AN ANALYSIS OF SELECTED VENDORS' APPROACHES TO TWO-WAY MOBILE/DIGITAL COMMUNICATIONS

PREPARED FOR:

STATE OF FLORIDA

BUREAU OF CRIMINAL JUSTICE

PLANNING AND ASSISTANCE

TALLAHASSEE, FLORIDA 32303

BY

IIT RESEARCH INSTITUTE

10 WEST 35 STREET

CHICAGO, ILLINOIS 60616

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IITRI

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FINAL REPORT
IITRI PROJECT NO. E6284

FOR: FLORIDA BUREAU OF CRIMINAL JUSTICE
PLANNING AND ASSISTANCE
TALLAHASSEE, FLORIDA 32303

Prepared by

R. M. Lester
D. Szarkowicz

IIT Research Institute
10 West 35th Street
Chicago, Illinois 60616

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FOREWORD

This document is IITRI's final report on the Analysis of Selected Vendors Approaches to Two-Way Mobile/Digital Communications study, performed for the Florida Bureau of Criminal Justice Planning and Assistance. This study, which was performed over a three month period, involved collecting data on four of the currently existing mobile/digital communication systems. These data were then used to develop guidelines for the implementation of mobile/digital communication systems in the more populous counties in Florida. This report contains the system data and the recommended guidelines.

IITRI would like to thank the following people and organizations for their cooperation during this study: George Hogshead and Harold Greene, the project directors for the Florida Bureau of Criminal Justice Planning and Assistance, Phil Byrd of the Division of Communications, Bob Edwards and his staff at the Department of Law Enforcement, and representatives of Kustom Electronics, Atlantic Research Corp., IBM and Motorola, Inc. In addition, IITRI would also like to acknowledge the cooperation of Captain William Miller of the Chicago Police Department. Thanks to the cooperation of these individuals and organizations, the data required for this study were able to be collected and evaluated in the short time available.

Respectfully Submitted,

Ralph M. Lester, Jr.
Project Engineer

Approved by

R. V. Janc
Manager
Communications Systems

TABLE OF CONTENTS

TABLE OF CONTENTS (cont.)

TABLE OF CONTENTS (cont.)

TABLE OF CONTENTS (cont.)

1.0 INTRODUCTION

This report presents the results of IITRI's investigation of four of the currently available mobile/digital two-way communication systems. The four systems investigated were the Kustom Electronics RADCOM-1 System, the IBM 2976 Mobile Terminal System, the Motorola MODAT Alphanumeric Terminal System and the Atlantic Research Corp. ARCOM System. The report is organized in the following manner. Section 2 is a functional and design analysis of mobile/digital communication systems. The purpose of the section is to define the functions that such systems can perform, present design criteria and discuss relevant design parameters in enough detail so that the reader has a basis to evaluate a given mobile/digital system.

Section 3 then presents overviews of the four systems, as well as cost data and IITRI's analysis of each of the systems. This section presents information on the systems only to a level of detail sufficient to give the reader a general idea of the nature and capabilities of the four systems. Detailed data on each of the four systems are contained in the Appendices.

Section 4 is a discussion of mobile/digital communications as applied to the State of Florida. The discussion defines design constraints and system structures which are required by the nature of criminal justice information systems and law enforcement communication systems in Florida.

Section 5 presents guidelines for mobile/digital communication system procurement in Florida and contains a performance specification for mobile/digital communication terminals.

The report has been structured so that the reader does not have to read the detailed system information unless he has a special interest. Thus, sections 2 and 3 enable planners in Florida to learn enough about these systems to make intelligent decisions concerning them. Sections 4 and 5 apply this information to the conditions existing in Florida and enable these planners to structure procurement plans. Section 5 also furnishes them with the nucleus for a system specification. Those interested in the details of a specific system can then refer to the proper appendix.

2.0 ELEMENTS OF MOBILE/DIGITAL SYSTEMS

2.1 The Need for Mobile/Digital Systems

2.1.1 An Introduction to Law-Enforcement Data Systems

Since 1967 the Federal Bureau of Investigation's National Crime Information Center (NCIC) has made available to state and local criminal-justice and law-enforcement agencies computer based files containing criminal records referencing vehicles, license plates, wanted persons' criminal histories, stolen articles, boats, firearms and securities.

The NCIC data base is estimated to contain 4 1/2 million active records, immediately accessable by over 6,000 agencies through 93 control terminals, 53 of which are computer-controlled. The files are continually updated as new data enter the system. A reply to an inquiry into the NCIC system can typically be obtained within 5 to 10 seconds.

To supplement this central file, many areas of the nation have developed regional computer-based files, containing criminal-justice and law-enforcement data of a state-wide or local nature. In the state of Florida, such a regional data system is the Florida Crime Information Center (FCIC).

The FCIC data system consists of two data processing elements, the Data Communications Processor (DCP) and the Central Computer System (CCS). This data system is accessed through a statewide network of data communication lines.

The DCP is the FCIC network controller. All user transactions (inquiries) are routed to their destination via the DCP. The DCP supervises all communications with and among field terminals, directs the inquiry and update activities of the CCS and performs the functions necessary to establish and maintain communication and other computer systems.

The CCS is responsible for maintaining and retrieving data from the FCIC data base files.

Users are connected to the FCIC computer system by two types of data communication lines, low speed lines and high speed lines. The low speed lines are multi-drop lines used to connect to user terminals, while the high speed lines are point-to-point, used to connect the DCP to other computer systems.

FCIC network users, in addition to having access to FCIC files, are also provided with data communication links to the National Crime Information Center (NCIC), the Florida Department of Highway Safety and Motor Vehicles (DHSMV), the National Law Enforcement Telecommunications System (NLETS) and to other law-enforcement agencies throughout the state of Florida.

2.1.2 Operation of the FCIC System

The FCIC files provide a central source of data on stolen firearms or serialized articles, stolen vehicles or license tags, wanted persons, and criminal histories for the state of Florida.

At the local level, these files are manually accessed, typically via an IBM 2740-2 terminal connected by a low speed line to the FCIC computer. When appropriate, the FCIC data system automatically forwards inquiries to the NCIC system. Responses from both the FCIC and NCIC systems are returned to the requesting terminal. The turnaround time, that is the delay between entry of an inquiry and receipt of a reply, typically is two to ten seconds for the FCIC system. Additional delay time, from two seconds to several minutes, are encountered when an inquiry is forwarded to the NCIC system. Further, the NCIC system accepts inquiries from FCIC on a "one in-one out" basis, accepting only one inquiry, searching the files, and returning a reply before accepting a second inquiry. Inquiries to FCIC, however, are accepted as they come into the DCP, queues being formed within the DCP. Therefore, the response time for inquiries which are forwarded to NCIC will be limited by the "one in-one out" philosophy of the link between FCIC and NCIC.

2.1.3 The Demand for a Mobile/Digital System

As a result of attempts to increase field officer effectiveness, safety and efficiency, manual procedures have been developed which permit field officers to request retrieval of information from the law-enforcement data systems. Generally, the officer verbally requests an inquiry, supplying the necessary reference data to the dispatcher, using the voice radio system.

The dispatcher logs the request and either forwards the inquiry for processing by a terminal operator or interrupts his dispatch operation and performs the entry task himself, via a teletypewriter or data terminal. When the reply is returned, the dispatcher verbally passes the response on to the field officer, via the voice radio system. Although a typical turn-around time of two to ten seconds is obtained for the computer inquiry/response process, several minutes may be required for the dispatcher to receive and copy the inquiry, for the request to be processed and forwarded, and for the reply to be verbally returned to the field officer.

This delay, mostly due to human intervention and delays in obtaining use of the radio channel, can cause serious difficulties which affect the efficiency of the entire law-enforcement communications system. For example, during peak activity hours, when data is often most urgently needed, especially in large-city environments, the data base inquiry function may be virtually suspended, because the voice radio system becomes saturated with priority dispatches and other non-inquiry message traffic. In fact, many departments prohibit data base inquiries on the voice channel during busy hours for this reason.

This situation may cause field officers to become reluctant to initiate inquiries, even during non-peak hours. The necessity to reduce congestion on the radio channel and relieve the dispatcher's work load therefore frustrates one of the intents of the data system.

One solution to this dilemma may have been achieved through the development of systems capable of providing field officers with direct access to the law-enforcement data base. Ideally, such systems eliminate delays due to human intervention, bypassing the dispatcher at the base station. By using non-voice data transmission techniques, they also reduce the amount of channel time devoted to data base inquiries.

These systems are called mobile/digital communication systems. The motivation for their development was to provide automated data base access. Other functions, however, which can increase the overall efficiency of law-enforcement operations, can also be performed by these systems.

2.2 Functional Analysis of Mobile/Digital Systems

Mobile/digital systems were originally developed to provide a means for automated data base access. Of more fundamental importance, however, is the capability of a mobile/digital system to perform terminal-to-terminal, or terminal-to-base station data communications. A mobile/digital system is, in fact, primarily a data communication network. This fact allows the utility of such systems to be substantially increased. From a design standpoint the functions which a mobile/digital system may be capable of performing are:

1) Terminal-to-terminal message transmission.
2) Automated data base inquiry and response.
3) Automated report generation and data collection.
4) Status maintenance.

5) Automated complaint entry.
6) Computer-assisted dispatching.

The requirements placed upon a typical mobile/digital system depend primarily on the specific application for which the user agency intends the system to be defined.

2.2.1 Functions Performed by Mobile/Digital Systems

A functional block diagram of a typical mobile/digital system is shown in Figure 1. A description of each available function is given below. From a design standpoint, the functions are listed in their relative order of importance.

2.2.1.1 Terminal-to-Terminal Message Transmission

Mobile/digital systems are fundamentally data communications networks. The system transmits messages in digital form between a central location (the network controller) where message addressing, routing, and processing are performed, and a network of various data terminals. A means is thus provided for controlling the network. The data terminals may be stationary devices such as cathode ray tube (CRT) data terminals and teletypewriters, or they may be specially designed data terminals placed in mobile units.

Inbound messages, addressed to a network controller or to other terminals in the network, may originate at any data terminal. Outbound messages may contain data or be used for network control, and are addressed by the network controller to single terminals, groups of terminals, or all terminals in the network.

