2701	2367	39	91.34785	0.294619	3.194133	901.632	10.52604	801.5363	2366.219	180.2189	-255.52	0.691992	7.018793	902.2038	8.469743	1133.697
114	1558	2638	2705	2329	28	95.17394	0.412006	3.604036	905.2361	8.246874	809.7832	2328.212	142.212	-113.308	0.792547	6.409292	908.6131	6.318305	1140.015
115	1569	2625	2706	2342	15	96.13046	0.543342	5.686995	910.9231	9.415842	819.199	2341.205	155.2051	41.89696	0.902289	8.632225	917.2454	6.817968	1146.833
116	1585	2608	2705	2422	-2	95.17394	0.719143	10.53984	921.4629	12.03793	831.2369	2421.198	235.1982	277.0952	1.066593	14.02438	931.2697	7.701733	1154.535
117	1605	2584	2700	2534	-26	90.39133	0.978209	16.58997	938.0529	11.17018	842.4071	2533.191	347.1913	624.2865	1.314084	19.3446	950.6143	5.078038	1159.613
118	1631	2557	2679	2549	-53	70.30437	1.344102	25.33478	963.3876	5.843704	848.2508	2548.184	362.1844	986.4708	1.570177	26	976.6143	0.016107	1159.629
119	1660	2539	2661	2380	-71	53.08697	1.626898	28.95437	992.342	-1.6261	846.6247	2379.177	193.1775	1179.648	1.706768	28.73233	1005.347	-3.93105	1155.698
120	1694	2536	2653	2226	-74	45.4348	1.71829	33.63085	1025.973	-4.99662	841.6281	2225.171	39.17056	1218.819	1.734465	33.54563	1038.892	-5.53993	1150.158
121	1731	2536	2651	2209	-74	43.52175	1.737281	36.48842	1062.461	-6.13151	835.4866	2208.164	22.16365	1240.983	1.750137	36.40658	1075.299	-6.60007	1143.558
122	1770	2535	2651	2219	-75	43.52175	1.743127	38.42232	1100.884	-6.68769	828.8089	2218.157	32.15674	1273.139	1.772874	38.20642	1113.505	-7.8275	1135.73
123	1811	2536	2650	2203	-74	42.56523	1.746939	40.3656	1141.249	-7.18457	821.6243	2202.15	16.14982	1289.289	1.784293	40.06914	1153.574	-8.68702	1127.043
124	1853	2537	2650	2188	-73	42.56523	1.741039	41.39284	1182.642	-7.11569	814.5086	2187.143	1.142912	1290.432	1.785101	41.03923	1194.614	-8.93207	1118.111
125	1898	2538	2652	2209	-72	44.47827	1.715556	44.52932	1227.171	-6.49148	808.0172	2208.136	22.136	1312.568	1.800753	43.81543	1238.429	-10.2571	1107.854
126	1946	2536	2652	2209	-74	44.47827	1.727731	47.41013	1274.581	-7.50199	800.5152	2208.129	22.12909	1334.697	1.8164	46.55955	1284.989	-11.6708	1096.183
127	1995	2537	2650	2198	-73	42.56523	1.741039	48.29164	1322.873	-8.30164	792.2135	2197.122	11.12218	1345.819	1.824264	47.43438	1332.423	-12.2874	1083.896
128	2045	2538	2650	2201	-72	42.56523	1.735016	49.32731	1372.2	-8.17414	784.0394	2200.115	14.11526	1359.935	1.834245	48.27488	1380.698	-13.0206	1070.875
129	2096	2538	2648	2202	-72	40.65219	1.754934	50.13782	1422.338	-9.33806	774.7013	2201.108	15.10835	1375.043	1.844928	49.0957	1429.794	-13.8063	1057.069
130	2147	2537	2648	2198	-73	40.65219	1.760819	50.082	1472.42	-9.63292	765.0684	2197.101	11.10144	1386.144	1.852777	48.98581	1478.779	-14.1912	1042.878
131	2198	2537	2648	2206	-73	40.65219	1.760819	50.082	1522.502	-9.63292	755.4355	2205.095	19.09453	1405.239	1.866279	48.78975	1527.569	-14.8513	1028.027
132	2250	2538	2647	2199	-72	39.69566	1.765065	51.02183	1573.524	-10.0386	745.3969	2198.088	12.08762	1417.326	1.874826	49.61518	1577.184	-15.5671	1012.46

133	2303	2538	2648	2201	-72	40.65219	1.754934	52.10401	1625.628	-9.70426	735.6927		2200.081	14.0807	1431.407	1.884782	50.40884	1627.593	-16.3691	986.0905
134	2356	2539	2648	2212	-71	40.65219	1.748925	52.16138	1677.789	-9.39097	726.3017		2211.074	25.07379	1456.481	1.902511	50.11073	1677.704	-17.2602	978.8303
135	2409	2537	2648	2204	-73	40.65219	1.760819	52.046	1729.835	-10.0107	716.291		2203.067	17.06688	1473.548	1.914576	49.89879	1727.603	-17.8637	960.9666
136	2461	2536	2648	2215	-74	40.65219	1.766581	51.00656	1780.842	-10.1159	706.1751		2214.06	28.05997	1501.608	1.934419	48.59995	1776.203	-18.4944	942.4722
137	2512	2535	2648	2205	-75	40.65219	1.772225	49.96887	1830.811	-10.2035	695.9716		2204.053	18.05306	1519.661	1.947184	47.42992	1823.633	-18.7457	923.7264
138	2562	2536	2649	2211	-74	41.60871	1.756706	49.13843	1879.949	-9.24202	686.7296		2210.046	24.04614	1543.707	1.964186	46.18074	1869.813	-19.1661	904.5603
139	2612	2538	2647	2210	-72	39.69566	1.765065	49.05945	1929.009	-9.65247	677.0771		2209.039	23.03923	1566.746	1.980477	45.8624	1915.678	-19.9158	884.6445
140	2662	2539	2647	2196	-71	39.69566	1.75913	49.11588	1978.125	-9.3611	667.716		2195.032	9.03232	1575.779	1.986864	45.73427	1961.41	-20.2083	864.4362
141	2713	2539	2648	2197	-71	40.65219	1.748925	50.19303	2028.318	-9.03659	658.6794		2196.025	10.02541	1585.804	1.993952	46.50167	2007.912	-20.9426	843.4935
142	2764	2538	2648	2195	-72	40.65219	1.754934	50.13782	2078.456	-9.33806	649.3413		2194.018	8.018496	1593.822	1.999622	46.38219	2054.294	-21.206	822.2876
143	2816	2537	2650	2203	-73	42.56523	1.741039	51.24827	2129.704	-8.8099	640.5314		2202.012	16.01158	1609.834	2.010943	47.04383	2101.338	-22.1558	800.1318
144	2867	2536	2649	2206	-74	41.60871	1.756706	50.1212	2179.825	-9.42686	631.1046		2205.005	19.00467	1628.839	2.024381	45.84298	2147.181	-22.3477	777.7841
145	2917	2534	2650	2203	-76	42.56523	1.758387	49.12282	2228.948	-9.32464	621.78		2201.998	15.99776	1644.836	2.035693	44.6934	2191.874	-22.4165	755.3676
146	2967	2533	2652	2195	-77	44.47827	1.745112	49.24227	2278.19	-8.67171	613.1082		2193.991	7.990846	1652.827	2.041343	44.56603	2236.44	-22.6687	732.6989
147	3016	2539	2646	2220	-71	38.73914	1.769452	48.0363	2326.226	-9.67025	603.438		2218.984	32.98394	1685.811	2.064665	43.14477	2279.585	-23.2278	709.4711
148	3064	2536	2644	2216	-74	36.8261	1.807162	46.66538	2372.892	-11.2402	592.1978		2214.977	28.97702	1714.788	2.085154	41.78922	2321.374	-23.6148	685.8563
149	3135	2535	2645	2199	-75	37.78262	1.80227	69.10638	2441.998	-16.2883	575.9095	575.9095	2197.97	11.97011	1726.758	2.093618	61.51537	2362.889	-35.4522	650.404
150	3159	2536	2644	2193	-74	36.8261	1.807162	23.33269	2465.331	-5.62011	570.2894		2191.963	5.9632	1732.722	2.097835	20.74321	2403.633	-12.0714	638.3326
151	3205	2535	2646	2198	-75	38.73914	1.79215	44.87765	2510.208	-10.0993	560.19		2196.956	10.95629	1743.678	2.105582	39.57739	2443.21	-23.4442	614.8884
152	3246	2534	2646	2214	-76	38.73914	1.79753	39.95064	2550.159	-9.21665	550.9734		2212.949	26.94938	1770.627	2.124637	34.87094	2478.081	-21.5643	593.3242
153	3283	2532	2644	2231	-78	36.8261	1.827824	35.78454	2585.944	-9.40567	541.5677		2229.942	43.94246	1814.57	2.155708	30.84916	2508.93	-20.4286	572.8955
154	3317	2530	2643	2232	-80	35.86958	1.847431	32.70732	2618.651	-9.28606	532.2817		2230.936	44.93555	1859.505	2.187481	27.73722	2536.667	-19.6633	553.2322
155	3347	2527	2639	2314	-83	32.04349	1.900491	28.38424	2647.035	-9.71263	522.569		2312.929	126.9286	1986.434	2.277229	22.82047	2559.488	-19.4737	533.7585
156	3376	2520	2623	2382	-90	16.73914	2.085039	25.2493	2672.285	-14.2644	508.3046		2380.922	194.9217	2181.356	2.415054	19.2643	2578.752	-21.6769	512.0816
157	3406	2514	2606	2424	-96	0.478261	2.263946	23.07712	2695.362	-19.1689	489.1357		2422.915	236.9146	2418.27	2.582571	15.9107	2594.663	-25.4332	486.6484
158	3436	2515	2586	2423	-95	-18.6522	-3.82038	18.8356	2714.197	-23.35	465.7858		2421.908	235.9079	2654.178	2.749377	11.46711	2606.13	-27.7219	458.9264
159	3470	2523	2567	2341	-87	-36.8261	-3.61384	15.46613	2729.663	-30.2787	435.5071		2339.901	153.901	2808.079	2.858197	9.507	2615.637	-32.6438	426.2826
160	3506	2524	2553	2267	-88	-50.2174	-3.48574	12.14628	2741.81	-33.8891	401.618		2265.894	79.89408	2887.973	2.914688	8.098647	2623.736	-35.0772	391.2054
161	3544	2525	2551	2240	-85	-52.1304	-3.46412	12.04452	2753.854	-36.0407	365.5774		2238.887	52.88717	2940.861	2.952084	7.158318	2630.894	-37.3197	353.8857
162	3583	2527	2553	2195	-83	-50.2174	-3.47015	12.58437	2766.439	-36.9139	328.6635		2193.88	7.880256	2948.741	2.957656	7.133166	2638.027	-38.3421	315.5436
163	3625	2527	2549	2192	-83	-54.0435	-3.43709	12.23108	2778.67	-40.1796	288.4839		2190.873	4.873344	2953.614	2.961101	7.539542	2645.567	-41.3177	274.2259
164	3667	2524	2551	2197	-86	-52.1304	-3.46931	13.51926	2792.189	-39.7647	248.7192		2195.866	9.866432	2963.481	2.968078	7.251114	2652.818	-41.3693	232.8566
165	3711	2525	2554	2200	-85	-49.2609	-3.48902	14.98103	2807.17	-41.3711	207.3481		2198.86	12.85952	2976.34	2.97717	7.202026	2660.02	-43.4066	189.45
166	3756	2526	2550	2192	-84	-53.087	-3.45065	13.68719	2820.857	-42.8679	164.4802		2190.853	4.852608	2981.193	2.980602	7.213345	2667.233	-44.4181	145.0319
167	3802	2527	2550	2194	-83	-53.087	-3.44523	13.75353	2834.611	-43.8958	120.5844		2192.846	6.845696	2988.038	2.985442	7.153775	2674.387	-45.4403	99.59155
168	3849	2526	2552	2200	-84	-51.1739	-3.46709	15.0297	2849.64	-44.5321	76.05228		2198.839	12.83878	3000.877	2.99452	6.88752	2681.274	-46.4926	53.09895
169	3894	2525	2550	2201	-85	-53.087	-3.45598	13.91552	2863.556	-42.7944	33.25791		2199.832	13.83187	3014.709	3.0043	6.158767	2687.433	-44.5766	8.522392
170	3939	2527	2549	2201	-83	-54.0435	-3.43709	13.10473	2876.661	-43.0496	-9.79167		2199.825	13.82496	3028.534	3.014076	5.722729	2693.156	-44.6346	-36.1122
171	3983	2526	2548	2206	-84	-55	-3.43454	12.70618	2889.367	-42.1254	-51.9171		2204.818	18.81605	3047.352	3.027381	5.014376	2698.17	-43.7133	-79.8256
172	4025	2524	2547	2200	-86	-55.9565	-3.43742	12.24432	2901.611	-40.1756	-92.0927		2198.811	12.81114	3060.163	3.03644	4.408281	2702.579	-41.768	-121.594
173	4065	2521	2546	2199	-89	-56.9131	-3.44532	11.9631	2913.574	-38.1692	-130.262	-130.262	2197.804	11.80422	3071.967	3.044786	3.866205	2706.445	-39.8127	-161.406
174	4105	2515	2557	2194	-95	-46.3913	-3.55999	16.25184	2929.826	-36.5497	-166.811	-166.811	2192.797	6.797312	3078.765	3.049593	3.674811	2710.12	-39.8308	-201.237
175	4144	2519	2555	2208	-91	-48.3044	-3.52626	14.63482	2944.461	-36.15	-202.961		2206.79	20.7904	3099.555	3.064293	3.011682	2713.131	-38.8835	-240.121
176	4183	2529	2556	2199	-81	-47.3478	-3.48528	13.14156	2957.602	-36.7192	-239.681		2197.783	11.78349	3111.339	3.072625	2.687609	2715.819	-38.9073	-279.028
177	4220	2528	2556	2194	-82	-47.3478	-3.49061	12.65312	2970.256	-34.7692	-274.45		2192.777	6.776576	3118.115	3.077417	2.372688	2718.192	-36.9238	-315.952
178	4257	2534	2552	2201	-76	-51.1739	-3.42165	10.22713	2980.483	-35.5585	-310.008	-310.008	2199.77	13.76966	3131.885	3.087153	2.013282	2720.205	-36.9452	-352.897
179	4282	2533	2550	2189	-77	-53.087	-3.41065	6.645642	2987.128	-24.1005	-334.109		2187.763	1.762752	3133.648	3.088399	1.329211	2721.534	-24.9646	-377.862
180	4306	2531	2551	2186	-79	-52.1304	-3.43097	6.848498	2993.977	-23.0021	-357.111		2184.756	-1.24416	3132.404	3.087519	1.297125	2722.831	-23.9649	-401.827
181	4327	2530	2553	2191	-80	-50.2174	-3.45371	6.448485	3000.425	-19.9854	-377.096		2189.749	3.748928	3136.152	3.09017	1.079396	2723.911	-20.9722	-422.799
182	4344	2529	2554	2194	-81	-49.2609	-3.46786	5.448663	3005.874	-16.1032	-393.2		2192.742	6.742016	3142.894	3.094937	0.792853	2724.704	-16.9815	-439.78
183	4357	2530	2555	2197	-80	-48.3044	-3.47105	4.205824	3010.08	-12.3009	-405.5		2195.735	9.735104	3152.63	3.101821	0.516898	2725.221	-12.9897	-452.77
184	4366	2529	2555	2196	-81	-48.3044	-3.47653	2.958354	3013.038	-8.49989	-414		2194.728	8.728192	3161.358	3.107992	0.302346	2725.523	-8.99492	-461.765
185	4370	2528	2554	2197	-82	-49.2609	-3.47329	1.302601	3014.341	-3.78196	-417.782		2195.721	9.72128	3171.079	3.114866	0.106894	2725.63	-3.99857	-465.764
186	4370	2527	2553	2194	-83	-50.2174	-3.47015	0	3014.341	0	-417.782		2192.714	6.714368	3177.793	3.119614	0	2725.63	0	-465.764
187	4370	2527	2551	2193	-83	-52.1304	-3.45345	0	3014.341	0	-417.782		2191.707	6.707456	3183.501	3.123649	0	2725.63	0	-465.764
188	4370	2527	2551	2193	-83	-52.1304	-3.45345	0	3014.341	0	-417.782		2191.701	5.700544	3189.201	3.12768	0	2725.63	0	-465.764
189	4370	2527	2551	2193	-83	-52.1304	-3.45345	0	3014.341	0	-417.782		2191.694	5.693632	3194.895	3.131706	0	2725.63	0	-465.764
190	4371	2527	2551	2193	-83	-52.1304	-3.45345	0.306825	3014.648	-0.95177	-418.734		2191.687	5.68672	3200.582	3.135727	0.005866	2725.636	-0.99998	-466.763
191	4373	2526	2551	2193	-84	-52.1304	-3.45883	0.623882	3015.271	-1.9002	-420.634		2191.68	5.679808	3206.262	3.139743	0.0037	2725.639	-2	-468.763
192	4378	2526	2550	2192	-84	-53.087	-3.45065	1.520798	3016.792	-4.76311	-425.397		2190.673	4.672896	3210.934	3.143047	-0.00727	2725.632	-4.99999	-473.763
193	4387	2526	2549	2190	-84	-54.0435	-3.44255	2.667942	3019.46	-8.59547	-433.993	-433.993	2188.666	2.665984	3213.6	3.144932	-0.03005	2725.602	-8.99995	-482.763
194	4400	2525	2548	2175	-85	-55	-3.43995	3.821366	3023.282	-12.4257	-446.419		2173.659	-12.3409	3201.26	3.136206	0.070026	2725.672	-12.9998	-495.763
195	4413	2525	2550	2160	-85	-53.087	-3.45598	4.020038	3027.302	-12.3628	-458.781	-458.781	2158.652	-27.3478	3173.912	3.116869	0.321375	2725.993	-12.998	-508.759
196	4427	2527	2552	2196	-83	-51.1739	-3.46176	4.40609	3031.708	-13.2886	-472.07		2194.645	8.645248	3182.557	3.122982	0.260537	2726.254	-13.9978	-522.757
197	4441	2529	2551	2256	-81	-52.1304	-3.4424	4.148138	3035.856	-13.3713	-485.441		2254.638	68.63834	3251.195	3.171514	-0.41884	2725.835	-13.9937	-536.751
198	4454	2536	2544	2385	-74	-58.8261	-3.3428	2.595596	3038.451	-12.7382	-498.18		2383.631	197.6314	3448.827	3.311255	-2.19505	2723.64	-12.8133	-549.564
199	4467	2551	2528	2559	-59	-74.1305	-3.11569	-0.33665	3038.115	-12.9956	-511.175		2557.625	371.6245	3820.451	3.574023	-5.44602	2718.192	-11.8033	-561.367

