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# Field Testing of a Pulse Trilateration Automatic Vehicle Monitoring System in Philadelphia. Volume II Test Results and Data

Hazeltine Corp., Greenlawn, NY

Prepared for

**Urban Mass Transportation Administration, Washington, DC**

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**16. Abstract**

This report describes the Pulse Trilateration Automatic Vehicle Monitoring (AVM) system developed by Hazeltine Corporation, and presents results of the Phase I test program in Philadelphia. This study is part of the U.S. Department of Transportation's multi-phase program to develop advanced AVM for multi-user applications. Volume II presents the Philadelphia Phase I test results and data. It describes the Hazeltine AVM system and the test configuration in detail, explains the data analysis and reduction techniques used, and proposes changes which would be made in the system prior to Phase II. During Phase I, Hazeltine implemented the key elements of its trilateration location technique in Philadelphia, collected and analyzed performance data, and documented the results in this report. The Hazeltine system determines the position of mobile units by measuring the arrival times of the leading edges of vehicle pulse transmissions at a limited number of fixed receiver sites. Differences in time-of-arrival of the transmissions are used by a central processor to compute the coordinates of the mobile units. Fixed signpost transmitters are used to improve time of passage accuracy at slow vehicle speed locations. The system covers fixed route, random route, and special-case situations in both low and high regions, and provides time-of-departure data for fixed route bus/transit applications. Data acquisition is automatic, with the basic data recorded on magnetic tape. Evaluation of the system's performance is provided by off-line simulation, which reflects the conditions and processing procedures proposed for the Phase II AVM tests in Los Angeles. A related report is: Experiments on Four Different Techniques for Automatically Locating Land Vehicles - A Summary of Results (PB 270-951), and is available from the National Technical Information Service.

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# FIELD TESTING OF A PULSE TRILATERATION AUTOMATIC VEHICLE MONITORING SYSTEM IN PHILADELPHIA

## Volume II: Test Results and Data

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AUGUST 1978

FINAL REPORT

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
URBAN MASS TRANSPORTATION ADMINISTRATION
Office of Technology Development and Deployment
Washington DC 20590

# PREFACE

The work reported herein was performed for the Department of Transportation, Transportation Systems Center (DOT/TSC) in support of the Urban Mass Transportation Administration's (UMTA) research and development efforts in Automatic Vehicle Monitoring (AVM), aimed at the development and testing of advanced location technologies suitable for multi-user vehicle systems.

Government representatives responsible for the overall management of the program and for directing the contractual work include Mr. D. Symes of DOT/UMTA and Messrs. B.E. Blood and B.W. Kliem of DOT/TSC.

Hazeltine personnel contributing to the program included: Messrs. A.R. Abraham, J.B. Cohen, W.L. Corrigan, F.R. Dayton, G.N. Kerness, P. Nikolados, J.F. O'Connor, A.H. Riccio, W.C. Rogoza, L.E. Smith, and S.M. Weinstein.

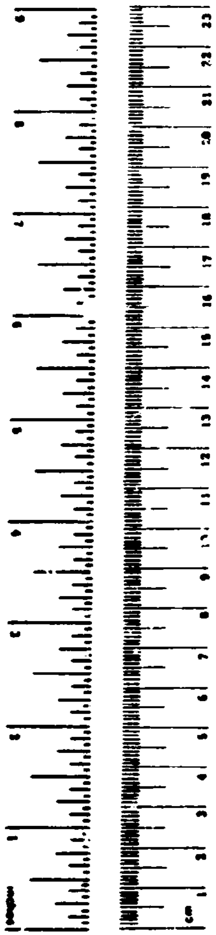
# NOTE

During the winter of 1976-77, four different techniques for automatically locating land vehicles were tested in both the low- and high-rise regions in Philadelphia, PA. The tests were carried out by four different companies under separate contracts to the U.S. Department of Transportation, Transportation Systems Center. The tests were designed to evaluate the techniques for their applicability as location subsystems for automatic vehicle monitoring systems. This document represents one of the contractor's final report. A summary report on all systems tested is available as report No. UMTA-MA-06-0041-77-2.

# METRIC CONVERSION FACTORS

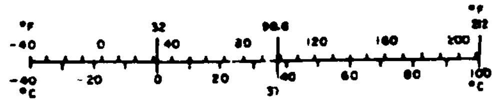
## Approximate Conversions to Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | 2.5 | centimeters | cm |
| ft | feet | 30 | centimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | miles | 1.6 | kilometers | km |
| | | **AREA** | | |
| in$^2$ | square inches | 6.5 | square centimeters | cm$^2$ |
| ft$^2$ | square feet | 0.09 | square meters | m$^2$ |
| yd$^2$ | square yards | 0.8 | square meters | m$^2$ |
| mi$^2$ | square miles | 2.6 | square kilometers | km$^2$ |
| | acres | 0.4 | hectares | ha |
| | | **MASS (weight)** | | |
| oz | ounces | 28 | grams | g |
| lb | pounds | 0.45 | kilograms | kg |
| | short tons (2000 lb) | 0.9 | tonnes | t |
| | | **VOLUME** | | |
| tsp | teaspoons | 5 | milliliters | ml |
| Tbsp | tablespoons | 15 | milliliters | ml |
| fl oz | fluid ounces | 30 | milliliters | ml |
| c | cups | 0.24 | liters | l |
| pt | pints | 0.47 | liters | l |
| qt | quarts | 0.95 | liters | l |
| gal | gallons | 3.8 | liters | l |
| ft$^3$ | cubic feet | 0.03 | cubic meters | m$^3$ |
| yd$^3$ | cubic yards | 0.76 | cubic meters | m$^3$ |
| | | **TEMPERATURE (exact)** | | |
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |



## Approximate Conversions from Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.4 | inches | in |
| m | meters | 3.3 | feet | ft |
| m | meters | 1.1 | yards | yd |
| km | kilometers | 0.6 | miles | mi |
| | | **AREA** | | |
| cm$^2$ | square centimeters | 0.16 | square inches | in$^2$ |
| m$^2$ | square meters | 1.2 | square yards | yd$^2$ |
| km$^2$ | square kilometers | 0.4 | square miles | mi$^2$ |
| ha | hectares (10,000 m$^2$) | 2.5 | acres | |
| | | **MASS (weight)** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1000 kg) | 1.1 | short tons | |
| | | **VOLUME** | | |
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| m$^3$ | cubic meters | 35 | cubic feet | ft$^3$ |
| m$^3$ | cubic meters | 1.3 | cubic yards | yd$^3$ |
| | | **TEMPERATURE (exact)** | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



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# 1. INTRODUCTION AND SYSTEM DESCRIPTION

Hazeltine's field testing of the Pulse Trilateration Automatic Vehicle Monitoring (AVM) System in Philadelphia for the U. S Department of Transportation (DOT) is another major step in the development of this type system for vehicle fleet management and control. The tests have provided significant new information to the engineering body of knowledge for the proper implementation of the Pulse Trilateration System. The test program and subsequent data reduction and analysis have shown the importance of judicious receiver-site selection and spacing to meet location requirements in geographically limited high-rise urban centers. Analysis of multipath delays of fast-rise-time pulsed waveforms during the test program necessitated modification of the original location-pulse spacings. The tests accomplished the following:

> Validated the system's capability to meet time-of passage and reliable base-to-mobile and mobile-to-base communications requirements.
>
> Demonstrated the capability of the system to meet vehicle location requirements in suburban areas using widely spaced remote receiver sites.
>
> Demonstrated a high degree of system immunity to urban electromagnetic noise.
>
> Identified, demonstrated and verified the need for supplemental receiver siting to accurately locate vehicles in high-rise urban centers.

The results of the test program provide assurance that the Pulse Trilateration AVM System will meet the requirements of transit (fixed and random route), law enforcement, trucking, taxi, and other users in Los Angeles and other locations. This can be accomplished with multiple users sharing the use and cost of a single system operating on one FCC-authorized frequency channel. The system will automatically provide accurate location, vehicle identification, and digital communication, on a non-interfering basis, with thousands of individual field units.

Section 1 of this Volume (System Description) provides a functional discussion of the AVM system, including background as to its evolvement, uses for which the system can be implemented, and a general panoramic system description. This section also provides a system technical description, including principal system features and a description of major subsystems. A discussion of the test categories to which the system was evaluated concludes this section of the report.

Section 2 (Test Configuration) includes a detailed description of the system and equipments used in the Philadelphia test program. The vehicle, receiver-site, and control-site equipments of the location and data-communication subsystems are discussed. Both the AVM system tested and the instrumentation system used for data gathering are described.

Section 3 (Data Analysis and Reduction Techniques) details the data collection system used. This includes the methods implemented to merge (time-correlate) control-site and vehicle-recorded data, and the various levels at which the test program data was recorded and evaluated. Data anlaysis and reduction techniques are described for fixed-route and random-route tests, as well as supplementary special tests, including noise-measurement, high-speed, GDOP, trilateration system time point and underpass tests. Data reduction algorithms, software, output formats, and other data reduction considerations are included.

Section 4 (Test Results and Data) presents the test data collected and the test results obtained during the Philadelphia test program. The tests performed are grouped into fixed-route, random-route, and special test categories. Data is presented in histogram, tabular, and map form.

Section 5 (Design Changes for the Los Angeles System) discusses system changes being implemented as a result of the tests performed during the Philadelphia test program and the subsequent analysis of the test data.

Section 6 (Permits and Licenses) addresses permit and licensing requirements for the Los Angeles implementation. The Appendix, which concludes this report, discusses the Philadelphia test program Equipment Operational Requirements. The operational requirements include the Philadelphia test system calibration and initialization procedures, the use and function of system controls and indicators, and various test procedures used to simulate bus-route operation. Random-route and special case tests are also addressed from the standpoint of restrictions, objectives, procedures, and data reduction, as applicable.

## 1.1 FUNCTIONAL DESCRIPTION

1.1.1 Background. The Pulse Trilateration AVM System is a highly flexible, proven approach for the automatic location and identification of, and communication with thousands of vehicles traveling fixed or random routes on land, water, or in the air. The system has emerged from Hazeltine's experience in radar-beacon transponder communications. This experience spans over thirty-five years of developing equipment and systems used in defense, mostly notably Identification Friend or Foe (IFF) systems, and Air Traffic Control applications. In adapting this experience to land-mobile vehicle location and communications, the basic AVM system has been extensively tested in a variety of environments. The system described for use in the DOT Multi-User AVM program is essentially identical to the system Hazeltine is presently implementing for City of Dallas Police Department use. The major deviation from the Dallas implementation is that the DOT Multi-User system makes use of a limited number of fixed signpost transmitters to enhance transit-system time-of-passage accuracy requirements necessitated by slow transit-vehicle speeds in congested-traffic areas. The system described is based on discussions between Hazeltine and many potential users in transit, police, and other fleet management and control applications.

1.1.2 System Use. In recent years, a number of advances have been made in command and control systems for vehicle fleet management through the use of computers. These advances include Automatic Vehicle Monitoring (AVM), Computer-Aided Dispatching, and Mobile Digital Communications. These innovations have permitted the reporting and analysis of transportation, crime, and freight patterns on a near-real-time basis, and faster reaction in response to calls for service. The use of off-line computer processing can further assist agencies improve vehicle-fleet operations. The vehicle location, communications and dispatch systems thereby constitute key elements of an advanced Management Information System.

The desire for AVM systems stems from the rapid and accurate car-location information and digital-communication capability provided to dispatching personnel. This information enables vehicle deployment in such a way so as to reduce response time to calls for service, improve coordination of activities, better supervise daily operations, and improve personnel safety. This is done without the need for location-reporting by voice, thereby reducing the workload of both field personnel and the dispatcher. In the case of the Pulse Trilateration AVM System, it also reduces congestion on crowded voice-radio channels. (The Pulse Trilateration System does not use land mobile radio channels. User inclusion into the system does not require the additional allocation of often scarce, land-mobile channels, or upgrading or purchase of new land-mobile radios.)

Improved management of resources can be provided through:

a) Expediting the dispatching of vehicles from a central point in response to requests for service.

b) Automatically tracking valuable cargo shipments against pre-arranged routes and schedules.

c) Automatic relaying of information (operator and passenger status, vehicle status, etc.) to a central station.

d) Automatic compiling of management information related to more efficient deployment of vehicles.

e) Automatic query of remote data bases from a vehicle terminal.

f) Increased productivity by enabling a vehicle to respond to more calls per shift or by matching assignments better to the the hours and locations of expected need.

g) Reduced [illegible] and preparation of reports.

h) Providing instant access to activity statistics and the use of such statistics in formulating budgets and deployment strategies.

1.1.3 <u>Hazeltine AVM System</u>. The Hazeltine vehicle location and communication system is a Pulse Trilateration Automatic Vehicle Monitoring (AVM) system. This AVM system uses a vehicle-locating method that determines the position of the mobile units by measuring the arrival times of the leading edges of vehicle pulse transmissions at a limited number of fixed receiver sites deployed in the operating area. Differences in the time-of-arrival (TOA) of the pulse transmissions at each fixed receiver site are used by a central fixed site to compute the coordinates of the mobile units. The vehicles' location and other ancillary data are displayed for use by vehicle fleet dispatchers and managers.

The principal system elements are:

a) The Central Station Transmitter.

b) Vehicle Transponders, one in each vehicle in the system.

c) Receiving Stations, located at strategic locations throughout the city.

d) The Central Computer and Command Display.

e) Fixed Signpost Transmitters (used only to enhance fixed-point time-of-passage accuracy necessitated by slow vehicle speeds in congested traffic areas).

The vehicular location data is derived by performing multilateration measurements using fixed-site receivers deployed at secure locations throughout the coverage area. These measurements are performed on pulsed transmission emanating from simple equipments in the vehicle and relayed from the fixed-site receivers to a central computer, where the location of the vehicle is computed and processed for display. A variety of displays are available, including tabular (alpha-numeric), geographic map displays, and combinations of tabular and map data. The Hazeltine AVM system also includes a two-way digital communications capability wherein vehicle status can be determined automatically by the dispatcher without use of the voice radio. The combined location and status information can be provided at displays located at a central station or at multiple remote locations in accordance with requirements.

Since the system has its own dispatcher display capability, it can be used on a stand-alone basis independent of other systems. However, it is also capable of interfacing with existing or planned computer-assisted dispatching systems (CADS), or it can be expanded to accomplish the CADS function in addition to vehicle location and digital communications.

The sequence of operation of the system elements is shown in figure 1-1. An operational cycle is initiated by the roll-call synchronization signal sent by the Central Station Transmitter. At the vehicle transponders (as many as 5000 in the system), this signal triggers an electronic clock that determines the interval between receipt of the signal and transmission of the reply. Each transponder has been programmed to reply after a different interval (figure 1-2). Vehicle transponders thereby respond in sequence, each in its preprogrammed two-millisecond time interval. This provides a unique identification of each vehicle through knowledge of the time-slot assignment at the Central Station. The vehicle emissions (pulsed signals) are received by three or more fixed-site receiving stations, where the time-of-arrival (TOA) of the vehicle's pulsed emission is measured. The TOA information and other ancillary digital message data is relayed to the Central Station Computer via telephone lines. At the Central Station the differences in times-of-arrival from three or more fixed receiver sites are processed (multilateration). The vehicle's position is computed as the intersection of two hyperbolic lines of position formed by the aforementioned time differences. In addition to performing the position location computations, the Central Station Processor operates on any ancillary vehicle status message data and coordinates the activities of display processors which drive the dispatcher display(s). These dispatcher displays may be located at the Central Station or at remote locations in accordance with user/dispatcher requrements.

All rf transmissions from the AVM system are pulsed-waveforms in Federal Communications Commission allocated spectrum in the frequency bands of 904 MHz to 912 MHz or 918 MHz to 926 MHz. Within the selected frequency band, pulsed emissions from the Central Station are transmitted (1) to the vehicles for vehicle transponder time-slot synchronization (to ensure that only one vehicle transmits at a given time) and (2) for supplemental base-to-mobile data transmission. The mobile vehicle transponder also emits signals in the same frequency band. Included in this emission is the pulsed waveform used for both time-of-arrival measurement and for conveying ancillary mobile-to-base messages.

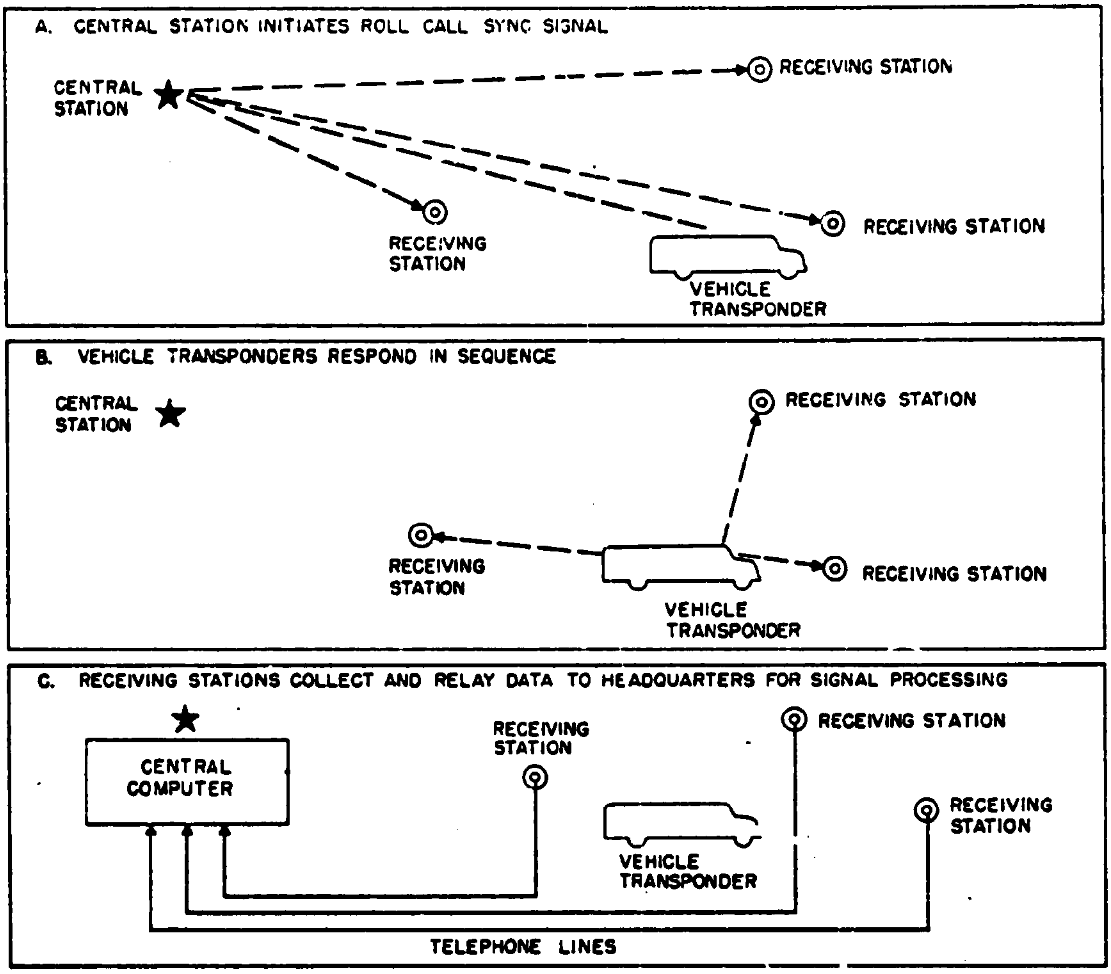


FIGURE 1-1. HAZELTINE AVM SYSTEM - SEQUENCE OF TRANSMISSIONS

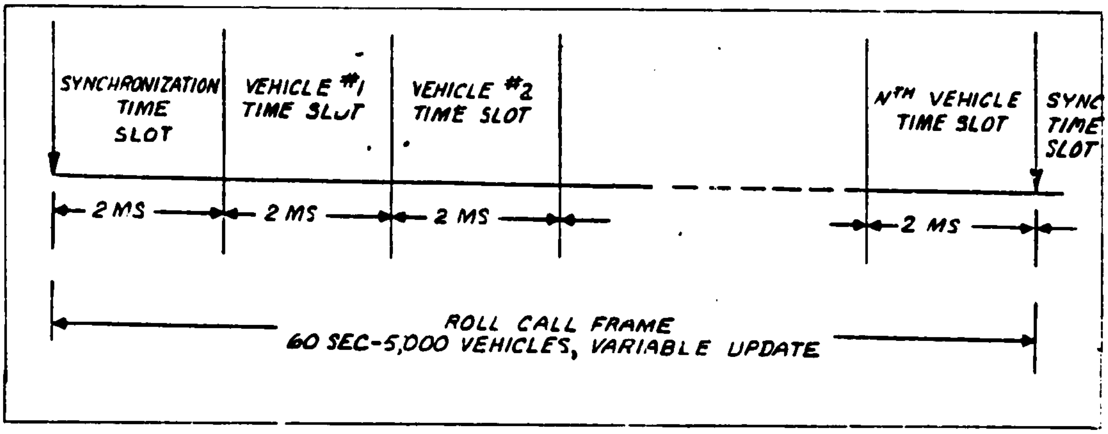


FIGURE 1-2. TIME SLOT SEQUENCE

As described, communication between the vehicle driver and headquarters takes place on the same frequency channel as the location information. The specific messages shown in figure 1-3 are encoded into the vehicle replies. The vehicle driver enters these messages at a conveniently located vehicle-mounted display and input panel.

The fixed signpost transmitters duplicate the Central Station Transmitter's signals to enhance the accuracy of departure-time readings for slow-moving vehicles in congested high-rise areas.

## 1.2 SYSTEM TECHNICAL DESCRIPTION

This section provides an overall summary of the concepts and principal features of the Hazeltine AVM system, including system operation and performance parameters. The Location Subsystem, Communications Subsystem, Data Processing Subsystem and Display Subsystem are separately discussed.

The principal features of the Pulse Trilateration AVM System include:

Meets user requirements:

- Random-route, multi-user, high-capacity, accurate, variable update-rate, digital communications.

Readily expandable:

- Cellular system for coverage growth.
- Very high capacity to serve additional uses.
- Expandable, built-in two-way mobile digital communications capability.
- Modular additions permit phased implementation.

Simple, dependable equipments:

- A small number of inexpensive fixed-site receivers provides large area coverage.
- Vehicle equipment based on well-developed proven beacon technology.
- Leading-edge pulse-time measurement technique is least affected by multipath environments.
- High reliability, which is inherent in the multiple receiver concept with multiple transmission and reception of messages.
- High probability of detection and low false-alarm rate.
- Signpost transmitters, all having identical coding and configuration, improve time of passage accuracy at slow-vehicle-speed locations.
- Straightforward computer software.

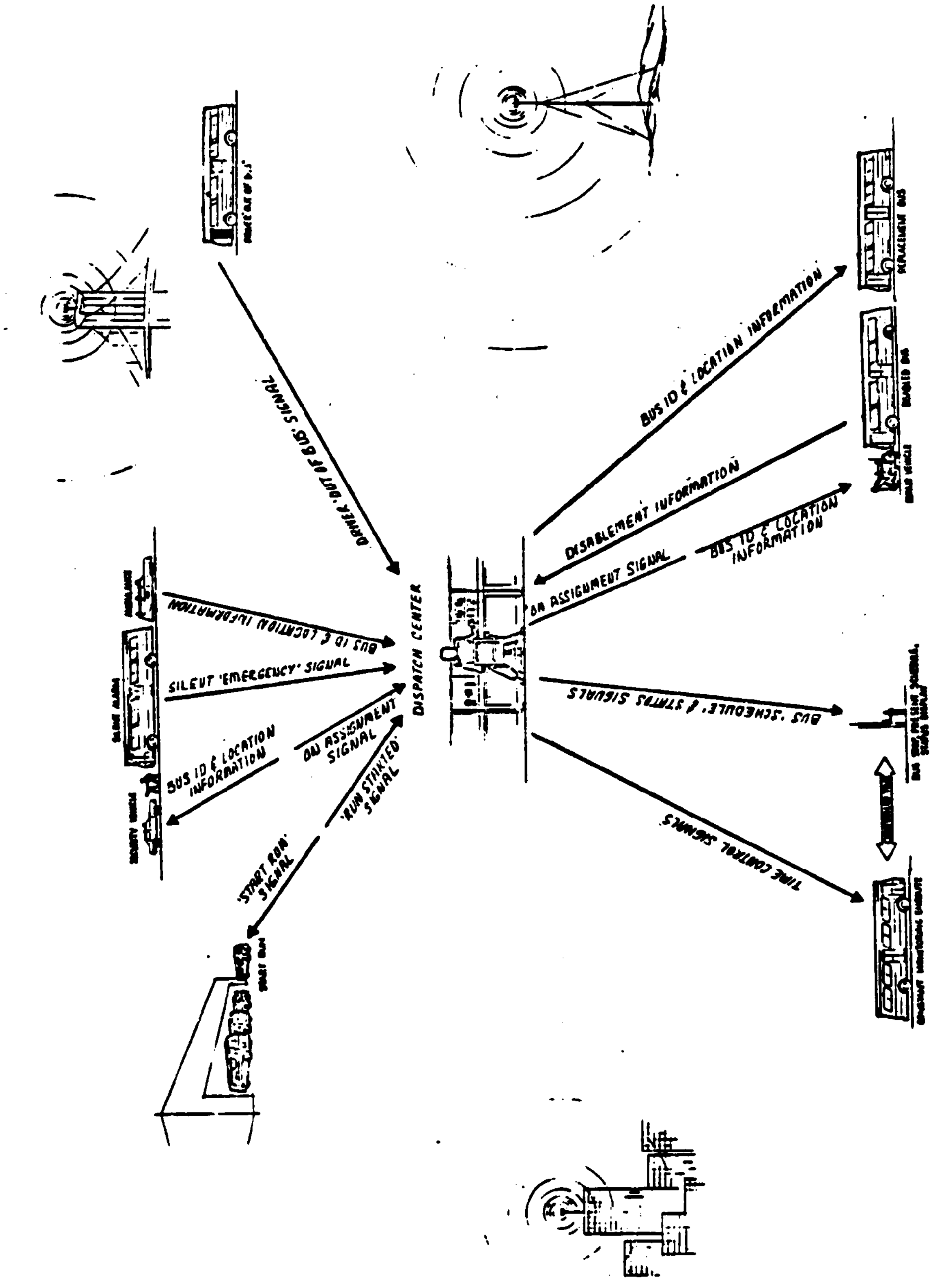


FIGURE 1-3. SYSTEM FUNCTIONAL DIAGRAM

Operationally self-contained:

No external location signals required.
Complete independence of in-vehicle radio and land-mobile frequencies.

Spectrum efficiency:

Shares spectrum otherwise unavailable for land mobile communications.
FCC authorized channel provides large user capacity for accurate location, identification and two-way digital data communication.

Risk is minimized:

Extensive development efforts completed or in process for nearly identical Dallas system.
Performance validated (New York City, Dallas, etc).

The Hazeltine AVM configuration is a completely self-contained system and is independent of any voice-communication equipment that may be on board the vehicle. In effect, redundancy in terms of data communications (including emergency signalling) is provided with two independent systems - one automatic (AVM) the second manual (normal voice channel).

1.2.1 Location Subsystem. The location subsystem contains the trilateration vehicle-location equipment, supplemented at specific points by signpost transmitters. It has been designed to provide random-route vehicle-location capability, which satisfies the transit bus requirement. It also has the capacity to handle any future police, taxi, truck and dial-a-ride transportation vehicle requirements. Its random-route capability includes coverage of moving vehicles on paved and unpaved streets, alleys, parking lots, and off-street operation, as well as situations where time reporting is required on fixed routes.

The receivers of the trilateration system are configured in triangular cells, an arrangement which lends itself to graceful growth through addition of receiver sites (figure 1-4). By proper siting, large coverage is obtained with a limited number of receivers. Receiver spacing of 5 miles in a low-rise urban environment provides satisfactory performance. Larger spacings in suburban and clear regions have been found acceptable.

The receiver stations collect 900-MHz pulse transmissions from the transponder, determine time of arrival (TOA), and relay the information via telephone lines to the central processor/computer. See figure 1-5.

Automatic multilateration (at least three station reports are used) is performed, based on the difference in TOA of signals

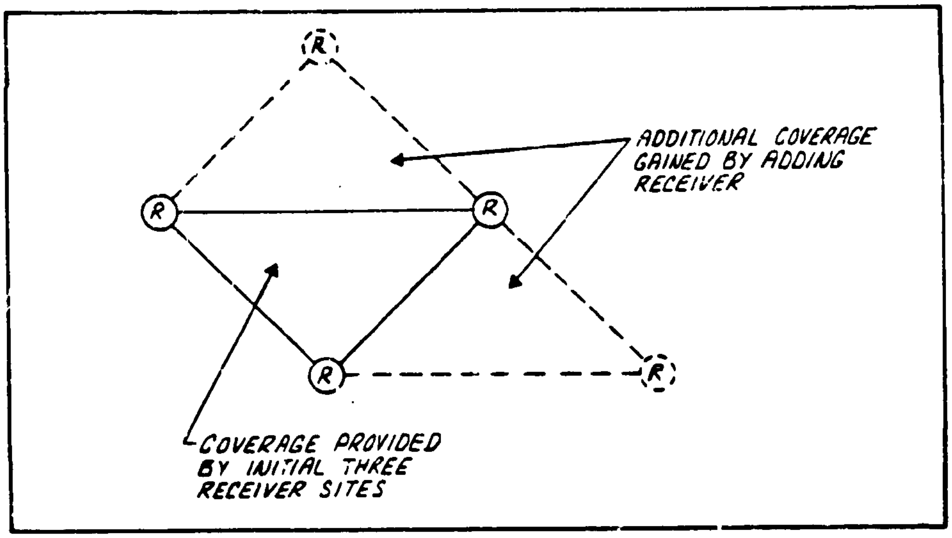


FIGURE 1-4. RECEIVER POSITIONING

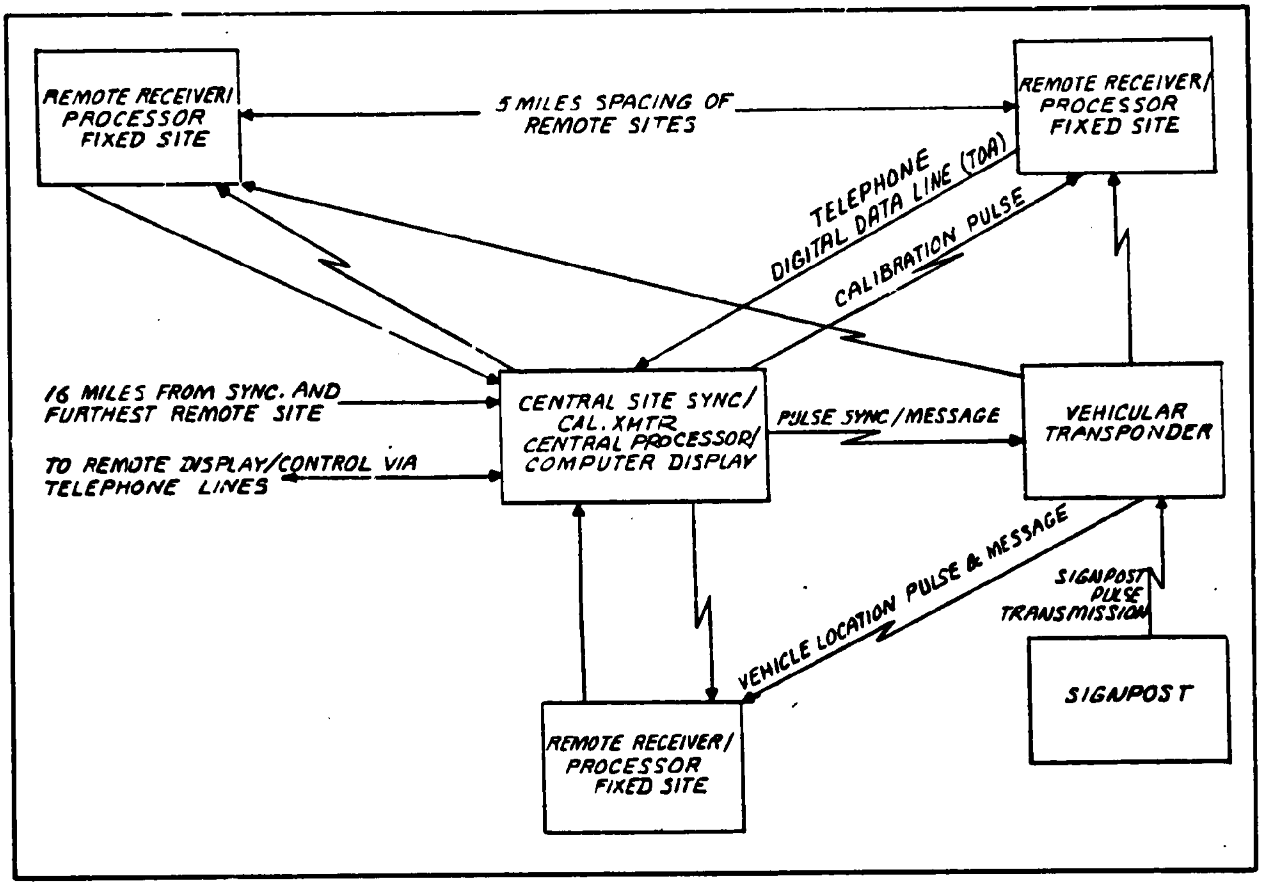


FIGURE 1-5. BASIC SYSTEM CONFIGURATION

from each vehicle at the different receivers. This technique permits location calculations to be made independent of sync and time anomalies of the transponder and receiver (eg, jitter and clock drift). The calculation of vehicle position is done by determining the intersection point of two hyperbolas through a simple, real-time, best-fit algorithm performed in a successive iteration mode in the central AVM computer.

Signpost devices supplement the trilateration position-location features to measure departure times of vehicles passing designated points at slow speeds. The signpost devices are not required for high-speed vehicles since system accuracy is within the ±15-second requirement for all but slow-moving vehicles. The low-power signpost transmissions are received only when the vehicles are near the signposts. All signposts transmit the same code and transmit on the same frequency as the Central Station Transmitter.

The system transmission modes used to implement the functional requirements are:

> Central Station Transmitter synchronization/message link to vehicle: pulse code modulation
>
> Signpost to vehicle link: pulse code modulation
>
> Vehicle location/message link to fixed receiver site: fast risetime pulse code modulation (7 mW average power)
>
> Fixed transmitter calibration transmission: low duty-cycle pulse
>
> Fixed receiver/processor site to central control: digital/1200-bps modem via unconditioned telephone lines

The Central Station Transmitter's synchronization signal is a simple three-pulse interval code sent during the synchronization time slot. A 16-bit message with the three-pulse interval preamble is sent during the first half of any vehicle's 2-millisecond report period. If no data is required to be sent to the vehicle, the Central Station Transmitter is quiet for that period.

The vehicle replies during the second half of its assigned report period with a locating pulse preamble, followed by any data (including signpost passage) that must be sent back to Central Control. The vehicle message contains 16 bits.

1.2.2 <u>Communication Subsystem</u>. The digital-pulse communication subsystem is an integral part of the pulse trilateration location subsystem. It is a natural extension of the pulse transmission mode used in the time-of-arrival measurements of the location subsystem.

Additional message data pulses may be added easily to the location and synchronization transmission formats. The advantage is that no additional rf channels are required to incorporate digital message-handling capability into the system. Vehicle location and data communication channel discipline is based on partitioning each 60 seconds of time (a frame) into 30,000 time-slots, each time slot occupying two milliseconds. Each vehicle in the system may be assigned one or more time slots in the 60 second frame depending on the required vehicle update rate. For example, a vehicle requiring a 60-second update would be assigned one time slot, whereas a vehicle requiring a ten second update rate would be assigned six time slots per frame. Vehicle emissions used for time-of-arrival (location) measurement and data communication between the vehicle and the central station occur only in the vehicle's assigned time slots. These time slots are referred to as the vehicle's reporting periods.

The Pulse Trilateration AVM system has substantial capacity to support a broad range of two-way data communication including (1) in- and out-of-car emergency signalling, (2) one- or two-way transmission of status messages as provided in the City of Dallas system through the use of the addition of a simple in-car terminal, and (3) a capability for complete two-way transmission and in-vehicle display of extended length alpha-numeric text messages. The system provides enhanced location and communications security through the use of broadband pulsed communications, and the use of only a small number of receiving stations normally placed at secure locations.

1.2.3 Data Processing Subsystem. The data processing subsystem used in the Philadelphia tests functioned essentially in the same manner as the one proposed for the Los Angeles system. A block diagram of the data processing subsystem planned for the Los Angeles AVM system is shown in figure 1-6. A PDP-11/45 computer is interfaced with the indicated peripherals to permit operator communication with the AVM system, display of information collected by the AVM system, recording of data on tape for subsequent off-line processing, and disc storage used by the AVM system during real-time data processing. In addition, the AVM computer interfaces with the central site interface unit to collect vehicle data on a periodic basis and to transmit various types of information to those vehicles. The location calculation is performed in the PDP 11/45 based on TDA information.

Information within the proposed AVM system flows in an orderly manner from the vehicle to the dispatcher and to the tape recorders that are used for collecting management information data. Each of the 225 vehicles to be tracked in the Los Angeles area will be assigned a group of report periods within the timing sequence that will ensure that vehicles respond once every 10 seconds. These responses, received at three or more of the receiver stations, are transmitted to the central site through various communication links. At the central site, the messages and signals for a given report period are collected and formatted in the central site interface unit for transmission to the computer. The computer accepts the data for further processing and position determination.

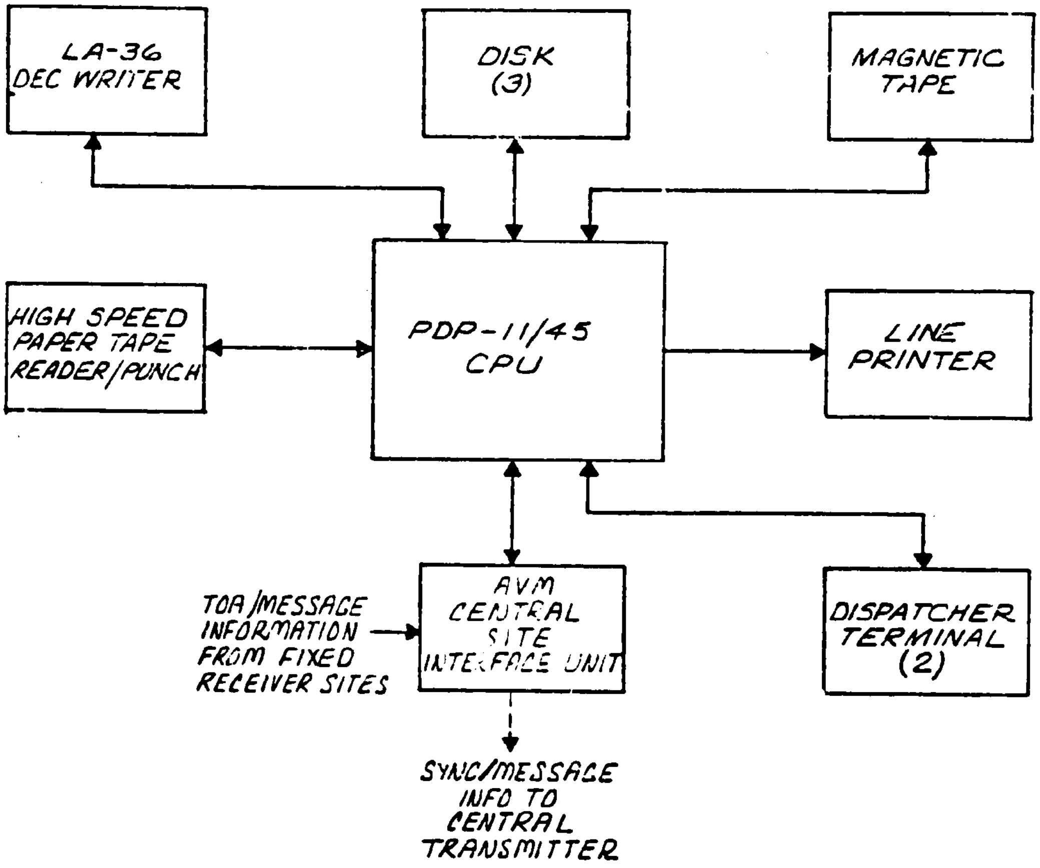


FIGURE 1-6. DATA PROCESSING SUBSYSTEM, BLOCK DIAGRAM

The computer selects the three most favorable sites on which to base the location calculations and updates the previous position using a technique which is essentially the Newton-Raphson iterative method. The iterations continue until the residual error is less than a preset value. (An error of 5 feet is used for processing the Philadelphia data and is planned for the Los Angeles system.)

The position of the vehicle is derived in an arbitrary X, Y coordinate system. Conversion of the X, Y coordinates to street locations is performed using a street-location look-up table stored on a disk. Once the position data has been derived, that information, along with time, message, and other derived vehicle information is stored in a vehicle record. The additional information, which is computed on the basis of the new position information, includes such items as schedule adherence and route deviation. Periodically, the data contained in the vehicle files is removed and displayed for the dispatcher's use (when he requests such information) and/or put onto the magnetic tape storage unit for subsequent off-line development of management information reports.

1.2.4 Display Subsystem. A cathode-ray tube display terminal provides a visual presentation of desired data. The dispatcher requests displays of interest by depressing the appropriate function keys on his console. Display performance, message generation, and entry of various sytem parameters is also subject to operator initiation and control.

## 1.3 EVALUATION OF SYSTEM PERFORMANCE

The demonstration system used to evaluate AVM system performance during the Phase I tests in Philadelphia was configured to provide a high rate of data sampling. A rate of ten times per second was used to accurately identify the location of the test vehicle at all times. In evaluating the performance of the system under conditions similar to those that will prevail in an operating system, only data based on every one hundredth system transmission (10-second intervals) or known check points was used. In addition, a full set of position location data, taken at 0.1-second intervals was calculated for full evaluation of the position-location subsystem.

To determine the actual position of the test vehicle at any time, distance travelled from accurately identified reference points, referred to as "event markers", is used. The passing of an event marker is noted in the next 1/10-second interval, and identified in the vehicle transmission and on a data tape recorded in the vehicle. Subsequently, accurate distance travelled from the event marker is determined by a fifth-wheel odometer, and recorded at tenth-second intervals on the vehicle's data tape. When ten-second-interval trilateration and signpost position reports are selected for analysis of system performance, they are compared with this precisely-tracked actual position data for an accurate assessment of the performance of the location system.

1.3.1 Test Categories. The tests performed during Phase I are grouped into three categories, (1) fixed-route tests, (2) random-route tests, and (3) special tests. Data gathered during the fixed-route tests shows the Location Subsystem performance, with the test vehicle operating along specific routes at speeds and stop sequences that simulate bus movements. The data gathered along a discrete path chosen in the random-route high-rise area includes speeds and stop-go sequences that simulate automobile movements. The special tests demonstrate the subsystem performance in specific areas and situations where acceptable coverage and location measurements were considered difficult. Details of the test procedures for all the Philadelphia tests are covered in subsequent sections of this report.

1.3.1.1 Fixed-Route Tests. The route covered by the test vehicle to demonstrate the fixed route AVM performance is shown in figure 1-7. The direction of travel is indicated by arrows, while dots along the route (1-15) show the time points (measured with the signpost equipment). Bus-route simulations were performed with the test vehicle passing the time points without stopping approximately 50% of the time and stopping for the remaining 50%.

1.3.1.2 Random-Route Tests. The random route test simulated speeds and stop-go sequences of automobile movements (ie, paratransit and others). The specific routes, specified by DOT/TSC, are within the dashed region of high-rise buildings shown in figure 1-7.

1.3.1.3 Special Tests. The special tests include a high-speed test, an underpass test, a 360-degree geometric dilution of precision (GDOP) test at one of the receiver sites, signpost tests including a test to demonstrate immunity to man-made interference, an AVM performance test with the vehicle near a power line, and an exploratory test of man-made noise levels within the chosen coverage area. An additional test was performed in the suburban area to demonstrate the time-point measurement accuracy utilizing the trilateration system without signpost inputs.

1.3.1.3.1 High-Speed Test. This test was performed on that section of the Philadelphia Schuylkill Expressway south of the Holiday Inn receiver site. Maximum speeds approaching 55 mph were used.

1.3.1.3.2 Underpass. The underpass test was performed on the Schuylkill Expressway north of the high speed test area between the City Line exit and the Franklin Parkway exit.

1.3.1.3.3 GDOP Test. A 360° region near the Landis State Hospital receiver site was explored to determine the effect of GDOP on the Location Subsystem. Approximately twenty randomly spaced points within a half-mile radius of the site were examined.

1.3.1.3.4 Signpost Tests. The radiation patterns of the signpost unit antenna array were measured at the Wheeler Laboratory antenna measurement facility at Smithtown, New York. The sum and difference patterns were measured at all azimuth angles and at three elevation angles. These controlled pattern tests demonstrated proper null-pattern characteristics and supported the field installation performance.

With the signpost unit installed in an operational environment in the town of Greenlawn, New York, radiation field intensity

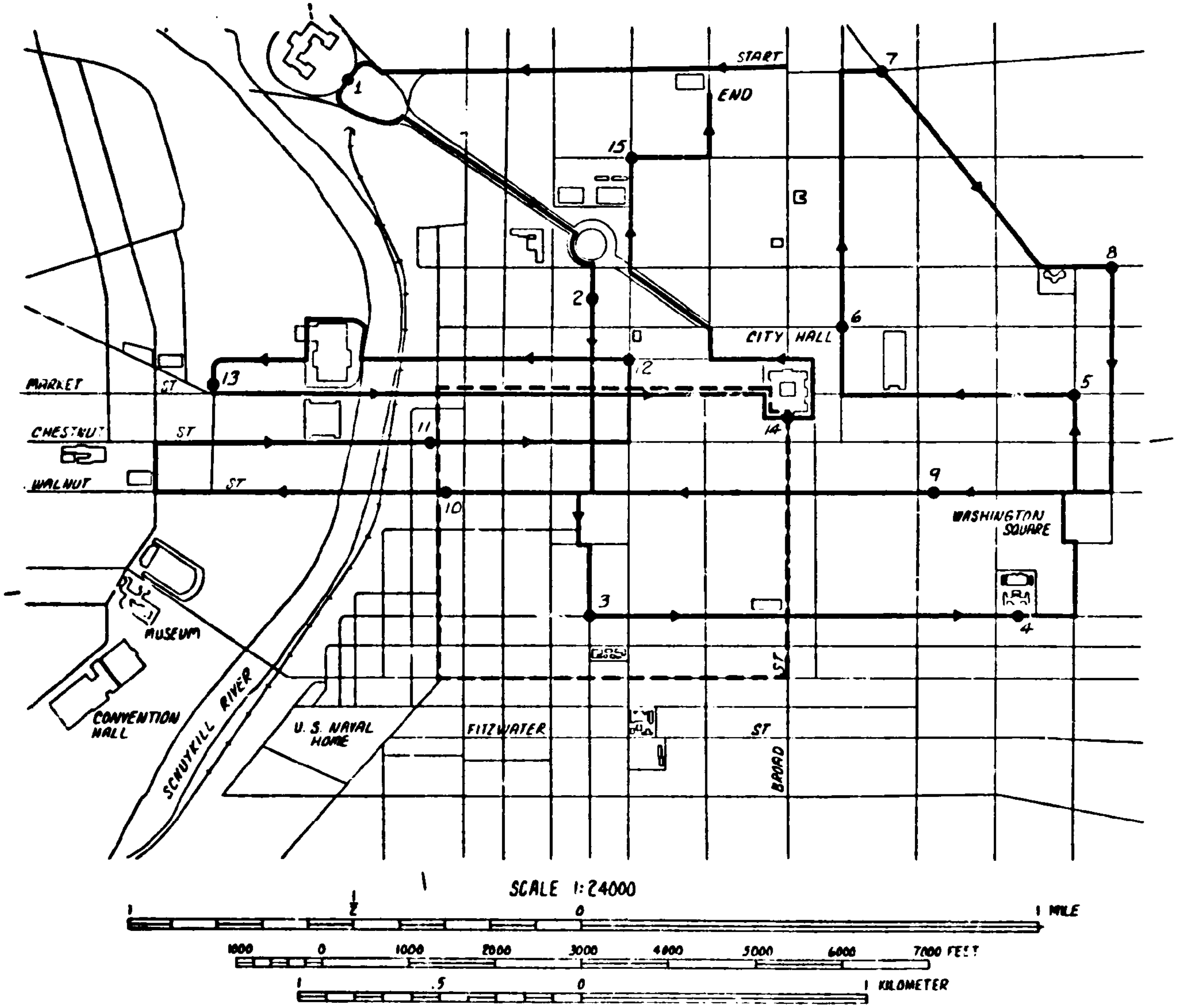


FIGURE 1-7. FIXED ROUTE AND RANDOM ROUTE AREA

along the roadway to and from the signpost was measured using the calibrated vehicle receiver. Tests are performed with the signpost unit mounted 10, 15, 20 and 25 feet above and along the roadway. Detection of the vehicle within 50 feet of the signpost was demonstrated with the vehicle traveling at various speeds past the signpost and with various combinations of secondary vehicles placed between the signpost and the AVM test vehicle. The immunity of the signpost detection process to man-made interference, such as automobile ignition interference, was demonstrated. Received signpost signals within the 30-degree decision sector are near saturation level of the vehicle receiver, and in most instances above the local noise level. The vehicle receiver noise blanker was implemented for these tests.

1.3.1.3.5 Power Line Interference Test. A special test of the vehicle traveling near transit power lines was performed in Philadelphia near the 30th Street Railroad Station.

1.3.1.3.6 Trilateration System Time Point Measurement. A time point test was configured using the basic trilateration system without signposts. A suburban area in Fairmont Park, near the East River Drive, was used.

## 2. TEST CONFIGURATION

The equipment configuration for the Philadelphia test is shown in figure 2-1. The major equipments are:

a. Four fixed receiver sites - which receive and process vehicle transponder replies and send the resulting data via the phone line to the central control station.

b. The central control station - which provides system synchronization and receives, formats, and records data received from the fixed receiver sites.

c. Vehicle equipment - which includes the transponder, data recording equipment and the fifth wheel for maintaining an accurate record of vehicle location.

d. Transmitter - which transmits the system synchronization and calibration signals.

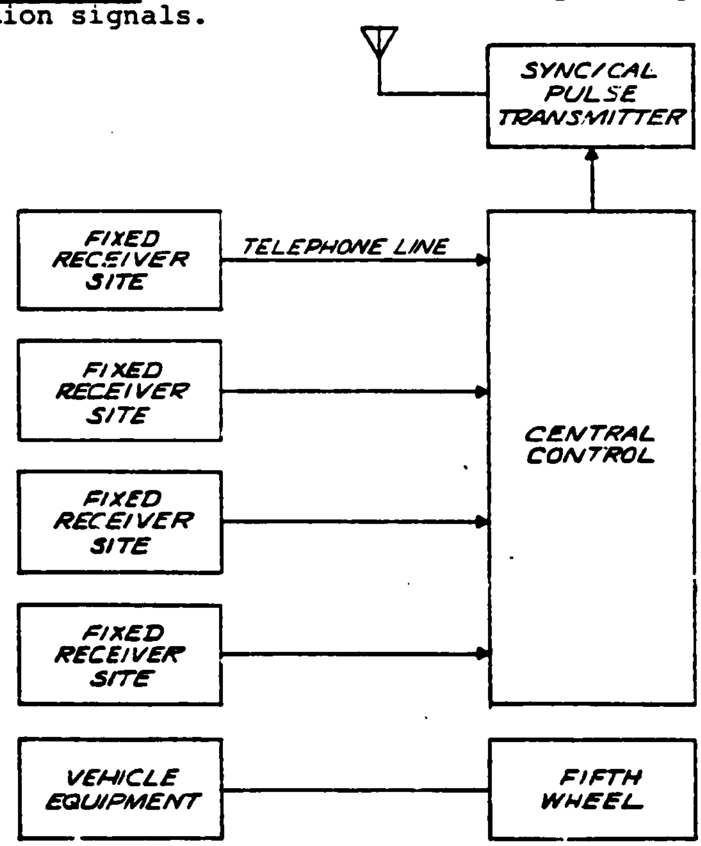


FIGURE 2-1. PHILADELPHIA TEST - EQUIPMENT CONFIGURATION

## 2.1 SYSTEM TEST CONFIGURATION

Four receiving sites are used in the Philadelphia test program. As shown in figure 2-2, these sites form two triangles. The larger triangle has a maximum leg length of 6.5 miles; the smaller triangle has a maximum leg length of 4.6 miles. The specific location of the sites are:

1) Holiday Inn on City Avenue near Schuylkill River,

2) ARCO Flare Tower in SW Philadelphia near Passyunk Avenue and Schuylkill River,

3) North Gate Apartments, Camden, New Jersey,

4) Smoke stack of the Landis State Hospital on Girard Avenue.

The large triangle is formed by sites 1, 2 and 3, and the small triangle is formed by sites 2, 3, 4. Data is taken simultaneously from all receiver sites. Location calculations for both triangles are handled separately.

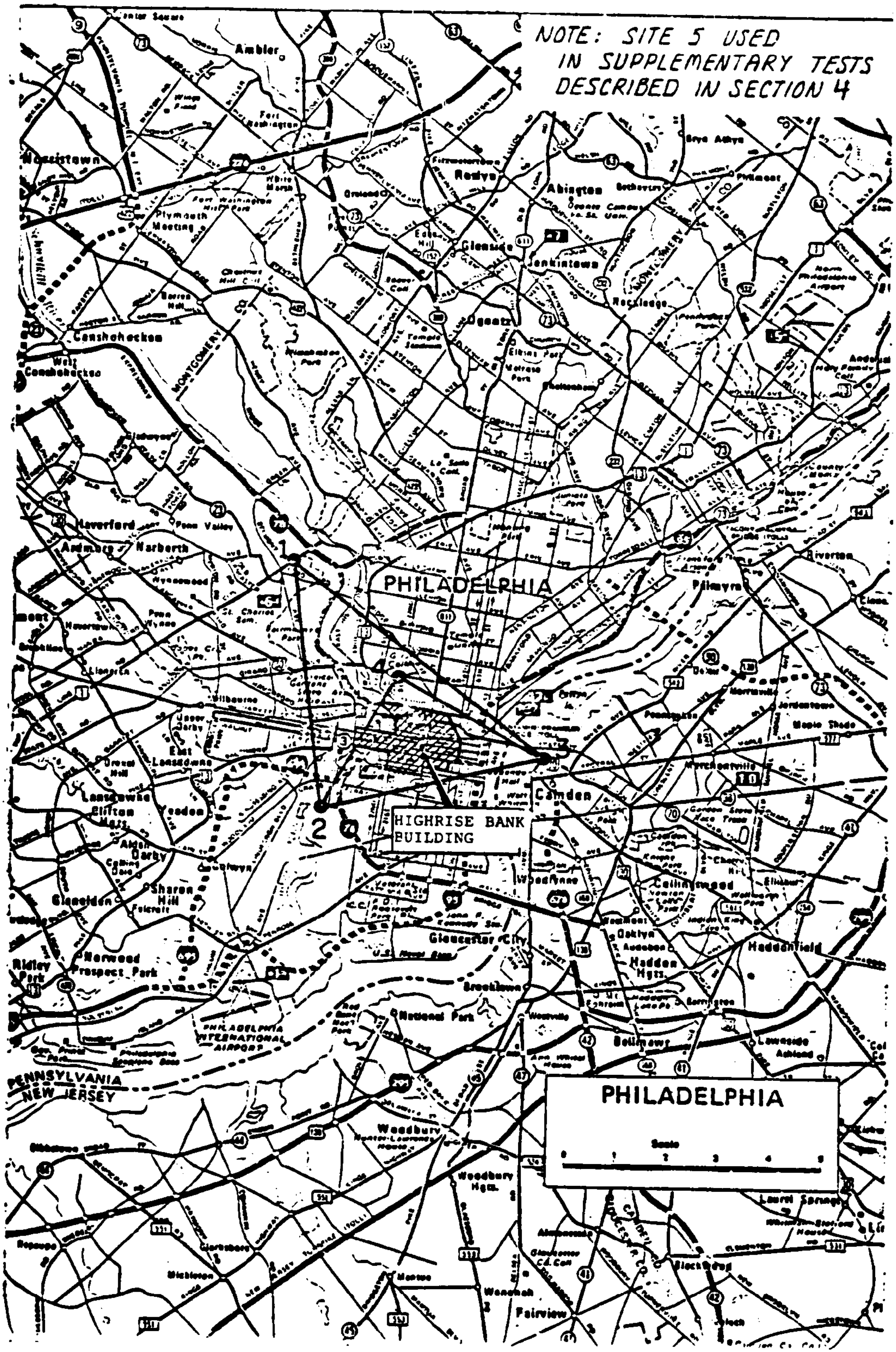
High gain antennas and transmission lines are installed at each of these sites. The Holiday Inn site also included an independent central site antenna for synchronization/calibration transmissions. Mikab Rental and Service Company of New Jersey was subcontracted to install the antennas and ancillary tower equipments. Telephone lines are installed at all receiver sites to central control at the Holiday Inn.

Hazeltine obtained experimental licenses from the FCC to perform the AVM tests both at Greenlawn, N.Y. and Philadelphia, Pa.

### 2.1.1 AVM Equipment

2.1.1.1 Receiver Site Equipment - Figure 2-3 is a block diagram of the fixed receiver site equipment. The station-master type antennas are 12-dBI omni Phelps Dodge Communication Company devices. The following is a list of antenna heights and ground elevation levels.

| | Structure Height (ft) | Ground Elevation (ft) |
|---|---|---|
| Holiday Inn Receiver and Transmitter Antennas | 240 | 230 |
| ARCO Flare Tower | 216 | 20 |
| North Gate Apartment | 200 | 20 |
| Landis Hospital Smoke Stack | 200 | 100 |



NOTE: SITE 5 USED IN SUPPLEMENTARY TESTS DESCRIBED IN SECTION 4

FIGURE 2-2. RECEIVER SITES, PHILADELPHIA AVM TEST

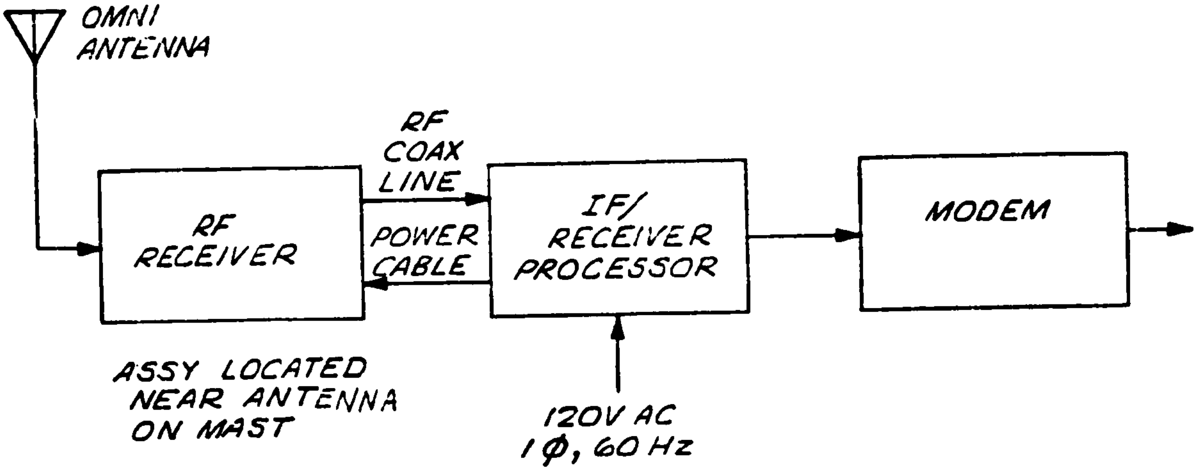


FIGURE 2-3. PHASE I FIXED RECEIVER SITE EQUIPMENT

The rf receiver assembly (approximately 12" x 10" x 6"), containing the low noise preamplifier, mixer, local oscillator, and IF preamplifier, is located close to the antenna on the tower or pole structure. Coaxial lines are used to limit the rf loss to less than one dB. Relatively long coaxial lines, carrying the received signal at the intermediate frequency, connect the rf receiver assembly with the IF receiver/processor unit. The IF unit with the telephone modem is sheltered in a room near the base of the antenna supporting structure. Leased Bell Telephone 1200 BPS modems are used for the Phase I tests.

Central Site Equipment - Figure 2-4 shows the equipment configuration of the central station for the Phase I test. Data is received from the telephone lines connected to each of the fixed receiver sites through individual 1200 baud modems. The Interface and Control unit generates the system signals for synchronization, calibration and message transmission, and it performs preliminary processing and reformatting of received data prior to recording on the Digi-Data Model 1309-8-132-H tape recorder.

The "reformatting" of data at the central site is provided to simplify the computer tape analysis. Data arriving from the four remote fixed sites may arrive in any sequence for a given time slot response. The reformatting consists of ordering the data for loading onto the tape recorder according to site number. First site 1 data is put on tape followed by site 2 data, site 3 and site 4.

Preliminary data processing does not change the data recorded on tape and is only used to display on the front panel of the unit, TOA, slot number, or message information received from each of the four sites. The display information is used as a quick look to determine that the system is up.

The central site Interface and Control unit includes a real-time clock, the outputs of which are used in 3 ways:

Real-time front panel display.

Recorded on tape every 0.1 second.

Transmitted to vehicle once every 2 seconds (for verification of time synchronization).

The unit includes frontpanel thumbwheel switches for entering the tape header information (tape #, file #, test #, date, time and transmitter power for both the sync and cal transmissions at the beginning and conclusion of each test). It also provides for buffering and organizing the modem data from each of the 4 sites before it is sent to the recorder format and control circuits. These circuits interface with the tape recorder.

Data arrives at the modems via telephone lines from the four fixed receiver sites. This data is stored on a per site basis in the modem data buffer. After the data from the four sites has

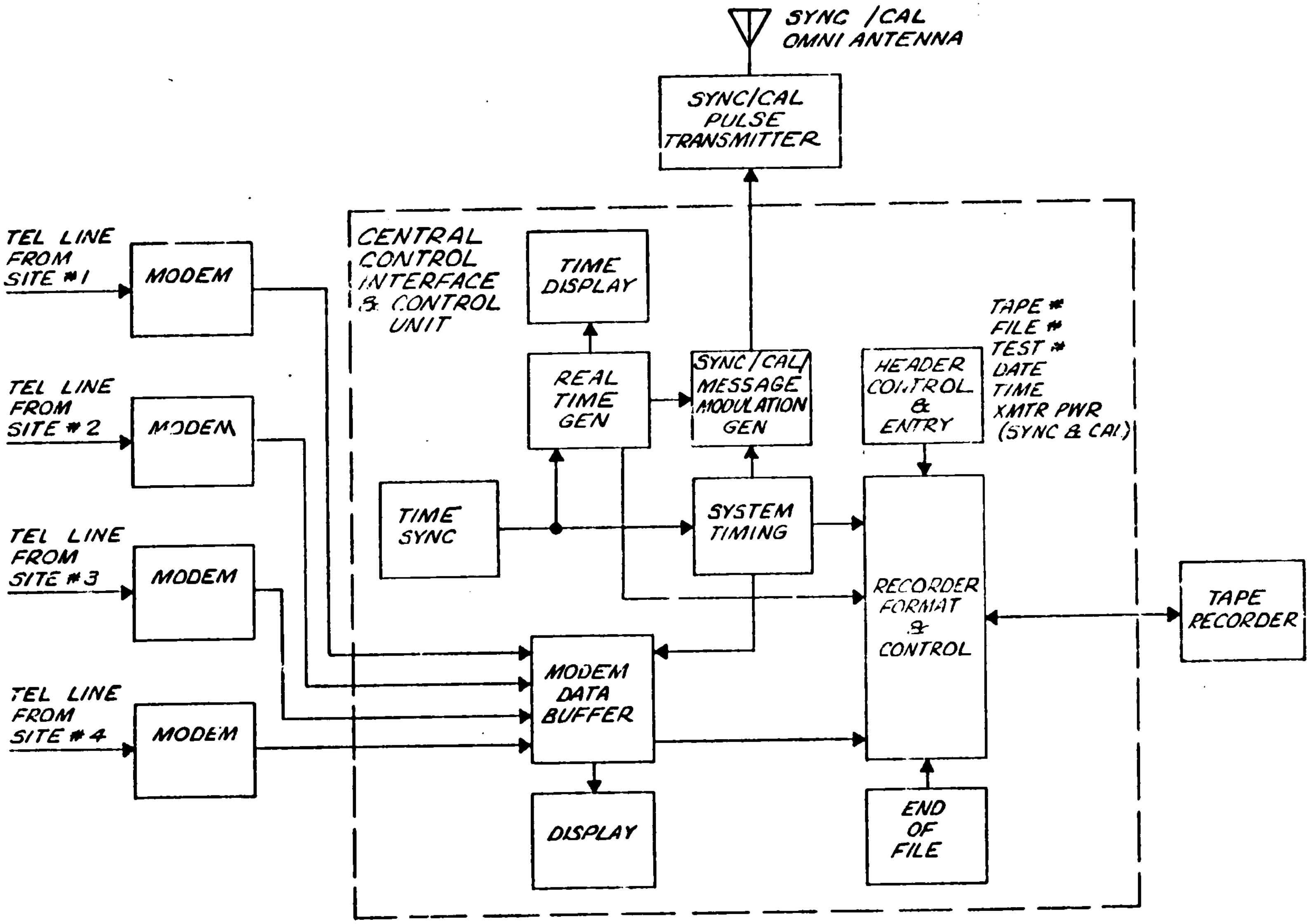


FIGURE 2-4. CENTRAL CONTROL STATION PHASE I TEST CONFIGURATION

been loaded in the buffer, the system timing initiates a data transfer cycle to the digital tape recorder. The data is sequenced out to the tape recorder in order (sites 1 through 4) via the recorder format and control logic. This logic also loads and sequences the front panel header information when entered. A specific preamble word identifies the type of data to be loaded on the recorder so that the computer processing can distinguish between header, site data, and end-of-file groups of information. Data is also available from the modem date buffer for front panel display of individual site time-of-arrival (TOA) or vehicle message.

A real-time generator keeps track of real time from an initial start of testing and outputs this time in message format to the vehicle via the sync/cal/message modulation generator and the transmitter. This real-time sequence is also displayed on the front panel.

The interface with the tape recorder includes:

8 data lines
write/step command
gap command
end-of-file (EOF) command
gap in process
write (HCEC) error.

The tape recorder, Digi-Data Model 1309-8-B2-H, is a 9-track, 800 bpi, 1200 ft reel, IBM compatible, ping-pong (dual 1024 buffer) incremental unit. It acts like an incremental recorder to the outside world, but actually records "continuously" when either one buffer is filled or an external gap command is provided, whichever occurs first. The write, or HCEC (head current echo check), error signal indicates that an error has been detected in the tape recorder write electronics.

A dual buffer (in this case 1024 bytes, or characters, for each of the buffers) configuration is used, in which the incoming data is stored in one buffer until it is filled; the incoming data is then routed to the second buffer and the contents of the first buffer are recorded on tape. When the second buffer is filled, the incoming data is routed to the first buffer and the second buffer's contents are recorded on the tape. This alternating action is continued, with the contents of each buffer representing a physical record (1024 bytes or characters) so that data acquired during the time an inter-record-gap is placed on tape does not have to be stored externally to the tape recorder.

The Synchronization/Calibration transmitter provides up to two kW peak power for the synchronization transmission and 500 W peak for the calibration transmission. The transmitter has the ability to frequency hop from the synchronization emission frequency to the calibration emmission frequency, generate the different pulse widths and power levels, and output to a single rf transmission line and antenna.

Central transmitter power levels are compatible with propagation losses expected in Los Angeles. The power level to achieve 17 mile maximum range from the Los Angeles central control transmitter antenna to the furthest vehicle is reduced to result in the same signal strength at the 5.5 mile maximum range for the Phase I Philadelphia configuration. In addition to maximum range test, the required power to achieve reliable communication with the vehicle in the high rise central business district (CBD) was determined by monitoring the sync decode signal in the vehicle. The loss in the CBD was found to be higher than the average for the Philadelphia coverage area. The higher than average loss in the CBD is offset in the LA configuration by locating the central transmitting antenna in an advantageous position relative to the high rise CBD.

Signpost Equipment - The signpost devices are used to improve the time reporting accuracy of transit vehicles. The signpost unit is approximately 9" wide by 6" deep by 7" high, with four 10" long dipole antennas mounted on the top cover. The unit is mounted on a 3-foot boom to decouple the antennas from any surrounding metal reflectors. A low-cost universal joint connects the enclosure to the boom to allow proper orientation of the antenna pattern null with reference to the street and time point locations. The other end of the boom is equipped with a universal mount to allow mounting on poles of various diameters or a flat mounting surface. The signpost power is provided by a self-contained battery whose life far exceeds the duration of the Phase I tests.

Fifteen of the signposts are located at the DOT/TSC designated points along the fixed route.

2.1.1.2 Vehicle Equipment. The vehicle instrumented for the Phase I tests is a leased 1974 Command motor home. A plan view of the vehicle layout is shown in figure 2-5. The equipment rack, antenna, gasoline generator and the fifth wheel are identified, along with the rack-mounted equipment. The gasoline generator is a 2.5 kW, 120 V 60 Hz unit with a gasoline consumption rate of 1/2 gallon per hour. The separate gas tank has a capacity of 10 gallons. Figure 2-6 depicts the vehicle equipment interfaces, including the recording equipment and measured parameters. In addition to the recording of data at central control, all data collected aboard the vehicle, such as time, marker events, checkpoint identification, fifth wheel distance readings, signpost signal reception and power consumption and rf radiated power of the AVM equipment is recorded on-board the vehicle.

The vehicle equipment contains the basic AVM transponder unit, a 5 dBI antenna mounted on the roof of the vehicle, a power amplifier

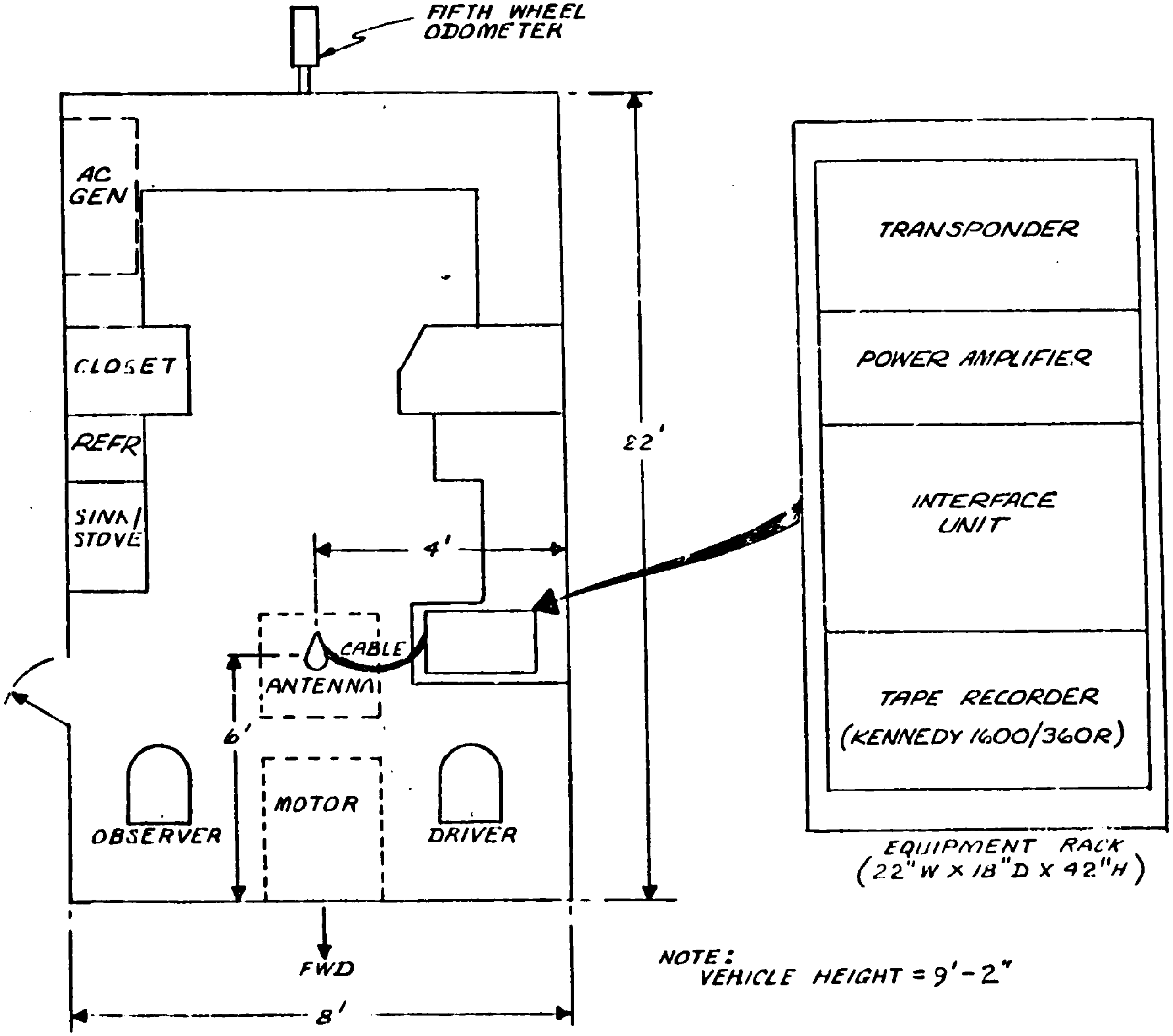


FIGURE 2-5. TEST VEHICLE

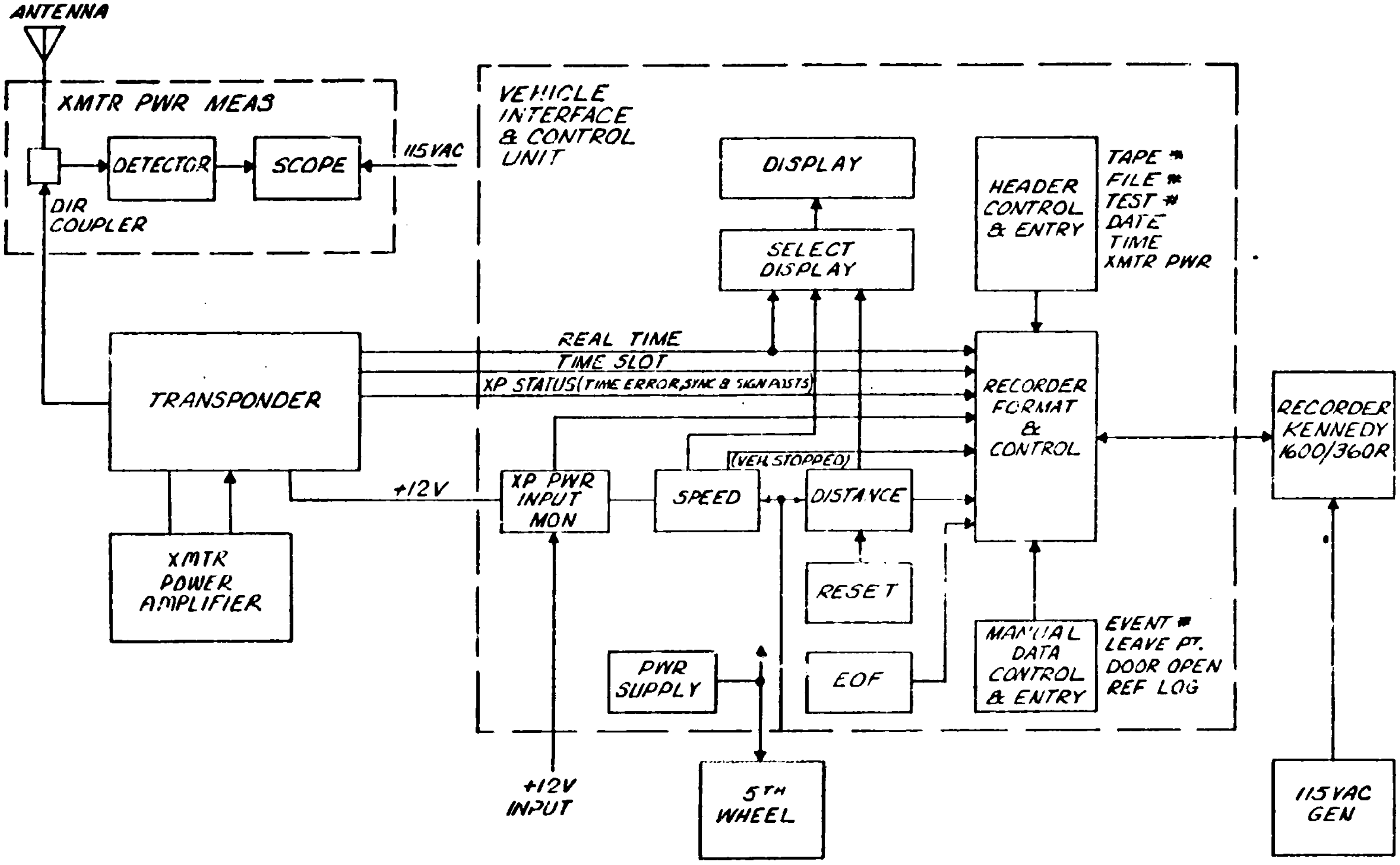


FIGURE 2-6. VEHICLE EQUIPMENT BLOCK DIAGRAM

unit, a fifth wheel odometer, a data interface unit, a tape recorder, rf power measurement capability, and a gasoline powered 120 VAC generator.

The vehicle transmitter operates at a nominal 400 watts peak.

In addition to transmitting replies, (including status bits message) in 20 discrete time slots during each 2 second interval, the transponder:

> decodes the message (time) sent by the central site once every 2 seconds, to verify synchronization of its own real-time clock,
>
> supplies real-time to the interface unit,
>
> provides the time of each reply to the interface unit,
>
> supplies 4 status bits to the interface unit:
>
> 1) sync signal decoded correctly
> 2) message error
> 3) signpost signal decoded
> 4) message preamble decode.

The fifth wheel assembly consists of a Laboratory Equipment Corporation fifth wheel (P/N 1968481) with a transmitter assembly (P/N 1969403) mounted on it. The assembly, which uses +5 volts from the interface unit, generates a square wave TTL-compatible output, with a rise-to-rise edge spacing representing 1/25 foot of travel, for use by the interface unit.

The vehicle interface and control unit:

> accepts fifth wheel inputs for conversion to feet (for recording) and tenths of feet (for in-vehicle display),
>
> accepts real-time inputs from the transponder for both recording and in-vehicle display,
>
> accepts status bits from the transponder for recording and front panel indication,
>
> provides front panel thumbwheel switches for entering the tape header information (tape #, file #, test #, date, time and transmitter power at the start and conclusion of each test) and manually entered data (event #, leave point, door open, and refer to log bit),

monitors the dc power (voltage and current) input to the transponder for recording,

formats the data for, and controls, the tape recorder.

The "vehicle stopped" indication is derived from the fifth wheel (speed less than 0.1 mph) and is one of the status bits (a "1" indicates the vehicle is stopped) which is both recorded on the vehicle tape (in byte #12 of each logical record) and transmitted by the transponder (in the sixth bit of the message) every 0.1 second. There is no special indication on the vehicle display.

The tape recorder, Kennedy Model 1600/360R, is a 9-track, 800 bpi, 1200-foot reel, IBM compatible incremental machine (the same unit which was used in Hazeltine's Dallas AVM tests). The interface includes:

8 data lines
write/step command
gap command
EOF command
gap in process
write (HCEC) error
recorder ready.

A 1200-foot reel of tape can record 12-1/2 hours worth of real-time data.

2.1.1.3 Data Acquisition Equipment. Figure 2-7 is a block diagram of the data acquisition system which gathers data to demonstrate that the Location Subsystem performs in compliance with bus transit operations. The central site data acquisition equipment is a subset of the central site equipment described in Section 2.1.1.1. The vehicle data acquisition equipment is a subset of the vehicle equipment described in paragraph 2.1.1.2.

The recorded tape format for the central site is shown in figure 2-8, and figure 2-9 shows the vehicle tape format.

2.1.1.4 Computer Processing Equipment. The computer, used for tape duplication and processing of the data in Philadelphia, is a DEC 10 located at the Medical School-Computer Facility, University of Pennsylvania, Richards Building C-511.

Data processing is performed both in Philadelphia and Greenlawn. The Philadelphia processing is sufficient to determine the state of the system while detailed processing of the test data is reserved for the Greenlawn installation.

Tape duplication is performed using the system program "TRANS."