Each block in Figure 1 which represents a system function can be regarded as a functional module. It represents a combination of software and hardware that permits the system to perform the function. When such a functional module is added to a mobile/digital system, it becomes the generator of more

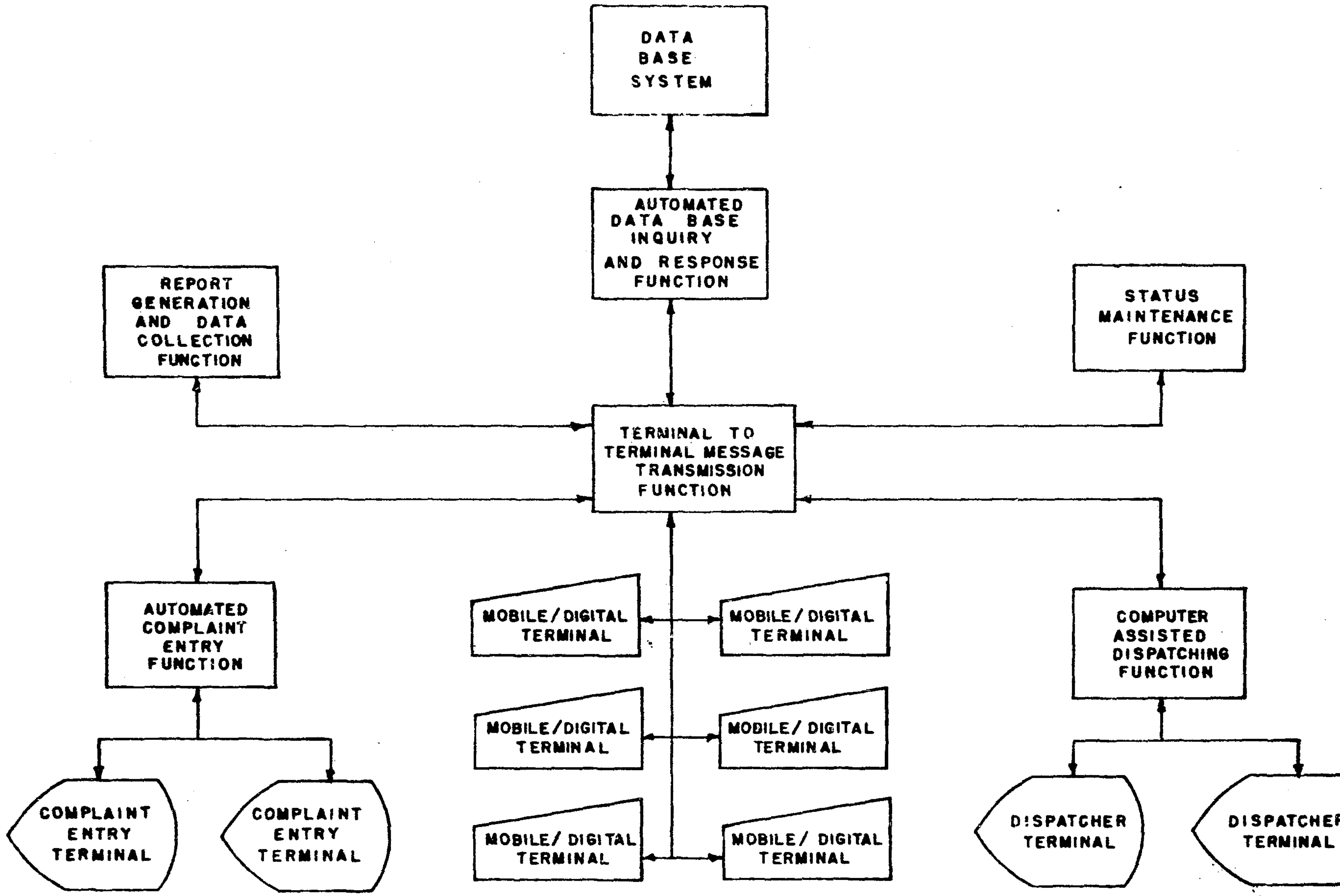


Fig. I TYPICAL MOBILE/DIGITAL SYSTEM FUNCTIONAL DIAGRAM inbound messages, which may be addressed to selected terminals, the network controller, or other modules in the system. A functional module may receive messages from the network of data terminals, the network controller, or other modules.

The capability to process, address and route messages in digital form is thus a prerequisite for the addition of other functions to a mobile/digital system.

2.2.1.2 Automated Data Base Inquiry and Response

Mobile/digital systems were initially developed to provide an on-line interface to local and remote law-enforcement data bases, such as NCIC and FCIC. At the central location, received messages requesting data retrieval or file additions, modifications or deletions are routed by the network controller through the data base inquiry and response functional module to the data base system. Performance of this function requires that the facilities for performing these message transfers be available and that terminal-to-terminal communications be possible. Replies from the data base are addressed to the proper data terminal and are routed to that terminal by the network controller.

Typically, reply messages are examined for the occurrence of "hits", or positive responses from the law-enforcement data base. Such positive responses are flagged for special processing, and logged for control and administrative purposes. The data base inquiry and response function includes the capability to perform this flagging and to initiate the logging of messages inbound to and outbound from the data base system.

2.2.1.3 Automated Report Generation and Data Collection

Often it is desirable to maintain data and generate reports concerning activities within the network of data terminals. For example, for messages received from the data base system which indicate "hits" and have been properly flagged, a report may be generated indicating the requesting terminal and the nature of the hit. Further, data can be collected relative to unit performance, unit activity, channel characteristics, response time to complaints and many other parameters descriptive of law enforcement agency performance. These data can be stored and processed to provide statistics on agency performance.

A mobile/digital system provides this capability, through an automated report generation and data collection function. Administrative records may be maintained and updated on the basis of reported data and received messages. This function generally includes the capability and facilities for local, limited data storage and retrieval. Operational data bases may be established, with files containing information of a daily, local or temporary nature. Limited processing capability allows calculation of statistical parameters describing system performance.

In some cases, field data for report generation can be entered at network terminals and held for later processing. One method for obtaining this type of data is for the system to lead the terminal operator through a sequence of question and answer messages. Another technique uses a predetermined message format "fill-in-the-blanks" approach. Statistical summaries may be generated to indicate the performance of the mobile/digital system, or of selected functions or units within the system.

2.2.1.4 Status Maintenance

Resource management is a continuous operation in a law-enforcement environment. A mobile/digital system can provide the means for maintaining status information on all available resources, including mobile units equipped with data terminals, and non-terminal-assigned resources such as foot-patrolmen.

A system which includes an automated complaint entry function (described below) may also be capable of maintaining complaint-oriented incident status information. When the computer-assisted dispatching function is included, the ability to maintain mobile unit status information is essential. In this case, dispatch-oriented incident status information will also be available.

The status maintenance function includes the capability for maintaining, retrieving and updating this data, as well as the facilities necessary for its storage and display.

2.2.1.5 Automated Complaint Entry

A mobile/digital system may include the facilities and capabilities for automating the complaint entry function. Complaint messages may be entered at one or more designated data terminals. Complaints can be entered, displayed and forwarded to other points in the system, for processing and logging. Complaints may be automatically routed to a selected dispatcher data terminal.

2.2.1.6 Computer Assisted Dispatching

A mobile/digital system can also be provided with the capability to automatically queue entered complaints, which have been forwarded to a selected dispatcher. In a computer-assisted dispatching system, the status of each mobile unit, and possibly each complaint and previous dispatch, is available from the status maintenance function. The computer-assisted dispatching function then may recommend the dispatch of an available mobile unit. Once a dispatch is made, the status maintenance function may record dispatch-oriented incident status information. The report generation function may record all dispatches, either logging or storing them for later analysis.

A computerized-dispatching mobile/digital system, with an extension of the computer-assisted dispatching function, allows complaints to be automatically assigned to available mobile units, on the basis of status and location. Dispatches are composed, addressed and routed automatically, and no dispatcher intervention is required.

2.2.1.7 Summary

It can be readily appreciated at this point that a mobile/digital system, originally developed to perform a simple inquiry function, can, by its very nature, be expanded to encompass all the dispatching operations as well as provide report and performance data that exceeds that currently available to many departments. The reason for this, of course, is the data processing element, the network controller, which is the heart of the system. The inherent flexibility and modularity of modern computers provid a law enforcement agency with a tool which can substantially increase its effectiveness as well as upgrade its efficiency and even its professionalism. Further, when cost/benefit ratios are considered, inclusion of many of the functions discussed above becomes almost necessary, if the cost of these systems is to be justified. These cost/benefit considerations will be elaborated upon in a later section.

2.2.2 Possible Benefits and Drawbacks to Mobile/Digital Systems

Based on the preceding discussion, a list of potential benefits and drawbacks to the use of mobile/digital communication systems is presented. It should be noted that digital transmission can allow the same information to be transmitted much more rapidly than by voice. Therefore, if many of the functions now performed by voice are shifted to digital transmission, radio channel utilization will decrease, given the same amount of traffic. Therefore, the channel can then support more voice traffic or greater numbers of digital messages.

2.2.2.1 Benefits

2.2.2.1.1 Increases in Officer Safety, Productivity and Efficiency

- Faster response to inquiries, even during hours of peak activity.
- Inquiry rate can be increased
- Reduction or elimination of police action on "no-record" cases.
- Accurate message transmission, recording and display.
- Elimination of inherent voice mode confusion
- Enhancement of resource control through status monitoring
- Reduction in time spent per case, through report generation.

2.2.2.1.2 Increases in Effectiveness of Radio Channel Utilization

- Congestion on existing voice channels reduced, allowing more time for emergency or high priority voice messages.
- Provides secure, private mode of communication.

2.2.2.2 Drawbacks

2.2.2.2.1 Increased Expenses and Hazards

- High unit cost.
- Require little, but rather specialized maintenance.
- System is subject to catastrophic failure, requiring a backup system or mode.

2.2.2.2.2 Possibly of Limited Value

- Rather high cost/benefit ratio.
- Response time for inquiries depends on number of users accessing the data base.
- Increased inquiry rates may saturate a voice-shared channel, absorbing all available time.
- "Hits" are not always identifiable, and human interpretation is often required.

- Message transmission is subject to radio channel errors, therefore transmission techniques require careful, detailed error-control analysis.
- An expanded system is required to support advanced functions.

2.2.3 Human Factors in Mobile/Digital Systems

2.2.3.1 The Mobile/Digital System-A New Man-Machine Interface

Mobile/Digital communication systems were originally developed to provide law-enforcement field officers with a direct means of accessing remote data bases. Perhaps more important, these same systems are also capable of performing allied functions as part of a unified law-enforcement communications service.

The addition of a mobile/digital system to an existing voice communication system cannot simply be viewed as the overlay of a new system addition upon an existing communications structure. Rather, a careful analysis is required to examine the effects of increased interaction between man, represented by the dispatchers and field officers, and machine; represented by the data base system, the mobile/digital system and the radio communication system. The difference is shown in Figures 2 and 3, where Figure 2 is a block diagram of an existing law-enforcement communications system and Figure 3 illustrates the same system, modified by the addition of a mobile/digital communication system.

At least two new man-machine interfaces will result from the addition of a mobile/digital system to an existing communication system. First, there is an interface of primary importance between the mobile data terminal and the terminal operator. Typically, the operator is a field officer, who previously worked only with a voice radio system. The mobile data terminal may be one designed specifically for use in a mobile unit's environment, or it may simply be a "copy" of an existing stationary data terminal.