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
203	4547	2658	2522	2223	48	-79.8696	-1.90232	-23.6387	2977.887	-8.13714	-557.694		2221.597	35.59686	4826.88	4.285647	-22.758	2650.781	-10.3477	-602.649
204	4576	2652	2514	2219	42	-87.5218	-1.99604	-26.4172	2951.47	-11.9637	-569.658		2217.59	31.58995	4858.47	4.307984	-26.6608	2624.12	-11.4107	-614.06
205	4608	2659	2516	2217	49	-85.6087	-1.9236	-30.029	2921.441	-11.0571	-580.715		2215.583	29.58304	4888.053	4.328901	-29.6757	2594.444	-11.973	-626.033
206	4644	2662	2518	2200	52	-83.6957	-1.88753	-34.2093	2887.232	-11.2126	-591.927		2198.576	12.57613	4900.629	4.337794	-33.5036	2560.941	-13.1723	-639.205
207	4684	2662	2516	2183	52	-85.6087	-1.89761	-37.8828	2849.349	-12.841	-604.768		2181.569	-4.43076	4896.198	4.334661	-37.1802	2523.76	-14.7524	-653.958
208	4727	2661	2514	2170	51	-87.5218	-1.91585	-40.4655	2808.884	-14.5446	-619.313		2168.562	-17.4377	4878.761	4.322331	-39.7701	2483.99	-16.3504	-670.308
209	4772	2661	2514	2193	51	-87.5218	-1.91585	-42.3476	2766.536	-15.2211	-634.534		2191.555	5.555392	4884.316	4.326259	-41.6868	2442.304	-16.9473	-687.255
210	4819	2663	2513	2185	53	-88.4783	-1.90376	-44.4186	2722.117	-15.3619	-649.896		2183.548	-2.45152	4881.865	4.324526	-43.5088	2398.795	-17.7759	-705.031
211	4867	2660	2514	2187	50	-87.5218	-1.92442	-45.0299	2677.088	-16.6225	-666.518		2185.542	-0.45843	4881.406	4.324201	-44.4286	2354.366	-18.1686	-723.2
212	4918	2657	2518	2193	47	-83.6957	-1.93179	-47.7129	2629.375	-18.0133	-684.532		2191.535	5.534656	4886.941	4.328115	-47.2806	2307.085	-19.1192	-742.319
213	4970	2657	2522	2200	47	-79.8696	-1.91157	-49.0098	2580.365	-17.3793	-701.911		2198.528	12.52774	4899.469	4.336973	-48.3785	2258.707	-19.0663	-761.385
214	5022	2658	2521	2193	48	-80.8261	-1.90756	-49.0791	2531.286	-17.1827	-719.094		2191.521	5.520832	4904.989	4.340877	-48.4525	2210.254	-18.8773	-780.263
215	5075	2658	2523	2207	48	-78.9131	-1.89699	-50.2053	2481.08	-16.9832	-736.077		2205.514	19.51392	4924.503	4.354674	-49.6451	2160.609	-18.5571	-798.82
216	5129	2660	2527	2225	50	-75.087	-1.85599	-51.8187	2429.262	-15.1927	-751.27		2223.507	37.50701	4962.01	4.381195	-51.0654	2109.544	-17.5593	-816.379
217	5183	2663	2528	2222	53	-74.1305	-1.82277	-52.2048	2376.867	-13.4629	-764.733		2220.5	34.5001	4996.51	4.405589	-51.4765	2058.066	-16.3085	-832.687
218	5239	2665	2530	2211	55	-72.2174	-1.78258	-54.6283	2322.339	-12.3185	-777.051		2209.493	23.49318	5020.004	4.422201	-53.6586	2004.407	-16.0234	-848.711
219	5293	2667	2530	2212	57	-72.2174	-1.77529	-52.8749	2269.464	-10.9658	-788.017		2210.486	24.48627	5044.49	4.439514	-52.002	1952.405	-14.553	-863.264
220	5348	2668	2531	2210	58	-71.2609	-1.7603	-54.0154	2215.448	-10.3602	-798.377		2208.479	22.47936	5066.969	4.455409	-53.1939	1899.211	-13.9788	-877.243
221	5403	2670	2533	2221	60	-69.3478	-1.73021	-54.3027	2161.146	-8.73047	-807.107		2219.472	33.47245	5100.442	4.479077	-53.5098	1845.701	-12.7161	-889.959
222	5459	2670	2536	2220	60	-66.4783	-1.70924	-55.4642	2105.681	-7.72802	-814.836		2218.466	32.46554	5132.907	4.502032	-54.7656	1790.936	-11.6933	-901.652
223	5515	2670	2539	2215	60	-63.6087	-1.68725	-55.6207	2050.061	-6.50663	-821.342		2213.459	27.45862	5160.366	4.521448	-54.9823	1735.953	-10.6279	-912.28
224	5570	2675	2540	2232	65	-62.6522	-1.63967	-54.8696	1995.191	-3.7852	-825.127		2230.452	44.45171	5204.818	4.552879	-54.3018	1681.652	-8.73592	-921.016
225	5627	2679	2541	2226	69	-61.6957	-1.60223	-56.9718	1938.219	-1.79158	-826.919		2224.445	38.4448	5243.262	4.580062	-56.5017	1625.15	-7.52064	-928.537
226	5685	2683	2541	2206	73	-61.6957	-1.57433	-57.9996	1880.22	-0.20519	-827.124		2204.438	18.43789	5261.7	4.593099	-57.5878	1567.562	-6.90241	-935.439
227	5743	2686	2540	2209	76	-62.6522	-1.56209	-57.9978	1822.222	0.504946	-826.619		2207.431	21.43098	5283.131	4.608253	-57.6858	1509.876	-6.02901	-941.468
228	5800	2687	2540	2210	77	-62.6522	-1.55568	-56.9935	1765.228	0.86146	-825.758		2208.424	22.42406	5305.555	4.624108	-56.778	1453.098	-5.02548	-946.493
229	5857	2686	2539	2222	76	-63.6087	-1.56954	-57	1708.228	0.071753	-825.686		2220.417	34.41715	5339.972	4.648444	-56.8835	1396.215	-3.6424	-950.136
230	5914	2684	2549	2195	74	-54.0435	-1.50345	-56.8708	1651.358	3.83587	-821.85		2193.41	7.41024	5347.383	4.653683	-56.9018	1339.313	-3.3443	-953.48
231	5972	2683	2549	2207	73	-54.0435	-1.50994	-57.8926	1593.465	3.527322	-818.323		2205.403	19.40333	5366.786	4.667403	-57.9413	1281.372	-2.60831	-956.088
232	6030	2682	2548	2215	72	-55	-1.525	-57.9392	1535.526	2.65551	-815.667		2213.396	27.39642	5394.182	4.686774	-57.981	1223.391	-1.48548	-957.574
233	6090	2683	2551	2214	73	-52.1304	-1.4928	-59.8176	1475.708	4.674943	-810.992		2212.39	26.3895	5420.672	4.705434	-59.9985	1163.392	-0.4173	-957.991
234	6150	2680	2552	2218	70	-51.1739	-1.50393	-59.8659	1415.842	4.008931	-806.983		2216.383	30.38259	5450.955	4.726917	-59.9937	1103.398	0.871634	-957.12
235	6211	2685	2554	2220	75	-49.2609	-1.45381	-60.5831	1355.259	7.119685	-799.864		2218.376	32.37568	5483.33	4.749809	-60.9573	1042.441	2.282081	-954.838
236	6273	2686	2556	2213	76	-47.3478	-1.42982	-61.3849	1293.874	8.71143	-791.152		2211.369	25.36877	5508.699	4.767747	-61.905	980.5361	3.430418	-951.407
237	6335	2684	2556	2200	74	-47.3478	-1.44186	-61.4654	1232.389	7.971846	-783.18		2198.362	12.36186	5521.061	4.776487	-61.8727	918.6634	3.97138	-947.436
238	6397	2685	2556	2204	75	-47.3478	-1.43578	-61.4358	1170.953	8.345314	-774.835		2202.355	16.35494	5537.416	4.788052	-61.8226	856.8408	4.686608	-942.749
239	6458	2686	2557	2215	76	-46.3913	-1.4207	-60.3142	1110.639	9.12124	-765.714		2213.348	27.34803	5564.764	4.807389	-60.7249	796.1159	5.786277	-936.963
240	6521	2688	2555	2206	78	-48.3044	-1.42714	-62.3511	1048.288	9.018944	-756.695		2204.341	18.34112	5583.105	4.820357	-62.6332	733.4827	6.788804	-930.174
241	6585	2687	2555	2204	77	-48.3044	-1.43294	-63.3928	984.895	8.795061	-747.9		2202.334	16.33421	5599.439	4.831907	-63.5434	669.9393	7.630954	-922.543
242	6650	2685	2557	2212	75	-46.3913	-1.42661	-64.3255	920.5694	9.339482	-738.56		2210.327	24.3273	5623.766	4.849108	-64.3935	605.5458	8.859095	-913.684
243	6715	2687	2557	2218	77	-46.3913	-1.41491	-64.2118	856.3576	10.09168	-728.469		2216.32	30.32038	5654.087	4.870547	-64.1887	541.3571	10.23748	-903.447
244	6779	2687	2558	2203	77	-45.4348	-1.40574	-63.1302	793.2274	10.51539	-717.953		2201.313	15.31347	5669.4	4.881375	-63.0884	478.2687	10.76371	-892.683
245	6842	2686	2558	2200	76	-45.4348	-1.41148	-62.2022	731.0252	9.994259	-707.959		2198.307	12.30656	5681.707	4.890077	-62.0081	416.2607	11.13551	-881.547
246	6905	2687	2558	2203	77	-45.4348	-1.40574	-62.1438	668.8813	10.35109	-697.608		2201.3	15.29965	5697.007	4.900895	-61.884	354.3767	11.80565	-869.742
247	6966	2686	2560	2200	76	-43.5218	-1.39273	-60.0355	608.8458	10.80446	-686.803		2198.293	12.29274	5709.299	4.909587	-59.8178	294.5589	11.95125	-857.79
248	7027	2686	2560	2219	76	-43.5218	-1.39273	-60.0355	648.8103	10.80446	-675.999		2217.286	31.28582	5740.585	4.931708	-59.5388	235.0201	13.27148	-844.519
249	7086	2688	2562	2222	78	-41.6087	-1.36271	-57.7272	491.0831	12.18875	-663.81		2220.279	34.27891	5774.864	4.955946	-57.2587	177.7614	14.22822	-830.291
250	7144	2692	2561	2215	82	-42.5652	-1.35147	-56.6105	434.4725	12.61942	-651.191		2213.272	27.272	5802.136	4.97523	-56.008	121.7534	15.06983	-815.221
251	7201	2691	2565	2199	81	-38.7391	-1.31877	-55.1993	379.2732	14.21389	-636.977		2197.265	11.26509	5813.401	4.983195	-54.9227	66.8307	15.24786	-799.973
252	7254	2693	2563	2201	83	-40.6522	-1.32811	-51.4468	327.8264	12.73663	-624.24		2199.258	13.25818	5826.659	4.992569	-50.9333	15.89741	14.65604	-785.317
253	7302	2692	2565	2205	82	-38.7391	-1.31401	-46.4262	281.4002	12.1906	-612.05		2203.251	17.25126	5843.911	5.004767	-45.9629	-30.0655	13.83506	-771.482
254	7343	2694	2565	2199	84	-38.7391	-1.30478	-39.5578	241.8424	10.77861	-601.271		2197.244	11.24435	5855.155	5.012718	-39.1648	-69.2303	12.12922	-759.353
255	7377	2694	2565	2195	84	-38.7391	-1.30478	-32.8041	209.0383	8.938356	-592.333		2193.237	7.23744	5862.392	5.017835	-32.4262	-101.657	10.22445	-749.128
256	7403	2695	2564	2195	85	-39.6957	-1.30957	-25.1179	183.9204	6.714855	-585.618		2193.231	7.230528	5869.623	5.022948	-24.7562	-126.413	7.945365	-741.183
257	7421	2695	2564	2200	85	-39.6957	-1.30957	-17.3893	166.531	4.646746	-580.969	-580.969	2198.224	12.22362	5881.848	5.031591	-17.0907	-143.504	5.648563	-735.534
258	7432	2694	2563	2201	84	-40.6522	-1.32339	-10.6651	155.866	2.693751	-578.275		2199.217	13.2167	5895.063	5.040936	-10.4116	-153.915	3.549352	-731.985
259	7439	2693	2564	2218	83	-39.6957	-1.31877	-6.77886	149.0871	1.745566	-576.53		2216.21	30.20979	5925.273	5.062297	-6.57583	-160.491	2.39968	-729.565
260	7443	2693	2566	2231	83	-37.7826	-1.29984	-3.85407	145.233	1.070594	-575.459		2229.203	43.20268	5968.476	5.092845	-3.71398	-164.205	1.485375	-728.1
261	7445	2693	2567	2225	83	-36.8261	-1.29026	-1.92181	143.3112	0.553748	-574.905		2223.196	37.19597	6005.672	5.119145	-1.83682	-166.042	0.791265	-727.309
262	7448	2696	2570	2216	86	-33.9565	-1.24872	-2.84574	140.4655	0.949617	-573.956		2214.189	28.18906	6033.861	5.139077	-2.73102	-168.773	1.241575	-726.067
263	7449	2697	2571	2215	87	-33	-1.23521	-0.94422	139.5213	0.329324	-573.627		2213.182	27.18214	6061.043	5.158297	-0.90222	-169.675	0.431277	-725.636
264	7449	2697	2573	2206	87	-31.087	-1.21585	0	139.5213	0	-573.627		2204.175	18.17523	6079.218	5.171148	0	-169.675	0	-725.636
265	7449	2697	2573	2196	87	-31.087	-1.21585	0	139.5213	0	-573.627		2194.168	8.16832	6087.387	5.176924	0	-169.675	0	-725.636
266	7449	2697	2573	2187	87	-31.087	-1.21585	0	139.5213	0	-573.627		2195.161	9.161408	6096.548	5.183402	0	-169.675	0	-725.636