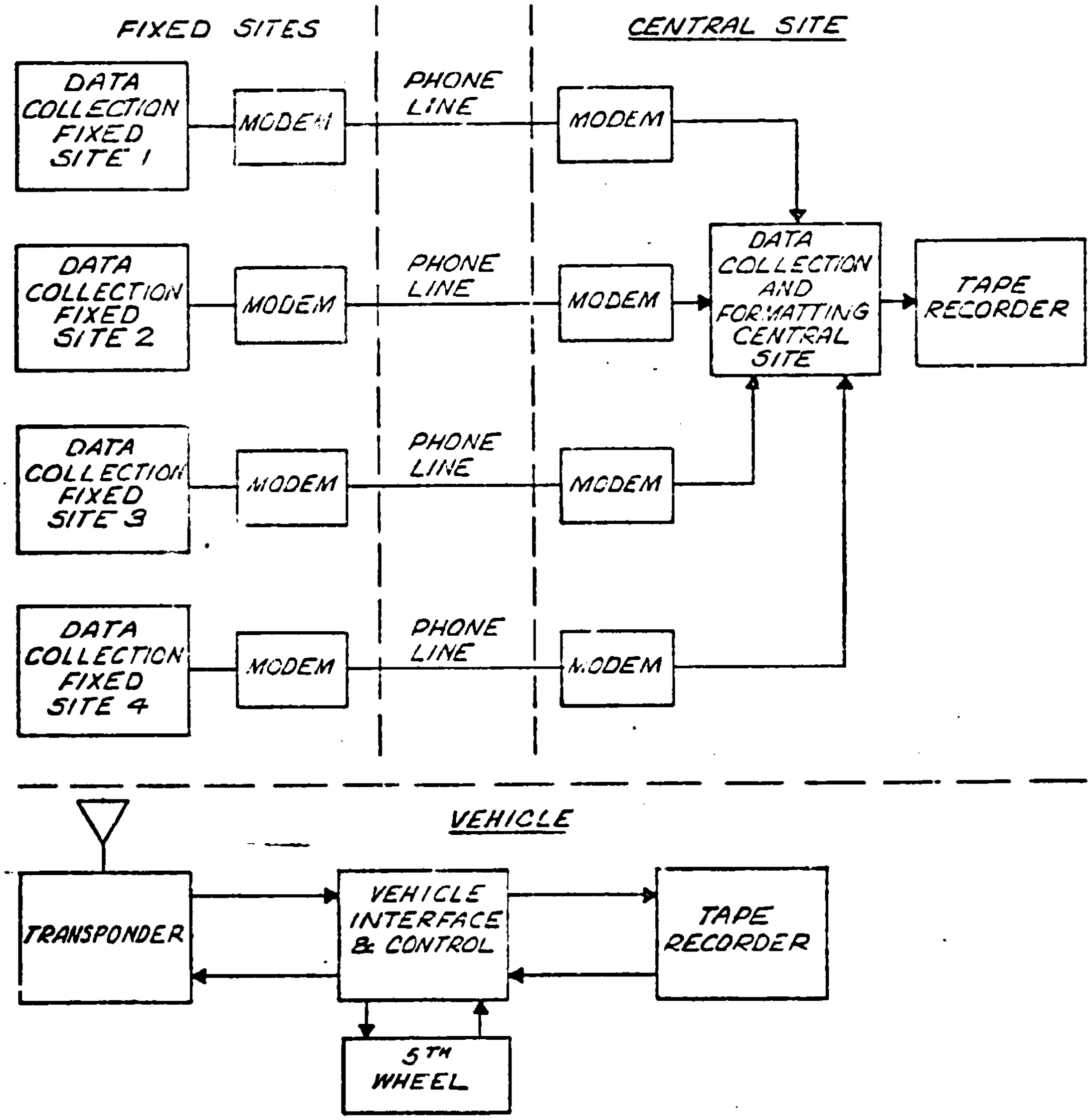


FIGURE 2-7. DATA ACQUISITION SYSTEM

| | FORMAT | MSB | | | | | | | LSB | AUTO. OR MAN. ENTRY | | BYTE CHAR No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HEADER @ TEST START | | | | | | | | | | M | | |
| CENTRAL TAPE & TEST START ID | | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | A | | 1 |
| TAPE # | BCD | ← TENS → | | | | ← UNITS → | | | | M | | 2 |
| FILE # | BCD | ← TENS → | | | | ← UNITS → | | | | M | | 3 |
| TEST # (MSB) | BCD | ← THOUSANDS → | | | | ← HUNDREDS → | | | | M | | 4 |
| " (LSB) | BCD | ← TENS → | | | | ← UNITS → | | | | M | | 5 |
| MONTH | BCD | | | | | | | | | M | | 6 |
| DAY | BCD | | | | | | | | | M | | 7 |
| YEAR | BCD | | | | | | | | | M | | 8 |
| HR. | BCD | | | | | | | | | M | | 9 |
| MIN. | BCD | ← TENS → | | | | ← UNITS → | | | | M | | 10 |
| XMTR PWR SYNC dBm (MSB) | BCD | 0 | 0 | 0 | 0 | ← TENS → | | | | M | | 11 |
| " " (LSB) | BCD | ← UNITS → | | | | ← TENTHS → | | | | M | LOGICAL ↓<br>PHYSICAL ↓ | 12 |
| " CAL (MSB) | BCD | 0 | 0 | 0 | 0 | ← TENS → | | | | M | | 13 |
| " " (LSB) | BCD | ← UNITS → | | | | ← TENTHS → | | | | M | | 14 |
| SPARE | | | | | | | | | | A | | 15 |
| " | | | | | | | | | | A | | 16 |
| (ZERO-FILL PHYS. RECORD) | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | A | | 1022 |
| EOR GAP | | | | | | | | | | A | | |
| | | | | | | | | | | | | |
| CONTINUOUS DATA | | | | | | | | | | A | | |
| BEGIN LOG. RECORD ID | B | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | A | | 1 |
| SITE #1 SLOT # (MSB) | B | | | | | | | | | A | | 2 |
| " (LSB) | B | | | | | | | | | A | | 3 |
| TOA (MSB) | B | | | | | | | | | A | | 4 |
| " (LSB) | B | | | | | | | | | A | | 5 |
| MESSAGE (MSB) | B | | | | | | | | | A/M | | 6 |
| " (LSB) | B | | | | | | | | | A/M | | 7 |
| SITE #2 SLOT # (MSB) | B | | | | | | | | | A | | 8 |
| " (LSB) | B | | | | | | | | | A | LOGICAL DATA RECORD<br>[illegible] | 9 |
| TOA (MSB) | B | | | | | | | | | A | | 10 |
| " (LSB) | B | | | | | | | | | A | | 11 |
| MESSAGE (MSB) | B | | | | | | | | | A/M | | 12 |
| " (LSB) | B | | | | | | | | | A/M | | 13 |
| SITE #3 SLOT # (MSB) | B | | | | | | | | | A | | 14 |
| " (LSB) | B | | | | | | | | | A | | 15 |
| TOA (MSB) | B | | | | | | | | | A | | 16 |
| " (LSB) | B | | | | | | | | | A | | 17 |
| MESSAGE (MSB) | B | | | | | | | | | A/M | | 18 |
| " (LSB) | B | | | | | | | | | A/M | | 19 |
| SITE #4 SLOT # (MSB) | B | | | | | | | | | A | | 20 |
| " (LSB) | B | | | | | | | | | A | | 21 |
| TOA (MSB) | B | | | | | | | | | A | | 22 |
| " (LSB) | B | | | | | | | | | A | | 23 |
| MESSAGE (MSB) | B | | | | | | | | | A/M | | 24 |
| (LSB) | B | | | | | | | | | A/M | | 25 |
| HOUR | BCD | ← TENS → | | | | ← UNITS → | | | | A | | 26 |
| MINUTE | BCD | | | | | | | | | A | | 27 |
| SECOND | BCD | | TENS | | | | | | | A | | 28 |
| SEC./10 | BCD | 0 | 0 | 0 | 0 | ← UNITS → | | | | A | | 29 |
| SPACE | | | | | | | | | | | | 30 |
| SPARE | | | | | | | | | | | | 31 |
| SPARE | | | | | | | | | | | | 32 |
| | A PHYSICAL DATA RECORD = 32 LOGICAL DATA RECORDS | | | | | | | | | | | (1024) |
| EOR GAP | | | | | | | | | | A | | |
| | AS MANY PHYSICAL RECORDS USED AS REQ'D. FOR DURATION OF THAT TEST | | | | | | | | | | | |

FIGURE 2-8. CENTRAL SITE TAPE FORMAT

| | FOR-MAT | MSB | | | | | | | LSB | AUTO. OR MAN. ENTRY | | BYTE/CHAR. NO. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HEADER @ TEST CONCL. | | | | | | | | | | M | | |
| CENTRAL TAPE & TEST CONCL'D. | | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | A | LOGICAL RECORD | 1 |
| TAPE # | BCD | ← TENS → | | | | ← UNITS → | | | | M | | 2 |
| FILE # | BCD | ← TENS → | | | | ← UNITS → | | | | M | | 3 |
| TEST # (MSB) | BCD | ← THOUSANDS → | | | | ← HUNDREDS → | | | | M | | 4 |
| " (LSB) | BCD | ← TENS → | | | | ← UNITS → | | | | M | | 5 |
| MONTH | BCD | | | | | | | | | M | | 6 |
| DAY | BCD | | | | | | | | | M | | 7 |
| YEAR | BCD | | | | | | | | | M | | 8 |
| HR. | BCD | | | | | | | | | M | | 9 |
| MIN. | BCD | ← TENS → | | | | ← UNITS → | | | | M | | 10 |
| XMTR. PWR. SYNC (MSB) | BCD | 0 | 0 | 0 | 0 | ← TENS → | | | | M | | 11 |
| " (LSB) | BCD | ← UNITS → | | | | ← TENTHS → | | | | M | PHYSICAL | 12 |
| CAL. (MSB) | BCD | 0 | 0 | 0 | 0 | ← TENS → | | | | M | | 13 |
| " (LSB) | BCD | ← UNITS → | | | | ← TENTHS → | | | | M | | 14 |
| SPACE | | | | | | | | | | A | | 15 |
| SPACE | | | | | | | | | | A | | 16 |
| (ZERO-FILL PHYS. RECORD) | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | A | | [illegible] |
| EOR GAP | | | | | | | | | | A | | |
| | | | | | | | | | | | | |
| EOF | | | | | | | | | | A | | |

FIGURE 2-8. CENTRAL SITE TAPE FORMAT (cont)

|  | FORMAT | 7 MSB | 6 | 5 | 4 | 3 | 2 | 1 | 0 LSB | AUTO. OR MAN. ENTRY |  | BYTE CHAR No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HEADER @ TEST START |  |  |  |  |  |  |  |  |  | M |  |  |
| LOGICAL RECORD IDENT. | B | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | A | HEADER LOGICAL RECORD<br>HEADER PHYSICAL RECORD | 1 |
| TAPE # | BCD | ← | TENS |  | → | ← | UNITS |  | → | M |  | 2 |
| FILE # | BCD | ← | TENS |  | → | ← | UNITS |  | → | M |  | 3 |
| TEST # (MSB) | BCD | ← | THOUSANDS |  | → | ← | HUNDREDS |  | → | M |  | 4 |
| " (LSB) | BCD | ← | TENS |  | → | ← | UNITS |  | → | M |  | 5 |
| MONTH | BCD |  |  |  |  |  |  |  |  | M |  | 6 |
| DAY | BCD |  |  |  |  |  |  |  |  | M |  | 7 |
| YEAR | BCD |  |  |  |  |  |  |  |  | M |  | 8 |
| HOUR | BCD |  |  |  |  |  |  |  |  | M |  | 9 |
| MINUTE | BCD | ← | TENS |  | → | ← | UNITS |  | → | M |  | 10 |
| XMTR PWR, dBW (MSB) | BCD | 0 | 0 | 0 | 0 | ← | TENS |  | → | M |  | 11 |
| " (LSB) | BCD | ← | UNITS |  | → | ← | TENTHS |  | → | M |  | 12 |
| SPARE |  |  |  |  |  |  |  |  |  | A |  | 13 |
| \| |  |  |  |  |  |  |  |  |  | A |  | 14 |
| \| |  |  |  |  |  |  |  |  |  | A |  | 15 |
| SPARE |  |  |  |  |  |  |  |  |  | A |  | 16 |
| (ZERO FILL PHYS. RECORD) |  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | A |  | 17-102 |
| EOR GAP |  |  |  |  |  |  |  |  |  | A |  |  |
| CONTINUOUS DATA |  |  |  |  |  |  |  |  |  | A |  |  |
| LOGICAL RECORD IDENT. | B | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | A | LOGICAL DATA RECORD (ONCE EACH 0.1 SEC) | 1 |
| HOUR | BCD | ← | TENS |  | → | ← | UNITS |  | → | A |  | 2 |
| MINUTE | BCD |  |  |  |  |  |  |  |  | A |  | 3 |
| SECOND | BCD | ← | TENS |  | → | ← | UNITS |  | → | A |  | 4 |
| TENTH SECOND | BCD | 0 | 0 | 0 | 0 | ← | UNITS |  | → | A |  | 5 |
| EVENT # (MSB) | BCD | ← | THOUSANDS |  | → | ← | HUNDREDS |  | → | A |  | 6 |
| " (LSB) | BCD | ← | TENS |  | → | ← | UNITS |  | → | A |  | 7 |
| 5TH WHEEL (MSB) | B |  |  |  |  |  |  |  |  | A |  | 8 |
| " (LSB) | B |  |  |  |  |  |  |  | (1 FT.) | A |  | 9 |
| INPUT VOLTAGE TO XP | B |  |  |  |  |  |  |  | (0.1 V) | A |  | 10 |
| " CURRENT " | B |  |  |  |  |  |  |  | (0.02 A) | A |  | 11 |
| STATUS (MSB) | B | SIGNPOST | SIGNPOST (1/2 SEC) | SYNC | REFER TO GO | LEAVE POINT | VEHICLE STOPPED | DOOR OPEN | DOOR OPEN (10 SEC) | A/M |  | 12 |
| " (LSB) | B | MESSAGE ERROR | NEW REC. DECODE | TRACK | 0 | 0 | 0 | 0 | 0 | A |  | 13 |
| SPARE |  |  |  |  |  |  |  |  |  | A |  | 14 |
| \| |  |  |  |  |  |  |  |  |  | A |  | 15 |
| SPARE |  |  |  |  |  |  |  |  |  | A |  | 16 |
|  |  | A PHYSICAL DATA RECORD = 64 LOGICAL DATA RECORDS |  |  |  |  |  |  |  |  |  | 1/02 |
| EOR GAP |  |  |  |  |  |  |  |  |  | A |  |  |
|  | AS MANY PHYSICAL DATA RECORDS USED AS REQ'D FOR DURATION OF THAT TEST |  |  |  |  |  |  |  |  |  |  |  |
| HEADER @ TEST END |  |  |  |  |  |  |  |  |  | M |  |  |
| LOGICAL RECORD IDENT. | B | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | A |  | 1 |
| TAPE # | BCD | ← | TENS |  | → | ← | UNITS |  | → | M |  | 2 |
| FILE # | BCD | ← | TENS |  | → | ← | UNITS |  | → | M |  | 3 |
| TEST # (MSB) | BCD | ← | THOUSANDS |  | → | ← | HUNDREDS |  | → | M |  | 4 |
| " (LSB) | BCD | ← | TENS |  | → | ← | UNITS |  | → | M |  | 5 |
| MONTH | BCD |  |  |  |  |  |  |  |  | M |  | 6 |
| DAY | BCD |  |  |  |  |  |  |  |  | M |  | 7 |
| YEAR | BCD |  |  |  |  |  |  |  |  | M |  | 8 |
| HOUR | BCD |  |  |  |  |  |  |  |  | M |  | 9 |
| MINUTE | BCD |  |  |  |  |  |  |  |  | M |  | 10 |
| XMTR PWR, dBW (MSB) | BCD | 0 | 0 | 0 | 0 | ← | TENS |  | → | M |  | 11 |
| " (LSB) | BCD | ← | UNITS |  | → | ← | TENTHS |  | → | M |  | 12 |
| SPARE |  |  |  |  |  |  |  |  |  | A |  | 13 |
| \| |  |  |  |  |  |  |  |  |  | A |  | 14 |
| \| |  |  |  |  |  |  |  |  |  | A |  | 15 |
| SPARE |  |  |  |  |  |  |  |  |  | A |  | 16 |
| (ZERO-FILL PHYS. RECORD) |  | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | A |  | 17-102 |
| EOR GAP |  |  |  |  |  |  |  |  |  | A |  |  |
| EOF |  |  |  |  |  |  |  |  |  | A |  |  |

FIGURE 2-9. VEHICLE TAPE FORMAT

All tapes are image binary, 800 bpi, odd parity. The duplicated tapes are identical to the originals in format, record length and density. All tapes are IBM compatible.

### 2.1.2 System Timing

The basic system timing and waveforms for the Phase I tests are the same as planned for the Phase II operation, ie, the basic synchronization and calibration transmissions are a 2-second repetition period with the overall roll call or frame sync on a 60-second repetition interval.

For Phase I tests only, interval sync is transmitted once every two seconds and the vehicle replies 20 times in that period. Figure 2-10 depicts this test sequence. Subsystem data is therefore available at a 10 per second rate. Data is extracted from the appropriate vehicle time slots by the data processing and software to derive one measurement every 10 seconds for the system level analysis.

The chosen timing sequence checks the roll call technique, the synchronization and calibration technique, and the digital communication capacity of the AVM system, and demonstrates the prime location accuracy of the system.

Figure 2-11 shows the various transmission waveforms of the AVM system. The rf transmission links are central control to vehicle and fixed sites for synchronization and calibration, vehicle to central control via the fixed site receivers for time-of-arrival measurement and message, and signpost to vehicle receiver for time of passage information. Special preamble codes are used (1101, 11101, etc.) to limit false decodes due to noise or other possible signals within the band. The time-of-arrival measurement is made on the third pulse of the vehicle transponder emission received at the fixed site receiver/processor. A modification of the vehicle emission was made to enhance TOA measurement accuracy by overcoming the "zero fill" due to multipath. (Refer to Section 4.3.5.2.)

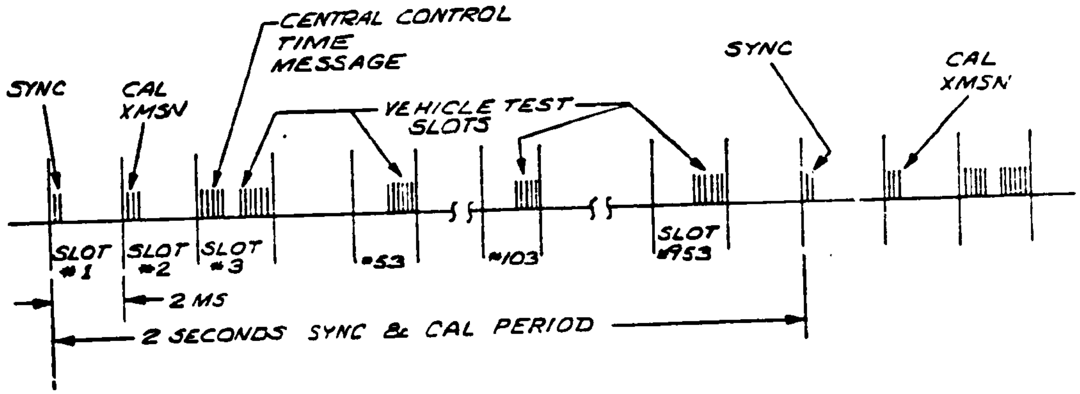


FIGURE 2-10. PHASE I SYSTEM TIMING

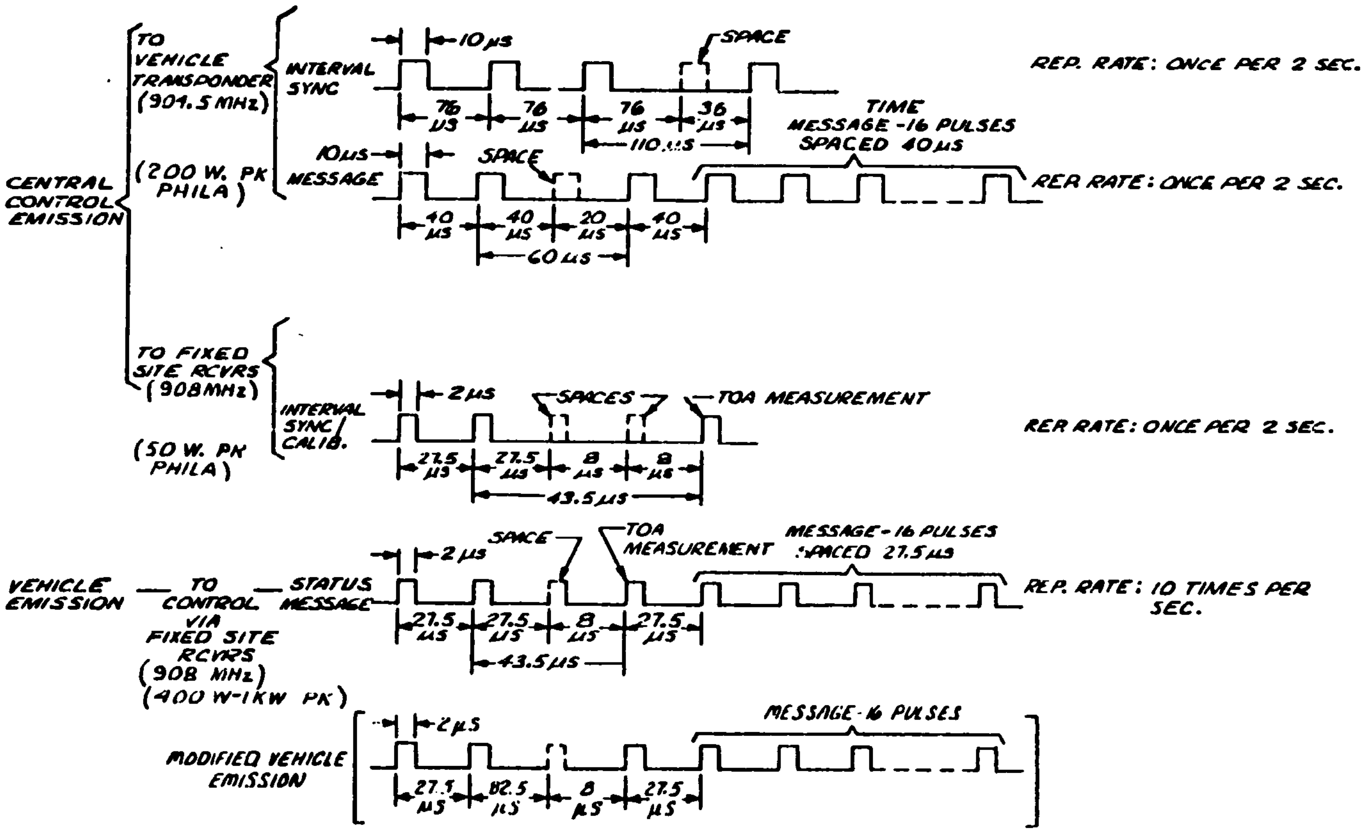


FIGURE 2-11. CENTRAL CONTROL & VEHICLE TRANSMISSION WAVEFORMS

The same waveforms are utilized for the Phase II operation, with the addition of a frame synchronization transmitted code to the vehicle and a frame synchronization/calibration transmission to the fixed site receivers. These waveforms are transmitted at the Phase II frame period of 60 seconds. Phase II transmitter power level for the central control emission is 2 kW peak for the synchronization code and 500 W peak for the calibration code.

The detailed characteristics of the signpost radiated signals are shown in figure 2-12. A 1101 code is used for the signpost recognition code. It is the same code (although wider pulses are used) as the preamble of the central control to vehicle message transmission to simplify vehicle decode circuitry. There is no confusion in code interpretation since the "in-system" synchronized vehicle receiver listens for the signpost transmission only during the second half of the two millisecond vehicle time slot. The receiver listens for its central control message during the first half of its assigned time slots (limited in number of slots per frame time).

The signpost code is transmitted on the sum antenna pattern. Forty microseconds after the leading edge of the last pulse of the code, a twenty microsecond pulse is transmitted on the difference antenna pattern. The vehicle processor performs a ratio measurement on the last pulse of the sum transmission and the pulse of the difference transmission to determine if it is in the signpost beam notch (large sum-to-difference ratio indicates beam notch).

## 2.2 TEST IMPLEMENTATION

### 2.2.1 Equipment Deployment

Fixed Sites - The receiver low noise rf amplifier assembly is configured in a drip-proof enclosure and mounted within 10 feet of the receiver antenna. Antenna heights vary from 200 to 280 feet above ground level. Low loss 1/2" diameter foam Wellflex or equivalent cable is used to connect the rf amplifier assembly with the receiver/processor unit which is either mounted on the roof of the building or in a room within the building. Primary power lines and telephone lines are installed and connected to the receiver/processor unit. One unconditioned phone line per site is used. The power is 120 VAC, 60 Hz at 70 watts. The fixed receiver sites are shown in figures 2-13 through 2-16.

Central Site - The synchronization/calibration transmitter and antenna are located at the City Line Holiday Inn, one of the receiver sites. This arrangement simplifies the test configuration. Low loss rf cable is also used between the transmitter and antenna. The interface and recording equipment are located in a control room within the building. Leased telephone lines are used between the fixed receiver sites and central control for data transmission. The power requirement is 120 VAC, 60 Hz, 2 kilowatts. The central site equipment is shown in figure 2-17.

NOTE: CODE IS RECOGNIZED AS SIGNPOST TRANSMISSION IN THE VEHICLE RECEIVER (VEHICLE LISTENS FOR CODE DURING SECOND HALF OF TIME SLOT PERIOD)

REP. RATE: 6 TRANSMISSION PAIRS PER SECOND

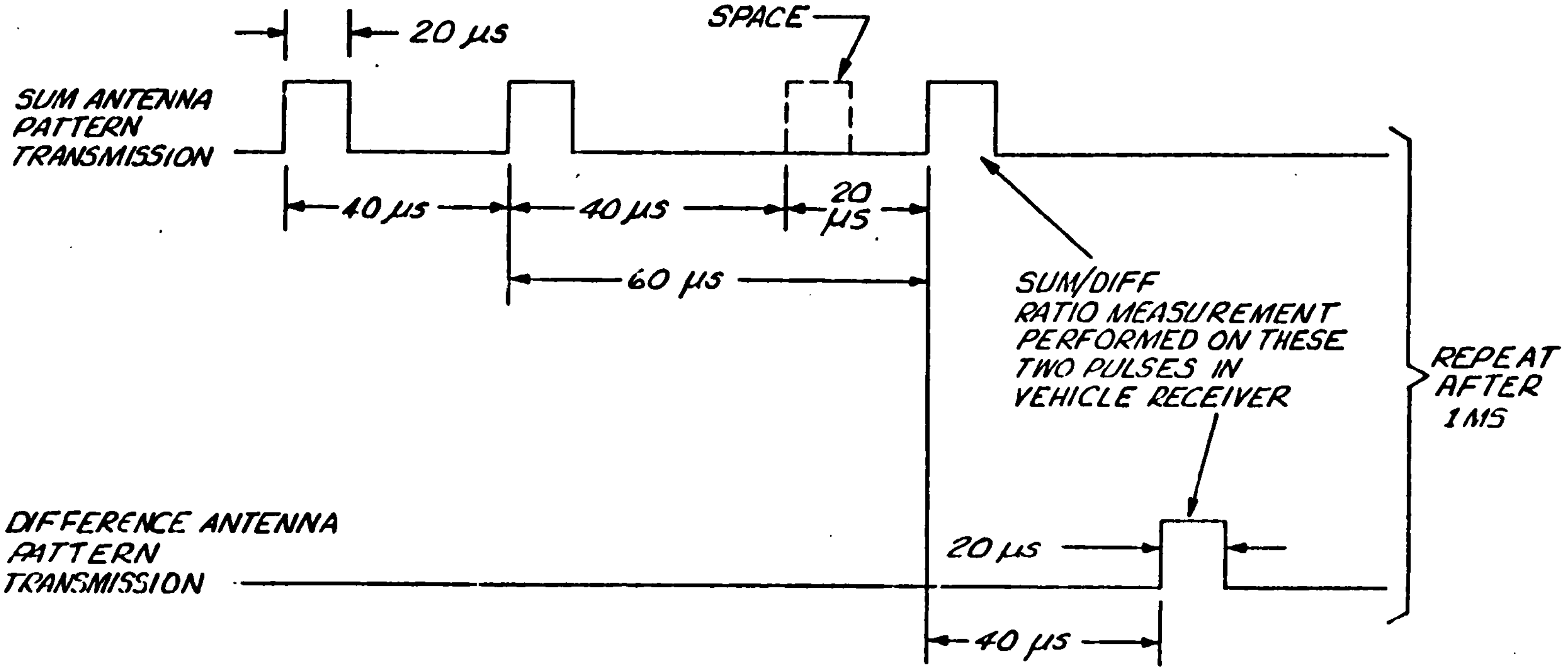


FIGURE 2-12. SIGNPOST RADIATED WAVEFORMS

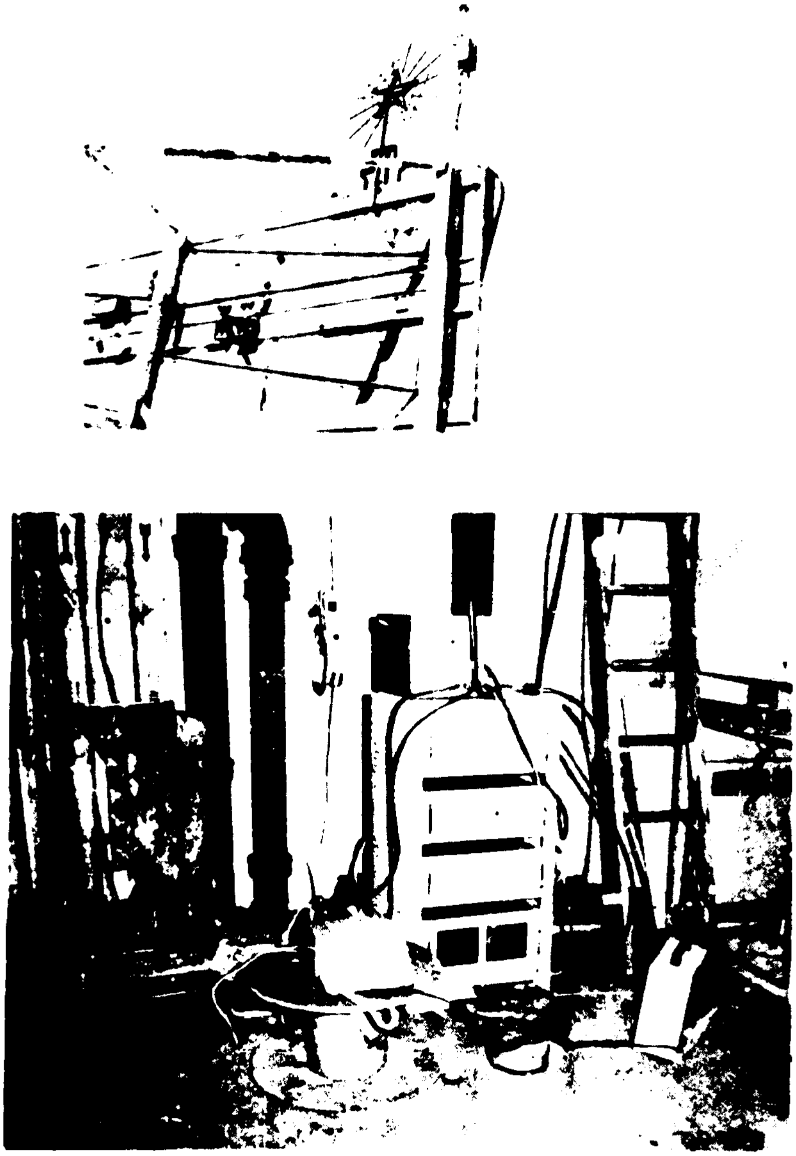


FIGURE 2-13. FIXED SITE - HOLIDAY INN

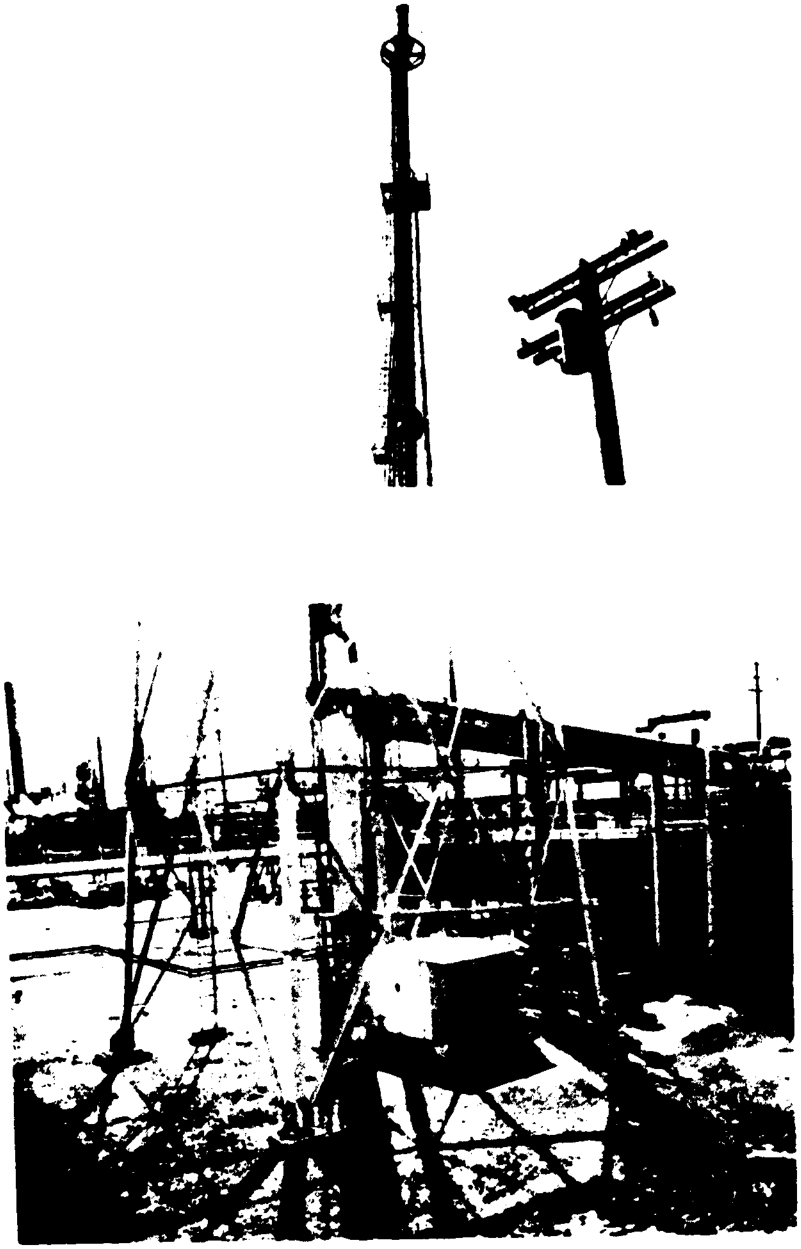


FIGURE 2-14. FIXED SITE - ARCO* FLARE TOWER

*Atlantic Richfield Co.

FIGURE 2-15. FIXED SITE - NORTH GATE APARTMENTS

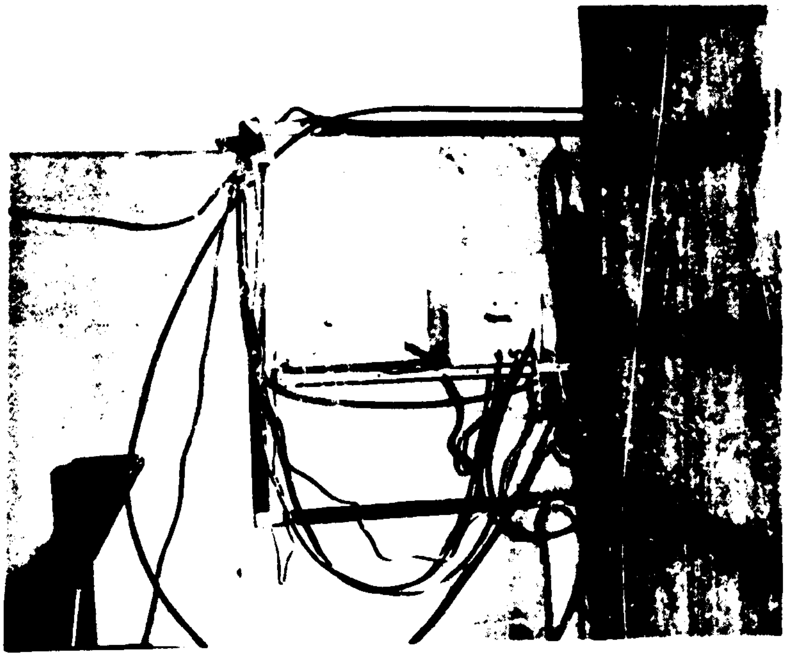


FIGURE 2-16. FIXED SITE - LANDIS STATE HOSPITAL

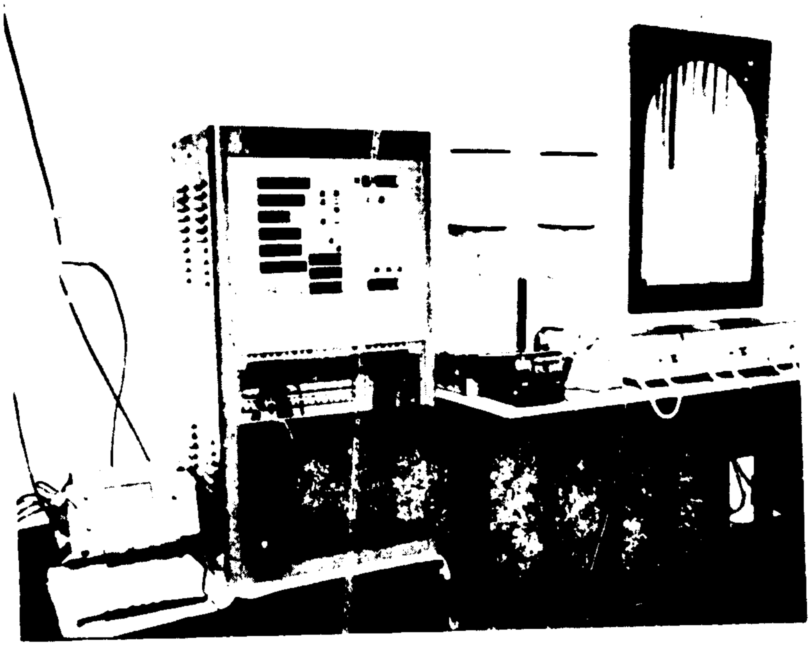


FIGURE 2-17. CENTRAL SITE

Vehicle Installation - Equipment installed in the vehicle consists of a transponder, a roof mounted omni-directional antenna, digital tape recorder, and a vehicle status and control (interface) terminal. The transponder power requirement is 2.5 Amps at 12 VDC. These equipments were installed in the vehicle at Greenlawn, New York, and the completely instumented vehicle driven to Philadelphia for the AVM tests. The fifth wheel assembly is also attached to the vehicle. Photographs of the vehicle equipment are shown in figure 2-18.

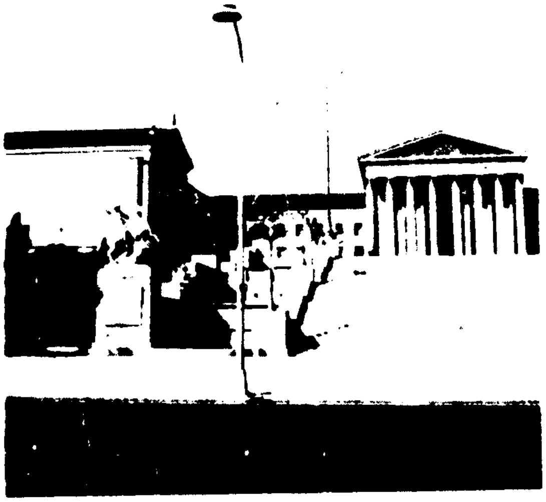
Signpost Installation - Fifteen signposts are installed at the designated positions along the DOT/TSC specified fixed route, as shown in figure 1-6. The optimum mounting height of 25 feet was determined during the preliminary signpost test at Greenlawn, New York. The units are battery powered and do not require any external wiring. Only a mechanical mounting to existing poles or building structures is made. Photographs of the signposts are shown in figure 2-19. Numerals under photos are keyed to the map of figure 1-7.

Licenses and Permits - Formal permits were not required for signpost installations; however, a letter of authorization was obtained from the City of Philadelphia, Department of State. Building modification permits were not required for the installations. An Experimental Research Radio Station License with the Federal Communications Commission for AVM field testing in Philadelphia was obtained.

### 2.2.2 Data Handling Logistics

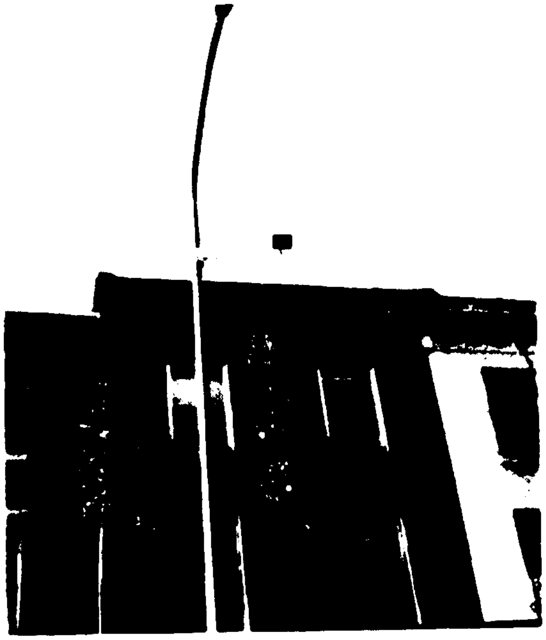
The AVM test program was directed by a test director located at the Philadelphia area. He directed the execution of specific tasks, kept logs of the test run, and transferred information tapes from the test site to the data processing facility. The logs that the test director kept described the test conditions for each test and incorporated comments regarding the performance of that test as to any extenuating circumstances and also identified the tapes which were used for data collection. Following completion of each test, the test director arranged for transfer to the data processing centers (locally at Philadelphia and Hazeltine, Greenlawn). Preliminary data processing was performed by the test team in Philadelphia using the data processing facility of the University of Pennsylvania Medical School. Following preliminary data analysis by the system analyst, any anomolies or problems were immediately communicated to the test director for his consideration in future test planning. Duplicate tapes were made for TSC, at the Hazeltine facility in Greenlawn and shipped to Mitre, McLean Virginia.

FIGURE 2-18. VEHICLE EQUIPMENT INSTALLATION

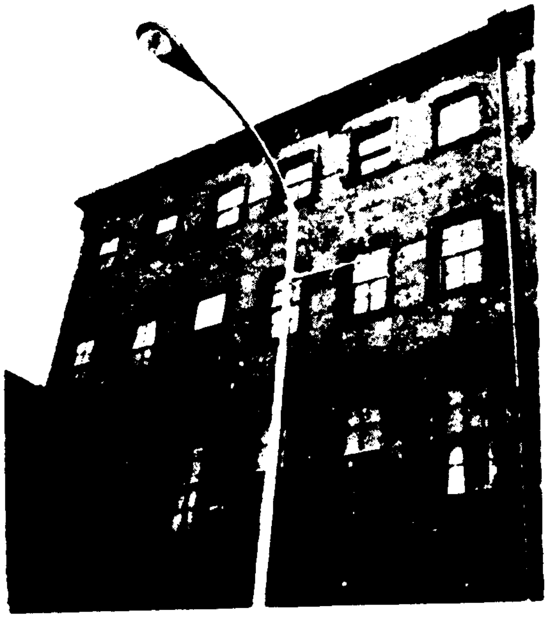


1

2



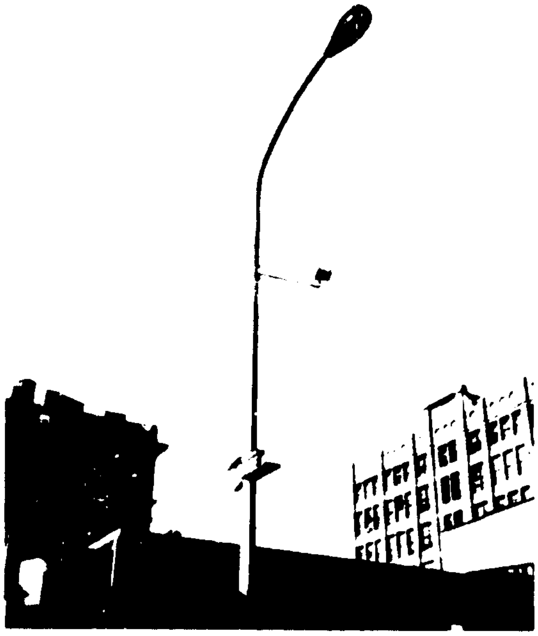
3



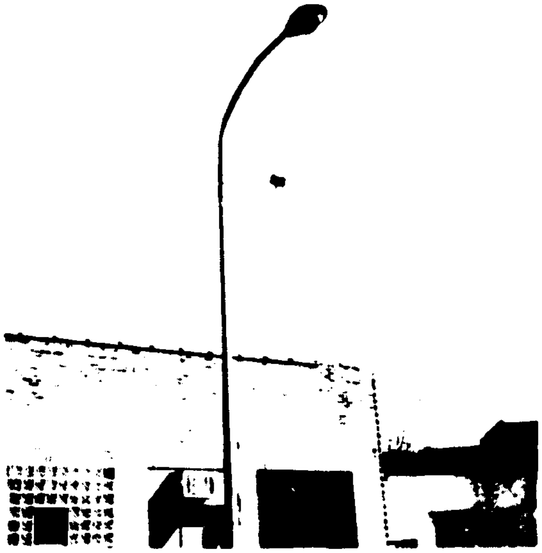
4

FIGURE 2-19. SIGNPOST LOCATIONS

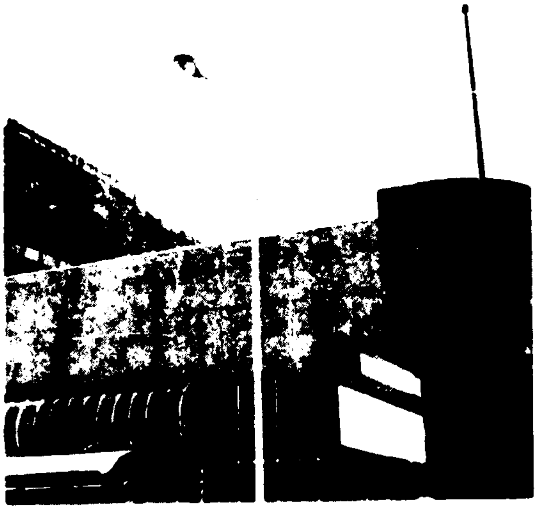
5



6

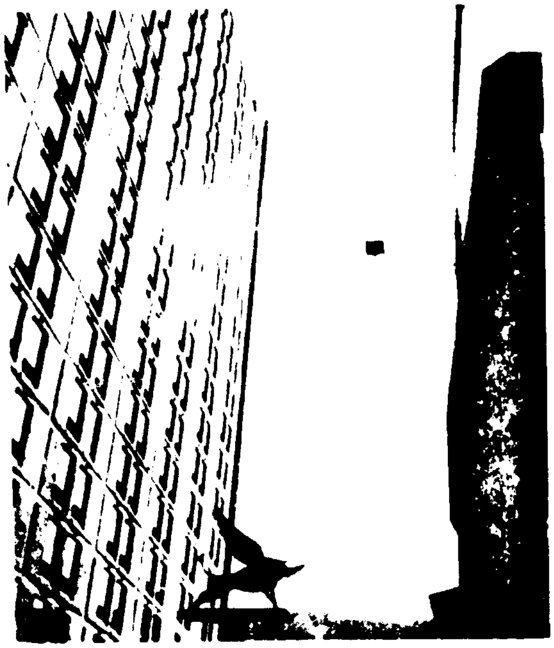


7

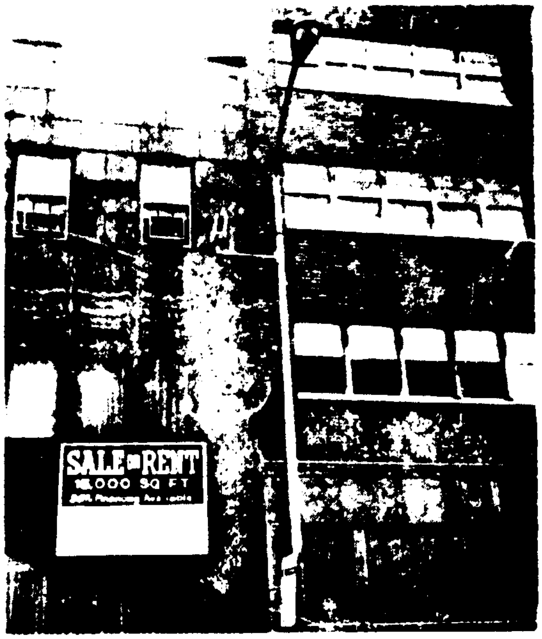


8

FIGURE 2-19. SIGNPOST LOCATIONS (cont)



9



10

11

12

FIGURE 2-19. SIGNPOST LOCATIONS (cont)

13

14

15

FIGURE 2-19. SIGNPOST LOCATIONS (cont)

# 3. DATA ANALYSIS AND REDUCTION TECHNIQUES

This section describes the methods used to collect data during the various vehicle tests and electrical noise measurements that were made to determine equipment design parameters. The description and purpose of each test is specified, and the method of analyzing the data is presented. The techniques used to reduce the large quantity of data collected at the Philadelphia tests are presented, together with the programs and algorithms used in the off-line computer.

## 3.1 DATA COLLECTION

The Location Subsystem test configuration provides automatic (hands-off) operation during the test run, except for manual data entry by the operator. A coding scheme was used for the manual entry to assist the off-line analysis. Raw position and time data in the specified areas and on the specified routes, and auxiliary inputs such as simulated door opening/closing operations were provided. A correlatable time base with a 0.1 second resolution was used in the location subsystem. Any data recorded and actions taken on the vehicle, and messages received at central control were identified with the system time base.

A preliminary survey of the rf spectral density (to obtain base-line data on existing signals) in the regions of the test area, such as substations and utility lines, electrified railroads and trolley tracks, was made to support the analysis of AVM coverage and accuracy performance. Measurements of internal and external noise were made to determine whether the noise is Gaussian or impulsive and its effect on the AVM performance.

### 3.1.1 Location System Data Collection

In addition to the recording of data at central control, all data collected aboard the vehicle was recorded on board the vehicle. This data included time-marker events, check-point identification, fifth-wheel distance readings, signpost signal reception, and AVM equipment power consumption and radiated rf power. Figure 2-4 depicts the vehicle equipment interfaces including the recording equipment and measured parameters.

The manual data entry aboard the vehicle was implemented with multiple thumbwheel switches utilizing pre-assigned coding for the different types of input information. The door open-close sensor in the operational bus system is a contact closure initiated by the door motion. This condition was simulated in the Phase I tests utilizing a toggle switch for manual entry. Power consumption of the on-board vehicle equipment was recorded throughout each test. Power output (dBW) from all transmitters was recorded at the beginning and at the end of each test.

3.1.1.1 Time Correlation. The following method was utilized for the time correlation of the central site recorded data and the on-board vehicle recorded data. Both the central site and the vehicle have real-time crystal-controlled clocks which indicate time in hours, minutes, seconds, and tenths of seconds. This time was displayed and recorded on magnetic tape with the data for each 0.1 second interval, both in the vehicle and the central site. Every two seconds the central site transmitted a 16-bit message in the time slot following the calibration slot. This 16-bit message is the time of the central clock in the following format:

| BIT POSITION | TIME UNIT |
|---|---|
| 1 | Seconds, 2 |
| 2 | Seconds, 4 |
| 3 | Seconds, 8 |
| 4 | Seconds, 10 |
| 5 | Seconds, 20 |
| 6 | Seconds, 40 |
| 7 | Minutes, 1 |
| 8 | Minutes, 2 |
| 9 | Minutes, 4 |
| 10 | Minutes, 8 |
| 11 | Minutes, 10 |
| 12 | Minutes, 20 |
| 13 | Minutes, 40 |
| 14 | Hour, 1 |
| 15 | Hour, 2 |
| 16 | Hour, 4 |

It was not necessary to transmit tenths of seconds or the one second bit because it was known that the message is only transmitted on an even number of seconds. In the vehicle, this central site time was compared each two seconds with the vehicle clock. If the two times disagree, a time-error bit was sent to the fixed sites in the status word. The error data is then sent over telephone lines to the central site, where it was recorded. Logic circuits in the vehicle determine if the vehicle clock will be "corrected" to the time received based on a consistent discrepancy, and not on a "one-time" corrupted message. If the time message was not received, the vehicle clock continued to run on its own. The accuracy of the two clocks was such that only a few corrections, each involving adding or inhibiting a single 0.1-second increment, was normally required. The procedure for initial synchronization of the two clocks is described in the Appendix.

### 3.1.2 Noise Measurements

Measurements of internal and external noise were made. Noise data was collected in representative urban, suburban, and industrial situations. The necessary noise data was obtained by using the AVM 200 kHz bandwidth vehicle receiver, and a commercial EMI/RFI field intensity meter (Empire Devices Noise Meter Model NF-105 with 900 MHz plug-in). Data was taken by hand after reading the equipment signal strength meters. The carrier pseudo peak (weighted peaks) positions on the standard field intensity meter were utilized and data was recorded in both positions. A switch was provided in the vehicle receiver so that noise measurements were made with and without the noise blanker circuit. Measurements were taken to determine the characteristics of the internal and external noise of the AVM receivers. Since, at 900 MHz, most of the noise affecting the vehicle is impulsive, a noise blanker circuit has been incorporated into the transponder receiver to suppress the impulsive noise.. The circuit proved to be very effective. Data on the impact of impulsive noise, with and without the blanker circuit, is presented in Section 4.3.8. The following items were measured:

Frequency of a noise impulse crossing at two threshold levels.

Frequency distribution of noise crossing a fixed threshold as a function of sampling interval.

## 3.2 DATA ANALYSIS

In determining location accuracy during the Philadelphia test program, performance was evaluated at both the system level and the subsystem level. Data was collected at a rate of 10 samples per second, although the proposed Hazeltine AVM system utilizes measurements for each vehicle at a rate of once every 10 seconds. The subsystem evaluation is based on the 10 per second sample rate so as to permit evaluation of the AVM location subsystem in local regions of interest. The performance of the system is determined with the data obtained at 10 second intervals to conform with the techniques proposed for use in Los Angeles.

The software of the off-line computer simulates the system level test by passing data to the location algorithm at 10 second intervals. The rest of the data is ignored.

In order to prevent the missing of signpost and door open data during the system level tests, a ten-second signpost bit and a ten-second door bit were included in the vehicle-to-central control message. These bits stay high for ten seconds after the actual signpost signal drops out to simulate the system level message.

The location reference for the system and subsystem level tests were the absolute locations in the event table if the vehicle is experiencing an event, or the current fifth wheel location if no event is present. The fifth wheel location was derived from the last event location, fifth wheel count and direction vector, found in the event file, and the current fifth wheel count.

### 3.2.1 Fixed Route Tests

Position and time point accuracy computations were performed off-line using the recorded data and the same processing methods as proposed for the actual full-scale system. Garbled or incomplete data samples are rejected automatically by a screening algorithm. The screening algorithms are based on apriori knowledge of vehicle route.

The fixed route supplied by D.O.T. contained 76 checkpoints. In addition, fifteen time points were included in the fixed route. In order to achieve the desired sample size for the time point test, it was necessary to repeat the route 30 times. Because of the time required to set up the checkpoints and time points, the 30 runs were made with the same checkpoints.

Route and event point data are provided as input to the computer program. The program uses this information to merge and synchronize the data taken at the central site with that taken on board the vehicle. The route of the vehicle is also a part of the input data and is used to detect departure from the route. A listing of the fixed route events is shown in table 3-1.

### 3.2.2 Random Route Test

The random route test was similar to the fixed route test with two important exceptions: (1) there were no time points in the random route test, and (2) apriori knowledge of the route is not used to determine the vehicle location.

The random route test consisted of 123 checkpoints, and was run six times. A listing of the random route events is shown in table 3-2.

### 3.2.3 Special Tests

The analysis of special case tests involves a comparison of special test data to data obtained in a similar environment without the special case situation.

3.2.3.1 High Speed Test. The high speed test contains approximately 400 subsystem level points. These points are compared with the fifth wheel data for location accuracy. The test was performed twice to ensure a successful run.

3.2.3.2 Power Line Interference Test. This test is included as part of the fixed route test. Data taken near the 30th Street Railroad Station was extracted from the fixed route test and presented separately. All points that fall within preassigned interference test event locations were extracted on each of the runs of the fixed test.

## TABLE 3-1. HAZELTINE FIXED ROUTE

Driving Instructions, 15 Timepoints and 58 Checkpoints

Event

1 - Start run on Spring Garden at 16th - (left turn and West on Spring Garden)

2 - Center of 18th

3 - Center of 20th

4 - Center of 22nd

5 - Half rt at Art Museum Circle

6 - Circle turn toward museum (R)

7 - Museum (TP 1)

8 - Circle turnaway from museum (L)

9 - Half rt onto Ben Franklin Pkwy

10 - Center of 22nd

11 - Center of 20th

12 - At Logan Circle (Race & 19th)

13 - After Cherry (TP 2)

14 - Near side of JFK Blvd [(R) (Short Post nearest JFK)]

15 - Near side of Market [(R) (No Right Turn sign)]

16 - Center of Ranstead

17 - Near side of Walnut [(R) No Parking Loading Zone Zone Sign]

18 - Right on Walnut

19 - Left at Rittenhouse

20 - Center of Locust

21 - Left at S. Rittenhouse

22 - Right at 19th St

23 - Center of Spruce

24 - Pine (TP 3)

25 - Left on Pine

26 - Center of Bouvier

27 - Center of Hicks

28 - Far side of Broad [(R) No Parking at Any Time sign]

29 - Center of Quince

Event

30 - Center of 10th

31 - Between 8th & 9th (TP 4)

32 - Near side of 7th [(R)(No stopping Bus Only sign)]

33 - Left on 7th

34 - Center of Spruce

35 - Left on S. Washington Sq.

36 - Right on W. Washington Sq.

37 - Half rt on Diagonal

38 - Half left on Walnut

39 - Far side of Walnut [No Parking Anytime Sign (R)]

40 - Center of Ranstead

41 - Left on Market

42 - Turn on Market (TP 5)

43 - Center of 9th

44 - Center of 11th

45 - Between 12th and 13th [Light pole No Stopping Anytime (R)]

46 - Right on 13th

47 - Center of Commerce

48 - Arch (TP 6)

49 - Center of Cherry

50 - Center of Summer

51 - Center of Carlton

52 - Center of Nectarine

53 - Right on Spring Garden

54 - Right on Ridge

55 - Turn onto Ridge (TP 7)

56 - Center of Hamilton

57 - Center of Callowhill

58 - Left on Race

59 - Center of 7th

60 - Right on Sixth

61 - Turn onto 6th (TP 8)

TABLE 3-1. HAZELTINE FIXED ROUTE (cont)

Event

62 - Center of Market
63 - Near side of Walnut [No Stopping sign (R)]
64 - Right on Walnut
65 - Center of 9th
66 - Between 10th & 11th (TP 9)
67 - Center of Camac
68 - Center of Juniper
69 - Center of Sydenham
70 - Center of 17th
71 - Near side of 21st
72 - 23rd (TP 10)
73 - Far side of Expressway [(R) Pole - Speed 25 Bus Stop signs]
74 - Near side of 33rd [(L) light pole]
75 - Right on 33rd
76 - Right on Chestnut
77 - Turn on Chestnut
78 - Center of 31st
79 - 23rd (TP 11)
80 - Center of 21st
81 - Left on 18th
82 - Center of Ludlow
83 - Left on JFK Blvd
84 - JFK Blvd (TP 12)
85 - Center of 21st
86 - Right on Penn RR Station
87 - Left on Arch
88 - Left on 30th
89 - Near side of JFK Blvd [(R) light pole]
90 - Right on JFK Blvd
91 - Follow JFK Blvd Left
92 - Measure at Market (TP 13)
93 - Left on Market

Event

94 - Center of 30th
95 - Center of 22nd
96 - Center of 20th
97 - Center of 17th
98 - Near side of 15th [(R) light pole - All Traffic Must Turn Right]
99 - Right on 15th
100 - Left at S. Penn Square
101 - Broad (TP 14)
102 - Left on Juniper
103 - Far side of Market [(L) pole - Tourist Center sign]
104 - Left on JFK Blvd.
105 - Right on 16th
106 - Center of 16th
107 - Right on 18th
108 - Center of Vine (North)
109 - Right on Callowhill
110 - Turn onto Callowhill (TP 15)
111 - Center of 17th
112 - Left on 16th
113 - Turn on 16th (wooden pole)
114 - Center of Hamilton
115 - END OF RUN AT BUTTONWOOD (L)

## TABLE 3-2. HAZELTINE RANDOM ROUTE

Driving Instructions, and 94 Checkpoints

Event

1 - START RUN at 23rd & Market (Proceed East on Market)
2 - Center of 22nd
3 - Center of 21st
4 - Center of 20th
5 - Center of 19th
6 - Center of 18th
7 - Center of 17th
8 - Center of 16th
9 - Right on 15th
10 - Left at Penn Square
11 - Broad Street [Girard Bank Doorway (R)]
12 - Right on Broad
13 - Center of Sansom
14 - Center of Walnut
15 - Center of Locust
16 - Center of Spruce
17 - Center of Pine
18 - Near side of Lombard [Parking lot entrance (R)]
19 - Right on Lombard
20 - Center of Carlisle
21 - Near side of 16th [Town Court Nursing Home sign (L)]
22 - Right on 16th
23 - Center of Waverly
24 - Center of Delancey
25 - Center of Latimer
26 - Center of Chancellor
27 - Center of Sansom
28 - Center of Ludlow
29 - Right on Market
30 - Right on 15th
31 - Center of Ranstead

Event

32 - Center of Ionic Street
33 - Center of Moravian
34 - Right on Walnut
35 - Center of Sydenham
36 - Center of 17th
37 - Between 18th and 19th [Mutual Benefit Life 1845 (R)]
38 - Center of 20th
39 - Center of Van Pelt
40 - Near side of 23rd [WPEN sign (L)]
41 - Left on 23rd
42 - Center of St. James
43 - Left on Locust
44 - Center of 22nd
45 - Center of 21st
46 - Near side of Rittenhouse Sq [222 Canopy (R)]
47 - Around Rittenhouse Square right turn
48 - Left turn
49 - Near side of 18th [1810 Rittenhouse Savoy entrance (R)]
50 - Exist on Locust heading East left turn
51 - Right turn
52 - Center of Bouvier
53 - Center of Sydenham
54 - Right on 15th
55 - Center of Manning
56 - Right on Spruce
57 - Center of 16th
58 - Near side of 18th [Great Scot Market (R)]
59 - Right on 18th
60 - Center of Chancellor

### TABLE 3-2. HAZELTINE RANDOM ROUTE (cont)

Event

61 - Center of Moravian
62 - Left on Sansom
63 - Center of 19th
64 - Center of 20th
65 - Left on 21st
66 - Center of Locust
67 - Center of Cypress
68 - Center of Addison
69 - Right on Lombard
70 - Center of Van Pelt
71 - Right on 22nd
72 - Center of Pine
73 - Center of Cypress
74 - Center of Latimer
75 - Near side of Walnut [Parking lot (R)]
76 - Near side of Sansom [(L) Gas station Official Inspection Station sign on wooden lamp-post]
77 - Left on Sansom
78 - Left on 23rd
79 - Center of Chancellor
80 - Center of Latimer
81 - Center of Spruce
82 - Center of Panama
83 - Center of Lombard
84 - Left on South
85 - Center of 22nd
86 - Near side of 20th [Laundromat sign (L)]
87 - Left on 20th
88 - Center of Lombard
89 - Center of Panama
90 - Center of Spruce
91 - Center of Chancellor
92 - Center of Sansom
93 - Center of Ranstead

Event

94 - Right on Market
95 - Between 19th and 20th [Avis (L)]
96 - Between 18th and 19th [Holiday Inn (R)]
97 - Between 17th and 18th [Greyhound Bus sign (L)]
98 - Right on 17th
99 - Center of Ranstead
100 - Center of Moravian
101 - Center of Locust
102 - Center of Delancey
103 - Left on Pine
104 - Center of Smedley
105 - Center of 15th
106 - Right on Broad
107 - Right on Lombard
108 - Center of 16th
109 - Near side of 18th [Park Here sign (L)]
110 - Right on 18th
111 - Center of Waverly
112 - Center of Cypress
113 - Left on Spruce
114 - Between 19th and 20th (1923 Canopy)
115 - Center of Van Pelt
116 - Left on 23rd
117 - Left on Pine
118 - Center of Van Pelt
119 - Center of 19th
120 - Right on 17th
121 - Center of Waverly
122 - Right on Lombard
123 - Center of 19th
124 - Left on 21st
125 - Left on South
126 - Center of 19th
127 - Center of 17th

Table 3-2. HAZELTINE RANDOM ROUTE (cont)

Event

128 - Center of 15th
129 - Left on Broad
130 - Center of Lombard
131 - Center of Pine
132 - Center of Spruce
133 - Center of Locust
134 - Center of Walnut
135 - Center of Sansom
136 - Center of Chestnut
137 - END OF RUN (South Penn Square)

3.2.3.3 GDOP Test. Three hundred location samples were taken at each of twenty fixed vehicle locations randomly spaced within a 1/2 mile radius of the site. The average errors in X, Y and radial from the true location were determined for each vehicle location.

3.2.3.4 Trilateration System Time Point Measurements. Eight time points were used spaced approximately 1/2 mile apart in Fairmont Park near the East River Drive. Ten passes of the route provides 80 time point measurements.

3.2.3.5 Underpass Test. Five underpasses are included in this test along the Schuylkill Expressway. Data was taken for the total run.

## 3.3 DATA REDUCTION

The program is divided into four major sections (figure 3-1). The first section initializes the test and brings the tapes to a common starting point, usually the first event. It also prompts the user to specify which options will be used (see table 3-3).

The second section simulates the real time operation of the Phase II system. It gathers data and provides for location calculations, as well as signpost and time point determinations. This section also performs the clock calibration in software.

Section 3 correlates the data of Section 2 with the data recorded on board the vehicle, and performs preliminary data analysis and formatting of outputs. This section also correlates the vehicle data to the event table, where possible, and records subsystem accuracy data.

The fourth section is entered after all the data is processed. This section takes the data files generated previously and through interaction with the user prints the tables and histograms.

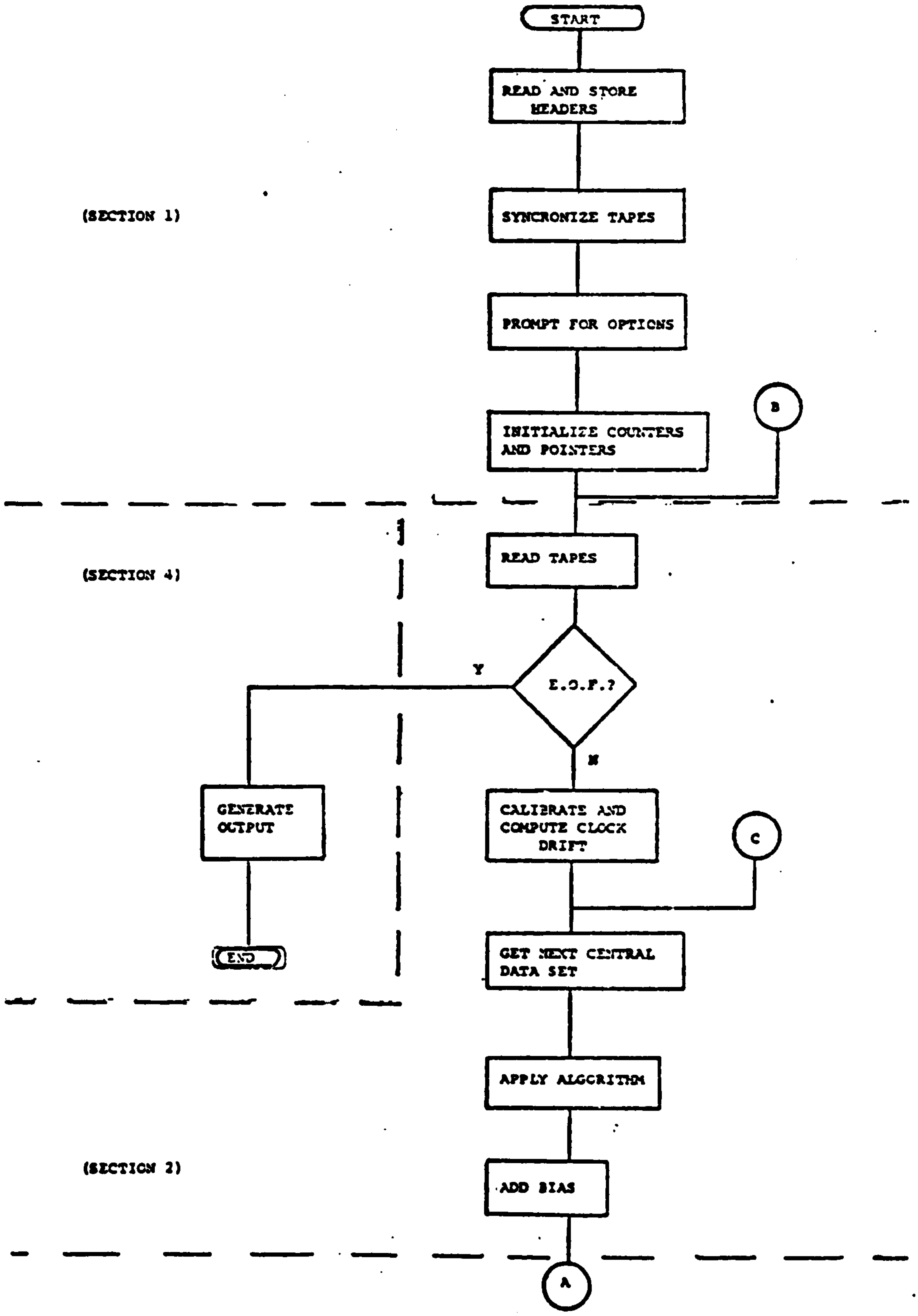


FIGURE 3-1. SYSTEM PROGRAM

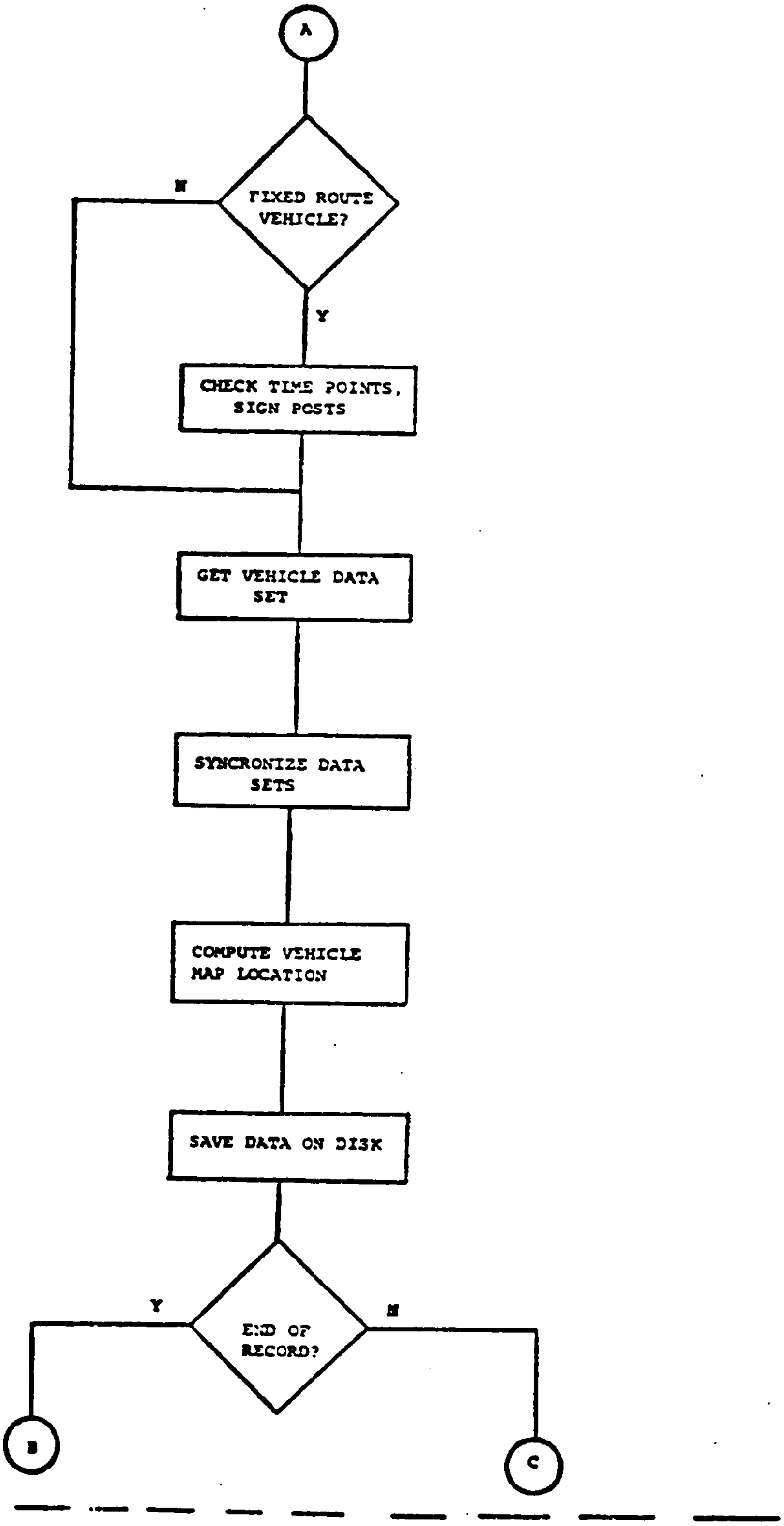


FIGURE 3-1. SYSTEM PROGRAM (cont)

## TABLE 3-3. USER SPECIFIED OPTIONS

1. Configuration Selection
2. File and Test Selection
3. Fixed or Random Route Test
4. Timeslot Option (process only selected time slots)
5. System Level Option (process one data set every 10 seconds)
6. Process Every N$^{th}$ Data Set
7. Save Data Every N$^{th}$ Data Set
8. Data Smoothing Option
9. Data Filtering Option
10. Extended Histogram Option (Histogram Printout of Intermediate Data)
11. Extended Histogram Chaining
12. Save Raw Data
13. Save Intermediate Data
14. Save Rejected Data
15. Save Data Between Limits of Time or Events
16. Histogram Format of Test Data

### 3.3.1 Algorithms

The following is a list of operations which the different sections of the program go through and a brief description of how they are accomplished. The descriptions supplement figure 3-1. Only two dimensional units are used in the program; they are COUNTS (time) and UNITS (distance). They are fixed only by the input dimension and the conversion factor KTTOD.

#### 3.3.1.1 Main Programs

##### 3.3.1.1.1 Central Site and Vehicle Tape Sync (Figure 3-2)

Interaction with the user is used to select the test file to be processed on both input devices. The headers are read from the tape and stored for reprint with the results. Next, the tapes must be brought to a common point, and since the test starts with the first event, this is the point used. If the first event is missing, the second is used and the error recorded. Tapes are matched to the nearest 1/10 second.

##### 3.3.1.1.2 Prompter (Figure 3-3)

This section of the program uses interaction with the user to set up options and initialize the program. The user selects the configuration and the required outputs as well as specifying how often a location fix is performed. This section also computes the distance between sites, and the starting points for the location algorithm.

##### 3.3.1.1.3 Calibration (Figure 3-4)

This section computes the drift in the site clocks relative to the base clock. Since the calibration signal arrives at each site at a different time, the TOA's must be compensated.

