NBS Special Publication 480-19

Digital Data Transmission Tests on Voice Channels

Law Enforcement Equipment Technology

42845 c.5

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards

ACKNOWLEDGMENTS

This report was prepared by the Law Enforcement Standards Laboratory of the National Bureau of Standards under the direction of Marshall J. Treado, Program Manager for Communications Systems, and Jacob J. Diamond, Chief of LESL. The principal investigator on this project was John Furze of Urban Sciences, Inc. The assistance and cooperation of the personnel of Allegheny County, Pennsylvania, is deeply appreciated.

NBS Special Publication 480-19

Digital Data Transmission Tests on Voice Channels

by
Urban Sciences, Inc.
177 Worcester Street
Wellesley, Mass. 02181

prepared by
Law Enforcement Standards Laboratory
Center for Consumer Product Technology
National Bureau of Standards
Washington, D.C. 20234

prepared for
National Institute of Law
Enforcement and Criminal Justice
Law Enforcement Assistance Administration
U.S. Department of Justice
Washington, D. C. 20531

Issued July 1977

U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, *Secretary*
Dr. Sidney Harman, Under Secretary
Jordan J. Baruch, Assistant Secretary for Science and Technology
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Acting Director*

Library of Congress Catalog Number: 77–6 000 23
National Bureau of Standards
Special Publication 480-19
Nat. Bur. Stand. (U.S.), Spec. Publ. 480-19, 63 pages
CODEN:XNBSAV

U.S. GOVERNMENT PRINTING OFFICE
WASHINGTON:

For sale by the Superintendent of Documents,
U.S. Government Printing Office, Washington, D.C. 20402
(Order by SD Catalog No. C13.10:480–19). Stock No. 003–01773–6 Price $2.10
(Add 25 percent additional for other than U.S. mailing).

FOREWORD

The Law Enforcement Standards Laboratory (LESL) of the National Bureau of Standards (NBS) furnishes technical support to the National Institute of Law Enforcement and Criminal Justice (NILECJ) program to strengthen law enforcement and criminal justice in the United States. LESL's function is to conduct research that will assist law enforcement and criminal justice agencies in the selection and procurement of quality equipment.

LESL is: (1) Subjecting existing equipment to laboratory testing and evaluation and (2) conducting research leading to the development of several series of documents, including national voluntary equipment standards, user guidelines, state-of-the-art surveys, and other reports.

This document is a law enforcement equipment report developed by LESL under the sponsorship of NILECJ. Additional reports as well as other documents are being issued under the LESL program in the areas of protective equipment, communications equipment, security systems, weapons, emergency equipment, investigative aids, vehicles, and clothing.

Technical comments and suggestions concerning the subject matter of this report are invited from all interested parties. Comments should be addressed to the Law Enforcement Standards Laboratory, National Bureau of Standards, Washington, D.C. 20234.

Jacob J. Diamond, *Chief*
Law Enforcement Standards
Laboratory

CONTENTS

LIST OF TABLES

Preceding page blank

DIGITAL DATA TRANSMISSION TESTS ON VOICE CHANNELS

To study the transmission and reception of digital data over typical voice channels, a series of tests was performed in Allegheny County, Pennsylvania, using existing local government transmitting sites and a specially equipped mobile unit. Carrier frequency, digital data transmission rate, modulation technique, range of transmission, speed of the mobile unit, and time of day were varied. The tests were conducted in both urban and suburban environments.

Key words: Data transmission tests; digital data transmission; mobile digital transmission equipment; voice channels for digital transmission.

1. INTRODUCTION

This report presents the details of tests of digital data transmission over typical voice grade FM mobile radio channels. The main objective of the tests was a determination of certain aspects of digital data propagation in the FM mobile radio environment. These tests were conducted in Allegheny County, Pennsylvania, during the period November 1973-January 1974.

Of significant importance to the operation of law enforcement digital communication equipment is the requirement that it interface with existing police radio networks. These networks provide the existing voice communications for police operations and will also provide the media for almost all future communications. The frequencies which compose these networks are selected from both the VHF and UHF bands allocated for law enforcement land-mobile usage. Each of these frequency bands have different propagation characteristics which affect digital data transmission in different ways. As a result of a prior study [8][1] it was found that the data rates which are used to transmit information digitally vary from about 300 to 3000 bits/second depending on the type of channel involved and the capability of the equipment being offered.

It was mainly because of these two variables that tests were undertaken to measure the message error rate at these two frequency bands and at various data rates. Other parameters which were varied during the tests were modulation technique, speed of vehicle, distance of vehicle from base station, and time of day. The amplitude and envelope delay vs. audio frequency responses of the two radio systems used in the tests were also measured. Test results are included in this report as appendices.

In addition, a general description of the tests is included along with a discussion of the location of the transmitting sites and the routes used during the tests. Characteristics of the FM radio equipment are also discussed along with the data modems and the data generating terminal equipment.

The section on test procedures includes those used in the alignment and adjustment of operating levels of the radio equipment. The detailed interface parameters between the modems and the radios are also described. Test methods for the frequency response and the digital data tests may also be found in this section.

The section on test results includes a comparison of the various data and a discussion of the effects of impulse noise, fading, and the speed of the test vehicle and carrier frequencies with respect to errors in the data. A comparison between the theoretical calculations and the empirical data with respect to probability of bit error is also provided.

[1] Figures in brackets indicate the literature references at the end of this paper.

2. GENERAL DISCUSSION OF THE TESTS

2.1. General

The testing consisted primarily of transmitting a known digital data message of fixed block length from a base site to a test vehicle. The test vehicle received and decoded the data and compared the received data with a replica of the transmitted data, thereby determining the error rate. The test vehicle was driven on predetermined routes and a test pattern transmission was initiated from the base location when the vehicle was at the selected test points.

Co-located VHF and UHF transmitters were used for the tests. The VHF transmitting frequency was 39.02 MHz, and is presently operational as the dispatching channel for the County of Allegheny Police. The UHF frequency used was licensed to the County Health Department at 453.8 MHz. Both transmitting sites were located on top of a knoll overlooking the city of Pittsburgh.

A number of parameters were varied during the tests in addition to the carrier frequency of operation (i.e., 39 vs. 454 MHz). The tests were performed with two modulation techniques, noncoherent frequency shift keying (FSK) and noncoherent phase shift keying (PSK), i.e., DPSK. Three data rates were investigated with FSK and two with DPSK, with one common data rate. The reasons for the selection of the data rates are discussed in paragraph 3.5. Vehicle speed was varied from 0-45 miles per hour at distances up to 10 miles.

2.2. Description of Base Site and Test Routes

The base transmitting site was located at the La Grande Apartments at Grandview Avenue and Sweetbriar Street in the Duquesne Heights area of Pittsburgh, Pennsylvania. This site is southwest of the downtown Pittsburgh area, and the apartment building consists of eight floors and is at a natural elevation of 1180 feet, giving an antenna height of approximately 1250 feet. The terrain of the greater Pittsburgh area becomes evident when it is observed that there is more than a 400-foot drop from the antenna site to the Ohio River in approximately two-tenths of a mile.

Three routes were selected for the mobile data tests; a downtown route, a north suburban route, and a south suburban route. The locations of the base transmitting site and the downtown route are shown in figure 1. There are 10 test points in the downtown route, as designated on the map. These test points are also listed in table 1. The north suburban and south suburban routes are shown in figure 2. Both routes consist of over 20 test points, as indicated on the map and in the lists of locations in tables 2 and 3.

TABLE 1. *Downtown route locations*

Location	Description
1	Strawberry Way & Grant
2	Grant & Oliver
3	Grant & 4th
4	Blvd. of Allies & Smith Field
5	Blvd. of Allies & Market St.
6	Stanwix & 3rd
7	Stanwix & Market St.
8	Liberty & Market St.
9	7th & Garrison
10	7th & William Penn

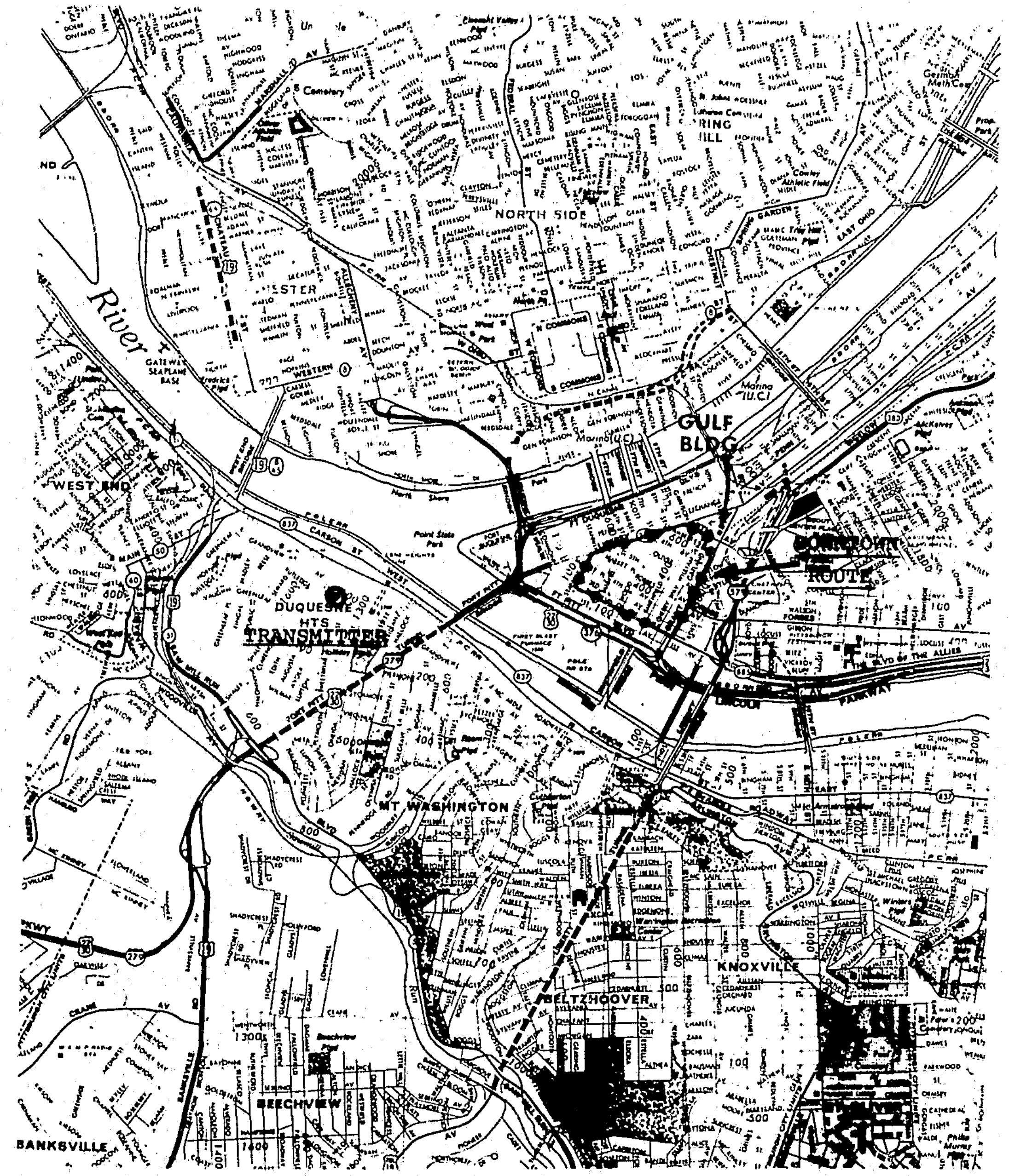


FIGURE 1. *Downtown route.*

In addition to the maps of the test areas, photographs of the area surrounding the test site were taken and are included to show the terrain; all were taken from the roof of the apartment building. The first photograph, figure 3, was taken looking east toward the downtown Pittsburgh area. Figures 4 and 5 are both of the north suburban route. The former is a photograph of the first leg of the route traveling northwest along the Ohio River, while the latter is of the return leg down the Allegheny River. Figure 6 was taken looking due south, the cross-country leg of the south suburban route being behind the first group of hills.

TABLE 2. *North suburban route locations*

Location	Description
1	Saw Mill Run & Rte 60
2	Ohio River Blvd. & Marshall Ave.
3	Ohio River Blvd. & McKees Rocks Brdg.
4	Ohio River Blvd. & Bellevue
5	Ohio River Blvd. & Fisk
6	Ohio River Blvd. & Greenbelt
7	Greenbelt & Crawford
8	Greenbelt & Lawries Run
9	Greenbelt & Heis Run
10	Greenbelt & Rte 19
11	Greenbelt & McKnight
12	Greenbelt & Duncan
13	Greenbelt & Hubbard
14	Greenbelt & Rte 8
15	Rte 8 & Elfin Wild
16	Rte 8 & Spencer
17	Rte 8 & Saxonburg
18	Rte 8 & Etna
19	Rte 8 & Parker
20	Rte 8 & Hoffman
21	Rte 8 & Herrs Island
22	Rte 8 & Heinz
23	9th St. & Railroad Brdg.

TABLE 3. *South suburban route locations*

Location	Description
1	Merimao St.
2	South 51 & Liberty Tubes
3	Rte 51 & Edgebrook
4	Rte 51 & Rte 88
5	Rte 51 & Brownsville Rd.
6	Rte 51 & Whitehall Boro Bldg.
7	Rte 51 & Curry Hollow Rd.
8	Curry Hollow & Brownsville
9	Broughton & E. Park
10	Broughton & Library
11	Connor & Oregon Trail
12	Washington & Mt. Lebanon Blvd.
13	Rte 19 & Washington
14	Rte 19 & Beverly
15	Rte 121 & Greentree
16	Main St., Carnegie
17	Entrance to Rte 79
18	Rte 279 & Chartiers
19	Rte 279 & Carnegie Exit
20	Rte 279 prior to Greentree
21	Rte 279 after Greentree
22	Rte 279 & Rte 51