267	7449	2697	2573	2198	87	-31.087	-1.21585	0	139.5213	0	-573.627		2196.154	10.1545	6106.702	5.190582	0	-169.675	0	-725.636
268	7449	2697	2573	2198	87	-31.087	-1.21585	0	139.5213	0	-573.627		2196.148	10.14758	6116.85	5.197757	0	-169.675	0	-725.636
269	7449	2697	2573	2198	87	-31.087	-1.21585	0	139.5213	0	-573.627		2196.141	10.14067	6126.991	5.204927	0	-169.675	0	-725.636
270	7449	2697	2573	2198	87	-31.087	-1.21585	0	139.5213	0	-573.627		2196.134	10.13376	6137.124	5.212093	0	-169.675	0	-725.636
271	7449	2697	2573	2197	87	-31.087	-1.21585	0	139.5213	0	-573.627		2195.127	9.126848	6146.251	5.218546	0	-169.675	0	-725.636
272	7449	2697	2573	2196	87	-31.087	-1.21585	0	139.5213	0	-573.627		2194.12	8.119936	6154.371	5.224287	0	-169.675	0	-725.636
273	7449	2697	2573	2196	87	-31.087	-1.21585	0	139.5213	0	-573.627		2194.113	8.113024	6162.484	5.230024	0	-169.675	0	-725.636
274	7450	2697	2573	2197	87	-31.087	-1.21585	-0.93766	138.5836	0.347543	-573.279		2195.106	9.106112	6171.59	5.236463	-0.86579	-170.541	0.500411	-725.135
275	7455	2697	2573	2203	87	-31.087	-1.21585	-4.68832	133.8953	1.737715	-571.541		2201.099	15.0992	6186.69	5.247139	-4.30198	-174.843	2.54813	-722.587
276	7466	2697	2574	2219	87	-30.1304	-1.20606	-10.2764	123.6189	3.923697	-567.618		2217.092	31.09229	6217.782	5.269124	-9.33884	-184.182	5.812586	-716.775
277	7482	2699	2580	2314	89	-24.3913	-1.14016	-14.5392	109.0797	6.679238	-560.938		2312.085	126.0854	6343.867	5.358276	-12.7771	-196.959	9.630512	-707.144
278	7503	2704	2596	2407	94	-9.08696	-0.96903	-17.3111	91.76857	11.888	-549.05		2405.078	219.0785	6562.946	5.513182	-14.6189	-211.578	15.07607	-692.068
279	7528	2709	2619	2439	99	12.91305	-0.74296	-16.9118	74.85676	18.4117	-530.639		2437.072	251.0716	6814.017	5.690709	-13.9604	-225.538	20.73901	-671.329
280	7555	2706	2636	2366	96	29.17392	-0.57764	-14.7433	60.11349	22.61937	-508.019		2364.065	178.0646	6992.082	5.816815	-12.1453	-237.683	24.11413	-647.215
281	7584	2700	2646	2276	90	38.73914	-0.4662	-13.0353	47.07815	25.90521	-482.114		2274.058	88.05773	7080.14	5.878878	-11.4081	-249.091	26.66188	-620.553
282	7614	2698	2654	2231	88	46.39132	-0.38751	-11.3367	35.74149	27.77553	-454.339		2229.051	43.05082	7123.19	5.909319	-10.9565	-260.048	27.92766	-592.625
283	7646	2694	2655	2209	84	47.34784	-0.35939	-11.2545	24.48696	29.95556	-424.383		2207.044	21.0439	7144.234	5.924198	-11.2424	-271.29	29.9601	-562.665
284	7680	2695	2655	2203	85	47.34784	-0.36444	-12.1184	12.36855	31.76703	-392.616		2201.037	15.03699	7159.271	5.934831	-11.606	-282.896	31.95781	-530.707
285	7716	2695	2660	2208	85	52.13045	-0.32252	-11.4106	0.957852	34.14379	-358.472		2206.03	20.03008	7179.301	5.948993	-11.8062	-294.705	34.00832	-496.699
286	7753	2698	2657	2188	86	49.26088	-0.35248	-12.7735	-11.8156	34.72516	-323.747		2186.023	0.023168	7179.325	5.94901	-12.1356	-306.84	34.9532	-461.746
287	7791	2693	2655	2184	83	47.34784	-0.35425	-13.1818	-24.9974	35.64044	-288.107		2182.016	-3.98374	7175.341	5.946193	-12.5647	-319.405	35.86263	-425.883
288	7829	2690	2654	2176	80	46.39132	-0.34716	-12.9288	-37.9261	35.733	-252.374		2174.009	-11.9907	7163.35	5.937715	-12.8683	-332.273	35.75481	-390.128
289	7867	2696	2658	2195	86	50.21741	-0.34415	-12.8211	-50.7472	35.77178	-216.602		2193.002	7.002432	7170.353	5.942666	-12.6911	-344.964	35.81809	-354.31
290	7905	2696	2657	2208	86	49.26088	-0.35248	-13.1188	-63.866	35.66368	-180.938		2205.996	19.99552	7190.348	5.956804	-12.1835	-357.148	35.99394	-318.316
291	7941	2693	2661	2216	83	53.08697	-0.30363	-10.7636	-74.6296	34.35323	-146.585	-146.585	2213.989	27.98861	7218.337	5.976594	-10.8652	-368.013	34.32125	-283.995
292	7981	2689	2667	2246	79	58.8261	-0.23261	-9.22058	-83.8502	38.92275	-107.662	-107.662	2243.982	57.9817	7276.318	6.017592	-10.4993	-378.512	38.59748	-245.398
293	8014	2678	2683	2234	68	74.13046	-0.04416	-1.45683	-85.307	32.96783	-74.6943		2231.975	45.97478	7322.293	6.0501	-7.62236	-386.135	32.10763	-213.29
294	8053	2680	2669	2251	70	60.73915	-0.15798	-6.13574	-91.4427	38.51432	-36.18		2248.968	62.96787	7385.261	6.094623	-7.31043	-393.445	38.30872	-174.881
295	8093	2681	2675	2255	71	66.47828	-0.12015	-4.79425	-96.237	39.71165	3.531668		2252.961	66.96096	7452.222	6.14197	-5.62987	-399.075	39.60183	-135.379
296	8135	2679	2677	2246	69	68.39132	-0.0917	-3.84587	-100.083	41.82355	45.35522		2243.954	57.95405	7510.176	6.182948	-4.20293	-403.278	41.78918	-93.5903
297	8178	2677	2679	2208	67	70.30437	-0.06321	-2.71601	-102.799	42.91414	88.26936		2205.947	19.94714	7530.123	6.197052	-3.69916	-406.977	42.84059	-50.7497
298	8221	2676	2683	2198	66	74.13046	-0.02931	-1.26018	-104.059	42.98153	131.2509		2195.94	9.940224	7540.063	6.20408	-3.39796	-410.375	42.86553	-7.88419
299	8263	2674	2680	2196	64	71.26089	-0.03364	-1.4125	-105.472	41.97624	173.2271		2193.933	7.933312	7547.997	6.20969	-3.08403	-413.459	41.88662	34.00243
300	8305	2675	2680	2201	65	71.26089	-0.04135	-1.73624	-107.208	41.9641	215.1912		2198.926	12.9264	7560.923	6.21883	-2.70106	-416.16	41.91306	75.91548
301	8345	2672	2682	2199	62	73.17393	-0.00479	-0.19162	-107.399	39.99954	255.1908		2196.919	10.91949	7571.843	6.226551	-2.26417	-418.424	39.93587	115.8514
302	8383	2670	2681	2200	60	72.21741	0.004876	0.185281	-107.214	37.99955	293.1903		2197.913	11.91258	7583.755	6.234974	-1.83132	-420.255	37.95585	153.8072
303	8417	2668	2680	2202	58	71.26089	0.014966	0.508825	-106.705	33.99619	327.1865		2199.906	13.90566	7597.661	6.244806	-1.30456	-421.56	33.97496	187.7822
304	8451	2672	2681	2222	62	72.21741	-0.01129	-0.38376	-107.089	33.99783	361.1843		2219.899	33.89875	7631.56	6.268775	-0.48992	-422.05	33.99647	221.7786
305	8487	2672	2675	2166	62	66.47828	-0.05242	-1.88641	-108.975	35.95054	397.1349		2163.892	-22.1082	7609.452	6.253143	-1.08135	-423.131	35.98378	257.7624
306	8527	2675	2674	2186	65	65.52176	-0.08327	-3.32691	-112.302	39.86141	436.9963		2183.885	-2.11507	7607.336	6.251648	-1.26129	-424.393	39.98011	297.7425
307	8569	2677	2678	2200	67	69.34785	-0.07005	-2.93964	-115.242	41.897	478.8933		2197.878	11.87802	7619.214	6.260046	-0.97175	-425.364	41.98876	339.7313
308	8613	2675	2676	2187	65	67.4348	-0.06888	-3.02848	-118.271	43.89565	522.7889		2184.871	-1.1289	7618.086	6.259248	-1.05313	-426.417	43.98739	383.7186
309	8659	2678	2677	2191	68	68.39132	-0.0844	-3.87767	-122.148	45.83627	568.6252		2188.864	2.864192	7620.95	6.261273	-1.00787	-427.425	45.98896	429.7076
310	8705	2680	2680	2192	70	71.26089	-0.07834	-3.59999	-125.748	45.85891	614.4841		2189.857	3.85728	7624.807	6.264001	-0.88243	-428.308	45.99154	475.6991
311	8751	2678	2681	2209	68	72.21741	-0.0572	-2.62967	-128.378	45.92477	660.4089		2206.85	20.85037	7645.657	6.278744	-0.20432	-428.512	45.99955	521.6987
312	8794	2678	2682	2208	68	73.17393	-0.05063	-2.17631	-130.554	42.94489	703.3538		2205.843	19.84346	7665.501	6.292775	0.41233	-428.1	42.99802	564.6967
313	8833	2680	2682	2199	70	73.17393	-0.0651	-2.53717	-133.091	38.91738	742.2712		2196.837	10.83654	7676.337	6.300437	0.672775	-427.427	38.9942	603.6909
314	8868	2681	2679	2184	71	70.30437	-0.09219	-3.22206	-136.313	34.85137	777.1225		2181.83	-4.17037	7672.167	6.297488	0.500579	-426.926	34.99642	638.6873
315	8899	2681	2680	2184	71	71.26089	-0.08543	-2.64519	-138.959	30.88694	808.0095		2181.823	-4.17728	7667.99	6.294534	0.351814	-426.575	30.998	669.6853
316	8925	2680	2680	2187	70	71.26089	-0.07834	-2.03478	-140.993	25.92026	833.9297		2184.816	-1.18419	7666.806	6.293697	0.2733	-426.301	25.99856	695.6839
317	8948	2683	2678	2189	73	69.34785	-0.11292	-2.59158	-143.585	22.85353	856.7833		2186.809	0.808896	7667.614	6.294269	0.25492	-426.046	22.99859	718.6825
318	8966	2685	2680	2201	75	71.26089	-0.11283	-2.02655	-145.611	17.88556	874.6688		2198.802	12.80198	7680.416	6.303321	0.362418	-425.684	17.99635	736.6788
319	8977	2683	2678	2209	73	69.34785	-0.11292	-1.23945	-146.851	10.92095	885.5988		2206.795	20.79507	7701.212	6.318025	0.383158	-425.301	10.99332	747.6722
320	8984	2678	2684	2292	68	75.08698	-0.03778	-0.26438	-147.115	6.995006	892.5938		2289.788	103.7882	7805	6.391411	0.758103	-424.545	6.959045	754.6312
321	8994	2668	2688	2324	58	77.00002	0.052558	0.525318	-146.59	9.986192	902.58		2321.781	135.7812	7940.781	6.487419	2.028169	-422.517	9.792167	764.4234
322	9008	2652	2694	2469	42	84.6522	0.237571	3.29479	-143.295	13.60678	916.1867		2466.774	280.7743	8221.555	6.685949	5.487468	-417.029	12.87074	777.3031
323	9025	2616	2697	2595	6	87.52176	0.629684	10.01113	-133.264	13.73963	929.9264		2592.767	406.7674	8628.323	6.973565	10.82611	-406.203	13.10707	790.4102
324	9048	2575	2687	2663	-35	77.95654	1.120127	18.90327	-114.361	9.146928	939.0733		2660.761	474.7605	9103.083	7.309258	17.96068	-388.242	10.88182	801.292
325	9072	2549	2662	2508	-61	54.04349	1.543925	25.99061	-88.3902	0.698575	939.7719		2505.754	319.7536	9422.837	7.535349	24.69128	-363.551	8.144982	809.437
326	9102	2541	2648	2257	-69	40.65219	1.736516	29.589	-58.8012	-4.94688	934.823		2254.747	68.74669	9491.583	7.583958	28.91204	-334.636	8.002624	817.4396
327	9137	2540	2646	2216	-70	38.73914	1.763466	34.35238	-24.4488	-6.70179	928.1212		2213.74	27.73978	9519.323	7.603572	33.90839	-300.73	8.67302	826.1126
328	9175	2540	2645	2194	-70	37.78262	1.773987	37.21825	12.76943	-7.68823	920.453		2191.733	5.732864	9525.056	7.607626	36.85269	-263.877	9.267113	835.3797
329	9216	2541	2646	2188	-69	38.73914	1.757347	40.28665	53.05807	-7.60427	912.8487		2185.726	-0.27405	9524.782	7.607432	39.76017	-224.117	10.00643	845.3862
330	9259	2541	2645	2191	-69	37.78262	1.767949	42.16701	95.22509	-8.42276	904.426		2188.719	2.71904	9527.501	7.609355	41.71979	-182.397	10.41436	855.8005
331	9306	2541	2646	2201	-69	38.73914	1.757347	46.18455	141.4096	-8.71709	895.7089		2198.712	12.71213	9540.213	7.616343	45.70118	-136.696	10.9728	866.7733
332	9354	2542	2646	2190	-68	38.73914	1.751091	47.22196	188.6316	-8.60734	887.1015		2187.705	1.705216	9541.918	7.619549	46.68702	-90.0088	11.14998	877.9233
333	9402	2542	2646	2180	-68	38.73914	1.751091	47.22196	235.8536	-8.60734	878.4942		2177.698	-8.3017	9533.617	7.613679	46.62077	-43.3881	11.42384	889.3472