The drift is:

$$\text{Drift A} = (\text{Site A count} - \begin{array}{l}\text{Propagation}\\ \text{Compensation}\\ \text{Count}\end{array} - \text{Base Site Count})$$

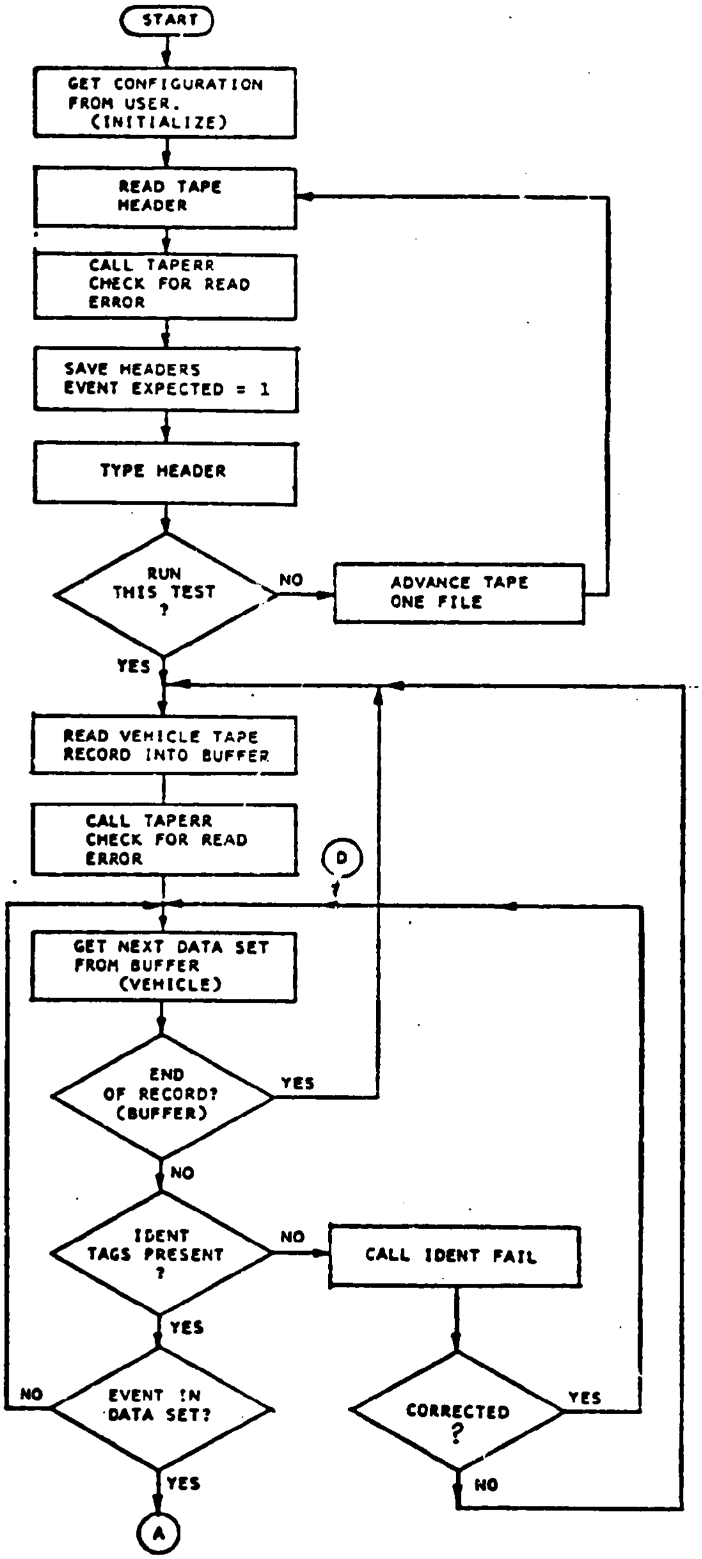


FIGURE 3-2. CENTRAL SITE AND VEHICLE TAPE SYNC

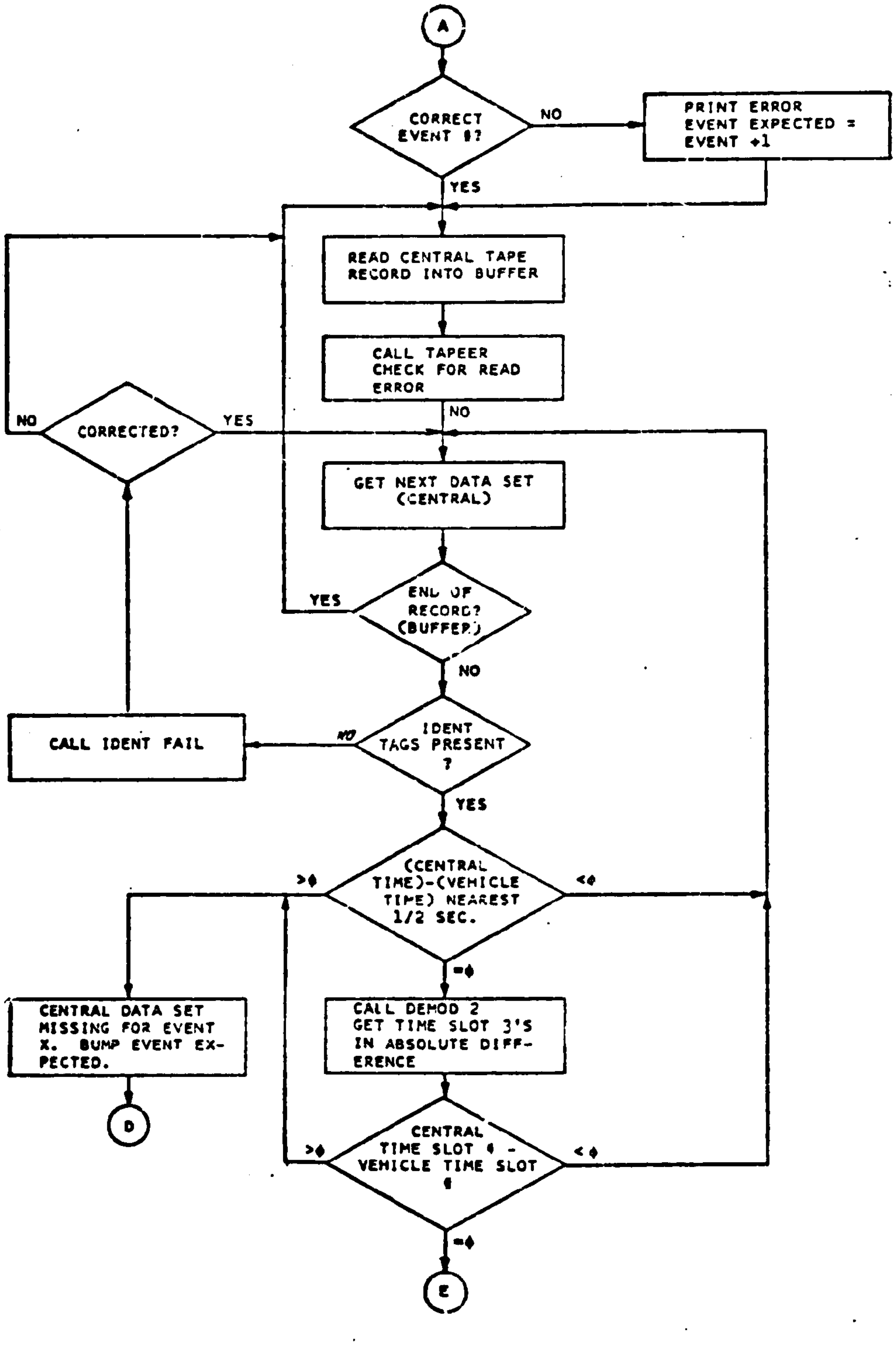


FIGURE 3-2. CENTRAL SITE AND VEHICLE TAPE SYNC (cont)

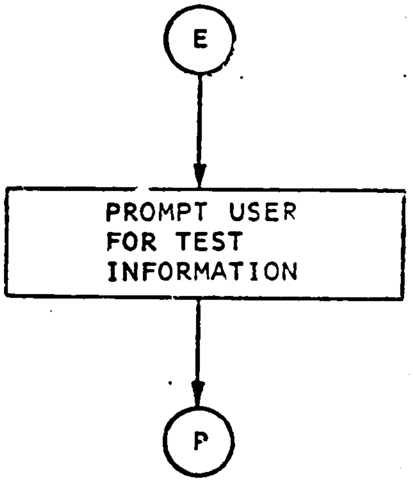


FIGURE 3-3. PROMPTER

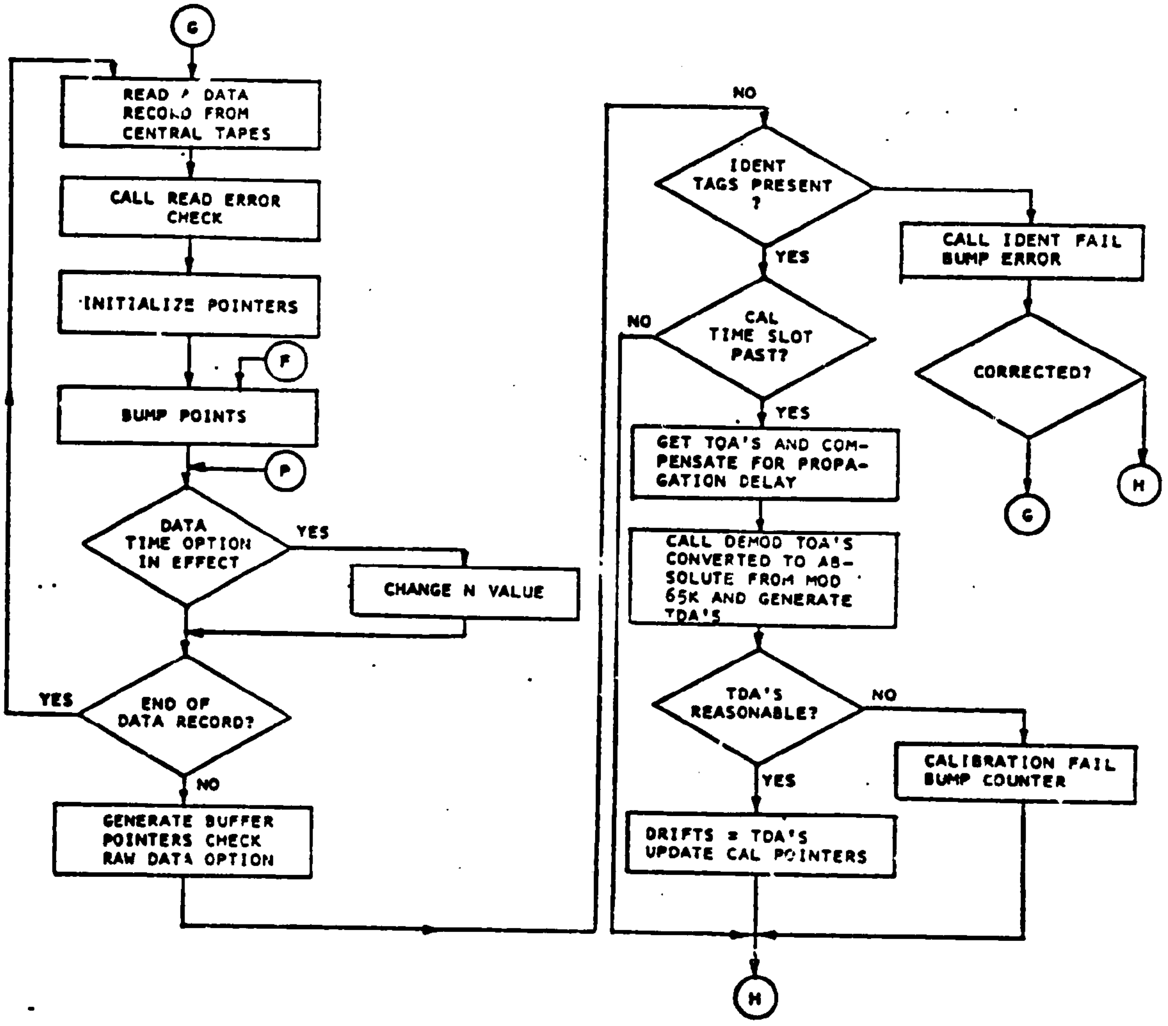


FIGURE 3-4. CALIBRATION

The particular calibration reading to be used is determined at the start of the loop by the updated vehicle and central time slot count.

### 3.3.1.1.4 Data Set Retrieval (Figure 3-5)

The function of this section is to provide the location algorithm with the necessary information. The TDA's are in clock counts. If a TDA exceeds the base line count between sites in magnitude, the Data Set is discarded. This test does not discard data outside the coverage area. A failure flag is checked to see if a look-up is required on the starting (X, Y). The failure flag threshold is set by the user at execution to the number of consecutive location failures allowed before a look-up is performed for that vehicle.

### 3.3.1.1.5 Location Algorithm (Figure 3-6)

This routine uses the TDA's and starting (X, Y) to determine the error in (X, Y). The program loops until the error meets the threshold or the maximum number of iterations is exceeded.

$$\begin{bmatrix} \Delta X \\ \Delta Y \end{bmatrix} = [H]^{-1} \begin{bmatrix} \text{TDA1 ERROR} \\ \text{TDA2 ERROR} \end{bmatrix}$$

Where [H] is the direction cosine matrix.

### 3.3.1.1.6 Bias (Figure 3-7)

The bias for X and Y are given in a 4-dimensional lookup table. The indexes given by (X, Y) are:

1. $X = \text{IFIX} \quad \dfrac{(X_{\text{Location}} - X_{\text{Offset}}) \text{ miles}}{\frac{1}{2} \text{ mile}}$

2. $Y = \text{IFIX} \quad \dfrac{(Y_{\text{Location}} - Y_{\text{Offset}}) \text{ miles}}{\frac{1}{2} \text{ mile}}$

3. Configuration (1 or 2)

4. Returned Value (X or Y) Bias.

### 3.3.1.1.7 Data Smoothing Option (Figure 3-8)

This section discards points which are far removed from the current vehicle position. If N points (N is set by the user) are missed,

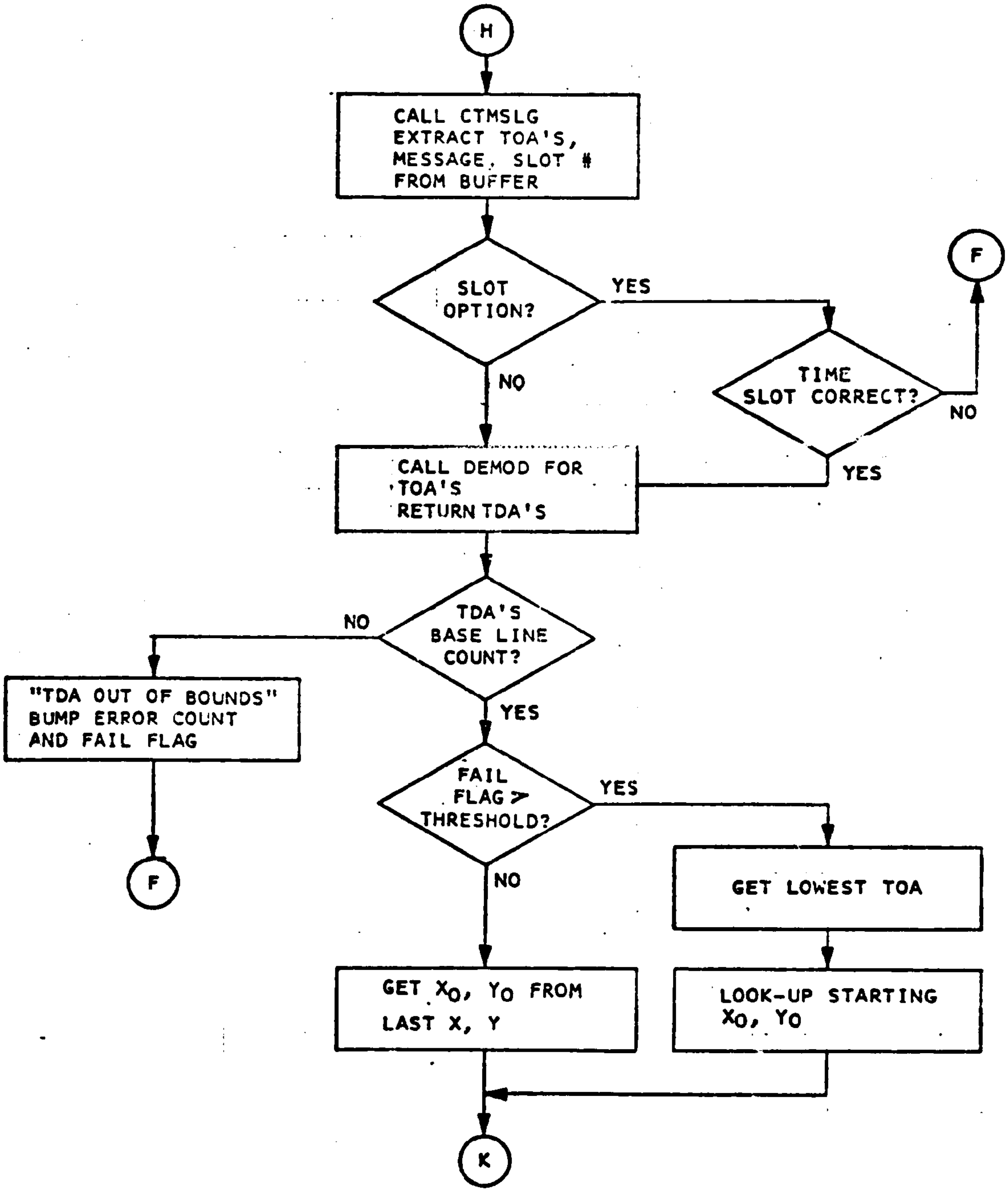


FIGURE 3-5. DATA SET RETRIEVAL

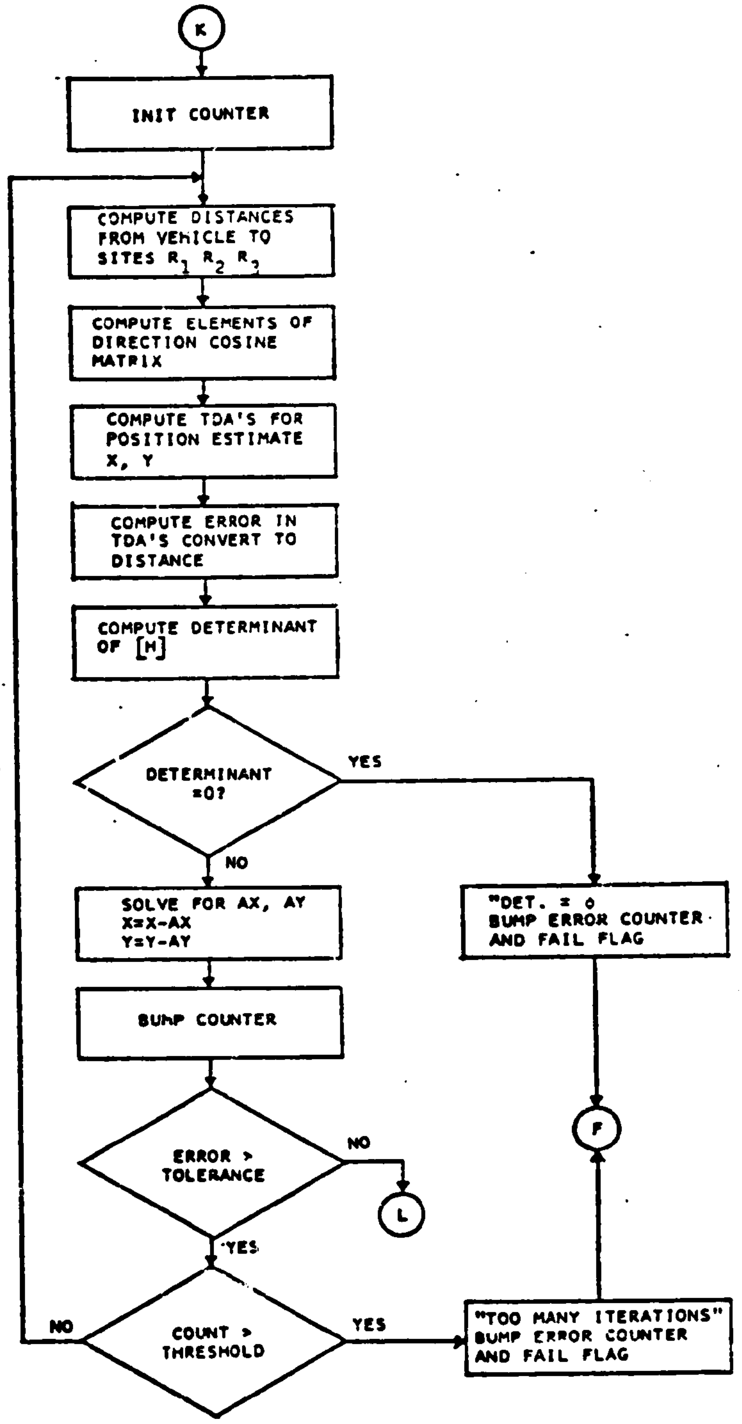


FIGURE 3-6. LOCATION ALGORITHM

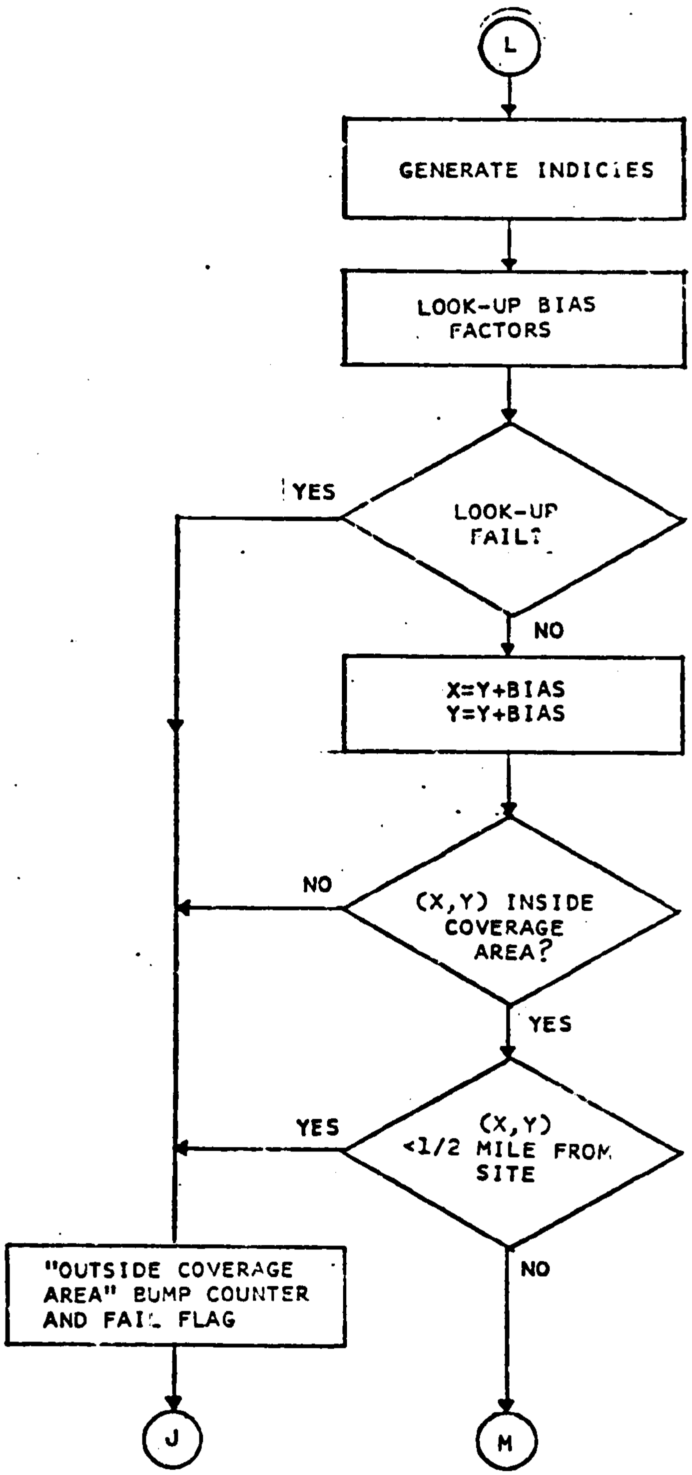


FIGURE 3-7. BIAS

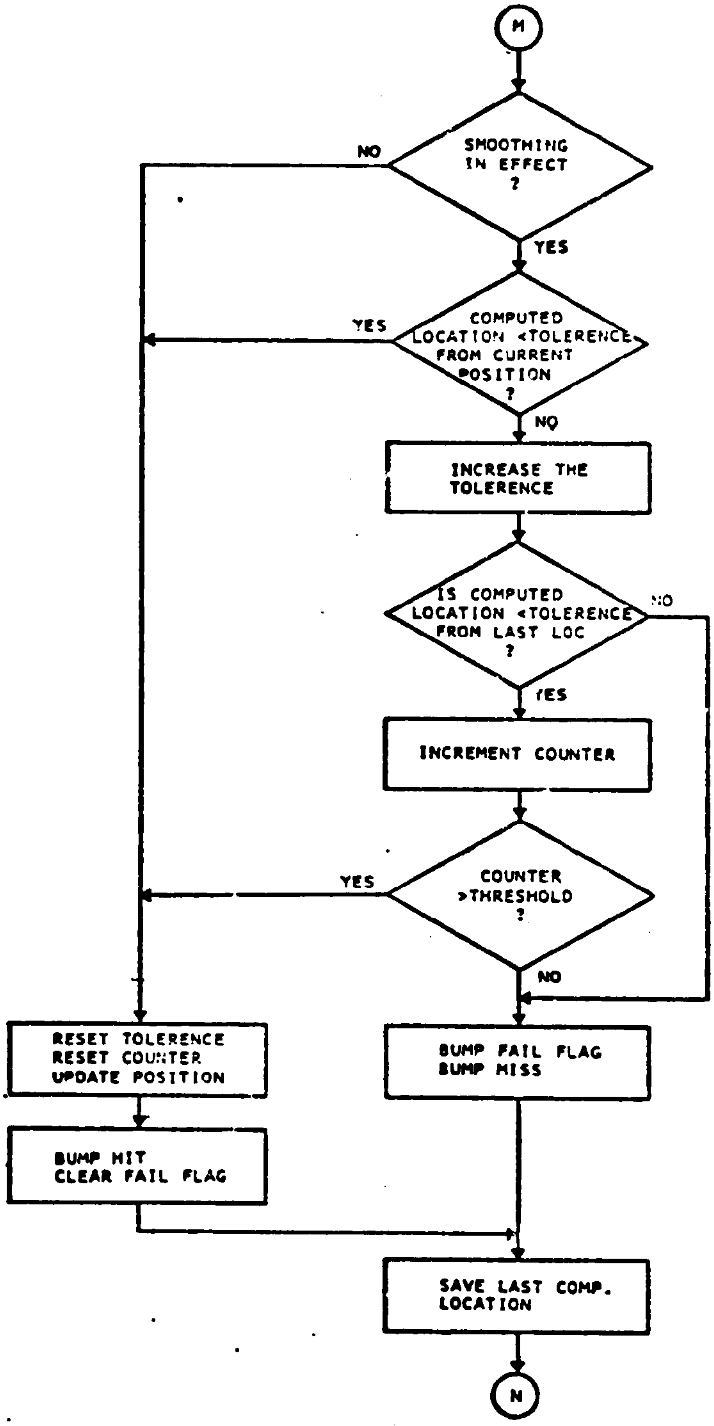


FIGURE 3-8. DATA SMOOTHING

the program searches for a new position fix anywhere in the coverage area.

### 3.3.1.1.8 Time Point Check (Figure 3-9)

Program level arrival at a time point which does not have a signpost is measured as the time of the first hit within a specified arrival radius. Likewise, program level departure is measured as the time of the first hit outside a specified departure radius. The departure radius is normally the larger in order to add hysteresis to the time point decision. At the system level, the time of arrival radius is 400 ft and the time of departure 450 ft. At the subsystem level, the time of arrival radius is 100 ft and the time of departure, 150 ft.

System and subsystem timepoint departure is defined as the average of the program level arrival and departure times if the door does not open; and as the door closure time if the door does open. This section is skipped for random route tests.

Program level arrival at a signpost is measured as the time when the vehicle relays the first signpost message. Program level departure is measured as the time when the signpost message drops out.

System and subsystem signpost departure is defined as the program level departure time minus one half the update rate (5 or 1/20 second) if the door remained closed, and as the time of closure if the door was open. The door and signpost status are detected from the vehicle-to-central control message.

### 3.3.1.1.9 Vehicle Sync (Figure 3-10)

The current vehicle record is checked for frame synchronization. If it is off, the pointers are moved to correct the error, the error is recorded, and the next frame is used.

### 3.3.1.1.10 Vehicle Map Location (Figure 3-11)

This routine scans the last N entries for an event. For 5th wheel calculations, it uses location and direction vector information from the event table to calculate the map location. If there is a location available in the event table, a subsystem accuracy check is performed.

### 3.3.1.1.11 Calibration

Calibration is done when the buffer pointer passes over a calibration time slot; the calibration pointer is updated using vehicle and central pointers as a reference. At the end of a data record the calibration pointer is reset.

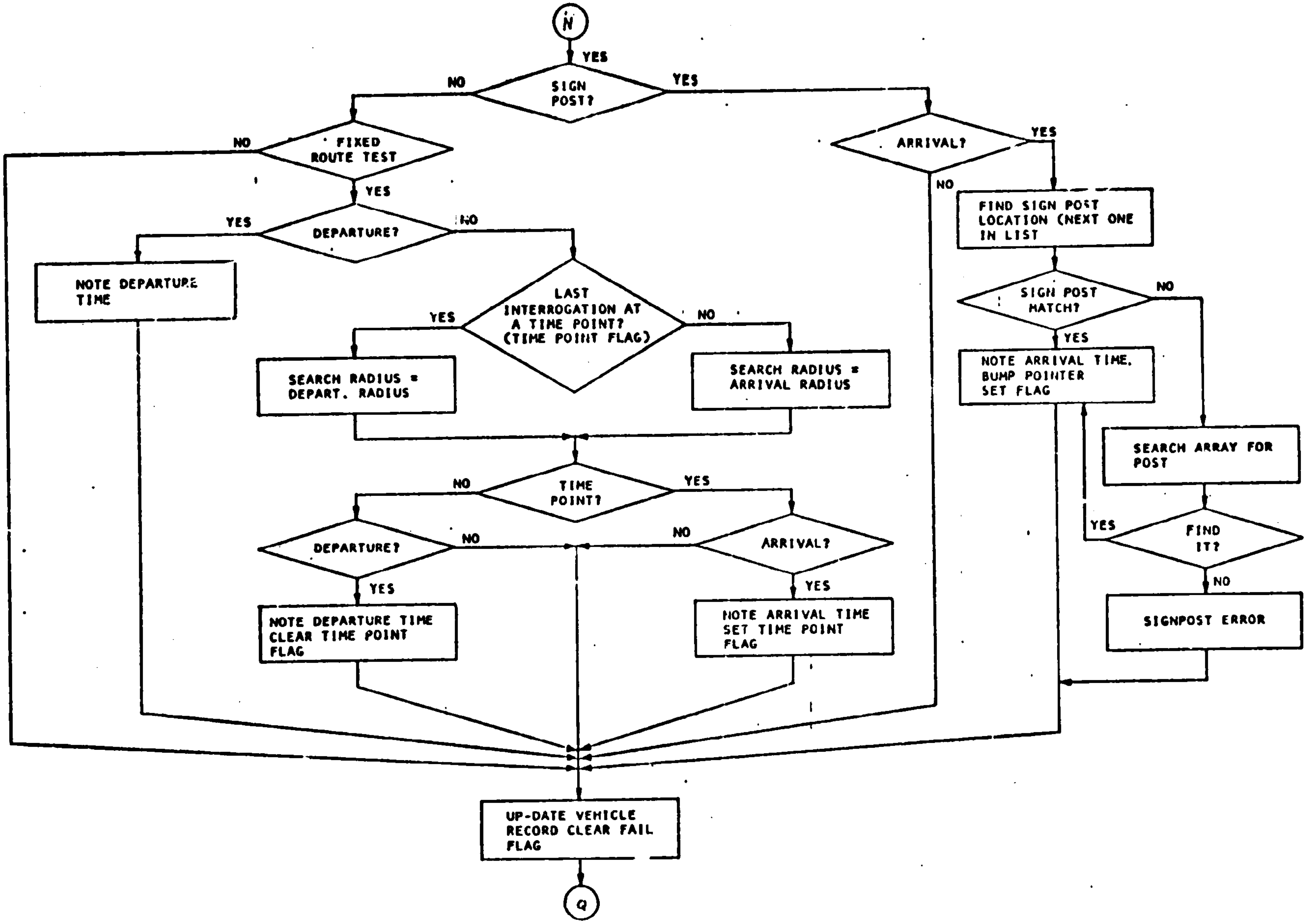


FIGURE 3-9. TIME POINT CHECK

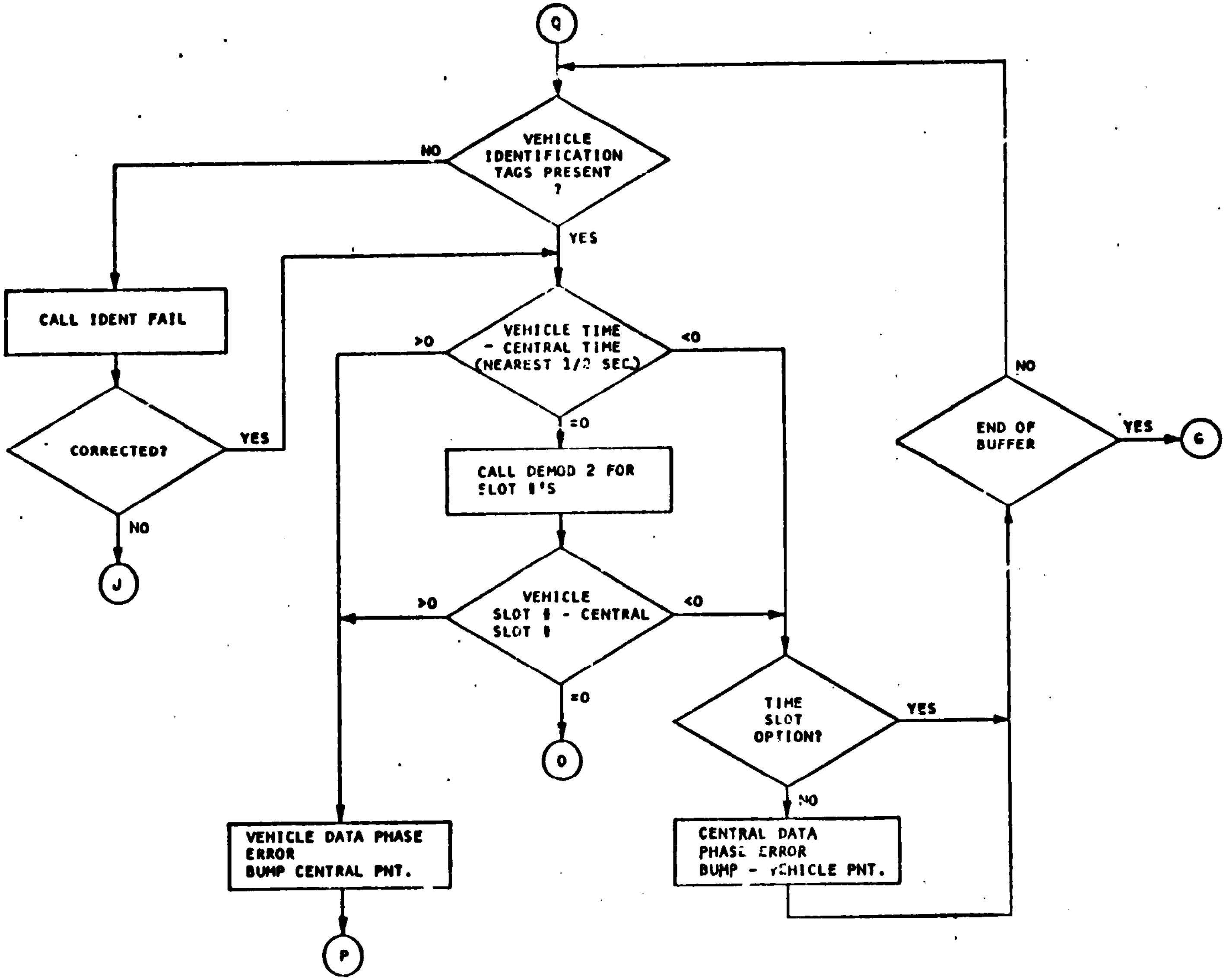


FIGURE 3-10. VEHICLE SYNC

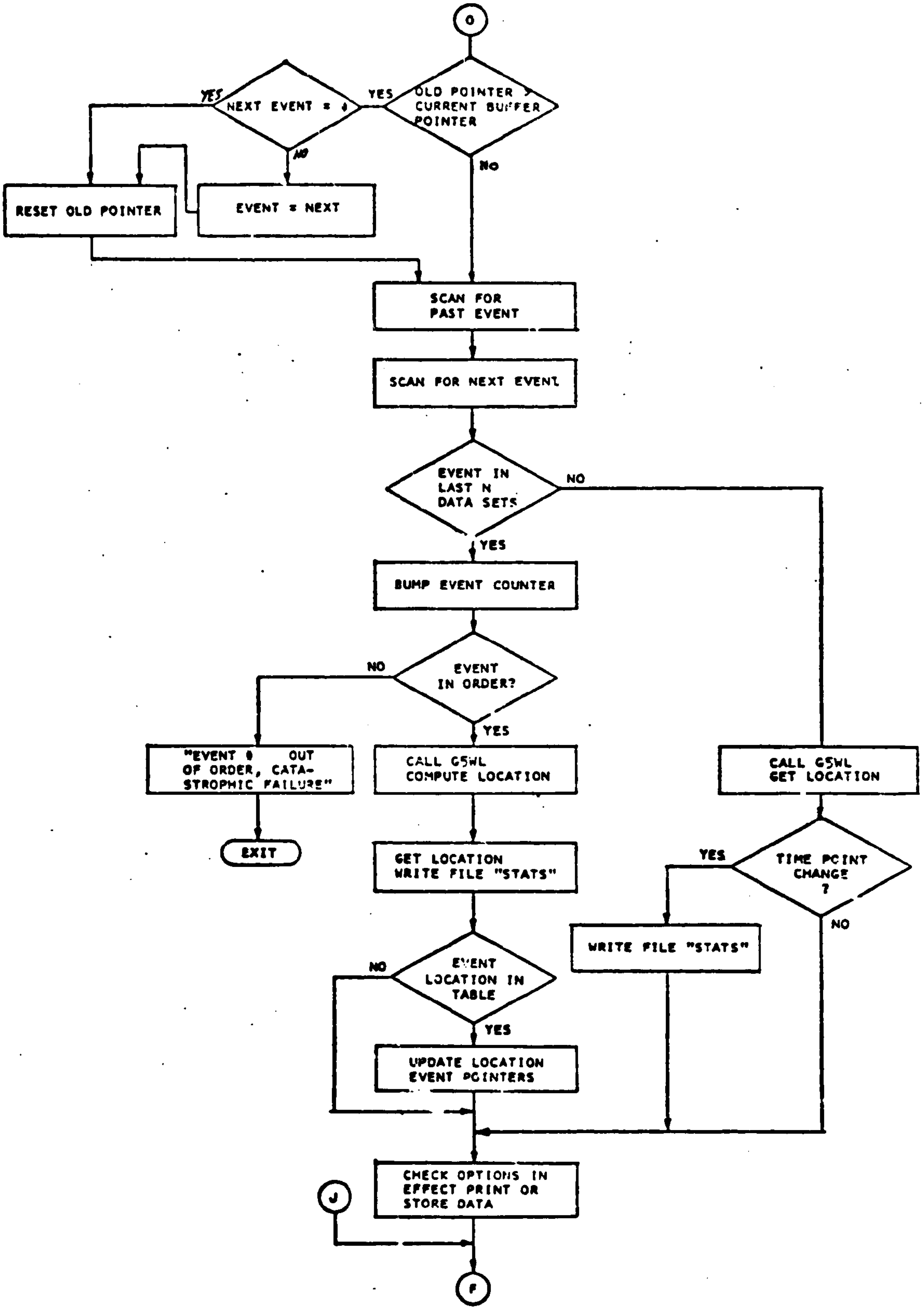


FIGURE 3-11. VEHICLE MAP LOCATION

### 3.3.1.1.12 Time Option

Over a specified time range, it is possible to "Look Close" at the data and results. This is the second specified Nth term option. When in effect, it replaces the primary Nth time variable with the second over the specified time range and records intermediate and/or raw data.

### 3.3.1.1.13 Time Slot Option

This option simulates a single vehicle reporting in one or more time slots. Unselected time slots are skipped. Up to 20 time slots can be selected for each run. As a further option, the user can specify the system update rate of 1 per 10 seconds simulating the system performance.

### 3.3.1.1.14 Data Presentation

The data files are closed and re-opened so that the data can be extracted from the beginning of the file. If the raw data option is in effect, this data is formatted and printed. Likewise, if the intermediate data option is in effect this data is formatted and printed. Next, the test point data is formatted and printed. Simultaneously, a histogram array is generated containing all the material on which a histogram might be requested. The requested histograms are printed along with the error records and the program exits.

### 3.3.1.2 Subroutines

**HISTO** - Given data, starting abscissa, final abscissa and interval, this routine formats and prints histograms (figure 3-12).

**IDNTFL** - This routine (figure 3-13) is called when a data type identifier is missing from a central or vehicle record. The subroutine attempts to find the next identification tag in the record. If a tag is found, the program returns; if not, an error flag is set and then it returns.

**DEMOD** - This routine (figure 3-14) takes 3 TOA's and converts them from Modulo $2^{16}$ to absolute. Then it computes TDA's by $TDA_x = (TOA_x - TOA_{base}) - (Drift_x) * \left(\frac{Slot\ \# - Calibration\ Slot\ \#}{Slots\ per\ Calibration}\right)$.

**DEMOD2** - This routine (figure 3-15) takes 2 time slot numbers module "MOD" and converts them to absolute.

**G5WL** - This routine computes the subsystem location from the fifth wheel data and the last location available at an event.

**CTMSLG** - This routine takes the contents of the central site input buffer and generates the TOA's, time slot numbers, and messages for the current data set. It returns a (-1) if the time slots don't match, a (1) if two of the three messages don't match and a (0) for a successful completion.

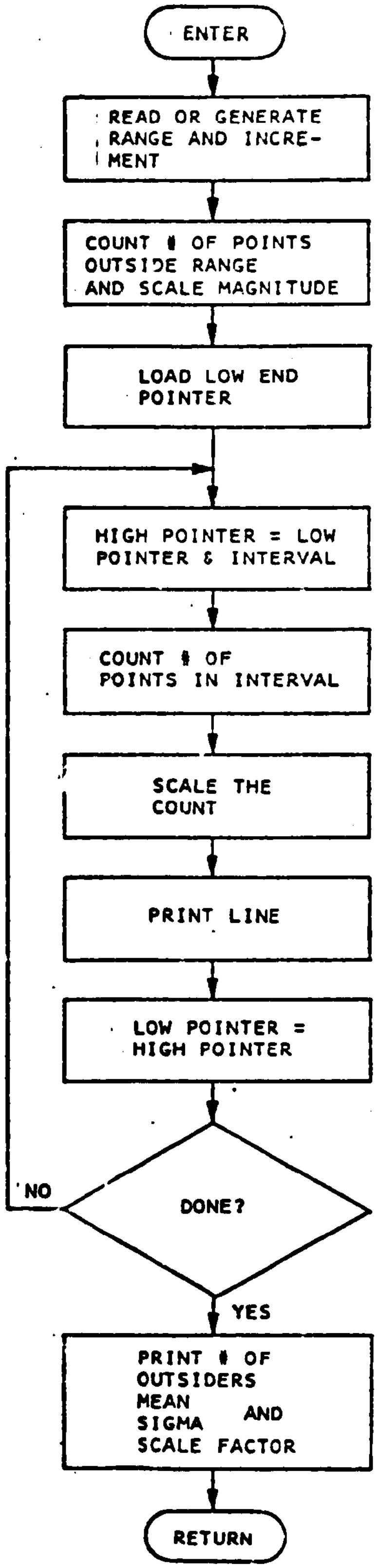


FIGURE 3-12. SUBROUTINE - HISTO

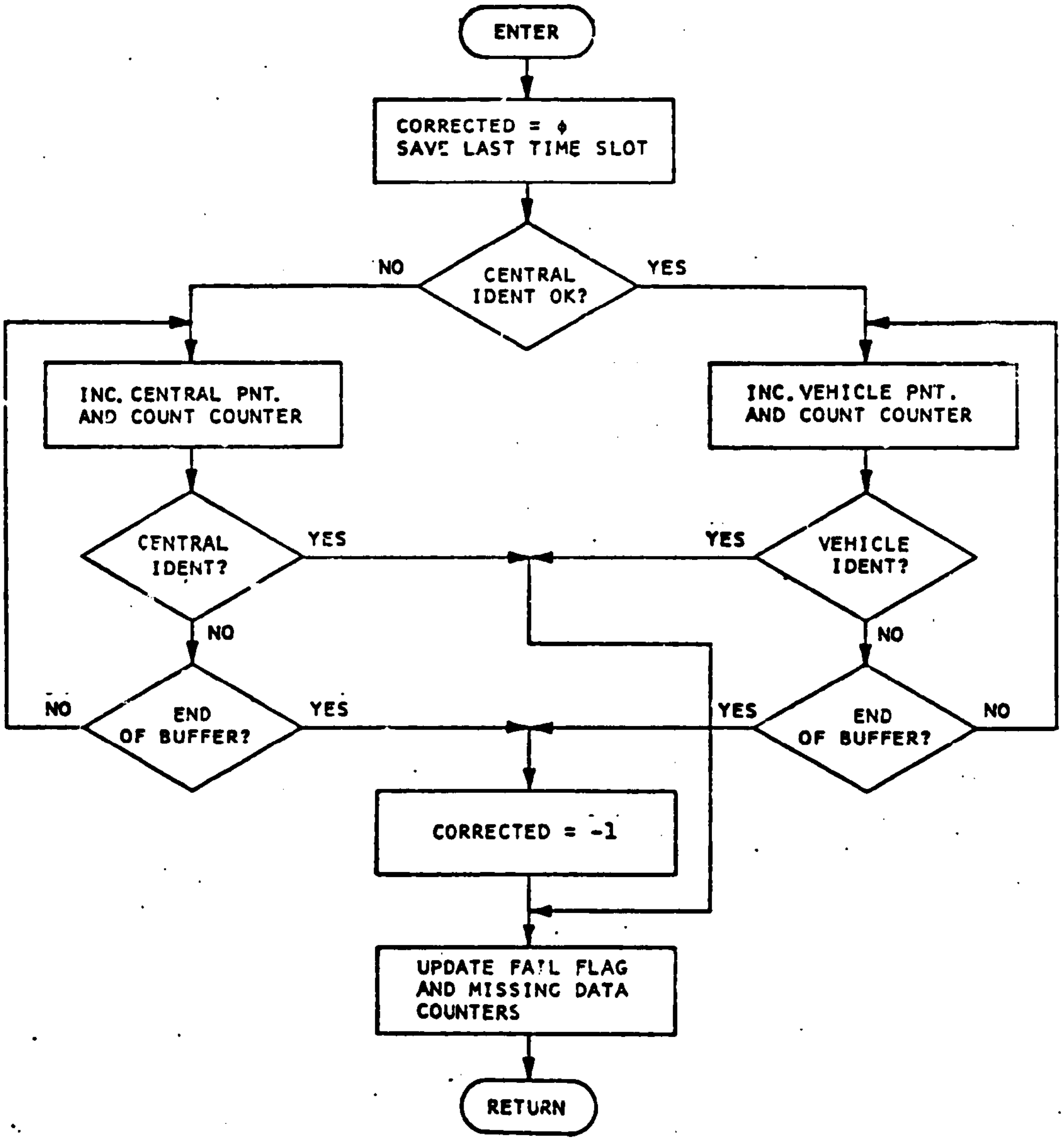


FIGURE 3-13. SUBROUTINE - IDNTFL

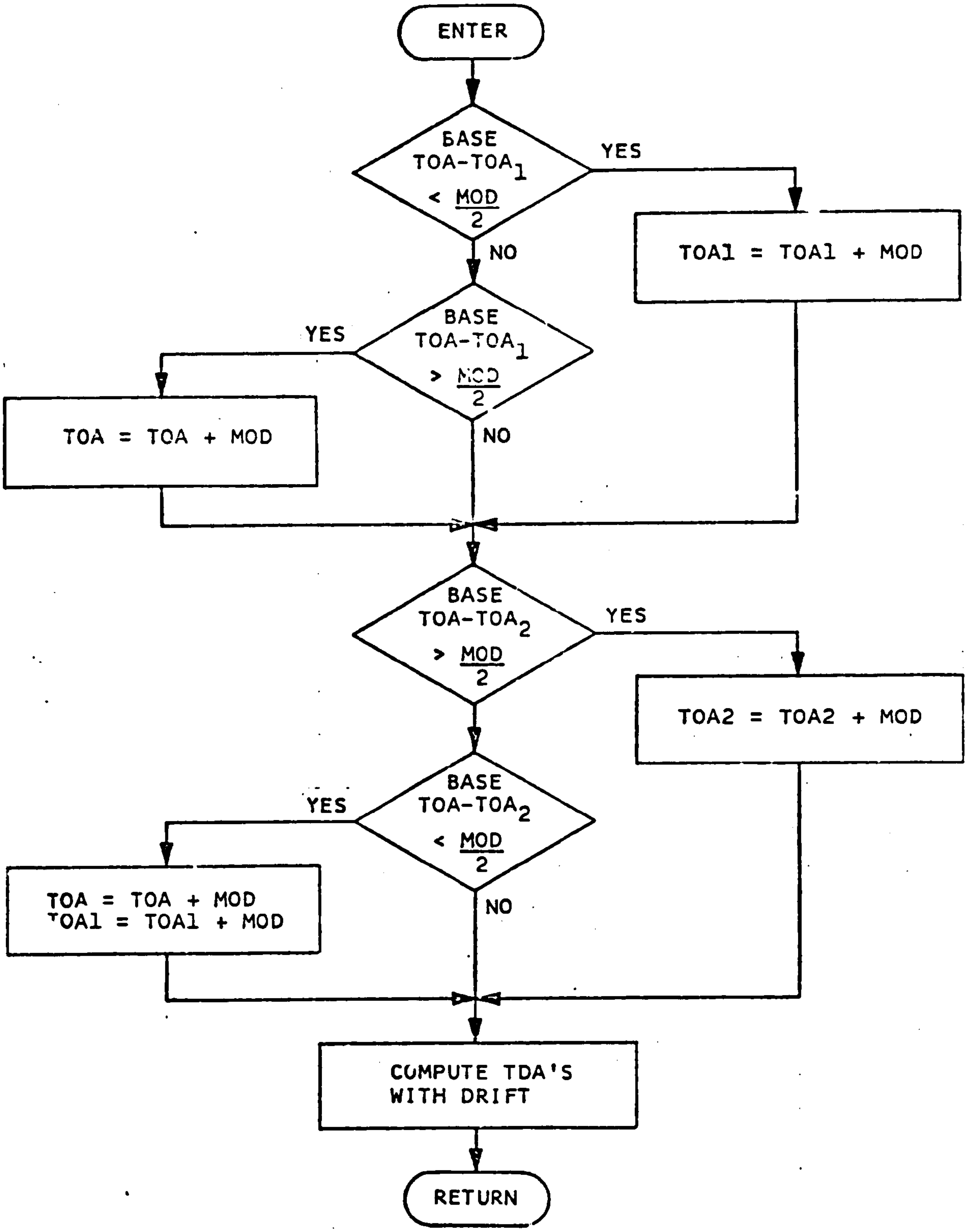


FIGURE 3-14. SUBROUTINE - DEMOD

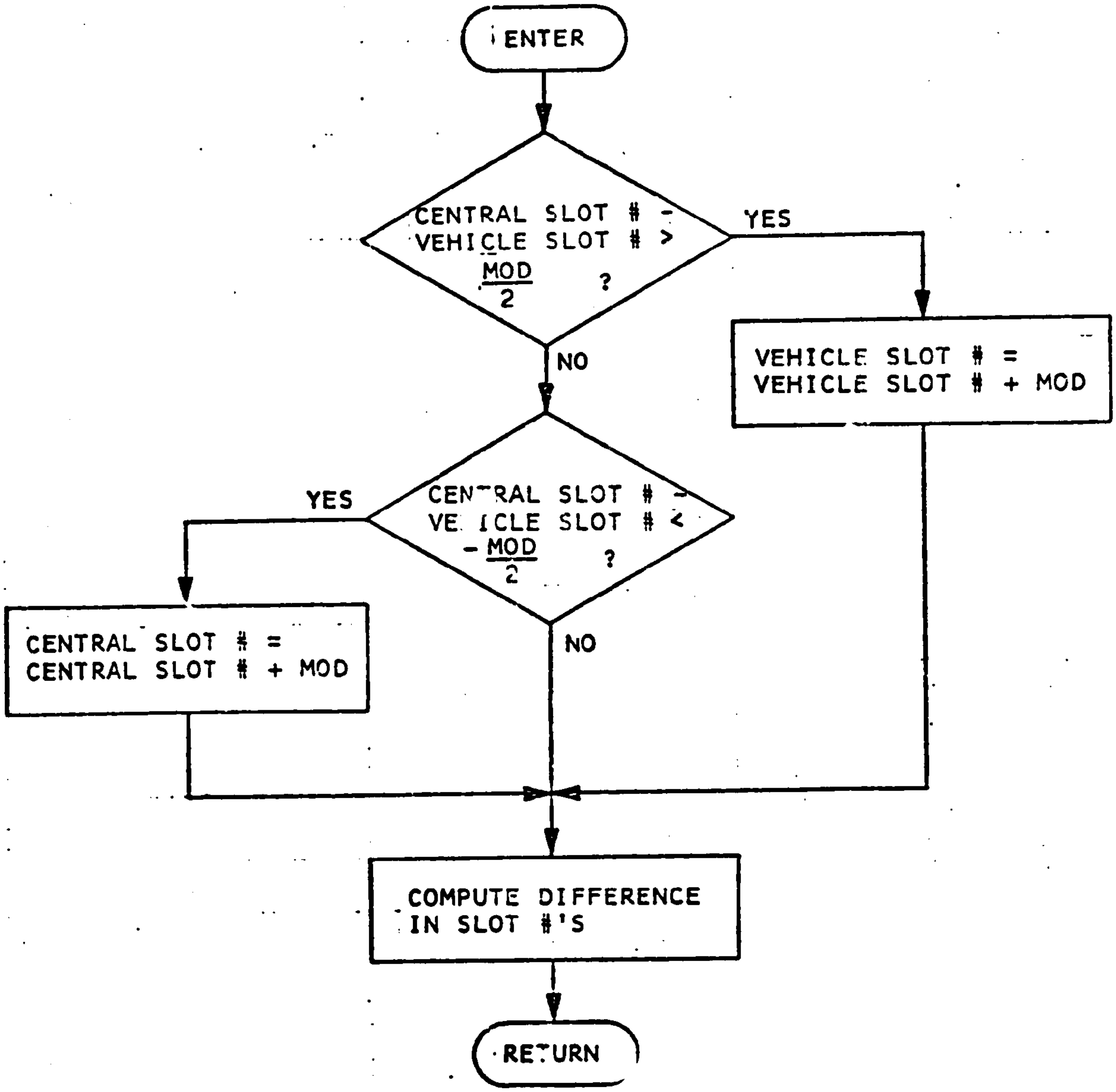


FIGURE 3-15. SUBROUTINE - DEMOD ②

MGTPC, MGTPV - This routine reads a data record from the central and vehicle tapes respectively; the drives are initialized for logical devices TAPC, TAPV respectively.

DATPRE - This routine (figure 3-16) controls the output of the test results.

HEADER - This routine recalls the tape headers and prints them at the top of a new page.

PRTLIN - This routine (figure 3-17) formats and prints a line of data from the output files.

FIXRUT - This routine (figure 3-18) is called for fixed route vehicles only. It uses the trilateration position to determine the vehicle position along the route. The routine also detects departures from the fixed route.

TIMCON - This routine takes the time from the data record in BCD and converts it to absolute tenths of seconds past midnight. It also does a preliminary check for valid data; and decodes the internal time in case of error.

ERROR - Is a routine which is called in case of error. It keeps a remaining control of the errors and generates the rejected data file for output.

INFO - This routine detects and prints changes in the status word (see table 3-4 and figure 3-19).

### 3.3.2 Software

The preceding flow charts and explanations are intended to supplement and add detail to figure 3-1. They represent the salient program functions. Section 3.3.1 provides an overview of the information in each chart.

### 3.3.3 ADP Requirements

The data reduction program requires a minimum of:

Two industry standard 9-track magnetic tape drives.

System software for supporting Fortran IV.

Approximately 20K words of memory.

Additional storage for six data files with read/write capability.

One high speed printer.

One interactive user terminal.

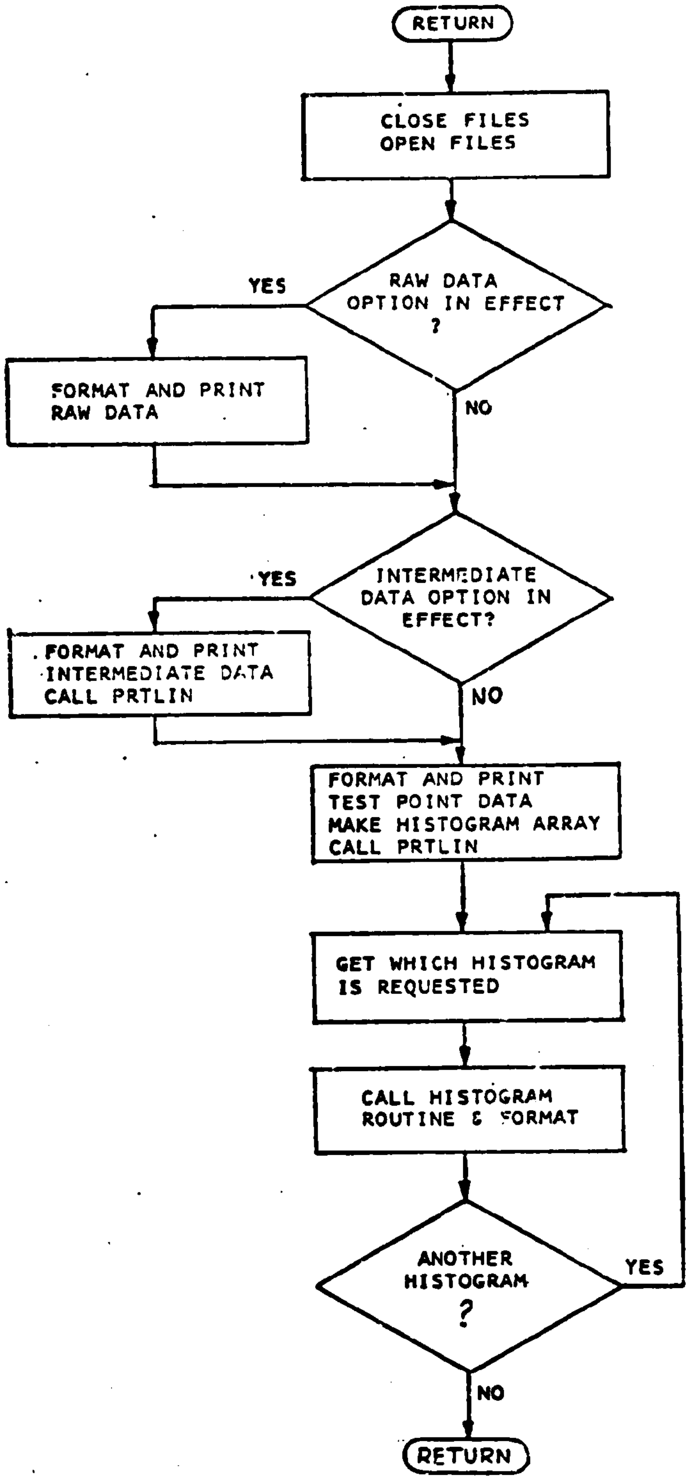


FIGURE 3-16. SUBROUTINE - DATPRE

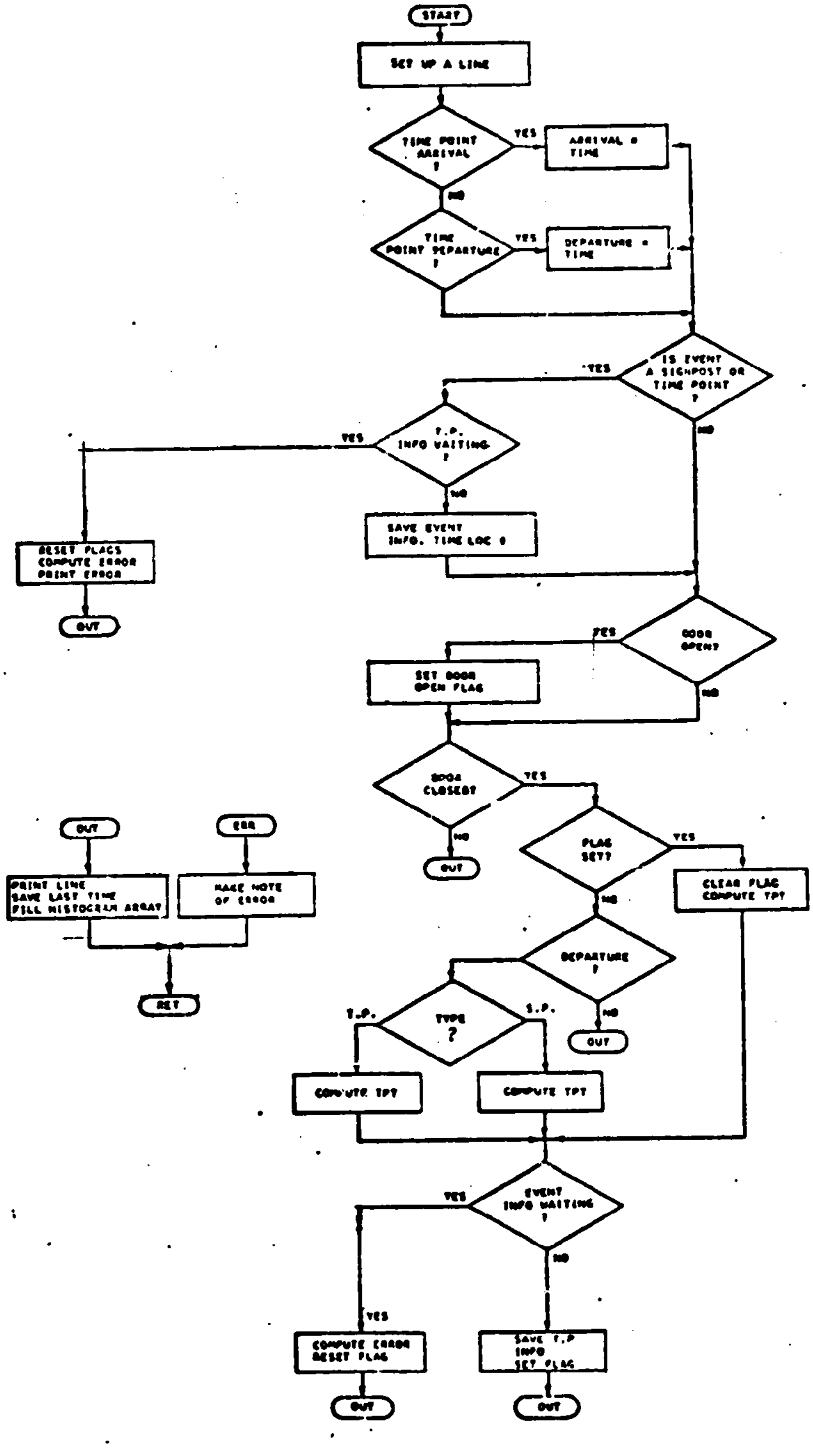


FIGURE 3-17. SUBROUTINE - PRTLIN

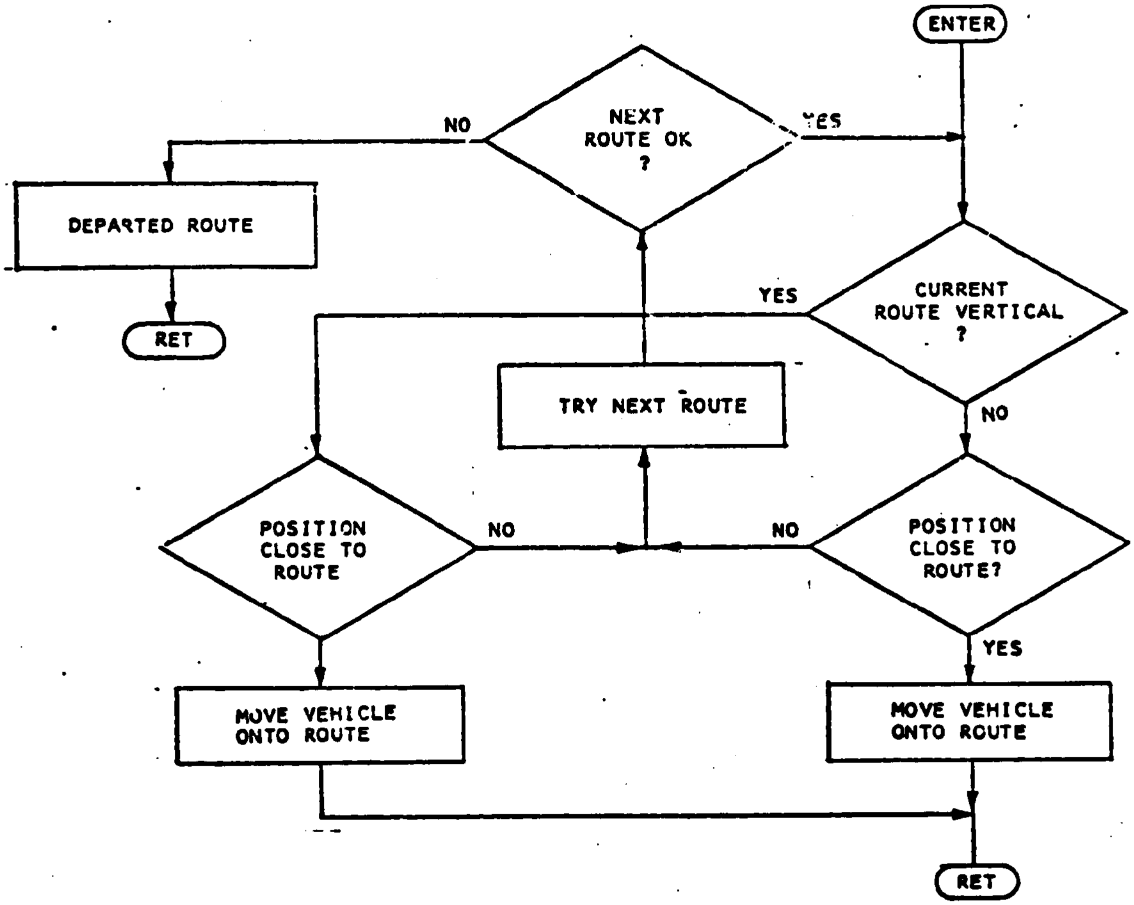


FIGURE 3-18. SUBROUTINE - FIXRUT

```
                              E X E C U T I O N   O U T P U T

                  NEXT EVENT   1                   PHILI.F4  VERSION 7-D

CENTRAL TAPE= 1     FILE= 2    TEST= 0 3     DATA176/ 7/14     SYNC XMTR PWR 130    CAL XMTR PWR 131
VEHICLE TAPE= 1     FILE= 2    TEST= 0 3     DATE176/ 7/14     XMTR PWR 120
TIME= 1: 2: 4.2    SLOT=  801   DOOR OPEN=0    SIGN POST=0    SYNC=1    REF. LOG=0    LEAVE PT.=0
TIME= 1: 2: 4.3    SLOT=  901   DOOR OPEN=0    SIGN POST=0    SYNC=0    REF. LOG=0    LEAVE PT.=0
TIME= 1: 2: 5.0    SLOT=  601   DOOR OPEN=0    SIGN POST=1    SYNC=0    REF. LOG=0    LEAVE PT.=0
TIME= 1: 2: 5.1    SLOT=  701|  DOOR OPEN=0    SIGN POST=0    SYNC=0    REF. LOG=0    LEAVE PT.=0
TIME= 1: 2: 5.A    SLOT=  401|  DOOR OPEN=1    SIGN POST=0    SYNC=0    REF. LOG=0    LEAVE PT.=0
TIME=15: 2: 5.9    SLOT=  501|  DOOR OPEN=0    SIGN POST=0    SYNC=0    REF. LOG=0    LEAVE PT.=0
```

FIGURE 3-19. PROGRAM OUTPUT

```
                                  R A W   D A T A

                 NEXT EVENT   0                        PHILI.F4  VERSION 7-0

CENTRAL TAPE= 1     FILE= 2     TEST= 0 3     DATA=76/ 7/14     SYNC XMTR PWR 130    CAL XMTR PWR 131
VEHICLE TAPE= 1     FILE= 2     TEST= 0 3     DATE=76/ 7/14     XMTR PWR 120
CONFIGURATION=1  FIXED ROUTE=1  LOCATION FIX EVERY     1  DATA SAVED EVERY     1  NUMBER OF SLOTS=  =1
SMOOTHING=0  FILTER=0
 STARTING AT  0: 0: 2.0  ENDING AT  0: 0: 0.0

TAG SLOT=  TOA  MESS  TAG SLOT=  TOA  MESS  TAG SLOT=  TOA  MESS  TAG SLOT=  TOA  MESS   TIME                                    CENTRAL
                                                                  TAG SLOT= EVENT WHEEL  TIME    VOLTAGE CURRENT STATUS    VEHICLE

 24   101 30230    0  25   101 32820    0  26   101 31290    0  27   101     0     0  1 2 3 5
                                                                  10     1     1   707  1 2 3 4     12      14      0
--------------------------------------------------------------------------------------------------------------------
 24   201 30230    0  25   201 32580    0  26   201 31181    0  27   201     0     0  1 2 3 6
                                                                  10     1     1   707  1 2 3 4     12      14      0
--------------------------------------------------------------------------------------------------------------------
 24   301 30230    0  25   301 32370    0  26   301 31064    0  27   301     0     0  1 2 3 7
                                                                  10     1     1   707  1 2 3 4     12      14      0
--------------------------------------------------------------------------------------------------------------------
 24   401 30230    0  25   401 32230    0  26   401 30948    0  27   401     0     0  1 2 3 8
                                                                  10     1     1   707  1 2 3 4     12      14      0
--------------------------------------------------------------------------------------------------------------------
 24   501 30230    0  25   501 32106    0  26   501 30835    0  27   501     0     0  1 2 3 9
                                                                  10     1     1   707  1 2 3 4     12      14      0
--------------------------------------------------------------------------------------------------------------------
 24   501 30230    0  25   501 32106    0  26   501 30835    0  27   501     0     0  1 2 3 9
                                                                  10   101     0  1414  1 2 3 5     12      14      0
--------------------------------------------------------------------------------------------------------------------
 24   501 30230    0  25   501 32106    0  26   501 30835    0  27   501     0     0  1 2 3 9
                                                                  10   201     0  2121  1 2 3 6     12      14      0
--------------------------------------------------------------------------------------------------------------------
 24   501 30230    0  25   501 32106    0  26   501 30835    0  27   501     0     0  1 2 3 9
                                                                  10   301     0  2828  1 2 3 7     12      14      0
--------------------------------------------------------------------------------------------------------------------
 24   501 30230    0  25   501 32106    0  26   501 30835    0  27   501     0     0  1 2 3 9
                                                                  10   401     2  3535  1 2 3 8     12      14      0
--------------------------------------------------------------------------------------------------------------------
 24   501 30230    0  25   501 32106    0  26   501 30835    0  27   501     0     0  1 2 3 9
                                                                  10   501     0  4242  1 2 3 9     12      14      0
--------------------------------------------------------------------------------------------------------------------
 24   601 30230    0  25   601 31973    0  26   601 30723    0  27   601     0     0  1 2 4 0
                                                                  10   601     0  4949  1 2 4 0     12      14      0
--------------------------------------------------------------------------------------------------------------------
 24   701 30230    0  25   701 31842    0  26   701 30616    0  27   701     0     0  1 2 4 1
                                                                  10   701     0  5656  1 2 4 1     12      14      0
--------------------------------------------------------------------------------------------------------------------
 24   801 30230    0  25   801 31711    0  26   801 30512    0  27   801     0     0  1 2 4 2
                                                                  10   801     3  6363  1 2 4 2     12      14     32
--------------------------------------------------------------------------------------------------------------------
 24   901 30230    0  25   901 31581    0  26   901 30413    0  27   901     0     0  1 2 4 3
                                                                  10   901     0  7070  1 2 4 3     12      14      0
--------------------------------------------------------------------------------------------------------------------
 24     0 30230    0  25     0 30020    0  26     0 30230    0  27     0     0     0  1 2 4 4
                                                                  10     1     4  8484  1 2 4 4     12      14      0
```

FICURE 3-19.  PROGRAM OUTPUT (cont)

```
                                  C A L C U L A T E D   D A T A

**1:ARRIVE TIMEPOINT, 2:DEPART TIMEPOINT, 3:ARRIVE SIGNPOST, 4:DEPART SIGNPOST

               NEXT EVENT   0                      PHILI.F4  VERSION 7-D

CENTRAL TAPE# 1     FILE# 2     TEST# 0 3     DATA:76/ 7/14     SYNC XMTR PWR 130    CAL XMTR PWR 131
VEHICLE TAPE# 1     FILE# 2     TEST# 0 3     DATE:76/ 7/14     XMTR PWR 120
CONFIGURATION=1  FIXED ROUTE=1  LOCATION FIX EVERY     1  DATA SAVED EVERY    1  NUMBER OF SLOTS=  -1
SMOOTHING=0  FILTER=0
 STARTING AT  0: 0: 2.0  ENDING AT  0: 0: 0.0

    TIME    SLOT# SYSTEM X,Y LOC.  SUBSYS X,Y LOC.  ACTUAL X,Y LOC.   SYSTEM ERR X,Y,RAD    SUBSYS ERR X,Y,RAD    EVENT  # TIME ERR
                                                                      (1)    (2)    (3)    (4)    (5)    (6)               (7)

 11 21 3.9   501    1250,  1150        0,     0  *******,*******  -1250  -1150   1698  *****  *****  *****      2  0  *****
 11 21 4.0   601    1300,  1200        0,     0  *******,*******  -1300  -1200   1769  *****  *****  *****      0  0  *****
 11 21 4.1   701    1350,  1250        0,     0  *******,*******  -1350  -1250   1839  *****  *****  *****      0  0  *****
 11 21 4.2   801    1400,  1300        0,     0     1400,   1300  -1400  -1300   1910   1400   1300   1910      3  1  *****
 11 21 4.3   901    1450,  1350     1450,  1350  *******,*******      0      0      0  *****  *****  *****      0  0  *****
 11 21 4.4     1    1500,  1400     1550,  1450     1500,   1400     50     50     70    -50    -50     70      4  2     -2
 11 21 4.5   101    1550,  1400     1571,  1400  *******,*******     21      0     21  *****  *****  *****      0  0  *****
 11 21 4.6   201    1599,  1400     1641,  1400  *******,*******     42      0     42  *****  *****  *****      0  0  *****
 11 21 4.7   301    1650,  1402     1712,  1400  *******,*******     62      0     62  *****  *****  *****      0  0  *****
 11 21 4.8   401    1699,  1400     1783,  1400  *******,*******     84      0     84  *****  *****  *****      0  0  *****
 11 21 4.9   501    1750,  1400     1854,  1400     1750,   1400    104      0    104   -104      0    104      5  3  *****
 11 21 5.0   601    1800,  1400     1821,  1400  *******,*******     21      0     21  *****  *****  *****      0  4     -1
 11 21 5.1   701    1850,  1400     1891,  1400  *******,*******     41      0     41  *****  *****  *****      0  0  *****
 11 21 5.2   801    1900,  1401     1962,  1400  *******,*******     62     -1     62  *****  *****  *****      0  0  *****
 11 21 5.3   901    1950,  1401     2033,  1400  *******,*******     83     -1     83  *****  *****  *****      0  0  *****
 11 21 5.4     1    1973,  1406     2174,  1400     2000,   1400    271     -6    271   -174      0    174      6  0  *****
 11 21 5.5   101    1964,  1357     2050,  1350  *******,*******     86     -7     86  *****  *****  *****      0  0  *****
 11 21 5.6   201    2024,  1339     2100,  1300  *******,*******     76     -9     76  *****  *****  *****      0  0  *****
 11 21 5.7   301    2083,  1261     2150,  1250  *******,*******     67    -11     67  *****  *****  *****      0  9  *****
 11 21 5.8   401    2143,  1210     2200,  1200  *******,*******     57    -10     57  *****  *****  *****      7  0  *****
 11 21 6.0   601    2263,  1111     2300,  1100  *******,*******     40    -11     41  *****  *****  *****      0  0  *****
 11 21 6.1   701    2317,  1059     2350,  1050  *******,*******     31     -9     32  *****  *****  *****      0  0  *****
 11 21 6.2   801    2380,  1006     2400,  1000  *******,*******     20     -6     20  *****  *****  *****      0  0  *****
 11 21 6.3   901    2439,   954     2453,   950  *******,*******     11     -4     11  *****  *****  *****      0  0  *****
 11 21 6.4     1    2465,   903     2550,   850     2500,    900    147    -53    156    -50     50     70      8  0  *****
 11 21 6.5   101    2544,   949     2550,   950  *******,*******     86      1     86  *****  *****  *****      0  0  *****
 11 21 6.6   201    2574,   995     2600,  1000  *******,*******     76      5     76  *****  *****  *****      0  0  *****
 11 21 6.7   301    2585,  1045     2650,  1050  *******,*******     65      5     65  *****  *****  *****      0     *****
 11 21 6.8   401    2645,  1093     2700,  1100     2700,   1100     55      7     55      0      0      0      9  0  *****
 11 21 6.9   501    2704,  1145     2750,  1150  *******,*******     46      5     46  *****  *****  *****      0  1  *****
 11 21 7.0   601    2763,  1195     2800,  1200  *******,*******     37      5     37  *****  *****  *****      0  2     -2
 11 21 7.1   701    2822,  1245     2850,  1250  *******,*******     28      5     28  *****  *****  *****      0  0  *****
 11 21 7.2   801    2881,  1290     2900,  1300  *******,*******     19      2     19  *****  *****  *****      0  0  *****
 11 21 7.3   901    2940,  1349     2950,  1350  *******,*******     10      1     10  *****  *****  *****      0  0  *****
 11 21 7.5     1    3011,  1369     3050,  1450  *******,*******     39     81     89  *****  *****  *****     10  0  *****
 11 21 7.6   101    3068,  1418     3100,  1500  *******,*******     32     82     88  *****  *****  *****      0  0  *****
 11 21 7.7   201    3124,  1469     3150,  1550  *******,*******     26     81     85  *****  *****  *****      0  0  *****
 11 21 7.8   301    3176,  1520     3200,  1600  *******,*******     22     80     82  *****  *****  *****      0  0  *****
 11 21 7.9   401    3231,  1571     3250,  1650  *******,*******     19     79     81  *****  *****  *****      0  0  *****
 11 21 8.0   501    3253,  1650     3300,  1700     3250,   1650     50     50     70    -50    -50     70     11  3  *****
```

FIGURE 3-19. PROGRAM OUTPUT (cont)

```
                                         T E S T   D A T A

*=1:ARRIVE TIMEPOINT, 2:DEPART TIMEPOINT, 3:ARRIVE SIGNPOST, 4:DEPART SIGNPOST


                   NEXT EVENT   0                    PHILI,F4  VERSION 7-0

CENTRAL TAPE# 1     FILE# 2     TEST# 0 3     DATA:76/ 7/14     SYNC XMTR PWR 130    CAL XMTR PWR 131
VEHICLE TAPE# 1     FILE# 2     TEST# 0 3     DATE:76/ 7/14     XMTR PWR 120
CONFIGURATION=1  FIXED ROUTE=1  LOCATION FIX EVERY     1  DATA SAVED EVERY     1  NUMBER OF SLOTS=   -1
SMOOTHING=0  FILTER=0
 STARTING AT  *1 01 2.0  ENDING AT  01 01 0.0


    TIME     SLOT# SYSTEM X,Y LOC.  SUBSYS X,Y LOC.  ACTUAL X,Y LOC.   SYSTEM ERR X,Y,RAD    SUBSYS ERR X,Y,RAU     EVENT  * TIME ERR
                                                                        (1)     (2)     (3)     (4)     (5)    (6)                (7)

 11 21 3.9    501      1253.     1150          0.        0  *******,*******   -1250   -1150    1698   *****   *****   *****       2  0  *****
 11 21 4.2    601      1400.     1300          0.        0     1400.    1300   -1400   -1300    1910    1400    1300    1910       3  1  *****
 11 21 4.4      1      1500.     1403      1550.      1450     1500.    1400      50      50      70     -50     -50      70       4  2     -2
 11 21 4.9    501      1750.     1400      1854.      1400     1750.    1400     104       0     104    -104       0     104       5  3  *****
 11 21 5.0    601      1800.     1400      1821.      1400  *******,*******      21       0      21   *****   *****   *****       0  4     -1
 11 21 5.4      1      1985.     1406      2174.      1400     2000.    1400     271      -6     271    -174       0     174       6  0  *****
 11 21 5.6    401      2143.     1210      2200.      1240  *******,*******      57     -10      57   *****   *****   *****       7  0  *****
 11 21 6.4      1      2483.      983      2550.       850     2500.     900     147     -53     156     -50      50      70       8  0  *****
 11 21 6.8    401      2645.     1093      2700.      1100     2700.    1100      55       7      55       0       0       0       9  0  *****
 11 21 6.9    501      2704.     1145      2750.      1150  *******,*******      46       5      46   *****   *****   *****       0  1  *****
 11 21 7.0    601      2763.     1195      2800.      1200  *******,*******      37       5      37   *****   *****   *****       0  2     -2
 11 21 7.5      1      3011.     1369      3050.      1450  *******,*******      39      81      89   *****   *****   *****      10  0  *****
 11 21 8.0    501      3250.     1650      3300.      1700     3250.    1650      50      50      70     -50     -50      70      11  3  *****
```

FIGURE 3-19.  PROGRAM OUTPUT (cont)

```
   >=        <    I  HISTOGRAM NUMBER 2
 -1300    -1272   I*          1
 -1272    -1244   I           0
 -1244    -1216   I           0
 -1216    -1188   I           0
 -1188    -1160   I           0
 -1160    -1132   I*          1
 -1132    -1104   I           0
 -1104    -1076   I           0
 -1076    -1048   I           0
 -1048    -1020   I           0
 -1020     -992   I           0
  -992     -964   I           0
  -964     -936   I           0
  -936     -908   I           0
  -908     -880   I           0
  -880     -852   I           0
  -852     -824   I           0
  -824     -796   I           0
  -796     -768   I           0
  -768     -740   I           0
  -740     -712   I           0
  -712     -684   I           0
  -684     -656   I           0
  -656     -628   I           0
  -628     -600   I           0
  -600     -572   I           0
  -572     -544   I           0
  -544     -516   I           0
  -516     -488   I           0
  -488     -460   I           0
  -460     -432   I           0
  -432     -404   I           0
  -404     -376   I           0
  -376     -348   I           0
  -348     -320   I           0
  -320     -292   I           0
  -292     -264   I           0
  -264     -236   I           0
  -236     -208   I           0
  -208     -180   I           0
  -180     -152   I           0
  -152     -124   I           0
  -124      -96   I           0
   -96      -68   I           0
   -68      -40   I*          1
   -40      -12   I           0
   -12       16   I*******        7
    16       44   I           0
    44       72   I**          2
    72      100   I*          1

             13 ENTRIES                 0 OUTSIDE RANGE
MEAN=   -178.5384600 STANDARD DEVIATION=     65.9733720
ONE *=             1
```

FIGURE 3-19.  PROGRAM OUTPUT (cont)

```
                                    R E J E C T E D   D A T A

                  NEXT EVENT   0                       PHILI.F4  VERSION 11-J

CENTRAL TAPE#28     FILE# 1     TEST# 0 1     DATE: 2/27/77     TIME:11:36     SYNC XMTR PWR 277    CAL XMTR PWR 0 2
VEHICLE TAPE#19     FILE# 1     TEST# 0 1     DATE: 2/27/77     TIME:11:43     XMTR PWR 263
CONFIGURATION=1  FIXED ROUTE=0  LOCATION FIX EVERY     1  DATA SAVED EVERY     1  NUMBER OF SLOTS=******
SMOOTHING=1  FILTER=3
 STARTING AT      1      ENDING AT      6

 REASON  NEXT EVENT  CENTRAL: TIME - SLOT  VEHICLE: TIME      LOCATION (X,Y)
    17          1        11:39:25.0    851     11:39:25.0     711398,245758
    17          1        11:39:26.6    251     11:39:26.6     711889,245815
     4          1        11:39:28.5    201      0: 0: 0.5     712891,245914
    13          1        11:39:28.5    201     11:39: 8.6     712891,245914
     4          1        11:39:28.5    201     11:39: 8.6     712891,245914
    17          1        11:39:31.7    801     11:39:31.7     713967,246770
    17          1        11:39:32.5    201     11:39:32.5     713879,245845
    17          1        11:39:33.4    651     11:39:33.4     714202,246815
    17          1        11:39:34.0    351     11:39:34.0     714357,246951
    17          1        11:39:39.0    851     11:39:39.0     715600,245800
    17          1        11:39:40.2     51     11:39:40.2     717210,249792
    17          1        11:39:45.4    651     11:39:45.4     717393,249610
     4          1        11:39:56.1      0     11:39:56.1     713923,245053
    17          2        11:40: 6.0    951     11:40: 6.0     715919,246502
     9          2        11:40: 7.0    451     11:40: 7.0     714840,245301
     4          2        11:40:11.4    651      0: 0: 0.0     714835,245146
    17          2        11:40:31.8    851     11:40:31.8     713732,244307
     4          2        11:40:34.1      0     11:40:34.1     715605,244527
     4          2        11:40:36.5    201     11:40:36.5     715686,244558
    17          2        11:40:38.5    201     11:40:38.5     714877,244478
    15          2        11:40:39.9    901     11:40:39.9     715809,244413
    17          2        11:40:41.5    701     11:40:41.5     715836,244341
    13          3        11:40:42.1      1     11:40:42.1     715889,244445
    17          3        11:40:42.2     51     11:40:42.2     717203,245961
    17          3        11:40:42.4    151     11:40:42.4     714553,244077
    17          3        11:40:42.6    251     11:40:42.6     715869,244639
    17          3        11:40:43.1    501     11:40:43.1     715808,244062
    17          3        11:40:45.0    451     11:40:45.0     716839,245074
    17          4        11:40:47.6    751     11:40:47.6     714410,243710
    17          5        11:41: 2.8    351     11:41: 2.8     714472,242983
     4          5        11:41: 6.1      0     11:41: 6.1     716101,243101
    17          5        11:41:11.5    701     11:41:11.5     715389,242746
    17          5        11:41:15.1    501     11:41:15.1     717286,243495
    17          5        11:41:15.4    651     11:41:15.4     717911,244515
    17          6        11:41:16.7    301     11:41:16.7     717135,243384
    17          6        11:41:17.1    501     11:41:17.1     717439,243895
    17          6        11:41:22.9    401     11:41:22.9     717254,243235
    17          6        11:41:23.9    901     11:41:23.9     717659,243483
    17          6        11:41:24.1      1     11:41:24.1     717526,243311
    17          6        11:41:25.4    651     11:41:25.4     717378,243186
    17          6        11:41:27.5    701     11:41:27.5     717659,243122
    17          6        11:41:28.0    951     11:41:28.0     718019,243686
    17          6        11:41:29.9    901     11:41:29.9     718701,244410
    17          6        11:41:31.0    451     11:41:31.0     718180,243671
    17          6        11:41:32.0    351     11:41:32.0     718042,243441
    17          6        11:41:33.0    451     11:41:33.0     717118,242254
```

FIGURE 3-19. PROGRAM OUTPUT (cont)

```
                    E R R O R   R E C O R D S

          NEXT EVENT   0                    PHILI,F4  VERSION 11-J

  CENTRAL TAPE#20     FILE# 1    TEST# # 1    DATE: 2/27/77    TIME:11130    SYNC XMTR PWR 277    CAL XMTR PWR # 2
  VEHICLE TAPE#19     FILE# 1    TEST# # 1    DATE: 2/27/77    TIME:11143    XMTR PWR 283
  CONFIGURATION:  FIXED ROUTE##  LOCATION FIX EVERY    1  DATA SAVED EVERY    1  NUMBER OF SLOTS######
  SMOOTHING:  FILTER#0
   STARTING AT     1      ENDING AT     6
  USABLE DATA 96%

             2105 HITS                    72 MISSES

                                       REASON       CENTRAL       VEHICLE
  DATA TAG MISSING                       4             0              4
  DATA PHASE ERROR                       5,6           0              5

  TIME SLOTS DONT MATCH                  7             0
  MESSAGE ERROR                          8            20
  TOA OUT OF BOUNDS                      9             1
  SIGNPOST OUT OF BOUNDS                10             0
  OUT OF COVERAGE AREA                  11             0
  DETERMINT IN ALGORITHM =0             12             0
  LOCATION DID NOT CONVERGE             13             2
  MISSED CALIBRATION                    14             0
  EVENT MISSING                         15             0
  TIME POINT MISSED                     16             0
  SMOOTHING DROPOUTS                    17            69
  TIME INCREMENT TOO LARGE              18             1
  SITE 1 MISS                           19             0
  SITE 2 MISS                           20             0
  SITE 3 MISS                           21             0
  SITE 4 MISS                           22             0
  MULTIPLE SITE MISS                    23             0
  VEHICLE LEFT FIXED ROUTE              24             0
```

FIGURE 3-19. PROGRAM OUTPUT (cont)

### 3.3.4 Data and Results Format

#### 3.3.4.1 Central Site Data

The first physical record of every test file is reserved for a header. The header record format is shown in table 3-4. Subsequent records may be either headers or data. The data record format is shown in table 3-5. No record can contain both header and data information.