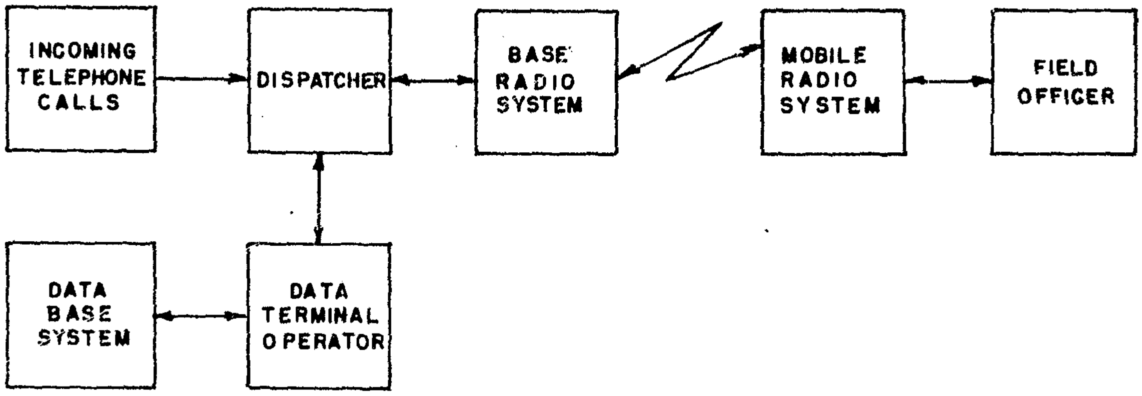


Fig. 2 EXISTING COMMUNICATION AND LAW-ENFORCEMENT DATA SYSTEM

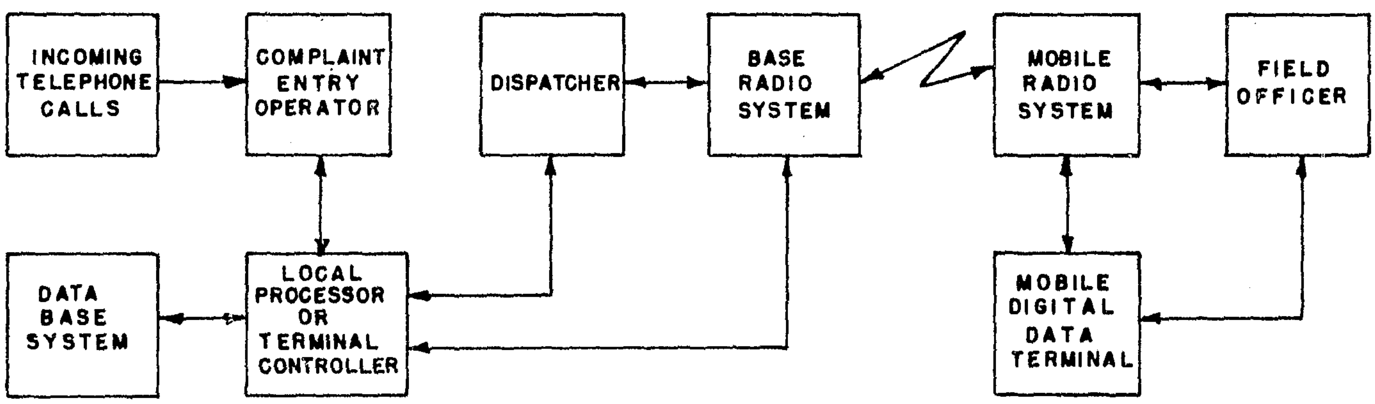


Fig. 3 A SYSTEM MODIFIED BY THE ADDITION OF A TYPICAL MOBILE/DIGITAL COMMUNICATIONS SYSTEM

The operator normally inputs data using some keyboard arrangement, complete with controls and switches to modify the terminal's operation. Input and output data are typically displayed via a light-emitting-diode (LED) or solid-state plasma display panel, similar to those now used on commercial electronic office calculators. Control and terminal status indications are also displayed using LED's or lighted panels.

A second interface forms at the base station, between the dispatcher or complaint entry operator and the local processor. Typically, the dispatcher uses a CRT data terminal, with a typewriter-like keyboard and a television-type cathode ray tube display. Some systems also include a teletypewriter at the base station, which may or may not also be connected to the National Law-Enforcement Telecommunications System (NLETS).

2.2.3.2 Factors Which Influence the Design, Application and Integration of Mobile/Digital Systems

The following list contains those questions which must be answered in analyzing the man-machine interfaces in a typical mobile/digital system. This list is included as a guide to those human factors which affect system design. In the following sections, the most important features of each available system will be discussed.

Physical Dimensions

- Has all equipment been designed for use by operators of average physical dimensions and characteristics?
- Is there any chance of accidental injury, especially in the mobile unit environment?
- Can the operator conveniently reach all keys, controls and switches, while the mobile unit is at rest or moving?
- Does the equipment occupy excessive space in the mobile unit, or at the base station?

- Does the equipment interfere with the operation of any of the other equipment in the mobile unit?

Data Sensing and Output Interpretation

- Are all displays, visual and audible, performed well within normal sensory limits? Can the operator read the display without strain, by night and day?
- Do any input/output tasks require discrimination by the operator? Must the operator detect relative or absolute conditions?
- Is any "filtering" of the system's output required due to the effects of noise within the system? Is there any possibility that the operator may have to interpret incomplete information?
- Are there special situations in which monitoring of men by machines, or vice versa, can aid overall system performance? Is this feature used to advantage? Is there any possibility of problems due to human distractability? Can messages be lost?

Data Processing and Input

- Are any routine, repetitive and generally boring tasks required to be performed by the operator? Is high-speed operation essential?
- Do any tasks require the operator to remember information? Are displays sufficiently buffered. Is the operator's task ever interrupted? Why?
- Is there a need for flexibility in operation? Is this capability provided?
- Do any tasks have a low error tolerance? Will input errors be recognized and rejected? Will correct procedures be indicated?
- Must information be encoded or formatted in any way? Can a variety of input forms be accepted? Is sufficient time available to perform the encoding?

- Are there any tasks which require the operator to improvise?
- Is the use of judgment required of the operator? Must the operator make decisions based on received or input data?
- May any tasks be simplified, or the number of required operations reduced? What is the transmit/receive sequence?
- What is the effect of training time? How much is required?

Human Capability for Learning and Recognition

- Do any tasks take advantage of human learning ability? Is the equipment arrangement easy to learn?
- Do any tasks resemble other familiar tasks? Are display and keyboard arrangements familiar?
- How critical is the duration of training time? Can it be reduced by partial or "on-the-job" training? Is the operation of any task difficult to learn?
- Are maintenance requirements measurably increased?
- What training is required for maintenance personnel?

Human Physical and Psychological Needs

- Do the tasks require performance by the operator, reliably, in the presence of extreme stress? What are responses to "hits", and actions in "emergency" situations?
- What are the effects of isolation, boredom, operator fatigue and morale? Will the operator be intimidated by the device? Will response times affect rates of operation?
- Is operator vigilance required, or are indications of changing conditions provided?
- Is operator performance feedback available, for use in guidance, training and motivation?

Environmental Sensitivity

- Are there adverse environmental conditions, such as temperature, noise, vibration, glare, which affect the man-machine interface?

Social Environment

- What social relationships (dispatcher-field officer, sergeant-field officer, etc.) are important in the system design? Are group calls desired, or will single unit calls suffice?
- Can the field officer-partner team operate conveniently? Does the mobile/digital system interfere with this relationship? Can both members easily operate the device?

Coordinated Human Action

- Is rapid response to any control signal or message ever required? What effects do emergency or priority conditions have on the system's operation?
- Is there likely to be interference with overall system performance due to human interaction and intervention? What are the effects of shared radio channel operation? How does the dispatcher affect performance?
- Can partial or catastrophic system failure occur, and what alternate actions may the operator take? What are the effects of lost messages?
- What are the effects of the physical and emotional needs of the operator?

Differences Among Individuals

- Has there been recognition of the fact that operators may differ widely in terms of skills, sensitivities, aptitudes and natures.

- What are the effects of differences in human performance, size, physical characteristics and motivation? Are all operators assumed to have near identical intellectual, training and experience backgrounds?

Man-Machine Links-Physical Interfaces-Displays

- What are the information requirements? How much data must be displayed? Is the necessary data displayed in the most usable, convenient format?

- Will the operator be able to read displays and see visual indicators accurately and conveniently? Will glare or parallax distort the display?
- Do indicators operate as "expected"?
- Are visual displays properly illuminated for all conditions? Is vibration likely to affect readability, especially in the mobile unit?
- Do visual displays provide a means for indicating that they are out of order?
- Are auditory links such as loud speakers and buzzers compatible with normal human hearing?
- Will simultaneous auditory signals come from several sources? What is the likelihood of the occurrence? What masking effects might these competing signals have?
- What ambient noise levels can be anticipated? Will these levels interfere with men working? Can the noise of devices such as printers be dampened?

Controls, Keys and Switches

- Are the control movements "natural" with respect to direction?
- Have functionally related controls been located near each other? Are the groupings distinguishable by color or spacing?

- Are all controls easily within reach, while the mobile unit is at rest or moving?
- Are the control actions positive, not loose or stiff?

Terminal and Console Layout and Configuration

- Do the base station consoles provide adequate knee room, sitting space and writing area? Are all displays and controls positioned for easy access by the operator?
- Are the controls located near the displays they affect?
- Are the controls arranged sequentially, in order of operation?
- Are the manual activities distributed evenly between the right and left hands?
- Has operator comfort been considered? Is sufficient space available for back or arm rests? Can the terminal height be adjusted? Is cushioning provided?
- If more than one operator may use the console, has sufficient room been provided, or may the unit be repositioned?
- Has adequate, non-glare illumination been provided?
- Can the coordination of controls and display be improved?

Workspaces at the Base Station, and in the Mobile Unit

- Has adequate illumination been provided?
- Are there differential requirements for illumination? What are the day-night lighting effects? Can intensities be adjusted?
- Is there ample space for all required equipment?
- Will the flow of operator traffic affect operation?
- Can bulky clothing or special equipment be accommodated?

Installation and Maintenance Entry

- Has the equipment been arranged with the maintenance technician's task in mind? Can parts be removed without dissassembly? Are all sides of each unit accessible?

- Are fasteners easily removed? Are any special tools required for access?
- Is color coding necessary? Has it been utilized?
- Has maintenance been simplified by the use of plug-in subassemblies? Disposable Units? Functional Indicators?
- Are legible, understandable, permanent maintenance instructions provided?

Environmental Impact

- What are the effects of heat, vibration or noise of the system upon the operator? Can these factors be minimized or controlled by design?

Voice Links

- At what point or time in the operation of the system may voice links be required? Will intelligibility be affected by interference or noise?

2.2.4 Interface Requirements

The mobile/digital system is only one element in a law enforcement communication (or information) system. This larger system must provide those functions which are not usurped by the mobile/digital system. Therefore, the mobile/digital system must interface with an existing voice radio system, with which it may share equipment and radio channels, a dispatch center, possibly an existing agency data processing/information retrieval system, and remote data systems. The influence of these interfaces upon mobile/digital system design will be treated in the following section.

2.3 System Design

2.3.1 What is a Mobile/Digital System?

A mobile/digital system is a configuration of specially designed electronic communications, control, and computing equipment enabling two-way transmission of messages in digital form between a central location and a network of mobile data terminals.

In a law-enforcement application, the central location is the communications control and dispatching center, and the mobile data terminals are mounted inside police cars.

The ability to transmit information in a format suitable for processing by high-speed computers allows a mobile/digital system to implement rapid data communications, remote data base access, report generation and message logging, mobile unit status maintenance, computer-assisted dispatching and automated complaint entry.

A communications link is required between the mobile data terminals and the central location, usually a voice-grade FM radio channel. Often, an existing radio channel will be used, in which case data messages time-share the channel with voice messages.

2.3.2 What Hardware Elements are Required in a Mobile/Digital System?

2.3.2.1 Classification of Mobile/Digital Systems

The development of mobile/digital systems, to date, has resulted in the emergence of two general classes of systems. First, a number of mobile/digital systems have been proposed for use by those law enforcement agencies who have existing data links to remote data bases such as NCIC and FCIC, but who do not have local data processing facilities. These systems will be referred to as local processor mobile/digital systems.

A second class has been developed for those agencies having access to local, centralized data processing facilities. A large city, for example, may have an existing law-enforcement data base system, with additional computer time available for message processing and communications control. These systems will be referred to as remote processor mobile/digital systems.

Both classes may be further sub-divided by radio channel requirements, line control techniques, and other factors. Only those factors relevant to the systems currently available are discussed below.

2.3.2.2 Elements of a Typical Local Processor Mobile/Digital System

A block diagram of a typical local processor mobile/digital system is shown in Figure 4. Those elements of the system assumed to be part of the user's existing communications equipment are shown as shaded blocks. No discussion of these shared elements, except as they affect the mobile/digital system, is necessary.