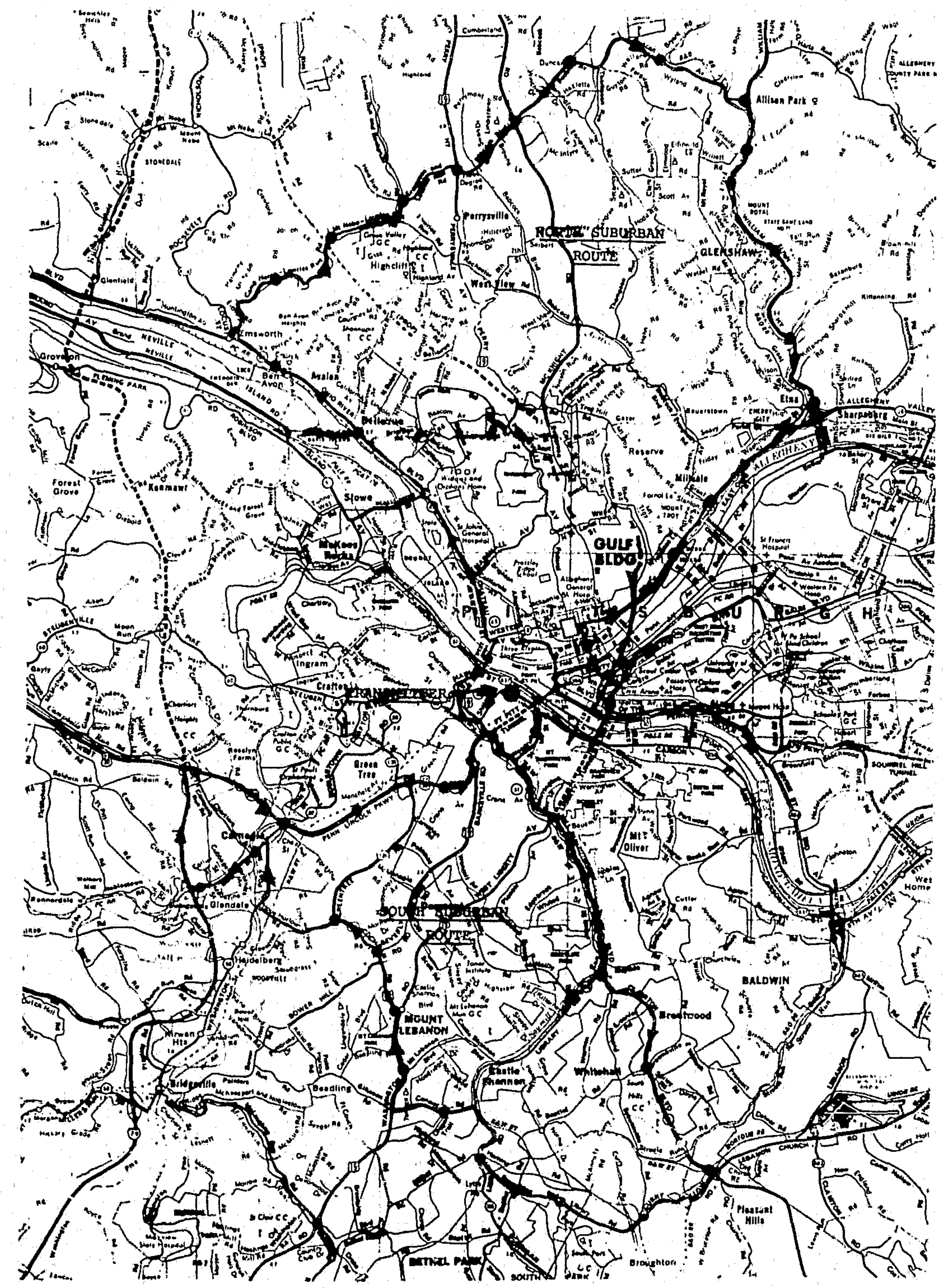


FIGURE 2. *Suburban routes.*

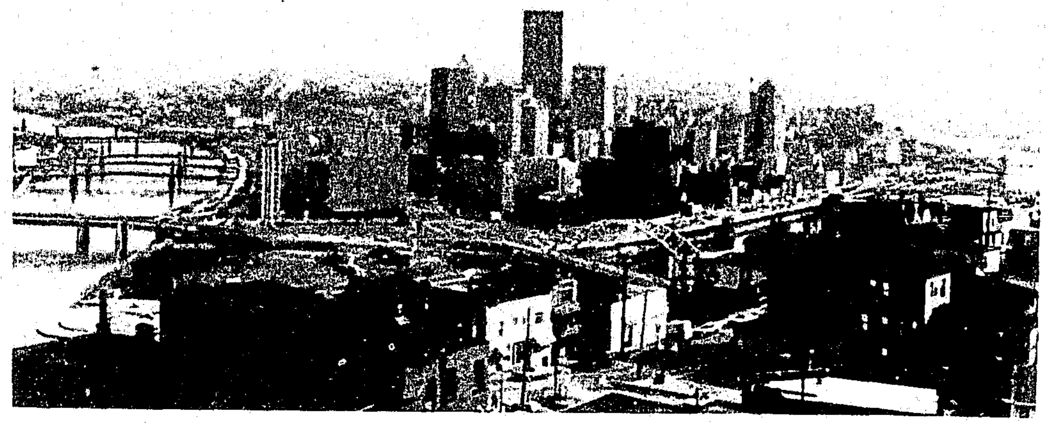


FIGURE 3. *View looking east from transmitter site.*

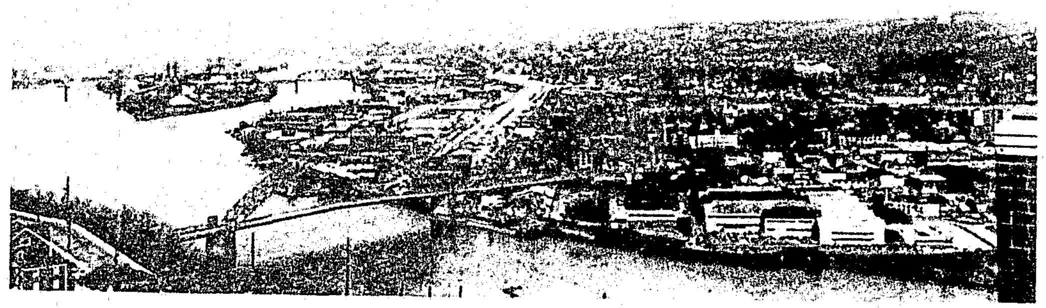


FIGURE 4. *View looking northwest from transmitter site.*

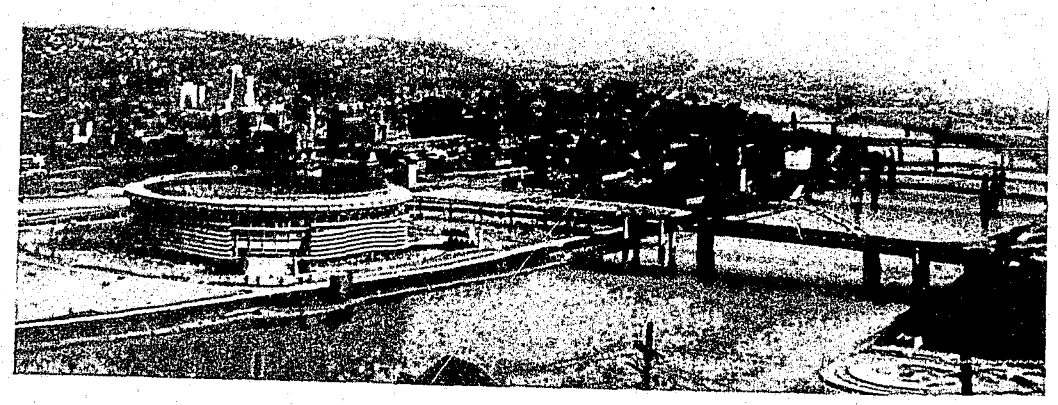


FIGURE 5. *View looking northeast from transmitter site.*

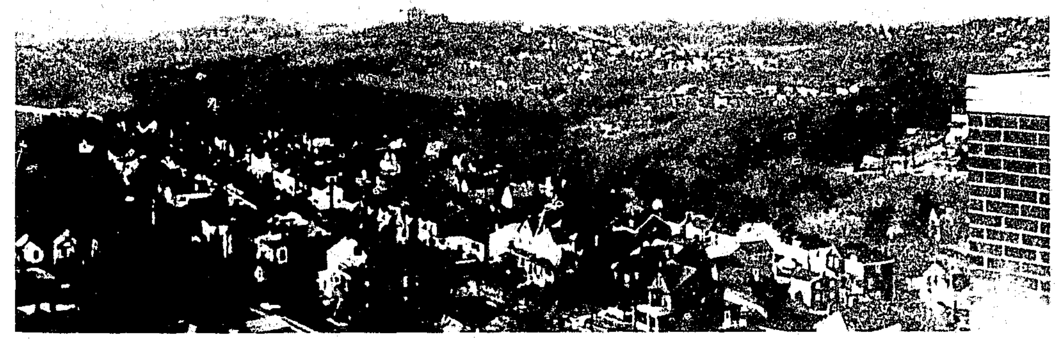


FIGURE 6. *View looking south from transmitter site.*

2.3. Description of Radio Equipment

Both the county police VHF system and the county health UHF system base station and mobile transceivers were of the same manufacture. They were hybrid equipment, primarily solid-state with a tube-type power amplifier.

The VHF base transmitter was floor mounted and rated at 330 watts of rf output power. It was connected to the rooftop antenna by 100 feet of 50 ohm aluminum-sheathed foam-filled cable. The antenna was a monopole antenna with gain equal to a half-wave dipole. The mobile transceiver used was rated at 100 watts of output power with a 12 dB SINAD sensitivity level of 0.25 μV. The 0 dB omnidirectional gain mobile antenna was mounted on the trunk.

The UHF base transmitter was also a floor mount installation located in the same room as the VHF base station. It was rated at 250 watts of output power. The antenna system consisted of a colinear array with 10 dB omnidirectional gain and was coupled to the base transceiver with 100 feet of 50 ohm corrugated copper foam-filled cable. The output power of the mobile transceiver was 75 watts and it had a 12 dB SINAD sensitivity level of 0.35 μV. The mobile trunk mount antenna had an omnidirectional gain of 5 dB. The base antennas are shown in figure 7 (camera looking northeast), while the mobile antennas are pictured in figure 8.

2.4. Description of Data Equipment

The base station data generating equipment was required to form a known bit pattern at baseband, convert the bit pattern into an analog signal by either of the two desired modulation techniques, transmit the data at each required transmission rate, and provide an analog signal compatible in level and frequency content with the radio equipment. The mobile data receiving equipment was required to decode the data at all transmission rates and accept the analog signal for decoding from a suitable output at the radio receiver, convert the analog signal into baseband data at each modulation technique, and determine the bit error rate.

The terminal equipment and modems, which were leased, consisted of two TLA-3000 Telephone Line Analyzers, two 1800B Data Modems and two 2400B-1 Data Modems.

One TLA-3000 served as the source of the baseband data, a 511-bit pseudo-random pattern normally used for checking error rates on telephone lines. The second telephone line analyzer served as a receiver of the baseband data in the test vehicle. The mobile telephone line analyzer also made a comparison between the received data and the known transmitted pattern (stored in memory) in order to determine the bit error rate

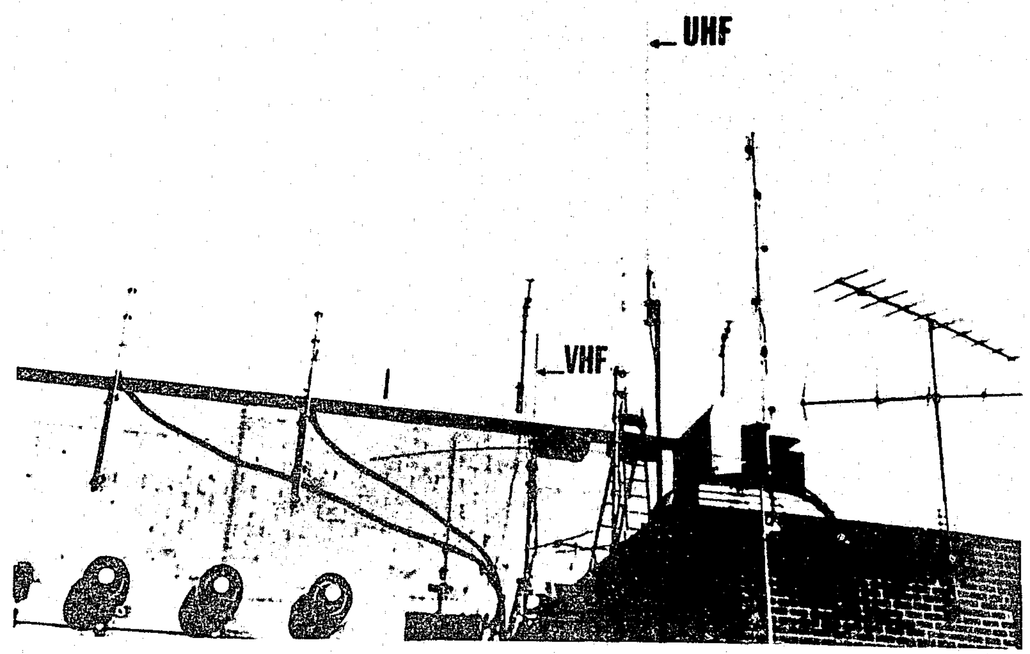


Figure 7. *Base station antenna site.*

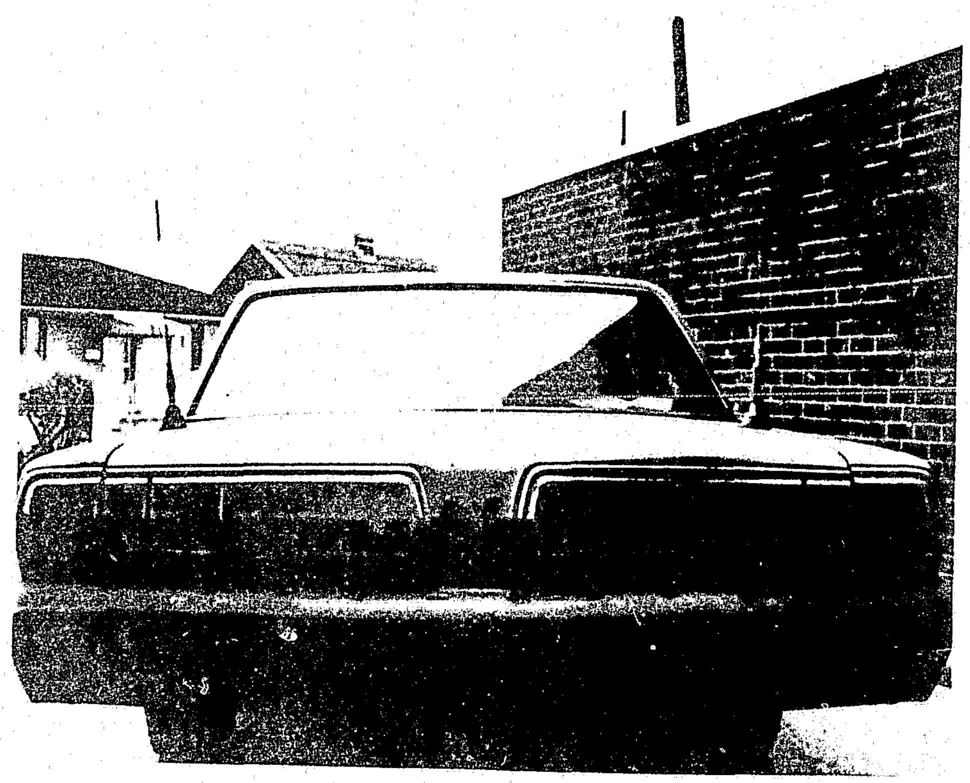


Figure 8. *Test vehicle with antennas.*

Both of the TLA-3000 terminal units were interfaced with the modems by means of standard connectors [2].

The 1800B data modem was an asynchronous FSK modem with an externally clocked variable data rate from 300 to 1800 bits per second. The analog transmit output provided the FSK information at 0 dBm at 600 Ω. The receiver of the modem was capable of decoding any compatible FSK signal within a dynamic range of 0 to −50 dBm.

The 2400B-1 modem employed a synchronous (internally clocked) DPSK modulation scheme. It operated at two data rates, 1200 and 2400 bits per second. Since it was a four-phase modem, this signaling rate was equivalent to 600 and 1200 baud. The analog transmit output and the received dynamic range were similar to the 1800B.

Both the TLA-3000's provided the necessary functions to determine the amplitude and envelope delay vs. audio frequency response of the FM radio system. The details of these tests are given in paragraph 3.4. Because of equipment voltage requirements, a dc-to-ac converter (inverter) was used to provide the 120 Vac, 60 Hz power in the test vehicle.

The receive analyzer and modem and the transmit analyzer and modem are shown in their test positions in figures 9 and 10. Basic block diagrams of the transmit and receive configurations are shown in figures 11 and 12.