334	9449	2543	2647	2188	-67	39.69566	1.734062	46.37498	282.2285	-7.63943	870.8548	2185.691	-0.30861	9533.308	7.613461	45.84706	2.258993	11.1958	900.543
335	9497	2544	2648	2194	-68	40.65219	1.716869	47.48882	329.7174	-6.98657	863.8682	2191.684	5.68448	9538.993	7.61748	46.66385	48.92285	11.24655	911.7895
336	9545	2544	2647	2190	-68	39.69566	1.727443	47.41228	377.1296	-7.48835	856.3799	2187.678	1.677568	9540.67	7.618666	46.67716	95.60001	11.19119	922.9807
337	9592	2544	2647	2188	-66	39.69566	1.727443	46.42453	423.5542	-7.33234	849.0475	2195.671	9.670656	9550.341	7.625504	45.77858	141.3786	10.64526	933.626
338	9640	2545	2648	2184	-65	40.65219	1.710028	47.5355	471.0897	-6.66155	842.386	2181.664	-4.33626	9546.005	7.622438	46.71904	188.0976	11.01505	944.641
339	9687	2544	2650	2177	-68	42.56523	1.696127	46.63135	517.721	-5.87512	836.5108	2174.657	-11.3432	9534.661	7.614418	45.65775	233.7554	11.15212	955.7931
340	9733	2541	2651	2188	-69	43.52175	1.706205	45.57893	563.3	-6.20976	830.3011	2185.65	-0.35008	9534.311	7.61417	44.68361	278.439	10.9259	966.719
341	9778	2541	2652	2191	-69	44.47827	1.696349	44.64579	607.9457	-5.63506	824.666	2188.643	2.643008	9536.954	7.616039	43.73212	322.1711	10.60667	977.3257
342	9819	2541	2653	2191	-69	45.4348	1.686618	40.72531	648.671	-4.73807	819.928	2188.636	2.636096	9539.59	7.617903	39.86277	362.0339	9.569575	986.9153
343	9855	2540	2653	2186	-70	45.4348	1.693208	35.73061	684.4017	-4.39582	815.5321	2183.629	-2.37062	9537.22	7.616226	34.98729	397.0212	8.478777	995.3941
344	9886	2543	2651	2188	-67	43.52175	1.692849	30.76938	715.171	-3.77425	811.7579	2185.622	-0.37773	9536.842	7.615959	30.12599	427.1472	7.309216	1002.703
345	9909	2543	2652	2191	-67	44.47827	1.682875	22.85569	738.0267	-2.57241	809.1855	2188.615	2.61536	9539.457	7.617809	22.36153	449.5087	5.381623	1008.085
346	9928	2540	2654	2222	-70	46.39132	1.683654	18.87913	756.9059	-2.13974	807.0457	2219.608	33.60845	9573.066	7.641572	18.57299	468.0817	4.005496	1012.09
347	9945	2535	2650	2329	-75	42.56523	1.752721	16.71945	773.6253	-3.07569	803.97	2326.602	140.6015	9713.667	7.740989	16.89159	484.9733	1.916795	1014.007
348	9963	2522	2635	2491	-88	28.2174	1.958634	16.66313	790.2884	-6.80737	797.1627	2488.595	302.5946	10016.26	7.954947	17.90833	502.8816	-1.81429	1012.193
349	9980	2511	2604	2606	-99	-1.43478	-3.99977	12.86304	803.1515	-11.115	786.0477	2603.588	417.5877	10433.85	8.250214	15.68287	518.5645	-6.56107	1005.632
350	10002	2518	2567	2595	-92	-36.8261	-3.63351	10.3909	813.5424	-19.3915	766.6563	2592.581	406.5808	10840.43	8.537699	17.05506	535.6195	-13.8969	991.7349
351	10027	2534	2537	2413	-76	-65.5218	-3.30276	4.011864	817.5542	-24.676	741.9803	2410.574	224.5739	11065	8.69649	16.63982	552.2594	-18.6579	973.077
352	10054	2543	2531	2216	-67	-71.2609	-3.19805	1.523569	819.0778	-26.957	715.0233	2213.567	27.56698	11092.57	8.715982	17.57485	569.8342	-20.4969	952.5801
353	10083	2545	2529	2202	-65	-73.1739	-3.16977	0.817068	819.8949	-28.9885	686.0348	2199.56	13.56006	11106.13	8.72557	18.66474	588.4989	-22.1952	930.3849
354	10112	2548	2526	2195	-62	-76.0435	-3.12748	-0.40938	819.4855	-28.9971	657.0377	2192.553	6.553152	11112.68	8.730204	18.5617	607.0606	-22.2815	908.1034
355	10142	2547	2527	2190	-63	-75.087	-3.14155	-0.00128	819.4842	-30	627.0377	2187.546	1.54624	11114.23	8.731297	19.17654	626.2372	-23.0708	885.0326
356	10172	2547	2528	2191	-63	-74.1305	-3.14787	0.188312	819.6725	-29.9994	597.0383	2188.539	2.539328	11116.77	8.733092	19.13509	645.3723	-23.1052	861.9275
357	10201	2546	2529	2203	-64	-73.1739	-3.16208	0.594105	820.2666	-28.9939	568.0444	2200.532	14.53242	11131.3	8.743368	18.26678	663.639	-22.5239	839.4036
358	10230	2546	2530	2195	-64	-72.2174	-3.16661	0.783304	821.0499	-28.9894	539.0549	2192.526	6.525504	11137.83	8.747982	18.16266	681.8017	-22.6079	816.7957
359	10258	2547	2528	2182	-63	-74.1305	-3.14787	0.175758	821.2257	-27.9994	511.0555	2179.519	-6.48141	11131.35	8.743399	17.63621	699.4379	-21.7477	795.0479
360	10286	2546	2529	2183	-64	-73.1739	-3.16208	0.573618	821.7993	-27.9941	483.0614	2180.512	-5.48832	11125.86	8.739518	17.72047	717.1584	-21.6791	773.3688
361	10313	2548	2529	2184	-62	-73.1739	-3.14638	0.129346	821.9287	-26.9997	456.0617	2181.505	-4.49523	11121.36	8.73634	17.15396	734.3123	-20.8505	752.5184
362	10339	2545	2529	2178	-65	-73.1739	-3.16977	0.732544	822.6612	-25.9897	430.072	2175.498	-10.5021	11110.86	8.728914	16.66727	750.9796	-19.955	732.5633
363	10365	2544	2530	2161	-66	-72.2174	-3.18391	1.099834	823.761	-25.9767	404.0953	2158.491	-27.5091	11083.35	8.709463	17.05223	768.0318	-19.6271	712.9363
364	10392	2541	2532	2185	-69	-70.3044	-3.2195	2.101262	825.8623	-26.9181	377.1772	2182.484	-3.51597	11079.84	8.706977	17.75871	785.7906	-20.3379	692.5984
365	10419	2540	2533	2218	-70	-69.3478	-3.23354	2.479058	828.3414	-26.8859	350.2912	2215.477	29.47712	11109.31	8.72782	17.33099	803.1215	-20.7035	671.8949
366	10446	2541	2533	2207	-69	-69.3478	-3.22634	2.285571	830.6269	-26.9031	323.3881	2204.47	18.47021	11127.78	8.740879	17.05913	820.1807	-20.9281	650.9668
367	10472	2541	2535	2210	-69	-67.4348	-3.24033	2.563021	833.19	-25.8734	297.5148	2207.463	21.4633	11149.25	8.756056	16.11958	836.3002	-20.4	630.5668
368	10496	2545	2533	2253	-65	-69.3478	-3.19651	1.317301	834.5073	-23.9638	273.5509	2250.456	64.45638	11213.7	8.801631	14.00624	850.3065	-19.4891	611.0777
369	10519	2550	2526	2317	-60	-76.0435	-3.11147	-0.69267	833.8146	-22.9896	250.5614	2314.449	128.4495	11342.15	8.892455	11.67333	861.9798	-19.8175	591.2602
370	10542	2558	2521	2368	-52	-80.8261	-3.01515	-2.9004	830.9142	-22.8164	227.745	2365.443	179.4426	11521.59	9.019335	9.07179	871.0516	-21.1353	570.1248
371	10563	2574	2515	2438	-36	-86.5652	-2.83757	-6.28649	824.6277	-20.037	207.708	2435.436	249.4356	11771.03	9.195706	4.768555	875.8202	-20.4514	549.6734
372	10585	2598	2514	2526	-12	-87.5218	-2.57972	-11.721	812.9067	-16.6177	189.0903	2523.429	337.4287	12108.46	9.434294	-0.20936	875.6108	-21.999	527.6744
373	10608	2631	2521	2536	21	-80.8261	-2.18926	-18.7397	794.1671	-13.3351	175.7552	2533.422	347.4218	12455.88	9.679949	-5.80545	869.8054	-22.2553	505.4191
374	10632	2658	2531	2411	48	-71.2609	-1.85069	-23.0661	771.101	-6.63	169.1252	2408.415	222.4149	12678.3	9.837214	-9.62021	860.1651	-21.9875	483.4316
375	10657	2671	2538	2270	61	-64.5652	-1.68645	-24.833	746.268	-2.88487	166.2403	2267.408	81.408	12759.7	9.894775	-11.3221	848.863	-22.2892	461.1424
376	10683	2676	2541	2214	66	-61.6957	-1.62437	-25.8627	720.3053	-1.39219	164.8481	2211.401	25.40109	12785.11	9.912736	-12.1894	836.6736	-22.9656	438.1768
377	10709	2677	2542	2208	67	-60.7391	-1.60909	-25.9809	694.3244	-0.99537	163.8528	2205.394	19.39418	12804.5	9.926449	-12.5032	824.1705	-22.7963	415.3805
378	10735	2687	2542	2231	77	-60.7391	-1.54055	-25.9881	668.3363	0.786251	164.639	2228.387	42.38726	12846.89	9.95642	-13.1807	810.9898	-22.4114	392.9691
379	10760	2675	2534	2242	65	-68.3913	-1.68346	-24.8414	643.4948	-2.81116	161.8278	2239.38	53.38035	12900.27	9.994164	-13.4779	797.5119	-21.0558	371.9133
380	10784	2682	2548	2213	72	-55	-1.525	-23.9748	619.52	1.098832	162.9267	2210.373	24.37344	12924.64	10.0114	-13.2852	784.2267	-19.9876	351.9257
381	10808	2681	2548	2173	71	-55	-1.53175	-23.9817	595.5383	0.936759	163.8634	2170.367	-15.6335	12909.01	10.00034	-13.0634	771.1633	-20.1332	331.7925
382	10831	2681	2540	2113	71	-62.6522	-1.59568	-22.9929	572.5454	-0.57237	163.2911	2110.36	-75.6404	12833.37	9.946861	-11.4698	759.6935	-19.936	311.8565
383	10854	2669	2532	2055	59	-70.3044	-1.74527	-22.6508	549.8946	-3.99247	159.2986	2052.353	-133.647	12699.72	9.852361	-9.53748	750.156	-20.9293	290.9272
384	10877	2657	2524	2035	47	-77.9565	-1.90091	-21.7581	528.1364	-7.4555	151.8431	2032.346	-153.654	12546.06	9.743716	-7.21184	742.9442	-21.8401	269.0871
385	10898	2643	2516	2057	33	-85.6087	-2.07554	-18.3813	509.7552	-10.1552	141.6879	2054.339	-131.661	12414.4	9.650621	-4.70249	738.2417	-20.4667	248.6204
386	10919	2632	2512	2123	22	-89.4348	-2.20226	-16.9504	492.8047	-12.3969	129.291	2120.332	-65.668	12348.74	9.604189	-3.74745	734.4942	-20.6629	227.9575
387	10940	2628	2511	2143	18	-90.3913	-2.2469	-16.3804	476.4243	-13.1409	116.1501	2140.325	-45.6749	12303.06	9.571893	-3.07828	731.4159	-20.7732	207.1843
388	10959	2622	2512	2106	12	-89.4348	-2.31008	-14.0401	462.3843	-12.8014	103.3487	2103.318	-82.6819	12220.38	9.51343	-1.68219	729.7337	-18.9254	188.2589
389	10979	2609	2511	2058	-1	-90.3913	-2.45452	-12.6855	449.6988	-15.4622	87.8865	2055.311	-130.689	12089.69	9.421023	0.075096	729.8088	-19.9999	168.2591
390	10998	2592	2511	2004	-18	-90.3913	-2.64002	-9.13523	440.5636	-16.6598	71.22674	2001.304	-184.696	11904.99	9.290429	2.544961	732.3538	-18.8288	149.4303
391	11016	2573	2514	1986	-37	-87.5218	-2.84343	-5.28783	435.2757	-17.2058	54.02096	1983.297	-202.703	11702.29	9.147102	4.934181	737.288	-17.3105	132.1198
392	11035	2558	2520	2049	-52	-81.7826	-3.00981	-2.4966	432.7791	-18.8353	35.1857	2046.29	-139.71	11562.58	9.048317	6.985006	744.273	-17.6695	114.4503
393	11053	2552	2524	2166	-58	-77.9565	-3.08311	-1.05202	431.7271	-17.9692	17.21647	2163.284	-22.7164	11539.87	9.032254	6.885383	751.1584	-16.631	97.81927
394	11071	2553	2521	2235	-57	-80.8261	-3.05768	-1.50865	430.2185	-17.9367	-0.72019	2232.277	46.27667	11586.14	9.064976	6.337606	757.496	-16.8474	80.97188
395	11088	2554	2514	2311	-56	-87.5218	-3.01266	-2.18577	428.0327	-16.8589	-17.5791	2308.27	122.2698	11708.41	9.15143	4.589264	762.0852	-16.3688	64.60304
396	11104	2558	2513	2380	-52	-88.4783	-2.9748	-2.65635	425.3764	-15.778	-33.357	2377.263	191.2628	11889.68	9.286668	2.202745	764.288	-15.8476	48.7554
397	11120	2578	2514	2433	-32	-87.5218	-2.79399	-5.45038	419.928	-15.043	-48.4001	2430.256	244.2559	12143.93	9.459376	-0.55346	763.7345	-15.9904	32.76497
398	11135	2606	2510	2468	-4	-91.3479	-2.48722	-9.1299	410.7961	-11.9015	-60.3016	2465.249	279.249	12423.18	9.656827	-3.44958	760.285	-14.598	18.16701
399	11149	2635	2513	2469	25	-88.4783	-2.16808	-11.5761	399.22	-7.87363	-68.1752	2466.242	280.2421	12703.42	9.85498	-5.83876	754.4462	-12.7243	5.442671
400	11165	2658	2522	2442	48	-79.8696	-1.90232	-15.1288	384.0912	-5.20777	-73.383	2439.235	253.2352	12956.66	10.03404	-9.15616	745.29	-13.1212	-7.67848