2.3.2.2.1 Base Station Elements

Located at the base station, the local processor, a minicomputer, is the essential controlling element in this class of mobile/digital systems. The minicomputer is responsible for transmission of data between terminals in the network, processing of messages within the system, maintenance of an operational interface to the remote data processing system and control of the network of remote terminals and the local peripheral devices.

A teletypewriter is normally included for minicomputer system control purposes, but is not an operational element of the mobile/digital system.

Typical peripheral devices used with a mobile/digital system include a high-speed line printer, for message logging and report output, CRT data terminals for complaint entry, dispatcher control, and display of entered and received messages, a status monitor, typically also a CRT data terminal, for display of various conditions within the system, and a communications line

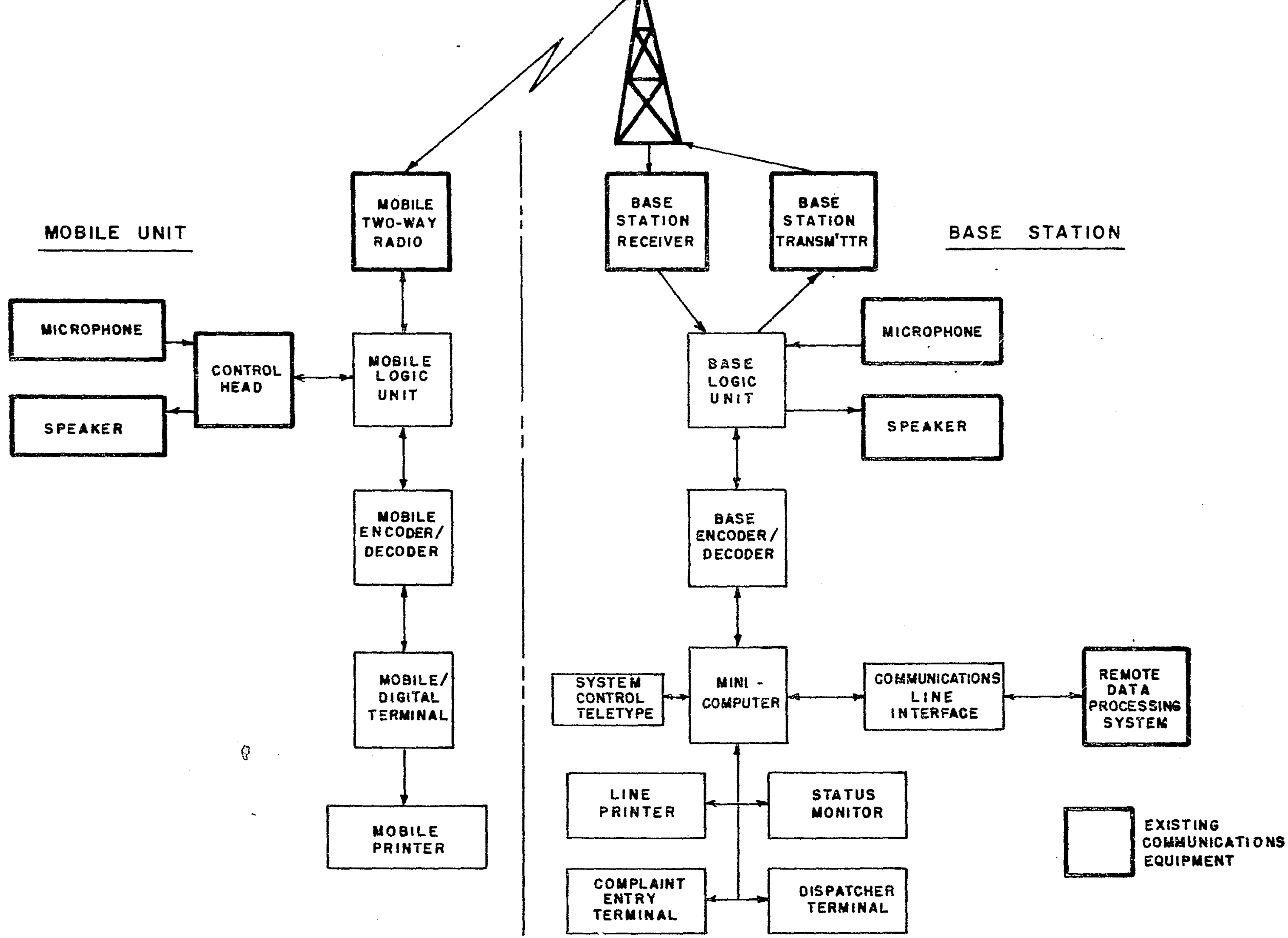


Fig. 4 LOCAL PROCESSOR SHARED CHANNEL MOBILE/DIGITAL SYSTEM BLOCK DIAGRAM

interface, for performing control, conversion, and buffering of data to and from the remote data processing system. These peripheral devices are standard equipment, all available for use with any system which employs a minicomputer.

Two unique elements of this type of mobile/digital system are the base logic unit and the base station encoder/decoder. The purpose of the base logic unit is to assign access to the base station radio system to either the existing voice radio equipment, represented by the elements labelled microphone and speaker, or to the local processor, through the base station encoder/decoder. The base logic unit then permits voice or data messages to be broadcast over the radio communication system. In systems which permit data and voice to time-share a radio channel, the base logic unit ensures that outbound voice traffic from the base station is given priority over outbound data messages.

The base station encoder/decoder is the key element which permits the minicomputer to send and receive messages over the voice channel. Essentially, the encoder/decoder converts d.c. digital messages required by the minicomputer, to audio digital messages which can be broadcast over the voice radio channel. Two general methods are used to accomplish this conversion, frequency shift-keying and phase-shift-keying. A description of these methods will be left to later sections. The important fact is that outbound digital data messages are "encoded" from a d.c. to an audio representation, while inbound digital messages are "decoded" into d.c. form from a received audio form.

2.3.2.2.2 Mobile Unit Elements

Within the patrol vehicle, or mobile unit, three functional elements are installed. The mobile logic unit directs the flow of inbound and outbound voice and data messages, assigning the available radio channel to either voice or data, with voice always receiving priority.

The mobile encoder/decoder functions exactly in the same manner as the base station encoder/decoder, converting between digital and audio signal formats. In most mobile/digital systems, both the base station and mobile logic units and encoder/decoder are electronically identical.

The mobile/digital terminal is the hardware interface between the terminal operator and the mobile/digital system. The mobile terminal includes a keyboard for data entry and a display, such as a solid state plasma or light-emitting-diode (LED) panel, for data output and message composition. Limited memory, or buffering, is often provided to store received messages while the operator is entering a message for transmission. Output or transmit buffers are also provided in case a repeat is requested by the base station.

Controls are also provided for terminal operation, and lights are used to indicate system and unit status, as well as for greater guidance.

A mobile printer is often available as an option, providing the capability for hard copy output. The printer typically operates at the command of the terminal operator, but may be operated remotely, upon receipt of a proper command from the base station. This feature permits messages to be transmitted to a mobile unit while the operator is out of the vehicle, eliminating the need for a large memory, store-and-forward operation at the base station.

2.3.2.2.3 System Operation

The operation of a local processor mobile/digital system is explained with reference to the block diagram of Figure 4. The system shown is assumed to operate over a time-shared voice radio channel, in a contention mode, with both voice and data traffic competing for control of the radio channel. For simplicity, a simplex radio channel is assumed. On a simplex channel, traffic is permitted in only one direction, inbound or outbound, at any given time.

2.3.2.2.3.1 Mobile-to-Base Station Operation

Either voice or data messages may be transmitted from a mobile unit. Voice messages, by FCC rule, must always override any data traffic on the channel. Voice operation is accomplished in the usual manner; the mobile logic unit senses the operation of the "push to talk" button, and yields the channel to the microphone. At the base station, the base logic unit recognizes the voice traffic and allows the loud speaker to output the received voice message.

Data messages, either terminal-to-terminal, status, or special function, are entered into the mobile/digital terminal using its keyboard. Transmission is initiated with the operator presses a transmit key (except, in some cases, for status messages, which require that only one key be depressed). The mobile logic unit first senses the presence of any FM carrier on the radio channel and when the channel clears, allows the message to be transmitted. The mobile encoder/decoder automatically converts the data message into an audio format.

At the base station, the received audio signal is inspected by the base logic unit. When a data message is found, the base station encoder/decoder automatically converts the message to d.c. and passes it on to the minicomputer for processing.

2.3.2.2.3.2 Base Station Operation

Outbound data message transmission to the network of mobile/digital terminals is always initiated by the minicomputer, which performs message forwarding, data processing and system control functions. The minicomputer acknowledges received messages, performs error checking, and forwards terminal-to-terminal messages to their addressed destination.

As a local data processor, the minicomputer receives input data and outbound messages from the complaint entry and dispatcher CRT data terminals, displays unit status on the monitor provided, and logs messages on the line printer. Applications programs may also provide for automatic report generation, with statistical and operational results printed for later use.

Voice radio operation proceeds as normal; the base logic unit always yields the radio channel to the voice communication system.

2.3.2.2.3.3 Extensions and Variations

Typical local processor mobile/digital systems are designed to operate with a network of up to one hundred mobile terminals. Operating experience is expected to provide some indication as to the maximum number of mobile/digital terminals which can be accommodated by such systems. Operating limitations will mainly result from channel restrictions on message traffic, not from base station or mobile network equipment configurations. This will be particularly true in the case of channels sharing voice and digital traffic.

An obvious variation is to use half-duplex or even full-duplex operation, which can easily be accommodated by the base and mobile logic units. Polling techniques may also be used. For absolute network control, a dedicated channel is required, although a modified polling scheme can be implemented on a time-shared channel.

2.3.2.3 Elements of a Typical Remote Processor Mobile/Digital System

Figure 5 is a block diagram of a typical remote processor mobile/digital system. In this class of mobile/digital system a data dedicated duplex radio channel is used to achieve more efficient network control.