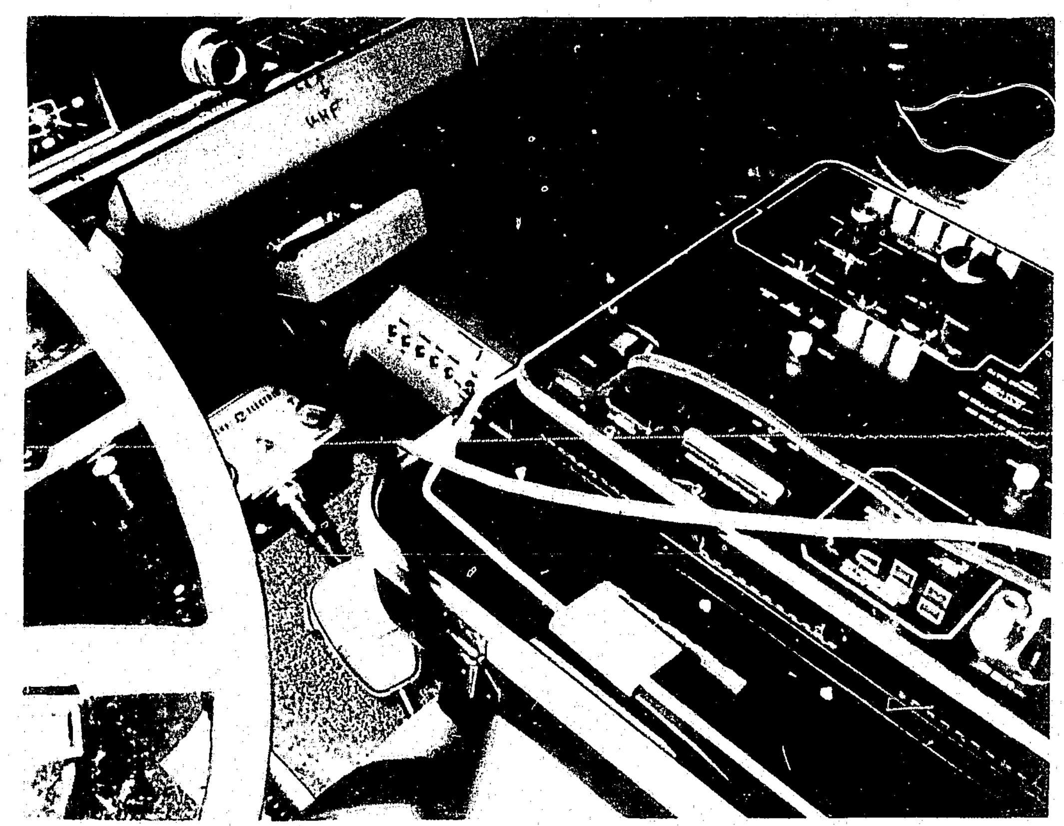


Figure 9. *Receive analyzer and modem in vehicle.*

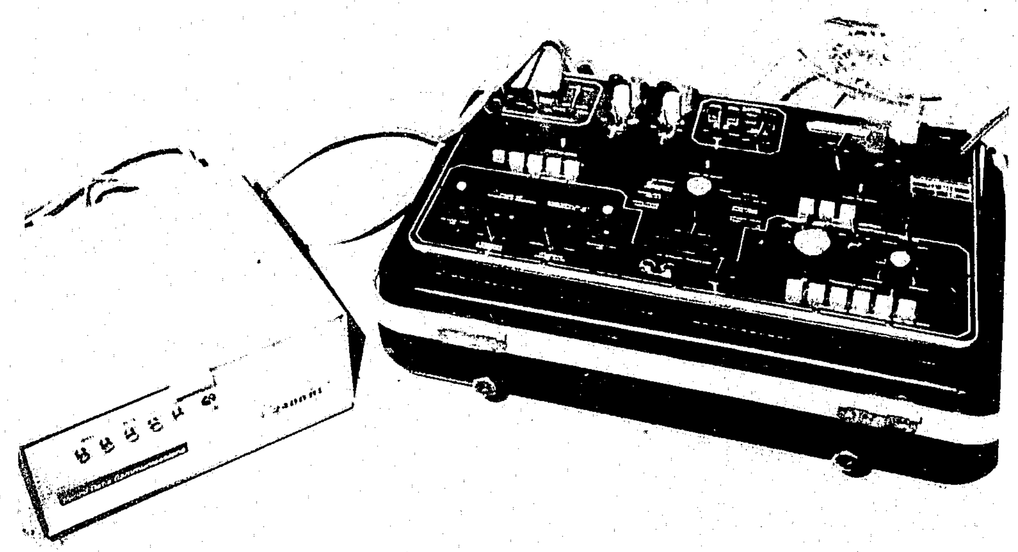
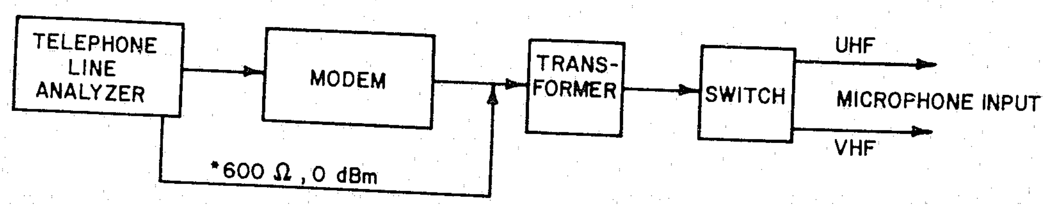
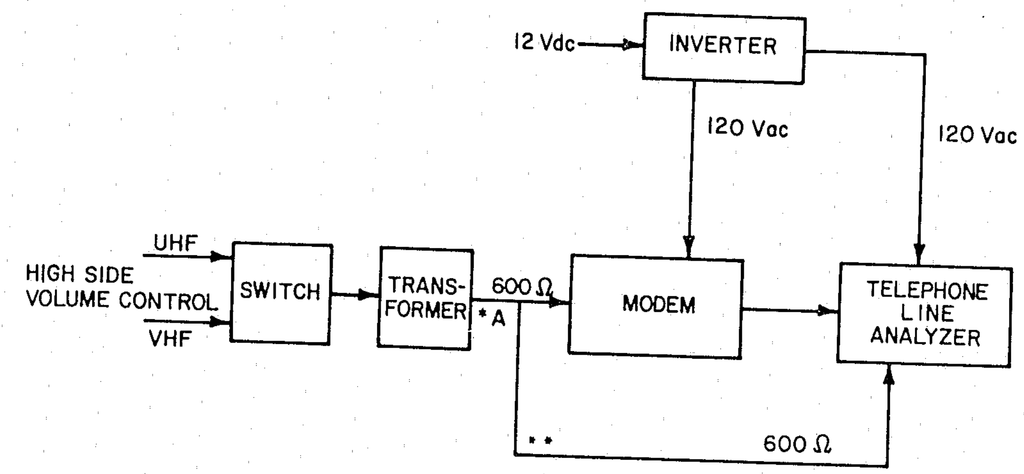


FIGURE 10. *Transmit analyzer and DPSK modem at base station.*



*USED FOR AMPLITUDE AND ENVELOPE DELAY RESPONSE TESTS

FIGURE 11. *Data transmit configuration.*



*LEVEL AT POINT A TO BE WITHIN DYNAMIC RANGE OF RECEIVE MODEM.
**USED FOR AMPLITUDE AND ENVELOPE DELAY RESPONSE.

FIGURE 12. *Data receive configuration.*

3. TEST PROCEDURE

3.1. General

The initial tests were performed on the mobile transceivers that were used to receive the data in the test vehicle. The radio manufacturer's adjustment and alignment procedure for the mobile receiver was followed. Both base transmitters had had preventive maintenance servicing within 3 months of the tests so they were not adjusted or aligned solely for the data tests. Tests were performed to determine the modulation index and signal levels needed to provide good data transmission quality. The effective radiated power of both transmitters was obtained (see par. 3.2).

In order to provide the proper interface between the modem and the transmitter and receiver, pads and transformers were selected so that the proper input/output levels would be achieved. The signal generator/power meter mode of the telephone line analyzer was very helpful in determining these values.

Test procedures were developed for the measurement of the amplitude and envelope delay response of each of the radio systems. The information recorded from these two tests was used for characterizing the channel with respect to bandwidth limitations. The frequency response information was also used to determine the equalizer settings on the modems.

3.2. Preliminary Tests

Initial tests were performed on both the VHF and UHF mobile receivers using procedures recommended by the manufacturer. The receiver alignment included discriminator and oscillator checks, rf amplifier and selectivity adjustments, and a rf frequency adjustment. The audio power output and distortion, usable sensitivity, and the modulation acceptance bandwidth were also measured and were found to be within acceptable limits.

The base station transmitters had received a service check 3 months prior to their use in the data tests so the transmitter alignment procedures were not instituted. The service check had indicated that both transmitters were within manufacturer's specifications. As the power output of the final power amplifier is a frequently adjusted variable, measurements of the incident and reflected power of both systems were made. The results of the measurements indicated that the effective power reaching the antenna terminals, accounting for all mismatches and line losses, was 100 watts in the VHF mode and 150 watts in UHF. The gain of the VHF monopole was approximately 2 dB, while the gain of the UHF colinear array was approximately 10 dB, above an isotropic radiator. Taking the antenna gains into account, the effective radiated power of each system, referenced to an isotropic radiator, becomes 160 watts for VHF and 1500 watts for UHF.

3.3. Modem—Radio Interface

The transmit and receive modem—FM radio interface required the use of impedance matching transformers and resistive attenuators in order to provide the proper signal levels for data transmission. However, the first step in the interface problem was the determination of the proper signal level at the transmit microphone input in order to produce a reasonable modulation index.

The 2400B-1 DPSK modem uses a carrier frequency of 1800 Hz while the mean of the two frequencies used in the 1800B FSK modem is 1700 Hz. The audio power output of both modems is 0 dBm. A variable level test tone at 1750 Hz was chosen because it was a tone central to the power spectra of all the data of both modems. A communications monitor was used to receive and display the test tone on a calibrated scale. With the deviation displayed, the signal level at the microphone input of the transmitter was increased until distortion of the received test tone was observed on the display. The distortion occurred at a deviation of ±2.8 kHz for both the VHF and UHF radio systems. The input signal level required to produce the highest distortionless deviation was read from the telephone line analyzer and recorded. Knowing this required input level and the standard output of the modems (0 dBm), an impedance-matching transformer and resistive attenuator were chosen.

The transmit connection to the modems (600 Ω balanced, 0 dBm) fed a 600 Ω balanced "H" attenuator which provided 40 dB of loss. A 500 Ω to 50 KΩ audio transformer provided the impedance match to the microphone input. The microphone input was bridged by the data transmit line in order to retain the capability to provide voice communication to the mobile and manual transmitter keying for data transmission.

The receiver interface was made to the high side of the audio volume control of the mobile radios. This point was chosen for two reasons: first, ease of accessibility (located in the front of the vehicle while the discriminator output was located in the trunk) and second, this point was prior to de-emphasis of the recovered audio. The level requirements for this, the data receive point, were not severe since the receive modem has a wide dynamic range. The receive data requirement was reduced to the problem of stripping the recovered audio data from the volume control without appreciably degrading voice coverage and yet coupling at least −45 dBm of signal into the receive modem. This was achieved by bridging the volume control with a 10 KΩ to 500 Ω audio transformer. Again the transmit telephone line analyzer was used as a test tone source at 1750 Hz in order to deviate the transmitters. However, since the input attenuator and matching transformer were connected to the microphone input, the output level was set at 0 dBm to simulate the audio level of the transmit modem. The second telephone line analyzer was used at the receiver as a power meter in order to determine whether or not the received audio power was within acceptable limits. With the previously mentioned audio transformer in place, the receive level at 1750 Hz was −19 dBm, well within the

range of the modem. These interface considerations pertained to both the VHF and UHF base transmitters and receivers so the same interface circuitry was used for both pieces of equipment.

3.4. Frequency Response Tests

Two independent tests of the frequency response of the VHF and the UHF radio systems were made. In one of the tests the variation in the received audio amplitude with frequency was recorded while an audio signal of constant power but variable frequency was used to modulate the transmitter. In a second test, the relative envelope delay vs. frequency was measured. As in the amplitude response test, an audio signal of constant power and variable frequency was used to modulate the transmitter. However, in the case of the envelope delay test, the audio test frequency was modulated to produce known sidebands, which when received, facilitated the actual measurement of the envelope delay.

The amplitude response and the envelope delay response were measured using the two telephone line analyzers. In the case of the amplitude response measurement, the transmit analyzer was set to a mode in which it served as a variable frequency signal generator. The audio output of the transmit analyzer was a constant 0 dBm and the frequency was swept manually from 300 to 3000 Hz. The receive analyzer was used as a frequency selective power meter when the amplitude response mode was selected. It provided a digital readout of the frequency and the absolute power level of the received audio test tone within a short settling time. In performing the actual tests, the transmitter was keyed and then the test tone was applied, resulting in the received tone level being displayed in the mobile unit. These tests were performed at several discrete frequencies throughout the 300 to 3000 Hz range. The relative received levels (referenced to the received level at 1750 Hz; −19 dBm) are plotted vs. frequency for both the VHF and the UHF systems in appendix B.

The envelope delay measurements were made in a similar manner except for the fact that the test tone was modulated to create sidebands. This modulated audio carrier was detected at the receive analyzer and the phase distortion introduced into the sidebands due to the frequency sensitive envelope delay of the channel was measured and displayed as relative envelope delay in microseconds. The telephone line analyzers were capable of making simplex envelope delay measurements through the use of a receiver synchronization technique. The initial tone transmission was made at 1800 Hz, and after a synchronization time in which the receive analyzer oscillator circuitry was corrected, the test was initiated. The transmit frequency was varied, searching for a minimum envelope delay reading on the receive analyzer. The frequency at which the minimum was found was used as the reference frequency. At this point, the synchronization process was repeated at the new reference frequency. Once the receive analyzer display was stabilized, the correction factor was inserted into memory by depressing a button on the receive analyzer. The transmit frequency was then varied throughout the audio range, and the received frequency and the relative delay in microseconds were recorded at the mobile unit. These tests were performed in early morning hours to avoid interfering with the normal dispatching procedures carried out on the radio systems. The envelope delay characteristics of the VHF and UHF radio systems are presented in appendix B. The frequency responses of both systems were quite similar. Therefore, their individual influences on data quality were considered sufficiently alike to allow a valid comparison of the propagation characteristics of VHF and UHF.

Since both amplitude and envelope delay distortion, when present to a significant degree, are detrimental to data quality, each modem was equipped with channel equalization. In the case of the DPSK modem, the equalization levels were strap selectable to discrete levels. The level of equalization selected was the minimum provided by the modem, that is, the equalization level for C2 conditioned, dedicated lines. The effect of this line equalization will be discussed later. When the FSK modem was used, the minimum or dedicated line equalization was selected by adjustment of a potentiometer.

3.5. Data Transmission Tests

In order to perform the data tests, one of the modems was inserted between the telephone line analyzer and the radio. The interface from the modem to the radio was identical to the interface used between the analzyers and the radios in the frequency response tests. The interface between the telephone line analyzer and the modem was made with a cable that met the requirements of [2].

To initiate a test transmission, the transmit and receive radio systems were selected at the base and at the mobile. Upon a voice request for data from the mobile, the transmit sequence was initiated. The transmit sequence consisted of depressing the push-to-talk switch on the proper microphone, muffling the microphone in a rubber pad, and initiating the transfer of baseband data from the telephone line analyzer to the modem by selecting a toggle switch. The baseband data was a 511-bit pseudo-random m-sequence generated pattern.

When the data were transferred between the analyzers and the modem, the modem began to convert the baseband bit stream into a corresponding analog pattern, either DPSK or FSK, at the required bit rate. In the case of the asynchronous FSK modem, the clocking signal was provided by the telephone line analyzer and provided continuously variable data rates from 300 to 1800 bits per second. With the DPSK modem, the clocking signal was internally generated and provided two fixed selectable rates: 1200 and 2400 bits per second. When the data were received at the mobile and coupled into the receive modem, the analog modulation was decoded into baseband data and transferred into the receive telephone line analyzer. After a short synchronization time, the two counters on the analyzer were zeroed. After release of the zeroing controls, one of the counters indicated the number of bits received while the other recorded the number of bits in error.