#### 3.3.4.2 Vehicle Site Data

The restrictions of paragraph 3.3.4.1 apply to vehicle data also. The header format is shown in table 3-6, the data format in table 3-7. The vehicle record need not be the same length as the central record.

#### 3.3.4.3 Program Control Data

This data is supplied by the user-created input files "MISC", "CONFD" and "EVENT" table 3-8. The entries in these files are defined in table 3-9 However, some restrictions on their use are noted here.

> CIDENT and VIDENT must be chosen so as to not conflict with any possible tape number. This can be done by choosing numbers which are not BCD decodable.
>
> NOOTSF is always 14.
>
> TOLORI is in units of distance.
>
> SKPTIM is in tenths of seconds.
>
> R5WTMC is in distance per 5th wheel count.
>
> CALPOF is 1 if the physical record length is equal to the central data set length. Otherwise it is the central data set length.
>
> RTTOD is in units of distance per TOA count.

### 3.3.5 Program Output Formats

Figure 3-19 shows the program execution output. One entry occurs for each header (central or vehicle); the next event is printed to give the user a reference point. At the end of a successful test, the next event is set to 0 and the test data is presented.

The reductions in figure 3-19 are self-explanatory and constitute the entirety of programmed output. The numbers shown are samples only and do not represent an actual test. Asterisks are used to indicate undefined or inconsistent data positions.

The reason-column in the rejected data corresponds to the reason-column in the error record.

The histogram number corresponds to the number in the test data header.

TABLE 3-4. CENTRAL SITE TAPE HEADER FORMAT

| Byte | Contents | Format |
|---|---|---|
| 1 | Tape Number | BCD |
| 2 | File Number | BCD |
| 3 | Test Number (MSB) | BCD |
| 4 | Test Number (LSB) | BCD |
| 5 | Month | BCD |
| 6 | Day | BCD |
| 7 | Year | BCD |
| 8 | Hour | BCD |
| 9 | Min. | BCD |
| 10 | Xmtr Power SYNC. (MSB) | BCD |
| 11 | Xmtr Power SYNC. (LSB) | BCD |
| 12 | Xmtr Power Cal. (MSB) | BCD |
| 13 | Xmtr Power Cal. (LSB) | BCD |
| 14 | 0 | |
| . | . | |
| . | . | |
| . | . | |
| END OF RECORD GAP | | |

TABLE 3-5. CENTRAL SITE TAPE DATA FORMAT

| Byte | Contents | Format |
|---|---|---|
| 1 | Site Identification Tag | Binary |
| 2 | Slot Number (MSB) | Binary |
| 3 | Slot Number (LSB) | Binary |
| 4 | TOA (MSB) | Binary |
| 5 | TOA (LSB) | Binary |
| 6 | Message (MSB) | Binary |
| 7 | Message (LSB) | Binary |
| 8 | Slot Number (MSB) | Binary |
| 9 | Slot Number (LSB) | Binary |
| 10 | TOA (MSB) | Binary |
| 11 | TOA (LSB) | Binary |
| 12 | Message (MSB) | Binary |
| 13 | Message (LSB) | Binary |
| 14 | Slot Number | Binary |
| 15 | Slot Number | Binary |
| 16 | TOA | Binary |

TABLE 3-5. CENTRAL SITE TAPE DATA FORMAT (cont)

| Byte | Contents | Format |
|---|---|---|
| 17 | TOA | Binary |
| 18 | Message | Binary |
| 19 | Message | Binary |
| 20 | Slot Number | Binary |
| 21 | Slot Number | Binary |
| 22 | TOA | Binary |
| 23 | TOA | Binary |
| 24 | Message | Binary |
| 25 | Message | Binary |
| 26 | Hour | Binary |
| 27 | Minute | Binary |
| 28 | Second | Binary |
| 29 | Second/10 | Binary |
| 30 | Spare | |
| 31 | Spare | |
| 32 | Spare | |

TABLE 3-6. VEHICLE TAPE HEADER FORMAT

| Byte | Contents | Format |
|---|---|---|
| 1 | Tape Number | BCD |
| 2 | File Number | BCD |
| 3 | Test Number | BCD |
| 4 | Test Number | BCD |
| 5 | Month | BCD |
| 6 | Day | BCD |
| 7 | Year | BCD |
| 8 | Hour | BCD |
| 9 | Minute | BCD |
| 10 | Xmtr Power (MSB) | BCD |
| 11 | Xmtr Power (LSB) | BCD |
| 12 | 0<br>•<br>•<br>•<br>END OF RECORD GAP | |

TABLE 3-7. VEHICLE TAPE DATA FORMAT

| Byte | Contents | Format |
|---|---|---|
| 1 | Vehicle Identification Tag | Binary |
| 2 | Hour | BCD |
| 3 | Minute | BCD |
| 4 | Second | BCD |
| 5 | Second/10 | BCD |
| 6 | Time Slot Number (MSB) | Binary |
| 7 | Time Slot Number (LSB) | Binary |
| 8 | Event Code (MSB) | BCD |
| 9 | Event Code (LSB) | BCD |
| 10 | 5th Wheel (MSB) | Binary |
| 11 | 5th Wheel (LSB) | Binary |
| 12 | Input Voltage | Binary |
| 13 | Input Current | Binary |
| 14 | Status* | Binary |
| 15 | Spare | Binary |
| 16 | Spare | Binary |

*Status is to be defined

TABLE 3-8. INPUT DATA FILES

I. Configuration Input File Dev (22) (CONFD)

X off, Y off
X1, Y1, Z1, X2, Y2, Z2, X3, Y3, Z3, X4, Y4, Z4
Prop (1), Prop (2)· Prop (3), Prop (4)
Bias (1,1,1,1), Bias (1,1,1,2)
Bias (1,2,1,1), Bias (1,2,1,2)
Bias (1,3,1,1), Bias (1,3,1,2)
•
•
•
Bias (1,12,1,1), Bias (1,12,1,2)
Bias (2,1,1,1), Bias (2,1,1,2)
•
•
•
Bias (12,12,1,1), Bias (12,12,1,2)
Bias (1,1,2,1), Bias (1,1,2,2)
•
•
•
Bias (12,12,2,1), Bias (12,12,2,2)

## TABLE 3-8. INPUT DATA FILES (cont)

### II. Miscellaneous Input Data File Dev (22) (MISC)

| Line | Code | |
|---|---|---|
| 1. | CIDENT, VIDENT, NOBRR | |
| 2. | NBPDSC, NBPDSV, NOOTSF | |
| 3. | NSLPC, NBIHC, NBIHV | |
| 4. | TOLORI, NOCHTF | |
| 5. | R5WTMC | |
| 6. | DPTRAD, ARIRAD, CALPOF | |
| 7. | FFT, ALERT, ALITT | |
| 8. | MODX, MOD5W | |
| 9. | FCALSN, RTTOD, NBIPR | |
| 10. | XRAD, RCTOFF, BIASIZ | |
| 11. | IDPTH, IRAD | |
| 12. | Cove 1X, Cove 1Y | |
| 13. | Cove 2X, Cove 2Y | |
| 14. | Cove 3X, Cove 3Y | |
| 15. | Cove 4X, Cove 4Y | |
| 16. | NOTP | |
| . | Event #, X Loc, Y Loc | |
| . | . | Time<br>Points |
| . | . | |
| . | . | |
| . | NOSP | |
| . | | |
| | Event #, X Loc, Y Loc | |
| | . | Sign<br>Posts |
| | . | |
| | . | |

### III. Event File (EVENT) Input File (on Dev 21)

| Line | Codes |
|---|---|
| 1. | Event #, X Loc, Y Loc, Time pt, Direction Vectors ΔX, ΔY, Test point flag. |
| 2. | Event #, X Loc, Y Loc, Time pt, Direction Vectors ΔX, ΔY, Test point flag. |
| .<br>.<br>. | Event #, X Loc, Y Loc, Time pt, Direction Vectors ΔX, ΔY, Test point flag. |
| 270 | X Location = Y Location = -1 (No position)<br>Time point: 1 = Yes, 0 = No |

TABLE 3-9. DEFINITIONS

| | | |
|---|---|---|
| CALPNT | Calibration Pointer | |
| FIXED | Fixed route vehicle flag | Logical |
| SGNPST | Vehicle at a signpost flag | Logical |
| TIMPNT | Vehicle at a time point flag | Logical |
| DPTRAD | Departure radius of search | Integer |
| ARIRAD | Arrival radius of search | Integer |
| DOPRAW | Raw Data option if effect | Logical |
| DOPINT | Intermediate data option if effect | Logical |
| EVENT C | Event # counter | Integer |
| FFT | Failure flag threshold | Integer |
| INBUFC | Central Tape Input Buffer | Integer Array (1995 + 1) |
| INBUFV | Vehicle Tape Input Buffer | Integer Array (1loo + 1) |
| CBUFPT | Central Buffer Pointer | Integer |
| VBUFPT | Vehicle Buffer Pointer | Integer |
| CONFIG | Configuration Select | Integer Value (1 or 2) |
| PROPD | Propogation Delay between Sites and Calibration x-mitter (counts) | Integer Array (4) |
| ALITC | Algorithm iterations counter | Integer |
| ALERT | Algorithm Error threshold | Integer |
| ALITT | Algorithm Iterations threshold | Integer |
| RH | Directional Cosin Matrix | Integer Array (2x2) |
| FCALSN | 1st calibration slot # | |
| DOPTSL | Data Option Time Slot | |
| NOSP | Number of Sign Posts | |
| SGNPNT | Signpost Pointer | |
| NOTP | Number of Time Points | |
| COVE1X<br>↓<br>COVE4Y | Coverage area | Integer Array (4 x 2) |

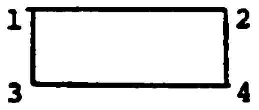


TABLE 3-9. DEFINITIONS (cont)

CALPOF - Calibration Pointer Offset

X OFF - Offset to X Bias Square (0)

Y OFF - Offset to Y Bias Square (0)

NOBRR - Number of Bytes Reporting Ratio (Number of time slots between slots that report.)

NBIPR - Number of Bytes in a physical record

HIT - # of successful interrogations

MISS - # of interrogations discarded

NSLPC - Number of slots per calibration service

NBPDSC - Number of bytes per central data set

NBPDSV - Number of bytes per vehicle data set

TEER - Tape Error Code

NOOTSF - Number of Outputs to Statistics File (14)

NBIHC - Number of Bytes in Central Header

NBIHV - Number of Bytes in Vehicle Header

NBYTSR - Number of Bytes Read

NLIBFC - Number of locations in Central Buffer

NLIBFV - Number of locations in Vehicle Buffer

R5WTMC - 5th wheel to distance conversion

MOD5W - 5th wheel Modulo

EVENT - Current Decoded event

MODX - Modulo of Time Slots

SNSTRT - Start Time for Second Nth Term Option

SNFIN - Finish Time for Second Nth Term Option

RTTOD - Time to Distance Conversion

XRAD - Coverage Area Exclusion Radius around Sights

RCTOFF - Reads Cutoff Frequency for Digital Filter - 3 db points

BIASIZ - Bias Square Size Units

CIDENT - Central Data Identification Tag Site I (8 bits)

VIDENT - Vehicle Data Identification Tag (8 bits)

STATUS - O:OK, 1: Message Error, -1:Time Slot Error, -2: Ident Error

TOLORI - Distance vehicle can travel in 1 time period

### 3.3.6 IBM Magnetic Tape Compatibility

The tape format shown in section 3.3.4 is compatible with any industry standard 9-channel magnetic tape drive, including IBM's. The tape is recorded at 800 bpi. The physical record length is 1024 eight bit bytes. The ninth bit of each byte is used for an odd parity bit. Inter-record gaps and end-of-file marks are industry standard.

# 4. TEST RESULTS AND DATA

## 4.1 INTRODUCTION

As outlined in the introduction to Section 1, data obtained from the Philadelphia tests disclosed special propagation characteristics in high-rise building areas which had not been experienced in prior tests of the AVM system in Dallas, and which had not been reported in published results of earlier investigations. The evaluation of these propagation effects resulted in two significant changes to the AVM system to bring its position-location performance to the high level of accuracy that had been achieved in previous applications of the system. This section describes the system changes, and the location and timing performance obtained after incorporating the changes, and compares this performance with that obtained before the changes were incorporated.

The section concludes with the data taken under each of the various test conditions, presented in three forms: histograms, maps, and tables. The data is summarized in histogram form showing x and y coordinate deviation of measured data from actual position, as well as histograms of radial error. Inspection of these summaries indicates excellent position location performance for most locations. Relatively few measurements showed substantial deviation from true position.

To help visualize systematic relationships between the points exhibiting substantial deviation from true position, the data for check points is presented in map form, graphically indicating the magnitude and direction of deviations. In addition, a tabular summary of data taken under each of the conditions averaged for 1/10 mile segments of the vehicle path is also presented.

### 4.1.1 SYSTEM IMPROVEMENTS

a. Zero Fill Modification

In the early portion of the Philadelphia test sequence, preliminary data evaluation disclosed poorer performance than had been expected in the high-rise area. Inspection of the system operation disclosed that the "reverberation" of pulse signals originating in the high-rise building areas of this city persisted for a longer period than had been experienced previously or had been reported in the literature. The AVM system had provided for a gap in the timing measurement pulse preamble of 37.5 microseconds to allow reverberating pulse echoes to die out. Measurements in Philadelphia, however, indicated reverberation past 45 microseconds (and as late as 75 μs), resulting in some distortion of the leading edge of the timing pulse.

A simple modification to the timing preamble, to provide an additional 55 microseconds space before the timing pulse, eliminated this difficulty and all subsequent official and supplementary data was taken with this modification.

The random route location data taken prior to the incorporation of this modification is not representative of system performance.

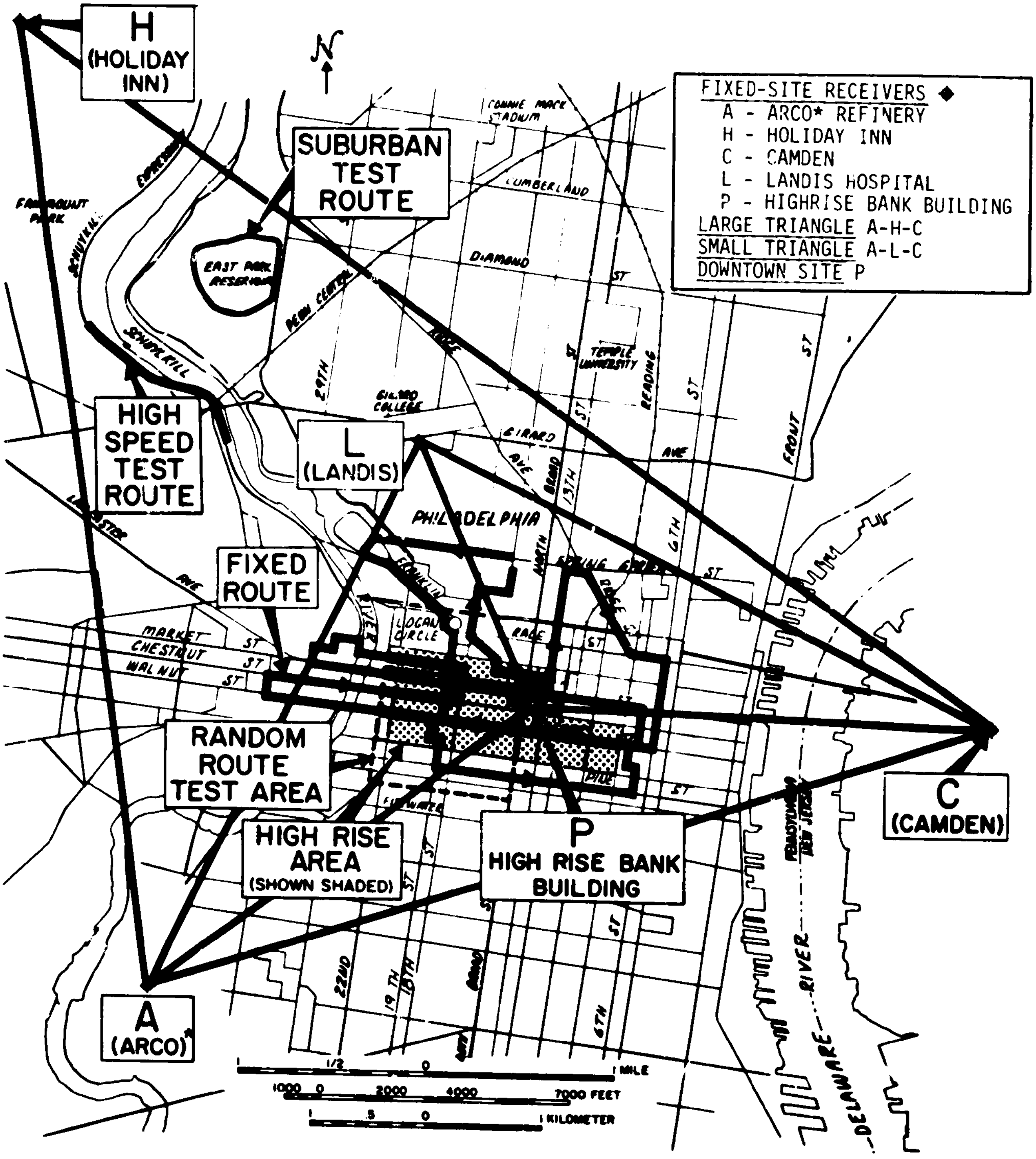
Sufficient position location data to assess performance of the system is contained in measurements taken in the one random-route and all of the fixed-route tests conducted after incorporation of this zero-fill modification.

b. Receiver Siting

Evaluation of position-location data with the receiver siting described in section 2 disclosed excellent performance in suburban areas, but showed some points of substantial location inaccuracy in high-rise areas. Analysis of the data shows that most inaccurate position-location points occur in isolated groups, and have a vector error pointing in a direction which corresponds to a disproportionately large multi-path delay in the propagation path to one of the receivers. Inspection of the maps shows that the effect is apparently caused by blockage of signals to the receiver located at the opposite side of the high-rise area.

Reconsideration of the receiver siting procedure disclosed that the proper approach would be to locate receivers as shown in figure 4-1. In this arrangement, each receiver has approximately the same amount of multi-path delay from all vehicle locations in the area of coverage. This represents a departure from the apparently desirable situation where there is a direct line-of-sight from the receiver to the vehicle in as many locations as possible. Such an arrangement was found to give a disproportionately short propagation path to the favored receiver, and created distortion of the position-location information. Accordingly, the siting of receivers for the Los Angeles areas has been modified to provide consistent amounts of multi-path for all receivers covering each area. The difficulty in predicting exact multi-path delays will be compensated for in the Los Angeles installation by making empirical measurements using round-trip ranging techniques.

To prove that the receiver-siting change would eliminate the areas of incorrect position location, an additional receiver was placed in the center of the Philadelphia high-rise area. After installing the new receiver at the High Rise Bank Building, tests were re-run. Comparison of data obtained before the change in receiver siting with that obtained for the same run and proper siting can readily be made by comparing the maps in the data section of this report. This comparison clearly shows that the areas of location-inaccuracy have been eliminated, and that the new location-accuracy and completeness of coverage meet the needs of the system.



*NOTE: ATLANTIC RICHFIELD CO.

FIGURE 4-1. PHILADELPHIA TEST SITE CONFIGURATIONS

### 4.1.2 TEST RESULTS

#### a. General

The results of the tests are summarized in the accompanying tabulations. Three basic types of tests are reported. Fixed-route tests were conducted to evaluate position-location and time-of-arrival accuracies utilizing identified check points and signposts in high-rise areas. Random-route tests were conducted to evaluate position-location accuracy on other streets. Special tests were conducted to evaluate the AVM system operation under worst-case conditions.

For both the fixed-route and random-route tests, data are presented showing the accuracy and coverage of the AVM system in its final configuration, principally utilizing supplemental data acquired after completion of the official test-plan sequence. For comparison purposes, data acquired in the official test plan prior to re-siting of the receiver is also included. The accompanying result-tabulations show the distribution of data at the 50, 68 and 95 percentile points, as well as the percentage coverage determined for each of the tests. Where data was obtained in more than one receiver triangle configuration, the configuration is identified by the three sites used to compute positions.

#### b. Position Location Accuracy Summary

Table 4-1 presents a summary of the results of position location tests under various conditions, and using various receiver siting combinations. From comparison of data for the different receiver triangle configurations, it is evident that the smaller configurations give superior performance in the high-rise areas, while the large-triangle configurations are fully adequate for suburban areas.

While some degradation of performance is noted in the underpass test, the system is seen to be unaffected by high speed and power-line interference.

#### c. Time Point Accuracy Summary

Table 4-2 presents the accuracy of time-of-crossing measurements for fixed route high-rise areas using signposts and for suburban routes without signposts. It is clear that the system performance is excellent in both areas.

#### d. Systematic Location Errors (Bias)

A test was conducated at an early stage of the test program to determine whether or not systematic errors, or "bias," existed in the system. This test consisted of gathering data samples at 15 designated map locations distributed throughout the coverage area, using both the large and the small triangular cells. Approximately 300 data samples were collected at each map point for each cell. Average

TABLE 4-1. POSITION LOCATION ACCURACY SUMMARY

| Test | Receiver | Radial Accuracy of Locations (ft) | | | | | Notes |
|---|---|---|---|---|---|---|---|
| | | 50% | 68% | 95% | 99.5% | Coverage | |
| **Fixed Route** | PNB/Landis/Camden | 141 | 212 | 460 | 940 | 98.5% | Based on supplemental data using Philadelphia National Bank receiving site |
| | Landis/ARCO*/Camden | 145 | 220 | 790 | >3000 | 90% | Test Plan data using small triangle |
| | Holiday/ARCO/Camden | 205 | 290 | 1780 | >3000 | 89.7% | Test Plan data using large triangle |
| **Random Route** | Landis/ARCO/Camden | 198 | 265 | 880 | 1960 | 87% | Test plan data using small triangle |
| | Holiday/ARCO/Camden | 206 | 300 | 1600 | >3000 | 84% | Test plan data using large triangle |
| **Special Tests** | | | | | | | |
| **Suburban Route** | Holiday/ARCO/Camden | 97 | 131 | 270 | 693 | 98.5% | Test Plan data |
| **High Speed** | Holiday/ARCO/Camden | 107 | 160 | 720 | 1220 | 95% | Test Plan data |
| **Underpass** | Holiday/ARCO/Camden | 200 | 570 | 1255 | 2340 | 94% | Test Plan data |
| **Power Line Interference** | Landis/ARCO/Camden | 140 | 180 | 400 | 1050 | 99.9% | Test Plan data |

*Atlantic Richfield Co.

## TABLE 4-2. TIME POINT ACCURACY SUMMARY

| Test | Receivers | Time of Crossing Accuracy (seconds) |  |  |  | Coverage(%) | Percentile (%) |  |
|---|---|---|---|---|---|---|---|---|
|  |  | 50% | 68% | 95% | 99.5% |  | ±15 sec | ±60 sec |
| Fixed Route High Rise Area With Signposts | Holiday/ARCO/Camden | ±5 | ±8 | ±25 | ±170 | 91 | 92 | 99 |
|  | Landis/ARCO/Camden | ±5 | ±8 | ±29 | ±118 | 91 | 93 | 99 |
| Suburban Route Without Signposts | Holiday/ARCO/Camden | ±8.3 | ±10 | ±21 | ± 27 | 99.8 | 92 | 100 |

error vectors were calculated to see if there was any observable trend in error direction or magnitude.

Examination of the data showed no immediately observable overall trend in either direction or magnitude of the errors. By selectively partitioning the coverage area it might be possible to arrive at an average local bias for some regions, but then the number of sampled map points becomes too small for any real confidence in the results. This preliminary test was, therefore, inconclusive. More data was needed to determine whether or not systematic bias errors were present.

The data gathered during later tests has been examined for bias indication with mixed results.

Basically it appears that some systematic bias error is present in suburban sections of the coverage area, in areas relatively free from site obstruction. Reprocessing the data with a bias removal step included in the position fixing computations significantly improved overall accuracy in this case.

In a high-rise environment covered by remote sites a different situation prevails. Here the various routes each exhibit a unique trend in error direction, but large dispersion in error magnitude. The direction of error is away from the site with the most obstructed path, and the average magnitude of the error depends very much on the extent of the high rise region blocking the path. Thus, in the case of parallel routes in a high-rise environment with the same site obstructed, the direction of the errors is the same for both routes, but the average error magnitudes are greater for the more distant route.

As a vehicle moves around in the high-rise region, the most obstructed site changes according to the density of high-rise buildings in each site path, and the directions of errors change accordingly. The magnitude of the error is large enough to mask the bias errors, if indeed there are any. In short, the position fixing errors in a dense urban section of an extended coverage area are environmentally caused and not readily corrected by software processing.

Figure 4-2 illustrates the logical grouping of the test data in a family tree format of the test data, including processing conditions and ID number test identification presented in this section. All location subsystem data was recorded 10 times per second. That is, location information was obtained every 1/10 of a second. The fixed route and random route data was processed at both a subsystem and system level. The basic difference in processing is the polling time interval. The subsystem level is defined as the check point data processed at a ten per second update rate utilizing the basic location algorithm without any filtering or on-route correction processes. The system level is defined as data processed at a 10 second polling rate (6 per minute) including filtering and "on-route" correction for the fixed route data or filtering only for the random route data, to demonstrate operational system location accuracy and time point performance. System level processing was applied to check point locations only, and also to all

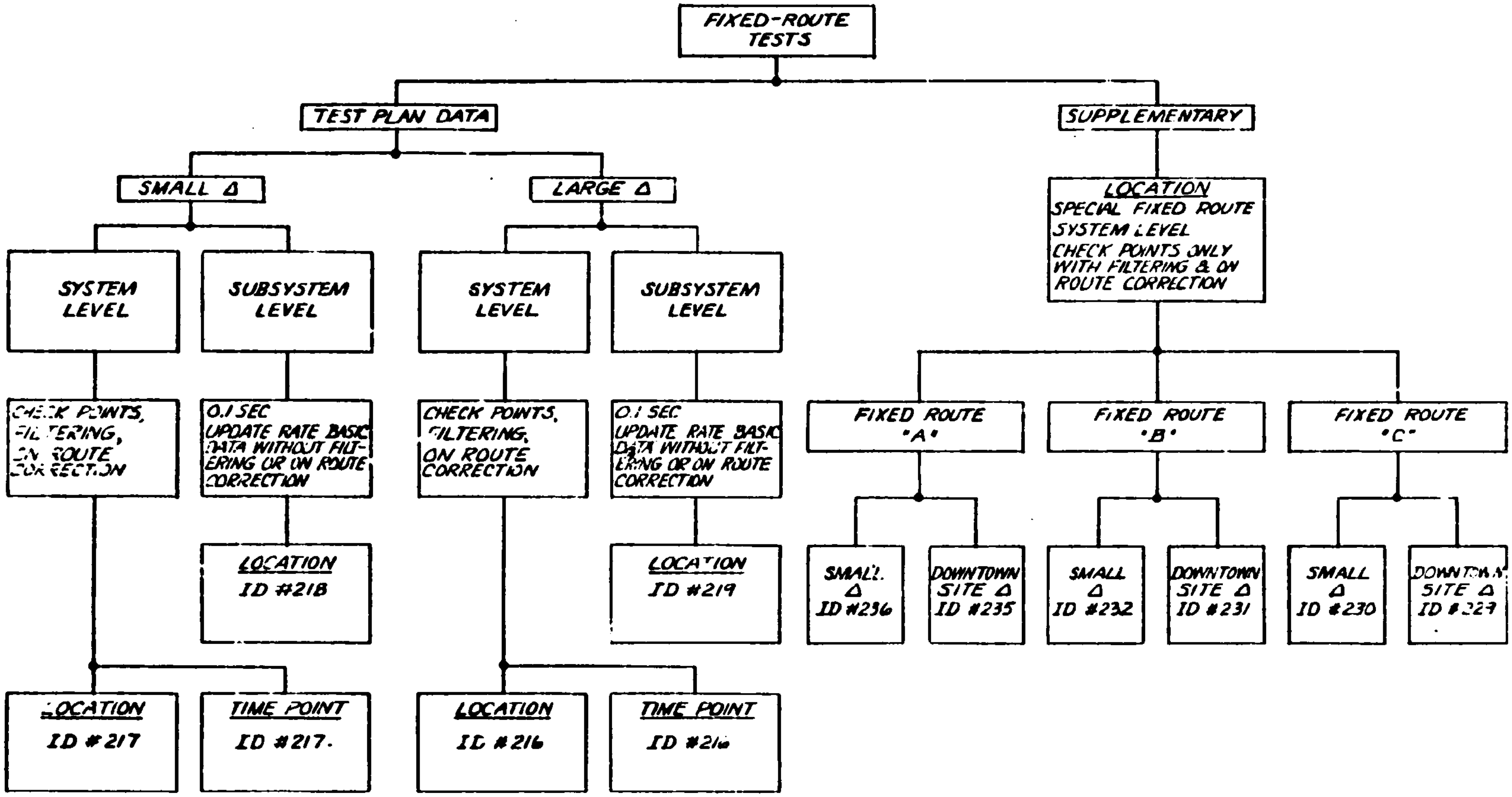


FIGURE 4-2. TEST DATA FAMILY TREE

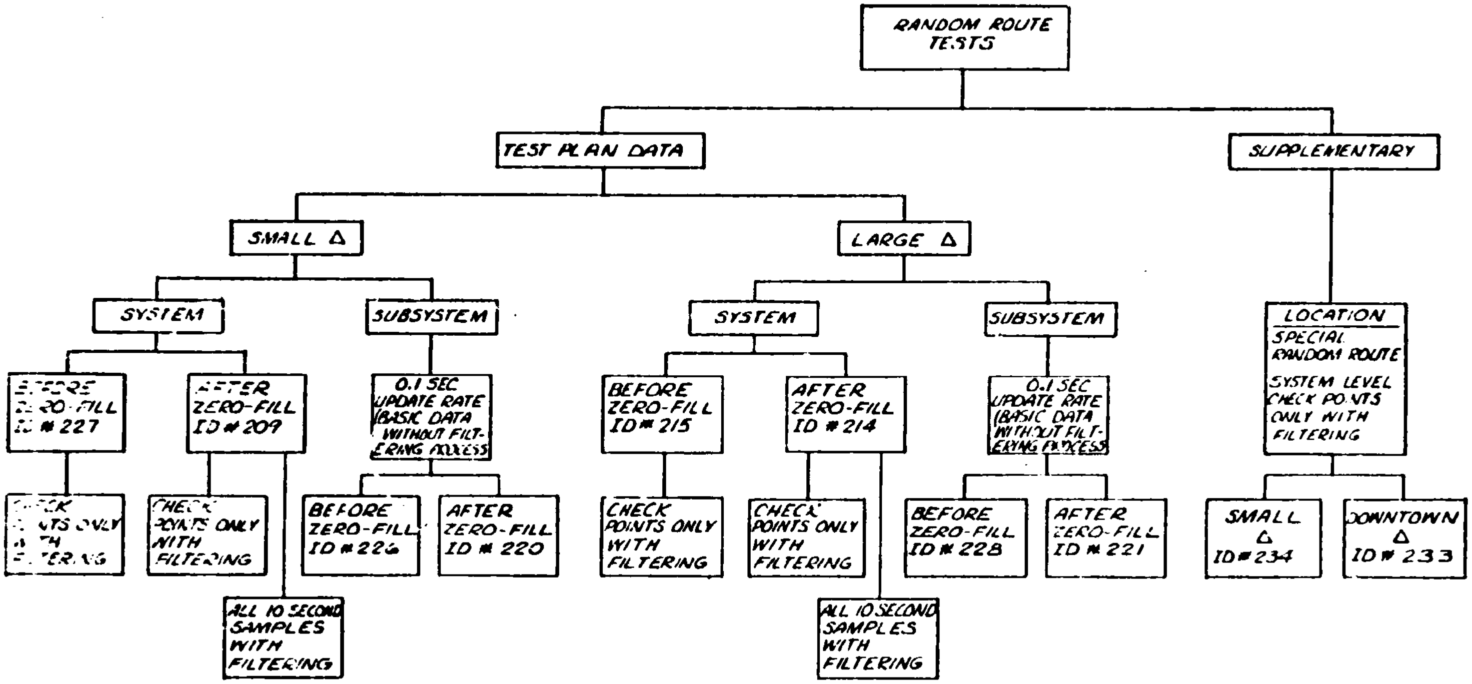


FIGURE 4-2. TEST DATA FAMILY TREE (cont)

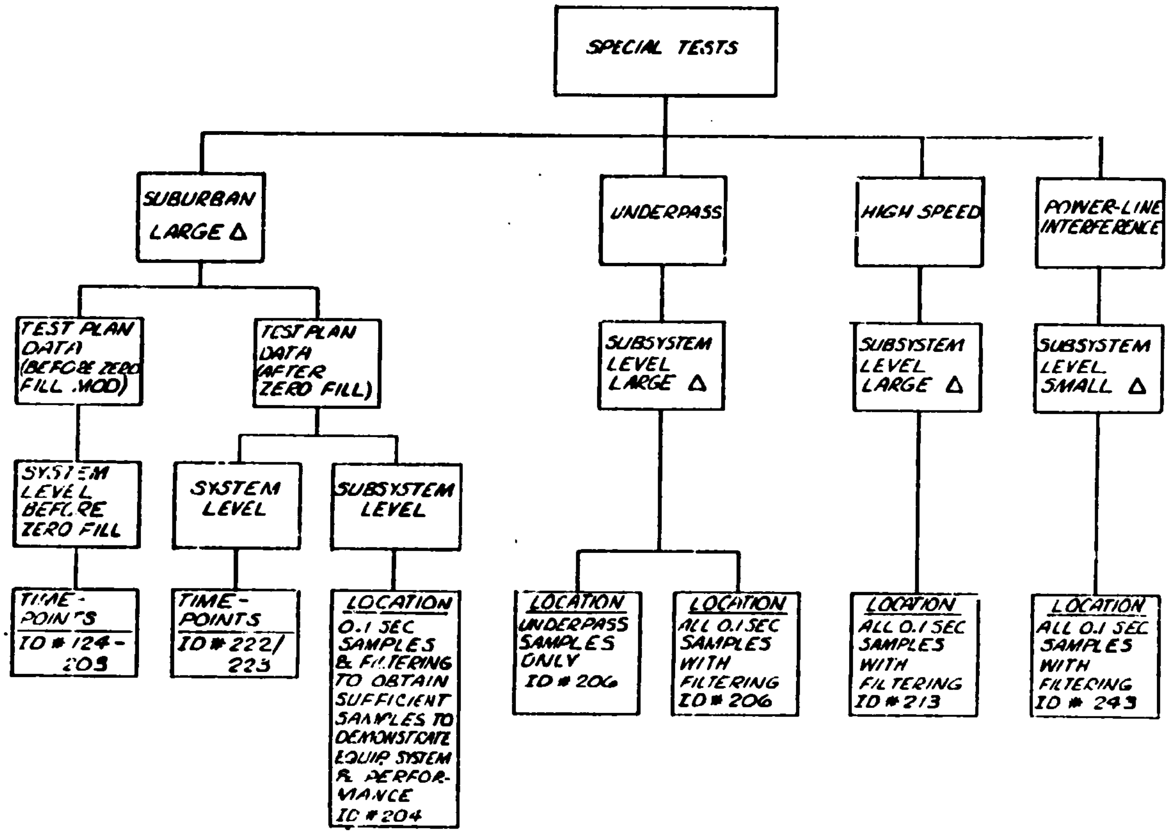


FIGURE 4-2. TEST DATA FAMILY TREE (cont)

10 second route samples. The performance level of check points only or at all of the 10 second samples is identical since the check point data is a subset of the 10 second sample data and both are processed at a 10 second polling rate. Only the one run of the "after zero fill" random route system data was processed to include every 10 second sample because of the limited number of check points for that run. The confidence of the histogram statistics for the check point only plot may be insufficient and therefore all 10 second sample data was processed and presented in histogram form.

In determining absolute location error the following ground rules were established. The trilateration error at the check points is defined as the difference between the trilateration location and the fifth wheel location at the same instant of time. When errors are shown for checkpoints only, the location data sample used is the closest polling interval sample previous to the check point at the specified update rate. For example, if a test is being processed at a 10 second polling rate and an event is entered at time T(E) the program calls up the previous trilateration and fifth wheel locations available at the 10 second update rate. These locations are derived from data at time T(U), a time previous to T(E). (Figure 4-3).

The trilateration location and the fifth wheel location taken at a time T(U) are compared to give the trilateration error. At a 10 per second update rate, the errors are computed in a similar manner with time T(E) minus T(U) less than 0.1 second.

It becomes apparent that the trilateration error is independent of the update rate. That is not to say that the same interrogations are used at all update rates, but the different interrogations used are statistically identical. This results in the system and subsystem level tests being statistically identical with the exception that at the system level "on road correction" and "filtering" may be used.

When performing the system level test a subset of the available data was extracted on most runs. This subset is the data relating to check points. This data was isolated from the total in order to eliminate the effects of vehicle speed on the statistics. For example, if the vehicle stops at a point where the data is good and then proceeds rapidly through a bad area, the data is biased by having more samples in the good area. By looking only at check points the data is no longer biased by the vehicle speed since only one sample is taken at each check point.

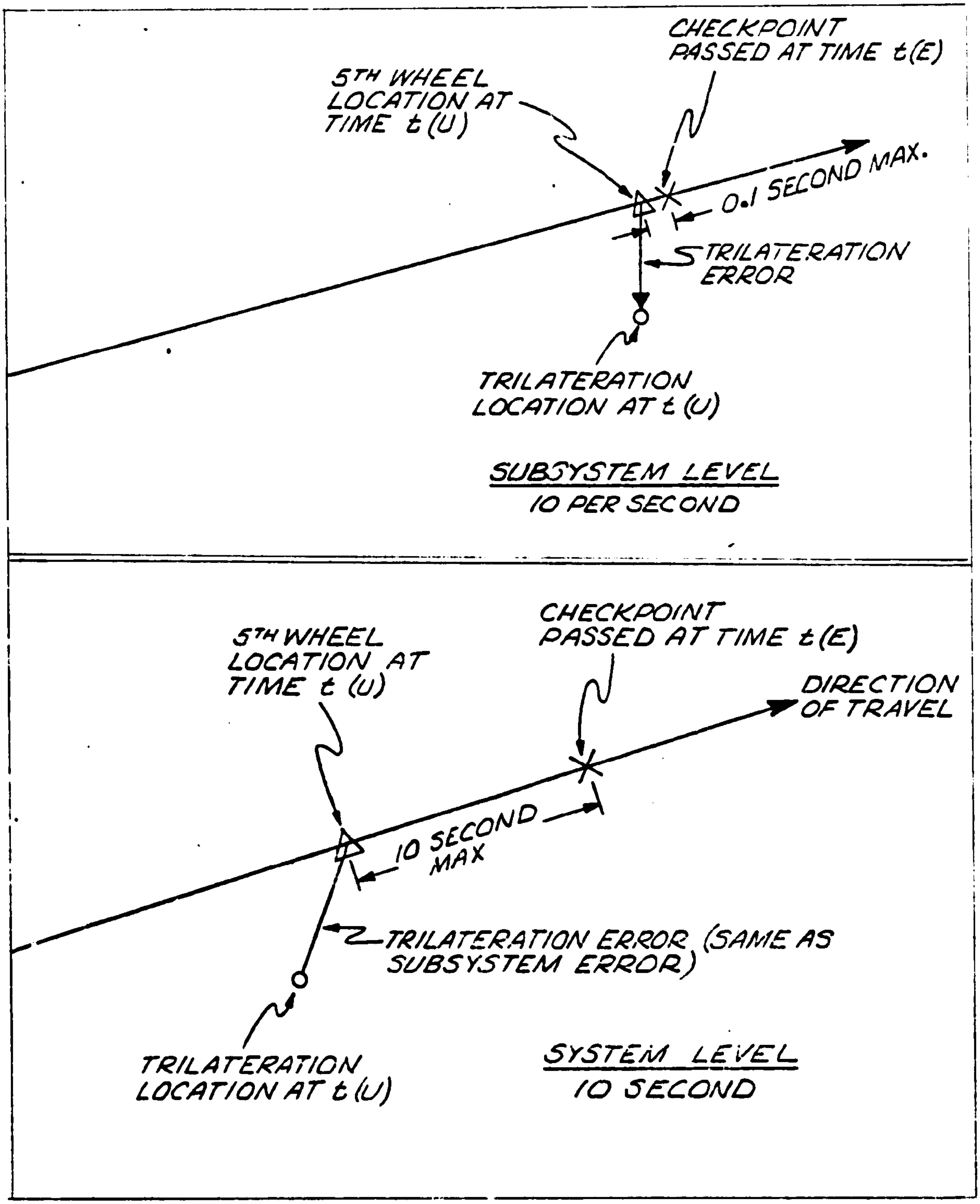


FIGURE 4-3. TRILATERATION ERROR AT SYSTEM AND SUBSYSTEM LEVEL

### 4.1.3 TEST DATA

The following pages present the data obtained for each of the test conditions of the supplemental and test plan tests. The test conditions and some comments on the data are provided for each test. The histograms for all of the tests performed are grouped in Volume 3 for ease of reference.

Early shakedown fixed route tests run with 200 watts peak radiated from the central site transmitter and 250 watts peak from the vehicle transponder transmitter, utilizing a blade style antenna on the vehicle, resulted in insufficient signal strength at the fixed site receivers. A change to a 5 dBI gain whip antenna, the removal of an air conditioner unit that blocked the vehicle radiation pattern, and the increase of the vehicle transmitter power to 600 watts peak improved the signal-to-noise ratio to an acceptable level for good coverage and improved location performance of the AVM system. Although early official suburban special tests run with the 200 watt radiated level from the synchronization transmitter resulted in good synchronization control and coverage, exploritory testing in the downtown area indicated sporadic coverage on South and Pine Streets. A decision was made to increase the sync power from 200 watts peak to at least 600 watts peak. Sufficient coverage was then obtained. All following tests were performed at these power levels and with the gain whip antenna. The power level and antenna gain are accounted for in the Los Angeles configuration (See Section 5) by relocating receiver sites and using the 5dBI whip.

The subsystem, 10 per second data, of the fixed and random route tests is presented as the basic location algorithm process applied to the check point data. The fixed and random route system level data is further processed with a filtering algorithm that rejects samples that deviate more than 1000 feet from the previous location. If the filtering algorithm is not satisfied, the radius,of search is increased by 1000 feet for each sample until the algorithm is satisfied or 4 samples fail in a row. When 4 samples fail in a row, the algorithm is reset and the next sample is accepted as the true trilateration location. The limit of 1000 feet was derived from an examination of the impact of 10 second update rate as opposed to a 2 sec update rate for Dallas where the filtering algorithm used a 350 foot limit.

The fixed route data has an additional system level correction process that translates the vehicle location, derived by the basic location algorithm, to a point on the route that is at a right angle path to the route, providing the raw location is within 500 feet of the route.

The special tests,where the vehicle traveled a short distance, were processed at the subsystem 10 per second data rate and the data filtered (1000 foot filter) to simulate equivalent system performance.

## 4.2 FIXED ROUTE

The object of the fixed route test was to determine the performance of the AVM system when the test vehicle traverses a fixed route that a transit vehicle would normally cover and simulate the normal stop and go cycle of a bus when discharging passengers. Tests were conducted during normal business days with particular emphasis on rush hour traffic to closely simulate an operational AVM system where more measurements were taken at rush hours than at any other time of day.

Location and time check point measurements were made on each run. Each run was assigned a test number. The vehicle passed the time point without stopping 50% of the time and simulated bus passage stops for the remaining 50%. The route used for this test is shown in figure 4-4. All the events and the general location of the time points and signpost units are identified on the route. The detailed signpost locations are shown on the figures in the Appendix.

The driving instructions for the fixed route are in section 3. As the vehicle traversed the specific fixed route, the operator in the vehicle input to the vehicle data acquisition system, event markers noting vehicle passage of DOT/TSC specified points. Event markers were also entered at turn points to initiate proper orientation of the fifth wheel into the software location program. A detailed itinerary with event coordinates of the fixed route is listed in table 4-3.

When the vehicle leaves the notch of the signpost radiated pattern, the time is automatically recorded on tape. At the direction of the DOT/TSC monitor, the vehicle either stopped prior to passing a time point in order to simulate picking up or discharge of passengers (identified on the recorder by the use of a switch to indicate a door opening) or the vehicle passed by a time point with time of departure being identified at the point where the antenna on the vehicle passed the point and the operator manually input an event mark.

4.2.1 Large Triangle (HAC) Performance. Data was recorded simultaneously from the large triangle (HAC) receivers and from the small triangle (LAC) receivers. The data was processed at the system level at a data rate of a sample every 10 seconds and at the subsystem level at a data rate of 0.1 seconds. The system and subsystem performance of the AVM system for the fixed route, utilizing the large triangle (HAC) data is summarized in table 4-4. Also listed are the time point accuracy measurements made at the signposts and stop/departure points. The time point histogram is shown in Volume 3, figure 1. As indicated, the percentile figure for all time point samples within ±15 seconds is 92%, just short of the 95% specification. Also the ±60 second specifications of 99.5% was almost matched with an AVM performance of 99% at ±60 seconds. The time point hit-miss statistic was 91% hits. Time point accuracy histogram for sign posts only is shown in Volume 3, figure 2. The percentiles are +2.6 seconds (50%), ±4.1 seconds (68%), ±54 seconds (95%) and ±170 seconds (99.5%).

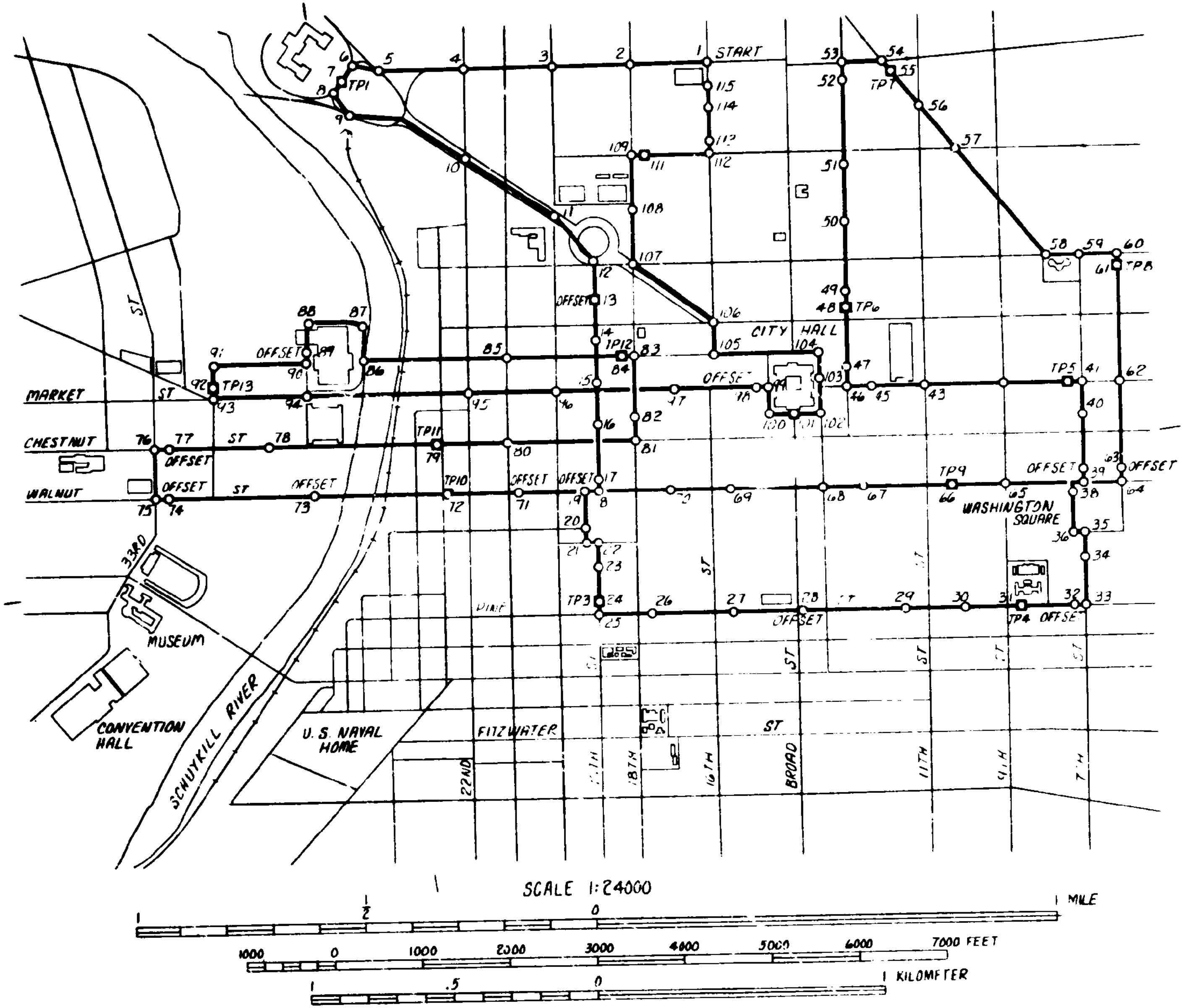


FIGURE 4-4. FIXED ROUTE TEST ROUTE

## TABLE 4-3. PHILADELPHIA AVM TEST FIXED ROUTE EVENT COORDINATES A

Date____________ Start Time____________ Initials____________ Page 1 of 4

\ Tape #____________ File#____________ Test#____________

| EVENT NO. | D. H | LOCATION X-COORD. | Y-COORD. | LV PT | DOOR O/C | LOG | COMMENTS |
|---|---|---|---|---|---|---|---|
| 1 | LT | 724 519 | 239 906 | | | | 8 6TH & Spring Garden |
| 2 | | 723635 | 240 019 | | | | 6 Spring Garden @ 18TH |
| 3 | | 722 729 | 240 126 | | | | 4 20TH |
| 4 | | 721 731 | 240 224 | | | | 2 22ND |
| 5 | RT | 720 920 | 240 340 | | | | "A" Spring Garden & Art Museum Circle |
| 6 | LT | 720 520 | 240 520 | | | | "B" Circle turn toward Museum |
| 7 | "SP" | 720 304 | 240 363 | | | | Signpost #1 |
| 8 | LT | 720 180 | 240 120 | | | | "C" Circle turn away from Museum |
| 9 | RT | 721 000 | 239 700 | | | | "G" Turn onto Ben Franklin Pkwy |
| 10 | | 721 570 | 239 212 | | | | 36 Ben Franklin Pkwy @ 22ND |
| 11 | RT | [illegible] | 238 379 | | | | 53 " " & 20TH |
| 12 | RT | [illegible] | 237 787 | | | | 86 Logan Circle Race & 19TH |
| A 13 | "SP" | 722 813 | 237 356 | | | | Signpost #2 |
| 14 | | 722 735 | 236 814 | | | | 19TH St into JFK [illegible] JFK (R) |
| 15 | | 722 690 | 236 459 | | | | Pass Market [illegible] (R) |
| 16 | | 722 632 | 236 023 | | | | @ [illegible] |
| 17 | | 722 508 | 235 315 | | | | Pass Walnut [illegible] (R) |
| 18 | RT | 722 493 | 235 253 | | | | 230 19th St & [illegible] |
| 19 | LT | 722 340 | 235 230 | | | | "D" Walnut & Ritt. Square |
| 20 | | 722 316 | 234 253 | | | | 250 Rittenhouse @ [illegible] |
| 21 | LT | 722 260 | 234 720 | | | | "E" " & S. Rittenhouse |
| 22 | RT | 722 444 | 234 693 | | | | 251 S. Rittenhouse & 19th |
| 23 | | 722 414 | 234 394 | | | | 274 19TH @ Spruce |
| 24 | "SP" | 722 346 | 233 971 | | | | Signpost #3 |
| 25 | LT | 722 332 | 233 880 | | | | 293 19TH & Pine |
| 26 | | 722 882 | 233 795 | | | | Pine @ [illegible] |
| 27 | | 723 920 | 233 659 | | | | [illegible] |
| 28 | | 724 750 | 233 552 | | | | past [illegible] (R) |
| 29 | | [illegible] | 233 407 | | | | 302 @ Quince |
| 30 | | 726 532 | 233 313 | | | | 304 @ 10TH |
| 31 | "SP" | [illegible] | [illegible] | | | | [illegible] |
| 32 | | 727 761 | 233 144 | | | | [illegible] 7TH [illegible] (R) |
| 33 | LT | [illegible] 862 | 233 138 | | | | 307 Pine & 7TH |
| 34 | | 727 916 | [illegible] | | | | [illegible] 7TH [illegible] |
| 35 | LT | [illegible] 975 | 233 941 | | | | [illegible] " & Washington Sq. |

## TABLE 4-3. PHILADELPHIA AVM TEST FIXED ROUTE EVENT COORDINATES A (cont)

Date__________ Start Time__________ Initials__________ Page 2 of 4

Tape #__________ File#__________ Test#__________

| EVENT NO. | D/H | LOCATION X-COORD. | Y-COORD. | LV PT | DOOR O/C | LOG | COMMENTS |
|---|---|---|---|---|---|---|---|
| 36 | RT | 727980 | 233960 | | | | "F" S. Washington Sq & W. Washington Sq. |
| 37 | RT | 727840 | 234460 | | | | "G" W. Washington & Diagonal |
| 38 | LT | 728039 | 234549 | | | | 244 7TH & Walnut |
| 39 | | 729072 | 234611 | | | | past Walnut No Parking Any Time Sign (R) |
| 40 | | 728142 | 235287 | | | | @ Ranstead |
| 41 | LT | 728176 | 235673 | | | | 177 7TH & Market |
| 42 | "SP" | 728051 | 235690 | | | | Market after 7TH (Signpost #5) |
| 43 | | 727321 | 235782 | | | | 175 @ 9TH |
| 44 | | 726427 | 235897 | | | | 173 11TH |
| 45 | | 725865 | 235958 | | | | .. past 12TH Light pole No Stopping Any Time (R) |
| 46 | RT | 725553 | 236009 | | | | 171 Market & 13TH |
| 47 | | 725565 | 236245 | | | | 169 13TH @ Commerce |
| 48 | "SP" | 725674 | 236915 | | | | after Arch (Signpost #6) |
| 49 | | 725705 | 237100 | | | | 111 @ Cherry |
| 50 | | 725796 | 237826 | | | | 365 Summer |
| 51 | | 725883 | 238470 | | | | Carlton |
| 52 | | 726033 | 239473 | | | | Nectarine |
| A 53 | RT | 726034 | 239670 | | | | 11 13TH & Spring Garden |
| 54 | RT | 726512 | 239618 | | | | 12 Spring Garden & Ridge |
| 55 | "SP" | 726735 | 239262 | | | | Ridge (Signpost #7) |
| 56 | | 726868 | 239052 | | | | 30 Ridge @ Hamilton |
| 57 | | 727222 | 238477 | | | | 47 Callowhill |
| 58 | LT | 727969 | 237158 | | | | 98 Ridge & Race |
| 59 | | 728423 | 237095 | | | | Race @ 7TH |
| 60 | RT | 728832 | 237038 | | | | 100 Race & 6TH |
| 61 | "SP" | 728807 | 236865 | | | | 6TH (Signpost #8) |
| 62 | | 728642 | 235608 | | | | 178 @ Market |
| 63 | | 728491 | 234527 | | | | before Walnut No Stopping Sign (R) |
| 64 | RT | 728484 | 234477 | | | | 245 6TH & Walnut |
| 65 | | 727165 | 234661 | | | | 242 Walnut @ 9TH |
| A 66 | "SP" | [illegible] | 234718 | | | | between 10TH & 11TH (Signpost #9) |
| 67 | | 725624 | 234856 | | | | 238 @ Camac |
| 68 | | 725109 | 234908 | | | | @ Juniper |
| 69 | | 724644 | 235054 | | | | 234 [illegible] |
| 70 | | 723382 | 235138 | | | | 232 Walnut @ 17TH |

## TABLE 4-3. PHILADELPHIA AVM TEST FIXED ROUTE EVENT COORDINATES A (cont)

Date__________ Start Time__________ Initials__________ Page 3 of 4

Tape #__________ File#__________ Test#__________

| EVENT NO. | EVENT D/H | LOCATION X-COORD. | LOCATION Y-COORD. | LV PT | DOOR O/C | LOG | COMMENTS |
|---|---|---|---|---|---|---|---|
| 71 | | 721562 | 235365 | | | | Walnut before 21ST No Parking Any Time (R) |
| 72 | "SP" | 720844 | 235469 | | | | between 22ND & 23RD (Signpost #10) |
| 73 | | 719446 | 235662 | | | | past Expwy Max Speed 25 Bus Stop Sign (R) |
| 74 | | 717637 | 235903 | | | | before 33RD Light Pole (L) |
| 75 | RT | 717469 | 235924 | | | 361 | Walnut & 33RD |
| 76 | RT | 717537 | 236481 | | | 356 | 33RD & Chestnut |
| 77 | | 717596 | 236474 | | | | Chestnut after turn Light Pole (R) |
| 78 | | 718828 | 236311 | | | 358 | @ 31ST |
| 79 | "SP" | 720681 | 236062 | | | | before 23RD (Signpost #11) |
| 80 | | 721599 | 235944 | | | 184 | @ 21ST |
| 81 | LT | 723042 | 235773 | | | 187 | Chestnut & 18TH |
| 82 | | 723075 | 236092 | | | | 18TH @ Ludlow |
| 83 | LT | 723169 | 236686 | | | 143 | 18TH & JFK |
| A 84 | "SP" | 723062 | 236698 | | | | JFK after turn (Signpost #12) |
| 85 | | 721719 | 236878 | | | 140 | @ 21ST |
| 86 | RT | 720052 | 237111 | | | 351 | JFK & PRR |
| 87 | LT | 719954 | 237570 | | | 349 | PRR & Arch |
| 88 | LT | 719475 | 237614 | | | 348 | Arch & 30TH |
| 89 | | 719457 | 237337 | | | | 30TH before JFK [illegible] SP (R) |
| 90 | RT | 719439 | 237171 | | | 350 | 30TH @ JFK |
| 91 | LT | 718340 | 237360 | | | "K" | JFK & 32ND |
| 92 | "SP" | 718330 | 236999 | | | | 32ND before Market (Signpost #13) |
| 93 | LT | 718520 | 236948 | | | 353 | 32ND & Market |
| 94 | | 719345 | 236825 | | | 354 | Market @ 30TH |
| 95 | | 721210 | 236565 | | | 159 | 22ND |
| 96 | | 722216 | 236455 | | | 161 | 20TH |
| 97 | | 723564 | 236256 | | | 164 | 17TH |
| 98 | | 724307 | 236177 | | | | before 15TH Light Pole – [illegible] (R) |
| 99 | RT | 724451 | 236163 | | | 166 | Market & 15TH |
| 100 | LT | 724425 | 235828 | | | 191 | 15TH & S. Penn Sq |
| 101 | "SP" | [illegible] | [illegible] | | | | S. Penn Sq @ [illegible] (Signpost #[illegible]) |
| 102 | LT | 725140 | 235760 | | | "I" | S. Penn Sq & Juniper |
| 103 | | 725239 | 236079 | | | | Juniper past Market [illegible] (L) |
| 104 | LT | 725220 | 236420 | | | "J" | Juniper & JFK |
| 105 | RT | 724056 | 236592 | | | 145 | JFK & 16TH |

## TABLE 4-3. PHILADELPHIA AVM TEST FIXED ROUTE EVENT COORDINATES (cont)

Date__________ Start Time__________ Initials__________ Page 4 of 4

Tape #__________ File#__________ Test#__________

| EVENT NO. | EVENT D/H | LOCATION X-COORD. | LOCATION Y-COORD. | LV PT | DOOR O/C | LOG | COMMENTS |
|---|---|---|---|---|---|---|---|
| 106 | [✓ LT] | 724109 | 236969 | | | | 124 16TH & Ben Franklin Pkwy |
| 107 | RT | 723313 | 237718 | | | | 87 Ben Franklin Pkwy & 18TH |
| 108 | | 723411 | 238422 | | | | 55 18TH & Vine ([illegible]) |
| 109 | RT | 723489 | 238978 | | | | 39 18TH & Callowhill |
| 110 | "SP" | 723650 | 238955 | | | | Callowhill after turn (Signpost #15) |
| 111 | | 723936 | 238915 | | | | 40 \| @17TH |
| 112 | LT | 724402 | 238850 | | | | 41 Callowhill & 16TH |
| 113 | | 724410 | 238918 | | | | 16TH after turn Wooden Pole (L) |
| 114 | | 724479 | 239406 | | | | 24 \| @Hamilton |
| A115 | END | 724[illegible]86 | 239612 | | | | 16TH @Buttonwood |

## TABLE 4-4. FIXED ROUTE PERFORMANCE - LARGE TRIANGLE (HAC)

### 1. SYSTEM LEVEL

Test Plan Data Summation - ID #216, Tests 1-3, 5-11, 17-18, 20, 22, 23, 25, 26, 28, 29, 31

Synchronization Transmitter Power: = 589 W Peak
Vehicle Transmitter Power: = 708 W Peak

A. Check Points Only (with filtering & "on" road correction) (1059 Samples)

Location "X" error 50% = ±90, 68% = ±160, 95% = ±1200, 99.5% = >±3000

"Y" error 50% = ±80, 68% = ±160, 95% = ±1090, 99.5% = >±3000

"R" error 50% = 205, 69% = 290, 95% = 1780, 99.5% = >3000 69% = 300 ft

Hit-Miss Statistics = 89.7% hits

Time Point Accuracy (signpost & arrival/departure time points) 50% = ±5, 68% = ±8, 95% = ±25, 99.5% = ±170, 92% = ±15 sec. 99% = ±60 sec.

Time Point Coverage - Hit-Miss Statistics = 91% hits

Time Point Accuracy (sign post only) 50% = ±2.6, 68% = ±4.1, 95% = ±54, 99.5% = ±170 84% = ±15 sec. 97% = ±60 sec.

B. 0.1 Mile Segment Average Location Error (10 Second Data) ID 249, Test 34
50% = 164, 68% = 220, 95% = 900, 99.5% = 1220, MAX = 3331

### 2. SUBSYSTEM LEVEL

Test Plan Data - ID #219, Test 34

Check points only at 0.1 second update rate (58 Samples)

Location "X" error 50% = ±100, 68% = ±155, 95% = ±550, 99.5% = ±980
"Y" error 50% = ±150, 68% = ±220, 95% = ±980, 99.5% = ±1640
"R" error 50% = 206, 68% = 260, 95% = 1020, 99.5% = 1720

0.1 Mile Segment Average Location Error (0.1 second data) = 81% within 450 ft.
50% = 233, 68% = 316, 95% = 900, 99.5% = 2760, MAX = 3382

The histograms of the check points for the system level and subsystem level, large triangle (HAC), are shown in Volume 3, figure 3 and 4. The percentile figures for the subsystem, where the check points are updated at a 0.1 second rate, when performing the 5th wheel location comparison, are 206 feet (50%), 260 feet (68%) and 1020 ft (95%). An improvement over the subsystem large triangle data was noticed in the small triangle (LAC) subsystem as shown in table 5. The radial error figures were 150 feet (50%), 220 feet (68%) and 720 feet (95%). Tenth mile average radial errors for both the system level 10 second data and the subsystem 0.1 second data for the large triangle (HAC) are shown in table 4 and in Volume 3, figures 5 and 6.

4.2.2 Small Triangle (LAC) Performance. The system level, small triangle fixed route performance is shown in the histograms of Volume 3, figure 7 with percentiles of 140 feet (50%), 220 feet (68%) and 790 feet (95%). The 300 foot percentile is 81%. The hit miss statistic was 90%, five percent short of the 95% specification. For comparison the histograms for the subsystem level is shown in Volume 3, figure 8.

The time point histogram for the small triangle (LAC) configuration at the system level is shown in Volume 3, figure 9. The percentile figures are very similar to the system level, large triangle performance. The percentiles are ±5 seconds (50%), ±8 seconds (68%), ±25 seconds (95%) and ±170 seconds (±99.5%). The ±15 second points were within the 92 percentile and the ±60 seconds within the 99 percentile, again, close to the specification levels. Volume 3, figure 10 is the time point histogram for the sign post only statistics. The percentiles are also listed in table 5.

Tenth mile average radial errors for both the system level 10 second data and the subsystem 0.1 second data for the small triangle (LAC) are shown in table 5 and in the histogram figures 11 and 12 (Volume 3).

To obtain an appreciation of the radial error pattern as the vehicle traverses the fixed route, a map plot of the 10 second radial error samples were scaled on the downtown street map. See figure 4-5. The dots are AVM algorithm locations without using any filtering or "on route" correction in the software programs. The lines joining the dots are the radial error magnitudes ending at the fifth wheel location coordinates. As can be seen, the fifth wheel data was very accurate and most of the time was less than 20 feet. What also is apparent are the large errors in the south east area of the route (along Pine Street) and in the north east corner along Spring Garden and Ridge. The radial errors point away from the single site that is producing excessive delay in the time-of-arrival measurement due to multipath and poor signal-to-noise ratio. In this case Landis hospital signal is marginal when the vehicle is at Pine Street and ARCO has difficulty when the vehicle is at Ridge. In both cases, the received signal must propagate through the downtown central high-rise region.

4.2.3 Central Site Small Triangle Performance. The implementation of the centrally located downtown receiving site afforded the opportunity to gather fixed route data in new smaller triangular configurations that reduced the blockage effect of tall buildings on the vehicle to fixed receiver site propagation paths. By reducing the extent of the multipaths and increasing the signal-to-noise

## TABLE 4-5. FIXED ROUTE PERFORMANCE - SMALL TRIANGLE (LAC)

### 1. SYSTEM LEVEL

Test Plan Data Summation, ID #217, Tests 1-3, 5-11, 13, 17-18, 20, 22, 23, 25-26, 28

Synchronization Transmitter Power = 562 W Peak
Vehicle Transmitter Power = 891 W Peak

A. Check Points Only (with filtering & "on" road correction) (967 samples)

Location "X" error 50% = ±80, 68% = ±148, 95% = ±620, 99.5% = ±2420
"Y" error 50% = ±60, 68% = ±140, 95% = ±520, 99.5% = ±2140
"R" error 50% = 145, 68% = 220, 95% = 790, 99.5% = >3000, 81% = 300

Hit-Miss Statistics = 90% hits

Time Point Accuracy 50% = ±5, 68% = ±8, 95% = ±29, 99.5% = ±118
(Signpost and Arrive/Departure Time Points) 93% = ±15 sec. 99% = ±60 sec.

Time Point Coverage - Hit-Miss Statistics = 91% hits

Time Point Accuracy 50% = ±3, 68% = ±4.2, 95% = ±39, 99.5% = ±118, 85% = ±15 sec.
(Signpost only) 98% = ±60 sec.

B. 0.1 Mile Segment Average Location error (10 second data) ID #248, Test 34
50% = 144, 68% = 180, 95% = 760, 99.5% = 1220, MAX = 1300

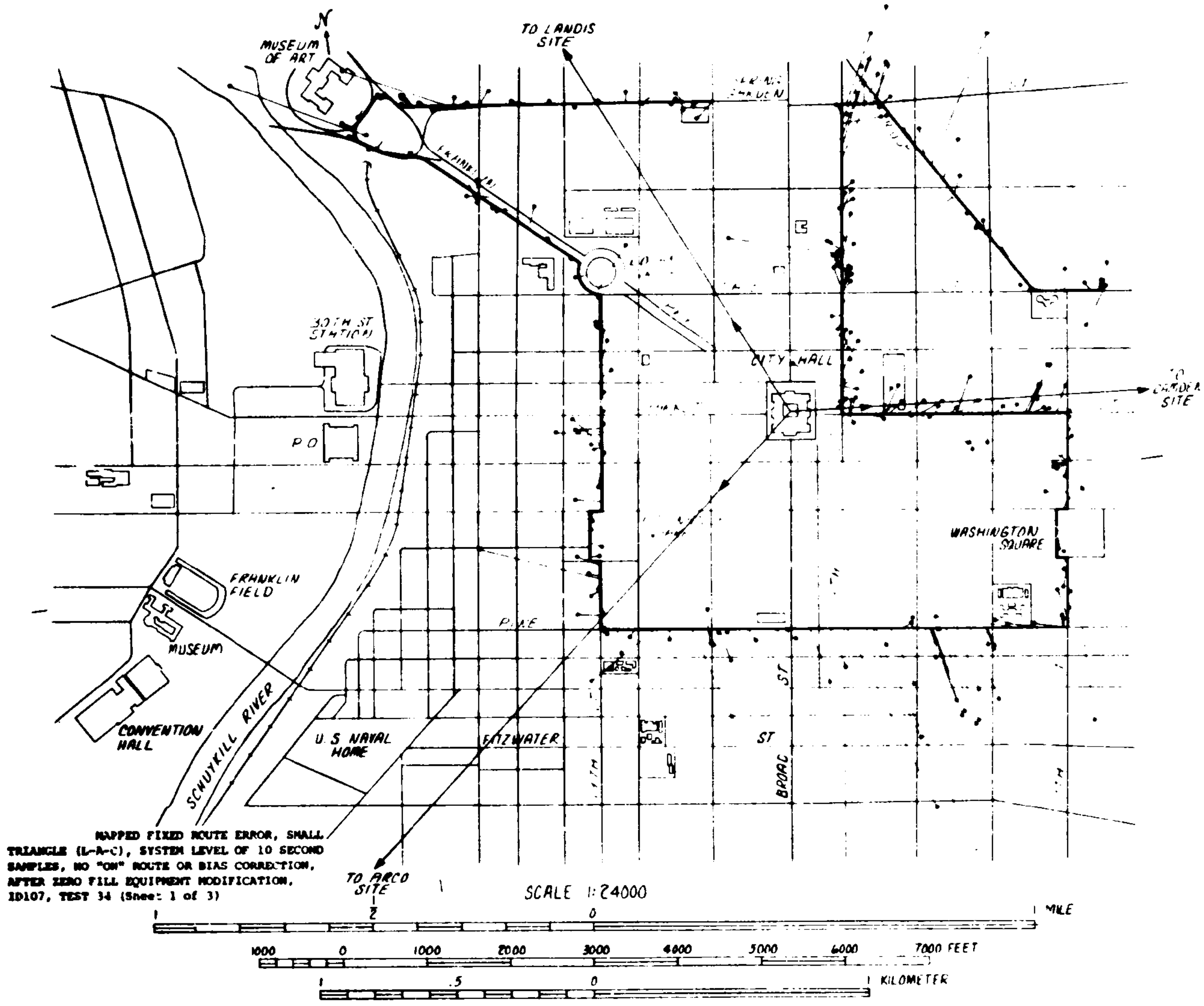
### 2. SUBSYSTEM LEVEL

Test Plan Data Summation - ID #218, Test 34

Check Points Only at 0.1 second update rate (58 samples)

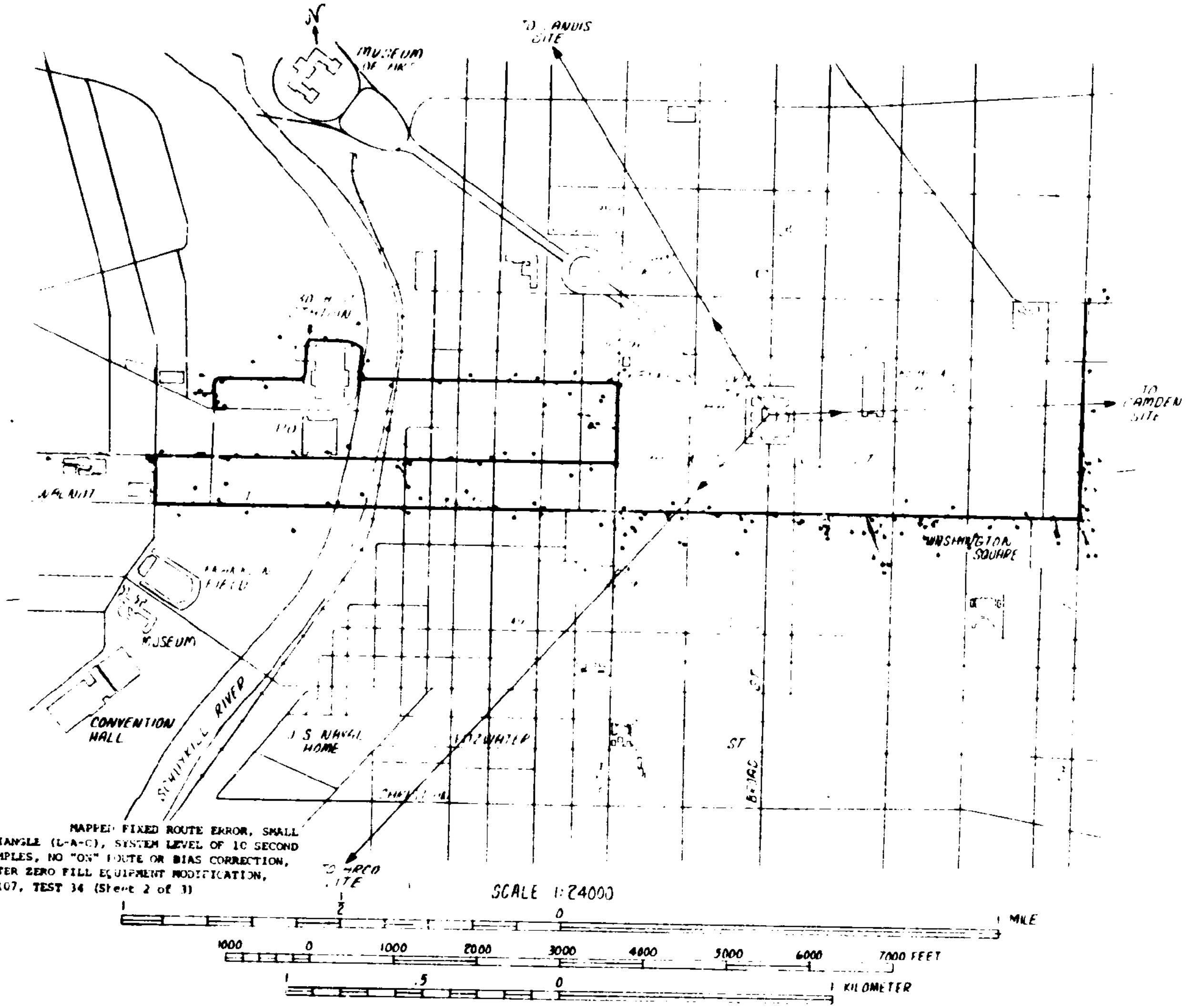
Location "X" error 50% = ±105, 68% = ±120, 95% = ±720, 99.5% = ±1700
"Y" error 50% = ±90, 68% = ±147, 95% = ±460, 99.5% = ±880
"R" error 50% = 150, 68% = 220, 95% = 720, 99.5% = 4100

0.1 Mile Segment Average Location error (0.1 second data) = 82% within 450 ft.
50% = 230, 68% = 300, 95% = 1000, 99.5% = 1695, MAX = 1695



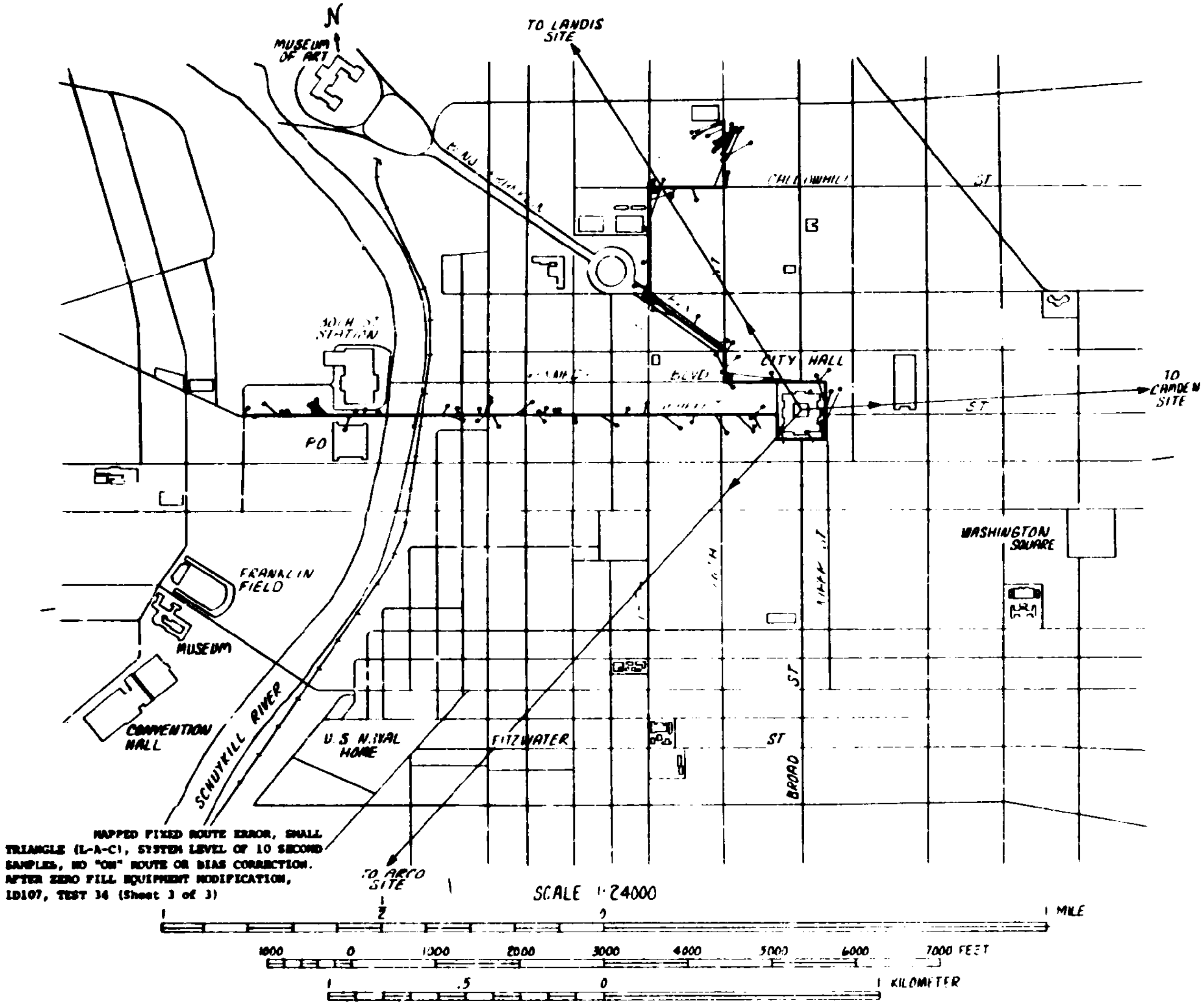
MAPPED FIXED ROUTE ERROR, SMALL TRIANGLE (L-A-C), SYSTEM LEVEL OF 10 SECOND SAMPLES, NO "ON" ROUTE OR BIAS CORRECTION, AFTER ZERO FILL EQUIPMENT MODIFICATION, ID107, TEST 34 (Sheet 1 of 3)

FIGURE 4-5. MAPPED FIXED ROUTE ERROR, SMALL TRIANGLE (LAC)



MAPPED FIXED ROUTE ERROR, SMALL TRIANGLE (L-A-C), SYSTEM LEVEL OF 10 SECOND SAMPLES, NO "ON" ROUTE OR BIAS CORRECTION, AFTER ZERO FILL EQUIPMENT MODIFICATION, ID107, TEST 34 (Sheet 2 of 3)

FIGURE 4-5. MAPPED FIXED ROUTE ERROR, SMALL TRIANGLE (LAC) (cont)



MAPPED FIXED ROUTE ERROR, SMALL TRIANGLE (L-A-C), SYSTEM LEVEL OF 10 SECOND SAMPLES, NO "ON" ROUTE OR BIAS CORRECTION. AFTER ZERO FILL EQUIPMENT MODIFICATION, 1D107, TEST 34 (Sheet 3 of 3)

FIGURE 4-5. MAPPED FIXED ROUTE ERROR, SMALL TRIANGLE (LAC) (ccnt) ratio at the receivers an improvement of the time-of-arrival measurements should be achieved. A number of special route tests were performed to measure the improvement.