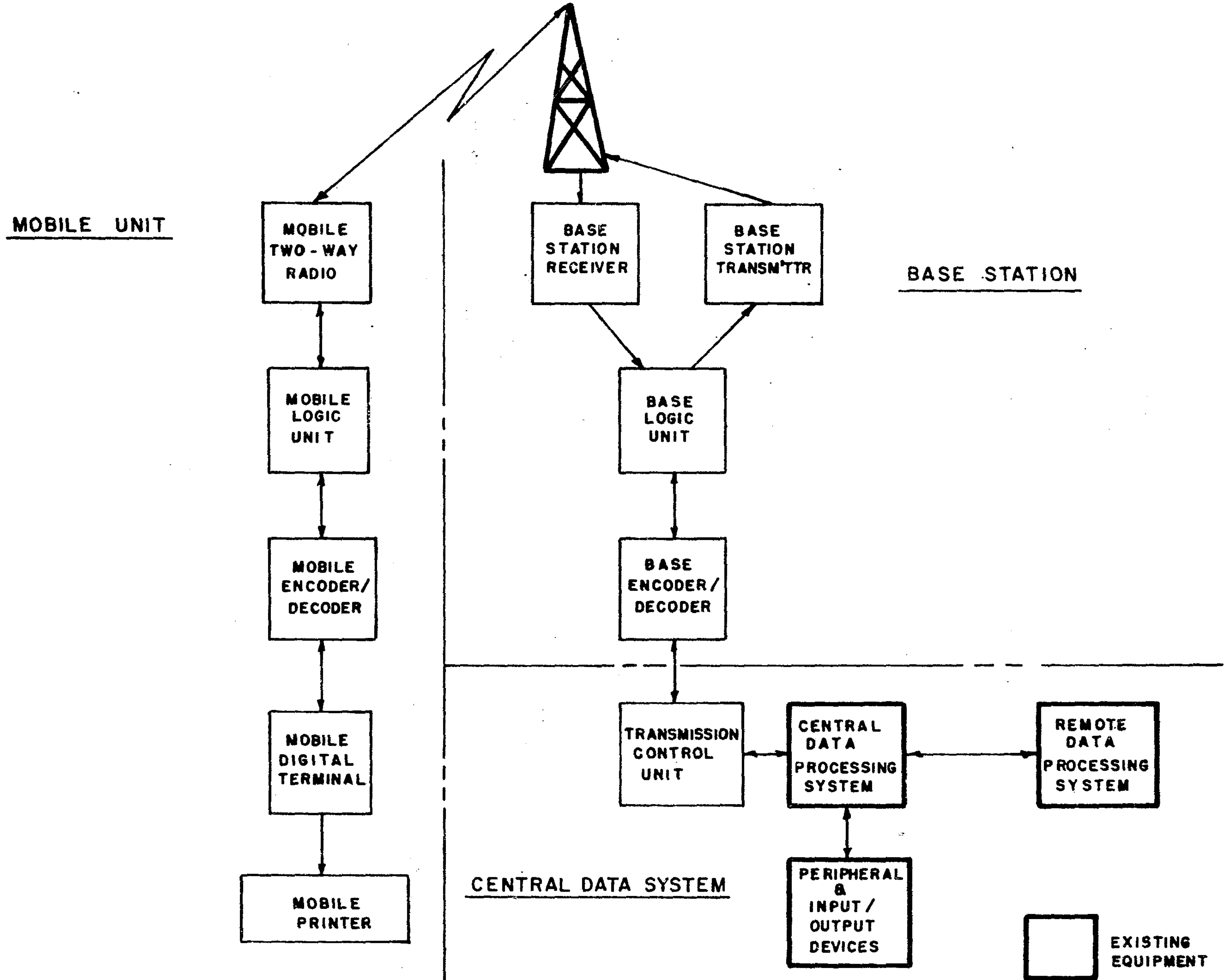


Fig. 5 TYPICAL REMOTE PROCESSOR DEDICATED CHANNEL MOBILE / DIGITAL SYSTEM BLOCK DIAGRAM

2.3.2.3.1 Base Station Elements

At the base station in a remote processor mobile/digital system, a transmission control unit performs these functions required for communication control, error detection, and message buffering. The transmission control unit does not perform any processing of information contained in the text of messages. All message interpretation is performed by the central data processing system. The entire mobile/digital system thus appears, to the central data processing system, as another input/output device. The base station encoder/decover converts the d.c. digital message format used within the transmission control unit to the audio, or voice like, tone format used for transmission of messages over the radio channel.

The base logic unit in a dedicated channel system senses the operation of the base station receiver and transmitter, directing outbound messages to the transmitter and accepting inbound messages from the base station receiver.

2.3.2.3.2 Mobile Unit Elements

In the patrol vehicle, or mobile unit, the mobile logic unit senses the operation of the mobile radio system. When a data message appears at the receiver output, the mobile logic unit permits the received audio tones to be converted to d.c. by the mobile encoder/decoder. The encoder/decoder converts between the audio tones used for data transmission over the radio channel and the d.c. digital format required by the mobile/digital terminal.

The mobile terminal includes a keyboard for data entry and possibly a solid-state plasma or light-emitting-diode (LED) display panel. The mobile printer may also serve as the only display. In that case, all received and transmitted messages are permanently recorded at the mobile unit.

The mobile terminal also includes mobile unit status indicators, operator guidance indicators, and controls for the operation of the terminal.

2.3.2.3.3 System Operation

The operation of a remote processor mobile/digital system is explained with reference to Figure 5.

The system shown is assumed to operate over a data-dedicated voice-grade duplex radio channel. It will be assumed that a polling technique is used to control the network; no contention between inbound and outbound traffic occurs. Simply stated, polling means that the base station exercises complete control over the network. No terminal is allowed to transmit or receive any messages unless commanded to do so by the base station. On the outbound channel, only polling command messages from the base station are present; no intermessage interference is possible. On the inbound channel, intermessage interference may result if two mobile units simultaneously transmit a message; this conflict can be resolved by careful timing of polling commands and the use of polling interrupts.

2.3.2.3.3.1 Mobile-to-Base Station Operation

Only data messages are transmitted on the inbound channel, since the system design excludes voice traffic. The terminal operator enters a message using the keyboard of the mobile/digital terminal. The mobile logic unit passes the d.c. digital signal which is generated to the mobile encoder/decoder, which converts the signal into an audio signal which can be transmitted by the mobile radio. The message cannot be transmitted, however, until the base station signifies that it is ready to receive it. When such a polling command is received, addressed to the mobile terminal in question, the previously entered message is then automatically transmitted to the base station.

At the base station, the base logic unit and the encoder/

decoder reproduce the message in d.c. digital form, and transfer it to the transmission control unit.

The transmission control unit forwards the received message to the central data system, but only when requested to do so by the central system. The central data system is responsible for processing the message text and forwarding the message to an addressed location, or on to a remote data processing system.

2.3.2.3.3.2 Base Station Operation

At the base station, the base logic unit senses the operation of the base station radio system, while the base station encoder/decoder converts between the audio signals required by the radio channel and the d.c. digital signals required by the transmission control unit.

The transmission control unit is responsible for maintaining the operational interface between the central data system and the network of mobile terminals, transmitting messages upon command from the central data system, and receiving and buffering messages prior to their transfer to the central data system.

2.3.2.3.3.3 Extensions and Variations

Remote processor mobile/digital systems, operating on data dedicated duplex radio channels, are capable of expansion up to a size limited by the nature of the polling scheme used. Clearly, a fixed-rate polling scheme permits a fixed number of mobile/digital terminals to be serviced. Variable rate techniques can permit more or fewer terminals to be serviced, depending on the activity of the users. In general, the network control provided by a polling scheme, together with the use of duplex operation, makes these systems well suited for applications requiring several hundred mobile/digital terminals in constant use.

2.3.3 Mobile/Digital System Design Constraints

In the design of a mobile/digital system, constraints arise due to the necessity for interfacing the hardware of the mobile/digital system with the user's existing or proposed communications and computing equipment, and the need for integrating the mobile/digital system's operation into the operation of the overall communication system.

Functional interfaces are required with the user's base and mobile voice radio systems (or a data-dedicated radio system, if used) and with remote law-enforcement data bases. In addition, an interface may be required with an existing central data processing system, if one is available.

Operational interfaces are required to successfully integrate the system's operation. Current operating practices will surely be modified. Voice traffic patterns may change, as data traffic is introduced.

2.3.3.1 Constraints Due to Functional Interfaces

2.3.3.1.1 Radio Frequency Spectrum Constraints

A police radio system must operate on a channel, which consists of one or more frequencies, assigned by the Federal Communications Commission (FCC). Such operation must be restricted to a small range of frequencies, called the operating bandwidth, about the assigned frequency.

The total of all possible radio frequencies makes up the radio frequency spectrum. Each radio transmission thus occupies some portion of the radio spectrum, takes a certain amount of time, and can be received over a certain geographic area. No two users of the radio spectrum can occupy the same portion of the spectrum, at the same time, in the same area, without interfering with each other. To prevent interference, users are separated in frequency, area of operation, and time.

The FCC has set aside portions of the radio spectrum for use by the Police Radio Service. Three frequency bands have been provided, in the low-band (about 37-46 MHz), the high-band (about 154-159 MHz), also called the 150 MHz or very-high-frequency band (VHF), and the ultra-high-frequency or 450 MHz band (about 453-465 MHz).

The FCC has also ruled that certain frequencies between 470 MHz and 512 MHz and between 806 MHz and 960 MHz may be used by land-mobile radio in the ten largest metropolitan areas in the United States. Only a portion of the channels in these bands will be available for use by the Police Radio Service.

In order to transmit information a small band of frequencies centered about the assigned frequency is required. In order to prevent adjacent channel interference, the spacing between assigned frequencies must be greater than one-half of the information bandwidth. For FM voice signals, all information must be transmitted within a band 20 kHz wide, centered about the assigned center frequency. Present channel assignments are thus spaced at 20 kHz in the low-band, 15 kHz in the high-band, and 25 kHz in the UHF-band. Each signal is limited to a maximum instantaneous frequency deviation of 5 kHz. The frequency deviation of an FM signal is the change in the carrier frequency produced by the audio modulating signal.

A mobile/digital system must then be capable of operation within a maximum radio frequency bandwidth of 20 kHz, when interfaced to a police radio system.

2.3.3.1.2 Channel Configuration

A channel is defined in terms of the number of frequencies assigned to support two-way communication. In practice, channels consist of one frequency, or two frequencies. In a two frequency channel, one frequency may be used for base station transmissions while the second frequency is used for mobile unit transmissions.

The channel configurations most commonly used are:

Single-frequency Channel, Simplex Operation - permits transmission from A to B or from B to A, but not in both directions simultaneously. Only one user may occupy the channel at any instant in time.

Two-frequency Channel, Duplex Operation - permits transmission from A to B and from B to A, simultaneously. The channel may be used by A and by B at the same time, implying that a user can be listening and talking at the same time.

Two-frequency Channel, Half-Duplex Operation - permits transmission from A to B and from B to A, simultaneously at the base station, but not simultaneously from the mobile units. Thus, if A is the base station, he can talk out while he is listening to B, but B can operate only in a simplex mode (he can talk or listen, not do both at the same time).

A mobile/digital system must be capable of operating over a user's existing, available radio channel. The ability of the channel to support the intended digital traffic must be estimated, based upon a knowledge of the current voice traffic, (if any) and estimates of the digital traffic to be added.

Certain mobile/digital systems, which use a full polling technique, require a dedicated half-duplex channel. In general, such a channel configuration will not be available to smaller, local agencies. The FCC has set aside two UHF two frequency channels for non-voice use in each of the 30 largest metropolitan areas of the United States, as determined by the 1970 Federal Census. (FCC Rules and Regulations 89.309 (h) (5)). These channels are 462.950-467.950 MHz and 462.975-467.975 MHz and they are available for assignment without regard to the coordination requirements of FCC Rules and Regulations 89.15 (b). All other channels assigned to the Police Radio Service are therefore primarily voice channels, and their use for data transmission must recognize the fact that, potentially, there might be voice traffic on them.

2.3.3.1.3 Audio Bandwidth Limitations

The FCC considers the maximum audio-frequency required for satisfactory voice intelligibility in the Police Radio Service to be 3000 Hz. Transmitters are therefore required to be equipped with suitable low-pass filters in order to reduce and prevent modulation of the r.f. carrier by frequencies higher than 3 kHz. (FCC Rules and Regulations 89.109)

A second limitation is imposed by the nature of telephone lines, which limit the maximum audio frequency transmitted to 3000 hertz.

Any mobile/digital system must therefore be capable of operation within an audio frequency bandwidth of 3000 hertz. This is often referred to as a "voice-grade channel". It is commonly accepted that the low frequency limit for such a channel is 300 Hz.

2.3.3.1.4 Time Allocation and the Two-Second Rule

On a radio channel which operates in a time-shared mode, with both voice and digital data traffic using the same frequency band, the FCC regulations require that the "maximum duration of a non-voice transmission, including automatic repeats, may not exceed 2 seconds". (FCC Rules and Regulations 89.105 (d) (4)).