The two modulation techniques used, binary FSK and four phase DPSK, were selected because they corresponded to those readily available in standard modems. The DPSK modem had a standard data rate of 2400 bits per second with an optional selectable rate of 1200 bits per second; both rates were used. Three data rates were used for the FSK tests: 600, 1200, and 1800 bits per second. The choice of 600 and 1200 bits per second for FSK data rates provided a direct correspondence with the 1200 and 2400 bits per second rates of the DPSK modem. This correspondence exists because the baud rates of the two modems are identical at 600 baud and 1200 baud. The 1800 bit per second rate for FSK was chosen to try to evaluate the bandwidth limitations of the channel, as FSK at this rate occupies the greatest bandwidth of all the modulation techniques. The bit block length selected for each transmission was 3000 bits.

Three test routes were chosen for the error rate measurements. The downtown route was driven 5 times at each frequency, taking 10 data points each time, switching between VHF and UHF on alternate trips. This procedure was repeated for each modulation scheme and data rate. Due to the high vehicular traffic density, data were taken at most of the test points while the vehicle was stopped or traveling at approximately 15 miles per hour. A total of 500 test transmissions were made in the downtown area. Test data, including the number of errors in each 3000-bit transmission, are shown in appendix C.

Both the north and south suburban routes were broken into three legs: one radially outward from the base site, one cross-country leg, and a return leg. The total length for

each route was approximately 25 miles, with reception locations at spacings of roughly 1 per mile. Each of the routes was driven twice. The first time a radial outgoing route was tested, the VHF transmitter was used, switching to UHF on the cross-country route, and reselecting VHF on the return leg. This sequence of data transmission was chosen to avoid continued use of a single channel over an extended period of time. The second time a suburban route was tested, the procedure was reversed.

At each test point, the data were taken three times at three different vehicle speeds. These speeds, along with the location, date, and time of test, data rate, modulation scheme, transmitter frequency, and measured errors are also given in appendix C. In order to account for time of day variations, certain portions of the suburban routes were rechecked on different dates. A total of over 1300 test transmissions was made on the suburban routes. Tables 4 and 5 summarize the error rates for each modulation scheme/data rate combination used in the tests.

TABLE 4. *VHF data tests*

Route \ Measured error rate	FSK			DPSK	
	600 bps	1200 bps	1800 bps	1200 bps	2400 bps
Downtown	2.0×10^{-5}	4.7×10^{-5}	6.7×10^{-5}	5.3×10^{-5}	5.3×10^{-5}
South Suburban	1.2×10^{-4}	8.3×10^{-5}	5.7×10^{-5}	1.0×10^{-4}	1.1×10^{-4}
North Suburban	1.5×10^{-5}	1.5×10^{-4}	1.7×10^{-4}	6.8×10^{-5}	9.2×10^{-5}
Both Suburban Rtes.	6.5×10^{-5}	1.2×10^{-4}	1.2×10^{-4}	8.5×10^{-5}	1.0×10^{-4}
All Data Tests	5.3×10^{-5}	9.8×10^{-5}	1.0×10^{-4}	7.6×10^{-5}	8.7×10^{-5}

TABLE 5. *UHF data tests*

Route \ Measured error rate	FSK			DPSK	
	600 bps	1200 bps	1800 bps	1200 bps	2400 bps
Downtown	6.7×10^{-6}	6.7×10^{-6}	2.7×10^{-5}	6.7×10^{-6}	1.3×10^{-5}
South Suburban	8.3×10^{-5}	1.4×10^{-4}	1.8×10^{-4}	8.9×10^{-5}	1.8×10^{-4}
North Suburban	3.2×10^{-4}	9.3×10^{-4}	1.3×10^{-3}	5.1×10^{-4}	1.3×10^{-3}
Both Suburban Rtes.	2.0×10^{-4}	5.5×10^{-4}	7.7×10^{-4}	3.1×10^{-4}	7.5×10^{-4}
All Data Tests	1.5×10^{-4}	4.0×10^{-4}	5.7×10^{-4}	2.2×10^{-4}	5.5×10^{-4}

4. MOBILE DIGITAL DATA TRANSMISSION

4.1. General

The major purpose of the tests was to determine empirically the error rates encountered with digital data transmission over a typical FM voice-grade mobile radio channel. Errors in data transmission are usually caused by two effects: bandwidth limitations, which result in intersymbol interference, and low predetection signal-to-noise ratios caused by low signal levels or high ambient noise, or both. In order to perform a valid comparison of propagation effects on data quality between two carrier frequencies, such as 39 MHz and 454 MHz, the bandwidth limitations and their effect on errors must be taken into account. The bandwidth characteristics of both the VHF and the UHF transmitters were measured prior to the data transmission tests. The results of these tests are presented in appendix B.

The error rate performance is presented in figure 13 as a probability of bit error vs. an average predetection signal-to-noise ratio based on statistical considerations. The noise model used in these calculations assumed a Gaussian distribution. Because skepticism often exists on how well calculated results compare with the actual performance of a real system, empirical data were obtained to support these theoretical results. A direct comparison for various points along the test routes is included in this report.

Other phenomena which affect data transmission over a radio channel are fading and impulse noise. Fading occurs when more than one signal from the same transmitter reaches the receiver and causes either a nulling or reinforcement of the direct-path signal. The secondary received signals are generally reflected into the vicinity of the receiver by nearby manmade structures. Fading phenomena are often characterized by a specific type of multiple signal reception termed Rayleigh fading. Rayleigh fading can be accounted for on an average basis by specifying that the values of the received signal follow a specific distribution based on certain assumptions. Generally, all calculated results presented are based on the assumption of slow and nonselective fading. Many times this first-order model is not applicable due to the fact that for every Rayleigh fading channel there are instants of time during which the signal fades to near the zero value. If the test vehicle were located at such a null (highly unlikely, since a voice request from the mobile has to be received at the base to initiate data transmission), all bits sent would have a high probability of being in error. The more likely effect would be short bursts of errors occurring during the time when a moving test vehicle passes through these deep fades.

Impulse noise is also of importance. This type of noise is usually generated by phenomena such as vehicle ignition and switching transients, and can result in very high probabilities of error. Most common instances of bit errors due to this phenomenon are due to high levels of impulse noise caused by buses or trains.

Both fading signal and impulse noise phenomena occur to different degrees depending on the carrier frequency of operation. These factors, along with the speed of the test vehicle and the data rate, cause the observed variations in the measured bit error rates.

Other matters considered in this report are variations due to changes in the time of day and the type of modulation scheme used. The time of day variations were relatively insignificant, but the effects of the modulation techniques are evident in the results. The relative transmission ranges of digital data and voice are also considered.

4.2. Bandwidth Limitations

In the analysis of most data channels, time dispersion effects of transmitted pulses can be attributed to the imperfect transfer characteristics or frequency response of the channel. In the case of the telephone line, for example, the transfer function is usually expressed in terms of attenuation and delay as a function of frequency. The envelope or group delay illustrates the relative arrival time of various frequency components of the transmitted signal. Attenuation distortion occurs when the relative magnitude of the various frequency components of the original signal is varied.

The frequency components of a binary FSK waveform are not limited to the two signaling frequencies but are spread throughout an infinite bandwidth due to the discrete nature of the signaling process. With this in mind, infinite-bandwidth channels might be considered necessary in order to receive a true replica of the transmitted waveform. However, it has been shown that the amount of bandwidth required is

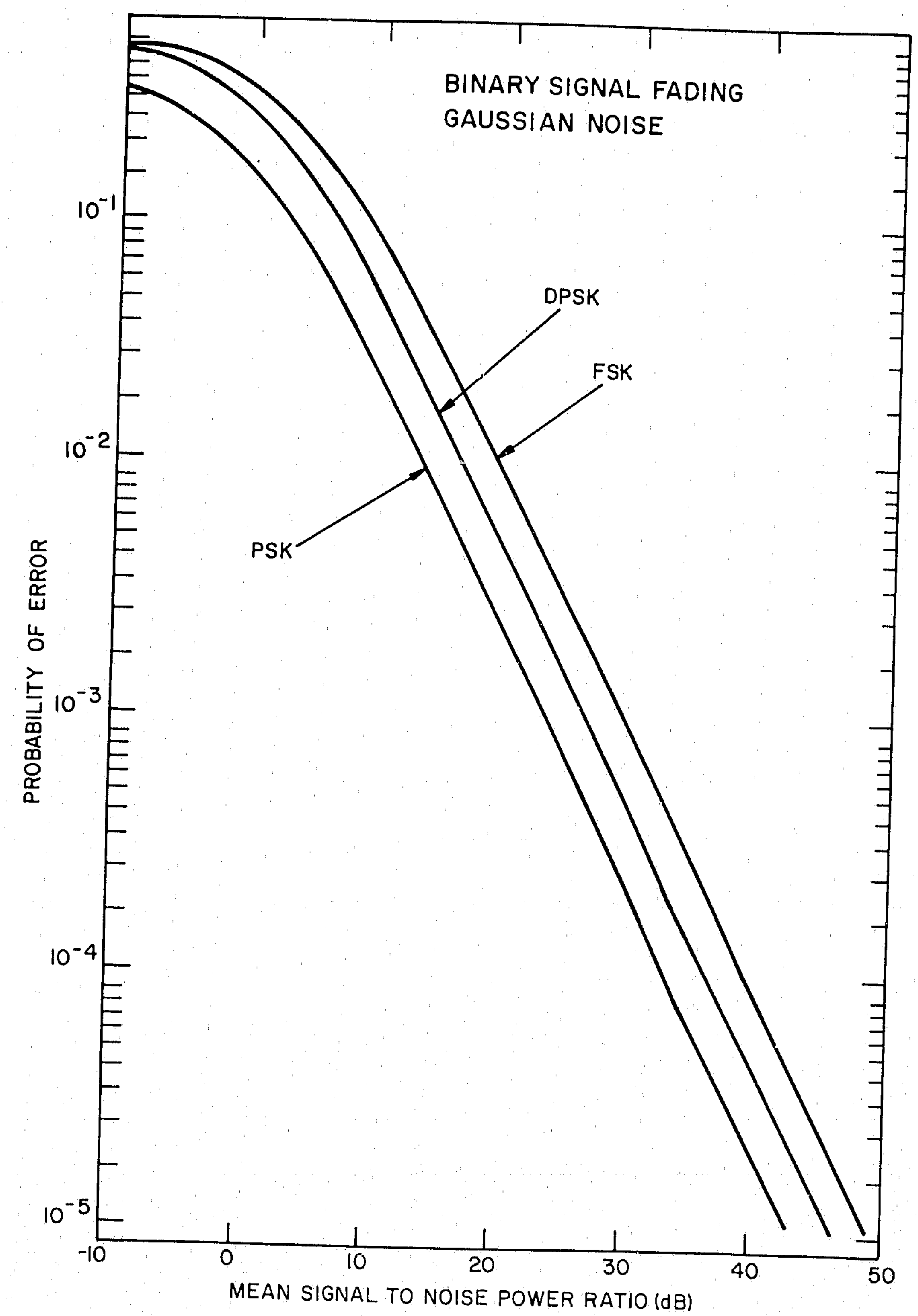


FIGURE 13. *Probability of error vs. signal-to-noise ratio for a Gaussian fading channel.*

theoretically equal to the baud rate of the transmitted waveform. These results assume a perfect characteristic within this bandwidth, e.g., no amplitude or envelope delay distortion. Practical bandwidths of x hertz will not necessarily support data rates of x baud, due to intersymbol interference.

If the effects of bandwidth limitations can be eliminated, either by using low signaling rates, transmitting over a reasonably good channel, or equalizing a poor channel, the bulk of the observed errors can be attributed to low signal-to-noise ratios and other related effects. This is believed to be the case with the results presented in this report.

The amplitude and envelope delay responses of both the VHF and UHF radio systems used for the data tests are shown in appendix B. On examination of these curves, it is evident that severe distortion of the transmitted waveforms should not occur at the modulation rates and audio carrier frequencies used by the modems. These curves were examined by the modem manufacturer, and the bandwidth limitations of the two channels were deemed no more severe than those encountered on C2 conditioned telephone lines. The main reason for the consultation was to ascertain the recommended equalizer settings for the FSK and the DPSK modems. The recommended settings were those that produced essentially no line equalization but did compensate for the distortion introduced by the modem circuitry itself. These settings resulted in a pattern of least intersymbol interference when the modems were operated back-to-back.

The transfer characteristics of the two radio channels were not considered severe enough to cause a significant amount of distortion, even at the higher data rates. However, it was found that bandwidth limitations did cause some of the errors recorded, and they did have a tendency to cause more errors at FSK than at DPSK at the same baud rates. This was due to the fact that FSK occupies more bandwidth due to the tone separation. The effects of slight differences in bandwidth limitations of the VHF and the UHF radio systems would not be recognizable, since the characteristics of the two systems are nearly identical, as shown in the graphs in appendix B.

4.3. Power Limited Errors

4.3.1. General

Most of the errors other than those caused by finite bandwidths are attributable to low signal-to-noise ratios. Poor signal-to-noise ratios can be due to factors such as high path loss, high values of instantaneous noise, and deep fading. These, in combination with other factors such as the carrier frequency of operation, time of day variations, and the speed of the vehicle result in significant variations in decoding errors. The interdependence of signal and noise effects, along with possible intersymbol interference, is very difficult to isolate empirically. Generally, results are stated in terms of gross variations or trends in the number of errors. The discussion of the error rates measured during these tests is included in section 4.4.

4.3.2. Overall Signal-to-Noise Effects

The signal strength received at a mobile FM receiver depends on the attenuation the radiated signal experiences traveling between the transmitter and the mobile. For a given effective radiated power, this loss depends on many factors, such as the frequency of operation and the distance and terrain between the two antennas. Average expected signal strengths at the mobile receiver can be measured or calculated through the use of proven methods and experience.

Based on average values of manmade noise and given the needed characteristics of the receiver, the expected detected noise level can be determined. When data transmission is under consideration, this noise power is usually defined by a Gaussian distribution of signal values. The behavior of digital data of a known modulation

technique, transmitted and subsequently received at a constant signal strength corrupted by Gaussian noise, is calculable. Such calculations are often carried out in order to compare the performance of the various modulation techniques to a first-order approximation.

The average received signal and noise power at a mobile receiver vary considerably when the VHF and UHF frequency bands are compared. Differences in the free space, flat-earth, and shadow losses encountered in radio transmission when using these two bands are the most significant contributors to these variations. These effects are so great that in practice high gain antennas along with higher power base stations are needed to provide UHF coverage comparable to lower frequency VHF coverage. Considerable variation in the level of manmade noise can also be expected, with the higher noise power levels at VHF.

4.3.3. Fading and Impulse Noise

The received rf signal strength and the level of manmade noise fluctuate considerably about their respective mean expected values. Multiple reflections from buildings and other vehicles produce an rf standing wave pattern throughout the coverage area. The values of the signal level in this pattern can be either higher or lower than the expected line-of-sight value due to signal reinforcement or cancellation. The depth and width of the resultant fade patterns show definite variations with radiated frequency due to the difference in wavelength of the signals and the reflection coefficients of the structures. If the mobile is positioned near the minimum of a deep fade, it is possible for the data quality to be extremely poor due to an extremely low peak value of signal-to-noise ratio. This effect was probably insignificant because the probability of stopping the vehicle in a very deep fade was low. The most prevalent fading errors occurred as a moving vehicle passed through these deep fades.

Impulse noise is characterized by the fact that during certain periods of time the noise voltage makes significant deviations from the mean. Urban manmade noise is very impulsive and appears even more transient when a moving vehicle passes by a localized source of manmade noise.

Both multipath fades and impulse noise can cause multiple bit errors or bursts of errors depending on their time duration and severity. These error bursts can vary in size not only because of changes in the fade depth and width but also because identical fades occupy more bit positions at higher data rates. At reasonable data rates, these effects are probably more significant factors in the increase of errors at higher data rates than bandwidth limitations. The size of the burst errors caused by multipath propagation and impulse noise are influenced by the speed of the vehicle. The vehicle's speed affects the percentage of time a fade or noise burst occupies the bit period.