4.2.3.1 Special Fixed Route (A). Data was gathered at a system level along a special fixed route on Pine Street, Walnut Street and 15th Street between events 27 and 38 and 65 and 70 utilizing the original small triangle (LAC) and the new small triangle (PAC). The results are shown in table 4-6. As shown, the 95 percentage improved to 670 when compared to the 790 foot figure of the system level small triangle (LAC) performance shown in table 4-5 and the 99.5 percentile improved from greater than 3000 feet to 1000 feet. Interestingly enough, the 50 and 68 percentiles were the same and the percentile at the 300 foot point remained at 80 percentile. The histograms for the two triangles of the special route test (A) is shown in Volume 3, figures 13 and 14.

The radial error patterns for the small triangle (LAC) configuration and the new small (PAC) configuration while the vehicle traversed the fixed route are depicted in figures 4-6 and 4-7. The decrease in the number of the large valued error samples for the PAC triangle is evident and strengthens the case for closer site spacing in the high-rise regions.

4.2.3.2 Special Fixed Route (B) Performance. A special test (B) of the northeast section of the fixed route was performed to determine the extent of improvement in location accuracy of the AVM system when utilizing the centrally located downtown receiver site. Data was taken simultaneously with the original ARCO, Landis Hospital and Camden Apartment fixed site receiver triangle (LAC) and the new triangle made up of the Landis Hospital, highrise bank building and the Camden Apartment (LCP). The leg lengths of this new triangle were 1.6 miles from the Hospital to Bank and Camden. The fixed route extended from 7th and Market, along Market to 13th, north on 13th to Spring Garden east of Spring Garden to Ridge, south on Ridge to Race, east on Race to 6th and south on 6th to Market. Twenty three runs were made on this route and the original check points and events entered. Figure 4-8 is a map plot of the vector errors at each 10 second sample along the route when utilizing the original LCA triangle with no filtering or on route correction process. Figure 4-9 demonstrates the improvement in performance especially around the Spring Garden and Ridge Avenue portions of the route when utilizing the centrally located site triangle configuration. Volume 3 figures 15 and 16 are histograms of the X, Y, and radial errors of the check point data gathered in both triangles after filtering and on route correction processes on both triangles, and table 4-7 lists the percentile figures.

As shown, the radial 50 percentile improved from 201 to 140 feet, the 68 percentile improved from 283 to 212 feet, and the 95 percentile improved from 820 to 460 feet. Three hundred feet is at the 84 percentile. The hit-miss statistic improved from an acceptable 95.8% to a high 98.5%.

## TABLE 4-6. SPECIAL FIXED ROUTE (A) AVM PERFORMANCE

### 1. SMALL TRIANGLE (LAC), SYSTEM LEVEL

Special Fixed Route on Pine, 7th, Walnut, 15th between events 27 and 38, and 65 and 70 - ID #236, Tests 1-10, 15-21

Synchronization Transmitter Power = 1260 W Peak
Vehicle Transmitter Power = 589 W Peak

Check Points Only (206 Samples)

| | | | | | | |
|---|---|---|---|---|---|---|
| Location | "X" error | 50% = ±90, | 68% = ±160, | 95% = ±580, | 99.5% = ±780 | |
| | "Y" error | 50% = ±50, | 68% = ±90, | 95% = ±480, | 99.5% = ±1140 | |
| | "R" error | 50% = 160, | 68% = 275, | 95% = 720, | 99.5% = 1200 | 71% = 300 ft. |

Hit-Miss Statistics = 91.1% hits

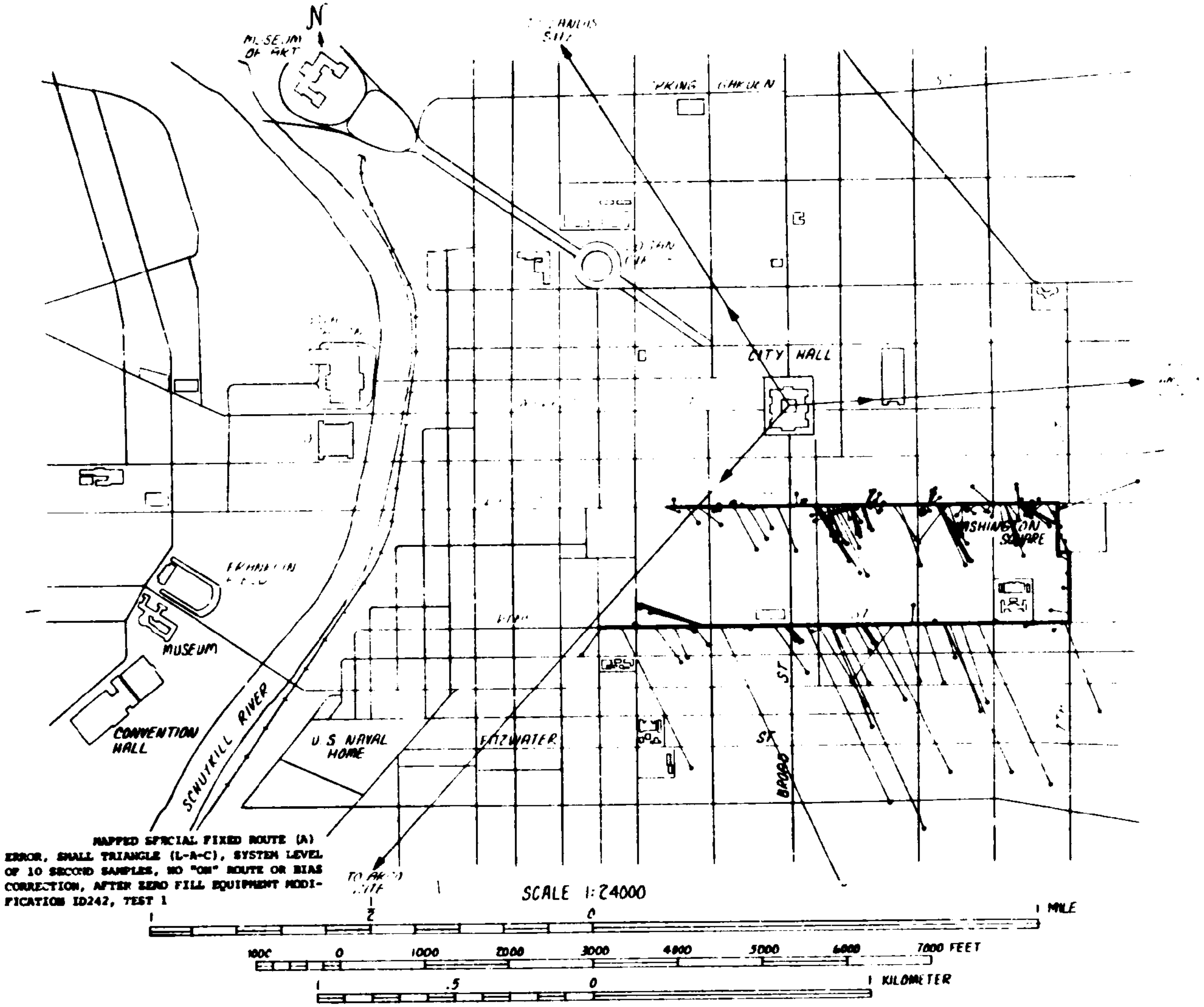
### 2. CENTRALLY LOCATED DOWNTOWN SITE, SMALL TRIANGLE (PAC), SYSTEM LEVEL

Special Fixed Route on Pine, 7th, Walnut, 15th, between events 27 and 38, 65 and 70 - ID #235, Tests 1-10, 15-21

Check Points Only (206 Samples)

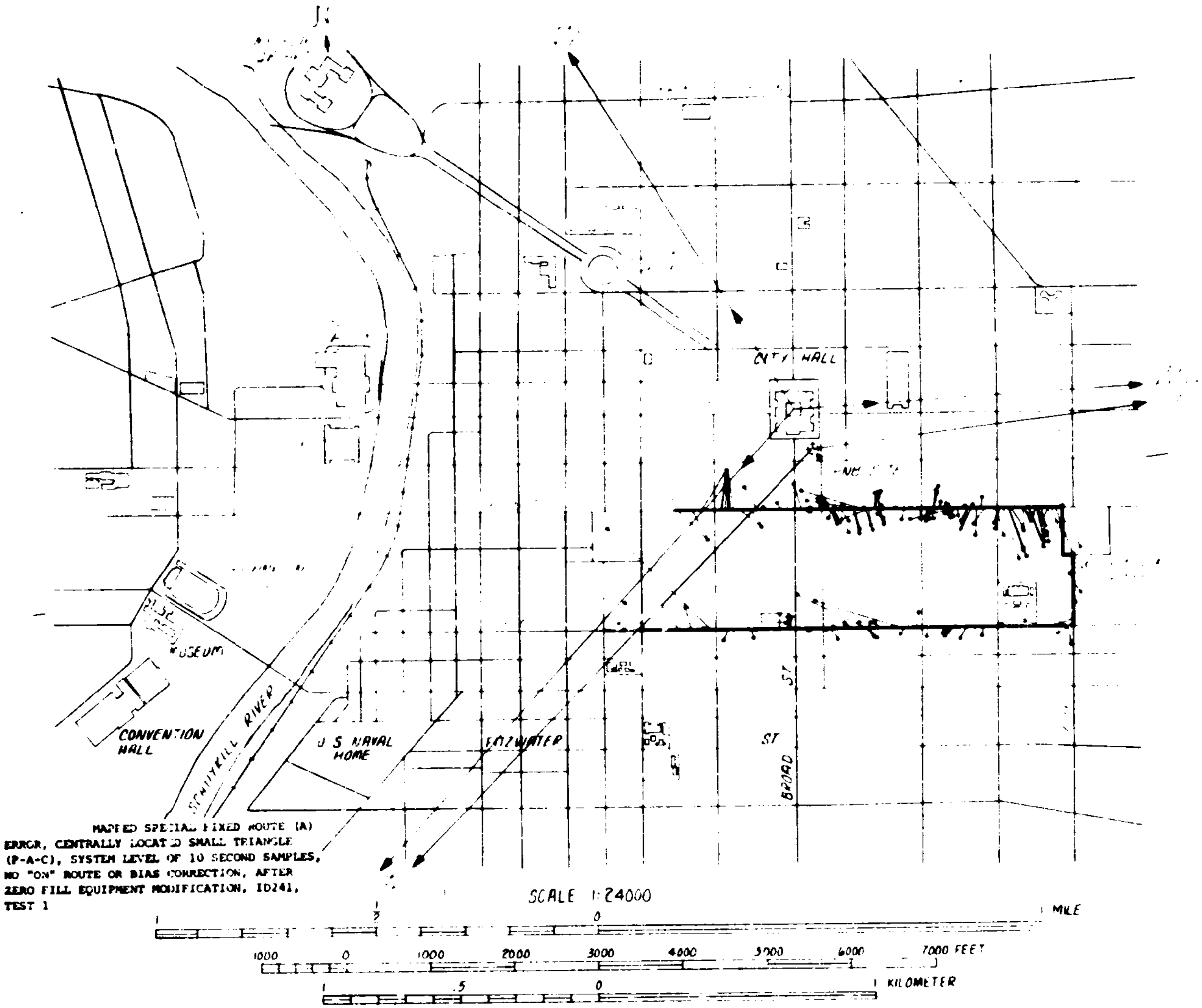
| | | | | | | |
|---|---|---|---|---|---|---|
| Location | "X" error | 50% = ±70, | 68% = ±110, | 95% = ±480, | 99.5% = ±980 | |
| | "Y" error | 50% = ±80, | 68% = ±180, | 95% = ±406, | 99.5% = ±660 | |
| | "R" error | 50% = 140, | 65% = 220, | 95% = 670, | 99.5% = 1000 | 80% = 300 |

Hit-Miss Statistics - 89% hits



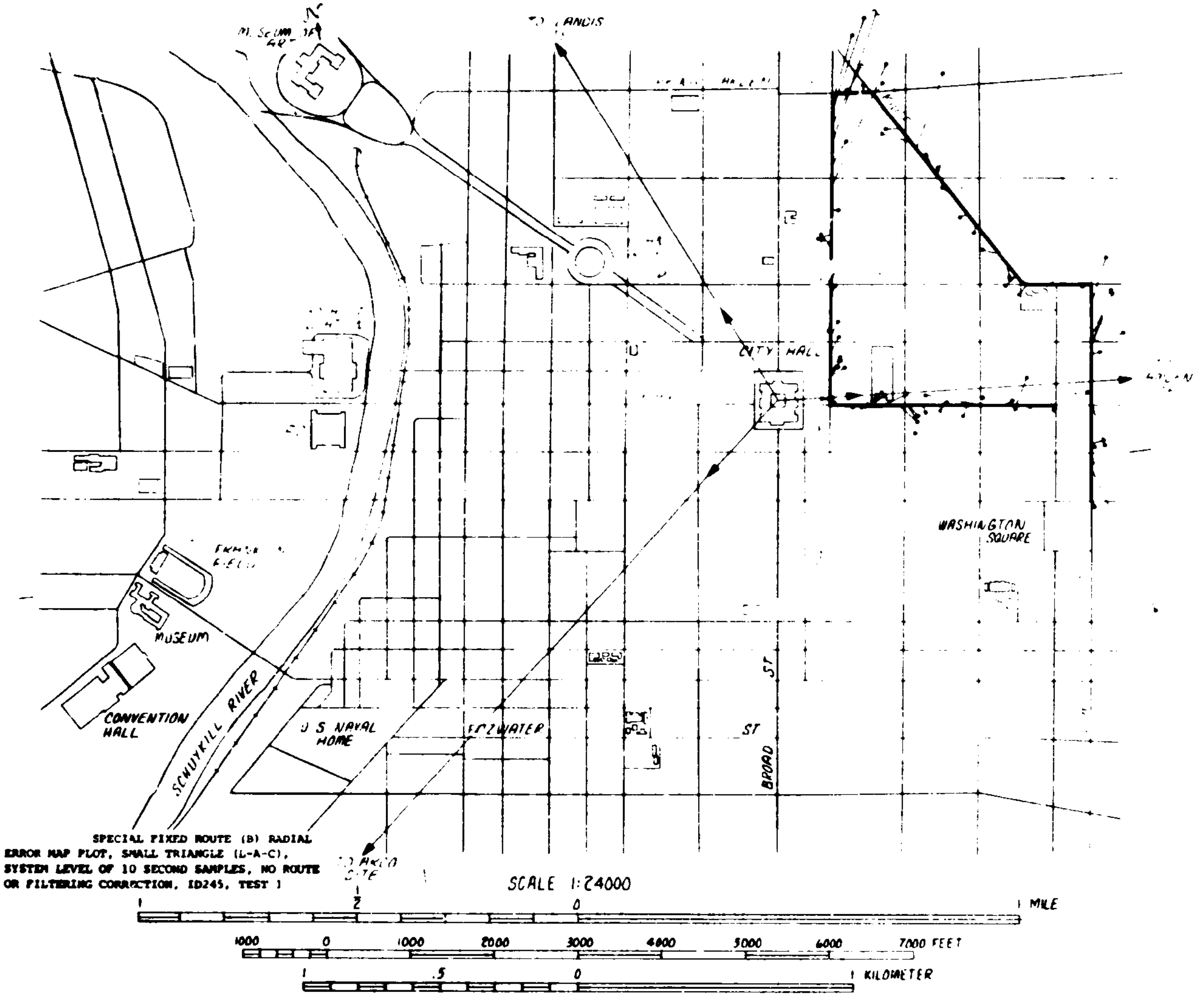
MAPPED SPECIAL FIXED ROUTE (A) ERROR, SMALL TRIANGLE (L-A-C), SYSTEM LEVEL OF 10 SECOND SAMPLES, NO "ON" ROUTE OR BIAS CORRECTION, AFTER ZERO FILL EQUIPMENT MODIFICATION ID242, TEST 1

FIGURE 4-6. MAPPED SPECIAL FIXED ROUTE (A) ERROR, SMALL TRIANGLE (LAC)



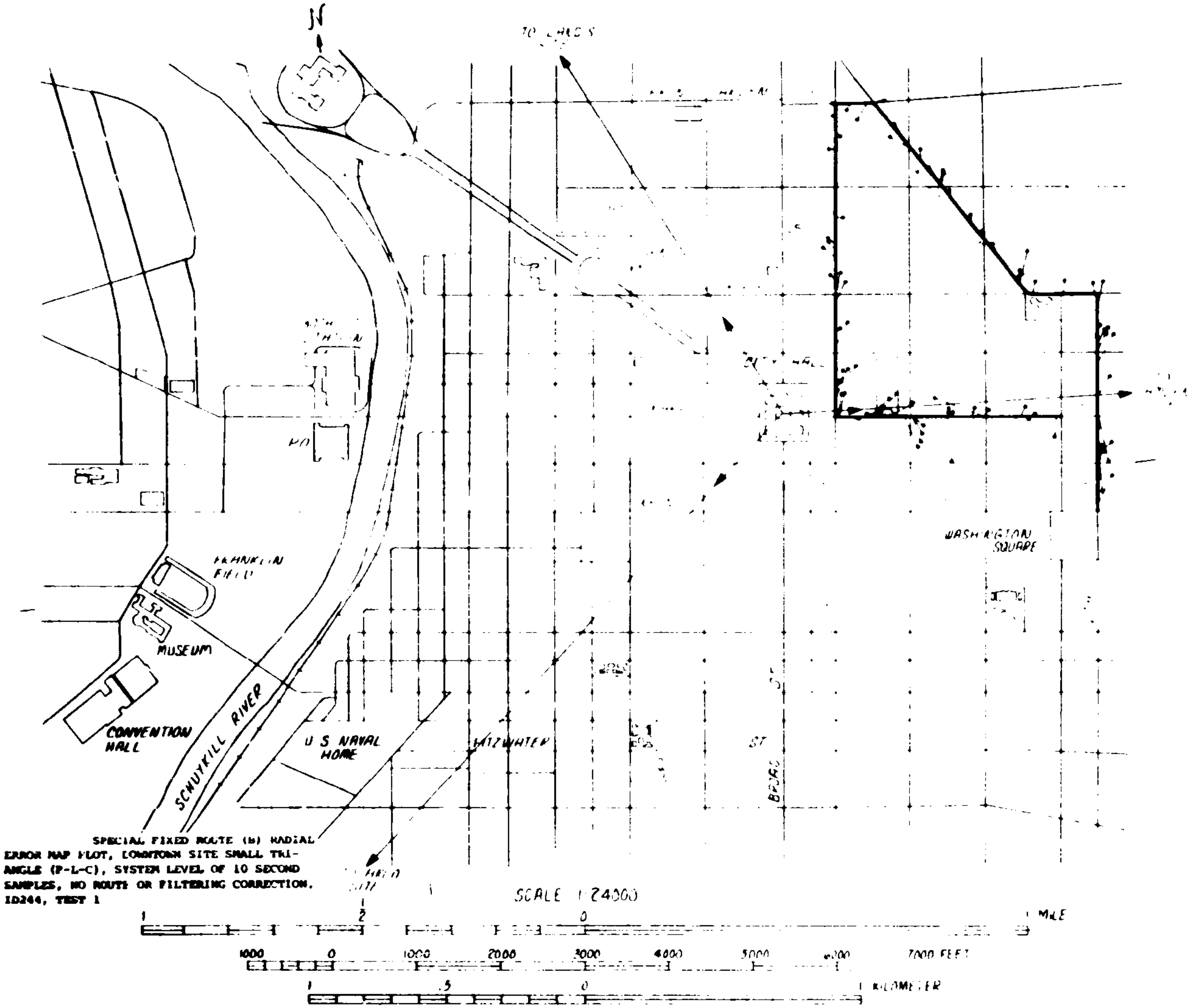
MAPPED SPECIAL FIXED ROUTE (A) ERROR, CENTRALLY LOCATED SMALL TRIANGLE (P-A-C), SYSTEM LEVEL OF 10 SECOND SAMPLES, NO "ON" ROUTE OR BIAS CORRECTION, AFTER ZERO FILL EQUIPMENT MODIFICATION, ID241, TEST 1

FIGURE 4-7. MAPPED SPECIAL FIXED ROUTE (A) ERROR, CENTRALLY LOCATED SMALL TRIANGLE (PAC)



SPECIAL FIXED ROUTE (B) RADIAL ERROR MAP PLOT, SMALL TRIANGLE (L-A-C), SYSTEM LEVEL OF 10 SECOND SAMPLES, NO ROUTE OR FILTERING CORRECTION, ID245, TEST 1

FIGURE 4-8. SPECIAL FIXED ROUTE (B) RADIAL ERROR MAP PLOT, SMALL TRIANGLE (L-AC)



SPECIAL FIXED ROUTE (B) RADIAL ERROR MAP PLOT, DOWNTOWN SITE SMALL TRIANGLE (P-L-C), SYSTEM LEVEL OF 10 SECOND SAMPLES, NO ROUTE OR FILTERING CORRECTION. ID244, TEST 1

FIGURE 4-9. SPECIAL FIXED ROUTE (B) RADIAL ERROR MAP PLOT, DOWNTOWN SITE SMALL TRIANGLE (PLC)

## TABLE 4-7. SPECIAL FIXED ROUTE (B) AVM PERFORMANCE

1. SMALL TRIANGLE (LAC), SYSTEM LEVEL

Special Fixed Route on 13th/Spring Garden/Ridge - 6th, Market between Events 41 and 62 - ID #232, Tests 1-23

Synchronization Transmitter Power = 447 W Peak
Vehicle Transmitter Power = 955 W Peak

Check Points Only (273 Samples)

Location "X" error 50% = ±86, 68% = ±165, 95% = ±440, 99.5% = ±660
"Y" error 50% = ±88, 68% = ±200, 95% = ±705, 99.5% = ±1120
"R" error 50% = 201, 68% = 283, 95% = 820, 99.5% = 1240

Hit-Miss Statistics = 95.8% hits

2. CENTRALLY LOCATED DOWNTOWN SITE, SMALL TRIANGLE (LPC), SYSTEM LEVEL

Special Fixed Route on 13th/Spring Garden/Ridge - 6th, Market Between Events 41 and 62 - ID #231, Tests 1-23

Check Points Only (273 Samples)

Location "X" error 50% = ±54, 68% = ±94, 95% = ±270, 99.5% = ±700
"Y" error 50% = ±73, 68% = ±168, 95% = ±387, 99.5% = ±560
"R" error 50% = 141, 68% = 212, 95% = 460, 99.5% = 940 300 = 84%

Hit-Miss Statistics = 98.5% hits

4.2.3.3 Special Fixed Route (C). A third special fixed route test was performed around the 30th street station using events 86 to 93 of the original fixed route. A number of runs were made to accumulate 190 data samples using the small triangle (LAC) and the central site small triangle (LA[illegible]) receiver configurations. Volume 3, figures 17 and 18 are the resultant histograms of the processed data; and the percentiles are tabulated in table 4-8. The percentile figures improved from 200 to 160 feet at 50 percentile, 280 to 260 at 68 percentile, 920 to 720 feet at 95 percentile and 1300 to 920 feet at the 99.5 percentile. The 300 foot percentile was 73.1%.

## 4.3 RANDOM ROUTE

The object of the random route test was to determine the location performance of the AVM system under driving patterns of the test vehicle that simulated the normal operation of a vehicle in urban traffic. The test was conducted during normal business days with particular emphasis on rush hour traffic to closely simulate an operational AVM system where more measurements are taken at hours than at any other time of the day.

Driving instructions for the random route are in section 3. As the vehicle ran the DOT/TSC specified route, the vehicle operator input event markers to the vehicle data acquisition system, noting vehicle passage of DOT/TSC specified points. Events at turns were also entered. A listing of the events and their coordinates are shown in table 4-9. Each random route run was assigned a test number.

The AVM Random Route performance utilizing the large triangle (HAC) is summarized for the system level of operation in table 4-10. These initial tests and data were gathered before the equipment "zero fill" modification, but with the software filtering operation, resulted in a radial error of 229 feet at the 50 percentile point, 413 feet at the 68 percentile and 1920 feet at the 95 percentile. A total of 386 check point samples were accumulated. The hit-miss statistic was 76% hits. The accuracy data is shown in histogram form in Volume 3, figure 19.

An additional formal run was made on the random route after the equipment was modified for the "zero-fill" fix. Utilizing the software filtering again, some improvement in accuracy was noted. The performance figures were 220 feet (50%), 338 feet (68%), and 1840 feet (95%). Only 94 checkpoints were totaled in this one run. To validate the percentile figures, all the 10 second data samples (444) were processed with the resultant accuracy figures essentially the same as the check

## TABLE 4-8. SPECIAL FIXED ROUTE (C) AVM PERFORMANCE

### 1. SMALL TRIANGLE (LAC), SYSTEM LEVEL

Special Fixed Route Near 30th St. Railroad Station, Between Events 86 and 93, ID #230, Tests 1-28

Synchronization Transmitter Power: = 468W Peak
Vehicle Transmitter Power: = 631W Peak

Check Points Only (190 Samples)

Location "X" error 50% = ±140, 68% = ±190, 95% = ±880, 99.5% = ±1180
"Y" error 50% = ±87, 68% = ±180, 95% = ±420, 99.5% = ±590
"R" error 50% = 200, 68% = 280, 95% = 920, 99.5% = 1300

Hit-Miss Statistics = 94 hits

### 2. CENTRALLY LOCATED DOWNTOWN SITE, SMALL TRIANGLE (LAP), SYSTEM LEVEL

Special Fixed Route Near 30th St. Railroad Station Between Events 86 and 93, ID #229, Tests 1-28

Check Points Only (190 Samples)

Location "X" error 50% = ±70, 68% = ±180, 95% = ±660, 99.5% = ±820
"Y" error 50% = ±70, 68% = ±140, 95% = ±350, 99.5% = ±440
"R" error 50% = 160, 68% = 260, 95% = 720, 99.5% = 920 73.1% = 300

Hit-Miss Statistics = 98.1% hits

## TABLE 4-9. PHILADELPHIA AVM TEST RANDOM ROUTE EVENT COORDINATES B

Date __________ Start Time __________ Initials __________ Page 1 of 4

Tape # __________ File# __________ Test# __________

| EVENT | | LOCATION | | LV | DOOR | | |
|---|---|---|---|---|---|---|---|
| NO. | D/H | X-COORD. | Y-COORD. | PT | O/C | LOG | COMMENTS |
| 1 | LT | 720972 | 236602 | | | | F 23rd & Market |
| B 2 | — | 721210 | 236565 | | | | 159 Market @ 22nd |
| 3 | | 721672 | 236510 | | | | 160 21st |
| 4 | | 722216 | 236455 | | | | 161 20th |
| 5 | | 722683 | 236390 | | | | 162 19th |
| 6 | | 723099 | 236331 | | | | 163 18th |
| 7 | | 723564 | 236256 | | | | 164 17th |
| 8 | | 723982 | 236208 | | | | 165 16th |
| 9 | RT | 724451 | 236163 | | | | 166 Market & 15th |
| 10 | LT | 724425 | 235828 | | | | 191 15th & S. Penn Sq. |
| 11 | | 724762 | 235760 | | | | Girard Bank on " |
| 12 | RT | 724870 | 235758 | | | | 194 S. Penn & Broad |
| 13 | | 724816 | 235222 | | | | 216 Broad @ Sansom |
| 14 | | 724789 | 234953 | | | | 236 Walnut |
| 15 | | 724730 | 234536 | | | | 257 Locust |
| 16 | | 724662 | 234121 | | | | 279 Spruce |
| 17 | | 724574 | 233564 | | | | 298 Pine |
| 18 | | 724595 | 233389 | | | | before Lombard parking lot entrance (R) |
| 19 | RT | 724550 | 233246 | | | | 319 Broad & Lombard |
| A 20 | | 724277 | 233284 | | | | Lombard @ Carlisle |
| 21 | | 723713 | 233339 | | | | before 16th Town Court Museum Sign (L) |
| 22 | RT | 723532 | 233341 | | | | 317 Lombard & 16th |
| A 23 | | 723609 | 233535 | | | | 16th @ Waverly |
| A 24 | | 723665 | 233936 | | | | DeLancey |
| A 25 | | 723765 | 234511 | | | | Latimer |
| A 26 | | 723813 | 234874 | | | | Chancellor |
| 27 | | 723865 | 235365 | | | | 214 Sansom |
| A 28 | | 723749 | 235967 | | | | Ludlow |
| 29 | RT | 723982 | 236208 | | | | 165 16th & Market |
| 30 | RT | 724451 | 236163 | | | | 166 Market & 15th |
| A 31 | | 724409 | 235919 | | | | 15th @ [illegible] |
| A 32 | | 724355 | 235400 | | | | Ionic |
| A 33 | | 724332 | 235171 | | | | Moravian |
| 34 | RT | 724322 | 235019 | | | | 235 15th & Walnut |
| A 35 | | 724064 | 235054 | | | | Walnut @ Sydenham |

TABLE 4-9. PHILADELPHIA AVM TEST RANDOM ROUTE EVENT COORDINATES B (cont)

Date__________ Start Time__________ Initials__________ Page 2 of 4

Tape #__________ File#__________ Test#__________

| EVENT NO. | D/H | LOCATION X-COORD. | Y-COORD. | LV PT | DOOR O/C | LOG | COMMENTS |
|---|---|---|---|---|---|---|---|
| 36 | | 723388 | 235138 | | | | 232 Walnut @ 17th |
| 37 | | 722670 | 235228 | | | | before 19th Mutual Benefit Life 1845 (R) |
| 38 | | 722078 | 235321 | | | | 229 @ 20th |
| A 39 | | 721304 | 235409 | | | | Van Pelt |
| 40 | | 720883 | 235462 | | | | before 23rd WPEN sign (L) |
| 41 | LT | 720735 | 235478 | | | | 226 Walnut & 23rd |
| A 42 | | 720702 | 235243 | | | | 23rd @ St. James |
| 43 | LT | 720675 | 235048 | | | | A 23rd & Locust |
| 44 | | 720994 | 235017 | | | | 247 Locust @ 22nd |
| 45 | | 721463 | 234972 | | | | 248 21st |
| 46 | | 722219 | 234866 | | | | before Rittenhouse Sq. 222 Canopy (R) |
| 47 | RT | 722316 | 234853 | | | | 250 Locust & W. " " |
| 48 | LT | 722260 | 234720 | | | | W. Rittenhouse & S. Rittenhouse |
| 49 | | 722689 | 234655 | | | | S. " before 18th 1810 [illegible] entrance (R) |
| 50 | LT | 722872 | 234634 | | | | 252 " " & 18th |
| 51 | RT | 722913 | 234780 | | | | 253 18th & Locust |
| A 52 | | 723102 | 234749 | | | | Locust @ Bouvier |
| A 53 | | 724005 | 234633 | | | | Sydenham |
| 54 | RT | 724242 | 234574 | | | | 256 Locust & 15th |
| A 55 | | 724211 | 234322 | | | | 15th @ Manning |
| 56 | RT | 724193 | 234166 | | | | 278 15th & Spruce |
| 57 | | 723722 | 234201 | | | | 277 Spruce @ 16th |
| 58 | | 722901 | 234333 | | | | before 18th Great Scot Market (R) |
| 59 | RT | 722841 | 234334 | | | | 275 Spruce & 18th |
| 60 | | 722942 | 234990 | | | | 18th @ Chancellor |
| A 61 | | 722989 | 235344 | | | | Moravian |
| 62 | LT | 722990 | 235477 | | | | 212 18th & Sansom |
| 63 | | 722565 | 235546 | | | | 211 Sansom @ 19th |
| 64 | | 722094 | 235592 | | | | 210 20th |
| 65 | LT | 721557 | 235647 | | | | 207 Sansom & 21st |
| 66 | | 721463 | 234972 | | | | 248 21st @ Locust |
| 67 | | 721371 | 234506 | | | | Cypress |
| A 68 | | 721308 | 233771 | | | | Delancey |
| 69 | RT | 721297 | 233640 | | | | 312 21st & Lombard |
| 70 | | 721076 | 233[illegible] | | | | Lombard @ Van Pelt |

TABLE 4-9. PHILADELPHIA AVM TEST RANDOM ROUTE EVENT COORDINATES B (cont)

Date__________ Start Time__________ Initials__________ Page 3 of 4

Tape #__________ File#__________ Test#__________

| EVENT NO. | D/H | LOCATION X-COORD. | Y-COORD. | LV PT | DOOR O/C | LOG | COMMENTS |
|---|---|---|---|---|---|---|---|
| 71 | RT | 720822 | 233716 | | | | 311 Lombard & 22nd |
| 72 | | 720879 | 234052 | | | | 290 22nd @ Pine |
| A 73 | | 720905 | 234377 | | | | Cypress (R) |
| A 74 | | 720971 | 234875 | | | | Latimer (R) |
| 75 | | 721057 | 235356 | | | | before Walnut Parking lot entrance (R) |
| 76 | | 721090 | 235604 | | | | before Sansom [illegible] gas station (L) |
| 77 | LT | 721101 | 235710 | | | | 208 22nd & Sansom |
| 78 | LT | 720790 | 235733 | | | | 207 Sansom & 23rd |
| A 79 | | 720715 | 235336 | | | | 23rd @ Chancellor (L) |
| A 80 | | 720655 | 234917 | | | | .. Latimer |
| 81 | | 720605 | 234599 | | | | B Spruce |
| A 82 | | 720571 | 234210 | | | | Panama |
| 83 | | 720506 | 233767 | | | | D Lombard |
| 84 | LT | 720470 | 233359 | | | | E ? 23rd & South |
| 85 | | 720789 | 233336 | | | | 330 South @ 22nd |
| 86 | | 721653 | 233223 | | | | before 20th Laundromat sign (L) |
| 87 | LT | 721792 | 233198 | | | | 332 South & 20th |
| 88 | | 721848 | 233663 | | | | 313 20th @ Lombard. |
| A 89 | | 721887 | 234076 | | | | Panama |
| 90 | | 721942 | 234419 | | | | 273 Spruce |
| A 91 | | 722043 | 235068 | | | | Chancellor (L) |
| 92 | | 722094 | 235582 | | | | 210 Sansom |
| A 93 | | 722156 | 236072 | | | | Ranstead (R) |
| 94 | RT | 722216 | 236455 | | | | 161 20th & Market |
| 95 | | 722556 | 236396 | | | | Market betw. 20th & 19th [illegible] (L) |
| 96 | | 722951 | 236340 | | | | 19th & 18th [illegible] (R) |
| 97 | | 723408 | 236269 | | | | 18th & 17th Greyhound Bus sign (L) |
| B 98 | RT | 723[illegible] | 236256 | | | | 164 Market & 17th |
| A 99 | | 723492 | 235883 | | | | 17th @ Ranstead |
| A 100 | | 723421 | 235295 | | | | [illegible] |
| 101 | | 723359 | 234787 | | | | 256 [illegible] |
| 102 | | 723252 | 234021 | | | | [illegible] |
| B 103 | LT | 723215 | 233756 | | | | 295 17th & Pine |
| A 104 | | 723502 | 233716 | | | | Pine @ 16th. |
| 105 | | 724129 | 233627 | | | | 297 " 15th |

TABLE 4-9. PHILADELPHIA AVM TEST RANDOM ROUTE EVENT COORDINATES B (cont)

Date__________ Start Time__________ Initials__________ Page 4 of 4

Tape #__________ File#__________ Test#__________

| EVENT | | LOCATION | | LV | DOOR | | |
|---|---|---|---|---|---|---|---|
| NO. | D/H | X-COORD. | Y-COORD. | PT | O/C | LOG | COMMENTS |
| 106 | RT | 724594 | 233564 | | | | 298 Pine & Broad |
| 107 | RT | 724550 | 233246 | | | | 319 Broad & Lombard |
| 108 | | 723582 | 233341 | | | | 317 Lombard @ 16th |
| 109 | | 722786 | 233481 | | | | before 18th PARK HERE sign (L) |
| 110 | RT | 722712 | 233483 | | | | 315 Lombard & 18th |
| A 111 | | 722740 | 233689 | | | | 18th @ Waverly |
| A 112 | | 722813 | 234162 | | | | Cypress |
| B 113 | LT | 722841 | 234334 | | | | 275 18th & Spruce |
| 114 | | 722275 | 235568 | | | | Spruce betw. 19th & 20th 1923 Canopy (R) |
| A 115 | | 721179 | 234532 | | | | .. @ Van Pelt (alt. 21st) |
| 116 | LT | 720605 | 234579 | | | | B Spruce & 23rd |
| 117 | LT | 720561 | 234059 | | | | C 23rd & Pine |
| 118 | | 721106 | 234026 | | | | Pine @ Van Pelt (R) |
| 119 | | 722332 | 233880 | | | | 293 19th |
| 120 | RT | 723215 | 233756 | | | | 295 Pine & 17th |
| 121 | | 723200 | 233618 | | | | 17th @ Waverly (R) |
| 122 | RT | 723191 | 233437 | | | | 316 17th & Lombard |
| 123 | | 722292 | 233521 | | | | 314 Lombard @ 19th |
| 124 | LT | 721297 | 233640 | | | | 312 Lombard & 21st |
| 125 | LT | 721240 | 233304 | | | | 331 21st & South |
| 126 | | 722245 | 233184 | | | | 333 South @ 19th |
| 127 | | 723113 | 233022 | | | | 335 17th |
| 128 | | 724010 | 232927 | | | | 337 15th |
| 129 | LT | 724507 | 232868 | | | | 338 South & Broad |
| 130 | | 724550 | 233246 | | | | 319 Broad @ Lombard |
| 131 | | 724574 | 233564 | | | | 298 Pine |
| 132 | | 724662 | 234121 | | | | 279 Spruce |
| 133 | | 724730 | 234536 | | | | 257 Locust |
| 134 | | 724788 | 234953 | | | | 236 Walnut |
| 135 | | 724816 | 235222 | | | | 216 Sansom |
| 136 | | 724857 | 235520 | | | | 115 Chestnut |
| B137 | — | 724990 | 235758 | | | | 194 Broad @ So. Penn Sq. |
| | | | | | | | |

point only sample. The figures were 206 feet (50%), 300 feet (68%), and 1600 feet (95%). The hig-miss statistics showed an improvement to 84% hits. The histogram for the check points and 10 second data are shown in Volume 3, figures 20 and 21.

The tenth mile average radial errors are shown in histogram form in Volume 3, figures 22 and 23 for the large triangle, system level of 10 second data before and after the zero fill modification.

A comparison of the subsystem level of performance is shown in table 4-11. A single run before and after the "zero-fill" modification was compared. The subsystem level is defined as check point data updated at a 0.1 second interval when the AVM algorithm solution is compared to the 5th wheel location reference. An increase in accuracy should be expected when comparing the 10 second system update solutions. The subsystem data is raw, without any software filtering or other smoothing operation. The accuracy results (before zero-fill) were somewhat poor at the high percentiles being 2400 feet at the 95% point, but an improvement to 1260 feet at the 95% point was noted after the zero-fill fix. The 50 percentile improved from 220 to 180, and the 68 percentile improved from 400 to 315 feet. The histograms for these two tests are shown in Volume 3, figures 24 and 25. There is no improvement on the 50 or 68 percentile points of all 10 second processed data over the raw subsystems data. It should be noted that the sample size for the subsystem data was only 94 check points.

The tenth mile average radial errors for the subsystem, 0.1 second data, large triangle are shown in table 4-11, and in histogram form for the before and after zero-fill in Volume 3, figures 26 and 27. The percentile improved from 49% to 69% for the average valued samples less than 450 feet.

The random route test data gathered with the small triangle (LAC) before the zero-fill fix is relatively poor with hit-miss statistics of 44% hits, but the data after zero-fill is dramatically improved. Also there is an improvement when compared to the large triangle after zero-fill data. As shown in table 4-12, all the 10 second data samples of the after zero-fill modification with software filtering resulted in percentiles of 198 feet (50%), 265 ft. (68%) and 880 ft. (95%) compared to the large triangle performance of 230 ft. (50%), 360 ft. (68%) and 1600 ft. (95%) (table 4-10) The hit-miss statistics improved from 84 to 87 hits. The histogram of the check points before and after zero-fill are in Volume 3, figures 28 and 29. All 10 second data sample histogram is shown in Volume 3, figure 30. Table 4-12 also contains the statistics of the tenth mile average radial errors for the small triangle, system level, 10 second data before and after the zero-fill. The associated histograms are shown in Volume 3, figures 31 and 32.

The improvement in performance from the large triangle configuration to the small triangle configuration (after zero-fill) is depicted in the random route radial error map plots of figures 4-10 and 4-11. These figures shown the AVM algorithm vehicle location solution as a dot and the end of the line connected to the dot, locates the 5th wheel solution. The line length is the radial error.

## TABLE 4-10. RANDOM ROUTE PERFORMANCE - LARGE TRIANGLE (HAC), SYSTEM LEVEL

1. TEST PLAN DATA SUMMATION (BEFORE ZERO FILL MOD.) = ID #215, Tests 1, 3, 4, 5

Synchronization Transmitter Power = 589 W Peak
Vehicle Transmitter Power = 692 W Peak

A. Check Points Only (376 Samples)

Location "X" error 50% = ±108, 68% = ±200, 95% = ±1210, 99.5% = ±2120
"Y" error 50% = ±220, 68% = ±240, 95% = ±1140, 99.5% = ±2680
"R" error 50% = 229, 68% = 413, 95% = 1920, 99.5% = >3000

Hit-Miss Statistics - 76% hits

B. 0.1 Mile Segment Average Location error (10 second data) ID #215, Test 3
50% = 270, 68% = 375, 95% = 980, 99.5% = 2258, MAX = 2258

2. TEST PLAN DATA (AFTER ZERO FILL MOD.) = ID #214, Test 6 only

Synchronization Transmitter Power = 589 W Peak
Vehicle Transmitter Power = 676 W Peak

A. Check Points Only (94 Samples)

Location "X" error 50% = ±96, 68% = ±120, 95% = ±1180, 99.5% = >3000
"Y" error 50% = ±157, 68% = ±230, 95% = ±1120, 99.5% = >5000
"R" error 50% = 220, 68% = 338, 95% = 1840, 99.5% = >5000

Hit-Miss Statistics = 84% hits

B. All 10 Second Samples (444 Samples)
Location "X" error 50% = ±100, 68% = ±120, 95% = ±1080, 99.5% = ±1840
"Y" error 50% = ±140, 68% = ±220, 95% = ±840, 99.5% = >3000
"R" error 50% = 206, 68% = 300, 95% = 1600, 99.5% = >3000, 68% = 300

Hit-Miss Statistics = 64% hits

C. 0.1 Mile Segment Average Location error (10 second data) ID #214, Test 6
50% = 253, 68% = 340, 95% = 1460, 99.5% = 5248, MAX = 5248

## TABLE 4-11. RANDOM ROUTE PERFORMANCE - LARGE TRIANGLE (HAC), SUBSYSTEM LEVEL

1. **TEST PLAN DATA SUMMATION (BEFORE ZERO-FILL MOD.) ID #228, TEST 1**

Synchronization Transmitter Power = 631 W Peak
Vehicle Transmitter Power = 708W Peak

Check Points Only at 0.1 Second Update Rate (95 Samples)

Location "X" error 50% = ±100, 68% = ±200, 95% = ±1500, 99.5% = ±4560

"Y" error 50% = ±120, 68% = ±220, 95% = ±1900, 99.5% = ±3220

"R" error 50% = 220, 68% = 400, 95% = 2400, 99.5% = 4600

0.1 Mile Segment Average Location Error (0.1 second data) = 49% within 450
50% = 460, 68% = 730, 95% = 2030, 99.5% = 2393, MAX = 2393

2. **TEST PLAN DATA (AFTER ZERO-FILL MOD.) ID #221, TEST 6**

Synchronization Transmitter Power = 851W Peak
Vehicle Transmitter Power = 857W Peak

Check Points Only at 0.1 Second Update Rate (95 Samples)

Location "X" error 50% = ±80, 68% = ±140, 95% = ±960, 99.5% = >±3000

"Y" error 50% = ±150, 68% = ±240, 95% = ±660, 99.5% = ±1760

"R" error 50% = 180, 68% = 315, 95% = 1260, 99.5% = >3000

0.1 Mile Segment Average Location Error (0.1 second data) = 69% within 450
50% = 330, 68% = 430, 95% = 1730, 99.5% = 2333, MAX = 2333

## TABLE 4-12. RANDOM ROUTE PERFORMANCE - SMALL TRIANGLE (LAC), SYSTEM LEVEL

1. TEST PLAN DATA SUMMATION (BEFORE ZERO FILL MOD.) - ID #227 TESTS 1, 3, 4, 5

Synchronization Transmitter Power = 631 W Peak
Vehicle Transmitter Power = 708 W

A. Check points Only (370 samples)

Location "X" error 50% = ±120, 68% = ±210, 95% = ±1460, 99.5% = ±2360
"Y" error 50% = ±180, 68% = ±340, 95% = ±2680, 99.5% = >±3000
"R" error 50% = 260, 68% = 460, 95% = >3000, 99.5% = >3000

Hit-Miss Statistics = 44% hits

B. 0.1 Mile Segment Average Location error (10 second data) ID #227, Test 3
50% = 240, 68% = 460, 95% = 2660, 99.5% = 5784, MAX = 5784

2. TEST PLAN DATA (AFTER ZERO-FILL MOD.) - ID #209, TEST 6 ONLY

Synchronization Transmitter Power = 562 W Peak
Vehicle Transmitter Power = 851 W

A. Check Points Only (94 samples)

Location "X" error 50% = ±110, 68% = ±180, 95% = ±620, 99.5% = -
"Y" error 50% = ±125, 68% = ±160, 95% = ±600, 99.5% = -
"R" error 50% = 190, 68% = 245, 95% = 926, 99.5% = -

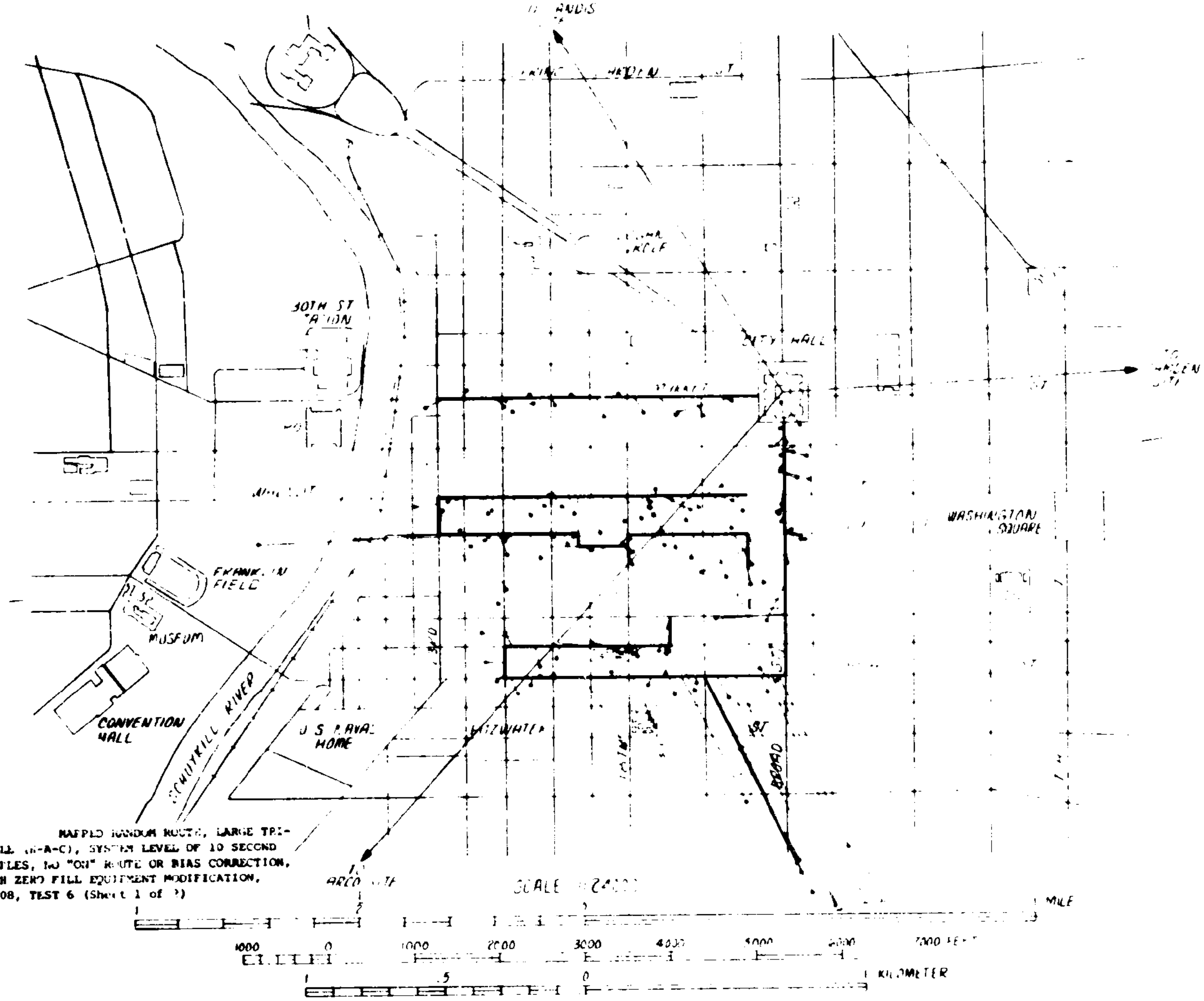
Hit-Miss Statistics = 87% hits

B. All 10-Second Samples (400 samples)

Location "X" error 50% = ±90, 68% = ±120, 95% = ±640, 99.5% = ±1580
"Y" error 50% = ±120, 68% = ±180, 95% = ±580, 99.5% = ±1280
"R" error 50% = 198, 68% = 265, 95% = 880, 99.5% = 1960, 75% = 300

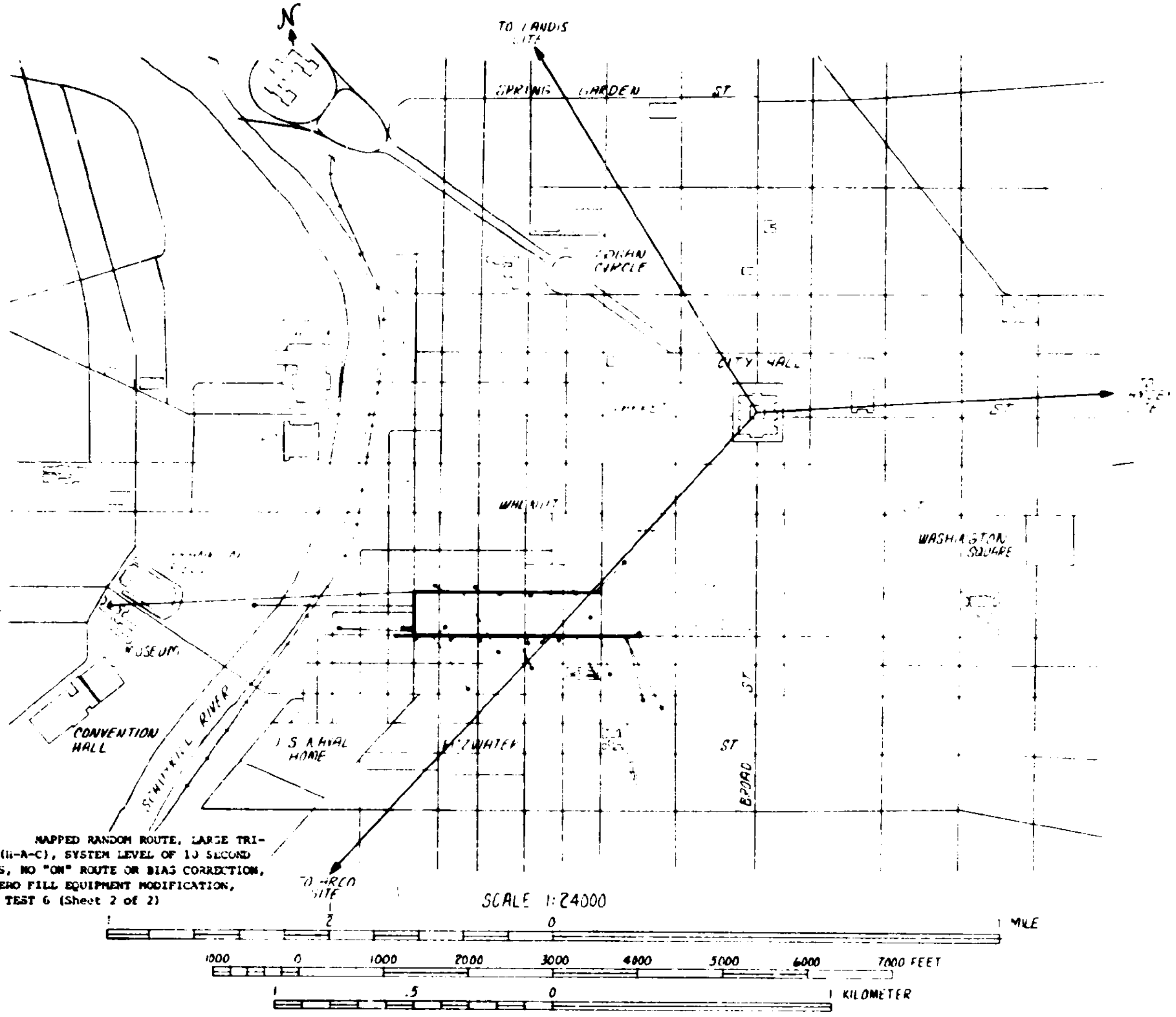
Hit-Miss Statistics = 87% hits

C. 0.1 Mile Segment Average Location error (10 second data) ID #209 TEST 6
50% = 216, 68% = 284, 95% = 790, 99.5% = 1605, MAX = 1605



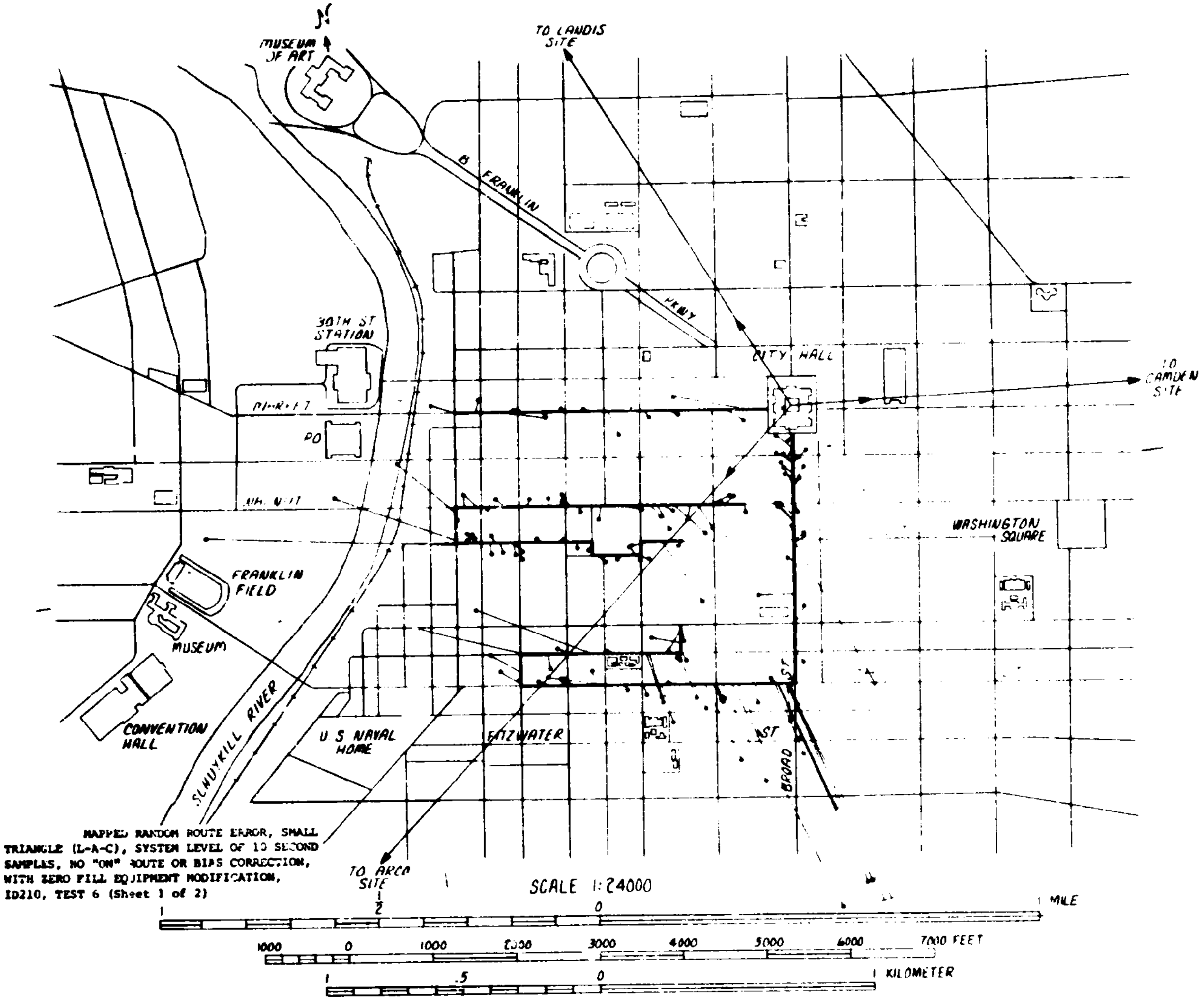
MAPPED RANDOM ROUTE, LARGE TRIANGLE (B-A-C), SYSTEM LEVEL OF 10 SECOND SAMPLES, NO "ON" ROUTE OR BIAS CORRECTION, WITH ZERO FILL EQUIPMENT MODIFICATION, .D208, TEST 6 (Sheet 1 of ?)

FIGURE 4-10. MAPPED RANDOM ROUTE, LARGE TRIANGLE (HAC)



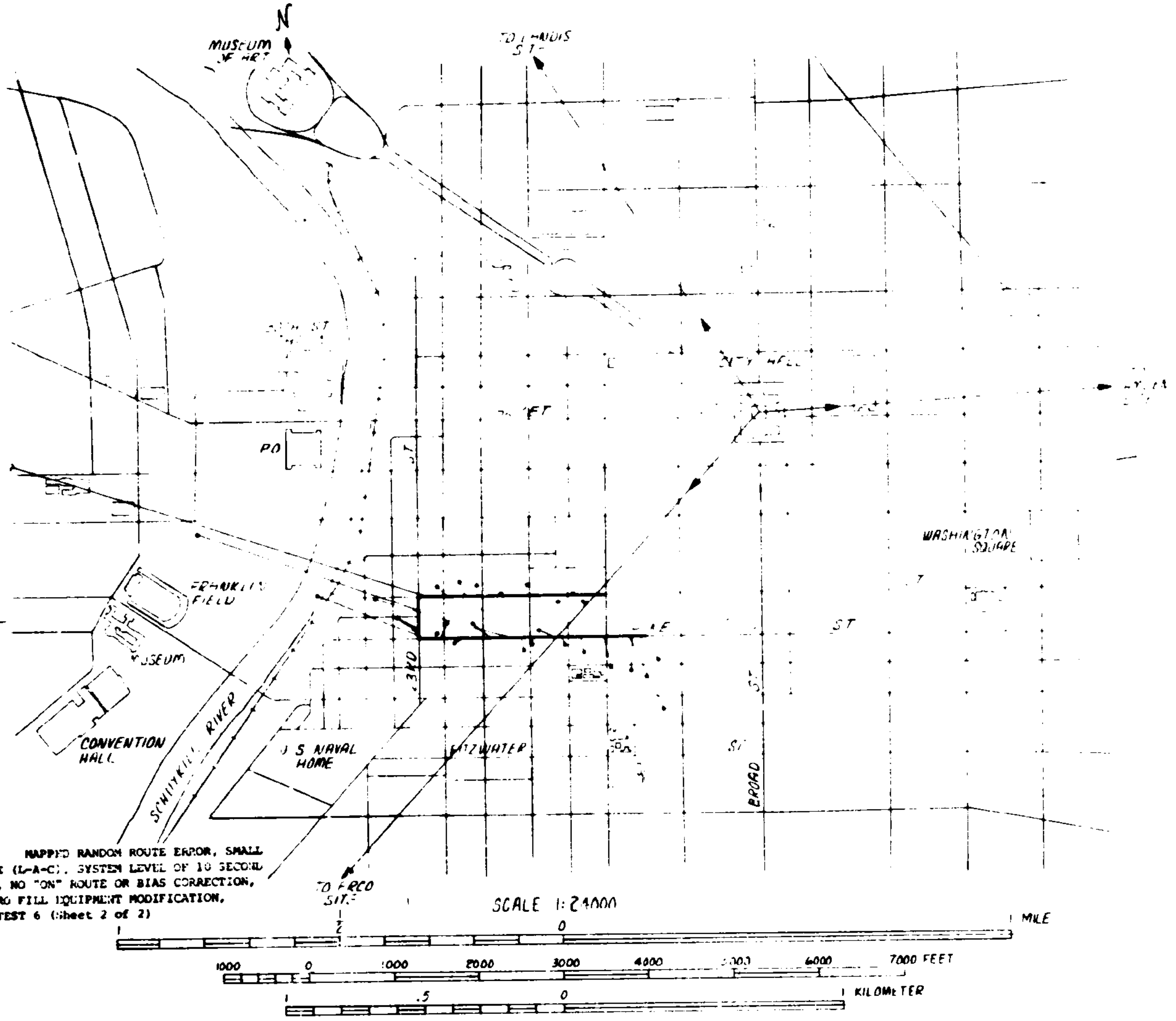
MAPPED RANDOM ROUTE, LARGE TRIANGLE (H-A-C), SYSTEM LEVEL OF 10 SECOND SAMPLES, NO "ON" ROUTE OR BIAS CORRECTION, WITH ZERO FILL EQUIPMENT MODIFICATION, ID208, TEST 6 (Sheet 2 of 2)

FIGURE 4-10. MAPPED RANDOM ROUTE, LARGE TRIANGLE (HAC) (cont)



MAPPED RANDOM ROUTE ERROR, SMALL TRIANGLE (L-A-C), SYSTEM LEVEL OF 10 SECOND SAMPLES, NO "ON" ROUTE OR BIAS CORRECTION, WITH ZERO FILL EQUIPMENT MODIFICATION, ID210, TEST 6 (Sheet 1 of 2)

FIGURE 4-11. MAPPED RANDOM ROUTE ERROR, SMALL TRIANGLE (LAC)



MAPPED RANDOM ROUTE ERROR, SMALL TRIANGLE (L-A-C). SYSTEM LEVEL OF 10 SECOND SAMPLES, NO "ON" ROUTE OR BIAS CORRECTION, WITH ZERO FILL EQUIPMENT MODIFICATION, ID210, TEST 6 (Sheet 2 of 2)

FIGURE 4-11. MAPPED ROUTE ERROR, SMALL TRIANGLE (LAC) (cont)

The location samples where the radial vectors point away from a receive site occur when that receiver is introducing an additional delay in the processing, due to the destructive effects on the leading edge of a possibly weak received pulse signal, and when the vehicle is in the central region of the receiver site triangle. As noted, there is a large reduction in radial error for the small triangle, but many are still excessive in magnitude.

The subsystem performance of the small triangle (LAC) is shown in table 4-13. The 95 percentile figures are somewhat larger than the system level performance, 1300 vs. 926, but there is no significant difference in the 50 or 68 percentiles. The 0.1 second segment average location error histograms for the small triangle (LAC) subsystem level performance before and after zero-fill are shown in Volume 3, figures 33 and 34. Figures 35 and 36 of Volume 3 are the accuracy histograms of the subsystem level before and after zero-fill.

A special random route test was performed using the triangle (LAP) formed by the additional downtown receiver site. This triangle is made up of the Landis Hospital, ARCO and the highrise bank building. Data was simultaneously taken with the original small triangle (LAC) made up of the Landis Hospital, ARCO, and the Camden Apartment. The original event markers that were within the new small triangle were entered in the special tests. They were between 13 and 27, 32 and 92 and 101 and 137. A number of passes were made of this route to accumulate 377 samples. The system level performance of this special test using the software filter process is shown in table 4-14. There is an improvement in performance over the original triangle data, the radial error percentile figures being 170 feet (50%), 260 feet (68%) and 950 feet (95%) compared to 220 feet (50%), 360 feet (68%) and 1440 feet (95%). Radial errors of less than 300 feet are at the 72 percentile. It should be noted though that the LAP triangle is not optimum in shape for GDOP. Also a large number of test points are outside the LAP triangle. The results are therefore in question, and better performance is anticipated. Histrograms of the LAC and LAP triangle performance are shown in Volume 3, figures 37 and 38.

## TABLE 4-13. SUBSYSTEM LEVEL RANDOM ROUTE PERFORMANCE - SMALL TRIANGLE (LAC)

1. Test Plan Data Summation (before zero fill mod.) ID #226 Test #1

Synchronization Transmitter Power = 631 W peak
Vehicle Transmitter Power = 708 W peak

Check points only at 0.1 second update rate (95 samples)

Location "X" error 50% = ±230, 68% = ±590, 95% = ±1720, 99.5% = ±2760

"Y" error 50% = ±210, 68% = ±680, 95% = ±3680, 99.5% = ±3678

"R" error 50% = 320, 68% = 1400, 95% = 4420, 99.5% = 8338

0.1 Mile Segment Average Locations Error (0.1 second data) = 31% within 450

50% = 740, 68% = 1120, 95% = 3592, 99.5% = 3839, MAX = 4228

2. Test Plan Data (after zero fill mod.) ID #220, Test #6

Synchronization Transmitter Power = 562 W peak
Vehicle Transmitter Power = 851 W peak

Check points only at 0.1 second uupdate rate (95 samples)

Location "X" error 50% = ± 80, 68% = ±130, 95% = ±740, 99.5% = ±1260

"Y" error 50% = ±115, 68% = ±180, 95% = ±620, 99.5% = ±1340

"R" error 50% = 170, 68% = 260, 95% = 1300, 99.5% = 3020

0.1 Mile Segment Average Location Error (0.1 second data) = 69% within 450

50% = 286, 68% = 434, 95% = 1800, 99.5% = 3035, MAX = 3470

## TABLE 4-14. SPECIAL RANDOM ROUTE PERFORMANCE

### 1. SMALL TRIANGLE (LAC), SYSTEM LEVEL

Special Random Route Between Events 13 and 27, 33 and 92, and 101 and 137 - ID #234, Tests 1-5

Synchronization Transmitter Power: = 1260 W
Vehicle Transmitter Power: = 603 W

Check Points Only (343 samples)

Location "X" error 50% = ±120, 68% = ±200, 95% = ±1310, 99.5% = >±3000

"Y" error 50% = ±150, 68% = ±260, 95% = ±900, 99.5% = ±2020

"R" error 50% = 220, 68% = 360, 95% = 1440, 99.5% = > 3000

61% = 300

### 2. CENTRALLY LOCATED DOWNTOWN SITE, SMALL TRIANGLE (LAP), SYSTEM LEVEL

Special Random Route Between Events 13 and 27, 33 and 92, and 101 and 137 - ID #233, Tests 1-5

Check Points Only (377 samples)

Location "X" error 50% = ±100, 68% = ±187, 95% = ±740, 99.5% = ±1280

"Y" error 50% = ±100, 68% = ±187, 95% = ±740, 99.5% = ±1260

"R" error 50% = 170, 68% = 260, 95% = 950, 99.5% = 1800

72% = 300

## 4.4 SPECIAL TESTS

These tests were configured to determine if any abnormalities exist in the Hazeltine AVM system operating under worst case conditions. They include high speed, underpass, and power line interference tests. Other special tests include a test to determine the effect of GDOP at the region around a receiver site, the variability of the signpost radiation patterns in a street environment, the measurement of noise levels in the Philadelphia test area, and the performance of trilateration timepoint measurements without using signpost units. Every run of each special test category was assigned a test number.

4.4.1 Trilateration Suburban Test. The object of the special trilateration system time point test was to demonstrate satisfactory AVM time point measurement without the need of signpost units for the operational situations where the vehicle is traveling at reasonable speeds in a suburban environment. The performance goals are ±15 seconds 95 percentile and ±60 seconds 99.5 percentile, with a hit-miss statistic of 95%.

This special test was performed in Fairmount Park on the roads that surround the reservoir. The test area is shown in figure 4-1. The original suburban test consisted of 38 runs around the reservoir, each run containing eight events. The coordinates of these events are shown in table 4-15. A suburban test was also conducted after the "zero-fill" equipment modification. This test consisted of 13 additional runs, each of which included the 13 events shown in table 4-16. Time point accuracy analyses were performed on both sets of data. Additional location accuracy analysis was performed on the zero-fill data.

Table 4-17 summarizes the test results. The time point accuracy as shown in figure 4-12 for the original data was ±9 seconds 50 percentile, ±12 seconds 68% percentile and +60 seconds 95 percentile. Seventy-six percent of the samples were within ±15 seconds and 95% within 60 seconds. This performance showed improvement in the test run after the zero-fill modification with results as shown in figure 4-13 of ±8.3 seconds (50%), ±10 seconds (68%), ±21 seconds (94%) and ±27 seconds (99.5%). The time point hit-miss statistics also improved from 89% to 99.8% hits.

A location accuracy analysis was performed on the zero-fill data to determine the AVM location performance in a suburban environment. The statistics of the data for the first run of the subsystem level of 0.1 second location samples is depicted in the X, Y and radial histograms, Volume 3, figure 39. A map plot of the radial X and Y coordinates determined by the AVM location algorithm and the connecting line ends at the 5th wheel determined X, Y locations is presented in figure 4-14. A bias was noted and calculated from the histograms data and applied to all the runs of the supplemental data in an attempt to improve location accuracy. Figure 4-15 is the map plot of the radial errors of the next test run with the bias removal operation.

Figure 40 of Volume 3 presents the X, Y and radial histograms of all 0.1 second subsystem samples (1,923,695) for all the supplementary data with bias removal and demonstrates similar suburban performance at that obtained in the Dallas, Texas tests. The redial error figures are 97 feet (50%), 131 feet (68%), 270 feet (95%) and 693 feet (99.5%), the hit-miss coverage statistics are 98.5%.

The tenth mile average radial error statistics for the system level (10 second data) after zero fill are shown in table 4-17. The histograms are shown in Volume 3, figure 41.