401	11184	2677	2535	2332	67	-67.4348	-1.6613	-18.9222	365.169	-1.71717	-75.1001	2320.228	143.2283	13099.89	10.13531	-12.3925	732.8975	-14.4023	-22.0808
402	11206	2680	2542	2233	70	-60.7391	-1.58735	-21.997	343.172	-0.36408	-75.4642	2230.221	44.22138	13144.11	10.16658	-14.8636	718.034	-16.2196	-38.3003
403	11229	2681	2543	2234	71	-59.7826	-1.5725	-23	320.172	-0.03921	-75.5034	2231.214	45.21446	13189.32	10.19855	-16.0733	701.9607	-16.4515	-54.7518
404	11255	2684	2547	2215	74	-55.9565	-1.5201	-25.9666	294.2054	1.317475	-74.1859	2212.208	26.20755	13215.53	10.21708	-18.5113	683.4494	-18.2574	-73.0092
405	11282	2678	2553	2192	68	-50.2174	-1.50876	-26.9481	267.2574	1.673924	-72.512	2189.201	3.20064	13218.73	10.21934	-19.2661	664.1833	-18.9161	-91.9253
406	11310	2677	2536	2192	67	-66.4783	-1.65415	-27.9028	239.3546	-2.33132	-74.8433	2189.194	3.193728	13221.92	10.2216	-20.0239	644.1595	-19.5715	-111.497
407	11337	2693	2543	2196	83	-59.7826	-1.49687	-26.9262	212.4283	1.994269	-72.8491	2193.187	7.186816	13229.11	10.22668	-19.4044	624.755	-18.7742	-130.271
408	11364	2689	2546	2196	79	-56.9131	-1.49696	-26.9264	185.5019	1.991683	-70.6574	2193.18	7.179904	13236.29	10.23176	-19.4995	605.2556	-18.6754	-148.946
409	11391	2685	2546	2198	75	-56.9131	-1.5218	-26.9676	158.5343	1.322375	-69.535	2195.173	9.172992	13245.46	10.23825	-19.6202	585.6354	-18.5485	-167.495
410	11417	2685	2546	2200	75	-56.9131	-1.5218	-25.9688	132.5655	1.273398	-68.2616	2197.166	11.16608	13256.63	10.24614	-19.0339	566.6015	-17.7118	-185.207
411	11443	2685	2545	2197	75	-57.8696	-1.52984	-25.9782	106.5873	1.064475	-67.1971	2194.159	8.159168	13264.79	10.25191	-19.1358	547.4656	-17.6017	-202.808
412	11465	2684	2548	2194	74	-55	-1.51183	-21.9618	84.62554	1.296563	-65.9006	2191.152	5.152256	13269.94	10.25555	-16.246	531.2196	-14.6347	-217.643
413	11483	2685	2547	2201	75	-55.9565	-1.51366	-17.9706	66.65492	1.027952	-64.8726	2198.145	12.14534	13282.09	10.26414	-13.3959	517.8237	-12.0229	-229.666
414	11496	2680	2550	2195	70	-53.087	-1.52151	-12.9842	53.6707	0.640453	-64.2322	2192.138	6.138432	13288.22	10.26848	-9.71242	508.1113	-8.64111	-238.307
415	11504	2676	2547	2190	66	-55.9565	-1.5759	-7.9999	45.67081	-0.04079	-64.273	2187.132	1.13152	13289.36	10.26928	-5.98113	502.1302	-5.31282	-243.62
416	11509	2675	2547	2194	65	-55.9565	-1.58344	-4.9996	40.67121	-0.06319	-64.3361	2191.125	5.124608	13294.48	10.2729	-3.75021	498.38	-3.30695	-246.927
417	11513	2675	2548	2192	65	-55	-1.57492	-3.99997	36.67124	-0.0165	-64.3527	2189.118	3.117696	13297.6	10.27511	-3.006	495.374	-2.63894	-249.566
418	11515	2675	2549	2194	65	-54.0435	-1.56628	-1.99998	34.67126	0.009026	-64.3436	2191.111	5.110784	13302.71	10.27872	-1.50776	493.8662	-1.31403	-250.88
419	11515	2675	2549	2195	65	-54.0435	-1.56628	0	34.67126	0	-64.3436	2192.104	6.103872	13308.81	10.28304	0	493.8662	0	-250.88
420	11515	2675	2549	2193	65	-54.0435	-1.56628	0	34.67126	0	-64.3436	2190.097	4.09696	13312.91	10.28594	0	493.8662	0	-250.88
421	11515	2675	2549	2191	65	-54.0435	-1.56628	0	34.67126	0	-64.3436	2188.09	2.090048	13315	10.28741	0	493.8662	0	-250.88
422	11515	2675	2549	2191	65	-54.0435	-1.56628	0	34.67126	0	-64.3436	2188.083	2.083136	13317.08	10.28889	0	493.8662	0	-250.88
423	11515	2675	2549	2191	65	-54.0435	-1.56628	0	34.67126	0	-64.3436	2188.076	2.076224	13319.16	10.29035	0	493.8662	0	-250.88
424	11515	2675	2549	2191	65	-54.0435	-1.56628	0	34.67126	0	-64.3436	2188.069	2.069312	13321.23	10.29182	0	493.8662	0	-250.88
425	11515	2675	2549	2190	65	-54.0435	-1.56628	0	34.67126	0	-64.3436	2187.062	1.0624	13322.29	10.29257	0	493.8662	0	-250.88
426	11515	2675	2549	2191	65	-54.0435	-1.56628	0	34.67126	0	-64.3436	2188.055	2.055488	13324.35	10.29402	0	493.8662	0	-250.88
427	11515	2675	2549	2190	65	-54.0435	-1.56628	0	34.67126	0	-64.3436	2187.049	1.048576	13325.4	10.29476	0	493.8662	0	-250.88
428	11515	2675	2549	2190	65	-54.0435	-1.56628	0	34.67126	0	-64.3436	2187.042	1.041664	13326.44	10.2955	0	493.8662	0	-250.88
429	11515	2675	2549	2189	65	-54.0435	-1.56628	0	34.67126	0	-64.3436	2186.035	0.034752	13326.47	10.29552	0	493.8662	0	-250.88
430	11515	2675	2549	2188	65	-54.0435	-1.56628	0	34.67126	0	-64.3436	2185.028	-0.97216	13325.5	10.29484	0	493.8662	0	-250.88
431	11515	2675	2549	2189	65	-54.0435	-1.56628	0	34.67126	0	-64.3436	2186.021	0.020928	13325.52	10.29485	0	493.8662	0	-250.88
432	11515	2675	2549	2190	65	-54.0435	-1.56628	0	34.67126	0	-64.3436	2187.014	1.014016	13326.53	10.29557	0	493.8662	0	-250.88
433	11515	2675	2549	2190	65	-54.0435	-1.56628	0	34.67126	0	-64.3436	2187.007	1.007104	13327.54	10.29628	0	493.8662	0	-250.88
434	11515	2675	2548	2189	65	-55	-1.57492	0	34.67126	0	-64.3436	2186	0.000192	13327.54	10.29628	0	493.8662	0	-250.88
435	11515	2676	2548	2189	66	-55	-1.5674	0	34.67126	0	-64.3436	2185.993	-0.00672	13327.54	10.29628	0	493.8662	0	-250.88
436	11515	2675	2548	2189	65	-55	-1.57492	0	34.67126	0	-64.3436	2185.986	-0.01363	13327.52	10.29627	0	493.8662	0	-250.88
437	11515	2675	2548	2189	65	-55	-1.57492	0	34.67126	0	-64.3436	2185.979	-0.02054	13327.5	10.29625	0	493.8662	0	-250.88
438	11515	2675	2548	2189	65	-55	-1.57492	0	34.67126	0	-64.3436	2185.973	-0.02748	13327.47	10.29623	0	493.8662	0	-250.88
439	11515	2675	2548	2187	65	-55	-1.57492	0	34.67126	0	-64.3436	2183.966	-2.03437	13325.44	10.29479	0	493.8662	0	-250.88
440	11515	2675	2548	2187	65	-55	-1.57492	0	34.67126	0	-64.3436	2183.959	-2.04128	13323.4	10.29335	0	493.8662	0	-250.88
441	11515	2675	2548	2189	65	-55	-1.57492	0	34.67126	0	-64.3436	2185.952	-0.04819	13323.35	10.29332	0	493.8662	0	-250.88
442	11515	2675	2548	2189	65	-55	-1.57492	0	34.67126	0	-64.3436	2185.945	-0.0551	13323.29	10.29328	0	493.8662	0	-250.88
443	11515	2675	2548	2189	65	-55	-1.57492	0	34.67126	0	-64.3436	2185.938	-0.06202	13323.23	10.29323	0	493.8662	0	-250.88
444	11515	2675	2548	2189	65	-55	-1.57492	0	34.67126	0	-64.3436	2185.931	-0.06893	13323.16	10.29319	0	493.8662	0	-250.88