4.3.4. Time of Day Variations

The multipath and manmade noise characteristics of channels vary with time of day. The reflective surfaces which create the standing wave pattern may move or change reflection coefficient. Manmade noise phenomena vary considerably with the time due to the daily life cycles of the populace. Some other noted variations are changes in intermodulation and co-channel interference.

5. TEST RESULTS

5.1. Measured Error Rates

The data in appendix C have been compiled into tables 4 and 5. Table 4 contains the condensed results of the VHF tests, while table 5 presents the UHF data.

The UHF test results follow an expected pattern. The modulation techniques listed in the order of increasing number of errors are: 600 bps FSK, 1200 bps DPSK, 1200 bps FSK, 2400 bps DPSK, and 1800 bps FSK. The 600 bps FSK had the lowest error rate, as expected. The 1200 bps DPSK had a lower error rate than the 1200 bps FSK because the longer signaling intervals associated with 1200 bps DPSK (600 baud DPSK) allowed longer integration times through short fade and noise bursts than the 1200 baud FSK. This effect was more than enough to compensate for the fact that errors occurred in bursts of two bits with DPSK signaling. The fact that the 1200 bps DPSK occupied less bandwidth than the 1200 bps FSK also contributed to the difference in error rate. The signaling methods with equivalent baud rates, such as 600 bps FSK and 1200 bps DPSK, were comparable in performance but, in general, the 1200 bps DPSK had more errors due to the tendency for errors to occur in bursts of 2 because of the differential phase reference. Through similar arguments, the relative number of errors that occurred at each data rate can be explained. This ordering of data was the same for both suburban routes and the downtown route.

In the case of the VHF tests, the preceding rationale is not exactly true. The pattern followed with respect to increasing error rate for the tests was: 600 bps FSK, 1200 bps DPSK, 2400 bps DPSK, 1200 pbs FSK, and 1800 bps FSK. The relative positions of the 2400 bps DPSK and the 1200 bps FSK are interchanged with regard to the expected results. Such a result is possible in limited testing when a relatively small sample size is used and a very small difference in error rate is involved. This result, along with the fact that 600 bps FSK had the highest error rate in the south suburban tests, was probably due to external factors. When the 600 bps FSK south suburban tests and the 1200 bps FSK north suburban tests were being done, there was some evidence of co-channel interference from another mobile unit on the same frequency. This type of interference was very detrimental to data quality in weak signal areas. However, in high data signal strength situations, it did not hamper reception due to the FM capture effect.

For all the data rates and modulation techniques, the downtown tests indicate better data quality at UHF. Since the base transmitter was relatively close to the downtown route, the bulk of the measured errors occurred in areas of high impulse noise in combination with a deep fade. This situation is more likely to occur in the VHF band due to the higher values of manmade noise. Most of the errors occurred in bursts of one to four bits, with the length of the bursts tending to increase with signaling rate. The errors recorded with DPSK generally occurred in bursts of at least two bits except in the cases when the error occurred on the last bit of the memory block. Some of the specific instances of error occurred when the test vehicle was close to a neon sign at point 7 on the downtown route and when a bus or trolley passed nearby. However, errors caused by bus and trolley noise were not frequent.

In most of the suburban tests, the measured error rates were lower at VHF. Although both systems were designed to cover the same area, the VHF system provided better signal strength at most of the test points due to the lower path and shadow loss. However, at a few test points, the UHF performance was superior to VHF. The additional errors at VHF in these cases were caused by manmade noise. One particular instance occurred when a passing train caused a burst of errors at VHF while testing in Carnegie.

When all the data are considered, VHF provided the lowest overall error rate at all data rates and modulation techniques. However, these tests were weighted by the fact that more data points were taken in suburban areas where the VHF coverage was significantly better. In any case, consideration of these results might lead to second thoughts about conversion to a UHF channel when the law enforcement agency is a County Police Department which spends little time patrolling urban areas.

In performing the tests, a qualitative estimate of the data vs. voice coverage was made. The results indicated that they were approximately the same, although in some instances data were received when no voice contact was possible. In these cases the received data were very highly prone to error.

The variation in error rate performance due to changes in the data rates and modulation techniques tested were not significant on an overall basis. Of course, there were isolated instances where wide variations did occur. The information throughput of the channel was not reduced at either VHF or UHF as the data rate was increased to 1800 and 2400 bits per second. Therefore, the point of severe bandwidth limitation was not reached. Although the higher data rates achieved more information throughput, the amount of errors also increased at the same time. In such cases, error detection and retransmission or, even better, error correction would be needed in order to utilize the increased throughput.

5.2. Comparison of Theoretical and Empirical Results

A path loss analysis was performed to calculate the values of signal-to-noise ratio at three selected points along the suburban routes. These values of signal-to-noise ratio were converted into probabilities of bit error for FSK signaling with Rayleigh fading in Gaussian noise using the graph in figure 13. These two sets of values are presented in table 6 along with the average measured error rates (averaged with respect to speed) for those points at the nominal data rate of 1200 bps FSK. The three selected test sites are coded in the following manner:

S15 121 & Greentree
S8 Curry & Brownsville
N13 Greenbelt & Hubbard

Table 6 also shows the "actual signal-to-noise ratio," converted from the measured error rate through the use of figure 13. This was done so that the theoretical and actual data could be compared as a difference in signal-to-noise ratio, shown in the last column of the table. The agreements between the actual and calculated values are within ±10 dB.

TABLE 6. *Comparison of theoretical and measured results*

Location	Frequency	Calculated S/N ratio	Calculated error rate	Actual error rate	Actual S/N ratio	S/N_{calc} S/N_{actual}
S15	VHF	40 dB	1.0×10^{-4}	7.7×10^{-4}	31 dB	9 dB
	UHF	37 dB	2.0×10^{-4}	1.1×10^{-3}	30 dB	7 dB
S8	VHF	34 dB	4.0×10^{-4}	2.2×10^{-4}	36 dB	−2 dB
	UHF	31 dB	8.0×10^{-4}	3.3×10^{-4}	35 dB	−4 dB
N13	VHF	27 dB	2.0×10^{-3}	5.5×10^{-4}	33 dB	−6 dB
	UHF	22 dB	5.0×10^{-3}	1.3×10^{-3}	29 dB	−7 dB

6. CONCLUSIONS

The following is a summary of the results determined from the evaluation of the test data:

° At all data rates tested (i.e., from 600 to 2400 bps) the bulk of the bit errors were caused by power-limited effects rather than by bandwidth limitations.

° Most of the downtown route bit errors were attributed to manmade noise effects, which resulted in more errors with the VHF carrier frequency. The burst errors tended to occur in groups of one to four bits.

° In general, the VHF carrier frequency provided superior data transmission performance on the suburban routes except in the rare cases when severe manmade noise was present.

° At UHF, the number of detected errors increased with increasing signaling rate. This was primarily due to the fact that the longer signaling intervals associated with the lower data rates allow for longer integration times through fades and noise bursts. The fact that the higher data rate signals occupy more bandwidth made a secondary contribution to the ordering of the various data rates with respect to increasing errors.

° In the case of VHF, the pattern of increasing error rate with increasing data rate was not exactly reproduced. This was probably due to the fact that co-channel interference was present at certain periods of time during the VHF tests. Co-channel interference was found to be very detrimental to the data quality when the mobile unit was in weak signal areas. However, in high data signal strength situations, it did not hamper reception due to FM capture.

° In general, the number of errors recorded at a particular test point decreased with increasing vehicle speed in the 10 to 40 mph range of the tests.

° The burst length of the errors was generally less than 7 bits and never more than 10 bits.

° Variation in co-channel interference was the most significant "time-of-day variation."

° High quality data reception was generally coincident with high quality voice reception.

° Even at the highest bandwidth occupancy (i.e., 1800 bps FSK), the bulk of the errors was not attributable to bandwidth limitation but to the fact that the fades or impulse noise spikes occupied more bit positions at the higher data rates.

° Although the higher data rates allowed more total information throughput, the number of errors increased to such an extent that error detection and retransmission, or error correction, would be required in order to utilize the increased throughput at the higher rates.

° The variations in measured error rate with changes in data rate and modulation technique were not considered significant enough to warrant avoiding the use of high data rates for FM radio data communication. Even though the 1800 bps FSK occupied considerable bandwidth, the limitations of the channel were not reached. The information throughput was still increasing at the higher data rates. At 600 bps FSK, 89 percent of the messages were received without error, while at 1800 bps FSK, 81 percent were received error free. Therefore, the throughput was 2.7 times higher at 1800 bps.

° The theoretical and empirical signal-to-noise ratios agreed within ±10 dB.

APPENDIX A

References

[1] Bruchert, E. J., and Sangster, J. H., *The Effects of Fading and Impulse Noise on Digital Transmission Over A Land Mobile Radio Channel*, (December 1969).

[2] EIA Standard RS-232-C, *Interface Between Data Terminal Equipment and Data Communications Equipment Employing Serial Binary Interchange*, (August 1969).

[3] Kelly, T. C., and Ward, J. E., *Investigation of Digital Mobile Radio Communications*, (Stock No. 2700-00233, U.S. Government Printing Office, Washington, D.C., October 1973).

[4] Lucky, R. W., Salz, J., and Weldon, E. J., Jr., *Principles of Data Communication*, (McGraw Hill, New York, N.Y., 1968).

[5] Peterson, W. W., and Weldon, E. J., Jr., *Error Correcting Codes*, (MIT Press, Cambridge, Mass., 2d Edition, 1972).

[6] Stein, S., and Jones, J. J., *Modern Communications Principles*, (McGraw Hill, New York, N.Y., 1967).

[7] Thomas, J. B., *Communication Theory*, (Wiley, New York, N.Y., 1969).

[8] Urban Sciences, Inc., *Final Report on a Study of Digital Communications Equipment for Law Enforcement Use*, (Wellesley, Mass., October 1973).