TABLE 4-15. ORIGINAL PHILADELPHIA SUBURBAN TEST LOG

**Date**__________ **Start Time**__________ **Initials**__________ **Page**____ **of**____

**Tape #**__________ **File#**__________ **Test#**__________

| EVENT |  | LOCATION |  | ~~LV~~ | ~~DOOR~~ |  |  |
|---|---|---|---|---|---|---|---|
| NO. | D/H | X-COORD. | Y-COORD. | ~~PT~~ | ~~O/C~~ | ~~LOG~~ | COMMENTS |
|  |  | ORIGINAL SUBURBAN ROUTE |  |  |  |  |  |
| 1 | RT | 717620 | 246361 |  |  |  | 33RD ST. & RESERVOIR |
| 2 |  | 716 133 | 246 788 |  |  |  | RESERVOIR & SMITH DAY NURSERY(1ST ON |
| 3 |  | 715 775 | 247093 |  |  |  | RESERVOIR & SMITH DAY NURSERY(2ND ONE |
| 4 |  | 715 272 | 248 382 |  |  |  | RESERVOIR & MT. PLEASANT |
| 5 |  | 716 898 | 249 295 |  |  |  | RESERVOIR & DIAMOND |
| 6 | RT | 718 001 | 249 065 |  |  |  | DIAMOND & 33RD |
| 7 |  | 717 892 | 248146 |  |  |  | 33RD & MONUMENT |
| 8 |  | 717 747 | 247147 |  |  |  | 33RD & CLIFFORD |

## TABLE 4-16. REVISED PHILADELPHIA SUBURBAN TEST LOG

**Date**__________ **Start Time**__________ **Initials**__________ **Page**____ **of**____

**Tape #**__________ **File#**__________ **Test#**__________

| EVENT | | LOCATION | | EST. ~~LV~~ | DOOR | (OLD NO.) | |
|---|---|---|---|---|---|---|---|
| NO. | D/H | X-COORD. | Y-COORD. | ~~PT~~ | O/C | ~~LOG~~ | COMMENTS |
| | | REVISED SUBURBAN ROUTE | | | | | |
| 1 | RT | 718 050 | 246 300 | | | | OXFORD & 32ND ST. BEGIN RUN |
| 2 | TP | 717 620 | 246 361 | | | (1) | OXFORD & 33RD ST. |
| 3 | | 716 133 | 246 788 | | | (2) | RESERVOIR & SMITH DAY NURSERY (1ST ONE) |
| 4 | TP | 715 775 | 247093 | | | (3) | RESERVOIR & SMITH DAY NURSERY (2ND ONE) |
| 5 | TP | 715 272 | 248 382 | | | (4) | RESERVOIR & MT. PLEASANT |
| 6 | "RT" | 715 460 | 249 840 | * | | | RESERVOIR AT BEND BY HOUSE |
| 7 | TP<br>RT | 716 890 | 249 295 | | | (5) | RESERVOIR & DIAMOND |
| 8 | TP<br>RT | 718001 | 249065 | | | (6) | DIAMOND & 33RD ST. |
| 9 | TP | 717 892 | 249 146 | | | (7) | 33RD & MONUMENT |
| 10 | TP | 717 747 | 247 147 | | | (8) | 33RD & CLIFFORD |
| 11 | LT<br>TP | 717660 | 248 850 | * | | | 33RD & COLUMBIA |
| 12 | RT | 719 120 | 246 780 | * | | | COLUMBIA & 32ND |
| 13 | | 718 080 | 246 530 | * | | | 32ND & TURNER (END RUN) |

## TABLE 4-17. SUBURBAN TRILATERATION SPECIAL TEST SUMMARY

### 1. LARGE TRIANGLE - SYSTEM LEVEL

A. Test Plan Data Summation (before zero fill mod.) - ID#124 to 203, Tests 1 to 36, 38 to 41

Synchronization Transmitter Power: = 200 W peak
Vehicle Transmitter Power: = 631 W peak

(1) Time Points Only (209 Samples)

Time Point Accuracy 50% = ±9 sec, 68% = ±12 sec, 95% = ±60 sec, 76% = ±15 sec,
95% = ±60 sec

Time Point Coverage, Hit-Miss Statistics = 89% hits

B. Test (after zero fill mod.) ID #222, & 223, Tests 3-12

Synchronization Transmitter Power: = 468 W peak
Vehicle Transmitter Power: = 794 W peak

(1) Time Points Only (102 Samples)

Time Point Accuracy 50% = ±8.3, 68% = ±10, 95% = ±21, 99.5% = ±27
92% = ±15 sec, 100% = ±60 sec

Time Point Coverage, Hit-Miss Statistics = 99.8% hits

(2) 0.1 Mile Segment Average Location Error (10 second data) ID 246
50% = 108, 68% = 150, 95% = 273, 99.5% = 560, Max. = 1020

## TABLE 4-17. SUBURBAN TRILATERATION SPECIAL TEST SUMMARY (cont)

**2. LARGE TRIANGLE - SUBSYSTEM LEVEL**

**A. Test Plan Test (after zero fill mod.) ID #204, Tests 3-12**

**Synchronization Transmitter Power: = 468 W peak**
**Vehicle Transmitter Power: = 794 W peak**

**(1) All 0.1 Second Samples (1,923,695 Samples)**

| | | | | | | |
|---|---|---|---|---|---|---|
| **Location** | **"X" error** | 50% = ±70, | 68% = ±100, | 95% = ±233, | 99.5% = ±580 | |
| **accuracy** | **"Y" error** | 50% = ±47, | 68% = ±70, | 95% = ±160, | 99.5% = ±320 | |
| | **"R" error** | 50% = 97, | 68% = 131, | 95% = 270, | 99.5% = 693, | 96.6% = 300 |

**Hit-Miss Statistics = 98.5% hits**

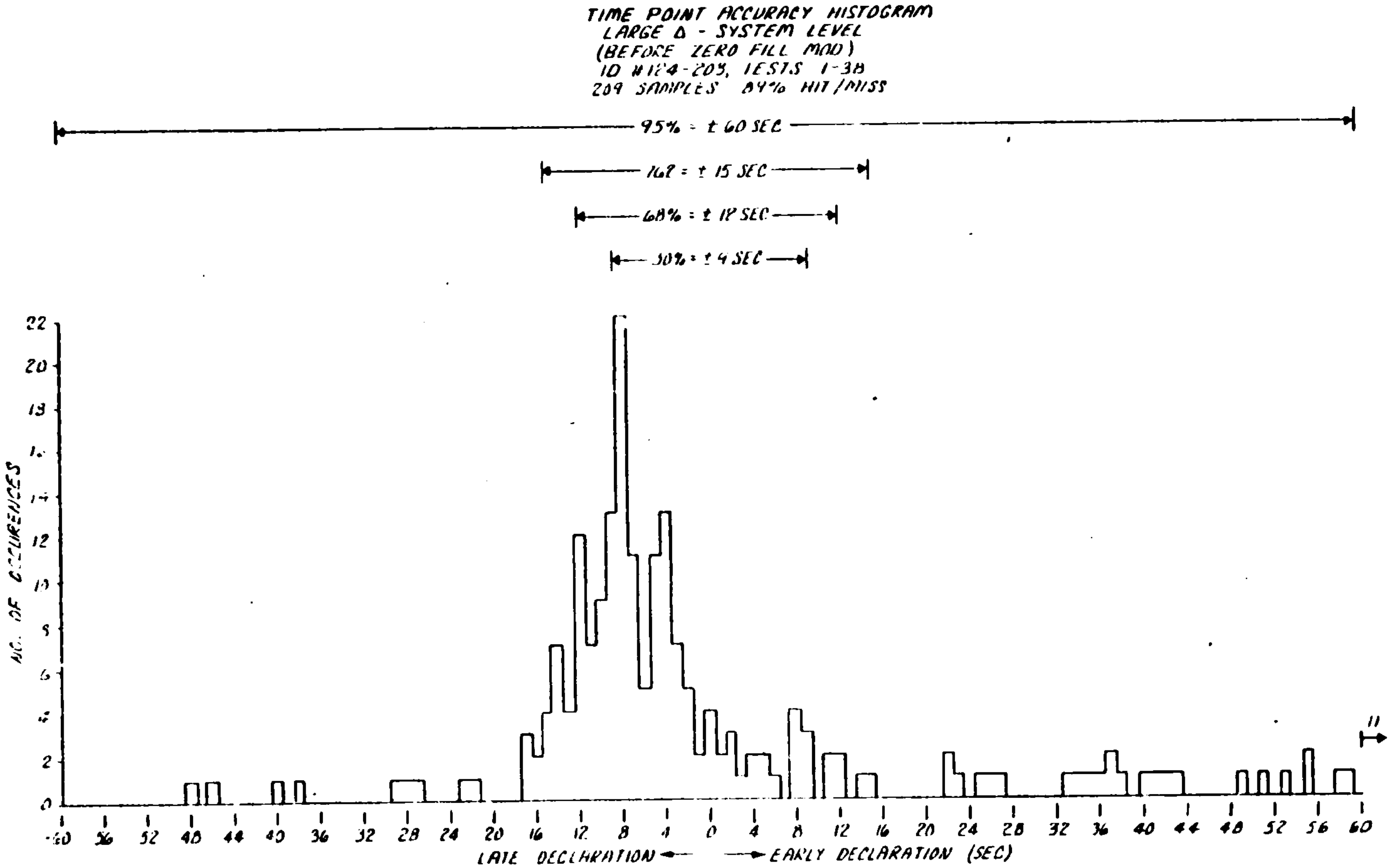


FIGURE 4-12. TIME POINT ACCURACY HISTOGRAM, LARGE TRIANGLE, SYSTEM LEVEL (BEFORE ZERO-FILL MOD)

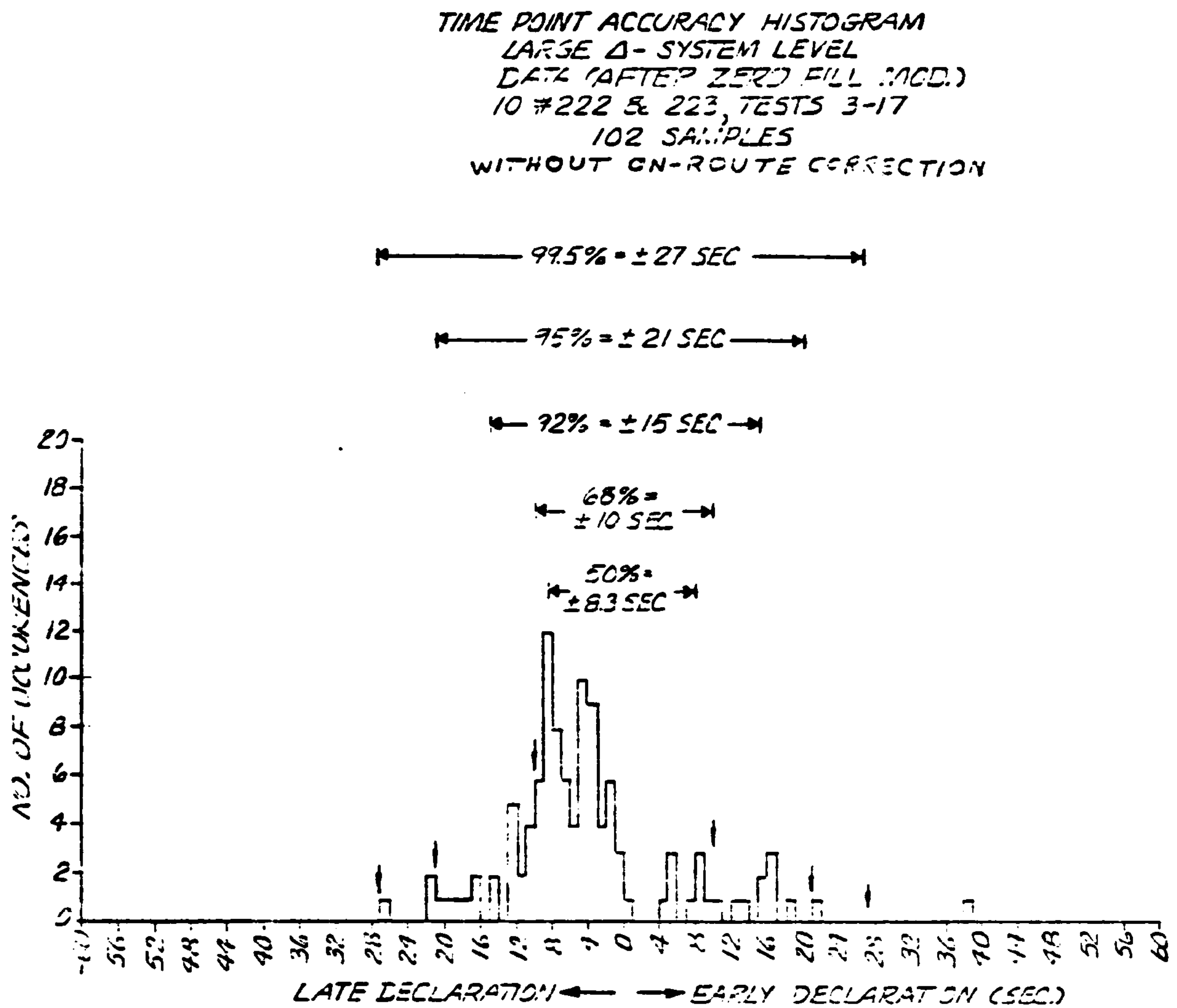
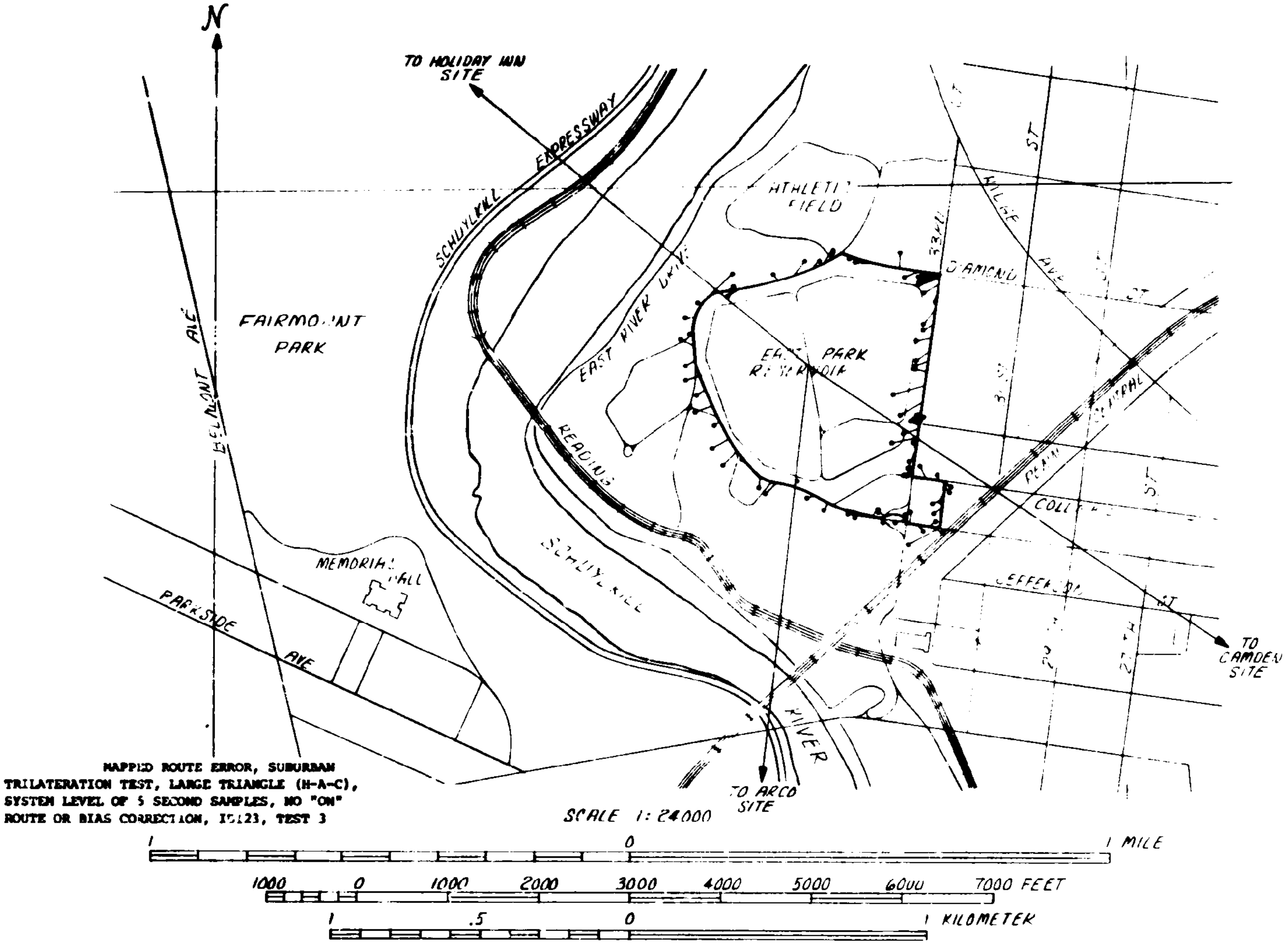
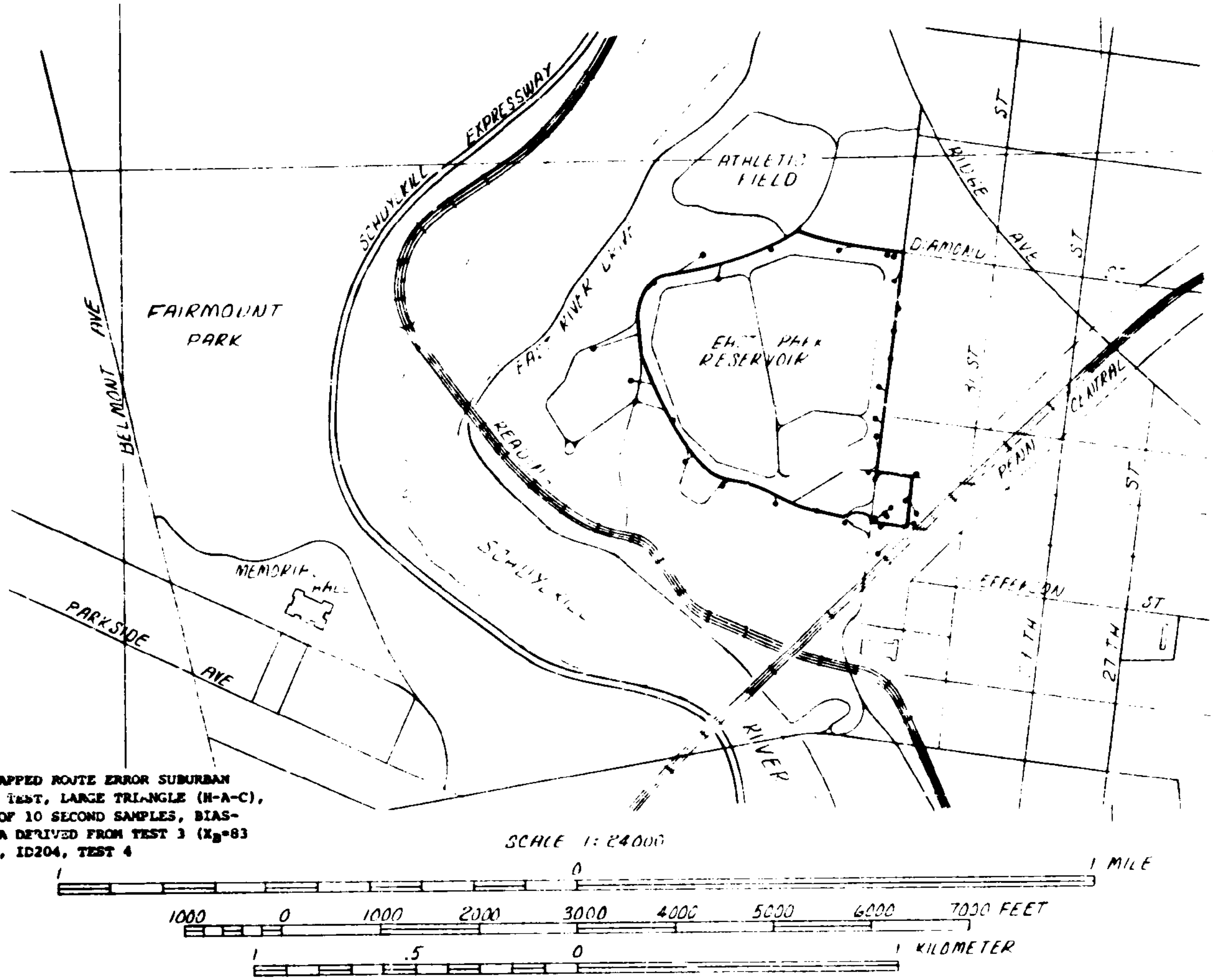


FIGURE 4-13. TIME POINT ACCURACY HISTOGRAM, LARGE TRIANGLE (AFTER ZERO-FILL MOD)



MAPPED ROUTE ERROR, SUBURBAN TRILATERATION TEST, LARGE TRIANGLE (H-A-C), SYSTEM LEVEL OF 5 SECOND SAMPLES, NO "ON" ROUTE OR BIAS CORRECTION, 15:23, TEST 3

FIGURE 4-14. MAPPED ROUTE ERROR, SUBURBAN TRILATERATION TEST



MAPPED ROUTE ERROR SUBURBAN TRILATERATION TEST, LARGE TRIANGLE (H-A-C), SYSTEM LEVEL OF 10 SECOND SAMPLES, BIAS-CORRECTED DATA DERIVED FROM TEST 3 ($X_B$=83 ft, $Y_B$=28 ft), ID204, TEST 4

FIGURE 4-15. MAPPED ROUTE ERROR, SUBURBAN TRILATERATION TEST, BIAS CORRECTED

### 4.4.2 GDOP Test

To verify the effects of GDOP (Geometrical Dilution of Precision) on position fixing accuracy, test data was taken with the test vehicle parked at designated map points. These map points were chosen to represent the full range of GDOP effects (from negligible to catastrophic) on position fixing accuracy. The main objective of the test was to make sure that GDOP degradation was minimum inside the coverage area of the triangular cell. A secondary objective was to indicate how much leeway existed for points outside the triangle before the position fix became unusable.

4.4.2.1 Background. GDOP degradation becomes significant when the lines from the test vehicle to a pair of receiver sites form a small angle. (For a given test location and triangular cell, the relevant site pair used in applying this criterion is the one which forms the smallest subtended angle.) As a practical limit, this angle can range downward to about 25° or 30° with little or no accuracy degradation. Beyond this, the effects of GDOP become increasingly severe.

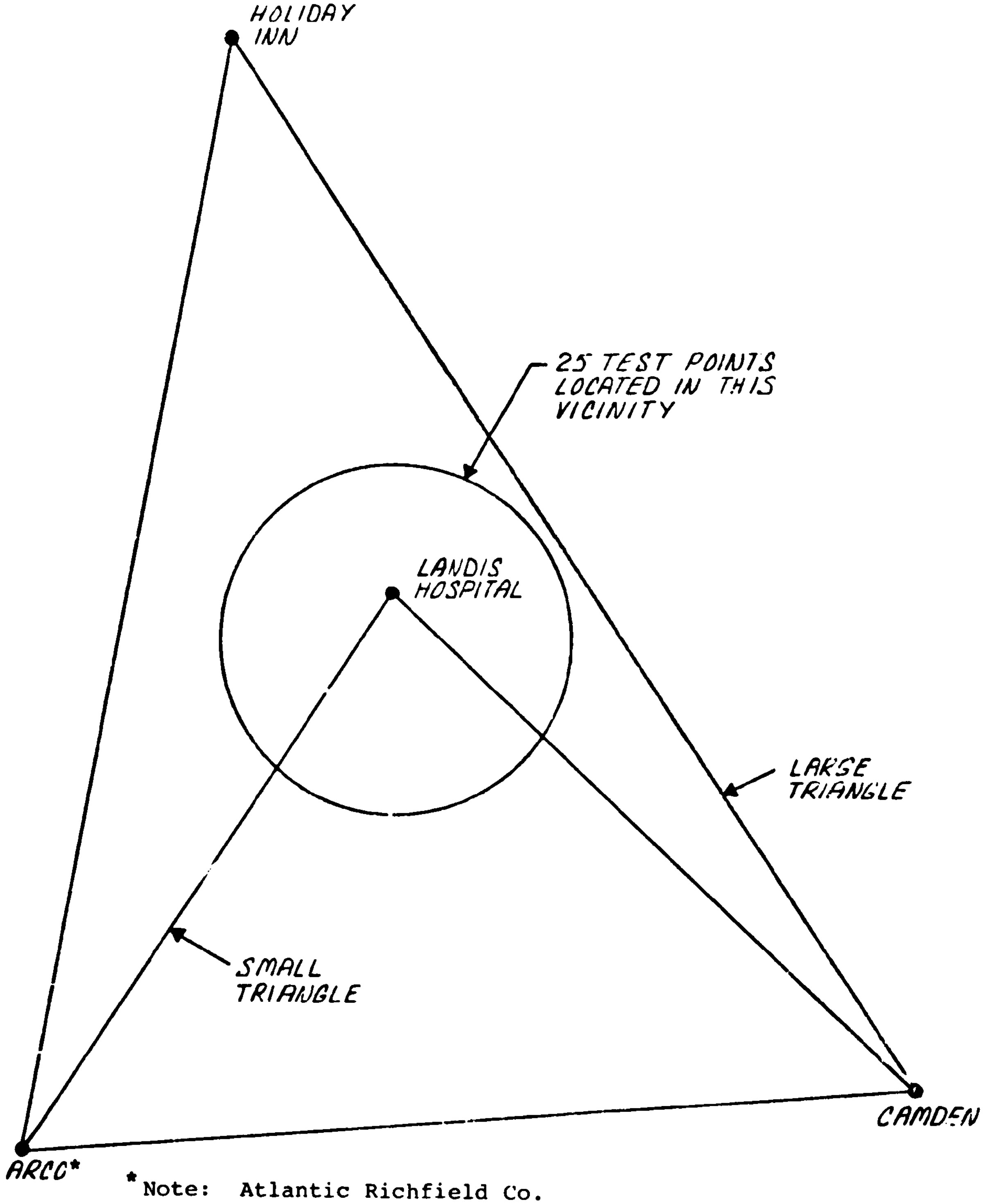
For a reasonable site configuration, the subtended angle described above is always large enough at all interior points so that no problem is presented by GDOP inside the coverage triangle. In fact. the angle subtended at any interior point is always greater than the smallest angle of the coverage triangle, so that it is possible to guarantee negligible GDOP by proper site selection.

At points outside the coverage triangle, the subtended angle can range downward to very small values far outside the triangle in any direction, or down to zero anywhere along the baseline extensions. At these points, hyperbolic position fixing breaks down. Attempts to obtain a position fix at such points often results in pathological behavior of the position fixing algorithm (eg, non-convergence, rapid convergence on a wrong answer, or very slow convergence on an answer which may or may not be correct).

4.4.2.2. GDOP Test Description. Data was taken at a number of locations surrounding the Landis Hospital site (figure 4-16). At each test location, position fixes were obtained for two different triangular cell site configurations - a large cell and a small cell - and using two different transponder power levels (200 watts and 800 watts) for each configuration.

The large cell consisted of the triangle formed by sites located at ARCO, Camden, and the Holiday Inn. All test points were well inside this triangular cell, in a region where little or no GDOP degradation would be expected. Data from this cell was used as a standard to measure GDOP degradation.

The small cell was the triangle formed by the sites at ARCO, Camden, and Landis Hospital. Since some of the test points fell outside



*Note: Atlantic Richfield Co.

FIGURE 4-16. LANDIS HOSPITAL SITE

this triangle in regions of moderate to high GDOP, accuracy degradation ranging from moderate to severe would be expected for these points when compared to the results from the large cell. For those test points inside the small triangle, little or no GDOP effects were anticipated, as in the case of the large cell. (An exception would be made in the case of a test point very close to the hospital site, even if it is within the triangular cell, since it is known that hyperbolic position fixing errors can occur at points extremely close to a vertex of the triangle.)

To determine the effect of vehicle transponder power on system performance, identical tests were made with the vehicle transponder power level at 200 watts and at 800 watts. Comparison of the results at these two power levels would indicate whether the system was range-limited by the vehicle reply when using the large triangular cell, or whether saturation effects would be produced by vehicle proximity to the hospital site when using the small triangular cell.

Twenty-five test locations with 300 interrogations recorded at each location were selected for data recording in the region surrounding Landis Hospital. The locations ranged west to east from 29th Street to 17th Street and north to south from Oxford Street to Brandywine. Of these 25 test locations, five were rejected because of excessive errors detected during processing. The major error condition was error code 13, indicating a failure to converge of the position fixing algorithm, but other errors, such as site drop out, were also observed. Three of the rejected points were outside the coverage area in high GDOP regions where non-convergence might be expected. The other two were interior points which exhibited both non-convergence and site drop-out due to unfavorable conditions in the immediate environment. The error rate at all five of these points was so high that insufficient error-free data remained for a statistically significant measure of performance at these particular test locations.

4.4.2.3 Test Results. Meaningful data was obtained from 20 of the 25 test locations and these are plotted in figures 4-17 and 4-18. Figure 4-17 shows the position error in feet plotted for both the large and small triangle with the vehicle transponder set to low power of 200 watts. Figure 4-18 is a similar plot with the vehicle transponder power set at high power of 800 watts. Examination of this data reveals:

a) Location errors encountered using the large triangle were reasonable (33 to 433 feet range) for all points as expected since these points are all within the large triangle where GDOP effects on that triangle are minimal.

b) The largest error with the large triangle was 406 feet (high power) and 433 feet (low power) and occurred at a point close to the vertex of the small triangle. The error may have been caused, in part, by proximity to the Landis Hospital.

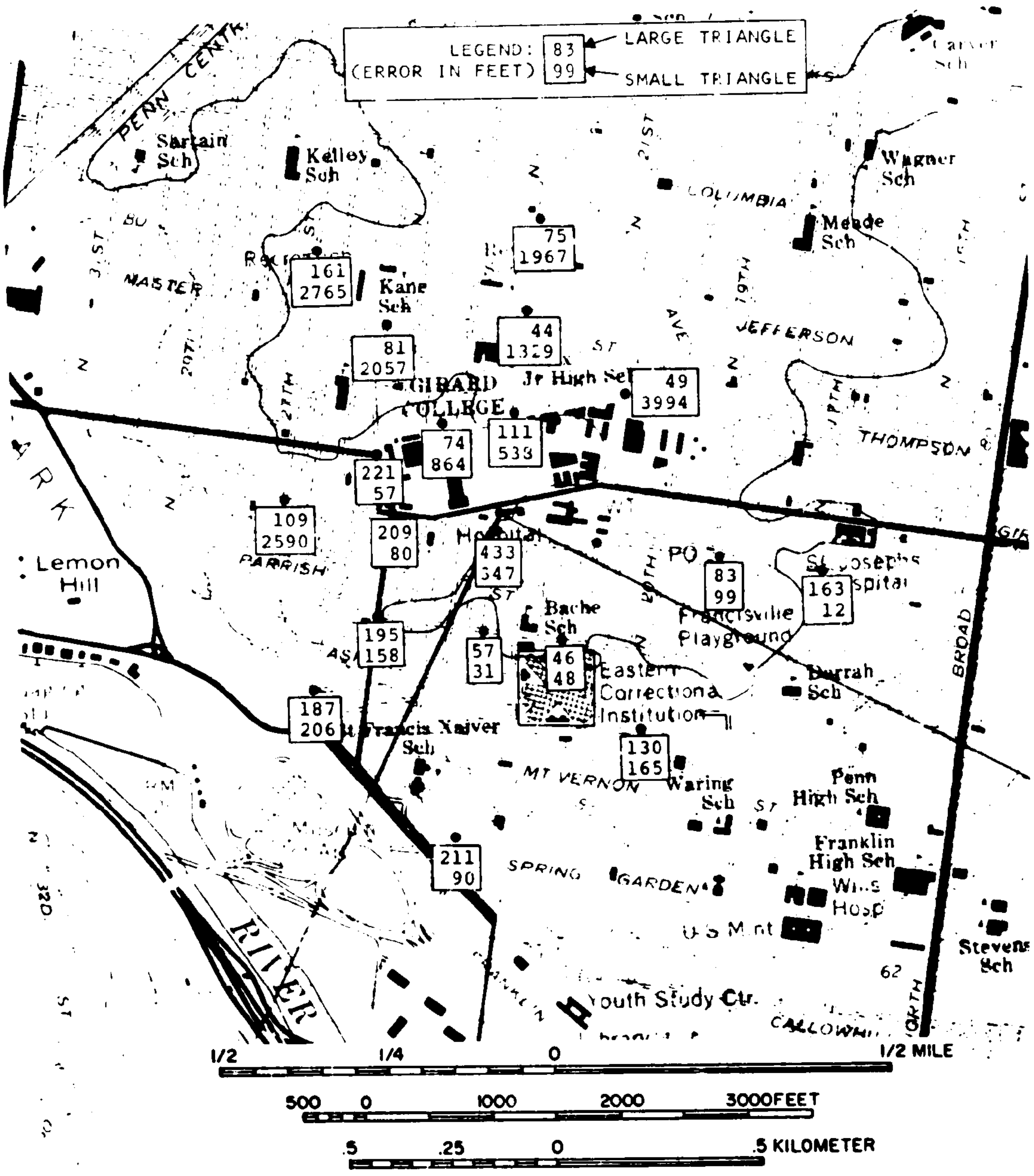


FIGURE 4-17. GDOP TEST: LOCATION SUBSYSTEM ERROR (200-WATT TRANSPONDER POWER)

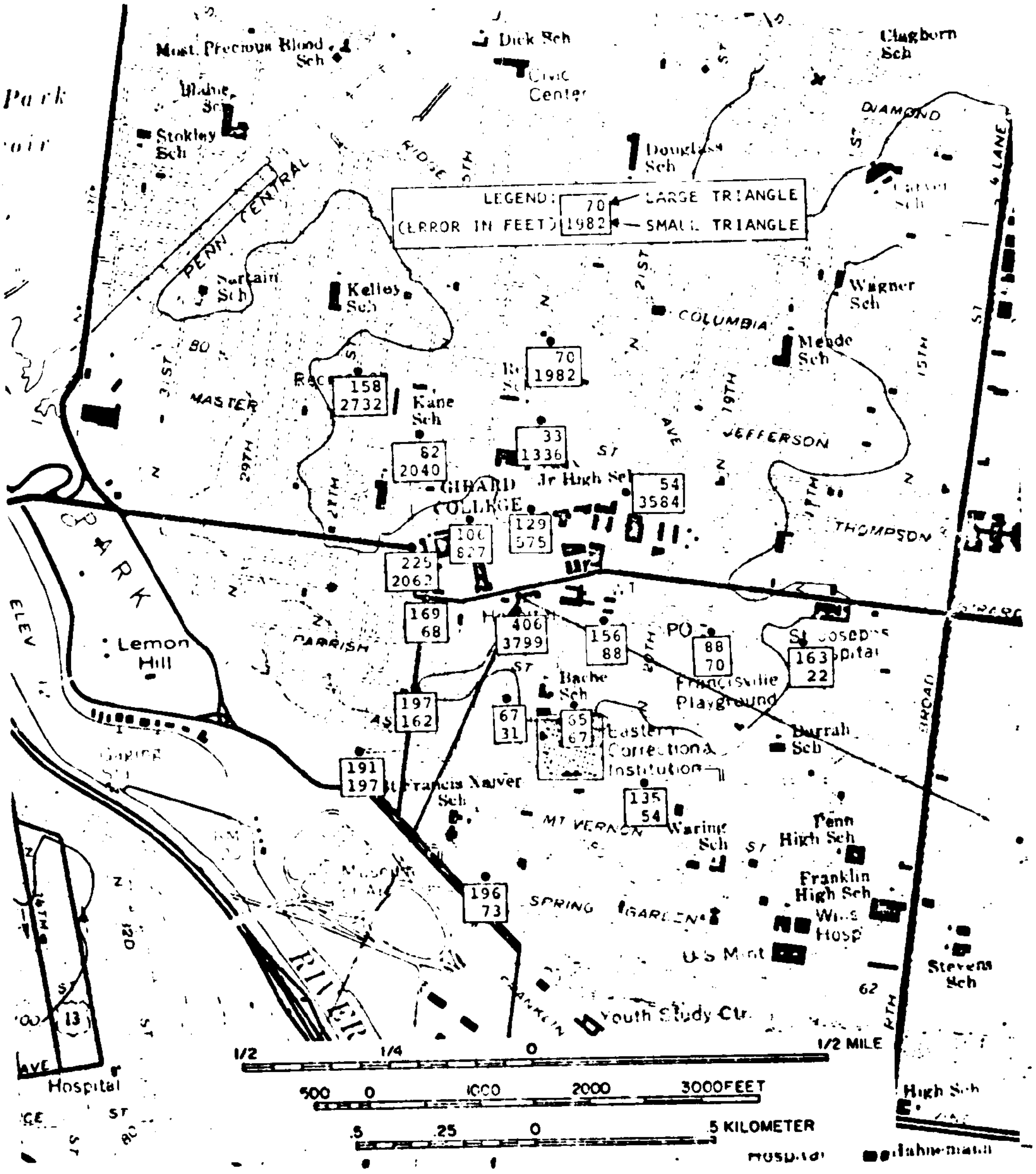


FIGURE 4-18. GDOP TEST: LOCATION SUBSYSTEM ERROR (800-WATT TRANSPONDER POWER)

c) As expected, GDOP effects resulted in very large location errors (up to 3994 feet) behind the vertex and along the baseline extensions of the small triangle.

d) The power level setting of the transponder does not reduce the deleterious effects of GDOP.

e) Some points near the baseline extensions did not yield very high expected location errors, but it is suggested that this is the result of convergence of the solution to any answer with a small error, but, nevertheless convergence to an erroneous answer.

4.4.2.4 Conclusions of the GDOP Testing. The effects of GDOP on location system accuracy can be significant and must be accounted for in the system design. Negligible GDOP can be guaranteed by the proper selection of receiving sites for use in the position finding algorithm.

4.4.3 High Speed Tests. The objective of the high speed test was to determine the location accuracy and hit-miss statistics of the AVM system with vehicles traveling at high speed. The portion of the Schuykill Expressway used for the test is shown in figure 4-1. Two passes were made with a vehicle speed of approximately 55 mph. Because of the limited road length of the test, subsystem 0.1 second sample data was used in the analysis. The test road length was only in the large triangular configuration and therefore only data from the large cell receivers were gathered for this test. The data was filtered by the smoothing algorithm usually performed at system level to simulated equivalent system performance.

The high speed test results are shown in histogram form in Volume 3, figure 42 and the percentiles are tabulated in table 4-18. A map plot of the radial location error as the vehicle traversed along the Schuylkill Expressway is depicted in figure 4-19. The percentile results are similar to the special underpass test histogram (Volume 3, figure 43) which contained all 0.1 sec data samples of that test route. The section of road along the expressway was the same for both the high speed and underpass tests. The percentile figures are 107 feet (50%), 160 feet (68%) and 720 feet (95%). Eighty five percent of the data samples had a radial error of less than 300 feet.

4.4.4 Underpass Test. The objective of the underpass test was to determine the location accuracy and the hit-miss statistics when the moving vehicle is under an underpass road configuration. This data was compared to location data for the location samples of the total run (including points before and after the underpass intervals). No performance accuracy figure is specified, but the goal is 300 feet (95%).

Five overpasses above the Schuylkill Expressway between City Line exit and the Franklin Parkway exit were used for the tests. Table 4-19 lists the coordinates of the enter and leave points of the overpass locations. Twelve passes of this section of road were made and data collected. The vehicle traveled at approximately 30 mph with the Hazeltine operator entering the event number at the time the vehicle entered the underpass and pressing a button switch upon leaving the underpass. Because of the limited distance traveled, subsystem 0.1 second samples were used in the statistics with a filtering process normally used at system level, applied to the raw data. The test section of road is only within the coverage

## TABLE 4-18. SPECIAL HIGH SPEED TEST AVM PERFORMANCE

1. Large Δ (HAC) - Subsystem

Test Plan Data Summation - ID #213, Tests 1 & 2

Synchronization Transmitter Power = 468 W peak
Vehicle Transmitter Power = 759 W peak

A. All 0.1 Second Samples (1438 samples)

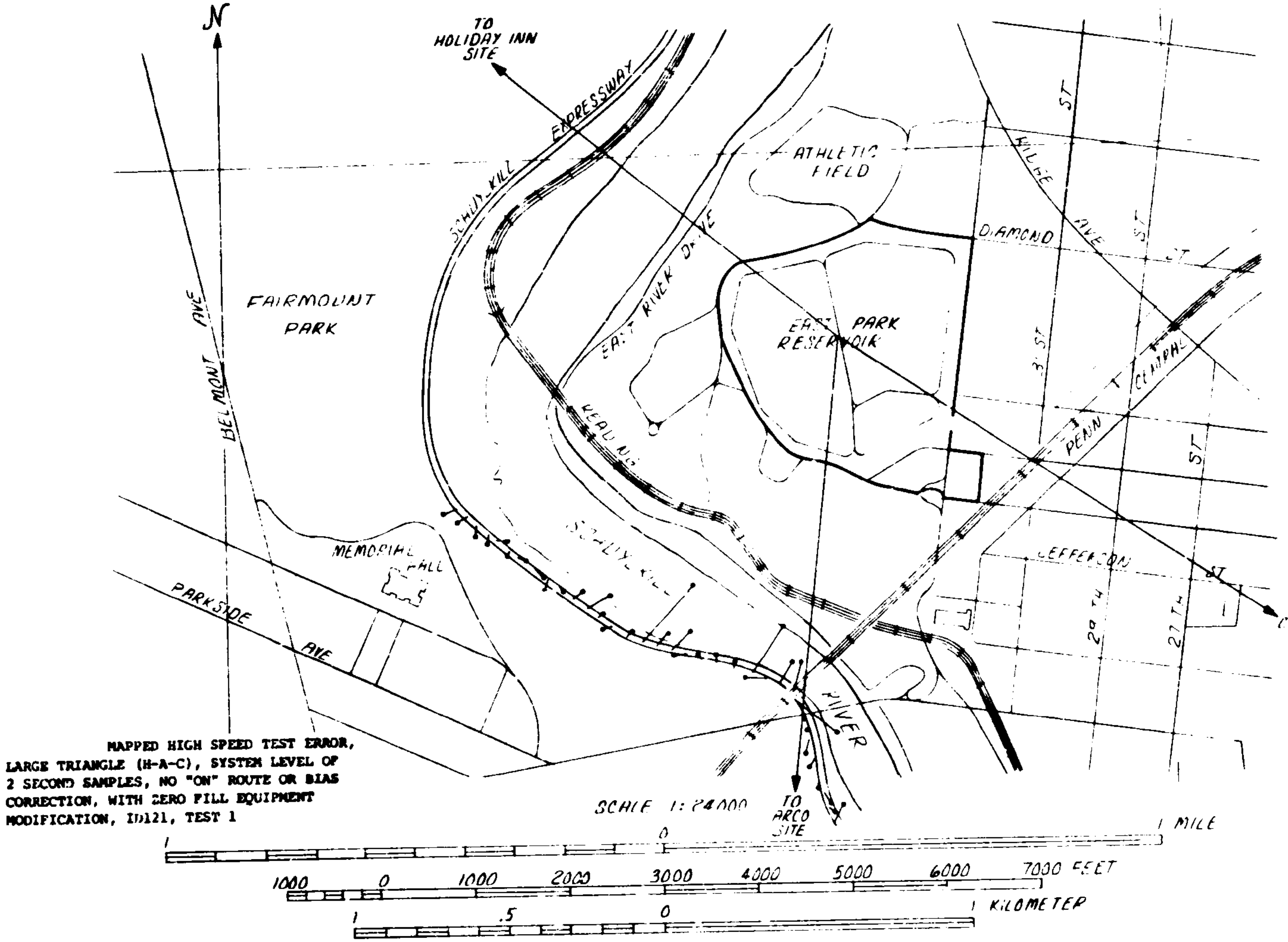
Location "X" error 50% = ±68, 68% = ±120, 95% = ±540, 99.5% = ±930

"Y" error 50% = ±70, 68% = ±100, 95% = ±370, 99.5% = ±890

"R" error 50% = 107, 68% = 160, 95% = 720, 99.5% = 1220 , 85% = 300

Hit-Miss Statistics = 95% hits 85% = 300

Average Speed During Run = 55 MPH



MAPPED HIGH SPEED TEST ERROR, LARGE TRIANGLE (H-A-C), SYSTEM LEVEL OF 2 SECOND SAMPLES, NO "ON" ROUTE OR BIAS CORRECTION, WITH ZERO FILL EQUIPMENT MODIFICATION, ID121, TEST 1

FIGURE 4-19. MAPPED HIGH SPEED TEST ERROR, LARGE TRIANGLE (HAC)

## TABLE 4-19. UNDERPASS AND HIGH SPEED TESTS LOG

Date 2/27/77 Start Time ____________ Initials ____________ Page ____ of ____

Tape # ____________ File# ____________ Test# ____________

| EVENT NO. | EVENT D/H | LOCATION X-COORD. | LOCATION Y-COORD. | LV PT | Δ DISTANCE CALC. ~~DOOR O/C~~ | Δ DISTANCE MEAS. LOG | COMMENTS |
|---|---|---|---|---|---|---|---|
| | | POINTS ON SCHUYLKILL EXPRESSWAY (SOUTHBOUND) FOR UNDERPASS & HIGH SPEED(*) TESTS | | | | | |
| *1 | | 712 420 | 246 320 | | | | 1.40 mi marker (start—no underpass) |
| | | | | | 2221 | 2205 | |
| *2 | | 714 160 | 244 940 | | | | West River Drive & R.R. Bridge |
| | | | | | 1796 | 1793 | |
| *3 | | 715 860 | 244 360 | | | | Penn Central R.R. stone Bridge |
| | | | | | 228 | 168 | |
| 4 | | 716 000 | 244 180 | | | | Girard Ave. Bridge |
| | | | | | 500 | 550 | |
| 5 | | 716 140 | 243 700 | | | | Girard Ave. exit ramp |
| | | | | | 1067 | 1057 | |
| *6 | | 716 420 | 242 670 | | | | Foot Bridge |
| | | | | | 5812 | | |

area of the large triangule (HCA); therefore only the HCA triangle data was processed.

Figure 43 of Volume 3 presents the X, Y and radial error histograms of the AVM performance only during the intervals when the vehicle is within the overpass, utilizing the 0.1 second samples of the subsystem. Volume 3, figure 44 shows the X, Y and radial histogram utilizing all the subsystem samples of the test runs. The 50, 68, 95 and 99.5 percentile figures are listed in table 4-2[illegible]. As shown, the 95 percentile figure degraded from 740 feet to 1255 feet, the 68% point from 184 to 570 feet and the 50% point from 116 feet to 200 feet. The hit-miss coverage statistic was 94%.

## TABLE 4-20. UNDERPASS SPECIAL TEST AVM PERFORMANCE

1. Large Δ (HAC) - Subsystem Level

Test Plan Data Summation - ID #206, Tests 1-3, 5-12

Synchronization Transmitter Power = 589 W peak
Vehicle Transmitter Power = 676 W peak

A. Only Samples During Underpass Intervals (858 samples)

Location "X" error 50% = ±170, 68% = ±420, 95% = ±920 , 99.5% = ±1660

"Y" error 50% = ±110, 68% = ±374, 95% = ±920 , 99.5% = ±1640

"R" error 50% = 200, 68% = 570, 95% = 1255, 99.5% = 2340, 56.5% = 300

Hit-Miss Statistics - 94% hits

B. All 0.1 Second Samples (12,449 samples)

Location "X" error 50% = ±74 ,68% = ±120, 95% = ±596, 99.5% = ±1080

"Y" error 50% = ±73 , 68% = ±110, 95% = ±420, 99.5% = ± 980

"R" error 50% = 116, 68% = 184, 95% = 740, 99.5% = 1420

Hit-Miss Statistics = 94% hits

### 4.4.5 Multipath

This section discusses the Philadelphia test program's findings regarding the performance of the pulse trilateration AVM system in the presence of multipath (reflection) signals representative of the dense high-rise building environment. Multipath signals are those signals which result from a reflection of the primary (vehicle to fixed site receiver) signal off of a building or other structure. Multipath usually is of a lesser magnitude, and arrives later than the primary signal since it travels a longer distance and undergoes additional path loss attenuation. Under certain conditions the direct signal path from transmitter to receiver may be blocked (highly attenuated) and the only available path may be via a reflection. In this case the reflected signal is of a larger magnitude than the direct signal which was blocked.

The test program shows that:

a. Multipath signals from the vehicle transponder were not limited to a particular fixed site receiver.

b. The AVM system design uses spacing between pulses of 27.5 μs. Hazeltine observations in New York City and published data indicated that the multipath decayed below threshold in 15 to 20 μs so that 27.5 μs appeared to give adequate design margin. However, in some cases during the Philadelphia testing, multipath signals arriving 27.5 μs later than the primary signal exceeded the fixed site receiver threshold and caused erroneous preamble decoding and subsequent erroneous T.O.A. errors impacting location subsystem accuracy. (There were no cases observed wherein multipath signals with delays of more than 75 μs exceeded receiver threshold.)

c. The erroneous preamble decoding caused by multipath was corrected by modification of the preamble such that multipath signals could not arrive with sufficient strength at a time when a "0" in the preamble was to be detected. This ensures that inter-symbol interference (of the type which changes a "0" to a "1") is precluded and permits accurate T.O.A. estimation.

d. Message errors caused by multipath-induced inter-symbol interference are to be eliminated by including an adaptive message detection threshold in the fixed site receivers which provides echo suppression and reduced message error rate caused by external noise sources.'

e. Blockages by Center City structures can cause high primary signal path loss. In some instances the primary signal was below threshold and the delayed multipath response was above threshold, resulting in a late TOA measurement and subsequent location subsystem error. This potential problem is alleviated significantly by including a fixed site receiver at the center of a high density cluster of buildings to reduce attenuation and reflection of the primary signal.

### 4.4.5.1 Test Conditions and Equipment

To visually demonstrate the effect of multipath on AVM system performance, log video signals received from the vehicle transmitter at two fixed receiver site locations were photographically recorded. Photographs were taken at site #3, located at the City Avenue Holiday Inn and Site #1, located at Northgate Apartments in Camden while the vehicle was in various locations. Pertinent equipment characteristics are:

Fixed Site Receiver/Processor

$f_o$ = 908 MHz

$f_{BW}$ = 6 MHz

Dynamic Range - 80 dB

Internal Noise Figure - 3 dB

Log Video - 22 mV/dB,

Vehicle Transponder

Peak Output = 800 Watts

Pulse Width = 2 μs

Antenna Gain = +5 dBi Omni,

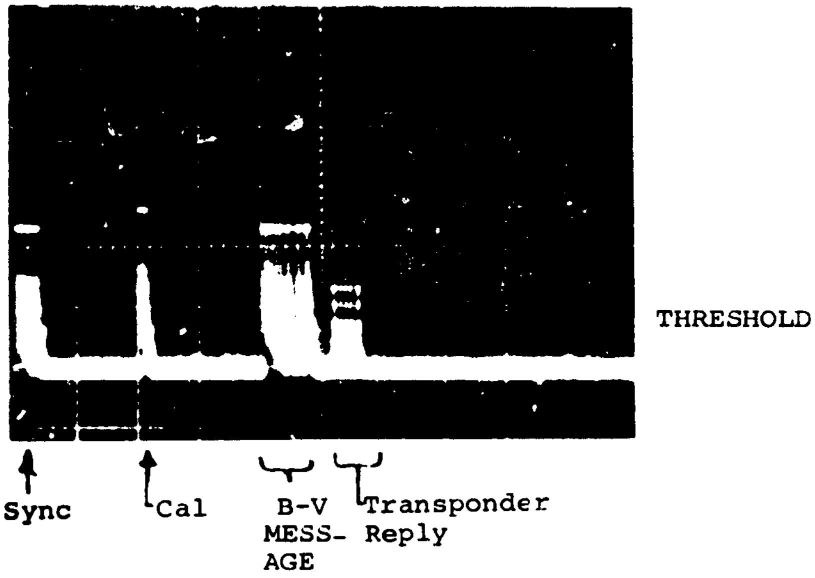
Oscilloscope

Tektronix Type 465 or 475
with 20 MHz Filter.

### 4.4.5.2 Inter-Symbol Interference

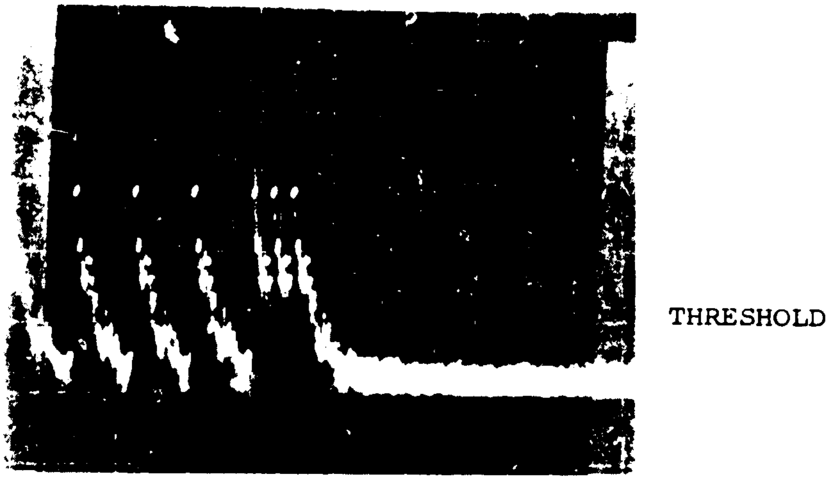
During the test program, inter-symbol interference (ie, zero-fill ) was observed at the fixed receiver sites. An investigation was undertaken to determine the degree of interference and to implement a solution.

The photo of figure 4-20 shows a set of AVM pulses. Four distinct groups are noted, from left to right they are: vehicle interval synchronization (base to vehicle) calibration (base to fixed site receiver), base-to-vehicle message, and transponder reply (to fixed site receiver). The photos of figures 4-21 and 4-22 are time expansions of a portion of a transponder reply sequence and clearly demonstrate inter-symbol interference due to multipath stretching past 27.5 μs.

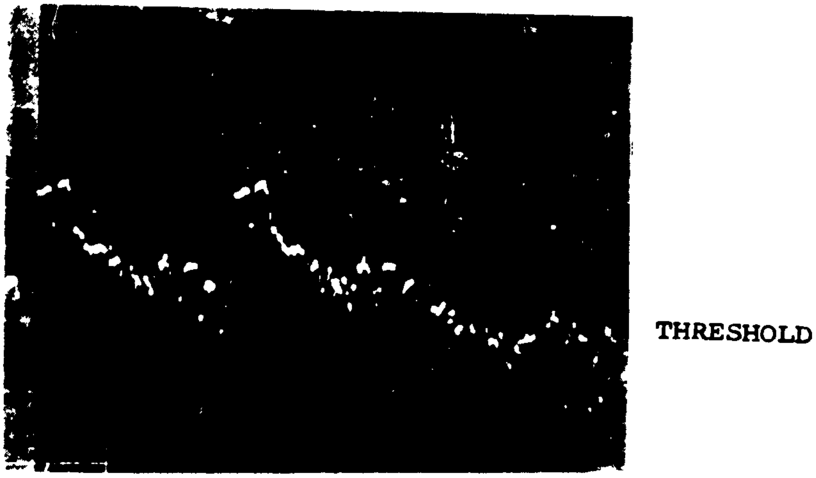


**Where** Taken: Site #1 (Camden)
**Vehicle** Position: Along Fixed Route
**Scope** Settings: V - 0.5 V/cm
H - 1 ms/cm

FIGURE 4-20. AVM PULSE SET

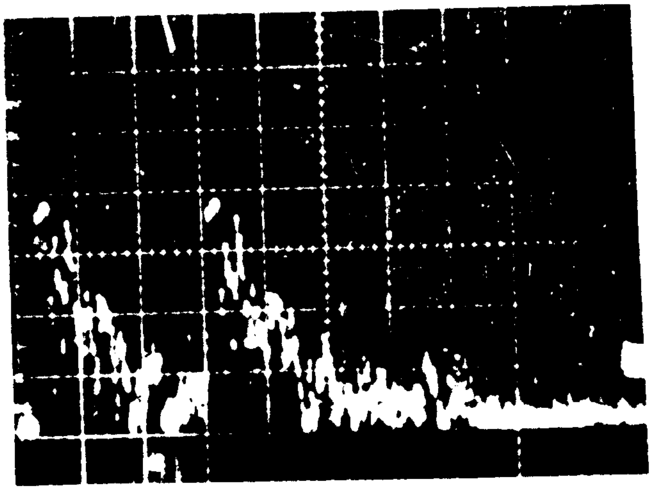


**Scope Settings:** V - 0.5 V/cm
H - 100 μs/cm
**Comments:** Note stretching due to multipath



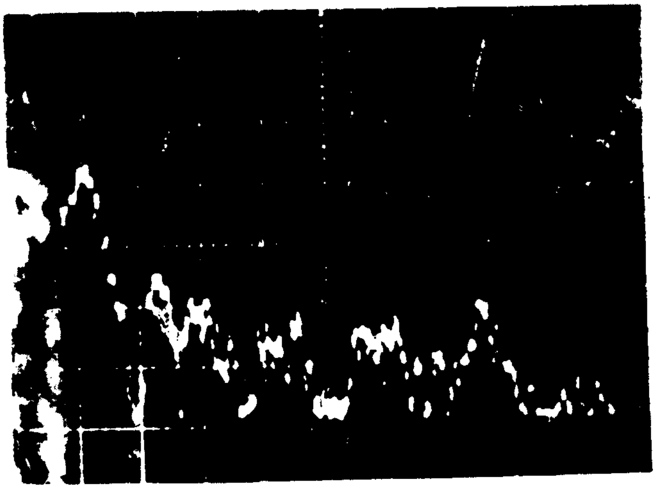
**Scope Settings:** V - 0.5 V/cm
H - 10 μs/cm
**Comments:** Multipath past 27.5 μs
(inter-symbol interference)

FIGURE 4-21. EXPANDED TRANSPONDER REPLY, SITE #3 (HOLIDAY INN)



Vehicle Position: Along Fixed Route
Scope Settings: V - 0.2 V/cm
H - 10 μs/cm

Expanded Transponder Reply



Vehicle Location: Along Fixed Route
Scope Setting: V - 0.2 V/cm
H - 5 μs/cm
Comments: Multipath in this case is not continuous but shows a number of discrete reflectors.

Single Transponder Reply

FIGURE 4-22. TRANSPONDER REPLY PULSES, SITE #1 (CAMDEN)

Oscilloscope observations at other sites during the test program indicate that inter-symbol interference was not limited to any particular site and could cause reduced accuracy due to a late time of arrival estimate at the affected site. To reduce the effect of long multipath interference, the preamble reply spacing was changed as shown in figure 4-23 and as photographed in figure 4-24. After implementing the change in the AVM equipment, quick-look data had shown an improvement in location accuracy when the 95th percentile points of the before and after histograms were compared.

Multipath can also cause message errors due to inter-symbol interference. To eliminate this problem, future fixed site processors will contain an adaptive process that sets the message detection threshold to a level that is approximately 10 dB below the peak signal strength of the T.O.A. pulse. In addition to echo suppression, this proposed modification will also decrease the message error rate for most signals by reducing the false firing rate from external noise sources.

### 4.4.5.3 Multipath with Short Delay

Multipath effects are not limited to causing inter-symbol interference problems. Fading effects at the leading edge and during the pulse have been observed and photographed. It should be noted that the photographs that follow demonstrate the destructive effects of urban multipath upon a leading edge and are not intended to be a representative sample. Figure 4-25 shows a vehicle reply with an undisturbed leading edge while figure 4-26 shows various degrees of fading during the edge and throughout the 2 microsecond primary pulse.

The fading effect is highly sensitive to vehicle location and can be expected to change with vehicle movements of several inches.

### 4.4 5.4 Blockage and Multipath

Scope observations were made when the direct path was compared to the delayed reflected signals at Camden (site #1) with the test vehicle located at Market Street and 33rd. Under these conditions, scope observations confirmed a weak 2 μs primary signal that was below the minimum threshold, followed by a strong 2 μs delayed signal due to a reflection. This set of conditions would result in a late T.O.A. measurement. One explanation for this is based on the assumption that Center City was directly between Camden and the vehicle, resulting in a high primary signal path loss. The 2 μs delayed secondary signal had a more favorable path loss, similar to the effect shown in figure 4-27 (although TOA is not corrupted in figure 4-27 since the primary pulse leading edge is good quality and the pulse is above threshold.) Scope observations at ARCO (site 2) and Holiday Inn (site 3) indicate that it is desirable to have a fixed site at the center of a high density cluster of buildings in order to reduce the effect of large reflectors and high attenuation of the primary signal. Higher antenna elevation for the fixed receiver sites will also provide better system performance.

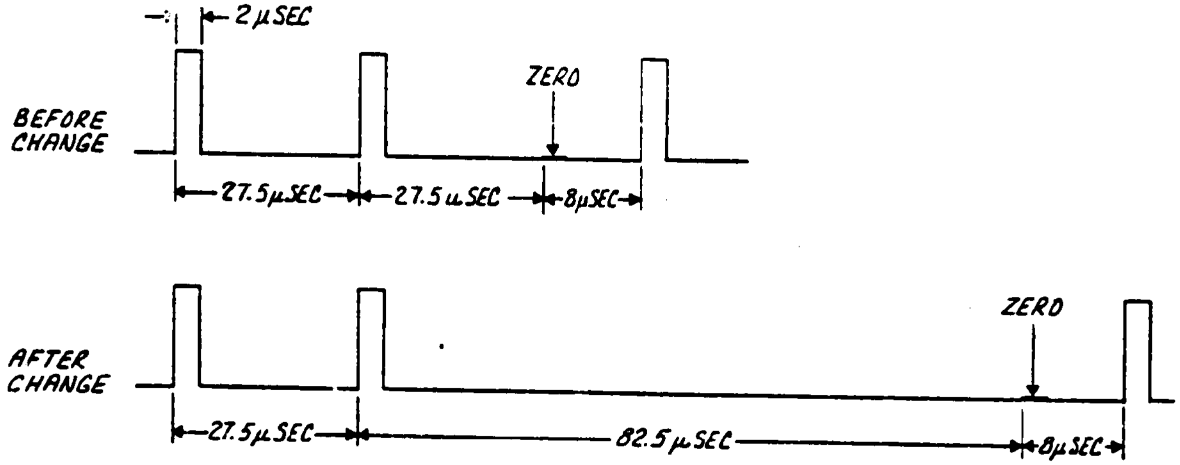
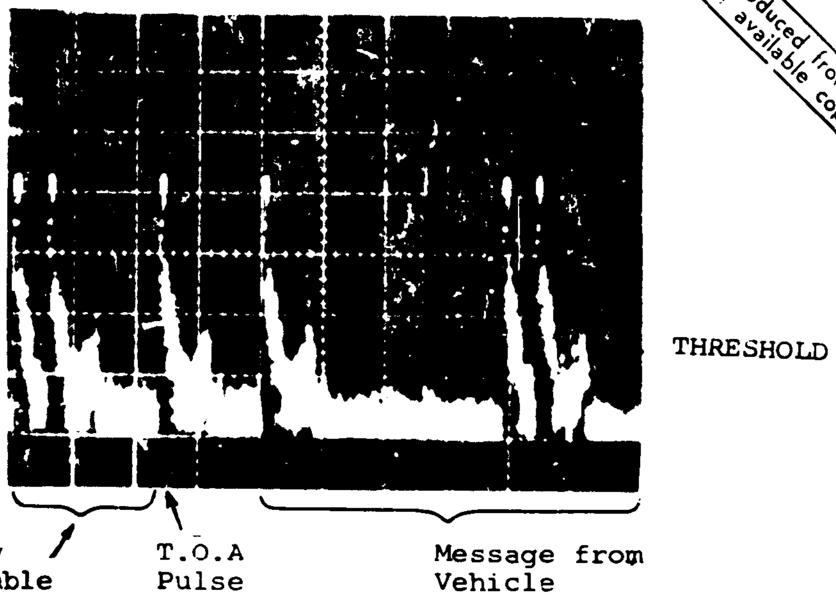
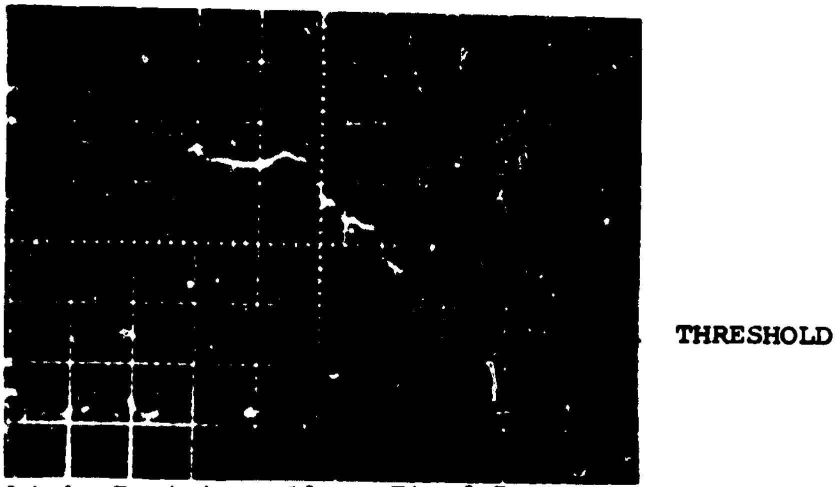


FIGURE 4-23. REPLY PREAMBLE SPACING



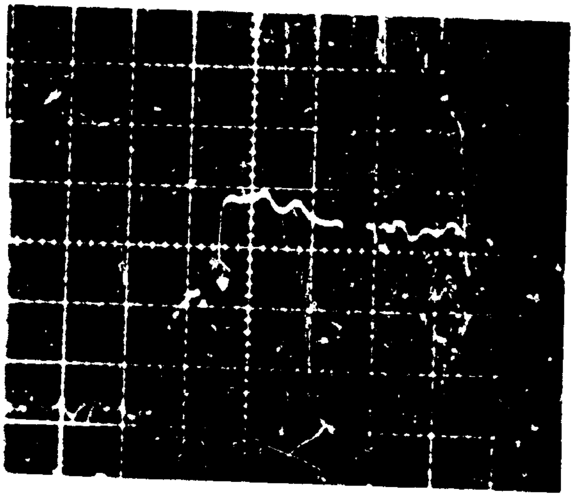
**Vehicle Position:** Along Fixed Route
**Scope Settings:** V - 0.2 V/cm
H - 50 μs/cm
**Comments:** Multipath past 27.5 μs, but no multipath at "zero" point of preamble and at time of T.O.A. pulse

FIGURE 4-24. TRANSPONDER REPLY WITH MODIFIED PREAMBLE, SITE #1, CAMDEN

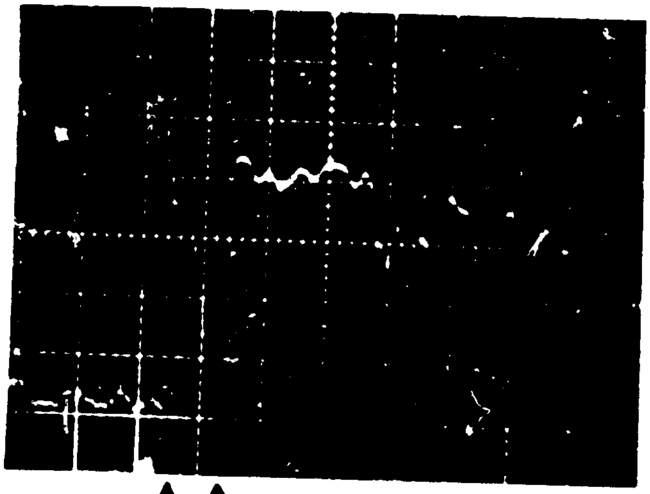


Vehicle Position: Along Fixed Route
Scope Setting: V - 0.2 V/cm
H - 1 μs/cm
Comments: Excellent leading edge; minor fading within 2 μs pulse.

FIGURE 4-25. EXPANDED REPLY PULSE, UNDISTURBED LEADING EDGE, SITE #1, CAMDEN

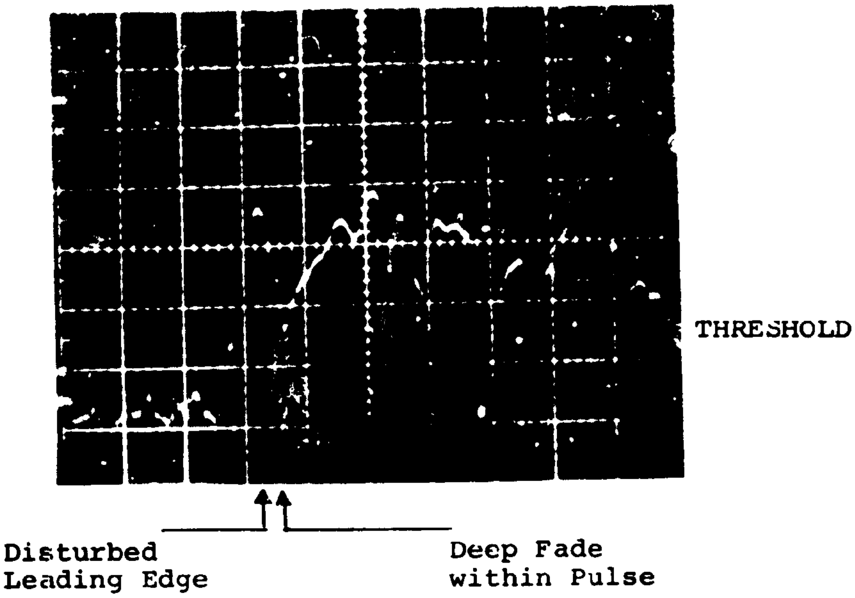


Location of Vehicle: Along Fixed Route
Scope Settings: V - 0.2 V/cm
H - 1 μs/cm
Comments: Note leading edge. If signal had been 10 dB weaker, first leading edge would have been missed. Second edge delayed by about 1μs.



Location of Vehicle: Along Fixed Route
Scope Settings: V - 0.2 V/cm
H - 1 μs/cm
Comments: Leading edge good; Note early fade into pulse.

FIGURE 4-26. REPLY PULSE, WITH FADING, SITE #1

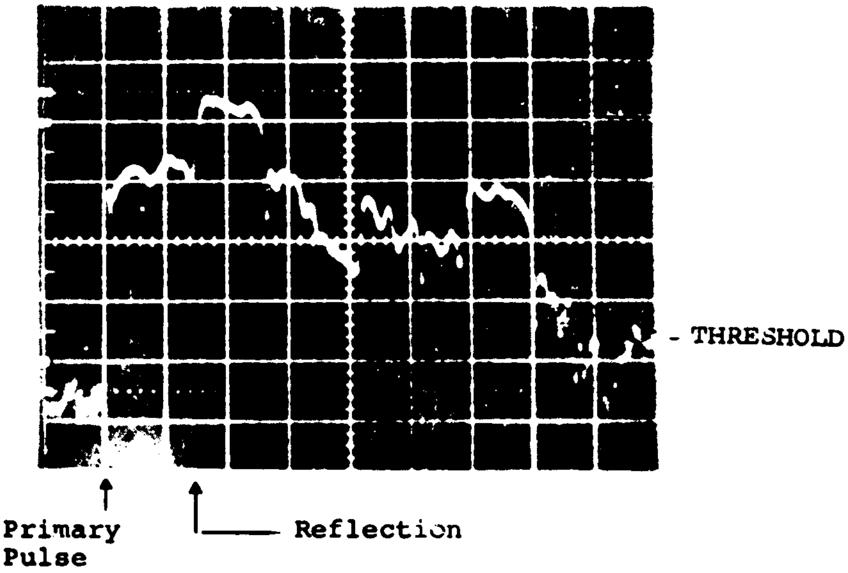


Location of Vehicle: Along Fixed Route

Scope Settings: V - 0.2 V/cm
H - 1 μs/cm

Comments: Note disturbed leading edge.
18 dB Pulse fade.

FIGURE 4-26. REPLY PULSE, WITH FADING, SITE #1 (cont)



**Location of Vehicle:** Along Fixed Route

**Scope Settings:** V - 0.2 V/cm
H - 2 μs/cm

**Comments:** 3 μs reflection is 10 db stronger than primary pulse. Good leading edge

FIGURE 4-27. REPLY PULSE, CAMDEN

### 4.4.6 Signpost Testing

The signposts are used to augment the performance of the pulse trilateration AVM system in the area of time-of-passage measurement for slow moving vehicles. The signposts' measured antenna patterns, shown in figures 4-28 4-29, and 4-30, exhibit the following angular widths for a 10 dB sum/difference pattern ratio.

| Elevation Angle | Angular Width (10dB Σ/Δ) |
|---|---|
| -30° | 27.5° (±13.75°) |
| 0° | 23.6° (±11.8°) |
| +30° | 23.6° (±11.8°). |

It was determined that a signpost mounting height of ten (10) feet above the street surface was inadequate since (a) the pattern was sometimes shadowed by other vehicles, and (b) not enough hits per beamwidth were obtained. These conditions were alleviated when the signpost was raised to twenty-five (25) feet and this height was used for the actual test program.

Temperature tests were performed to verify the operation of a signpost over the range -22°F to +122°F. Power consumption of the unit is 20 milliwatts, broken down as shown below.

| | CURRENT (MA) | | (POWER (MW) | |
|---|---|---|---|---|
| | +12V | +6V | +12V | +6V |
| LOGIC | 0.8 | 0.7 | 9.6 | 4.2 |
| RF | 0.5 | 0 | 6.0 | 0 |
| TOTAL | 1.3 | 0.7 | 15.6 | 4.2 . |

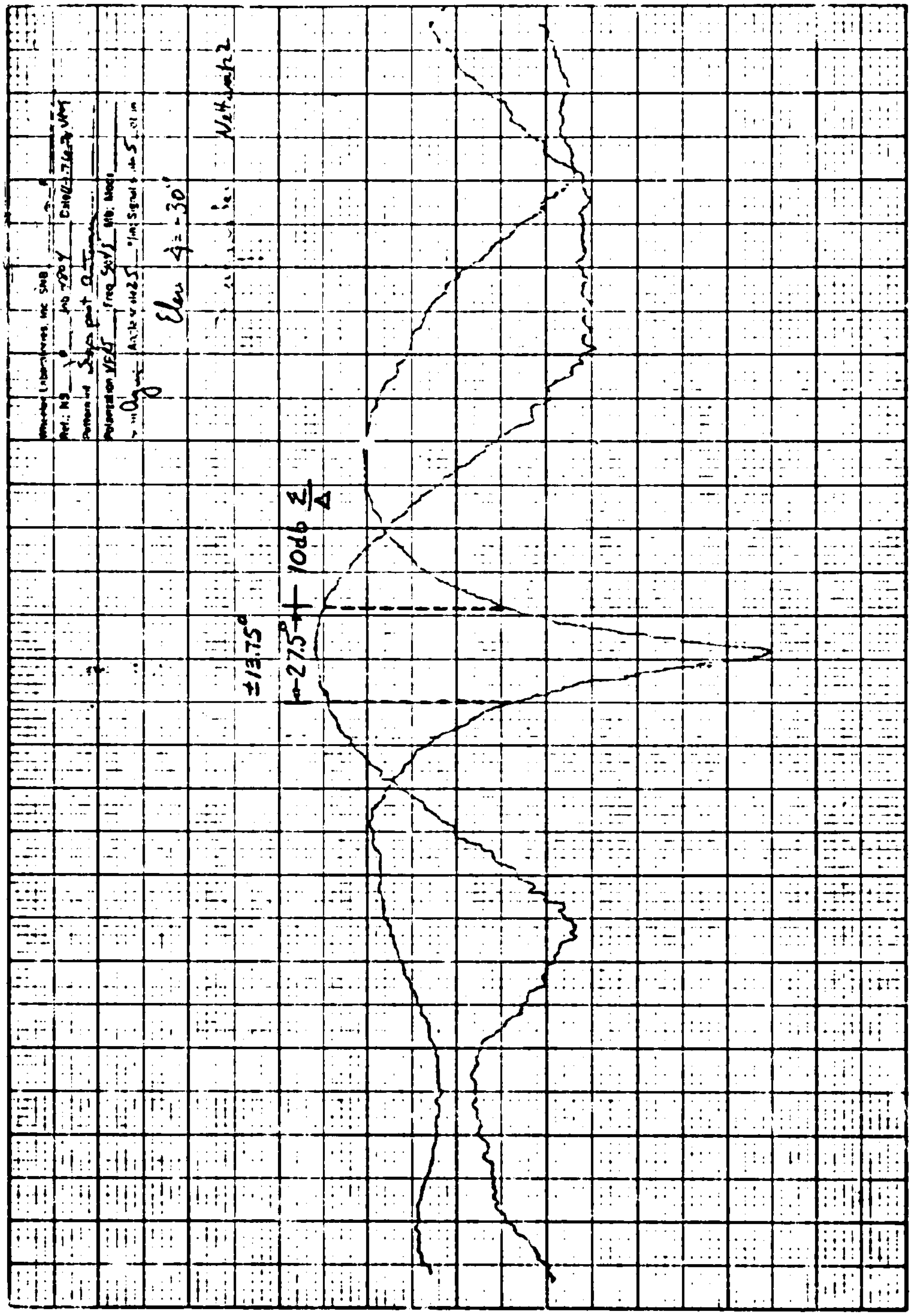


FIGURE 4-28. SIGNPOST ANTENNA PATTERNS (-30° ELEVATION)

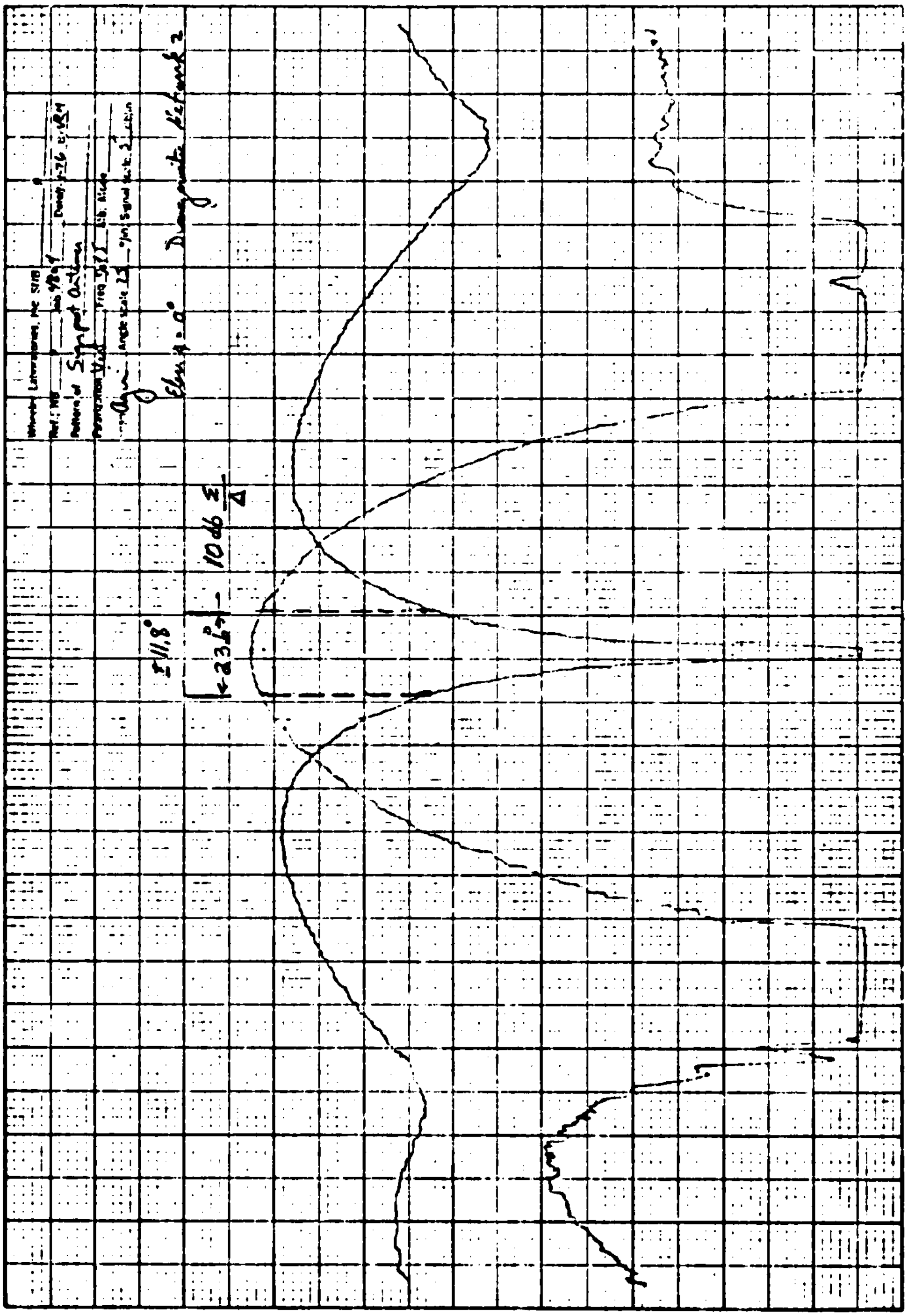


FIGURE 4-29. SIGNPOST ANTENNA PATTERNS (0° ELEVATION)

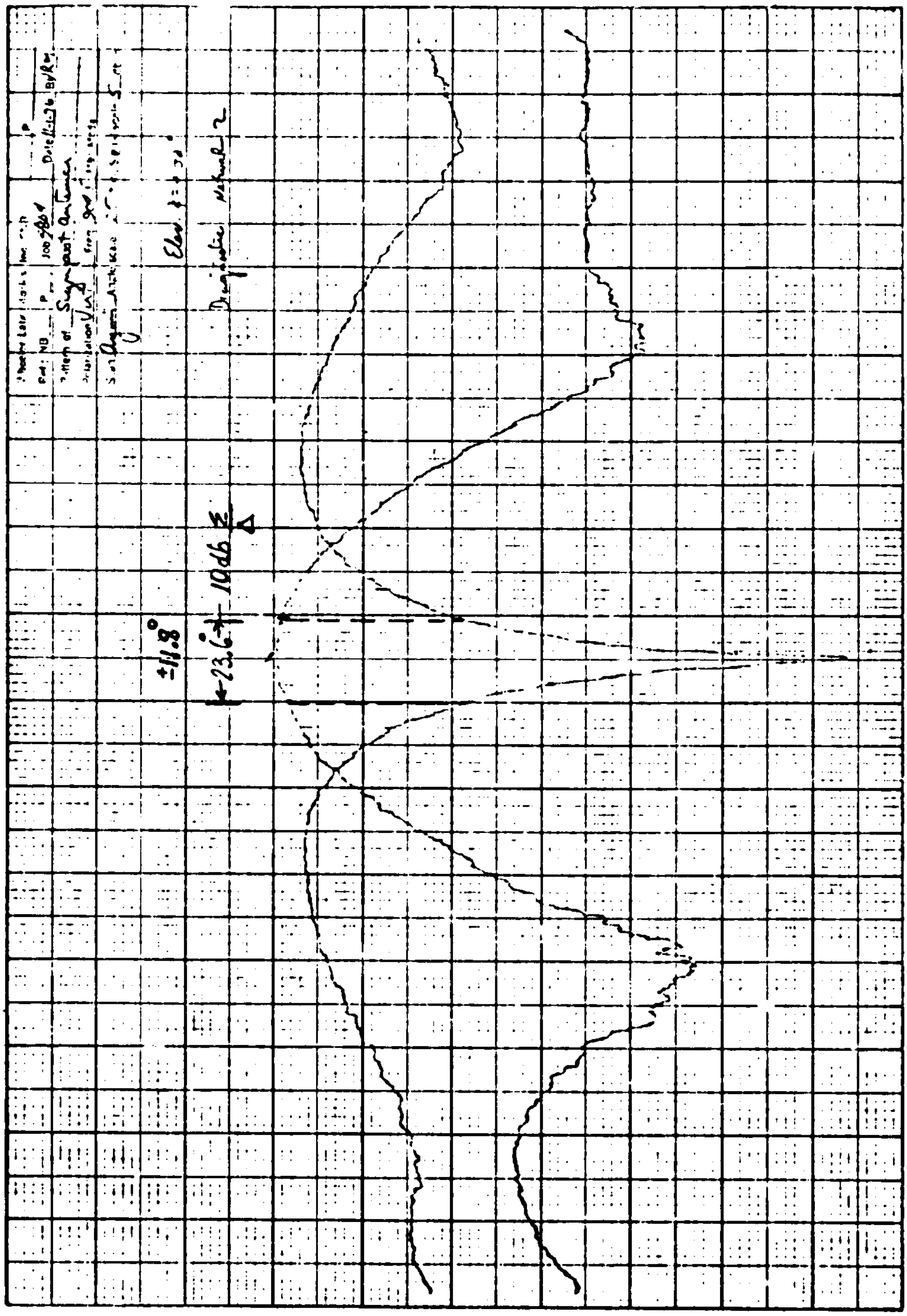


FIGURE 4-30. SIGNPOST ANTENNA PATTERNS (+30° ELEVATION)

4.4.7 Power Line Interference Test. The effect of power line interference on the AVM accuracy and coverage performance was demonstrated in the region near the Philadelphia 30th Street Railroad Station. The electrified high voltage supply lines for the electric locomotive trains run parallel to JFK starting near 22nd Street and cross 30th Street Station to event 88 at 30th and Arch. These event data were extracted from the fixed route test data and processed separately to derive the AVM accuracy and hit-miss statistic in a noisy environment.