Further, "Operations must be on a secondary, non-interference basis to any authorized radiotelephony operation" (FCC Rules and Regulations 89.105 (d) (2)). These regulations imply that a mobile/digital system may not interrupt a voice transmission in order to perform a data transmission. Voice messages must always receive priority access to the channel, even if that access requires overriding a data transmission. Also, a data message, consisting of everything required for a complete one-way transmission, is limited to a total duration of two seconds, including automatic repeats.

If the repeats are truly automatic and independent of any base station action, for example if transmissions of a data message is always followed by a repetition of that same data message, the interpretation of the two-second rule becomes ambiguous, since no reference is made in the rules to the transmission of required data control messages between message repeats.

It seems reasonable, however, to infer that the intent of the rule is to restrict all one-way data messages to a maximum two-second interval, including any control signalling necessary. This insures that a shared channel will be essentially free for voice communication..

2.3.3.1.5 Data Processing Constraints

Mobile/digital systems may be classified as either local or remote processor mobile/digital systems.

Remote processor systems require that sufficient central processor time, data memory, and peripheral devices be available to support the "on-line" operation of the mobile/digital system. In general, this means that the required transmission control unit will appear, to the central data system, as an additional input/output device, operating in a time-shared mode.

Data communication and processing systems generally require that any communication lines used to interconnect various system elements adhere to the EIA RS-232-C standard. Further, all data rates must be adequate to support projected system demands, and the available time on each line must be allocated between traffic from the proposed mobile/digital system and other users of the data link in a manner that allows all users to be served within time periods that enable each user to meet its requirements.

Mobile/digital systems which contain a local processor must communicate with a remote data base. Again, the data link will be of an RS-232-C standard type which must be both available and able to support the required data rate.

2.3.3.2 Constraints Due to Operational Interfaces

2.3.3.2.1 Manpower Requirements

The addition of a mobile/digital system to a law-enforcement information and communications system requires that field personnel be trained in the operation of the mobile/digital data terminal, that base station personnel be trained in the operation of dispatcher and complaint entry CRT data terminals, line printers, and the like, and that some provision for maintenance of all base station and mobile unit equipment be made. Generally, this would be accomplished through a training and service contract.

Software maintenance may be handled in the same manner, or, in remote processor systems, data processing personnel may be required to assume this responsibility. In this case, both applications programming for the central data system and the necessary control programming for the transmission control unit must be completed before the mobile/digital system will be operable.

2.3.3.2.2 Operating Practices

The introduction of mobile unit status maintenance facilities and computer-assisted dispatching routines can eliminate the "dispatcher-bottleneck" to some extent, but only if the operation of the mobile/digital system is carefully coordinated with all the other operations performed within the communication systems. This will almost certainly result in substantial modifications to the procedures used in the communication center, and will produce effects throughout the entire agency, because of the pervasive influence of data processing and communications upon the operation of law enforcement agencies.

2.3.4 Mobile/Digital System Implementation

2.3.4.1 Mobile/Digital Data Terminal Design Parameters

The mobile/digital data terminal serves as the interface between its operator and either the local or remote processor. The link between the data terminal and the processor includes a voice-grade radio channel. The facilities of the processor are shared by all the data terminals in the network. Therefore, a well designed data terminal can enhance the overall performance of the mobile/digital system, especially from the viewpoint of the terminal operators.

Some terminal designs may include the mobile encoder/decoder and/or mobile printer as an integral part of the data terminal. In fact, the printer may represent the only display. However, this section reviews only those features of the data terminal's design which affect system performance. The encoder/decoder and printer will be reviewed in a following section.

Functionally, the main elements of a mobile/digital data terminal are the keyboard, memory, display, indicators and controls. Each of these elements has characteristics and functions, shown in the following list, which affect the operation of the mobile/digital system.

Element	Important Characteristics and Functions
Keyboard	Number of keys Size of character set Information code Keyboard technique
Memory	Single or double buffer Number of characters stored
Display	Number of characters displayed Display size Display contrast Character Generation Technique
Indicators	Terminal status Terminal control Operator guidance
Controls	Display brightness Edit Tab Read

The primary function of any mobile/digital system is to transmit messages between a central location and a network of mobile/digital data terminals. Assuming that this can be accomplished, a data terminal must be selected which will permit those messages to be entered and received as quickly and as accurately as possible. The messages themselves, then, largely determine the terminal design, and they, in turn, are dependent upon the functions to be performed within the overall mobile/digital system.

If a listing of typical messages can be assembled, the size of the required character set can be determined. From this, the minimum information code length can be found. This is illustrated in the following table, for various character sets.

Information Code Required for Various Character Sets

Required Character Set	No. of Characters	Minimum bits Required	Bits with Parity	Maximum Available Characters	Typical Information Code
0-9	10	4	5	16	5-bit ASCII subset
A-Z	26	5	6	32	6-bit ASCII subset
0-9 and A-Z	36	6	7	64	7-bit ASCII subset
0-9, A-Z, and 28 others	64	6	7	64	7-bit ASCII subset
More than 64	--	7	8	128	8-bit ASCII

All the information codes listed are subsets of the basic 8 bit (7 information bits plus 1 parity bit) American Standard Code for Information Interchange (ASCII). Other codes are used but the ASCII codes seem favored for these systems. Note that each typical code normally includes one additional bit as a parity check bit. This bit is selected to make the total number

CONTINUED

1 OF 4

of logical ones in the character either an even or an odd number.

Following determination of the character code which will be used, the next step is to examine the list of messages in order to find the longest required message. This gives an indication of the memory size required, and the maximum number of characters which it might be necessary to display. Plasma panel displays are available in sizes of 16, 32 and 256 characters. LED displays are available in multiples of 3, 4 or 5 characters. One typical LED display uses 16 characters. The character sizes of these two types of display are shown in the following table.

Possible Display Sizes

Plasma Panel	16, 32 or 256 Characters
LED Displays	3, 6, 9, ...characters
	4, 8, 12, 16, ...characters
	5, 10, 15, 20.....characters

Required memory size is completely dependent upon the expected maximum message length. Typical memory sizes are 64, 80 and 256 characters. Additional memory space may be reserved for use by the mobile/digital data terminal. The important ideas here are that messages must be stored temporarily prior to and during transmission, and that the maximum message length, including control information which is not displayed, determines the memory requirement.

Terminals which permit simultaneous reception and composition of messages require two buffer memories, one for received messages and a second for messages to be transmitted. In general, a double buffer can improve performance by permitting the operator to compose a message while a message is being received by the data terminal, eliminating the need for the operator to interrupt his task. For certain messages of a priority nature, however, it may still be desirable to interrupt the operator.

Controls and indicators are provided which guide the operator's actions, and control certain terminal features. These should be clearly labeled, and grouped by function. Keyboard technique, both arrangement and construction, should be such that the operator is easily trained in its operation.

2.3.4.2 Encoder/Decoder Design Parameters

In a mobile/digital system, encoder/decoder units are required in order to connect the mobile terminals and either the local processer or transmission control unit at the base station to the voice radio system. The mobile terminals, as well as the processers at the base station, operate by means of d.c. binary digital signals. In other words, they operate using serial trains of bi-level signals, one level representing a logical 1 and the other level representing a logical 0. However, the input to the voice radio system is required to be an a.c. signal, with a frequency (ies) in the 300 to 3000 Hz range. Therefore, the d.c. digital signal required by the data processing elements in the system must be used to modulate an audio frequency carrier, if the information is to be transmitted over the radio system. This can be accomplished in several ways, by varying the frequency, phase and/or amplitude of the audio carrier, but the device which accomplishes this signal transformation is the encoder/decoder. It is really a modulator/demodulator (commonly called a modem) because, for outbound transmissions, it modulates an audio carrier with digital information, and, for inbound transmissions, it derives digital information from an audio signal.

The encoder/decoder may also perform control functions to coordinate the flow of data into and out of the element to which it is connected, but the fundamental design parameters of interest in this discussion are the modulation/demodulation technique used and the data rate at which it operates, in bits per second.

The audio channel over which the data are transmitted differs from a telephone data channel because a voice-bandwidth radio system is included. The data stream is thus subject to errors caused by the radio channel. Such errors include channel dropouts, impulse noise and fading. Error detection and correction methods can be used to reduce the effects of these errors, and will be discussed in a later section.

To transmit binary digital information over the channel an audio signal is transmitted between the mobile and base station encoder/decoder units. During successive time intervals, this signal, the audio carrier, is varied in amplitude, frequency, phase, or some combination of the three.

Two modulation methods are generally used. Binary frequency modulation, or binary frequency-shift-keying (FSK), is usually chosen when equipment design simplicity, reliability and economy are more important than the efficiency with which the available bandwidth is used.

Typically, the frequency shift, in hertz, between the two transmitted tones is one-half to three-quarters of the maximum bit rate to be transmitted. The audio bandwidth required is approximately equal to twice the maximum bit rate. For a data rate of 1200 bits per second, then an audio bandwidth of at least 2400 Hz is required, and the audio tones used might be

600 Hz and 1800 Hz. The frequency of the audio carrier would thus be shifted between 600 Hz and 1800 Hz in correspondence with the state of the input binary data signal.

One form of detection, or demodulation, of such a received FSK signal is based on the rate of zero crossings of the received signal. A second method involves comparing the received signal with a portion of this received signal which has been passed through a phase shifting network which has a linear phase shift versus frequency over the frequency range of interest.

Binary phase modulation, or binary phase-shift-keying (PSK) requires somewhat more sophisticated equipment design than an FSK system, which results in a higher cost per unit, but PSK techniques offer a slightly more efficient method of transmission than do FSK techniques.

The maximum data rate achievable with binary phase-shift-keying is 2400 bits per second, assuming a channel bandwidth of 3 KHz. Current system designs which use binary PSK operate at a data rate of 1200 bits per second.

Detection of phase-shift-keyed audio signals must be done coherently, and requires that a local carrier be available at the receiver to provide a reference to the phase and frequency of the transmitted signal. One method of obtaining this local carrier is to transmit a small amplitude audio subcarrier, of different frequency than the primary carrier, but of the same phase. At the receiver, this subcarrier is separated from the received signal, and is used to time the generation of a local reference carrier. The power required to transmit the subcarrier is negligible compared to the total carrier power.

When audio FSK or PSK signals are transmitted over a channel corrupted only by white, Gaussian (random) noise, the coherent PSK system provides an approximately 3 db advantage in received signal-to-noise ratio, assuming the same probability of a single bit error, the same data rate, and the same audio bandwidth.

When the channel, on the other hand, includes a VHF or UHF radio channel, the effects of channel noise, amplitude vs. frequency, phase vs. frequency and nonlinear distortions, frequency offsets, and spurious amplitude and phase variations make the problem of comparing the modulation systems (on the basis of the ratio of average transmitted power to noisepower in the baseband, for a given probability of error) much more difficult.

In general, it is desirable to operate at the maximum feasible nominal speed of transmission (bits per second per cycle of bandwidth), given a minimum acceptable baseband signal-to-noise ratio, that will result in the desired single bit error probability.

It is not yet clear, therefore, whether coherent PSK modulation techniques actually offer any improvement in the performance of systems, in practice, when compared to FSK techniques. This question can only be answered when the error statistics of practical channels have been determined.

An acceptable value for P_e, the probability of a single bit error, is 10^{-5} or 0.00001; this means that, on the average, a single bit error will be observed once in every 100,000 bits. Under continuous operation, at a transmission rate of 2400 bits per second, an error would be expected to occur about once every 42 seconds.

Typically, mobile/digital systems send and receive data at a rate of 1200 bits per second.