APPENDIX B

Frequency Response Measurements

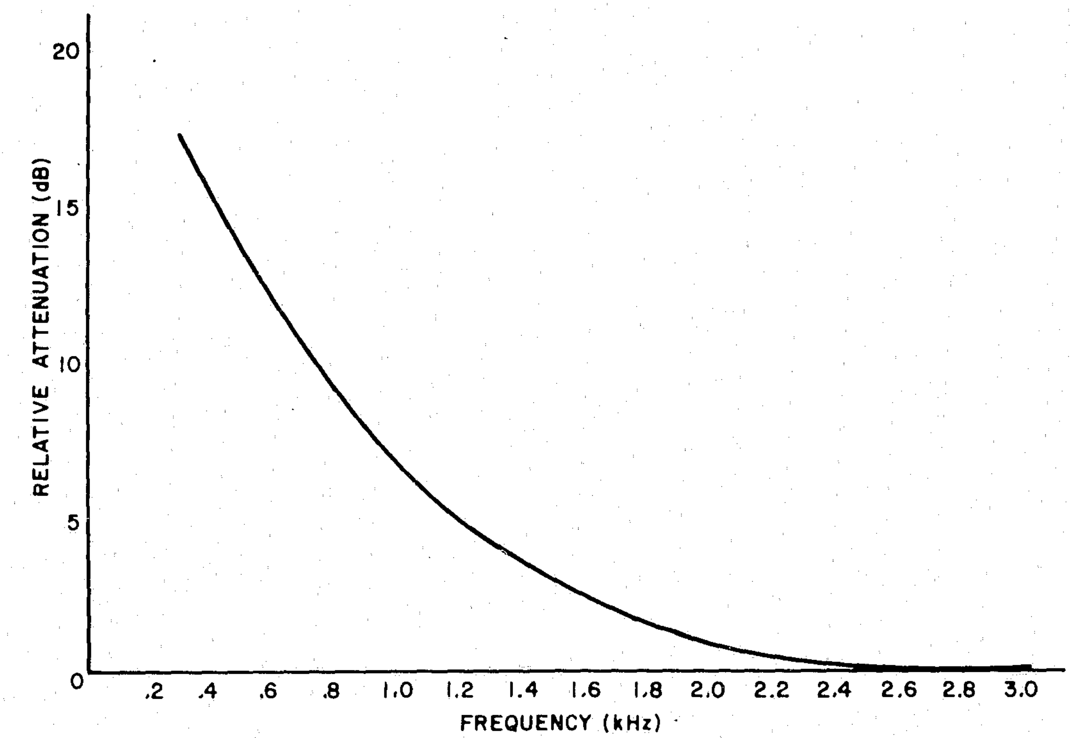


FIGURE B1. *Relative attenuation vs. audio frequency—VHF.*

Preceding page blank

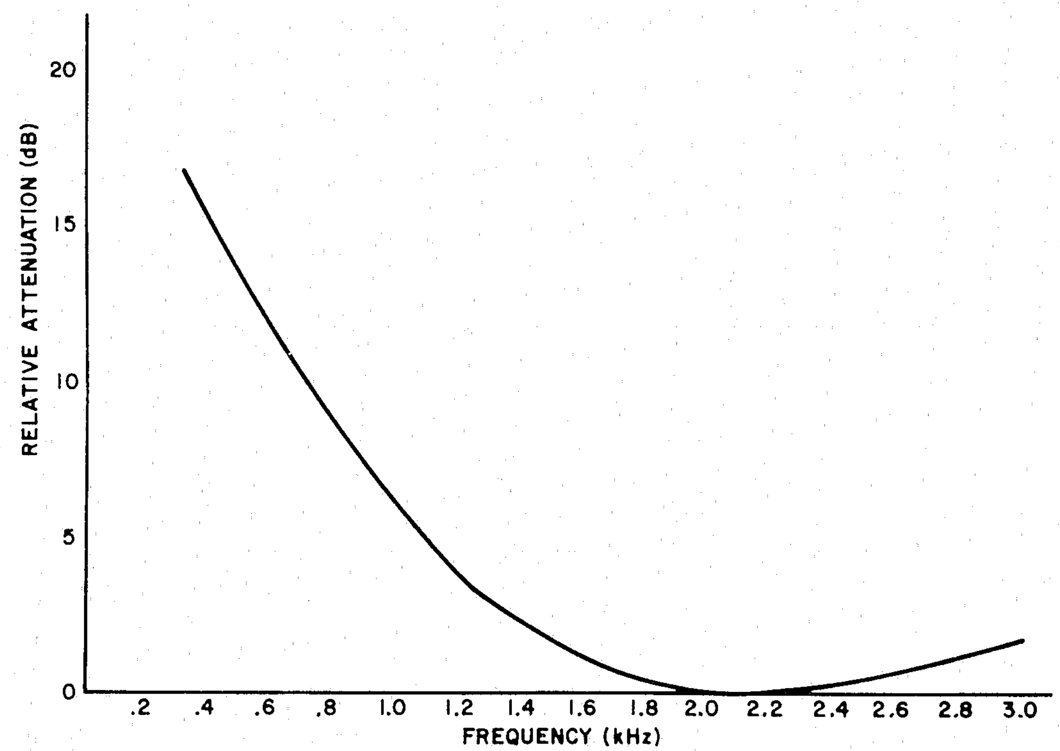


FIGURE B2. *Relative attenuation vs. audio frequency—UHF.*

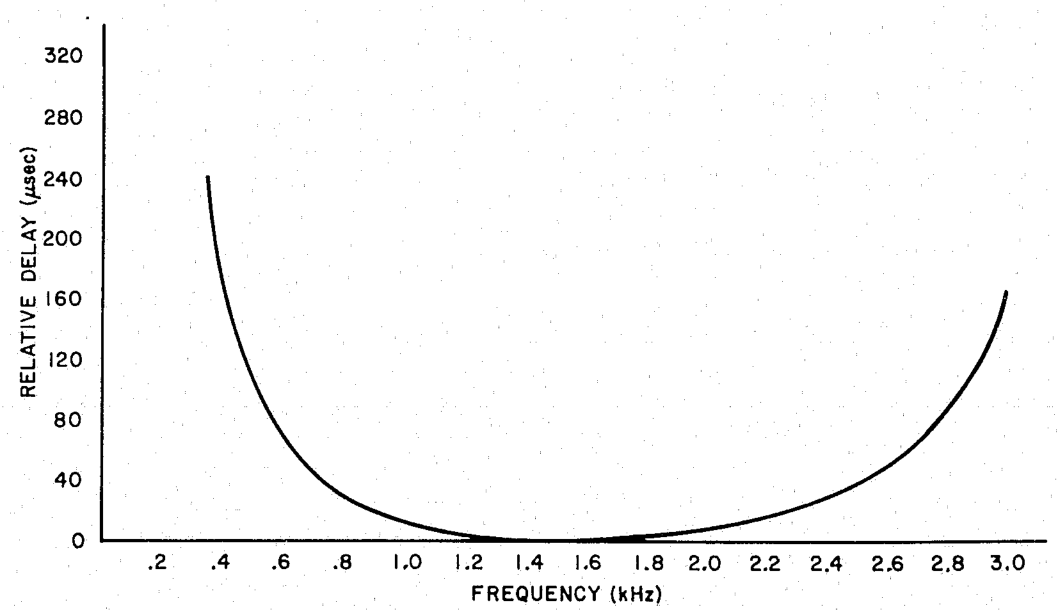


FIGURE B3. *Relative envelope delay vs. audio frequency—VHF.*

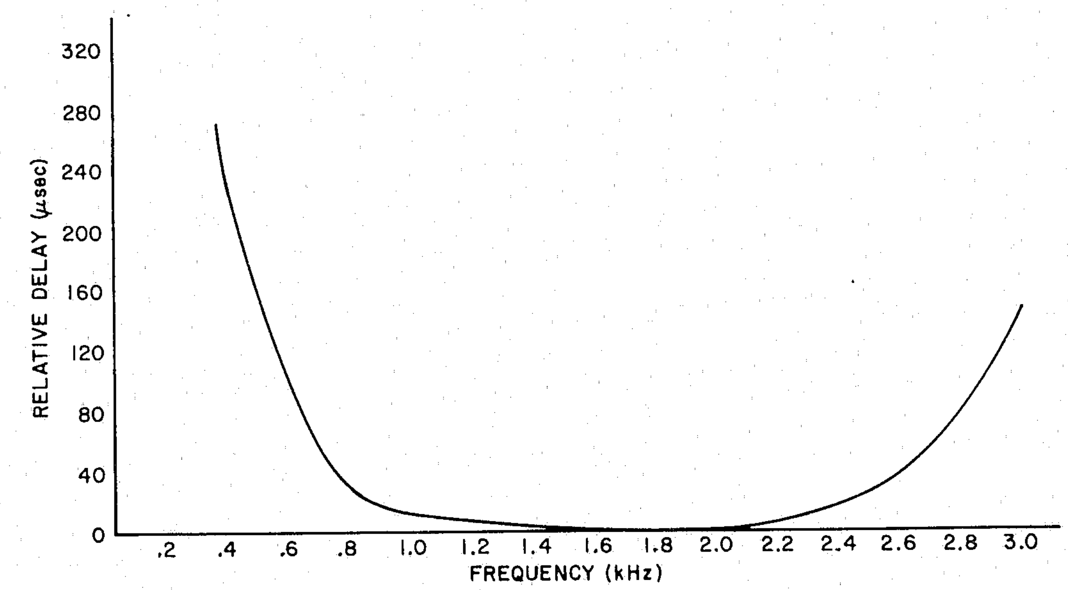


FIGURE B4. *Relative envelope delay vs. audio frequency—UHF.*

APPENDIX C

Test Results

DOWNTOWN AREA

DATA RATE: 600 bps MOD: FSK

Time: 8:00 to 12:00 a.m.—12/27 FREQ: UHF

Location	*Speed (mph)*	*Errors*
1	0	0
2	15	1
3	15	0
4	15	0
5	15	0
6	15	0
7	15	0
8	15	0
9	15	0
10	15	0

Time: 8:00 to 12:00 a.m.—12/27 FREQ: VHF—low band

Location	*Speed (mph)*	*Errors*
1	0	0
2	15	0
3	15	0
4	15	0
5	15	0
6	15	0
7	15	0
8	15	0
9	15	0
10	15	0

Time: 8:00 to 12:00 a.m.—12/27 FREQ: UHF

Location	*Speed (mph)*	*Errors*
1	0	0
2	15	0
3	15	0
4	15	0
5	15	0
6	15	0
7	15	0
8	15	0
9	12	0
10	15	0

Time: 8:00 to 12:00 a.m.—12/27 FREQ: VHF—low band

Location	*Speed (mph)*	*Errors*
1	0	0
2	15	0
3	15	0
4	20	0
5	15	0
6	15	0
7	15	0
8	20	0
9	15	0
10	15	2

DATA RATE: 600 bps MOD: FSK

Time: 8:00 to 12:00 a.m.—1/3 FREQ: UHF

Location	*Speed (mph)*	*Errors*
1	0	0
2	15	0
3	15	0
4	15	0
5	15	0
6	15	0
7	15	0
8	15	0
9	15	0
10	15	0

Time: 8:00 to 12:00 a.m.—1/3 FREQ: VHF—low band

Location	*Speed (mph)*	*Errors*
1	0	0
2	15	0
3	15	0
4	20	0
5	20	0
6	0	0
7	15	0
8	15	1
9	15	0
10	15	0

Time: 8:00 to 12:00 a.m.—1/3 FREQ: UHF

Location	*Speed (mph)*	*Errors*
1	0	0
2	15	0
3	15	0
4	15	0
5	20	0
6	20	0
7	25	0
8	20	0
9	20	0
10	15	0

Time: 8:00 to 12:00 a.m.—1/3 FREQ: VHF—low band

Location	*Speed (mph)*	*Errors*
1	0	0
2	15	0
3	10	0
4	20	0
5	12	0
6	20	0
7	30	0
8	15	0
9	15	0
10	10	0

DOWNTOWN AREA

DATA RATE: 600 bps — **MOD: FSK**

Time: 1:00 to 5:00 p.m.—1/3 — **FREQ: UHF**

Location	*Speed (mph)*	*Errors*
1	0	0
2	15	0
3	15	0
4	20	0
5	15	0
6	15	0
7	15	0
8	20	0
9	15	0
10	15	0

Time: 1:00 to 5:00 p.m.—1/3 — **FREQ: VHF—low band**

Location	*Speed (mph)*	*Errors*
1	0	0
2	20	0
3	15	0
4	20	0
5	15	0
6	10	0
7	0	0
8	15	0
9	15	0
10	15	0

DATA RATE: 1200 bps — **MOD: FSK**

Time: 1:00 to 5:00 p.m.—1/8 — **FREQ: UHF**

Location	*Speed (mph)*	*Errors*
1	0	0
2	15	0
3	15	0
4	15	0
5	15	0
6	15	0
7	15	0
8	15	0
9	15	0
10	15	0

Time: 1:00 to 5:00 p.m.—1/8 — **FREQ: VHF—low band**

Location	*Speed (mph)*	*Errors*
1	0	0
2	15	0
3	15	0
4	15	0
5	15	0
6	15	0
7	15	0
8	15	0
9	5	0
10	15	0

Time: 1:00 to 5:00 p.m.—1/8 — **FREQ: UHF**

Location	*Speed (mph)*	*Errors*
1	0	0
2	15	0
3	15	0
4	15	0
5	25	0
6	15	0
7	15	0
8	20	0
9	15	0
10	15	0

Time: 1:00 to 5:00 p.m.—1/8 — **FREQ: VHF—low band**

Location	*Speed (mph)*	*Errors*
1	0	0
2	15	0
3	15	0
4	20	0
5	15	0
6	15	0
7	15	0
8	20	2
9	20	0
10	15	0

DOWNTOWN AREA

DATA RATE: 1200 bps — **MOD: FSK**

Time: 6:00 to 12:00 p.m.—1/8 — **FREQ: UHF**

Location	*Speed (mph)*	*Errors*
1	0	0
2	15	0
3	15	1
4	15	0
5	15	0
6	15	0
7	10	0
8	15	0
9	15	0
10	10	0

Time: 6:00 to 12:00 p.m.—1/8 — **FREQ: VHF—low band**

Location	*Speed (mph)*	*Errors*
1	0	3
2	15	0
3	15	0
4	15	0
5	15	0
6	15	0
7	10	0
8	15	2
9	15	0
10	15	0

Time: 6:00 to 12:00 p.m.—1/8 — **FREQ: UHF**

Location	*Speed (mph)*	*Errors*
1	0	0
2	15	0
3	20	0
4	15	0
5	15	0
6	18	0
7	15	0
8	20	0
9	15	0
10	15	0

Time: 6:00 to 12:00 p.m.—1/8 — **FREQ: VHF—low band**

Location	*Speed (mph)*	*Errors*
1	0	0
2	15	0
3	20	0
4	25	0
5	20	0
6	0	0
7	15	0
8	15	0
9	15	0
10	15	0

DATA RATE: 1200 bps — **MOD: FSK**

Time: 6:00 to 12:00 p.m.—1/8 — **FREQ: UHF**

Location	*Speed (mph)*	*Errors*
1	0	0
2	15	0
3	15	0
4	25	0
5	25	0
6	15	0
7	15	0
8	15	0
9	15	0
10	15	0

Time: 6:00 to 12:00 p.m.—1/8 — **FREQ: VHF—low band**

Location	*Speed (mph)*	*Errors*
1	0	0
2	15	0
3	15	0
4	15	0
5	15	0
6	15	0
7	15	0
8	15	0
9	15	0
10	15	1

DOWNTOWN AREA

DATA RATE: 1200 bps **MOD: DPSK**

Time: 6:00 to 12:00 p.m.—1/23 **FREQ: UHF**

Location	*Speed (mph)*	*Errors*
1	0	0
2	15	0
3	15	0
4	15	0
5	15	0
6	15	0
7	15	0
8	15	0
9	20	0
10	15	1

Time: 6:00 to 12:00 p.m.—1/23 **FREQ: VHF—low band**

1	0	0
2	15	0
3	15	0
4	25	0
5	20	0
6	15	0
7	15	0
8	10	0
9	20	0
10	15	0

Time: 6:00 to 12:00 p.m.—1/23 **FREQ: UHF**

1	0	0
2	15	0
3	15	0
4	15	0
5	20	0
6	15	0
7	15	0
8	15	0
9	0	0
10	18	0

Time: 6:00 to 12:00 p.m.—1/23 **FREQ: VHF—low band**

1	0	0
2	15	2
3	15	0
4	15	0
5	15	0
6	15	0
7	18	0
8	20	0
9	15	0
10	15	0

DATA RATE: 1200 bps **MOD: DPSK**

Time: 6:00 to 12:00 p.m.—1/23 **FREQ: UHF**

Location	*Speed (mph)*	*Errors*
1	0	0
2	20	0
3	15	0
4	15	0
5	0	0
6	20	0
7	18	0
8	10	0
9	15	0
10	15	0

Time: 6:00 to 12:00 p.m.—1/23 **FREQ: VHF—low band**

1	0	0
2	20	0
3	20	0
4	25	0
5	15	0
6	10	0
7	15	0
8	15	2
9	15	0
10	15	0

Time: 1:00 to 5:00 p.m.—1/24 **FREQ: UHF**

1	0	0
2	15	0
3	20	0
4	25	0
5	15	0
6	15	0
7	15	0
8	0	0
9	15	0
10	15	0

Time: 1:00 to 5:00 p.m.—1/24 **FREQ: VHF—low band**

1	0	0
2	20	0
3	20	0
4	20	0
5	22	0
6	15	0
7	15	0
8	20	2
9	15	0
10	15	2

DOWNTOWN AREA

DATA RATE: 1200 bps **MOD: DPSK**

Time: 1:00 to 5:00 p.m.—1/24 **FREQ: UHF**

Location	*Speed (mph)*	*Errors*
1	0	0
2	20	0
3	15	0
4	25	0
5	15	0
6	15	0
7	15	0
8	15	0
9	15	0
10	15	0

Time: 1:00 to 5:00 p.m.—1/24 **FREQ: VHF—low band**

1	0	0
2	15	0
3	15	0
4	15	0
5	25	0
6	15	0
7	0	0
8	15	0
9	15	0
10	20	0

DATA RATE: 1800 bps **MOD: FSK**

Time: 8:00 to 12:00 a.m.—1/16 **FREQ: UHF**

Location	*Speed (mph)*	*Errors*
1	0	0
2	15	0
3	15	0
4	15	0
5	20	0
6	15	0
7	15	0
8	15	0
9	15	0
10	15	0

Time: 8:00 to 12:00 a.m.—1/16 **FREQ: VHF—low band**

1	0	0
2	15	0
3	20	0
4	5	0
5	18	0
6	15	0
7	15	0
8	0	0
9	18	0
10	15	0

Time: 8:00 to 12:00 a.m.—1/16 **FREQ: UHF**

1	0	0
2	10	0
3	16	0
4	20	0
5	20	0
6	15	0
7	15	0
8	20	0
9	15	0
10	15	1

Time: 8:00 to 12:00 a.m.,—1/16 **FREQ: VHF—low band**

1	0	0
2	15	0
3	10	0
4	15	0
5	25	3
6	20	0
7	15	0
8	15	0
9	10	0
10	10	0

DOWNTOWN AREA

DATA RATE: 1800 bps MOD: FSK

Time: 1:00 to 5:00 p.m.—1/16 FREQ: UHF

Location	Speed (mph)	Errors
1	0	0
2	12	0
3	15	0
4	20	0
5	25	0
6	16	2
7	0	0
8	0	0
9	15	0
10	15	0

Time: 1:00 to 5:00 p.m.—1/16 FREQ: VHF—low band

Location	Speed (mph)	Errors
1	0	0
2	15	0
3	15	0
4	15	0
5	20	0
6	12	0
7	5	0
8	15	0
9	20	0
10	15	0

Time: 1:00 to 5:00 p.m.—1/16 FREQ: UHF

Location	Speed (mph)	Errors
1	0	0
2	20	0
3	15	1
4	10	0
5	15	0
6	15	0
7	10	0
8	18	0
9	15	0
10	15	0

Time: 1:00 to 5:00 p.m.—1/16 FREQ: VHF—low band

Location	Speed (mph)	Errors
1	0	0
2	15	0
3	0	0
4	20	0
5	15	0
6	15	0
7	15	0
8	15	3
9	20	0
10	15	0

DATA RATE: 1800 bps MOD: FSK

Time: 1:00 to 5:00 p.m.—1/16 FREQ: UHF

Location	Speed (mph)	Errors
1	0	0
2	15	0
3	15	0
4	15	0
5	20	0
6	10	0
7	0	0
8	15	0
9	15	0
10	15	0

Time: 1:00 to 5:00 p.m.—1/16 FREQ: VHF—low band

Location	Speed (mph)	Errors
1	0	0
2	15	0
3	15	0
4	15	0
5	20	0
6	0	0
7	15	0
8	15	0
9	15	0
10	15	0

DOWNTOWN AREA

DATA RATE: 2400 bps MOD: DPSK

Time: 8:00 to 12:00 a.m.—1/28 FREQ: UHF

Location	Speed (mph)	Errors
1	0	2
2	15	0
3	15	0
4	15	0
5	15	0
6	15	0
7	10	0
8	5	0
9	15	0
10	15	0

Time: 8:00 to 12:00 a.m.—1/28 FREQ: VHF—low band

Location	Speed (mph)	Errors
1	0	0
2	10	0
3	20	0
4	15	0
5	18	0
6	20	0
7	10	0
8	15	2
9	15	0
10	15	0

Time: 8:00 to 12:00 a.m.—1/28 FREQ: UHF

Location	Speed (mph)	Errors
1	0	0
2	15	0
3	20	0
4	10	0
5	15	0
6	15	0
7	5	0
8	15	0
9	15	0
10	20	0