The results have shown the AVM systems immune to the noise in this region of Philadelphia. The 898 data samples taken on the small triangle (LAC) and processed at the subsystem 0.1 second level resulted in good performance. As shown in table 4-21, the radial error percentile figures were 140 feet (50%), 180 feet )68%) and 400 feet (95%). The 300 foot points on the radial histogram of Volume 3, figure 45 was at the 88.7 percentile. Only the filtering process without "on" route correction was applied in the data processing.

## TABLE 4-21. SPECIAL POWER LINE INTERFERENCE TEST AVM PERFORMANCE

1. SMALL TRIANGLE (LAC) - SUBSYSTEM LEVEL

Test Plan Data - Near 30th Railroad Station - ID #243, Test 34, events 85 to 88

Synchronization Transmitter Power: = 562 W peak
Vehicle Transmitter Power: = 891 W peak

All 0.1 Second Samples in Route Segment (896 samples)

Location "X" error 50% = ±100, 68% = ±150, 95% = ±360, 99.5% = ±940
"Y" error 50% = ±80, 68% = ±115, 95% - ±230, 99.5% = ±460
"R" error 50% = 140, 68% = 180, 95% = 400, 99.5% = 1050, 88.7% = 300

Hit-Miss Statistics = 99.9%

4.4.8 Noise Measurement . Internal equipment noise measurements and external man-made measurements were performed to determine the characteristics of the suburban and urban noise environment that the Hazeltine AVM system must encounter. The measurements showed that the external noise at 900 MHz has an "impulsive" characteristic. The effectiveness of the vehicle receiver equipment noise blanker against automobile ignition and other types of spark noise was demonstrated.

In general, the average level of external noise in the UHF band is below the AVM receiver threshold. However, the dominant noise in this band is impulsive - the type of noise generated by vehicle ignitions, contact closures, arc-welding equipment, power-line corona, etc. These high-amplitude noise spikes extend above the threshold level at fairly high rates. The relationship between the noise spikes and the average noise level is defined as "impulsiveness," the decibel ratio of rms noise to average noise. Various studies[1] have shown impulsiveness in the UHF band to be 6 to 16 dB, ie, the rms noise level is 6 to 16 dB above the average noise level.

Measurements have shown that the noise spikes vary in width, but within a range significantly less than the 2 to 10 μs width of the AVM pulses. This unique characteristic of impulse noise allows pulse-width-discrimination and blanking circuits to eliminate noise pulses, and thereby preventing false decodes in the AVM receiver processing circuits.

A noise-blanker circuit was designed and incorporated into the AVM transponder receiver (figure 4-31). The circuit uses the amplitude and pulse-width differences between impulsive noise and AVM signals to eliminate the impulsive noise, while still passing the signal. The following sections describe the noise blanker theory of operation, laboratory test results using simulated impulse noise, and field tests performed at both Greenlawn, Long Island, N. Y. and Philadelphia, Pa.

4.4.8.1 Operation of Impulsive-Noise Blanker. The noise blanker prevents narrow, high-amplitude impulses from being applied to the 200-kHz second IF filter. This is accomplished by turning off the second mixer for periods up to 1 microsecond whenever an impulse exceeds the blanking threshold. Because most external noise is impulsive and of high amplitude, the blanking threshold is set at a level that allows low-amplitude signals to pass through the receiver without activating the blanker. Signals or noise pulses that continuously exceed the blanking threshold for more than 1 microsecond disable the blanker. Recovery time is a function of the incoming signal or noise pulse width, but is not greater than 4 microseconds.

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[1] Thomas C. Kelly, Impulsive Noise and Mobile Radio Data Transmission, Report GTE Sylvania Inc., Needham, Mass. 02194

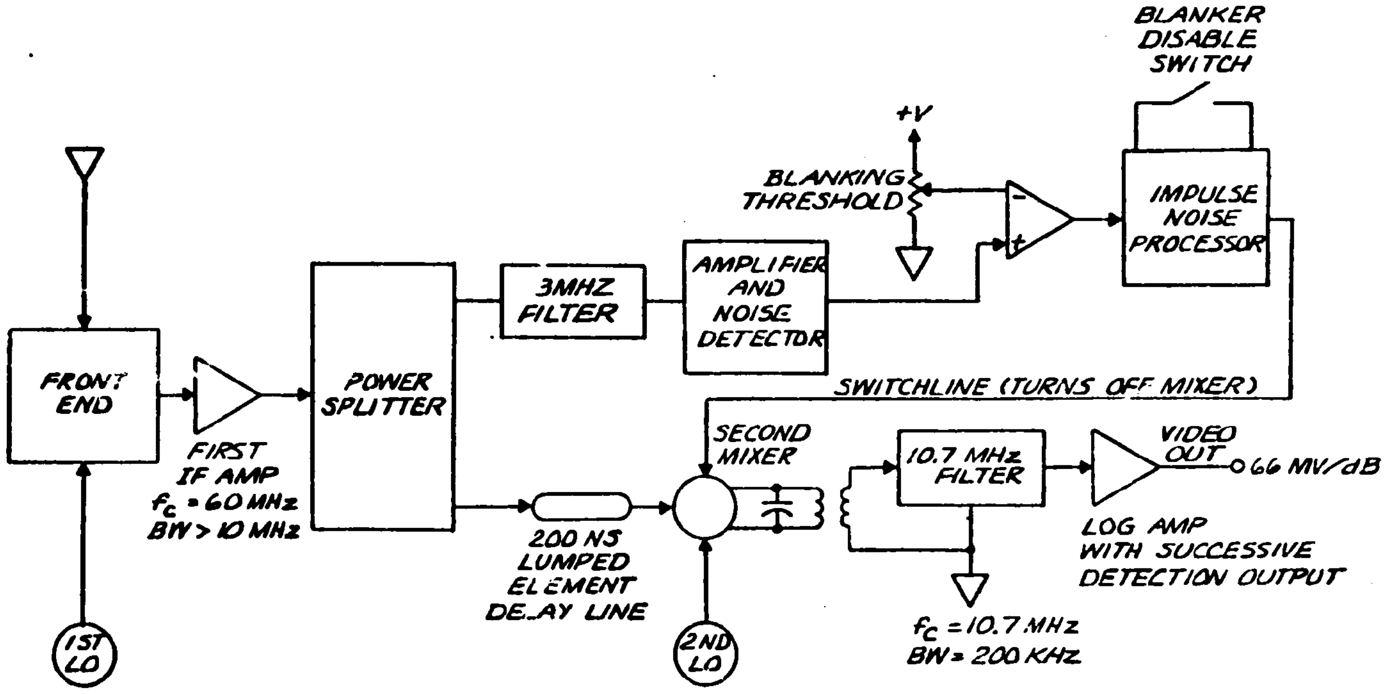


FIGURE 4-31. TRANSPONDER RECEIVER, BLOCK DIAGRAM

4.4.8.2 Laboratory Testing of Noise Blanker Circuit. Initial testing was performed in the laboratory using a simulated noise source and a blanking threshold of about -75 dBm. Figure 4-32(A) shows 10-microsecond pulses interspersed between simulated noise. The noise was created by applying a 10-volt, 10-nanosecond pulse at the antenna input. Figure 4-32(B) shows the results for the same input conditions as 4-32(A), with the blanker circuit enabled. Figure 4-32(C) shows a time-expanded sweep and points out the position of a blanked noise spike residing next to a true pulse. Note that the blanker circuit effectively eliminates the noise spikes, while allowing the 10 µs pulses to pass.

4.4.8.3 Field Tests at Hazeltine's Greenlawn, N.Y. Facility. Figures 4-33 and 4-34 show the effect of the blanker circuit on two different types of noise. The ignition noise in figure 4-33 is from the test vehicle, and the electrical disturbances in figure 4-34 were observed when the test vehicle was adjacent to high-tension lines and transformers belonging to the Long Island Lighting Company. Both blanked and unblanked cases are shown. Note in both cases (figures 4-33 and 4-34) how impulse noise is suppressed when the blanking circuit is enabled.

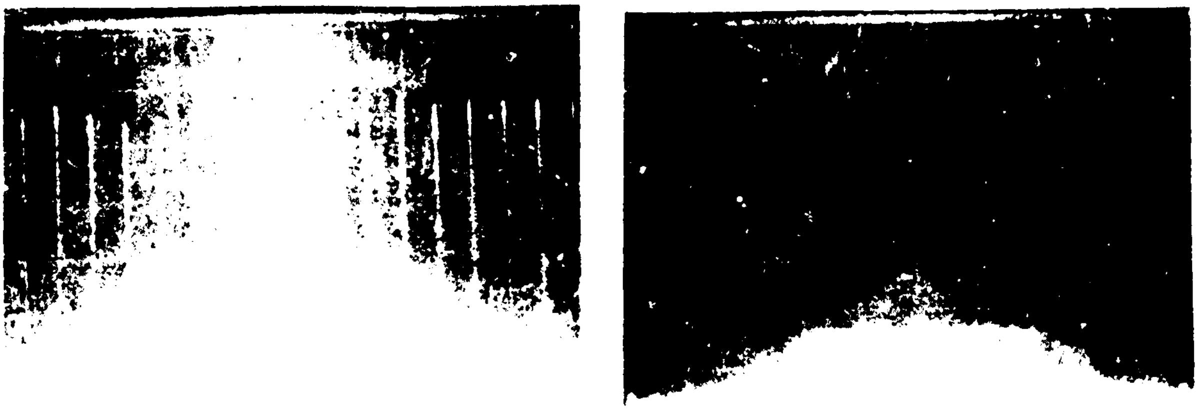
4.4.8.4 Long Island Threshold-Crossing Test. To demonstrate the effectiveness of impulse-noise blanking, data was collected in a moderate-to-severe noise environment. The experiment was performed with the vehicle parked in the Eastbound rest area, 1 mile east of Deer Park Road on the Long Island Expressway. Threshold crossing data at -93 dBm was continuously collected during the afternoon rush hour, using the test set-up shown in figure 4-35. A total of 620 10-second samples were recorded, half of which involved the use of the noise-blanker circuit.

Figure 4-36 presents a histogram of the frequency of occurence for a fixed threshold crossing with the blanker disabled. Figure 4-37 is a histogram to the same X-axis scale as figure 4-36 for a fixed threshold crossing with the blanking enabled. Figure 4-38 shows the same information as figure 4-37 with the X-axis magnified by 10.

The significant reduction in threshold crossings is apparent. The average number of crossing for a given sample period is reduced by 76%, from 1962 to 478. Even more significantly, the median of crossing was reduced by 90% from 1400 to 120.

This data indicates most ignition interference is impulsive, with a width less than 1 microsecond, and that major improvement in performance in the presence of impulsive noise is obtained by incorporation of the described noise blanker.

4.3.8.5 Philadelphia Threshold-Crossing Test. Threshold crossing data was also collected at the 30th Street Railroad Station in Philadelphia. This area contains numerous overhead high-voltage lines that supply power to the electrified railroad cars, and heavy



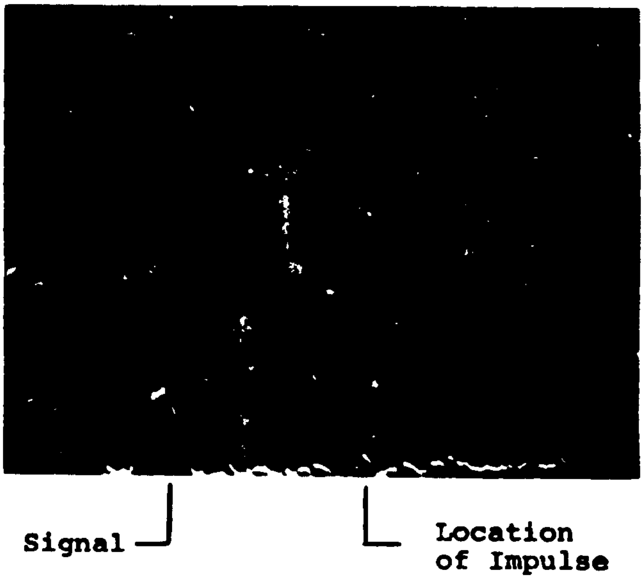
(A) Blanker Disabled

(B) Blanker Enabled

H: 10 ms/cm

H: 10 ms/cm

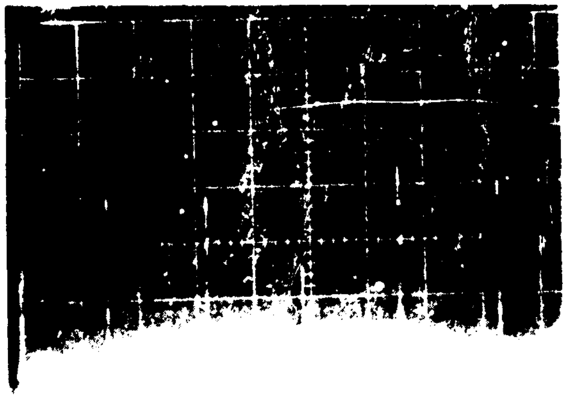
(C) Blanker Enabled



H: 10 µs/cm

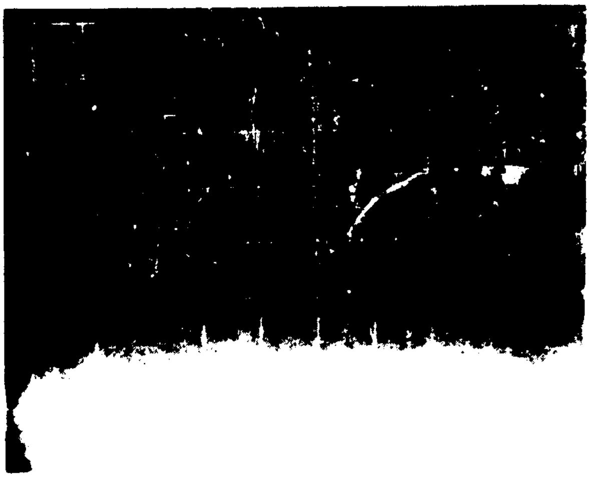
For all oscillographs: AVM Transponder Receiver Log Video Output (66 mV/dB) Signal at -93 dBm. Single Sweep; Vertical Sensitivity: 0.2 V/cm

FIGURE 4-32. EFFECT OF BLANKING CIRCUIT ON SIMULATED IMPULSE NOISE



Blanker Disabled

**Scope:** H 5 ms/cm; V 0.5 V/cm
Single Sweep
**Level:** -93 dBm

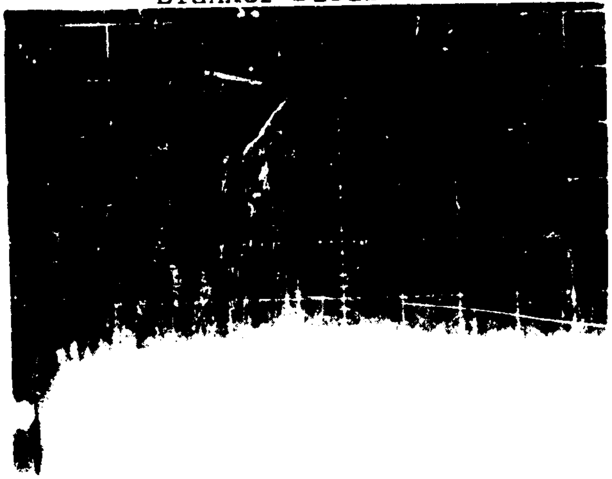


Blanker Enabled

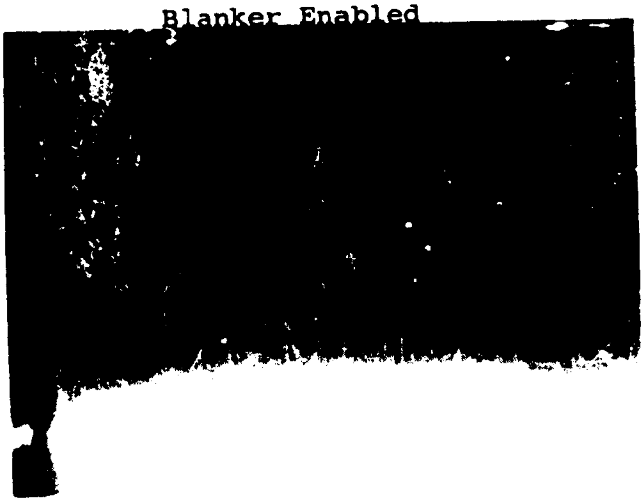
**Scope:** H 5 ms/cm; V 0.5 V/cm
Single Sweep
**Level:** -93 dBm

FIGURE 4-33. IGNITION NOISE FROM TEST VEHICLE, AVM TRANSPONDER FIELD TEST (LOG VIDEO OUTPUT 66 mV/dB)

Blanker Disabled



Blanker Enabled



Taken in vicinity of LILCO high voltage poles and transformers behind Hazeltine, Building #1. AVM Transponder Field Test (Log Video 66 mV/dB)

Scope: H 5 ms/cm
V 0.2 V/cm
Single Sweep
Level: -93 dBm

FIGURE 4-34. POWER LINE RADIATED NOISE

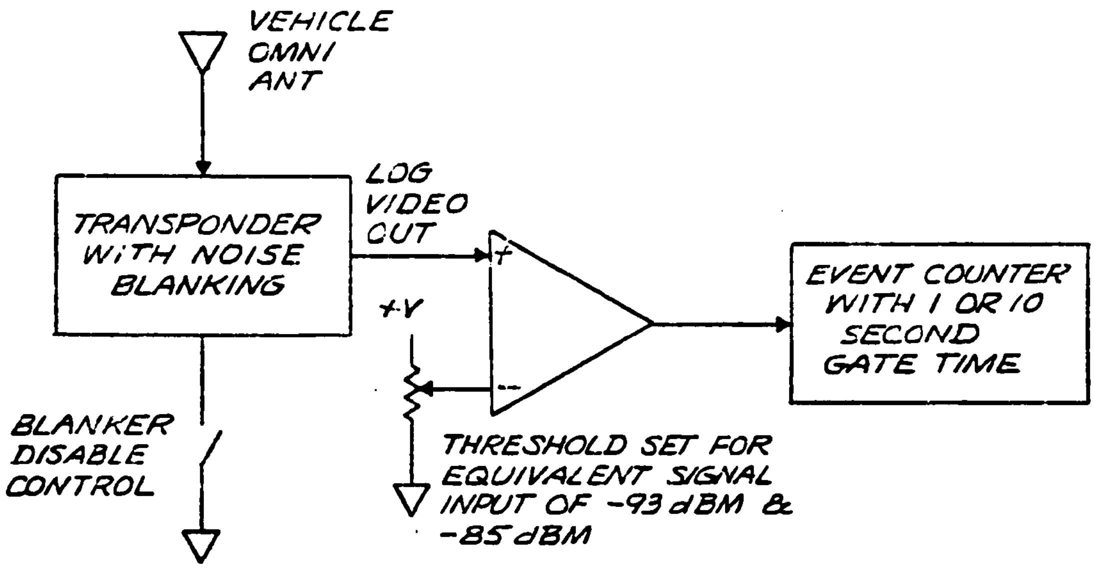


FIGURE 4-35. NOISE THRESHOLD CROSSING TEST SETUP

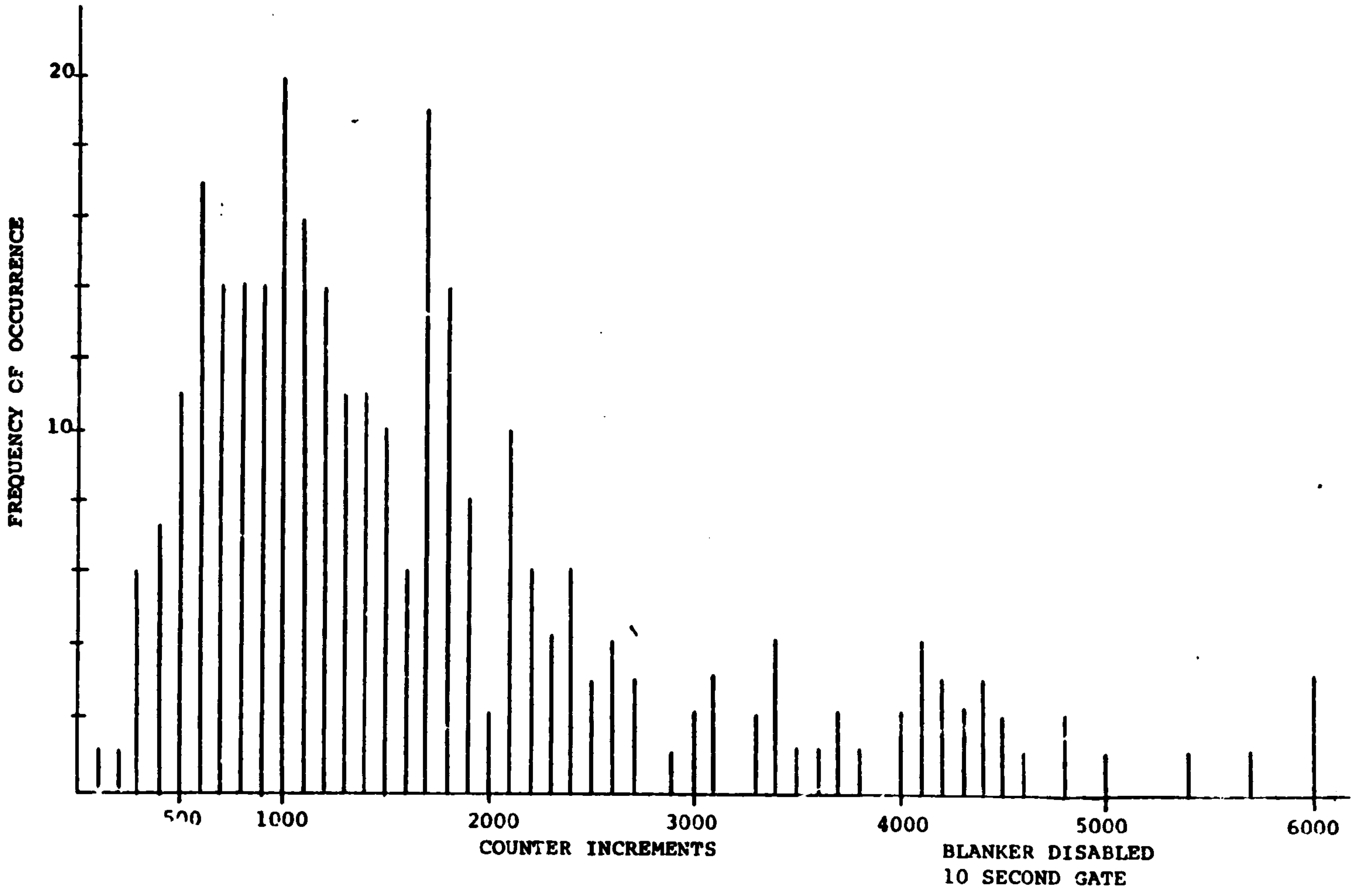


FIGURE 4-36. NOISE THRESHOLD CROSSING AT -93 dBm, LONG ISLAND LOCATION, BLANKER DISABLED

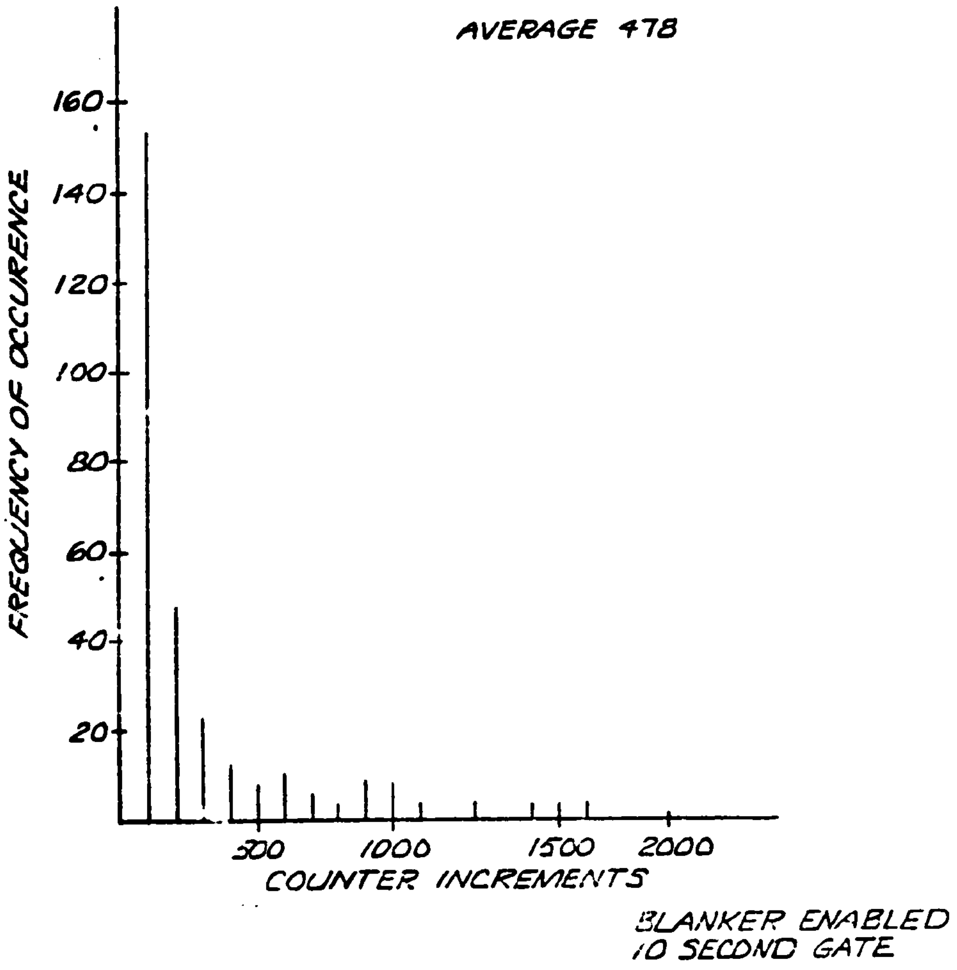


FIGURE 4-37. NOISE THRESHOLD CROSSING AT -93 dBm
LONG ISLAND LOCATION, BLANKER ENABLED

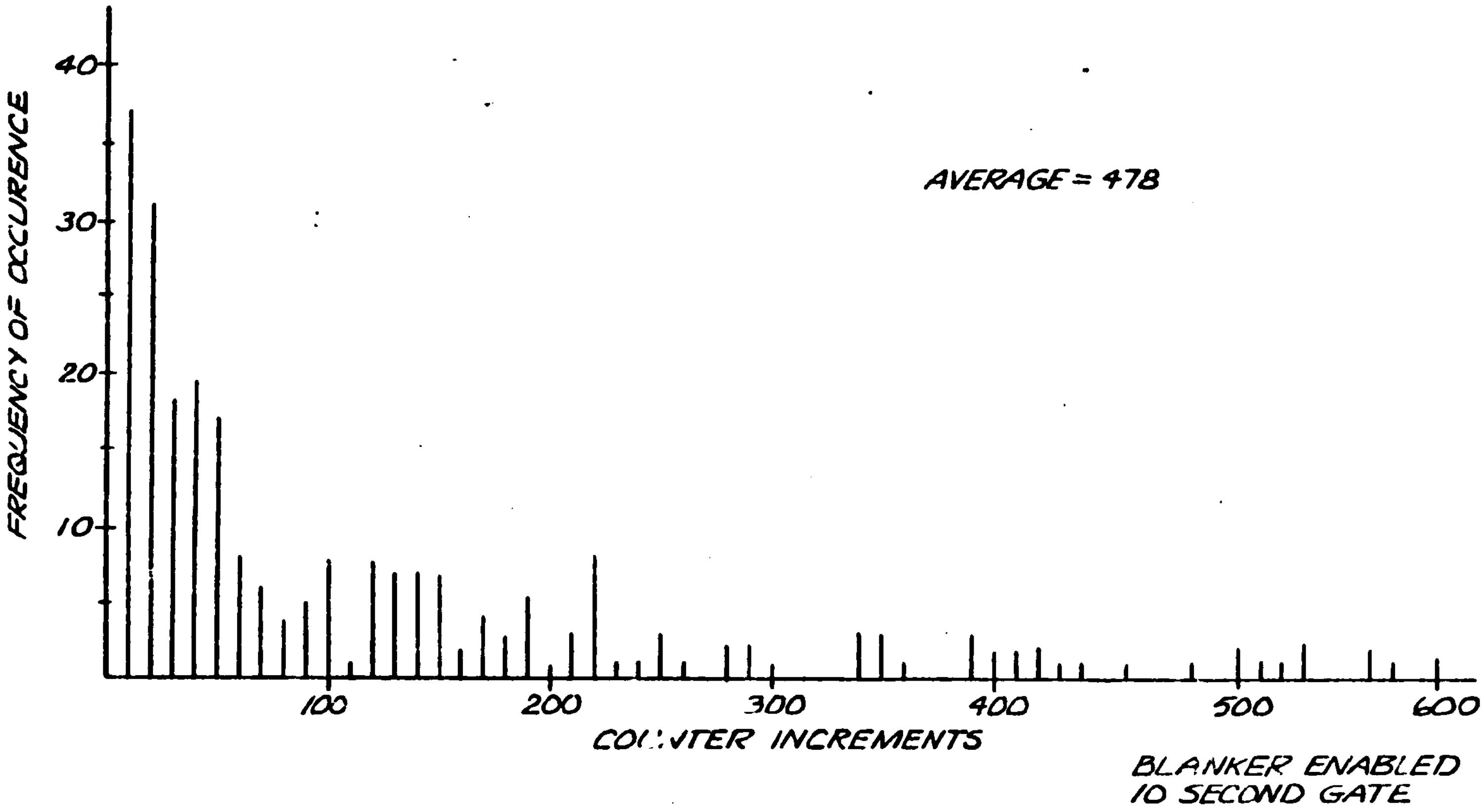


FIGURE 4-38. NOISE THRESHOLD CROSSING AT -93 dBm (EXPANDED), LONG ISLAND LOCATION, BLANKER ENABLED

automobile traffic on Market Street and JFK Boulevard. The AVM test van was parked in the parking lot on the side of the railroad building facing JFK Boulevard.

The threshold crossing setup was similar to the Long Island tests, except that the counter-gate interval was set to one second instead of 10 and the counts were automatically printed on paper tape. Figure 4-39 shows the frequency of occurrence of noise crossing at a -93 dBm threshold with the blanker disabled. It is believed that many of the noise pulses and event crossings were due to the ignition system of the gasoline engine driving the AVM van's 120-volt AC generator. Figure 4-40 shows the great reduction in crossings when the blanker was enabled. The 0 to 1 interval of the X-axis includes all the 1-second intervals that had zero crossings during the overall test period. Figures 4-41 and 4-42 show the performance of the transponder with the threshold set at the signpost-detection receiver threshold of -83 dBm.

The Philadelphia test data confirmed the significant improvement in performance provided by the blanker circuit. The level of impulse-noise suppression was consistent with that obtained during the Long Island tests.

4.4.8.6 Field Strength Measurements with Standard Noise Meter. Measurements of the noise environment were made utilizing the Empire Devices Noise and Field Intensity Meter, Model NF105, with the T-3/NF105 RF head and the spiral antenna. The instrument was placed on the roof of the Holiday Inn, and the roof of the Camden Northgate building near the fixed-site receiving antennas. Measurements were made every fifteen minutes from morning to night, including rush-hour periods. Readings were taken at 950 MHz when the sync transmitter was functioning, and at 908 MHz when the AVM system was shut down. All peak-noise readings were at or below the broadband sensitivity of the instrument. With the spiral antenna and the 30-foot interconnecting cable, the minimum detectable field strength at 950 MHz and 908 MHz is 60 dB μV/Mtr/MHz.

A measurement was performed at street level at the 30th Street Railroad Station using the AVM van 120-volt AC gasoline-driven power source. No usable readings were obtained, because excessive noise was leaking into the measurement instrument via its AC input connections. (Peak noise readings were noted even with the antenna disconnected. See Figure 4-43.)

While the broadband noise measurements were somewhat limited, due to measuring instrument limitations, the AVM equipment measurements clearly show that the ambient noise is impulseive and above the receiver threshold. This noise does not compromise the system performance due to the discrimination provided by the decoding circuits.

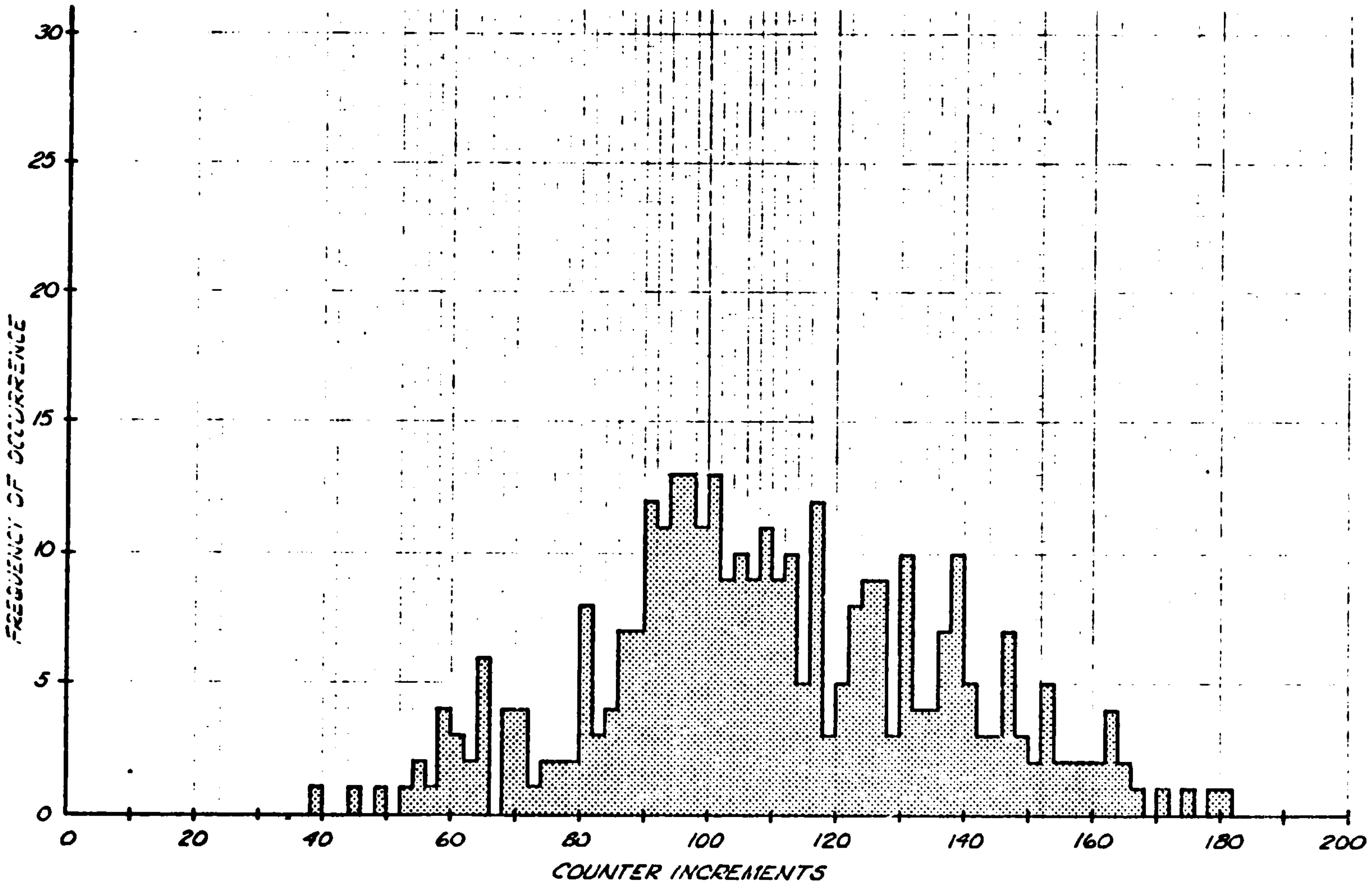


FIGURE 4-39. NOISE THRESHOLD CROSSING AT -93 dBm, PHILADELPHIA 30th ST. LOCATION, BLANKER DISABLED

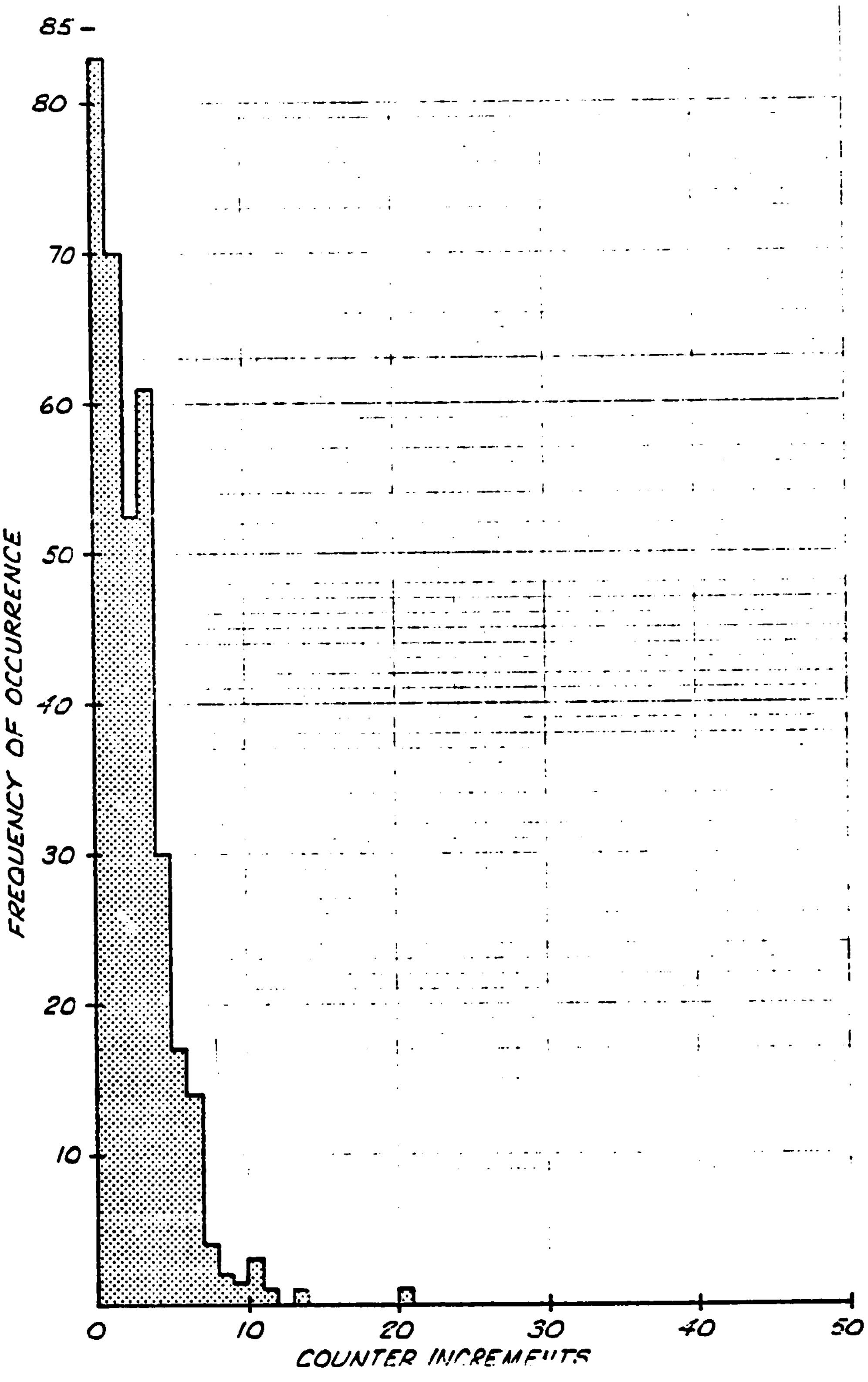


FIGURE 4-40. NOISE THRESHOLD CROSSING AT -93 dBm, PHILADELPHIA 30th ST. LOCATION, BLANKER ENABLED

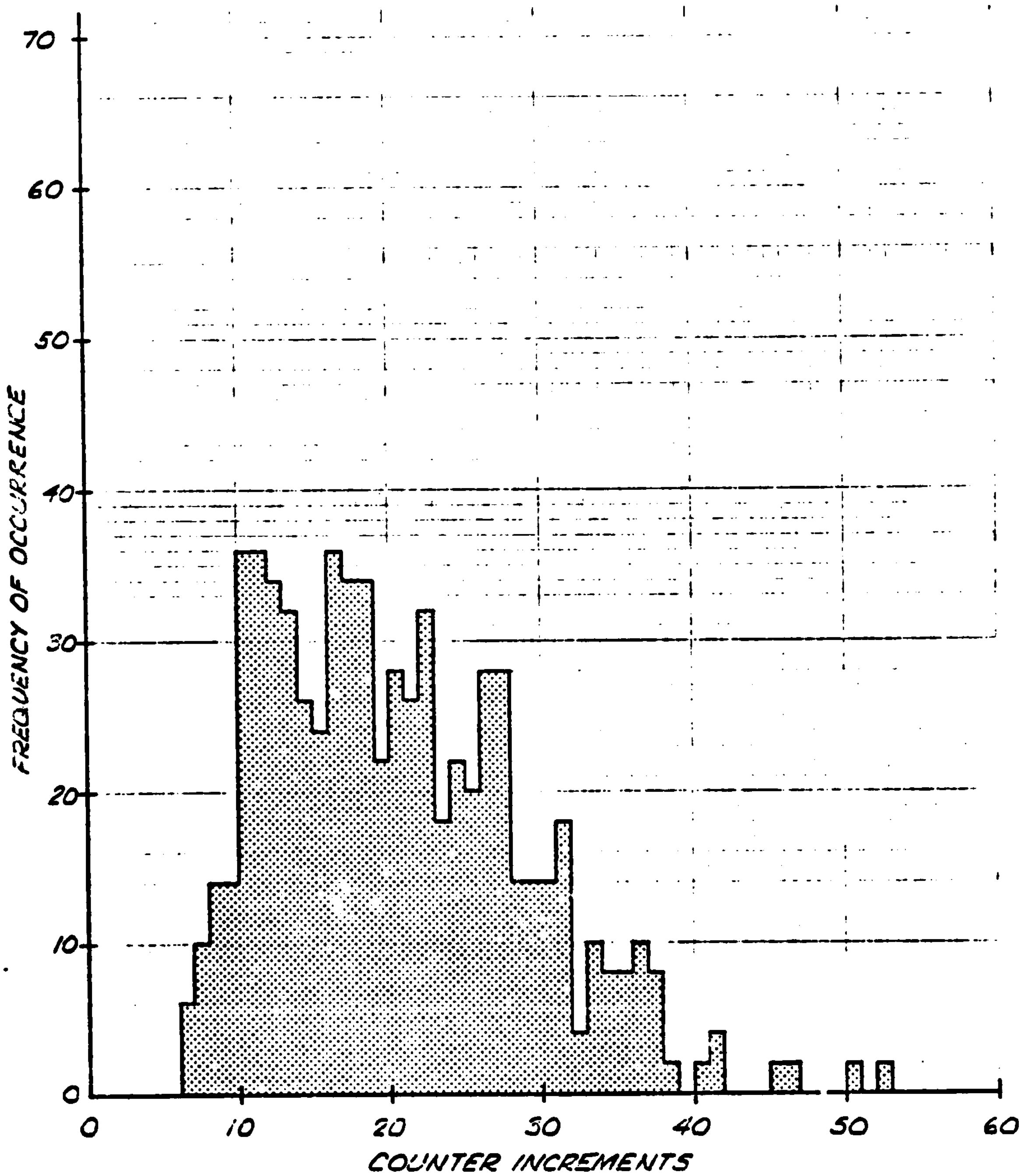


FIGURE 4-41. NOISE THRESHOLD CROSSING AT -83 dBm, PHILADELPHIA 30th ST. LOCATION, BLANKER DISABLED

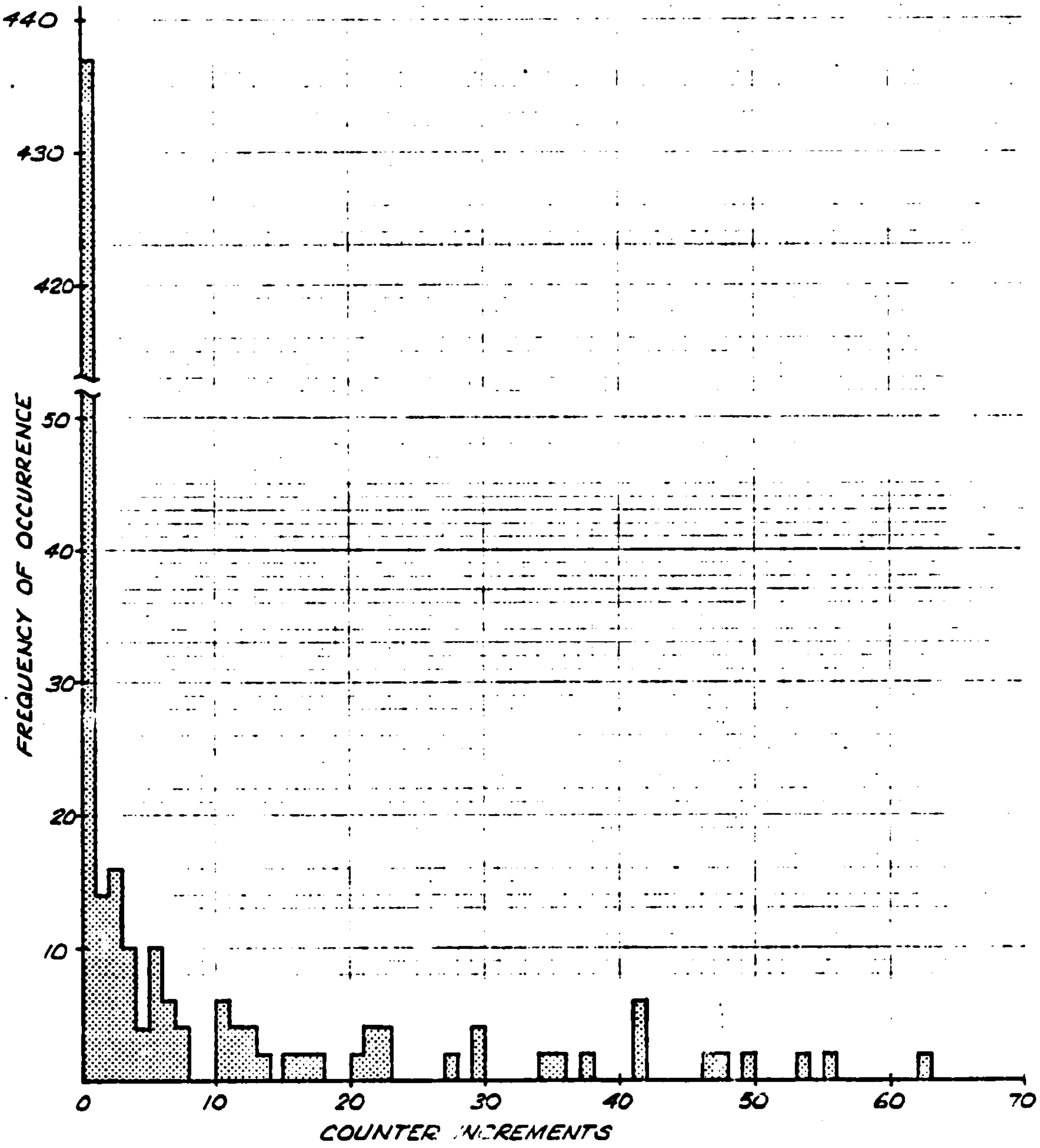
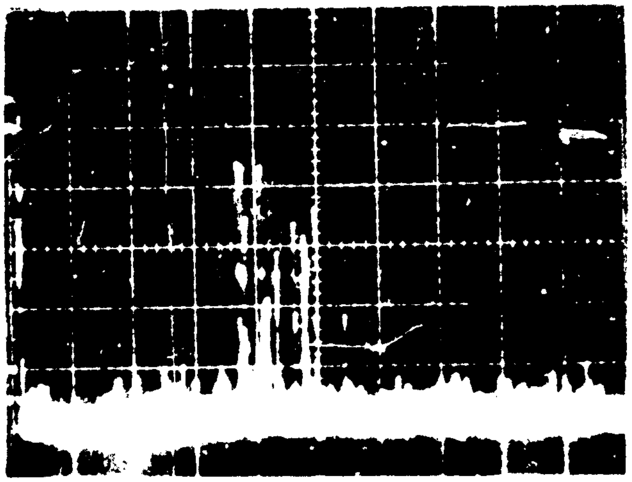
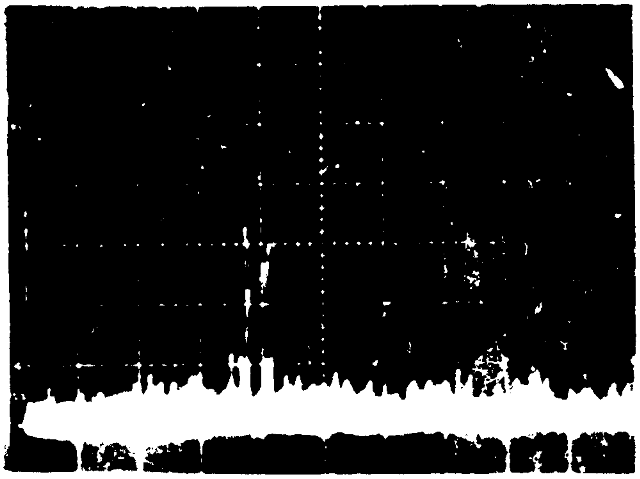


FIGURE 4-42. NOISE THRESHOLD CROSSING AT -83 dBm, PHILADELPHIA 30th ST, LOCATION, BLANKER ENABLED



TRANSPONDER BLANKER DISABLED
V = 0.5V, H = 0.5 ms, LOGGING 70 mV/dB



TRANSPONDER BLANKER ENABLED
V = 0.5 V, H = 0.5 ms, LOGGING 70 mV/dB

FIGURE 4-43. EXCESSIVE AC MOTOR GENERATOR NOISE
2/23/77 (RAINY DAY)

# 5.DESIGN CHANGES FOR THE LOS ANGELES SYSTEM

The results of the Philadelphia tests have demonstrated the ability of the Hazeltine Automatic Vehicle Monitoring (AVM) system to meet the DOT requirements for a multi-user AVM system. In addition, information obtained during the tests will lead to improvements over the originally proposed Los Angeles System.

The test program demonstrated the system's capability to:

Meet DOT/TSC requirements for time-of-passage accuracy,

Meet DOT/TSC requirements for location accuracy in suburban areas using widely spaced receiver sites,

Provide reliable two-way base/mobile communications,

Meet all operational requirements in the presence of urban electromagnetic noise.

Analysis of test data provided new insights, showing the importance of proper receiver siting for meeting location requirements in geographically limited high-rise urban areas; it also led to analysis of multipath decay of the AVM vehicle to fixed site pulse waveforms, resulting in revision of the original pulse spacing.

This section discusses system performance vs requirements as demonstrated by the Philadelphia tests, and describes proposed changes to the Los Angeles system based on information gathered through these tests.

## 5.1 SUMMARY OF TEST RESULTS VS REQUIREMENTS

The following paragraphs provide a summary of system requirements, and a discussion of Hazeltine AVM performance against these requirements, as demonstrated by Philadelphia test data and extrapolated to the proposed Los Angeles system. The discussion includes reference to specific design changes proposed in Section 5.2 to improve overall system performance in Los Angeles.

### 5.1.1 General

5.1.1.1 Area-Wide Coverage. The capability of the Hazeltine AVM system to provide the required area-wide coverage can be extrapolated from the results of the Philadelphia tests. Vehicle location and two-way communication capability was demonstrated within an area covered by a transmitter and three receiver sites

(4 receiver sites during the special supplementary tests). By adding receiver sites, to form new triangles, coverage can be increased to blanket almost any area, limited only to the transmitter power required to reach vehicles at the maximum range. (Additional transmitters could also be used to extend coverage.) Coverage for the proposed Los Angeles system is discussed in Section 5.2.1.1.

5.1.1.2 Multi-User Capability. In the Hazeltine AVM system, each user is assigned a unique 2 millisecond time slot in the AVM frame. In the proposed Los Angeles system (as in the Philadelphia test configuration), there are 5000 time slots to accommodate up to 5000 vehicles with an update rate of 10 seconds. (To permit fine-grain analysis, the Philadelphia test vehicle was assigned 20 time slots, but only data in one time slot was used for system-level performance evaluation.) Each vehicle (user) is independent, receiving and transmitting only during the time slot preset into its transponder. Furthermore, many different types of vehicles can be mixed: buses, police cars, fire engines, ambulances, taxis - each transmitting and receiving its own type of data. The central computer sorts and distributes the data for the various users.

Finally, independent users can be assigned different update rates, either higher or lower than the 10-second rate demonstrated in Philadelphia, to serve the maximum number of users in the most efficient manner. This would be accomplished by the submultiplexing or supermultiplexing of assigned time slots within the AVM frame, as described in section 5.1.2.

5.1.1.3 Cost-Sharing Capability. The independent multi-user capability of the Hazeltine AVM system permits cost sharing of the common equipment (transmitter, receiver sites, central control station) by many users, because the allocation of time slots is independent of the type of user. The only constraint is the required update rate of the user, although the system can accommodate various update rates, as described in Section 5.1.2. In fact, costs could even be allocated to the various users on a basis related to their individual update rate; the lower the update rate, the lower the share of the common equipment costs.

5.1.1.4 Efficient Use of Spectrum. The Hazeltine AVM system operates in the 902-928 MHz ISM band. It does not overlap the frequency channels which are used for vehicle voice communications. Furthermore, the system makes maximum use of the allocated channel by providing a capability for time-sharing it among thousands of independent users.

5.1.2 Capacity and Coverage. The Hazeltine AVM system proposed for Los Angeles provides approximately 5000 independent time slots, each of which could be assigned to a different vehicle, to provide locati. and data communications functions at a 10-second update rate for each vehicle. The system also offers the capability for

for submultiplexing and supermultiplexing. In submultiplexing, the same time slot is assigned to different vehicles on successive frames to accommodate a larger number of vehicles at a lower update rate; in supermultiplexing, multiple time slots in a single frame are assigned to a single vehicle to obtain a higher update rate.

The operation of this multiplexing concept was demonstrated in the Philadelphia tests, and provides that the system can clearly accomodate the required 25 transit-support vehicles and 200 buses, with the great majority of the system's time slots still available for additional SCRTD and other users. Users can be added to the system in a modular fashion with little impact on the system hardware as growth is implemented.

Since, for the most part, the initial system hardware configuration will provide the timing (including the computational capability of the central-site computer) and hardware capability for 5000 vehicles, the only areas impacted by growth in vehicle count are:

a) Central computer memory capacity - as vehicles are added, and the cummulative data storage requirement for the vehicles in the system passes certain fixed increments, additional memory will be added to the computer via plug-in memory boards.

b) Communications facilities - as vehicle count passes certain increments, additional telephone lines and associated modems must be added between the receiver sites and the central site to accommodate the resulting higher rate of location and communication data. The system will be configured to accept these hardware elements on a plug-in basis, as needed. This is already being done in the Hazeltine Dallas AVM system.

All system users can be serviced over the entire coverage area of the system, ie, the transit support vehicles could be serviced anywhere within the 150 square miles covered by the proposed Los Angeles receiver sites (Section 5.2.1.1). Figure 5-1 shows the 200 route-miles of bus service covered by the proposed Los Angeles system. This area includes 140 time points, 30 of which require the use of signposts to meet the time of passage requirements in the center city area.

As well as being modularly expandable with respect to the number of vehicles, the system is also modularly expandable with respect to coverage area. In general, coverage can be extended by installing an additional fixed-receiver site, in a position relative to two existing sites to form a new triangle covering the area of interest. In this case, the extension of coverage is relatively inexpensive since two of the three receiver sites are already installed, and the central station computer and transmitter are already in place.

5.1.3 Location Accuracy. The Philadelphia tests (including special supplementary tests) demonstrated an accuracy in the suburban areas of 270 feet (95%), and an accuracy in the center city area of 300 feet (84%). It has been determined that the major cause of errors in the center city highrise area was blockage causing a path loss significantly greater than predicted by published data[1]. The addition of a fourth receiver site during the special supplementary tests, though not in an optimum position, resulted in a significant improvement of 2 to 1 in accuracy in the applicable area. Based on the improvements noted with the fourth receiver site, Hazeltine has formulated a preliminary revised site plan for Los Angeles which will provide the required system accuracy. Furthermore, to insure the adequacy of these sites, comprehensive site surveys and ranging tests will be conducted during Phase II, and sites will be shifted as necessary. (Section 5.2.1).

5.1.4 Time-of-Passage Accuracy. The Philadelphia tests demonstrated a time-of-passage accuracy of ±15 seconds (93%) for the center-city area, where the signposts were used. For the suburban runs, where the signposts were not used, the system does quite well, with a demonstrated time of passage accuracy of ±15 seconds (92%).

In view of the successful results with the signpost technique, we believe the time-of-passage requirement will be met in Los Angcles with the installations of 30 signposts as originally proposed. However, steps will be taken to improve signpost performance to an even greater degree by increasing transponder immunity to false signpost detection (Section 5.2.2.2).

In addition, an improved processing algorithm will be developed for the suburban time point calculation (Section 5.2.2.1). This improved algorithm, in conjunction with the steps being taken to improve overall location accuracy (Section 5.3.1) will bring the time post accuracy for suburban runs within the ±15 second (95%) requirement.

5.1.5 Update Rates. The proposed AVM system, as demonstrated in the Philadelphia tests, provides location and data-communications functions for up to 5000 vehicles, with an update rate of 10 seconds for each vehicle. This capability is inherent in the AVM time-multiplex technique in which 5000 independent time slots make up a 10-second frame (for Philadelphia and Los Angeles). This ten-second update capability, for all vehicles, far exceeds the stated 10 second to 55 second update requirement for the various classes of vehicles in the Los Angeles system.

5.1.6 Communications. The capability of the Hazeltine AVM system for data communications was demonstrated during the Philadelphia tests. Time messages were sent to the test vehicle, and status data (e.g., signpost, stop/start, door open/close) was sent from the vehicle to the central control station. The update interval

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[1] Jakes, J. R., Jr., Microwave Mobile Communications. New York: John Wiley & Sons, Inc., 1974.

in both directions was 10 seconds, the same as the location-update rate, since the location time slots are used for data transmission.

The message error rate was approximately 1% and 3/4% for base-to-vehicle and vehicle-to-base communications respectively; ie, at least 99 out of each 100 messages were received successfully. The vehicle-to-base error rate includes the effects of the telephone link between the fixed-site receivers and the central control station. These results clearly demonstrate the communication capability of the system.

Although 16-bit messages were used in Philadelphia, the AVM time slots can accommodate an additional 4 bits to meet the 20 bit message requirement. The Los Angeles system will provide for 20 bit status messages (Section 5.2.3.3).

In the AVM system, data communication is accomplished through time multiplexing on the same frequency channel used by the location system; frequency channels currently authorized for SCRTD are not required. The coverage for data communication is the same wide area as for the AVM location system, because the same channel and same type of signals are used. In those areas where location can be determined, bi-directional communications can be achieved.

## 5.2 PROPOSED CHANGES TO THE LOS ANGELES SYSTEM

5.2.1 Improvements to Location Accuracy. Reduction and analysis of the Philadelphia test data have led to the following design changes to the originally proposed Los Angeles system:

a) Revised receiver-site locations; to provide smaller triangles in the highrise, center-city area and to equalize multipath delays.

b) The addition of an on-route correction algorithm to the location computation, to improve location accuracy by taking advantage of the knowledge of the fixed-bus routes.

c) The incorporation of the zero-fill fix, which was actually installed in the Philadelphia equipment and used for a substantial portion of the test.

We believe the incorporation of these changes will significantly improve location accuracy to meet and exceed system performance requirements for location and time of passage.

5.2.1.1 Los Angeles Receiver-Site Locations. The initial Philadelphia tests indicated that path losses through highrise areas of the city were higher than the published data that was used for the initial site selection. The high propagation loss and the multipath delay of transponder emissions caused delayed TOA readings, resulting in undesirable location errors. Supplemental tests, with an additional receiver site at the center of the highrise area, yielded improvements of 2 to 1 in location accuracy.

Therefore, we have re-examined the proposed Los Angeles antenna sites. We believe that judicious relocation of fixed-receiver sites, to provide triangular cell leg lengths in the order of 2 miles in the central business district, will provide more accurate TOA measurements. The resulting location accuracy will meet system requirements. Also, to ensure complete vehicle-route coverage in the canyons of the north and northeast sections of Los Angeles, receiver sites will be placed at the crests of the surrounding hills.

Figure 5-1 shows the revised Los Angeles siting configuration superimposed on a road map, showing the bus routes being covered. Figure 5-2 shows the site configuration relative to the location of highrise office and apartment buildings. A large number of the highrise apartment and office buildings (taller than 7 stories) are located in an area bounded by the Hollywood Freeway on the north, Harbor Freeway on the west, Santa Monica Freeway on the south, and Main Street on the east. Good coverage of these areas will be provided by the cluster of four sites: 1, 15, 16 and 17 of figure 5-3. Based on Philadelphia test results, these sites are more closely spaced than originally proposed, and the central site is placed at the highest possible elevation (62 stories) to minimize direct-path loss and multiple delay.

Figure 5-3 also shows the Phase II Los Angeles random route test area, indicated by the dashed boundary line. Because of the closely positioned receiver sites in this area, several combinations of sites can be selected to form the trilateration cell, thus ensuring complete coverage in the highrise test region.

It should be noted that in the Philadelphia tests excellent location accuracy was achieved in all areas outside the central business district. In Los Angeles, the central highrise district covers one square mile out of a total system coverage area of 150 square miles. Although there are other highrise sections, the highrise building densities are significantly lower than in the Los Angeles or Philadelphia central business districts. Where highrise concentrations do exist, along Wilshire Boulevard for example, the buildings are situated in a way that they cause low signal attenuations in comparison with the dense building concentrations of the center city area. In these areas the originally proposed receiver spacing is adequate.

Furthermore, a significant feature of the Hazeltine AVM system is that it does not distinguish between fixed and random route coverage capability. Random route location and communication coverage is provided to all vehicles traveling within the triangle formed by the receiver sites, as shown in figure 5-1.

Table 5-1 is a tabulation of the central-control transmitter and fixed-receiver sites, listing the location and height of the structures. There are 19 receiver sites; site No. 13 also includes the central control transmitter antenna.

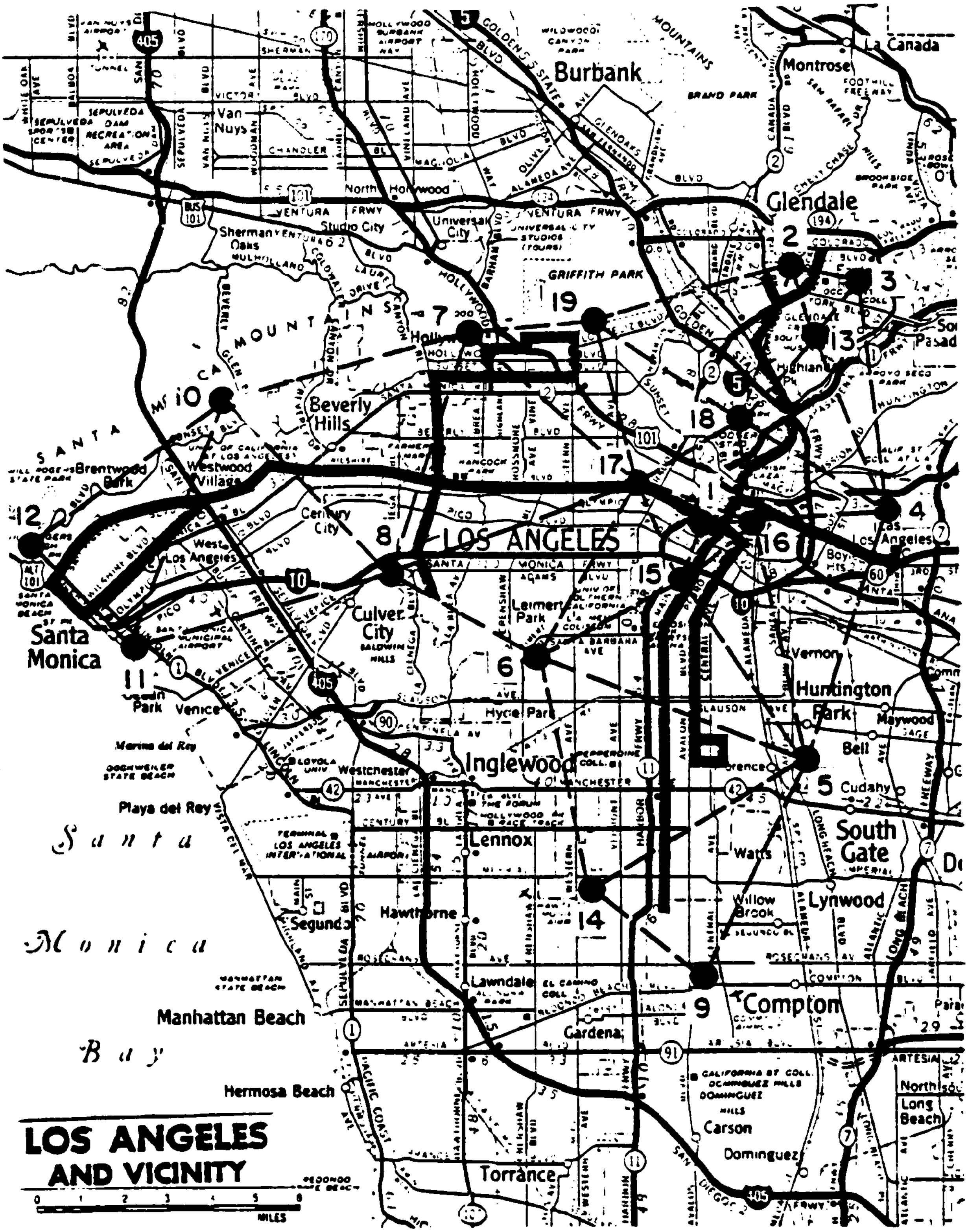
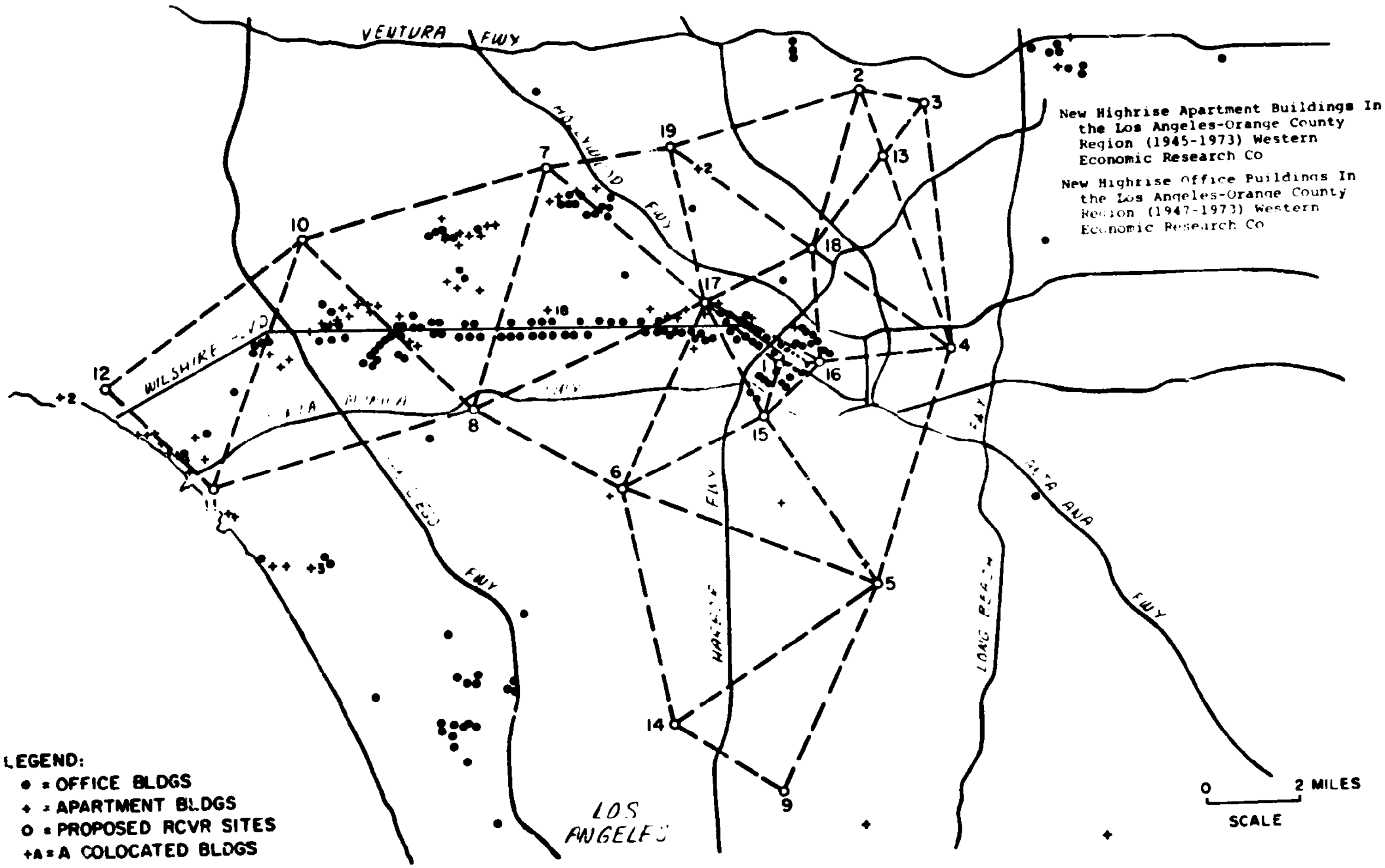


FIGURE 5-1. LOS ANGELES SITING CONFIGURATION



New Highrise Apartment Buildings In the Los Angeles-Orange County Region (1945-1973) Western Economic Research Co

New Highrise Office Buildings In the Los Angeles-Orange County Region (1947-1973) Western Economic Research Co

FIGURE 5-2. HIGHRISE OFFICE AND APARTMENT BUILDINGS IN LOS ANGELES, AREA 1

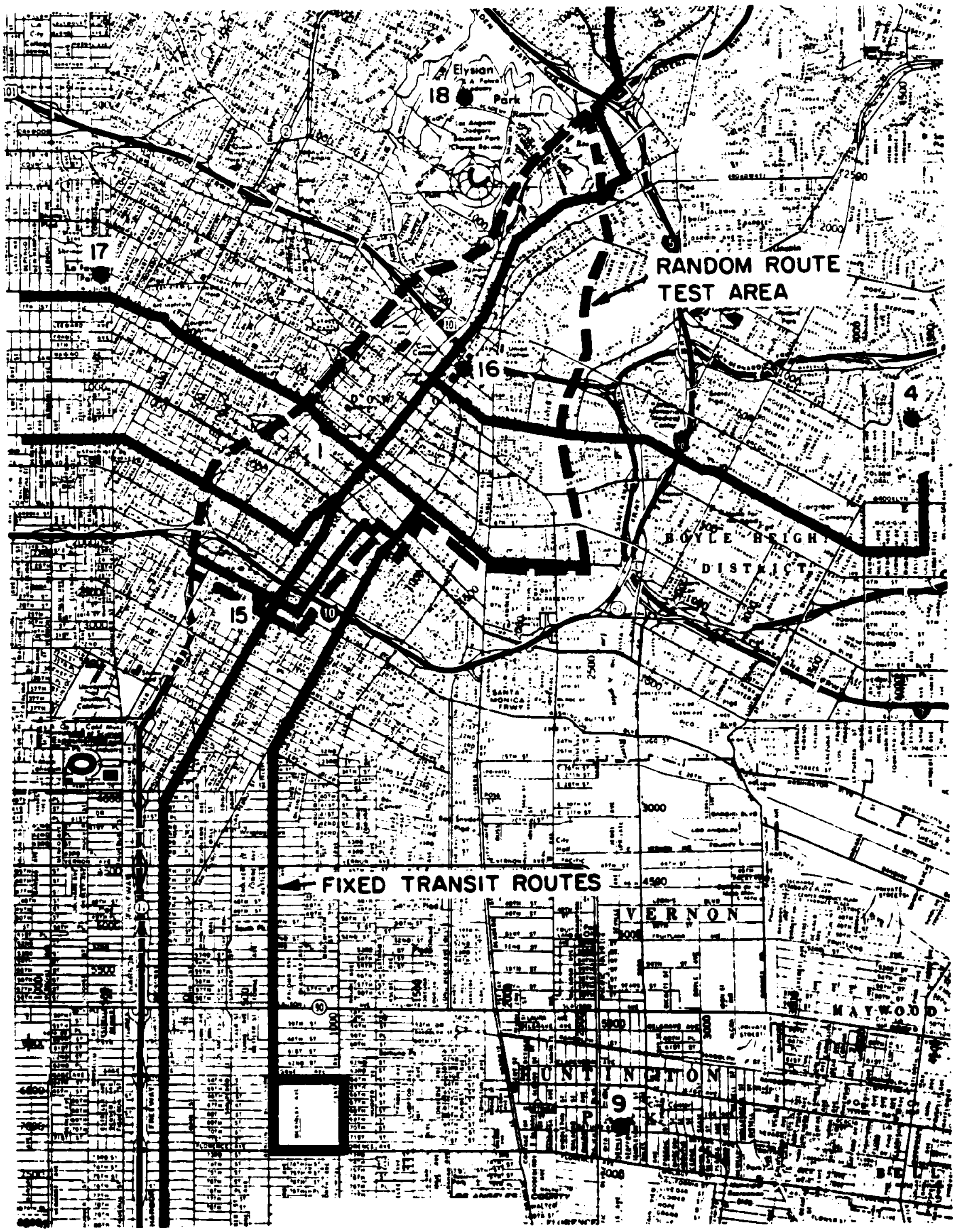


FIGURE 5-3. FIXED AND RANDOM ROUTE TEST AREAS

Table 5-1

## LOS ANGELES CENTRAL CONTROL TRANSMITTER AND FIXED RECEIVER SITE LOCATIONS

| Location No. | Building or Antenna Structure Location | Structure Height (ft) | Ground Elev. (ft) |
|---|---|---|---|
| 1 | United California Bank Hdq.<br>707 Wilshire Blvd.<br>Los Angeles, California | 750 | 250 |
| 2 | Site near Radio Tower WHOP<br>Glendale, California | 100 | 850 |
| 3 | Water tank east of Occidental College, Los Angeles, California | 100 | 800 |
| 4 | Water Tank<br>City Terrace, California | 100 | 580 |
| 5 | Concord Huntington Park<br>9600 Sevilla Avenue<br>Huntington Park, California | 180 | 150 |
| 6 | Good Shepherd Manor<br>4411 11th Avenue<br>Los Angeles, California | 150 | 130 |
| 7 | Pole on hill west of Hollywood Boulevard | 40 | 1000 |
| 8 | New Tower | 190 | 100 |
| 9 | Water Tower, east of Avalon,<br>West of Central Avenue,<br>North of Campton Blvd.,<br>South of Rosecrans Road | 100 | 120 |
| 10 | Pole on hill on Bellaire Road and Nimes Road | 40 | 720 |
| 11 | Santa Monica Shores<br>2700-800 Neilson Way<br>Santa Monica, California | 210 | 30 |
| 12 | New Tower | 190 | 30 |
| *13 | Mt. Washington Communication Site<br>Lat. 34°, 06', 19" N<br>Long. 118°, 12', 51" W | 100 | 800 |

| | | | |
|---|---|---|---|
| 14 | St. Frances Cabrini School<br>Rosecrans, California | 40 | 225 |
| 15 | L.A. Home Furniture Mart<br>Downtown<br>1933 S. Broadway<br>Los Angeles, California | 160 | 220 |
| 16 | L.A. City Hall East<br>Downtown<br>200 N. Main<br>Los Angeles, California | 240 | 280 |
| 17 | CNA Building<br>Wilshire Dist<br>600 S. Commonwealth<br>Los Angeles, California | 230 | 240 |
| 18 | Police Academy Radio Tower<br>Elysian Park<br>Los Angeles, California | 100 | 720 |
| 19 | Griffith Observatory<br>Griffith Park, California | 40 | 1100 |

* Also control transmitter antenna site

Location of the fixed receivers is a significant factor in determining system performance. But since optimum locations cannot always be determined by analysis, some on-site ranging tests will be conducted to verify the above preliminary site placement. Changes in siting will be made, if indicated by the results of the ranging tests.

5.2.1.2 Zero-Fill Fix. During the Philadelphia tests, it was noted that multipath caused pulses to appear at the fixed-site receivers in the position of the zero in the 1101 preamble code. To alleviate this condition, the delay between the leading 11 and the trailing 01 of the preamble code was increased from 27.5 μs to 82.5 μs. This essentially eliminated late preamble detection and late TOA measurements, as evidenced by the improvement of up to 2 to 1 in location accuracy. This design change will be incorporated into the Los Angeles system.

An additional design change will be evaluated during Phase II to significantly reduce errors in TOA measurement due to noise. A second TOA pulse will be considered, delayed from the first TOA pulse by approximately 100 μs. The second TOA pulse could provide a second chance for a good TOA measurement if the measurement on the first TOA pulse is in error due to premature noise triggering. If the time difference between the two TOA measurements is less than 100 μsec, then it is presumed that the measurement on the second TOA pulse is in error, and the first TOA would be used. If the difference is greater than 100 μsec, it is presumed that the first TOA measurement is in error due to premature noise triggering, and TOA for the second pulse would be used.

5.2.1.3 On-Route Correction. For the Los Angeles system, Hazeltine proposes to implement an additional computer-processing technique for fixed-route, on-route corrections, which we believe will provide significant improvement in location and time of passage performance.

On-route correction makes use of a priori knowledge of the fixed routes, which can be stored in the central-site computer. Location measurements can be corrected by projection along the perpendicular to the bus route. Criteria will be established for declaring the bus off the route (a system performance requirement) based on magnitude and consistancy of deviation from the route.

In addition, in areas where one fixed route loops back to run in parallel with itself, the algorithm will include a tolerance window to ensure that the calculated location is not corrected to the wrong route. Based on our experience with a preliminary on-route correction algorithm in Philadelphia, we believe the technique will provide significant improvement in performance in Los Angeles.

The on-route correction processing adds only a small increment to the total data processing load because the computations are simple in comparison to the triangulation algorithms. In addition, route parameters are already stored in the computer for the off-route detection functions. Also, the data per route is small since only the end points and the turning points of the route need be stored.

5.2.2 Improvements to Time-of-Passage Accuracy. Analysis of Philadelphia test data indicates that improved time-of-passage performance can be achieved through a combination of hardware and software techniques. The following techniques will be developed and evaluated during Phase II, and implemented in the proposed Los Angeles system.

a) Improved time-of-passage algorithms, which make use of bus direction and speed.

b) Improved signpost performance through increased resistance to false signpost detection due to noise.

5.2.2.1 Improved Time of Passage Algorithm. The Philadelphia tests demonstrated a suburban time-point accuracy of ±15 sec (92%) which is slightly above the specification requirement. We believe the suburban time-of-passage accuracy can be brought within the required limits in Los Angeles by revising the processing algorithm. The algorithm used for the Philadelphia test was based on the use of an arrival circle of 300-foot radius and a departure circle of 400-foot radius, centered at the time point. When measured location was within the 300-foot circle, the time was recorded. When a subsequent location measurement was outside the 400-foot circle, the time was again recorded. The time of departure was then computed as the average of the two recorded times. Of course, if the door of the bus is opened and closed, a resulting bit in the data message was used for departure time.

Time-point accuracy can be improved by using knowledge of the bus direction when recording departure time. For example, when the bus is moving north, a measurement 450 feet to the south should not be accepted as a departure. This revision will be incorporated in the Los Angeles system.

Another source of error is skewing. This results when the bus moves toward the time point at a speed significantly different than its departure speed, so that resulting average time can be biased toward the high or low side. This situation might occur when the bus was caught in traffic, or hit stop lights on approach, but not departure, or vice-versa.

During Phase II, a new algorithm will be developed and tested, which varies the size of the arrival and departure circles as a function of bus velocity. The approximate average velocity can be determined from the number of measurements that fall within the initial arrival and departure circles. These circle radii can then be decreased until only 2 or possibly 3 location measurements fall within the circles, and the departure time would be computed as the average of the times at which these measurements were made.

It is expected that implementation of the on-route correction algorithm, and the other features of Section 5.2.1, which improve location accuracy, will bring time-of-passage accuracy within system performance requirements.