2.3.4.3 <u>Errors and Error Rates</u>

Error rates, on any channel, can be expected to vary with time, due to interference, noise, fading, etc. These errors can be either single bit errors, produced by impulsive type noise or burst errors due to interference, fading, etc. Design goals for digital data communication systems typically include an error rate of 10^{-5}, that is, the error rate should not exceed 1 error in 10^5 bits. This error rate also seems appropriate for mobile/digital communication systems.

The effective data rate, or information rate, is often considerably less than the transmission data rate, because of the necessity for start-stop bits or characters, redundant transmissions for error control, and so forth. This effective rate defines the "through put" rate of the data system.

Error control schemes can improve system performance. Some schemes may only sense errors, and request retransmission of the block of data containing the error. Other schemes use forward error correcting codes to detect and correct errors, eliminating the necessity for retransmissions. Still other schemes use redundant techniques. A message may be sent twice, and in the case of a discrepancy, the correct portions of each message may be retained while the system requests and retransmission of the portions in error. Many variations and combinations of these techniques can be used, but it is important to note that error control techniques reduce the error rate only at the expense of reduced through put rate and increased hardware requirements, as compared to error-free systems. The occurrence of errors in practical systems, however, usually requires adoption of some scheme for error control, if any through put rate at all is to be sustained.

2.3.4.4 <u>Error Control Techniques</u>

Error control techniques are used to insure that digital data messages will be received exactly as sent, despite errors introduced during transmission. Redundant data elements, or elements used solely for error control, are inserted into the message to permit controlled error detection and correction. The simplest example of an error control technique is the use of triply-redundant transmission. Each message block is sent three times, and each bit is compared with the two corresponding bits in the redundant message blocks. A majority decision (2 out of 3) determines the correct value for each bit. This method detects and corrects any single bit error within a message block. It is, however, inefficient in that the effective data rate is reduced to one-third the transmission rate. Other techniques can provide increased protection with more efficient use of the available channel capacity.

2.3.4.4.1 Forward Error Correction

In a forward-error-correction, or FEC system, redundancy is inserted into the transmitted bit stream, reducing the effective data rate. At the receiving terminal, this redundancy is used to detect and correct errors introduced during transmission. The amount of redundant information required for error correction is greater than that for error detection alone. Either block or non-block code structures may be used. Non-block or convolutional structures can reduce the complexity of the error control system.

A forward-error-correction technique may be used with continuous data streams, as in synchronous data transmission. Only a minimum of buffering is required during the error control process. The delay between the input of a message block and its redundant output depends on the number of bits required to encode the data.

2.3.4 4.2 Error Detection and Automatic Repeat Request (ARQ)

In an ARQ system, data is encoded in blocks, each block containing redundant bits. These redundant bits reduce the effective data rate. When an error is detected at the receiving terminal, a request for repeat (ARQ) is automatically sent to the transmitting terminal. In a mobile/digital system, this request is not sent until the entire message transmission is completed. It is also possible to simply not acknowledge the receipt of a message, in which case it is automatically retransmitted following a finite time delay. Another general procedure is to allow a mobile/digital terminal to send successive message blocks only after receiving an acknowledgment of the previous one from the base station. The technique requires coordination of error control and line control methods within the system.

2.3.4.4.3 Basic Code Structures

The three basic code structures are replicate, or repeated transmission, block codes, and non-block, or convolutional codes.

The simplest form of coding is to repeat the message. This is a brute force method, and by itself does not permit efficient use of the channel capacity. At the receiving end, a majority decision must be made, or an ARQ approach must be adopted.

Block codes, or parity check codes, are more efficient than replicate codes. Each coded element of the message has a fixed length, the block length. Parity check codes permit error detection, and error correction by forming mathematical relations between the information bits and a group of added parity check bits. Classes of block codes have been developed which correct errors due to random noise or bursts of noise over various types of channels.

Non-block, or convolutional codes, are effective when the data stream is continuous, rather than in block form. These codes do not have a fixed block structure. The input information bits are coded one at a time, instead of in groups as with a block code.

An error control system may use any one or all of these techniques. For example, a character parity check block code may be used to encode each character of a message block. The block may then be sent in replicate form, and both received versions compared to locate errors. Errors may often be corrected by examining the parity checks, and if they are not correctable, an ARQ technique may be used to repeat the entire transmission. Another technique uses character parity checks, a block code over the entire message, including the character parity bits, and then the use of a convolutional code which interleaves more check and message bits.

2.3.4.4.4 Choice of a Coding Technique

In general, the choice of the coding technique to be used depends on the requirements imposed by the overall system. If only error detection is required, as in an ARQ system, either simple redundant or block coding techniques may be used.

For forward error correction, convolutional codes are the clear choice, since they are easily implemented in a continuous data transmission system.

A parameter of block codes which is important is the code rate, defined as the ratio k/n, where n is the message block length, and k is the number of information bits in the block. For convolutional codes the rate is also k/n, where n is the number of transmitted bits, consisting of k information bits and (n-k) check bits. The number of information bits, k, from which the (n-k) check bits were computed is called the convolutional code constraint length.

Note that the ratio k/n is the efficiency of data transmission. Thus if a half-rate (k/n = 1/2) convolutional code is used over a channel operating at a bit rate of 2400 bits per second, the effective data rate is 1200 bits per second.

The capability of a code describes the number of errors which can be detected and/or corrected within a block of n bits, or within a constraint length of n bits.

2.3.4.5 Radio Channel Configurations

Mobile/digital systems may be designed to share existing radio channels with voice communications or to operate on data-dedicated radio channels.

Available radio channels are presently used as either simplex or half-duplex channels. On a simplex channel, either the base station or a mobile unit may transmit at a given time, but neither may simultaneously transmit and receive. Simplex channels are therefore generally single frequency channels. On a half-duplex channel, the base station may transmit and receive simultaneously, while the mobile units are restricted to simplex operation.

Before a mobile/digital system is added to an existing voice channel, an estimate of the channel occupancy should be made. Consider a simplex channel as an example. A typical voice message may be initiated at either the base station or a mobile unit. Each message involves a complete conversation between the mobile operator and the dispatcher. In this case, the message duration is the time required, in seconds, for the complete conversation; consisting of all transmissions necessary to exchange the required information. The rate at which the dispatcher initiates these conversations is the base station message generation rate, in messages per second. The rate at which each mobile unit initiates these conversations is its message generation rate. The total message generation rate of all mobile units is simply the sum of the individual mobile unit rates. Assuming that the base station and each of the mobile units initiates messages independently, and at random, the simplex channel can be modeled as a single-server queueing system, in which the base and mobile units all compete for occupancy of the channel. If it is assumed that the message durations are distributed according to the negative exponential probability distribution whose mean value is equal to the average message duration, then the following results are true:

- The total message generation rate on a simplex channel is equal to the sum of the base station generation rate and the total mobile unit generation rate. Call this total rate a, in terms of messages per second. The average interarrival time is then $1/a$ seconds.
- The average message duration on a simplex channel is equal to the inverse of the channel service rate. Call this service rate b, in terms of messages per second. ($b = 1/$average message duration, seconds)
- The fraction of time that the simplex channel is occupied is a/b.
- The expected number of operators (mobile operators or dispatcher) waiting for access to the channel is $a^2/b(b-a)$.
- The expected time that an operator must wait for access to the channel is $a/b(b-a)$.

On a half-duplex channel, two frequencies are used, one for inbound mobile unit-to-dispatcher messages, and a second for outbound dispatcher-to-mobile unit messages. Here a typical voice message may be initiated at either the base station or a mobile unit, and again consists of a sequence of transmissions between dispatcher and mobile unit.

Again, the necessary statistics are the base station and mobile unit message generation rates and the average message duration.

If it is assumed that the dispatcher does not interrupt any conversations in progress, then the queueing model for the half-duplex and simplex radio channels are identical, even though the channels are physically different. This situation will prevail most of the time on a half-duplex channel where the base station repeats mobile transmissions. A half-duplex channel with mobile repeat thus operates as a simplex channel, except in emergencies, when the dispatcher then can use his full duplex capability. The statistics presented for the simplex channel are thus equally valid for the half-duplex channel with mobile repeat.

A final set of statistical quantities necessary to analyze the effects of a mobile/digital system upon channel occupancy is a classification of voice messages according to type. Types of messages include acknowledgments, inquiries, status entries, dispatches, and others. Some of these message types may be replaced by digital messages on a shared channel.

An estimate must then be made of the expected generation rates for digital data messages. Again, messages must include any two-way digital "conversation" required to convey a complete one-way message. From this estimate, the average duration of a digital message may be obtained.

The preceding discussion has established that the following information must be available for the channel (the channel being a half-duplex or simplex channel where "messages" are complete conversations conveying a single idea, initiated by either the base station or a mobile unit):

Measured Quantities:

- a = average number of voice messages initiated per second (TOTAL)
- $1/a$ = average voice message interarrival time, in seconds
- $1/b$ = average voice message duration, in seconds
- b = voice message service rate

Estimated Quantities:

a_d = average number of digital data messages to be initiated per second (TOTAL)

$1/a_d$ = average data message interarrival time, in seconds

$1/b_d$ = average data message duration, in seconds

b_d = data message service rate

For voice traffic alone, the expected number of operators (including the dispatcher) waiting to access the channel is given by

$$N = a^2 / b\,(b-a)$$

Similarly, the expected time that an operator must wait for access to the channel is given by

$$T = a/b\,(b-a) = N/a \text{ seconds.}$$

The effects of allowing digital data and voice messages to time share an existing channel can now be estimated. For both the simplex and half-duplex channels described above, the following results hold:

- The expected time that an operator (or mobile/digital terminal) must wait for access to the channel is given by

$$T = \frac{(a/b^2) + (a_d/b^2_d)}{1 - \frac{a}{b} - \frac{a_d}{b_d}} \quad \text{seconds}$$

- The fraction of time that the channel is occupied is given by

$$R = \%\text{ occupancy} = \frac{a}{b} + \frac{a_d}{b_d} \times 100$$

It should be noted that these results assume that a non-preemptive situation exists, in which voice traffic never interrupts data. This is a good approximation if the average message duration for data is much smaller than that for voice messages, thereby minimizing the chance of interruption.

Finally, the expected number of operators (or mobile/digital terminals) waiting for access to the channel, from the point of view of a mobile operator or terminal, is

$$N = TA$$

where $A = a + a_d$ = total average message generation rate

An example of how these results may be used is shown in Figure 6. In constructing this figure, it was assumed that voice and digital data messages time share a simplex or half-duplex channel. The average duration of a voice message was taken to be 10 seconds (This number has been determined by IITRI to be typical of voice traffic on police radio channels, based upon data collected in several programs) and the average duration of a digital data message is taken to be 1 second (This agrees fairly well with the average transmission time in the New York State Police experiment and is, in IITRI's opinion, a desirable goal). Assuming that all transmissions are random, Figure 6 shows the relationship between voice message generation rate, digital message generation rate, mean access delay and channel occupancy.

For example, assuming a voice message generation rate of 0.02 per second (1 message every 50 seconds), and a mean access delay of 5 seconds, Figure 6 shows that digital messages could be generated at a rate of 0.330 per second, or one message every 3 seconds. For this example, the presence of voice traffic alone on the channel would result in a channel occupancy of 20 percent. The addition of digital traffic at the indicated rate would raise the channel occupancy to 53 percent.