Time: 8:00 to 12:00 a.m.—1/28 FREQ: VHF—low band

Location	Speed (mph)	Errors
1	0	0
2	0	0
3	15	0
4	15	0
5	20	0
6	10	0
7	15	0
8	25	0
9	20	0
10	10	0

DATA RATE: 2400 bps MOD: DPSK

Time: 8:00 to 12:00 a.m.—1/28 FREQ: UHF

Location	Speed (mph)	Errors
1	0	0
2	15	0
3	10	0
4	15	0
5	20	0
6	0	0
7	15	0
8	20	0
9	15	0
10	15	0

Time: 8:00 to 12:00 a.m.—1/28 FREQ: VHF—low band

Location	Speed (mph)	Errors
1	0	0
2	15	0
3	15	0
4	10	5
5	15	0
6	15	0
7	15	0
8	0	1
9	15	0
10	15	0

Time: 1:00 to 5:00 p.m.—1/28 FREQ: UHF

Location	Speed (mph)	Errors
1	0	0
2	15	0
3	15	0
4	15	0
5	15	0
6	20	0
7	10	0
8	15	0
9	5	0
10	15	0

Time: 1:00 to 5:00 p.m.—1/28 FREQ: VHF—low band

Location	Speed (mph)	Errors
1	0	0
2	15	0
3	15	0
4	15	0
5	15	0
6	15	0
7	15	0
8	15	0
9	15	0
10	15	0

DOWNTOWN AREA

DATA RATE: 2400 bps MOD: DPSK

Time: 1:00 to 5:00 p.m.—1/28 FREQ: UHF

Location	*Speed (mph)*	*Errors*
1	0	0
2	15	0
3	20	0
4	25	0
5	25	0
6	20	0
7	12	0
8	20	0
9	10	0
10	15	0

Time: 1:00 to 5:00 p.m.—1/28 FREQ: VHF—low band

Location	*Speed (mph)*	*Errors*
1	0	0
2	15	0
3	20	0
4	20	0
5	25	0
6	20	0
7	20	0
8	15	0
9	15	0
10	15	0

SOUTH SUBURBAN ROUTE

DATA RATE: 600 bps MOD: FSK

Time: 1:00 to 5:00 p.m.—12/27 FREQ: UHF

Location	*Speed (mph)*	*Errors*
1	0	0
	20	1
	30	0
2	0	0
	20	0
	30	0
3	0	0
	20	0
	30	0
4	0	0
	30	0
	40	0
5	0	0
	30	0
	45	0
6	0	0
	20	0
	35	0
7	0	0

Time: 8:00 to 12:00 a.m.—1/2 FREQ: VHF—low band

Location	*Speed (mph)*	*Errors*
1	0	0
	20	0
	35	0
2	0	0
	15	0
	30	0
3	0	0
	20	0
	35	0
4	0	0
	20	0
	35	0
5	0	0
	20	0
	35	0
6	0	0
	25	0
	35	0
7	0	0

DATA RATE: 1200 bps MOD: FSK

Time: 8:00 to 12:00 a.m.—1/9 FREQ: UHF

Location	*Speed (mph)*	*Errors*
1	0	0
	20	0
	35	0
2	0	0
	15	0
	30	0
3	0	0
	20	0
	30	0
4	0	0
	20	0
	35	0
5	0	0
	30	0
	40	0
6	0	4
	25	2
	35	3
7	0	0

Time: 1:00 to 5:00 p.m.—1/10 FREQ: VHF—low band

Location	*Speed (mph)*	*Errors*
1	0	0
	20	0
	40	0
2	0	0
	20	0
	30	0
3	0	0
	20	0
	30	0
4	0	0
	15	0
	40	0
5	0	0
	25	0
	30	0
6	0	0
	30	0
	40	0
7	0	0

SOUTH SUBURBAN ROUTE

DATA RATE: 1200 bps MOD: DPSK

Time: 8:00 to 12:00 a.m.—1/23 FREQ: UHF

Location	*Speed (mph)*	*Errors*
1	0	0
	20	0
	30	0
2	0	0
	20	0
	30	0
3	0	0
	20	0
	35	0
4	0	0
	10	0
	20	0
5	0	0
	20	0
	35	0
6	0	0
	15	2
	30	2
7	0	0

Time: 6:00 to 12:00 p.m.—1/24 FREQ: VHF—low band

Location	*Speed (mph)*	*Errors*
1	0	0
	15	0
	35	0
2	0	0
	5	0
	25	0
3	0	0
	20	0
	35	0
4	0	0
	10	0
	20	0
5	0	0
	10	0
	20	0
6	0	0
	20	0
	35	2
7	0	0

DATA RATE: 1800 bps MOD: FSK

Time: 8:00 to 12:00 a.m.—1/12 FREQ: UHF

Location	*Speed (mph)*	*Errors*
1	0	0
	20	0
	35	0
2	0	1
	20	4
	35	6
3	0	0
	30	0
	40	0
4	0	0
	30	0
	40	0
5	0	0
	20	0
	30	0
6	0	1
	15	2
	30	2
7	0	0

Time: 8:00 to 12:00 a.m.—1/14 FREQ: VHF—low band

Location	*Speed (mph)*	*Errors*
1	0	0
	20	1
	40	0
2	0	0
	15	0
	30	0
3	0	0
	25	0
	35	0
4	0	0
	30	0
	40	0
5	0	0
	20	0
	40	0
6	0	0
	20	0
	35	0
7	0	0

SOUTH SUBURBAN ROUTE

DATA RATE: 2400 bps MOD: DPSK

Time: 8:00 to 12:00 a.m.—2/1 FREQ: UHF

Location	*Speed (mph)*	*Errors*
1	0	0
	20	0
	35	2
2	0	0
	20	0
	35	0
3	0	0
	20	0
	35	0
4	0	0
	20	0
	35	0
5	0	0
	20	2
	30	4
6	0	0
	20	0
	30	0
7	0	0

Time: 8:00 to 12:00 a.m.—2/2 FREQ: VHF—low band

Location	*Speed (mph)*	*Errors*
1	0	0
	15	0
	30	0
2	0	0
	20	0
	35	0
3	0	0
	20	0
	30	0
4	0	0
	5	0
	35	0
5	0	0
	20	0
	40	0
6	0	0
	20	2
	25	0
7	0	0

SOUTH SUBURBAN ROUTE

DATA RATE: 600 bps **MOD: FSK**

Time: 1:00 to 5:00 p.m.—1/2 **FREQ: UHF**

Location	*Speed (mph)*	*Errors*
8	0	0
	20	3
	30	0
9	0	0
	10	0
	30	0
10	0	0
	20	0
	30	0
11	0	0
	20	0
	30	0
12	0	0
	30	0
	40	0
13	0	0
	15	0
	30	0
14	0	0
	20	1
	32	1
15	0	0
	20	6
	35	3
16	0	0
	20	0
	30	0
17	0	0
	20	0
	45	0

DATA RATE: 600 bps **MOD: FSK**

Time: 8:00 to 12:00 a.m.—12/28 **FREQ: VHF—low band**

Location	*Speed (mph)*	*Errors*
8	0	0
	20	5
	40	2
9	0	0
	15	0
	30	1
10	0	0
	20	0
	30	2
11	0	0
	20	3
	40	0
12	0	0
	20	0
	30	0
13	0	0
	25	0
	30	1
14	0	0
	25	1
	40	0
15	0	0
	20	4
	30	3
16	0	0
	20	0
	30	0
17	0	0
	20	0
	50	0

SOUTH SUBURBAN ROUTE

DATA RATE: 1200 bps **MOD: FSK**

Time: 6:00 to 12:00 p.m.—1/10 **FREQ: UHF**

Location	*Speed (mph)*	*Errors*
8	0	0
	20	2
	35	1
9	0	0
	20	0
	30	0
10	0	0
	25	0
	35	0
11	0	0
	10	0
	25	0
12	0	0
	30	0
	40	0
13	0	0
	25	1
	30	0
14	0	0
	15	2
	25	0
15	0	1
	20	7
	30	2
16	0	0
	15	0
	30	0
17	0	0
	5	0
	20	0

DATA RATE: 1200 bps **MOD: FSK**

Time: 1:00 to 5:00 p.m.—2/9 **FREQ: VHF—low band**

Location	*Speed (mph)*	*Errors*
8	0	0
	10	2
	25	0
9	0	0
	10	1
	25	0
10	0	0
	30	0
	40	0
11	0	0
	20	1
	30	1
12	0	0
	10	0
	25	0
13	0	0
	20	1
	40	0
14	0	0
	15	0
	30	1
15	0	0
	15	4
	25	3
16	0	0
	20	0
	40	0
17	0	0
	20	2
	35	0

SOUTH SUBURBAN ROUTE

DATA RATE: 1200 bps MOD: DPSK

Time: 8:00 to 12:00 a.m.—1/25 FREQ: UHF

Location	*Speed (mph)*	*Errors*
8	0	0
	10	0
	40	0
9	0	0
	15	0
	25	0
10	0	0
	20	0
	30	0
11	0	0
	12	0
	30	0
12	0	0
	20	0
	35	0
13	0	0
	5	0
	25	0
14	0	0
	10	2
	35	2
15	0	0
	15	4
	25	3
16	0	0
	10	0
	35	0
17	0	0
	20	0
	30	0

DATA RATE: 1200 bps MOD: DPSK

Time: 1:00 to 5:00 p.m.—1/23 FREQ: VHF—low band

Location	*Speed (mph)*	*Errors*
8	0	0
	15	4
	35	3
9	0	0
	10	0
	25	2
10	0	0
	15	0
	25	0
11	0	0
	10	0
	15	0
12	0	0
	15	0
	25	0
13	0	0
	10	0
	30	2
14	0	0
	20	1
	25	0
15	0	0
	10	2
	25	2
16	0	0
	20	0
	30	0
17	0	0
	10	0
	25	2

SOUTH SUBURBAN ROUTE

DATA RATE: 1800 bps MOD: FSK

Time: 1:00 to 5:00 p.m.—1/14 FREQ: UHF

Location	*Speed (mph)*	*Errors*
8	0	0
	15	3
	30	1
9	0	0
	15	0
	30	1
10	0	0
	30	0
	40	1
11	0	0
	20	0
	30	2
12	0	0
	15	0
	25	0
13	0	0
	15	0
	30	0
14	0	0
	25	0
	35	0
15	0	2
	20	1
	35	6
16	0	0
	15	0
	30	0
17	0	0
	15	0
	25	0

DATA RATE: 1800 bps MOD: FSK

Time: 8:00 to 12:00 a.m.—1/12 FREQ: VHF—low band

Location	*Speed (mph)*	*Errors*
8	0	0
	15	0
	30	0
9	0	0
	20	0
	30	2
10	0	0
	30	0
	40	0
11	0	0
	25	0
	40	0
12	0	0
	15	0
	30	0
13	0	0
	15	0
	35	0
14	0	0
	15	0
	30	1
15	0	0
	20	1
	35	2
16	0	0
	15	0
	30	0
17	0	0
	20	3
	40	1

SOUTH SUBURBAN ROUTE

DATA RATE: 2400 bps — MOD: DPSK

Time: 1:00 to 5:00 p.m.—2/2 — FREQ: UHF

Location	*Speed (mph)*	*Errors*
8	0	0
	25	0
	40	4
9	0	0
	20	0
	35	0
10	0	0
	15	0
	35	0
11	0	0
	23	0
	45	0
12	0	0
	15	0
	35	8
13	0	0
	25	0
	30	1
14	0	0
	25	0
	35	5
15	0	0
	15	0
	40	4
16	0	0
	15	0
	35	0
17	0	0
	35	0
	50	2

DATA RATE: 2400 bps — MOD: DPSK

Time: 8:00 to 12:00 a.m.—2/1 — FREQ: VHF—low band

Location	*Speed (mph)*	*Errors*
8	0	0
	20	0
	35	0
9	0	0
	15	0
	35	0
10	0	0
	15	0
	35	0
11	0	0
	15	0
	30	0
12	0	0
	20	0
	30	0
13	0	0
	25	0
	40	0
14	0	0
	20	0
	30	0
15	0	0
	15	2
	40	2
16	0	0
	15	5
	30	0
17	0	0
	20	0
	45	2

SOUTH SUBURBAN ROUTE

DATA RATE: 600 bps — MOD: FSK

Time: 1:00 to 5:00 p.m.—12/28 — FREQ: UHF

Location	*Speed (mph)*	*Errors*
18	0	0
	20	0
	40	0
19	0	0
	35	0
	50	1
20	0	0
	30	0
	50	0
21	0	0
	30	0
	45	0
22	0	0
	15	0
	25	0

Time: 6:00 to 12:00 p.m.—1/2 — FREQ: VHF—low band

Location	*Speed (mph)*	*Errors*
18	0	0
	25	0
	45	0
19	0	0
	20	0
	45	1
20	0	0
	30	0
	45	0
21	0	0
	20	0
	40	0
22	0	0
	20	0
	30	0

DATA RATE: 1200 bps — MOD: FSK

Time: 8:00 to 12:00 a.m.—1/10 — FREQ: UHF

Location	*Speed (mph)*	*Errors*
18	0	0
	25	0
	40	0
19	0	0
	20	1
	40	0
20	0	0
	20	0
	40	0
21	0	0
	30	0
	45	0
22	0	0
	20	0
	35	0

Time: 6:00 to 12:00 p.m.—1/10 — FREQ: VHF—low band

Location	*Speed (mph)*	*Errors*
18	0	0
	20	0
	35	0
19	0	0
	15	0
	35	0
20	0	0
	25	0
	45	0
21	0	0
	30	0
	45	0
22	0	0
	15	0
	35	0

SOUTH SUBURBAN ROUTE

DATA RATE: 1200 bps **MOD: DPSK**

Time: 8:00 to 12:00 a.m.—1/24 **FREQ: UHF**

Location	*Speed (mph)*	*Errors*
18	0	0
	15	0
	40	0
19	0	0
	20	0
	30	0
20	0	0
	20	2
	25	0
21	0	0
	15	0
	25	0
22	0	0
	20	0
	30	0

Time: 1:00 to 5:00 p.m.—1/25 **FREQ: VHF—low band**

Location	*Speed (mph)*	*Errors*
18	0	0
	20	0
	30	0
19	0	0
	15	0
	35	0
20	0	0
	20	0
	45	0
21	0	0
	15	0
	40	0
22	0	0
	10	0
	25	0

DATA RATE: 1800 bps **MOD: FSK**

Time: 1:00 to 5:00 p.m.—1/12 **FREQ: UHF**

Location	*Speed (mph)*	*Errors*
18	0	0
	20	0
	50	1
19	0	0
	15	0
	40	0
20	0	0
	20	0
	40	0
21	0	0
	30	0
	45	0
22	0	0
	25	1
	40	0

Time: 1:00 to 5:00 p.m.—1/14 **FREQ: VHF—low band**

Location	*Speed (mph)*	*Errors*
18	0	0
	25	0
	50	0
19	0	0
	20	0
	45	0
20	0	0
	25	0
	45	0
21	0	0
	35	0
	45	0
22	0	0
	15	0
	30	0

SOUTH SUBURBAN ROUTE

DATA RATE: 2400 bps **MOD: DPSK**

Time: 1:00 to 5:00 p.m.—2/1 **FREQ: UHF**

Location	*Speed (mph)*	*Errors*
18	0	0
	20	0
	50	0
19	0	0
	40	0
	45	0
20	0	0
	25	2
	40	0
21	0	0
	25	0
	40	0
22	0	0
	30	0
	40	0

Time: 1:00 to 5:00 p.m.—2/2 **FREQ: VHF—low band**

Location	*Speed (mph)*	*Errors*
18	0	0
	20	0
	45	0
19	0	0
	30	0
	45	0
20	0	0
	25	0
	50	0
21	0	0
	25	0
	30	0
22	0	0
	20	0
	30	0