G.2 GPS

5-CH GPS	TIME	LAT	LONG	-LONG	1-CH GPS	TIME	LAT	LONG	-LONG
	211128	3833.32	12126.15	-12126.2		211155	3833.33	12126.14	-12126.1
	211129	3833.32	12126.15	-12126.2		211156	3833.33	12126.14	-12126.1
	211130	3833.32	12126.15	-12126.2		211156	3833.33	12126.14	-12126.1
	211130	3833.32	12126.15	-12126.2		211158	3833.33	12126.14	-12126.1
	211130	3833.32	12126.15	-12126.2		211159	3833.33	12126.14	-12126.1
	211133	3833.32	12126.15	-12126.2		211200	3833.33	12126.14	-12126.1
	211134	3833.32	12126.15	-12126.2		211200	3833.32	12126.14	-12126.1
	211135	3833.32	12126.15	-12126.2		211202	3833.32	12126.14	-12126.1
	211136	3833.32	12126.15	-12126.2		211203	3833.32	12126.14	-12126.1
	211137	3833.32	12126.15	-12126.2		211204	3833.32	12126.14	-12126.1
	211138	3833.32	12126.15	-12126.2		211205	3833.32	12126.15	-12126.2
	211139	3833.32	12126.15	-12126.2		211207	3833.32	12126.15	-12126.2
	211140	3833.32	12126.15	-12126.2		211208	3833.32	12126.15	-12126.2
	211141	3833.32	12126.15	-12126.2		211209	3833.32	12126.15	-12126.2
	211141	3833.32	12126.15	-12126.2		211210	3833.32	12126.14	-12126.1
	211141	3833.32	12126.15	-12126.2		211211	3833.32	12126.14	-12126.1
	211142	3833.32	12126.15	-12126.2		211212	3833.32	12126.14	-12126.1
	211144	3833.32	12126.15	-12126.2		211213	3833.32	12126.14	-12126.1
	211145	3833.32	12126.15	-12126.2		211213	3833.32	12126.14	-12126.1
	211146	3833.32	12126.15	-12126.2		211214	3833.34	12126.15	-12126.2
	211147	3833.32	12126.15	-12126.2		211216	3833.34	12126.15	-12126.2
	211148	3833.32	12126.15	-12126.2		211217	3833.34	12126.14	-12126.1
	211149	3833.32	12126.15	-12126.2		211218	3833.34	12126.14	-12126.1
	211150	3833.32	12126.15	-12126.2		211218	3833.34	12126.14	-12126.1
	211151	3833.32	12126.15	-12126.2		211220	3833.32	12126.13	-12126.1
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	211155	3833.32	12126.15	-12126.2		211224	3833.32	12126.12	-12126.1
	211156	3833.32	12126.15	-12126.2		211225	3833.31	12126.1	-12126.1
	211157	3833.32	12126.15	-12126.2		211226	3833.31	12126.1	-12126.1
	211158	3833.32	12126.15	-12126.2		211228	3833.31	12126.09	-12126.1
	211159	3833.32	12126.15	-12126.2		211228	3833.31	12126.09	-12126.1
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211645	3833.42	12126.1	-12126.1
211646	3833.43	12126.1	-12126.1
211648	3833.43	12126.09	-12126.1
211648	3833.43	12126.09	-12126.1
211649	3833.44	12126.12	-12126.1
211650	3833.44	12126.12	-12126.1
211651	3833.44	12126.11	-12126.1
211653	3833.44	12126.11	-12126.1
211653	3833.44	12126.11	-12126.1
211654	3833.44	12126.11	-12126.1
211655	3833.44	12126.1	-12126.1
211657	3833.44	12126.09	-12126.1
211658	3833.43	12126.09	-12126.1
211658	3833.43	12126.09	-12126.1
211659	3833.44	12126.08	-12126.1
211700	3833.43	12126.08	-12126.1
211702	3833.43	12126.06	-12126.1
211703	3833.43	12126.05	-12126.1
211703	3833.43	12126.05	-12126.1
211704	3833.42	12126.03	-12126
211705	3833.41	12126.02	-12126
211707	3833.41	12126.01	-12126
211708	3833.4	12126	-12126
211708	3833.4	12126	-12126
211709	3833.4	12126	-12126
211710	3833.4	12125.99	-12126
211712	3833.39	12125.98	-12126
211713	3833.39	12125.98	-12126
211713	3833.39	12125.98	-12126
211714	3833.39	12125.96	-12126
211715	3833.39	12125.95	-12126
211717	3833.38	12125.95	-12126
211718	3833.38	12125.95	-12126
211718	3833.38	12125.95	-12126
211719	3833.38	12125.94	-12125.9
211720	3833.38	12125.94	-12125.9
211721	3833.37	12125.95	-12126
211723	3833.37	12125.95	-12126
211723	3833.37	12125.95	-12126
211724	3833.37	12125.97	-12126
211725	3833.36	12125.97	-12126
211727	3833.36	12125.97	-12126
211728	3833.35	12125.97	-12126
211728	3833.35	12125.97	-12126
211729	3833.34	12125.96	-12126
211730	3833.34	12125.96	-12126
211732	3833.33	12125.96	-12126
211733	3833.33	12125.96	-12126