5.2.2.2 Improved Signpost Performance. During the Philadelphia tests, occurrances were noted of false signpost detection due to noise, particularly during the period when the van-mounted power generator was out of adjustment. Although this effect did not prevent meeting the time of passage requirement, a study will be conducted during Phase II to reduce the occurrance of false signpost decodes. The following techniques will be considered:

1. Use of a more powerful code, possibly a 11001 code, which can provide greater immunity to noise.

2. Improvement in the transponder's receiver-noise-blanker circuit (described in section 4.3.8) to increase its noise rejection capability.

3. Standardization of power output from each signpost to permit a more effective (higher) threshold setting in the transponder receiver.

4. Increase in signpost antenna gain to permit raising receiver threshold, while not increasing battery drain.

5.2.3 Improvements in Communications. The capability for bi-directional data communication between vehicles and base was demonstrated by the low message error rates experienced during the Philadelphia tests. The error rates were less than 1%, including the effects of telephone links between the fixed receiver sites and the central control station. In spite of these excellent results, additional measures will be taken in Phase II to improve overall message transmission performance. These are:

a) Incorporate an adaptive message threshold in the fixed site receivers to reduce intersymbol interference due to multipath.

b) Incorporate an error detection/correction technique.

c) Increase mobile to base message length to 20 bits in accordance with performance requirements.

5.2.3.1 Adaptive Threshold for Message Data. It was shown in section 5.2.1.2 that multipath responses can be delayed up to 75 μs, and that the delayed signal caused delayed preamble detection and TOA measurement. This problem was resolved by the zero-fill fix that moved the trailing "01" of the preamble code beyond the maximum possible multipath delay.

This same multipath delay can cause intersymbol interference in the transmitted message, because a delayed multipath pulse can occur in the message stream in the position where a zero should have been.

In this case an alternate solution is proposed for the Los Angeles system which does not increase the required time slot duration.

In the Los Angeles system an adaptive threshold will be implemented for detection of message bits. The threshold level will be set to 10 dB below the level of the received preamble bits. Since the preamble bits are the strongest received signal (either direct or multipath), interfering signals and noise will be significantly lower than the desired message bits. This proposed design change should significantly decrease frequency of message-bit error due to multipath and receiver noise. In addition, it should be noted that the redundancy and space diversity of three (or more) receiver sites provides a reliable means for acquisition of correct data and detection of errors.

5.2.3.2 Error Detection/Correction Techniques. Although the expected message-error rate, as verified by the Philadelphia tests, is quite small, provision must be made to detect and correct errors when they occur. During Phase II, alternate error detection/correction techniques will be evaluated, and a specific technique selected for incorporation into the Los Angeles system.

The most promising approach appears at this time to be the echo technique being incorporated into the Hazeltine Dallas AVM system. Base-to-vehicle messages transmitted during the first half of a designated time slot are echoed back to the base during the second half of the time slot via three or more receiver sites. If the transmitted and echoed messages do not match, the base station retransmits the message during the next frame. Error detection/corrections can be provided in a similar manner for vehicle-to-base messages, with the vehicle retransmitting the message if the echo from the base does not match the transmitted vehicle message.

5.2.3.3 Increase Message to 20 Bits. A 16-bit data message was used for the Philadelphia data communications tests. The design will be changed for Los Angeles to provide the required 20-bit mobile-to-base message. This will make the mobile-to-base message duration a total of 668 μs, including the preamble code. This is well within the 1 ms allowed for this function.

5.2.4 Other Design Changes. The following additional changes will be incorporated into the Los Angeles System.

a) Replace originally proposed quarter-wave whip antenna with a gain antenna. This change will increase gain.

b) Repackage signpost unit. This will be done to increase reliability.

c) Specify lithium battery for signpost. This will improve maintainability.

5.2.4.1 Gain Antenna. The vehicle antenna originally proposed for Los Angeles (roof-mounted blade) will be replaced by a Phelps Dodge Model 1065A Mobile Roof Top Antenna, Figure 5-4. An electrically equivalent antenna was actually used for all of the Philadelphia tests since it provides higher gain than can be achieved with the blade antenna. The model 1065A is a 5/8 wavelength antenna, designed to satisfy the Bell Telephone specifications in the HCMTS assigned band of 825 - 890 MHz. It was modified by Phelps Dodge for use in the Hazeltine AVM band. Its gain is 3 dB higher than a quarter-wave antenna at the horizon; and it has a vswr of 1.5 to 1, or less, over its designed bandwidth. The model 1065A elevation antenna pattern is given in figure 5-5, which also gives a direct comparison with a quarter-wavelength whip antenna.

The model 1065A antenna incorporates a spring near its base, which allows the antenna to flex when encountering as little as 4 inches of clearance to the roof of the vehicle. This feature allows the antenna to remain on a vehicle being washed in an automatic car wash. The antenna is used with the 880 low-profile mount, shipped with the antenna (figure 5-6). A 10-foot length of low-loss cable, terminated in a male N type plug is also supplied with each antenna.

5.2.4.2 Signpost Repackaging. During the Philadelphia tests, several incidents of internal shorting were experienced. These were caused by the proximity of the semi-rigid coax cable to other electrical contact points. The signpost package will be redesigned to ensure that this does not occur in the Los Angeles system. The new design will provide ample clearances that can be achieved through standard production assembly techniques.

5.2.4.3 Lithium Battery. A lithium battery will be used in the Los Angeles systems, in place of the originally proposed alkalide batteries, since it provides greater energy storage per unit volume. The lithium battery will be purchased as a custom assembly of cells, with taps brought out for the specific required voltages.

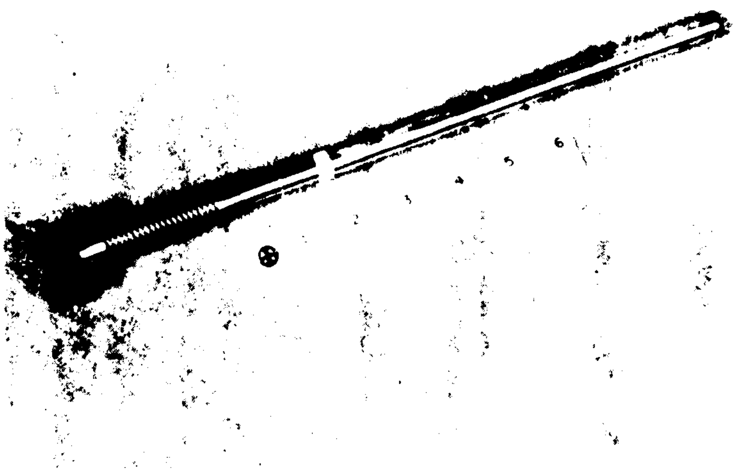


FIGURE 5-4. PHELPS-DODGE MODEL 1065A MOBILE ROOF-TOP ANTENNA

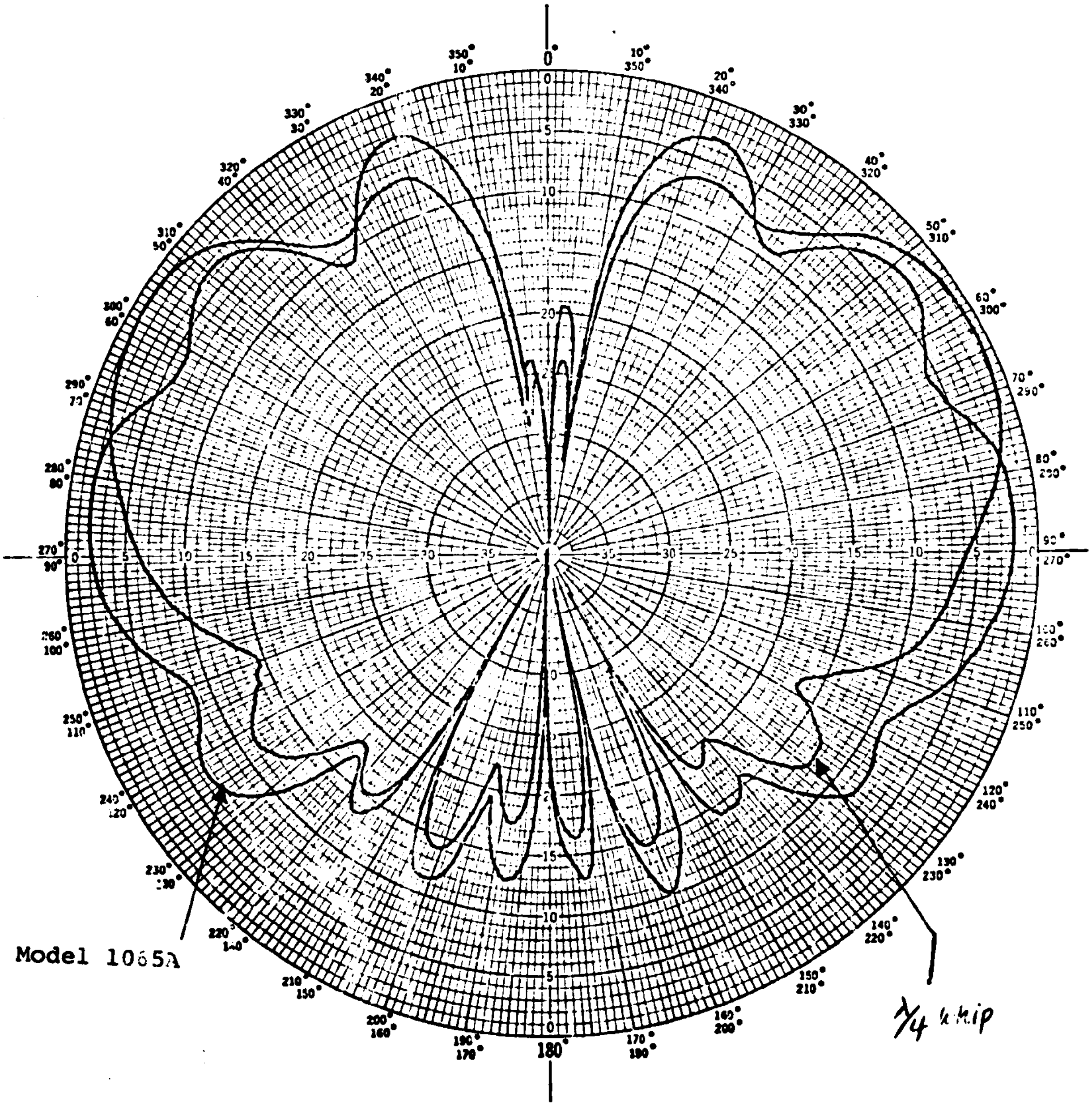


FIGURE 5-5. COMPARISON OF PHELPS-DODGE MODEL 1065A AND QUARTER-WAVE WHIP ANTENNA

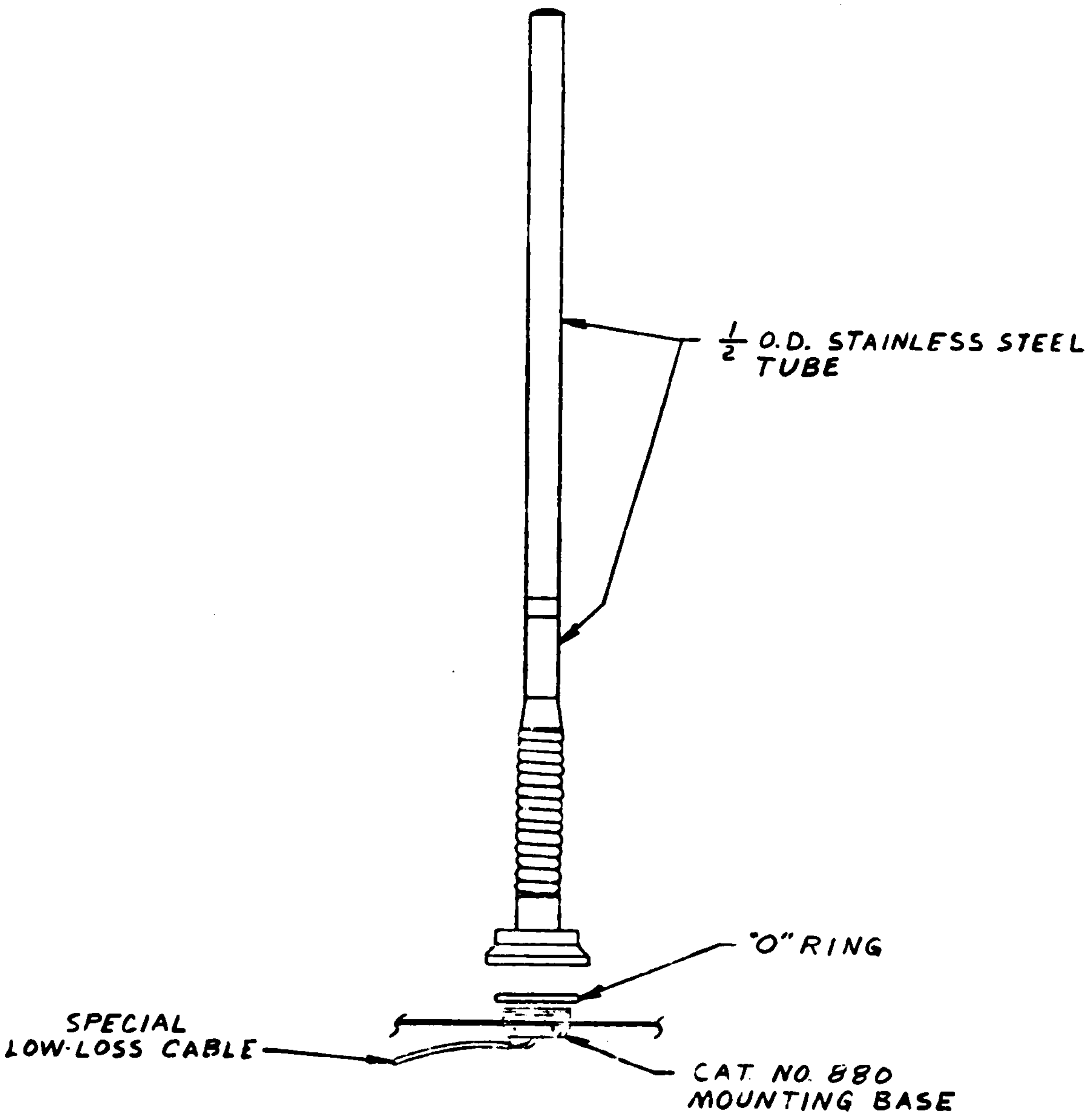


FIGURE 5-6. PHELPS-DODGE MODEL 1065A ANTENNA AND MODEL 880 ANTENNA MOUNT

# 6. PERMITS AND LICENSES

Installation of the complete AVM system in Los Angeles requires an FCC authorization to operate on the required frequencies and permission from the cognizant authority to mount signpost units on existing telephone/light poles. The FCC authorizations have been obtained by Hazeltine. We have not yet been able to obtain authorization or obtain information on procedures to be followed in installing time of passage signposts in Los Angeles.

Enclosed are copies of the VCC Experimental Radio Station Construction Permit and Licenses for the vehicle transmitter (KS2XEX) and the central control transmitter (KS2XEW) with special temporary authorization to operate in the City of Los Angeles.

The KS2XEX license is for the vehicle transmitter operating at 500 watts peak at the unit output terminals (after the internal duplexer assembly) and with an antenna gain of three. The authorized power level is 1.5 kW peak. The KS2SEW license is authorization for the synchronization and calibration fixed transmitter emissions. These power levels are 2 kW and 750 W respectively and the antenna gain is 20. The authorized radiated power levels are 40 kW peak for the synchronization emission and 1.5 kW peak for the calibration emission.

Paragraphs 89.120(e), 91120(e), and 93.120(e) of the FCC Rules and Regulations indicate that type acceptance and type certification are not required for the signpost equipment. Also, a discussion with Mr. Love of the FCC (on 10/18/76) indicated that it would not be necessary to submit a request for license modification to utilize the signpost units since the frequency is the same as the synchronization transmitter and the power level is so low (less than 1 mW radiated).

UNITED STATES OF AMERICA
FEDERAL COMMUNICATIONS COMMISSION
EXPERIMENTAL
RADIO STATION CONSTRUCTION PERMIT
AND
LICENSE

EXPERIMENTAL (DEVELOPMENTAL)
(Nature of service)

EXPERIMENTAL XD FX
(Class of station)

K S 2 X E W (New)
(Call sign)

2024-ER-PL-75
(File number)

NAME HAZELTINE CORPORATION

Greenlawn, New York - Lat. 40 52 00 N; Long. 73 22 10 W.
(Location of station)

(Location of authorized remote control point)

Subject to the provisions of the Communications Act of 1934, subsequent acts, and treaties, and all regulations heretofore or hereafter made by this Commission, and further subject to the conditions and requirements set forth in this license, the licensee hereof is hereby authorized to use and operate the radio transmitting facilities hereinafter described for radio communication.

| *Frequency* | *Emission Designator* | *Authorized Power (Watts)* | *Special Provisions* |
|---|---|---|---|
| 904.5 MHz | 1000P9 | 40 kW (peak) | |
| 925.5 MHz | 1000P9 | 40 kW (peak) | |
| 908.0 MHz | 5000P9 | 1.5 kW (peak) | |
| 922.0 MHz | 5000P9 | 1.5 kW (peak) | |

Equipment: (4) Hazeltine

Frequency Tolerance: 0.03%

Hours of Operation: Unlimited

Operation: In accordance with Section 5.252(a) of the Commission's Rules.

**The above frequencies are assigned on a temporary basis only and are subject to change at any time without hearing.**

**This authorization is granted subject to the condition that no harmful interference is caused to any other station or service and may be cancelled at any time without hearing if, in the judgment of the Commission, such action should be necessary.**

**This license is issued on the licensee's representation that the statements contained in licensee's application are true and that the undertakings therein contained, so far as they are consistent herewith, will be carried out in good faith. The licensee shall, during the term of this license, render such service as will serve public interest, convenience, or necessity to the full extent of the privileges herein conferred.**

**This license shall not vest in the licensee any right to operate the station nor any right in the use of the frequencies designated in the license beyond the term hereof, nor in any other manner than authorized herein. Neither the license nor the right granted hereunder shall be assigned or otherwise transferred in violation of the Communications Act of 1934. This license is subject to the right of use or control by the Government of the United States conferred by Section 606 of the Communications Act of 1934.**

**This authorization effective** January 20, 1976 **and**
**will expire 3:00 A.M. EST** March 1, 1978

FEDERAL COMMUNICATIONS COMMISSION.

76

6-2

UNITED STATES OF AMERICA
FEDERAL COMMUNICATIONS COMMISSION
EXPERIMENTAL
RADIO STATION CONSTRUCTION PERMIT
AND
LICENSE

~~EXPERIMENTAL~~ (DEVELOPMENTAL)
(Nature of service)

EXPERIMENTAL XD MO
(Class of station)

K S 2 X E X (new)
(Call sign)

7042-ED-PL-75
(File number)

NAME HAZELTINE CORPORATION

Mobile: Within 20 mile radius of Greenlawn, N.Y.; Philadelphia, Pa.; Dallas, Texas and Los Angeles, California
(Location of station)

(Location of authorized remote control point)

Subject to the provisions of the Communications Act of 1934, subsequent acts, and treaties, and all regulations heretofore or hereafter made by this Commission, and further subject to the conditions and requirements set forth in this license, the licensee hereof is hereby authorized to use and operate the radio transmitting facilities hereinafter described for radio communication.

| *Frequency* | *Emission Designator* | *Authorized Power (Watts)* | *Special Provisions* |
|---|---|---|---|
| 908.0 MHz | 5000P9 | 1.5 kW(peak) | |
| 922.0 MHz | 5000P9 | 1.5 kW(peak) | |

Equipment: (3) Hazeltine Corporation

Frequency Tolerance: .03%

Hours of Operation: Unlimited

Operation: In accordance with Section 5.252(a) of the Commission's Rules.

**The above frequencies are assigned on a temporary basis only and are subject to change at any time without hearing.**

**This authorization is granted subject to the condition that no harmful interference is caused to any other station or service and may be cancelled at any time without hearing if, in the judgment of the Commission, such action should be necessary.**

**This license is issued on the licensee's representation that the statements contained in licensee's application are true and that the undertakings therein contained, so far as they are consistent herewith, will be carried out in good faith. The licensee shall, during the term of this license, render such service as will serve public interest, convenience, or necessity to the full extent of the privileges herein conferred.**

**This license shall not vest in the licensee any right to operate the station nor any right in the use of the frequencies designated in the license beyond the term thereof, nor in any other manner than authorized herein. Neither the license nor the right granted hereunder shall be assigned or otherwise transferred in violation of the Communications Act of 1934. This license is subject to the right of use or control by the Government of the United States conferred by Section 606 of the Communications Act of 1934.**

**This authorization effective** January 20, 1976 **and**
**will expire 3:00 A.M. EST** March [illegible], 1978

-76

FEDERAL COMMUNICATIONS COMMISSION.

Ben F. Waple

*Secretary.*

6-3

F.C.C. - WASHINGTON, D. C.

FCC Form 150-D
May [illegible]

UNITED STATES OF AMERICA
FEDERAL COMMUNICATIONS COMMISSION

EXPERIMENTAL
SPECIAL TEMPORARY AUTHORIZATION

EXPERIMENTAL (DEVELOPMENTAL)
(Nature of service)

K S 2 X E W
(Call sign)

EXPERIMENTAL XD FX
(Class of station)

S-7024-ED-75-5
(File number)

NAME HAZELTINE CORPORATION

Los Angeles, California - Lat. 34 06 50 N; Long. 118 20 00 W.
(Location of station)

(Location of authorized remote control point)

Special Temporary Authority is hereby granted to operate the radio transmitting apparatus described below:

| Frequency | Emission Designator | Authorized Power (Watts) | Special Provisions |
|---|---|---|---|
| 904.5 MHz | 1000P9 | 40000 (peak) | |
| 925.5 MHz | 1000P9 | 40000 (peak) | |
| 908.0 MHz | 5000P9 | 1500 (peak) | |
| 922.0 MHz | 5000P9 | 1500 (peak) | |

This special temporary authorization is granted upon the express condition that it may be terminated by the Commission at any time without advance notice or hearing if in its discretion the need for such action arises. Nothing contained herein shall be construed as a finding by the Commission that the authority herein granted is or will be in the public interest beyond the express terms hereof.

This special temporary authorization shall not vest in the grantee any right to operate the station nor any right in the use of the frequencies designated in the authorization beyond the term hereof, nor in any other manner than authorized herein. Neither the authorization nor the right granted hereunder shall be assigned or otherwise transferred in violation of the Communications Act of 1934. This authorization is subject to the right of use or control by the Government of the United States conferred by Section 606 of the Communications Act of 1934.

This authorization effective June 1, 1977 and

will expire 3:00 A.M. EST December 1, 1977.

FEDERAL COMMUNICATIONS COMMISSION

F.C.C. - WASHINGTON, D. C.

# APPENDIX A

# EQUIPMENT OPERATIONAL REQUIREMENTS

## A.1 CALIBRATION PROCEDURES

### A.1.1 Clock Calibration

Philadelphia test system calibration of the fixed site clocks is performed with the software program and the initialization is in the order of minutes upon first turning on the fixed site equipments.

The method of time-of-arrival (TOA) measurement and transmission of data to the central control was chosen on the basis of satisfactory performance with the lowest implementation cost. Another factor was the life-cycle cost of the operational system. Preliminary digital processing at the receiver sites with data transmission using relatively low speed modems and low cost telephone lines appears to be the optimum system approach resulting in lowest overall cost. The asynchronous clocks at the fixed sensor sites necessitate an automatic calibration and count correction procedure. The differences in clock and counter rates are taken into account with a central control computer software program.

### A.1.2 Mapping

Systematic location error or "bias" is calibrated out of the coverage areas of interest. Preliminary data taken of vehicle positions randomly spaced throughout the region and the average location deviations on the X and Y map coordinates are calculated. These average values are subtracted from all future formal vehicle location data. It is anticipated that the correction factor will be different for the two cells of the trilateration test configuration due to the uncertainties of the receiver site locations.

Data is gathered for the mapping correction by driving the vehicle over the fixed route specified by DOT/TSC and the portion of the Schuylkill Expressway used for the high speed special test. This data is used for the mapping correction of both the large and small triangular cells. Another run will be taken near the East River Drive using only the large triangular cell fixed receivers and the derived correction factor compared with the fixed route test. The East River Drive is the area for the special trilateration time point test without signpost units.

The 10 per second data of the AVM subsystem is used to derive the X and Y map coordinate average location error values.
It is anticipated that a single X, Y correction for the area of interest (values for each triangular cell) will be sufficient to reduce the residual bias error to an acceptable magnitude.

### A.1.3 Test Equipment 5th Wheel Calibration

The fifth wheel manufacturer provides certification of the accuracy of wheel output at a specific tire pressure (35 psi) to be ±0.2%. Based on the given spacing (500 to 1000 feet) between checkpoints, the error in fifth wheel readings between checkpoints is negligible (2 feet or less), and it is not necessary to perform any special calibration procedures. The fifth wheel is reset to zero only at the beginning of a test.

## A.2 INITIALIZATION PROCEDURES

At the beginning of each day, or each data taking session if desired, the following procedure is used to synchronize the real-time clocks in the central site and the vehicle, utilizing a mobile telephone for voice communications.

At both the central site and the vehicle, the thumbwheel switches are used to set the hour and minute for synchronization.

At both sites, a momentary switch is actuated to preset this time into the clock registers and to interrupt the 0.1 second clock pulses. Releasing the switch in the vehicle readies the transponder for decoding a time message from the central site. Releasing the switch at the central site starts its clock running which first generates a frame sync and calibration transmission, followed by a time message in the next slot (and each 2 seconds thereafter). When the first time message is decoded at the vehicle, all 0.1 second and faster time counter stages are reset and the clock is enabled. The vehicle real-time clock is then synchronized to that of the central site.

## A.3 TEST CONDITIONS/CONTROLS

This section describes the operational use and function of both the Vehicle and Central Site controls and indicators.

### A.3.1 Vehicle Controls and Indicators

Table A-1 lists the controls and indicators located on the vehicle interface unit shown in figure A-1. In the discussion which follows, the numbers in parentheses reference the control or indicator designation in table A-1.

At the beginning of a test day, or the beginning of a test, the POWER switch (21) is turned on and the time of day is set on the front panel thumbwheels for the HOUR (7) and MINUTE (8). The tape recorder tape is threaded to the take-up reel (if not already done), and power is turned on. If the tape has not already been advanced to the Load Point Marker, press the LOAD

FIGURE A-1. VEHICLE CONTROL PANEL

## TABLE A-1. VEHICLE CONTROLS & INDICATORS

| FUNCTION | TYPE |
|---|---|
| **A. Controls** | |
| (1) Tape # | Thumbwheels, 2 BCD digits |
| (2) File # | 2 |
| (3) Test # | 4 |
| (4) Month | 2 |
| (5) Day | 2 |
| (6) Year | 2 |
| (7) Hour | 2 |
| (8) Minute | 2 |
| (9) Xmtr. Pwr. | 3 |
| (10) Event # | Thumbwheels, 4 BCD digits |
| (11) Test Start Header Enter | Momentary |
| (12) Test End Header/End of File (EOF) Enter | |
| (13) Event Enter | |
| (14) Leave Point | |
| (15) Refer to Log | |
| (16) 5th Wheel Reset | |
| (17) Master Reset | |
| (18) Write Error Reset | |
| (19) Time Set | Momentary |
| (20) Door Open | Toggle, 2 positions |
| (21) Power | Toggle, 2 position |
| **B. Indicators** | |
| (22) Power On | Light (LED) |
| (23) Write Error | |
| (24) Sync Decode | |
| (25) Signpost Decode | |
| (26) Message Error | |
| (27) Track | |
| (28) Ready | |
| (29) Header | |
| (30) Data | |
| (31) EOF/GAP | Light (LED) |

TABLE A-1. VEHICLE CONTROLS & INDICATORS (cont)

| FUNCTION | TYPE |
|---|---|
| B. Indicators (cont) | |
| (32) Time | Digital Display (LED) |
| (33) 5th Wheel Distance | \| \| |
| (34) Speed | Digital Display (LED) |

FORWARD pushbutton on the tape recorder. When the READY light (28) comes on on the I.U. front panel, the TIME SET (19) locking toggle switch is pulled and momentarily actuated to initiate the real-time synchronization with the Central Site. The MESSAGE ERROR (26) light remains on until the Vehicle real-time clock time is synchronized with that of the Central Site.

Before beginning each test, the fifth wheel distance is set to zero (this is normally the only time that distance is reset) by pulling and actuating the DISTANCE RESET (16) locking toggle switch, and the Start Test Header information is set up by the thumbwheels as follows. The two TAPE (1) thumbwheels are set to the number of the tape in use. The two FILE (2) thumbwheels are set to indicate the particular file number on that tape. The four TEST (3) thumbwheels are set to indicate the number of the test which is to be recorded. The date is set using the thumbwheels for MONTH (4), DAY (5), and YEAR (6), and the time of the start of the test is indicated using the thumbwheels for HOUR (7) and MINUTE (8). The transponder transmitter peak power is measured in dBW and set on the three DBW (9) thumbwheels (the least significant digit representing tenths). Pushing the START HEADER (11) pushbutton enters the header record on tape as indicated by the HEADER (29) light coming on for about 6 1/2 seconds. At the end of the header record, the HEADER (29) light goes out, the EOF/GAP (31) light comes on for about 1/2 second, after which the DATA (30) light comes on and data is recorded.

Prior to each event (time point, check point, etc.), the four EVENT NUMBER (10) thumbwheels are set to the number of the next upcoming event (events are numbered in sequence). At the time the event occurs, the EVENT ENTER (13) pushbutton is actuated to enter the event number on tape at the next 0.1 second interval. In a case (such as an underpass) when two events occur so close together that there is insufficient time to set up a new event number, the LV.PT. (14) pushbutton is depressed at the time of the second event. The DOOR (20) toggle switch, which is normally in the CLOSED position, is set to the OPEN position to simulate a door opening and then returned to the CLOSED position to simulate the door closing. If something unusual occurs during a test, the REFER TO LOG (15) pushbutton is actuated and an appropriate explanation is entered in the written log.

If the WRITE ERROR (23) light comes on (indicating an error has been detected in the tape recorder write electronics), it normally (if only a momentary condition) can be extinguished by actuating the WRITE ERROR RESET (18) pushbutton. If the light continues to come on, it indicates a tape recorder malfunction.

At the end of a test, the transponder transmitter power is again measured and entered on the DBW (9) thumbwheels, and the time is set on the time (7 and 8) thumbwheels. The other header thumbwheels ordinarily need not be changed from their setting at the beginning of the test, except for the date if the test ran past midnight. The END HEADER (12) pushbutton is actuated to enter that header record on tape as soon as the data record in progress is completed. The DATA (30) light goes out, the HEADER (29) light comes on for about 6 1/2 seconds. The EOF/GAP (31) light then comes on for about 3 1/2 seconds while the end-of-file (EOF) is put on tape. Following this, the READY (28) light comes on indicating the interface unit (I.U.) is awaiting operator action, such as a new start header for the next test or a time set.

The TIME (32) digital readouts show real-time in hours, minutes, and seconds; the right-hand decimal point of the seconds units digit illuminates for 0.1 second each second (for the 0.0 to 0.1 second interval). The DISTANCE (33) digital readout indicates fifth wheel cumulative distance from 0 to 99,999.9 feet. The SPEED (34) digital readout, which is updated every 0.68 seconds, displays speed from 0 to 99.9 mph.

The POWER (22) light is actuated by the +5 volts from the I.U. power supply. The MESSAGE ERROR (26) light, which is updated at 2-second intervals, indicates that the time message received from the Central Site does not agree with the vehicle real-time clock. The TRACK (27) light indicates the vehicle transponder is tracking the sync signal from the Central Site with its narrow window tracking gate. The SYNC (24) light blinks on, normally at 2-second intervals, to indicate decoding of the sync signal from the Central Site. The SIGNPOST (25) light is on while the transponder is receiving and decoding signpost transmissions.

### A.3.2 Central Site Controls and Indicators

Table A-2 lists the controls and indicators located on the central site interface unit shown in figure A-2. In the discussion which follows, the numbers in parentheses reference the control or indicator designation in table A-2.

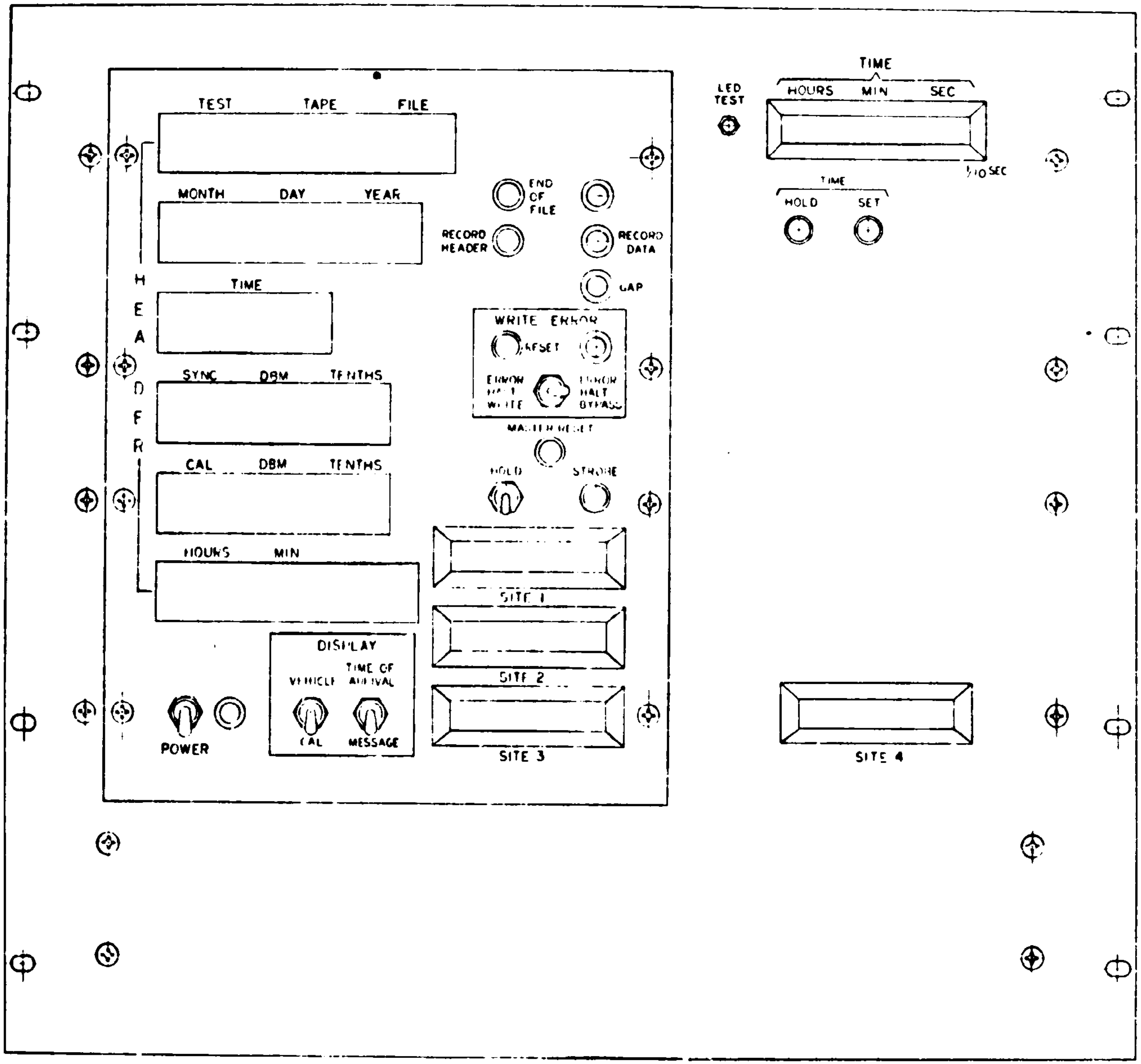


FIGURE A-2. CENTRAL CONTROL PANEL

TABLE A-2. CENTRAL SITE CONTROLS & INDICATORS

| FUNCTION | TYPE |
|---|---|
| A. Controls | |
| (1) Tape # | Thumbwheels, 2 BCD Digits |
| (2) File # | 2 |
| (3) Test # | 3 |
| (4) Month | 2 |
| (5) Day | 2 |
| (6) Year | 2 |
| (7) Time | 4 |
| (8) Hour | 2 |
| (9) Minute | 2 |
| (10) Xmtr.Pwr (Sync/DBM/Tenths) | 3 |
| (11) Xmtr Pwr (Cal/DBM/Tenths) | Thumbwheels, 3 BCD Digits |
| (12) Test Start (Record Header) | Momentary |
| (13) End of File | |
| (14) Master Reset | |
| (15) Write Error Reset | |
| (16) Time Set/Hold | Momentary |
| (17) Power | Toggle |
| B. Indicators | |
| (18) Power | Light |
| (19) Write Error | |
| (20) Record Data | |
| (21) Gap | |
| (22) End of File | Light |
| (23) Time | Digital Display |
| (24) Site 1 | |
| (25) Site 2 | |
| (26) Site 3 | |
| (27) Site 4 | Digital Display |
| (28) LED Test | Momentary |

At the beginning of a test day, or the beginning of a test, the POWER switch (17) is turned on and the time of day is set on the front panel thumbwheels for the HOUR (8), MINUTE (9) and TIME (7). The remaining header information is set up on the thumbwheels as follows:

The two TAPE (1) thumbwheels are set to the number of the tape in use. The two FILE (2) thumbwheels are set to indicate the particular file number on that tape. The three TEST (3) thumbwheels are set to indicate the number of the test which is to be recorded. The date is set using the thumbwheels for MONTH (4), DAY (5), and YEAR (6). The sync/cal transmitter peak power is measured in dBW (sync and cal) and set on the three DBW (10)(11) thumbwheels (the least significant digit representing tenths). Pushing the RECORD HEADER (12) pushbutton enters the header record on tape as indicated by the RECORD DATA (20) light going off. At the end of the header record, the RECORD DATA (20) light goes on, and data starts being recorded.

At the end of a test, the sync/cal transmitter power is again measured and entered on the DBW (10)(11) thumbwheels, and the time is set on the TIME (7) thumbwheels. The other header thumbwheels ordinarily need not be changed from their setting at the beginning of the test, except for the date if the test ran past midnight. The END OF FILE (13) switch is actuated to enter that header record on tape as soon as the data record in progress is completed. The END OF FILE (22) light then comes on, while the end-of-file (EOF) is put on tape. Following this, the unit is then awaiting operator action, such as a new start header for the next test or a time set.

The TIME (23) digital readouts show real-time in hours, minutes, and seconds; the right-hand decimal point of the seconds units digit illuminutes for 0.1 second each second (for the 0.0 to 0.1 second interval).

The POWER (18) light is actuated by the +5 volts from the Interface Unit power supply.

## A.4 TEST PROCEDURES

### A.4.1 Bus Route Simulation

As the vehicle traverses the specified fixed route, the operator in the vehicle inputs to the vehicle data acquisition system event marks noting vehicle passage of DOT/TSC specified points. A detailed itinerary of the fixed route is listed in table A-3. Under the direction of the DOT/TSC monitor, the vehicle may stop prior to passing a time point in order to simulate picking up or discharge of passengers (identified on the recorder by the use of a switch to indicate a door opening) or the vehicle may pass

## TABLE A-3. HAZELTINE FIXED ROUTE

Start run at Broad Street and Spring Garden - Proceed West on Spring Garden

Left around rotary onto Ben Franklin Parkway

Measure in front of museum (TP)

Proceed Southeast on Ben Franklin Parkway

Proceed around Logan Circle and exit on 19th

Measure at Cherry (TP)

Proceed around Rittenhouse Sq.

Measure at Pine (TP)

Left on Pine

Measure between 8th and 9th (TP)

Left on 7th

Left around Wash Square

Measure at Market (TP)

Left on Market

Right on 13th

Measure at Arch (TP)

Right on Spring Garden

Measure at Ridge (TP)

Right on Ridge

Left on Race

Measure at 6th (TP)

Right on Sixth

Right on Walnut

Measure between 10th & 11th (TP)
Measure at 23rd (TP)

Right on 33rd

Right on Chestnut

Measure at 23rd (TP)

Left on 18th

Measure at JFK Blvd. (TP)

Left on JFK Blvd.

Right at Penn RR Station

Left on Arch

Left on 30th

Right on JFK Blvd.

Follow JFK Blvd. around to left

Measure at Market (TP)

Left on Market

Right on 15th

Left at S. Penn Sq.

Measure at Broad (TP)

Left on Juniper

Left on JFK Blvd.

Right on B.F. Parkway

Right on 18th

Measure at Callowhill (TP)

Right on Callowhill

Left on 16th

END OF RUN

by a time point with time of departure being identified at the point where the front end of the vehicle passes the time point and the operator manually inputs an event mark.

Tests are conducted during normal business days with particular emphasis on rush hour traffic to closely simulate an operational AVM system where more measurements are taken at rush hours than at any other time of day. The test vehicle passes the time points without stopping 50% of the time and simulates bus passage stops for the remaining 50%. Thirty passes of the fixed route are made to accumulate sufficient statistical data samples for the 15 time points of the fixed route.

A.4.1.1 Signpost Locations. Figures A-3 to A-17 depict the time points on the fixed route. The chosen locations of the signpost equipment are designated with a square symbol on the diagrams. The locations of the time points are described in table A-4.

### A.4.2 Random Route Restrictions

As the vehicle traverses the DOT/TSC specified route, the operator aboard the vehicle inputs, to the vehicle data acquisition system, event markers noting vehicle passage of DOT/TSC specified points.

The driving patterns of the test vehicle simulate the normal operation of a vehicle in urban traffic. The exact vehicle route for the random route test was supplied by DOT/TSC 48 hours before the formal test. The test is conducted during normal business days with particular emphasis on rush hour traffic to closely simulate an operational AVM system where more measurements are taken at rush hours than at any other time of the day.

### A.4.3 Special Case Tests

The special tests are configured to determine if any abnormalities exist in the Hazeltine AVM system while operating under worst case conditions. They include high speed tests, underpass tests, and power line interference tests. Other special test configurations include a test to determine the effect of GDOP at the region around a receiver site, the variability of the signpost radiation patterns in a street environment, the measurement of rf noise levels in the Philadelphia test area, and the performance of the trilateration system time point measurement without the use of signpost units.

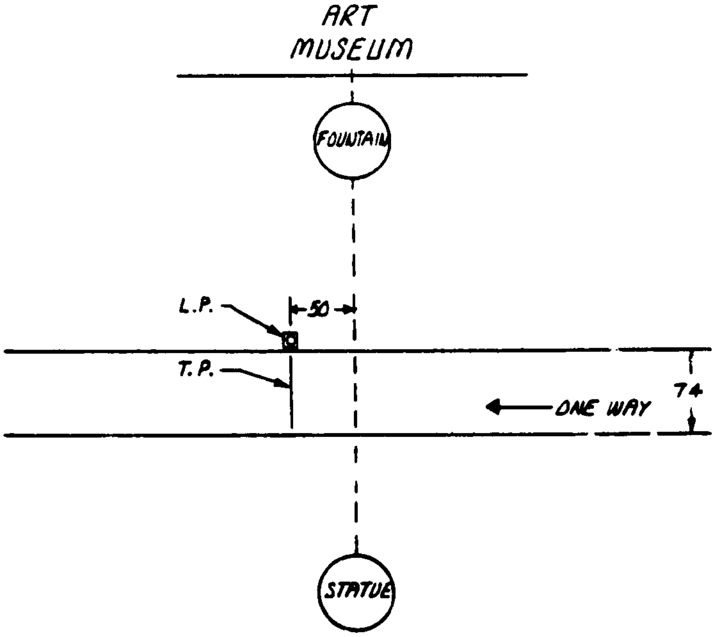


FIGURE A-3. TIMEPOINT #1

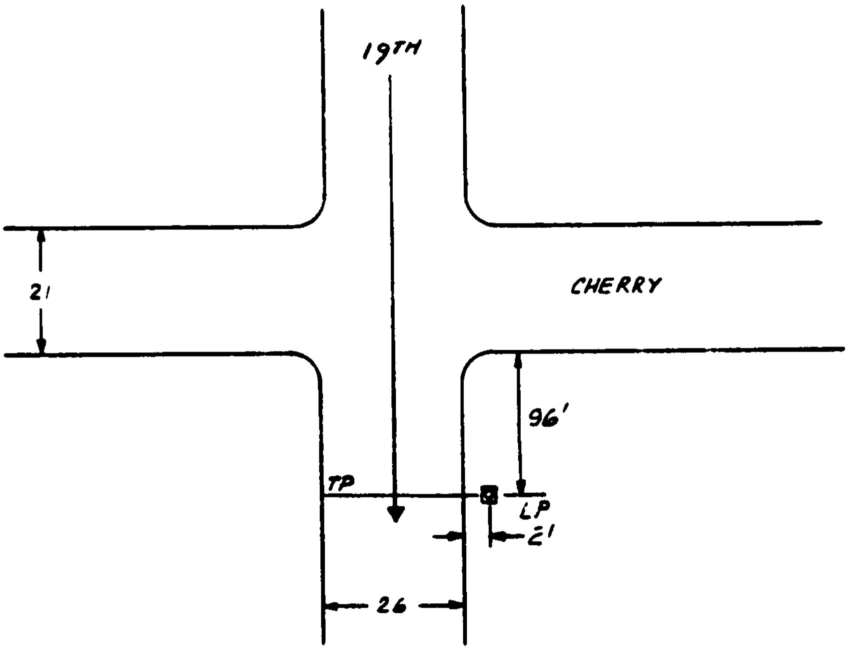


FIGURE A-4. TIMEPOINT #2

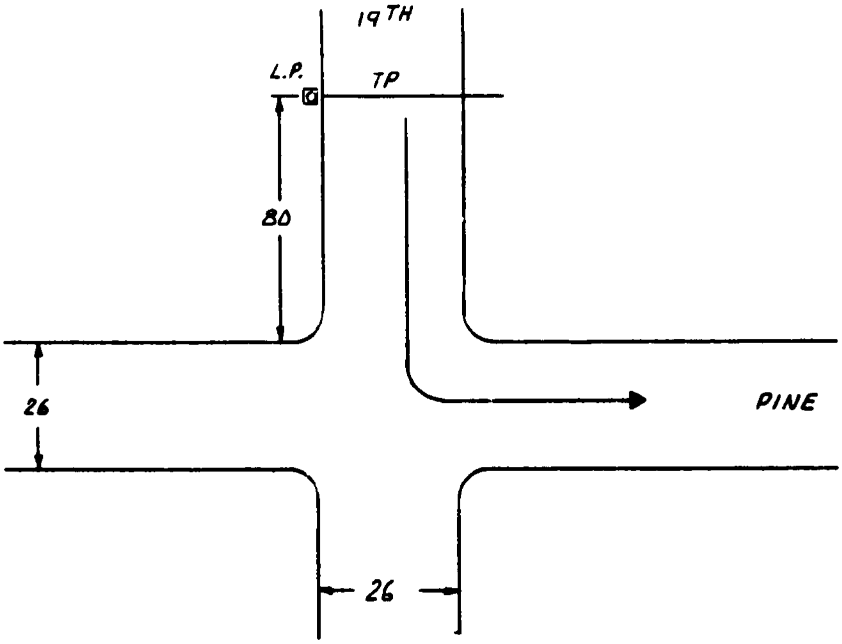


FIGURE A-5. TIMEPOINT #3

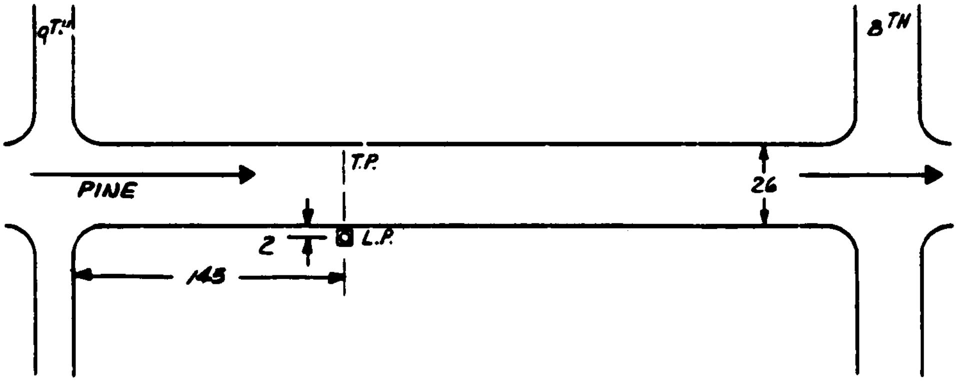


FIGURE A-6. TIMEPOINT #4

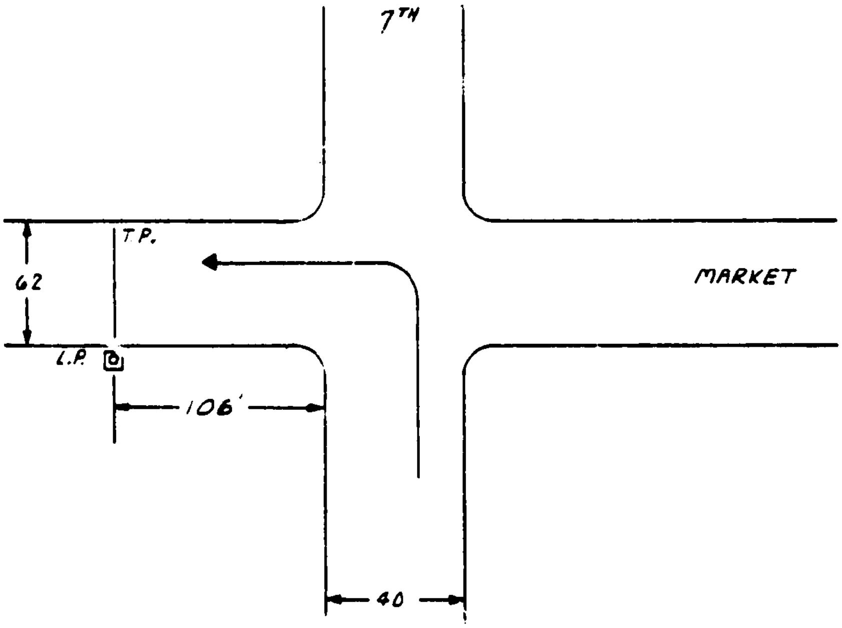


FIGURE A-7. TIMEPOINT #5

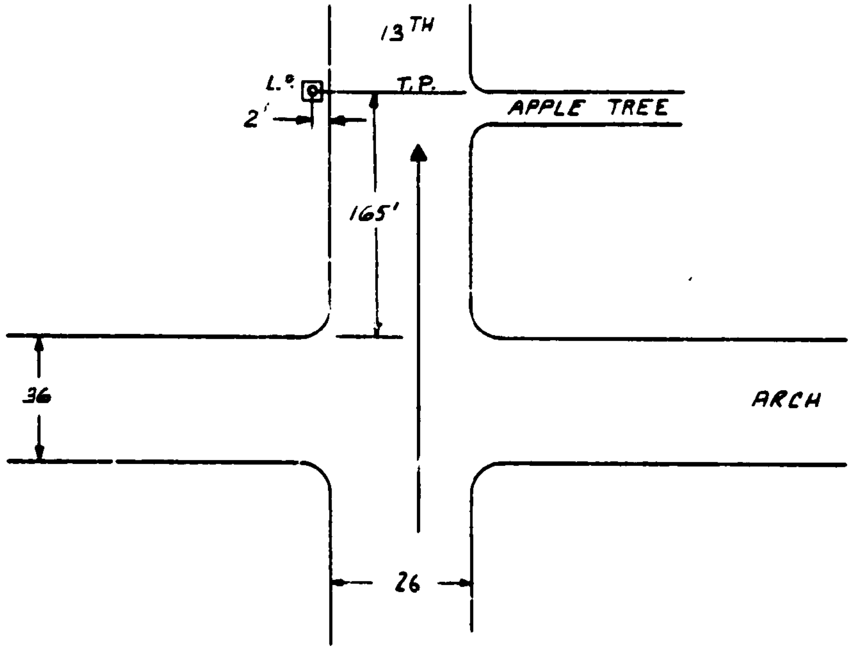


FIGURE A-8. TIMEPOINT #6

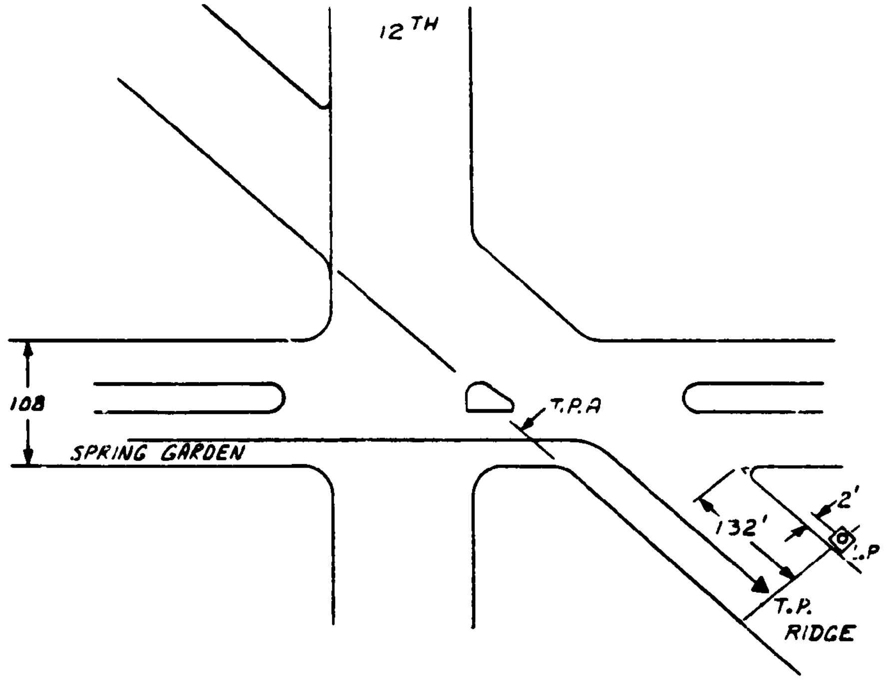


FIGURE A-9. TIMEPOINT #7

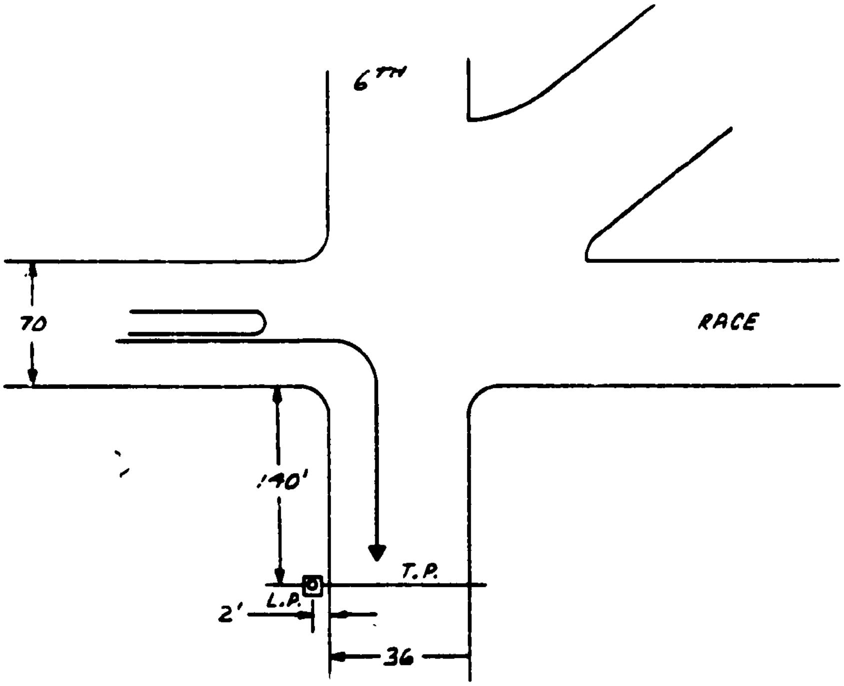


FIGURE A-10. TIMEPOINT #8

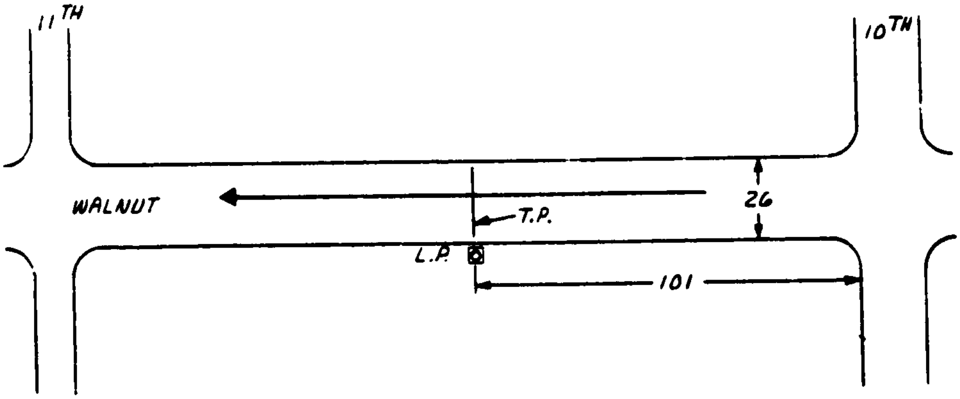


FIGURE A-11. TIMEPOINT #9

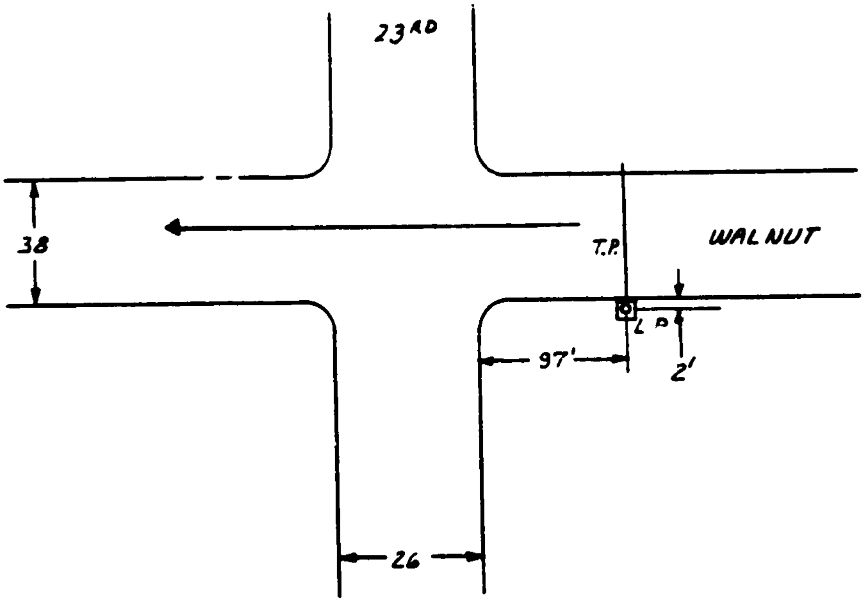


FIGURE A-12. TIMEPOINT #10

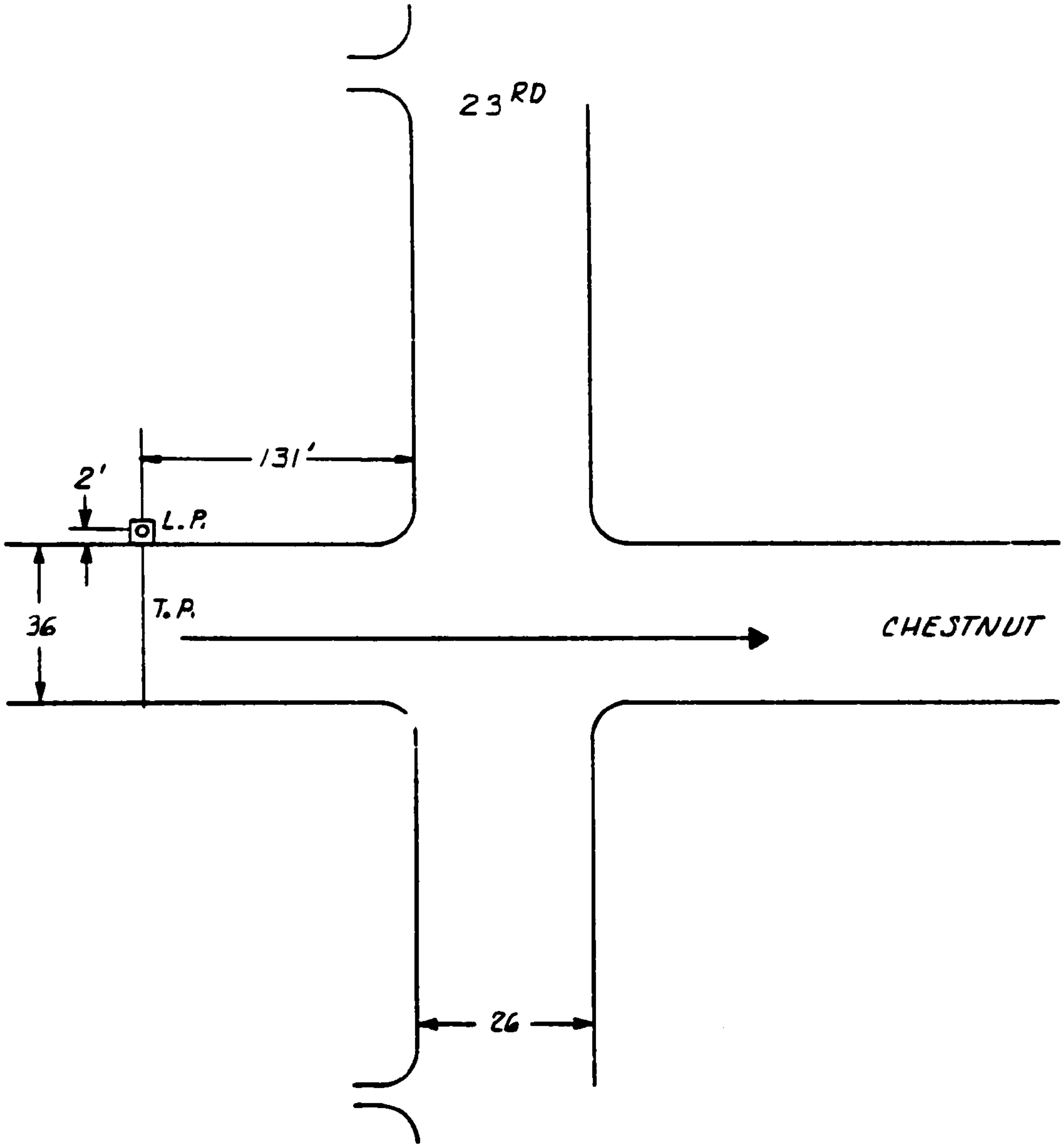


FIGURE A-13. TIMEPOINT #11

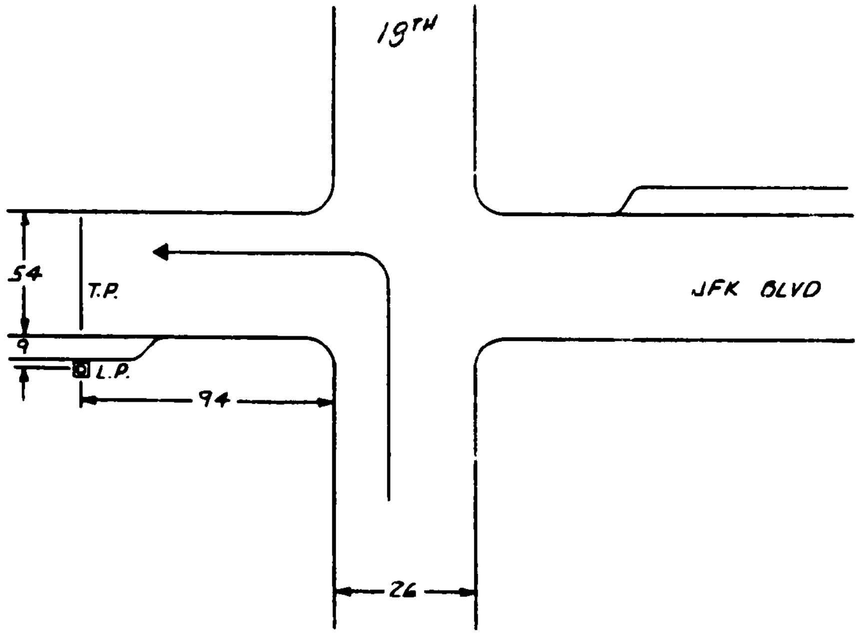


FIGURE A-14. TIMEPOINT #12

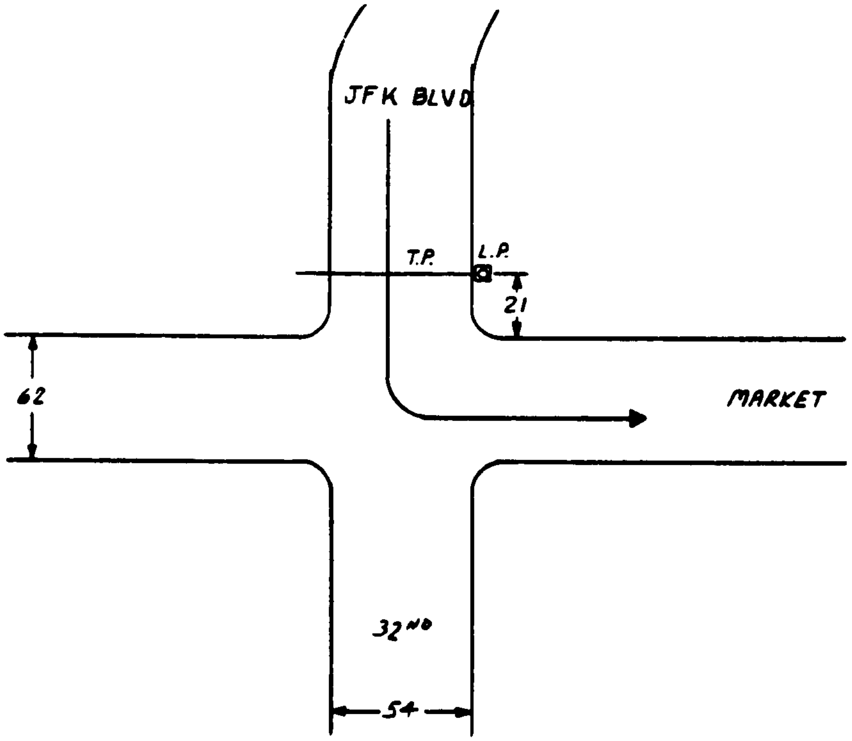


FIGURE A-15. TIMEPOINT #13

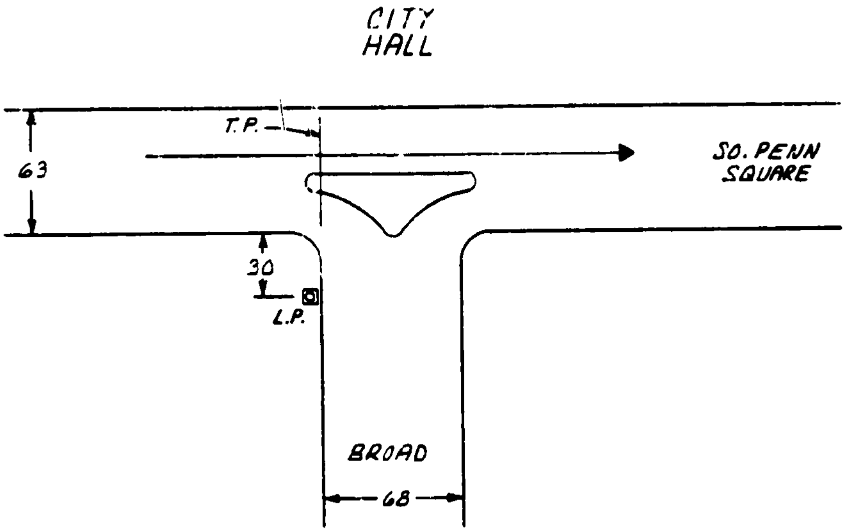


FIGURE A-16. TIMEPOINT #14

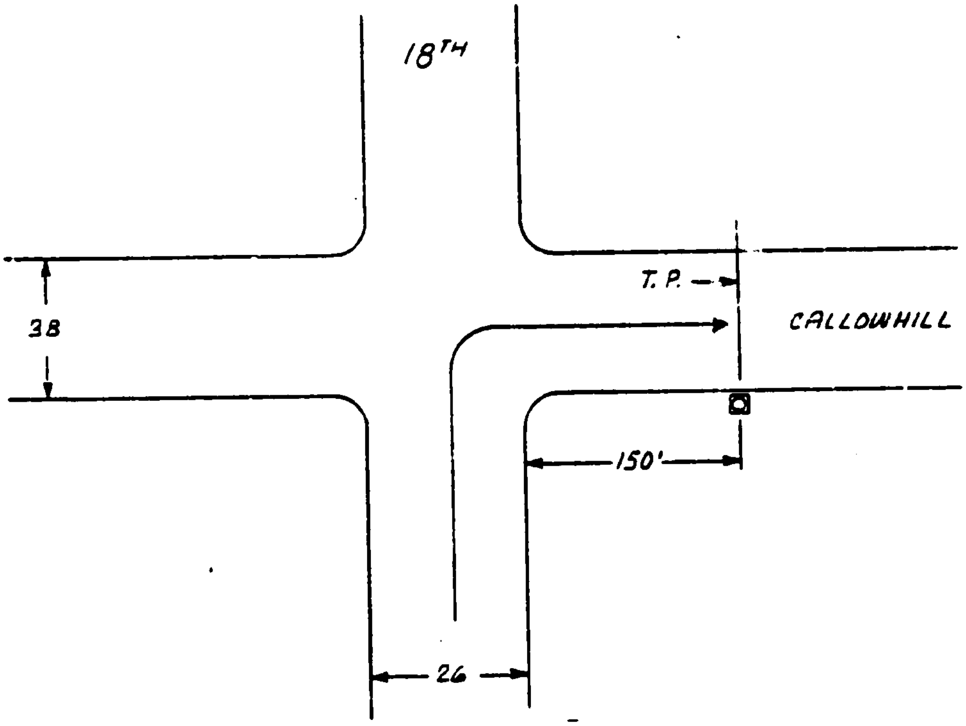


FIGURE A-17. TIMEPOINT #15

## TABLE A-4. TIMEPOINT LOCATIONS

| TIMEPOINT | POSSIBLE SPECIFIC LOCATIONS | TSC SELECTED LOCATION | STATE PLANE COORDINATES AT INTERSECTION | OFFSET | CORRECTED STATE PLANE COORDINATES |
|---|---|---|---|---|---|
| 1 | Light pole 50 ft beyond line connecting fountain-museum dome-statue | | | | |
| 2 | Line crossing 19th 96 feet south ot far (south) side of Cherry. | | | | |
| 3 | Line across 19th 80 feet north of near (north) side of Pine. | | | | |
| 4 | Light pole 145 ft. past far (east) curb line of 9th. | | | | |
| 5 | Line crossing Market 106 ft. West of west curb of 7th. | | | | |
| 6 | Line crossing 13th 165 ft. north of far (north) side of Arch. | | | | |
| 7 | Line crossing Ridge 132 ft south of curb on Spring Garden. | | | | |
| 8 | Line crossing 6th 140 feet south of curb on Race. | | | | |
| 9 | Light pole 101 ft. past west curb line of 10th. | | | | |

TABLE A-4. TIMEPOINT LOCATIONS (cont)

| TIMEPOINT | POSSIBLE SPECIFIC LOCATIONS | TSC SELECTED LOCATION | STATE PLANE COORDINATES AT INTERSECTION | OFFSET | CORRECTED STATE PLANE COORDINATES |
|---|---|---|---|---|---|
| 10 | 97 feet east of near (east) curb line of 23rd on Walnut. | | | | |
| 11 | 137 ft. west of near (west) curb line of 23rd on Chestnut. | | | | |
| 12 | 94 ft. west of west curb line of 18th crossing JFK. | | | | |
| 13 | 21 ft. north of north curb line of Market crossing JFK. | | | | |
| 14 | Near (west) curb line of Broad crossing so. Penn Square. | | | | |
| 15 | 150 feet east of east curb line of 18th crossing Callowhill. | | | | |

The in-vehicle equipment configuration for special case testing is the same as that required for fixed and random route tests.

### A.4.3.1 High Speed Test

Objective. The objective of the high speed test is to determine the location accuracy and hit-miss statistics of the AVM system with vehicles traveling at high speeds.

Procedure. The portion of the Schuylkill Expressway used for the test is the section of road between the city avenue entrance and the Girard Avenue exit.

The maximum speed of the vehicle approaches 60 mph but the actual test speed will be determined by the vehicle operator at the time of the test. The safety of the personnel during the test is paramount and because of the type of camper vehicle used for the test and the variable weather conditions, maximum safe speed can only be determined at the time of the tests. Two test runs will be made to ensure satisfactory data.

Data Reduction. The location accuracy at each interrogated vehicle position (at the subsystem data rate) is determined as well as the average location error figures. Hit-miss statistics are processed to determine the AVM coverage of the test route.

### A.4.3.2 Underpass Test

Objective. The objective of the underpass test is to determine the location accuracy and the hit-miss statistics when the moving vehicle is under an overpass road configuration.

Procedure and Processing. Three overpasses above the Schuylkill Expressway between the City Line exit and the Franklin Parkway exits are used for the test. Twelve passes of this section of road are made and data collected at each underpass. With the vehicle traveling at 20 to 30 mph, the Hazeltine operator enters an event number at the time the vehicle passes a known location marker along the road, which is just before the underpass entrance. Upon leaving the underpass region, the operator presses the leave point button.

Data Reduction. All the data gathered during the underpass interval (identified by the event marks) is processed to obtain accuracy and hit-miss statistics.

### A.4.3.3 GDOP Test

Objective. The GDOP test is performed to demonstrate the effect of GDOP (Geometric Dilution of Precision) on the measurement location accuracy of a basic trilateration AVM system. A 360 degree region around a receiver site is tested utilizing the AVM instrumented vehicle.

Procedure. The GDOP test is a fixed vehicle test with the vehicle placed at twenty randomly spaced points within a half mile radius from the Landis State Hospital receiver site. The test points are located utilizing the DIME maps and the identified street intersection node points. The X and Y coordinates are inputted via the central site control panel. Three hundred data points are gathered at each test location and the average location deviation along the X map coordinate, Y map coordinate and the radial error component will be calculated and documented.

Data Reduction. GDOP test data is processed independently for large and small triangular cells.

### A.4.3.4 Signpost Tests

Objective. The Greenlawn signpost tests are made to determine the effect of the street environment on the performance of the signpost units.

Procedure & Data Recording. Initially, antenna pattern tests divorced of the street environment were made at the Hazeltine Smithtown Wheeler Laboratory test range. Sum and difference patterns at three elevation angles were recorded and shown to be within specification.

The signpost unit was then mounted on a light pole on Cuba Hill Road, east of the Hazeltine Building #1, and signpost detection tests performed. The trailing edge of 10 dB notch (-15 degrees from boresite) will be placed at right angles to the street by orientation of the signpost unit. In this street environment, radiation field intensity measurements along the road will be taken with the signpost mounted at 10, 15, 20 and 25 feet above the roadway. A ratio measurement of the sum and difference signals received by the AVM transponder receiver will be made, utilizing an oscilloscope, as the vehicles pass by the signpost to demonstrate proper time point passage. Data will be recorded with the vehicle traveling at 10, 15, 20 and 30 mph past the signpost. Also, tests with a Hazeltine truck parked in front of the signpost and between the signpost and the moving vehicle will be performed with the signpost at the specified heights to determine any detrimental effects on the signpost performance due to blockage or multipath.

The effect of ignition noise from other vehicles in the area on the time point detection process will be examined utilizing the oscilloscope.

A controlled laboratory temperature test will be made on the signpost unit to demonstrate proper performance of the unit over temperature extremes. Total power consumption from the unit battery source will also be recorded.

### A.4.3.5 Power Line Interference Test

Objective. The effect of power line interference on the AVM accuracy and coverage performance will be demonstrated in the region near the Philadelphia 30th Street Railroad Station.

Procedure and Processing. The subsystem data gathered during the 18 passes of the fixed route test from the time the vehicle leaves John F. Kennedy Boulevard to travel around the R.R. Station to the time the vehicle returns to this road will be processed separately to derive the AVM accuracy and hit-miss statistics in a noisy environment. The start and end points of the vehicle noise test run will be identified by event markers.

### A.4.3.6 Trilateration System Time Point Measurement

Objective. The object of the trilateration system time point test is to demonstrate satisfactory AVM time point measurement without the need of signpost units for the operation situations where the vehicle is traveling at reasonable speeds in a suburban environment.

Procedure & Analysis. This special test will use a Fairmount Park road near the East River Drive. Three time points will be located, utilizing the DIME node map, approximately 0.5 miles apart. Ninety passes will be taken past these points to obtain sufficient data for the time point statistical analysis. Past Dallas test data of the Hazeltine AVM system has demonstrated the statistical independence of points that are as close as 10 feet apart and also of data taken at the same point at different times. Therefore, the proposed test configuration should produce valid statistical data of AVM time point performance. The vehicle will travel the prescribed test route at a speed of 20 to 30 mph.

Time point data will also be gathered during the fixed route test as the vehicle passes the time points (signpost locations) of this route. Therefore, this data is also available for analysis of time point AVM performance in an urban environment.

### A.4.3.7 Noise Measurements

Objective. Internal equipment noise measurements and external man-made noise measurements will be performed to determine the characteristics of the suburban and urban noise environment which the Hazeltine AVM system must encounter. It will be determined if the external noise at 900 MHz has a Gaussian or an impulsive characteristic.

The effectiveness of the vehicle receiver equipment noise blanker against automobile ignition and other types of spark noise will be demonstrated. Also, the effect of the noise at the fixed site receiver locations on pulse preamble decoding of the synchronization/calibration transmitter emissions will be evaluated.

Procedure and Analysis. A preliminary survey of the test area will be made with the Empire Devices 105A noise meter and the AVM transponder mounted in the test vehicle, using the blade antenna that is mounted on the roof of the vehicle. High intensity noise areas will be searched, especially near the 30th Street Railroad Station. Measurements with the 105A meter with the selector in the carrier and peak positions will be made and their level ratio calculated to determine if the noise is impulsive in nature.

Vehicle Receiver Tests. A controlled test will be made with the AVM transponder receiver at the 30th Street location to determine the frequency of noise pulse crossings at the 15 and 30 dB threshold settings above internal noise. The sampling interval will be set at one second. The test will be made with and without the noise blanker in the receiver circuit. The test will be made during the morning and evening rush hours and a quiet hour during the early morning. Two hundred seventy samples will be taken for each test. The data with and without noise blanker will be plotted in a histogram format.

Fixed Receiver Site Tests. Similar tests as described above will be made at all four fixed receiver sites. Because it is impractical to gather noise data at the fixed site receiver antenna located on a tower several hundred feet high, the AVM fixed site antenna and the AVM rf receiver assembly and its associated 60 MHz IF output cable will be used for collection of noise data, rather than the standard Empire field intensity measurement antenna.

The 60 MHz output of the AVM receiver front end will be connected to the Empire 105A meter and the carrier and peak values of the noise measured. Their calculated ratio will determine if the noise is impulsive or Gaussian in nature.

Utilizing the AVM rf receiver assembly and the receiver/processor assembly will allow measurements of the frequency of noise pulse crossings. The frequency of noise crossing of the 15 and 30 dB thresholds above internal noise will be taken at the one second sample interval. Also, the number of false decodes of the synchronization and calibration preamble codes will be taken over a one hour period. The 30 dB threshold is normally set for the calibration decode period. The 15 dB threshold level is normally used during the vehicle reception period. The receiver is blanked off except for the time slot period of vehicle transmitter emission.

The test will be made during the morning and evening rush hours and a quiet hour during the early morning. The data will be plotted in the histogram format.

# APPENDIX B

## Report of Inventions

Phase I of this contract called for the demonstration and testing only of off-the-shelf components of an AVM system. Therefore, there were no inventions conceived or first actually reduced to practice under this contract.

However, in the course of the testing program, adjustments were made in two of the system parameters. These were described in this report in Volume II, Section IV, Paragraph 4.01, System Improvements. The improvements describe the Zero Fill Modification and the change in fixed receiver Siting.

In addition, the signposts were shown to operate at the same frequency as the assigned system frequencies. Reference Volume II, Section II, Paragraph 2.1.2, System Timing.

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