NORTH SUBURBAN ROUTE

DATA RATE: 600 bps MOD: FSK

Time: 8:00 to 12:00 a.m.—1/4 FREQ: UHF

Location	*Speed (mph)*	*Errors*
1	0	0
	20	0
	30	0
2	0	0
	15	0
	25	0
3	0	0
	20	0
	30	0
4	0	0
	10	0
	25	0
5	0	0
	15	0
	30	0
6	0	0
	10	0
	20	0

Time: 1:00 to 5:00 p.m.—1/3 FREQ: VHF—low band

Location	*Speed (mph)*	*Errors*
1	0	0
	15	0
	30	0
2	0	0
	20	0
	40	0
3	0	0
	5	0
	15	0
4	0	0
	15	0
	35	0
5	0	0
	20	0
	25	0
6	0	0
	15	0
	30	0

DATA RATE: 1200 bps MOD: FSK

Time: 8:00 to 12:00 a.m.—1/7 FREQ: UHF

Location	*Speed (mph)*	*Errors*
1	0	0
	25	0
	40	0
2	0	0
	25	0
	40	0
3	0	0
	15	0
	32	0
4	0	0
	15	0
	35	1
5	0	0
	5	0
	35	0
6	0	0
	15	0
	30	0

Time: 8:00 to 12:00 a.m.—1/11 FREQ: VHF—low band

Location	*Speed (mph)*	*Errors*
1	0	0
	20	0
	35	1
2	0	0
	20	0
	40	0
3	0	0
	15	0
	35	0
4	0	0
	25	0
	35	0
5	0	0
	15	0
	30	0
6	0	0
	15	0
	30	0

NORTH SUBURBAN ROUTE

DATA RATE: 1200 bps MOD: DPSK

Time: 8:00 to 12:00 a.m.—1/22 FREQ: UHF

Location	*Speed (mph)*	*Errors*
1	0	0
	25	0
	40	0
2	0	0
	15	0
	25	0
3	0	0
	15	0
	40	0
4	0	0
	15	0
	30	0
5	0	0
	20	0
	40	0
6	0	0
	20	0
	40	0

Time: 8:00 to 12:00 a.m.—1/21 FREQ: VHF—low band

Location	*Speed (mph)*	*Errors*
1	0	0
	15	0
	20	0
2	0	0
	10	0
	25	0
3	0	0
	20	0
	25	0
4	0	0
	15	0
	40	0
5	0	0
	15	0
	40	0
6	0	0
	25	0
	35	0

DATA RATE: 1800 bps MOD: FSK

Time: 8:00 to 12:00 a.m.—1/15 FREQ: UHF

Location	*Speed (mph)*	*Errors*
1	0	0
	25	0
	30	0
2	0	0
	15	0
	40	0
3	0	0
	10	0
	35	0
4	0	0
	20	0
	30	0
5	0	0
	5	0
	15	0
6	0	0
	20	0
	35	2

Time: 8:00 to 12:00 a.m.—1/18 FREQ: VHF—low band

Location	*Speed (mph)*	*Errors*
1	0	0
	5	0
	40	0
2	0	0
	15	0
	25	0
3	0	0
	25	0
	35	0
4	0	0
	30	0
	40	0
5	0	0
	15	0
	30	0
6	0	0
	10	0
	35	0

NORTH SUBURBAN ROUTE

DATA RATE: 2400 bps MOD: DPSK

Time: 8:00 to 12:00 a.m.—1/30 FREQ: UHF

Location	Speed (mph)	Errors
1	0	0
	15	1
	30	0
2	0	0
	20	0
	40	0
3	0	0
	20	0
	45	0
4	0	0
	15	0
	35	0
5	0	0
	20	0
	40	0
6	0	0
	15	0
	30	0

Time: 8:00 to 12:00 a.m.—1/31 FREQ: VHF—low band

Location	Speed (mph)	Errors
1	0	0
	20	0
	30	0
2	0	0
	20	0
	40	0
3	0	0
	20	0
	35	0
4	0	0
	15	0
	30	0
5	0	0
	25	0
	45	0
6	0	0
	20	0
	35	0

NORTH SUBURBAN ROUTE

DATA RATE: 600 bps MOD: FSK

Time: 6:00 to 12:00 p.m.—1/3 FREQ: UHF

Location	Speed (mph)	Errors
7	0	0
	15	0
	30	0
8	0	0
	25	2
	35	1
9	0	0
	20	3
	35	2
10	0	0
	20	6
	35	4
11	0	0
	20	6
	35	4
12	0	0
	20	2
	35	0
13	0	0
	20	0
	35	0
14	0	0
	15	14
	35	6

Time: 8:00 to 12:00 a.m.—1/4 FREQ: VHF—low band

Location	Speed (mph)	Errors
7	0	0
	20	0
	30	0
8	0	0
	20	0
	40	0
9	0	0
	20	0
	35	0
10	0	0
	25	1
	35	0
11	0	0
	15	0
	30	0
12	0	0
	20	0
	35	0
13	0	0
	15	2
	30	0
14	0	0
	20	0
	35	0

DATA RATE: 1200 bps MOD: FSK

Time: 1:00 to 5:00 p.m.—1/11 FREQ: UHF

Location	Speed (mph)	Errors
7	0	0
	20	0
	35	4
8	0	0
	20	4
	35	3
9	0	2
	20	5
	30	4
10	0	2
	30	9
	40	6
11	0	4
	20	0
	30	0
12	0	0
	10	1
	30	0
13	0	0
	20	9
	40	3
14	0	38
	15	27
	30	42

NORTH SUBURBAN ROUTE

DATA RATE: 1200 bps MOD: FSK

Time: 1:00 to 5:00 p.m.—1/7 FREQ: VHF—low band

Location	*Speed (mph)*	*Errors*
7	0	0
	20	0
	30	0
8	0	0
	20	0
	35	0
9	0	0
	15	2
	30	0
10	0	0
	25	2
	35	0
11	0	7
	25	0
	35	0
12	0	0
	20	0
	40	1
13	0	0
	30	3
	40	2
14	0	0
	15	1
	30	0

DATA RATE: 1200 bps MOD: DPSK

Time: 1:00 to 5:00 p.m.—1/21 FREQ: UHF

Location	*Speed (mph)*	*Errors*
7	0	0
	20	4
	35	3
8	0	0
	15	3
	25	2
9	0	0
	25	3
	40	4
10	0	0
	30	7
	40	5
11	0	2
	15	0
	30	0
12	0	0
	15	2
	35	0
13	0	0
	15	2
	35	0
14	0	4
	15	12
	30	21

NORTH SUBURBAN ROUTE

DATA RATE: 1200 bps MOD: DPSK

Time: 1:00 to 5:00 p.m.—1/22 FREQ: VHF—low band

Location	*Speed (mph)*	*Errors*
7	0	0
	15	0
	30	0
8	0	0
	20	0
	30	0
9	0	0
	10	0
	25	0
10	0	0
	15	0
	35	0
11	0	0
	20	3
	30	0
12	0	0
	5	0
	25	0
13	0	0
	20	2
	35	2
14	0	0
	15	2
	30	0

DATA RATE: 1800 bps MOD: FSK

Time: 1:00 to 5:00 p.m.—1/18 FREQ: UHF

Location	*Speed (mph)*	*Errors*
7	0	0
	20	17
	35	14
8	0	0
	25	5
	35	4
9	0	1
	25	6
	35	4
10	0	4
	15	26
	35	14
11	0	0
	20	5
	30	4
12	0	2
	20	5
	35	0
13	0	0
	20	4
	30	2
14	0	25
	15	42
	30	27

Time: 1:00 to 5:00 p.m.—1/15 FREQ: VHF—low band

7	0	0
	25	0
	35	0
8	0	0
	15	1
	40	0
9	0	0
	15	0
	35	0
10	0	0
	20	3
	35	0
11	0	0
	20	0
	30	3
12	0	0
	15	0
	25	0
13	0	0
	20	3
	35	0
14	0	0
	20	5
	35	9

NORTH SUBURBAN ROUTE

DATA RATE: 2400 bps MOD: DPSK

Time: 1:00 to 5:00 p.m.—1/31 FREQ: UHF

Location	*Speed (mph)*	*Errors*
7	0	0
	20	14
	35	12
8	0	0
	20	5
	40	4
9	0	0
	30	5
	35	5
10	0	0
	30	20
	35	15
11	0	0
	15	0
	30	8
12	0	0
	20	11
	35	0
13	0	0
	15	0
	35	0
14	0	0
	30	6
	40	4

Time: 1:00 to 5:00 p.m.—1/30 FREQ: VHF—low band

7	0	0
	15	0
	35	0
8	0	0
	15	0
	40	2
9	0	0
	15	0
	35	0
10	0	0
	10	0
	30	0
11	0	0
	10	0
	30	0
12	0	0
	15	0
	35	0
13	0	0
	20	0
	35	0
14	0	0
	30	8
	35	7

NORTH SUBURBAN ROUTE

DATA RATE: 600 bps MOD: FSK

Time: 1:00 to 5:00 p.m.—1/4 FREQ: UHF

Location	*Speed (mph)*	*Errors*
15	0	0
	20	7
	-	-
16	0	2
	20	6
	30	4
17	0	0
	15	2
	30	1
18	0	0
	10	1
	35	0
19	0	0
	20	0
	40	0
20	0	0
	15	0
	30	0
21	0	0
	15	0
	30	0
22	0	0
	20	0
	30	0
23	0	0
	15	0
	30	0

Time: 6:00 to 12:00 p.m.—1/3 FREQ: VHF—low band

15	0	0
	20	0
	30	0
16	0	0
	15	0
	30	0
17	0	0
	15	0
	30	0
18	0	0
	20	0
	30	0
19	0	0
	10	0
	35	0
20	0	0
	20	0
	35	0
21	0	0
	15	0
	35	0
22	0	0
	15	0
	35	0
23	0	0
	10	0
	30	0

DATA RATE: 1200 bps MOD: FSK

Time: 8:00 to 12:00 a.m.—1/8 FREQ: UHF

Location	*Speed (mph)*	*Errors*
15	0	0
	20	1
	35	3
16	0	12
	30	6
	40	0
17	0	0
	20	4
	35	2
18	0	0
	15	0
	40	1
19	0	0
	20	0
	35	0
20	0	0
	20	0
	40	0
21	0	0
	20	0
	30	0
22	0	0
	20	0
	35	0
23	0	0
	20	0
	30	0

NORTH SUBURBAN ROUTE

DATA RATE: 1200 bps — MOD: DPSK

Time: 1:00 to 5:00 p.m.—1/21 — FREQ: VHF—low band

Location	*Speed (mph)*	*Errors*
15	0	0
	20	0
	35	0
16	0	0
	15	0
	20	0
17	0	0
	15	3
	30	2
18	0	0
	20	0
	35	0
19	0	0
	15	0
	25	0
20	0	0
	20	0
	30	0
21	0	0
	15	0
	25	0
22	0	0
	20	0
	35	0
23	0	0
	25	0
	35	0

DATA RATE: 1200 bps — MOD: DPSK

Time: 1:00 to 5:00 p.m.—1/22 — FREQ: UHF

Location	*Speed (mph)*	*Errors*
15	20	12
	-	-
	-	-
16	0	0
	25	10
	30	6
17	0	0
	15	2
	30	0
18	0	0
	20	2
	40	0
19	0	0
	15	0
	30	0
20	0	0
	20	0
	35	0
21	0	0
	10	0
	25	0
22	0	0
	15	0
	35	0
23	0	0
	20	0
	35	0

NORTH SUBURBAN ROUTE

DATA RATE: 1200 bps — MOD: FSK

Time: 1:00 to 5:00 p.m.—1/11 — FREQ: VHF—low band

Location	*Speed (mph)*	*Errors*
15	0	0
	20	0
	40	0
16	0	0
	25	0
	40	0
17	0	2
	20	0
	40	0
18	0	0
	20	1
	40	0
19	0	0
	20	0
	30	0
20	0	0
	30	0
	45	0
21	0	0
	15	0
	35	0
22	0	0
	20	0
	25	0
23	0	0
	15	0
	25	0

DATA RATE: 1800 bps — MOD: FSK

Time: 6:00 to 12:00 p.m.—1/15 — FREQ: UHF

Location	*Speed (mph)*	*Errors*
15	0	0
	25	2
	35	5
16	0	5
	20	17
	40	7
17	0	0
	15	14
	35	6
18	0	0
	20	2
	35	0
19	0	0
	25	0
	40	0
20	0	0
	15	3
	35	0
21	0	0
	20	0
	35	0
22	0	0
	20	0
	30	0
23	0	0
	20	0
	35	0

Time: 1:00 to 5:00 p.m.—1/11 — FREQ: VHF—low band

Location	*Speed (mph)*	*Errors*
15	0	0
	25	0
	35	0
16	0	0
	20	5
	35	2
17	0	0
	20	1
	30	0
18	0	0
	15	3
	35	1
19	0	0
	20	0
	35	0
20	0	0
	20	0
	30	0
21	0	0
	15	0
	35	0
22	0	0
	20	0
	25	0
23	0	0
	15	0
	35	0

NORTH SUBURBAN ROUTE

DATA RATE: 2400 bps MOD: DPSK

Time: 6:00 to 12:00 p.m.—1/30 FREQ: UHF

Location	*Speed (mph)*	*Errors*
15	20	42
	.	.
	.	.
16	0	58
	40	38
	.	.
17	0	0
	20	5
	40	12
18	0	0
	15	0
	40	0
19	0	0
	35	0
	40	0
20	0	0
	20	2
	40	0
21	0	0
	20	0
	30	0
22	0	0
	20	0
	30	0
23	0	0
	20	0
	25	0

Time: 6:00 to 12:00 p.m.—1/31 FREQ: VHF—low band

15	0	0
	20	0
	35	0
16	0	0
	20	0
	40	0
17	0	0
	20	0
	40	0
18	0	0
	15	0
	40	2
19	0	0
	30	0
	47	0
20	0	0
	30	0
	45	0
21	0	0
	30	0
	35	0
22	0	0
	30	0
	35	0
23	0	0
	20	0
	30	0

TIME OF DAY DATA

DATA RATE: 1200 bps MOD: FSK

DOWNTOWN AREA

Time of day variations are included in the original data.

SOUTH SUBURBAN

Time: 6:00 to 12:00 p.m.—1/16 FREQ: UHF

Location	*Speed (mph)*	*Errors*
6	0	0
6	20	3
6	35	3
7	0	0

Time: 8:00 to 12:00 a.m.—1/18 FREQ: UHF

8	0	0
8	20	1
8	35	1

Time: 6:00 to 12:00 p.m.—1/16 FREQ: VHF low band

6	0	0
6	25	0
6	35	0
7	0	0
8	0	0
8	15	1
8	25	0

NORTH SUBURBAN

Time: 8:00 to 12:00 a.m.—1/18 FREQ: UHF

Location	*Speed (mph)*	*Errors*
7	0	0
7	20	3
7	35	2
8	0	0
8	20	3
8	30	2
9	0	1
9	20	5
9	30	3

Time: 8:00 to 12:00 a.m.—1/18/74 FREQ: VHF low band

7	0	0
7	20	0
7	30	0
8	0	0
8	20	0
8	35	0
9	0	0
9	20	1
9	30	0

☆ U.S. GOVERNMENT PRINTING OFFICE : 1977 O—234-513

ANNOUNCEMENT OF NEW PUBLICATIONS ON NATIONAL CRIME AND RELATED SUBJECTS

Superintendent of Documents,
Government Printing Office,
Washington, D.C. 20402

Dear Sir:

Please add my name to the announcement list of new publications to be issued on the above subjects (including this NBS series):

Name ______________________________

Company ______________________________

Address ______________________________

City ______________ State __________ Zip Code __________

(Notification key N-351)

END