211702	3833.41	12126.05	-12126.1
211702	3833.41	12126.05	-12126.1
211703	3833.41	12126.04	-12126
211704	3833.41	12126.04	-12126
211705	3833.41	12126.03	-12126
211706	3833.4	12126.02	-12126
211707	3833.4	12126.01	-12126
211708	3833.4	12126	-12126
211709	3833.4	12126	-12126
211711	3833.39	12125.98	-12126
211711	3833.39	12125.98	-12126
211713	3833.39	12125.97	-12126
211713	3833.39	12125.97	-12126
211715	3833.38	12125.95	-12126
211715	3833.38	12125.95	-12126
211716	3833.38	12125.95	-12126
211717	3833.37	12125.94	-12125.9
211718	3833.37	12125.93	-12125.9
211719	3833.37	12125.92	-12125.9
211720	3833.37	12125.92	-12125.9
211722	3833.36	12125.97	-12126
211723	3833.36	12125.96	-12126
211723	3833.36	12125.96	-12126
211724	3833.36	12125.95	-12126
211725	3833.35	12125.95	-12126
211725	3833.35	12125.95	-12126
211728	3833.33	12125.98	-12126
211729	3833.33	12125.98	-12126
211730	3833.32	12125.98	-12126
211731	3833.32	12125.99	-12126
211732	3833.32	12125.99	-12126
211733	3833.31	12125.99	-12126
211734	3833.31	12125.99	-12126
211734	3833.31	12125.99	-12126
211734	3833.31	12125.99	-12126
211737	3833.3	12126	-12126
211738	3833.3	12126	-12126
211739	3833.3	12126	-12126
211740	3833.3	12126.01	-12126
211741	3833.3	12126.01	-12126
211742	3833.3	12126.01	-12126
211743	3833.3	12126.02	-12126
211744	3833.3	12126.02	-12126
211744	3833.3	12126.02	-12126
211745	3833.31	12126.03	-12126
211745	3833.31	12126.03	-12126
211746	3833.31	12126.04	-12126
211748	3833.32	12126.05	-12126.1
211749	3833.32	12126.05	-12126.1
211750	3833.32	12126.05	-12126.1
211751	3833.32	12126.06	-12126.1
211752	3833.32	12126.06	-12126.1
211753	3833.31	12126.07	-12126.1
211754	3833.31	12126.07	-12126.1
211755	3833.31	12126.07	-12126.1
211755	3833.31	12126.07	-12126.1
211756	3833.31	12126.08	-12126.1
211758	3833.31	12126.08	-12126.1
211800	3833.3	12126.09	-12126.1
211801	3833.3	12126.09	-12126.1
211802	3833.3	12126.09	-12126.1
211802	3833.3	12126.09	-12126.1
211804	3833.3	12126.09	-12126.1
211804	3833.3	12126.09	-12126.1
211805	3833.3	12126.09	-12126.1
211806	3833.3	12126.09	-12126.1
211807	3833.3	12126.1	-12126.1

211734	3833.32	12125.97	-12126
211736	3833.31	12125.97	-12126
211736	3833.31	12125.97	-12126
211737	3833.31	12125.98	-12126
211738	3833.3	12125.98	-12126
211739	3833.3	12125.99	-12126
211741	3833.3	12125.99	-12126
211741	3833.3	12125.99	-12126
211742	3833.3	12126	-12126
211743	3833.3	12126	-12126
211744	3833.31	12126.01	-12126
211746	3833.32	12126.01	-12126
211746	3833.32	12126.01	-12126
211747	3833.32	12126.02	-12126
211748	3833.32	12126.02	-12126
211749	3833.33	12126.03	-12126
211751	3833.33	12126.04	-12126
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
(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

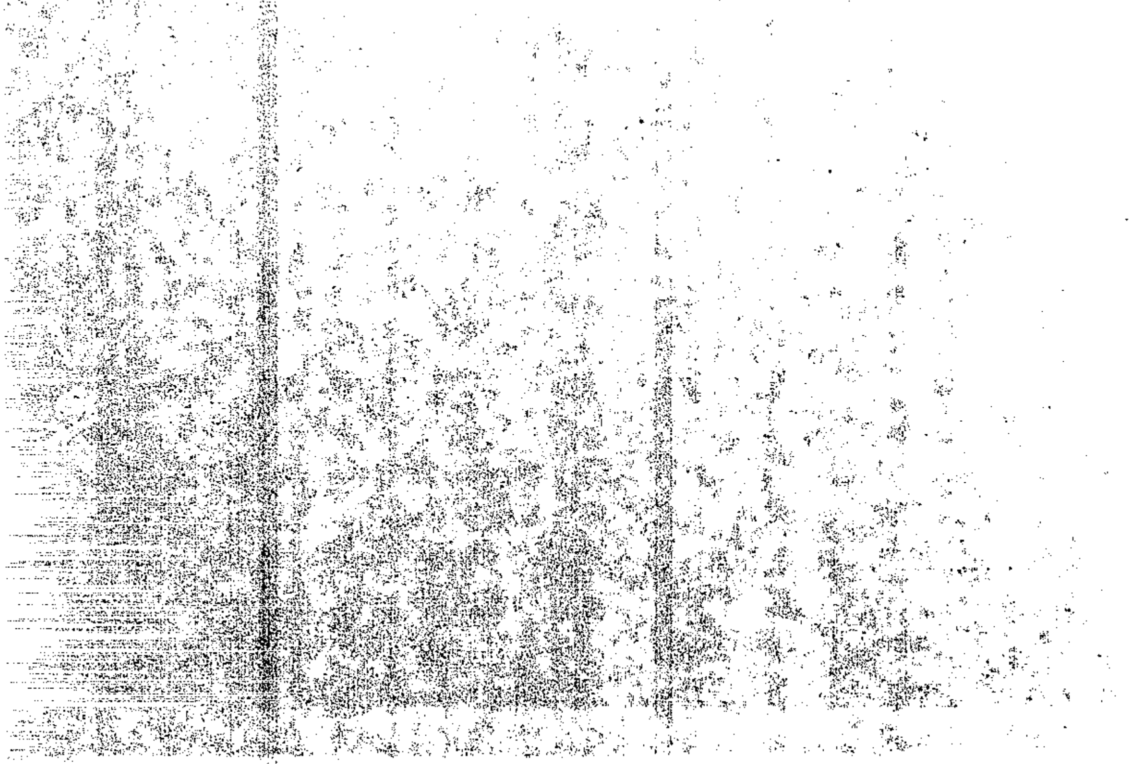
Date: 6-12-92
Start time: 13:30:28
Loop: 20
Frequency: 29485.5
Odometer: 169163
Loop detected at elapsed time 0:33:11.669

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



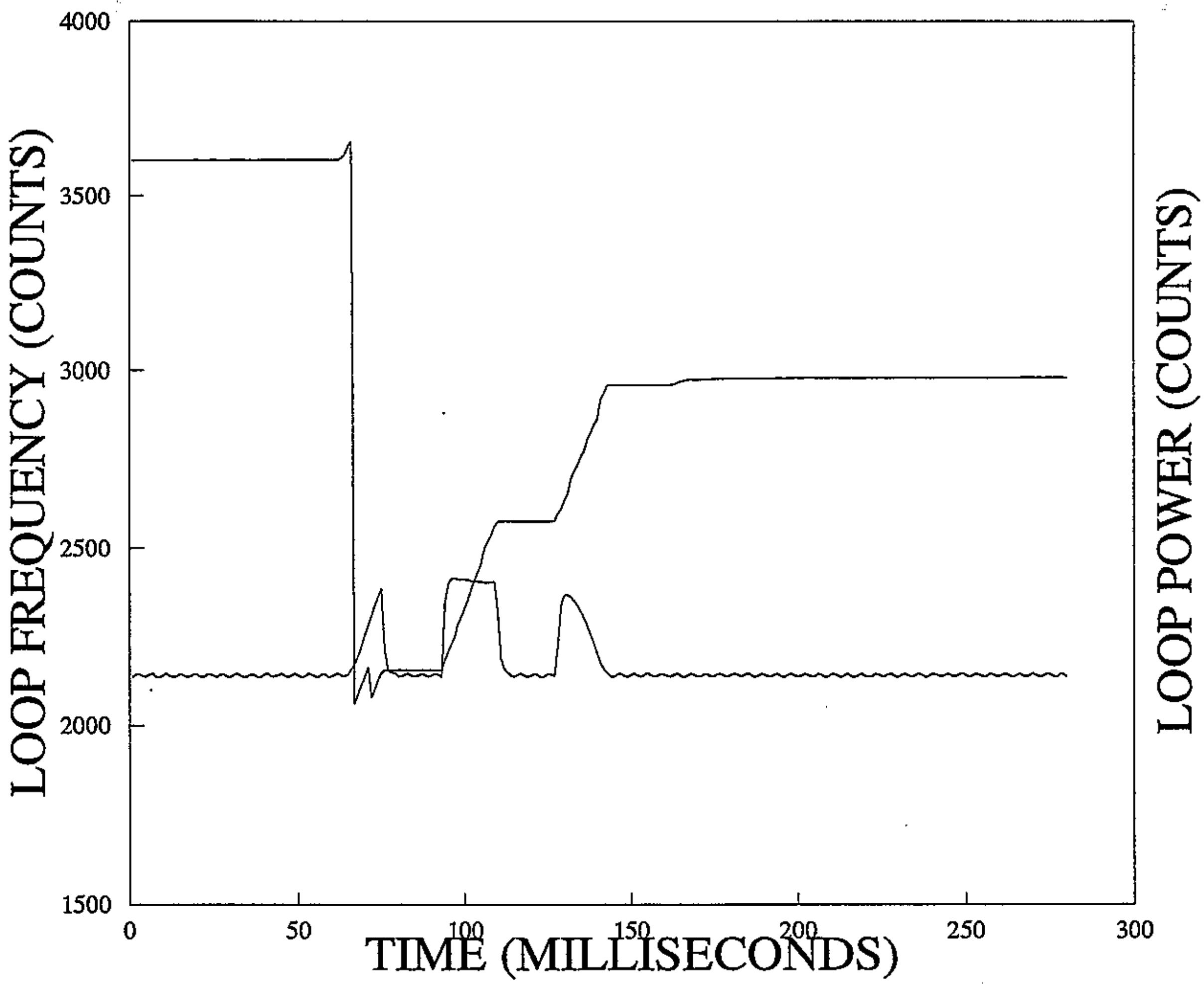


Figure H1 Inductive Loop 6
Route 3 June 12, 1992

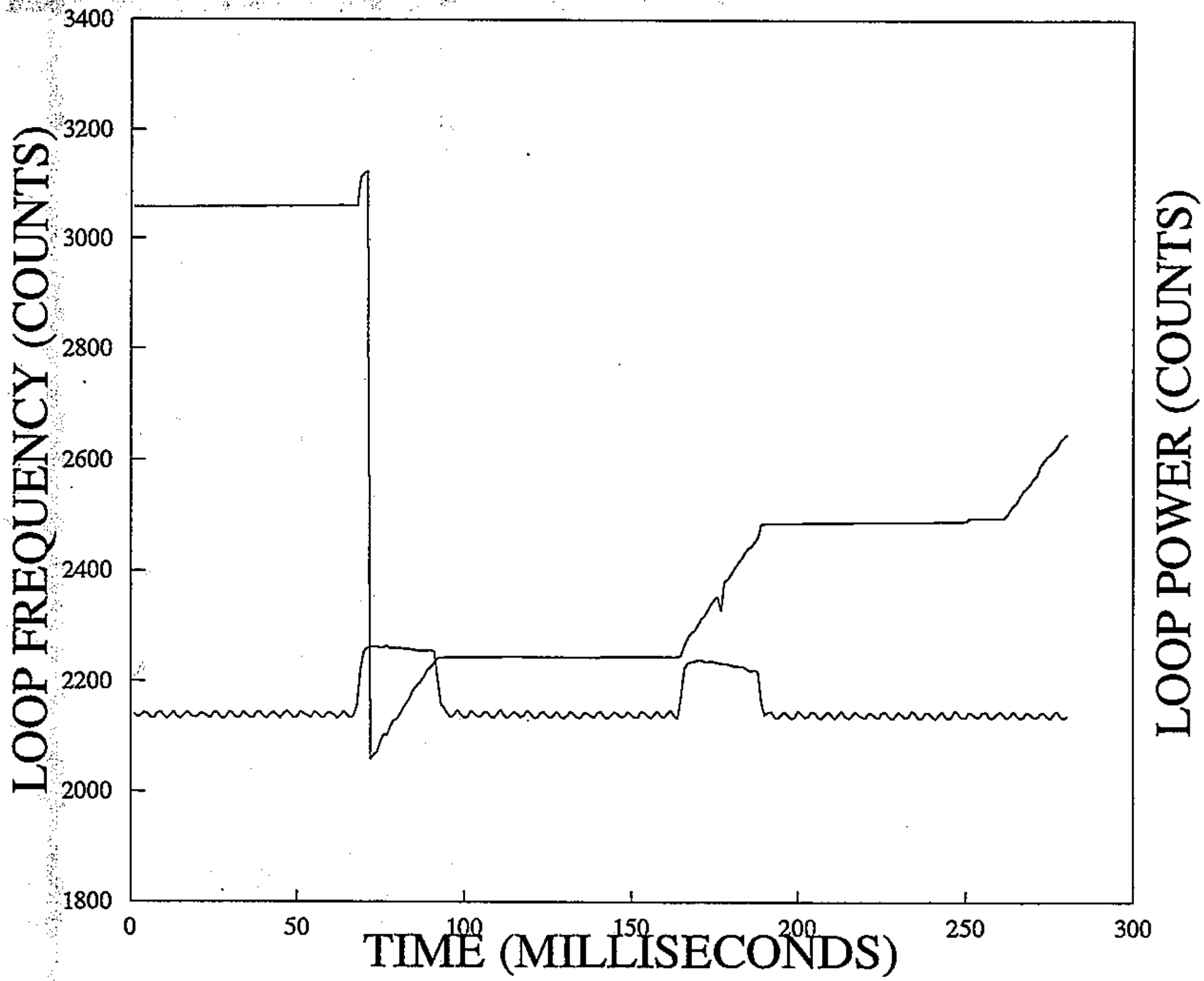


Figure H2 Inductive Loop 7
Route 3 June 12, 1992

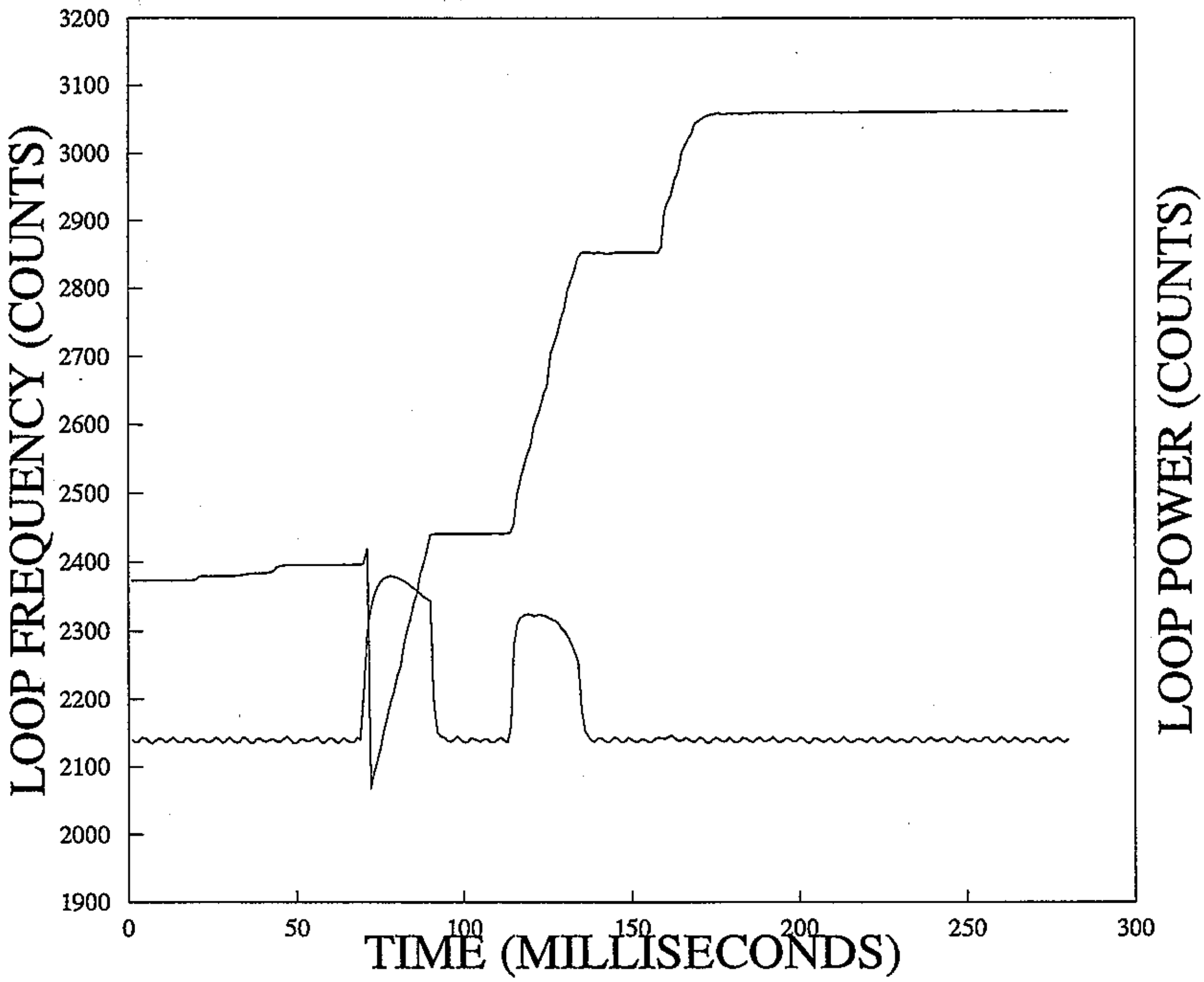


Figure H3 Inductive Loop 13
Route 3 June 12, 1992

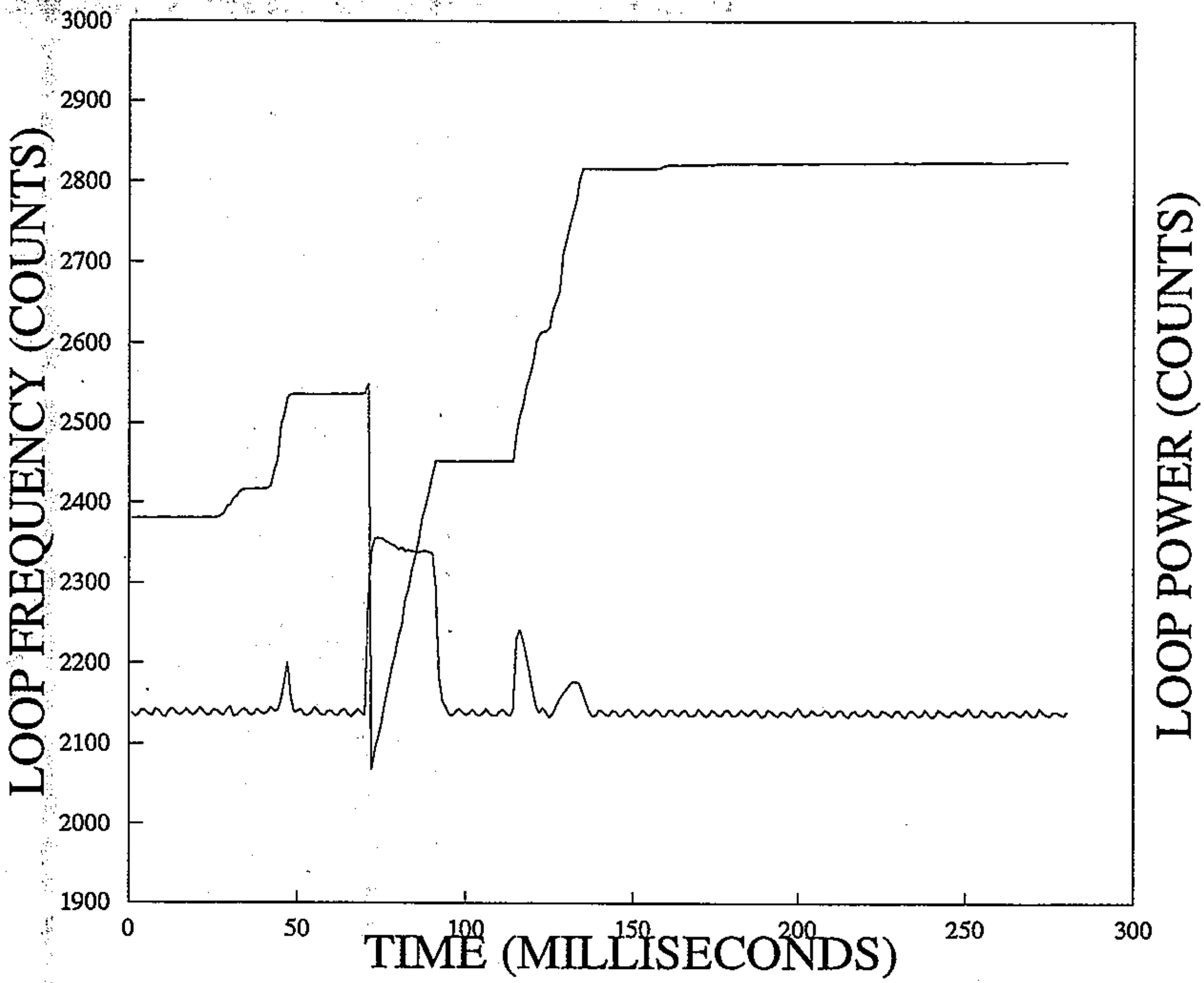


Figure H4 Inductive Loop 15
Route 3 June 12, 1992

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 $Y = A + (B/X)$

$Y = -14.7266 + 4097819 / X$

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