A mean access delay of 5 seconds is a generally accepted standard for police voice radio channels. A saturated channel, by this criterion, occurs when the voice message generation

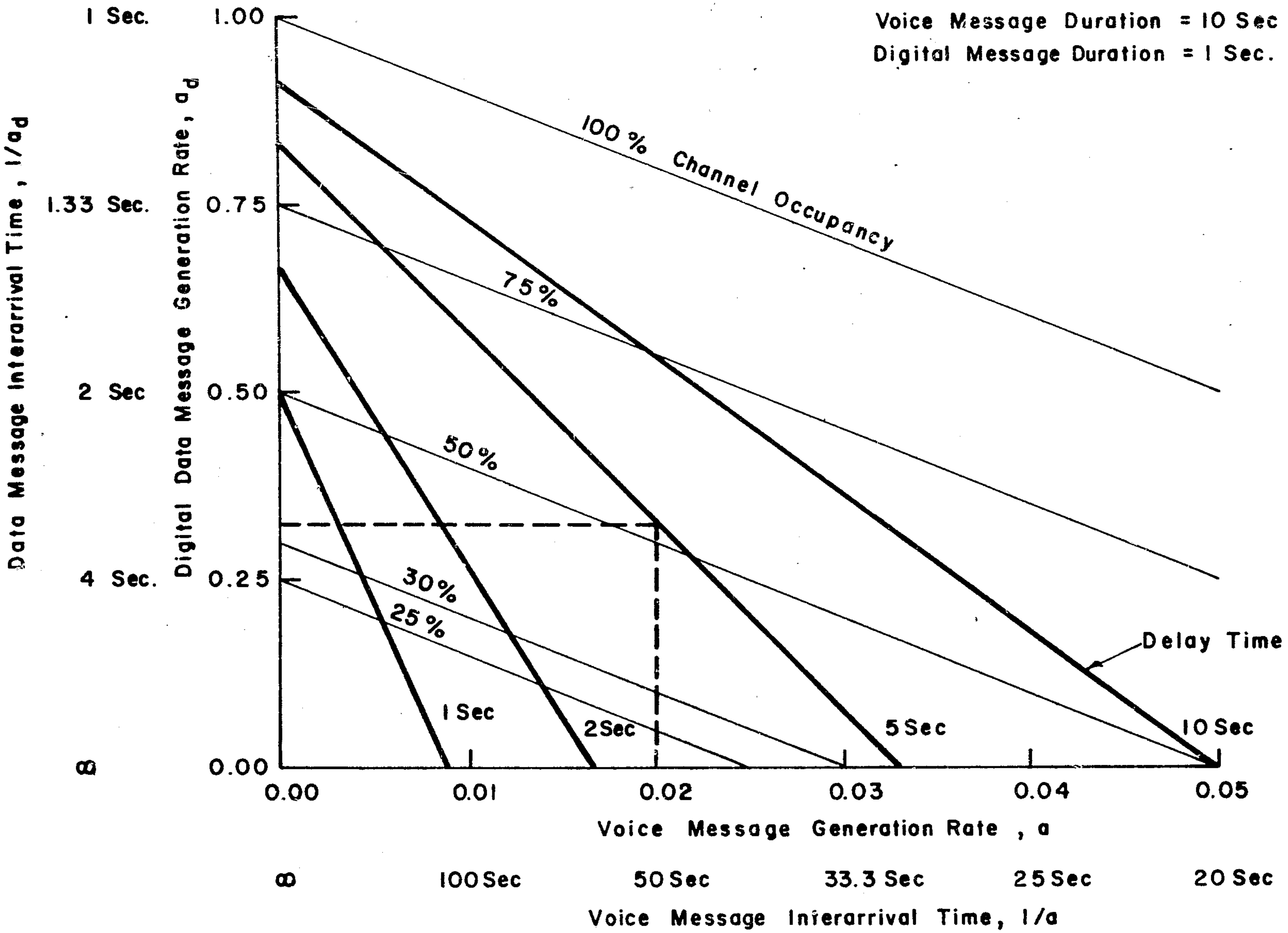


Fig. 6 EFFECT OF SHARED VOICE AND DIGITAL DATA TRAFFIC ON A RADIO CHANNEL

rate reaches 0.033, or one message every 30 seconds. Such a voice channel would permit no digital data traffic without increasing the mean access delay time. A mean access delay time of five seconds might not be satisfactory for digital traffic, however. If a data base inquiry and response is to be completed within ten seconds, on the average, then clearly a five second channel access delay is too long. This ten second criterion seems a reasonable one to use, if the advantages of installing mobile/digital terminals in patrol vehicles are to be realized. If it is assumed that a response is received from the remote data base within two seconds (which is the best that the FCIC system normally does), then the mean access delay should probably be on the order of three seconds or less. Note that for the parameters assumed, the mean access delay time cannot be less than 2.5 seconds, if any digital traffic at all is to be allowed on the channel. If a three second mean access delay is used in Figure 6, then a voice message generation rate of 0.02 per second (1.2 messages per minute) would allow a digital message generation rate of 0.1 per second, or six digital messages per minute.

The conclusion is valid, however, if the digital data transmission system is error free. If errors occur that cause retransmissions to be made, the results change dramatically. For example, assuming a three second mean access delay time, if, on the average, two transmissions are required to enable reception of a message (of 1 second duration) then the digital message generation rate decreases to 1.3 messages per minute.

Thus, for certain simplex and half-duplex radio channels, if the voice and digital data message generation rates are known, or can be estimated, it is possible to estimate the effects of time-sharing the radio channel between voice and digital traffic. If time-sharing is not possible, a data-dedicated radio channel must be used.

In general, it can be said that a shared channel configuration may yield satisfactory performance only for those agencies whose mobile units do not generate much voice traffic under present conditions and who do not anticipate an extreme increase in traffic due to the introduction of mobile/digital terminals.

2.3.4.6 Line Control

Line controls are considered to be the hardware and software protocols used to accomplish the transfer of information between two points in a data communication network. Line control implies the establishment of a communication link, synchronization between both sending and receiving terminals, the transfer of data, and error detection and correction.

In mobile/digital systems, line control includes the adoption of either contention or polling as the basis for access to the radio channel, synchronization within messages or on a continuous basis, selection of message formats and data code systems, and error control procedures, such as parity checks, block codes and redundant transmission.

Error controls and data codes have been previously discussed. Message formats are largely dependent on the desires of the user and the size of the mobile terminal display. Contention and polling schemes have been described in connection with radio channel configurations. Finally, data synchronization, within the message, is largely dependent upon the modulation method used. The nature of mobile/digital systems suggests that message transmission be on an asynchronous basis. At present, there is no standardization on any of the line control aspects listed, by either the manufacturers or users of mobile/digital systems.

2.3.4.7 The Effect of Digital Traffic on the Remote Data Base

From studies of current voice message traffic, an estimate can be obtained of the amount of traffic directed from the law-enforcement agency to the FCIC and NCIC data bases. The introduction of a mobile/digital system with direct access to these remote data bases can be expected to greatly increase any existing inquiry rate, if sufficient time is available for each field officer to initiate inquiries during the course of normal operations. In present manual systems, the dispatcher may prohibit inquiries until he is free to process them, reducing the rate of inquiry generation. In a mobile/digital system, inquiries will normally bypass the dispatcher. Any interface to a remote data base must therefore be capable of buffering and forwarding the expected maximum number of inquiries, and the data base must process and return the necessary responses within a time period which satisfies the user's requirements, typically five seconds. An important point is that a failure in the data base system can rapidly congest any mobile/digital system. Also, long response times from the remote data base can frustrate the intent of the system design.

The service rate, in messages per second, of the remote data base must therefore be greater than the anticipated maximum inquiry rate, if excessively long queues of nonprocessed, delayed messages are to be avoided. The design of the mobile/digital system must be compatible with that of the statewide criminal justice information system, if both are to provide their designed services in a cost-effective manner.

2.3.4.8 Peripheral Devices

The peripheral devices required at the base station in a mobile/digital system are generally dependent upon the applications intended for the system, and the functions to be performed.

Typically, in a local processor mobile/digital system, a teletypewriter is supplied for control of the processor itself (maintenance and program loading). Due to its slow operating speed, this teletypewriter is not used for system operations. A high-speed line printer is usually provided for message logging and other operations which require the generation of printed output.

For monitoring mobile unit status, CRT data terminals are normally provided, since updating may be rapidly and easily accomplished. CRT data terminals are also used for dispatch and complaint entry positions, because of their flexibility and assistance in message generation (for fixed format messages).

Other peripherals, such as magnetic tape storage, paper tape reader/punches, and disk storage units are also generally available.

2.3.4.9 Communications Processor Requirements

Mobile/digital systems have been divided into two classes, those with a local data processor for overall system control, and those which rely upon a remote processor to perform all major system functions. In the remote processor system, a transmission control unit forms the hardware interface between the network of mobile/digital terminals and the remote central data processing system.

Perhaps the most important requirement for a local processor is that it be expandable. Expandability requires that input/output capability be provided to meet future demands, that memory expansion modules be available for the addition of future functions, and that the software systems be sufficiently flexible to allow the system to be adapted to the user's changing needs.

Transmission control units, on the other hand, are relatively fixed-form controllers, the flexibility being provided at the remote processor. Such a unit must therefore be capable of accepting future additions to the number of terminals, controlling the entire network while operating at a sufficiently high data rate, and buffering all anticipated messages. The potential for failures in the central data system means that the transmission control unit must also be able to store all inbound messages, in such cases, until the central data system resumes operation.

3.0 Current Mobile/Digital Communication Systems

3.1 State-of-the-Art

There are six mobile/digital communication systems known to IITRI, four of which have been investigated for this report. These six systems are:

- RADCOM-I System, manufactured by Kustom Electronics, Inc.
- IBM 2976 Mobile Terminal Syste by IBM.
- MODAT Alphanumeric Terminal System, manufactured by Motorola, Inc.
- ARCOM System, manufactured by Atlantic Research Corp.
- MOSCAN, manufactured by Sunrise Electro-Service Corp.
- A mobile/digital terminal manufactured by E-Systems, Inc.

IITRI has investigated the first four of these systems and descriptions are provided in this report. Of these four systems, only Kustom has actually delivered operating systems. The IBM and ARCOM systems are in production, but no systems have been delivered as of the date of this report, and the exact status of the Motorola system is not known. Sunrise Electro-Service Corp. has stated that their MOSCAN system is in production, but IITRI does not know of any operating systems. The system manufactured by E-Systems is a modification of the Sylvania Digi-Com 300 system, which they obtained from Sylvania when Sylvania phased out its Socio-Systems Products Group. IITRI is not aware of the status of the E-Systems mobile/digital system.

The E-Systems and Sunrise systems were not investigated in this study. However, for the sake of completeness, IITRI did receive some data for the Sunrise MOSCAN, which has not been checked but will simply be stated here. MOSCAN has a 32 character display, double buffers of 256 characters each, full typewriter keyboard, 12 status switches and a printer option.

Sunrise claims that it can operate in either contention or polling environments and is an asynchronous system. The data rate used was not listed but is probably fairly high. The broad characteristics of this system are similar to those of systems which IITRI has investigated. This report will therefore provide an adequate background to enable the reader to evaluate the Sunrise and other mobile/digital systems which fall into the two main categories discussed; i.e., shared channel, contention systems and dedicated channel, polling systems.

IITRI feels compelled to emphasize that mobile/digital systems are in their infancy. In order to assess the utility and effectiveness of such systems, the following questions must be answered:

a) What functions should these systems perform for law-enforcement agencies?
b) How are the effectiveness of these systems to be judged?
c) How well does the system perform in its operational environment?
d) Can quantitative cost/benefit ratios be determined?

The first question should, ideally, be answered by law enforcement agencies, but, so far as IITRI is aware, has not really been addressed to date. The second question is bound up with measuring police effectiveness in general. What functions should, for example, a patrol officer perform and how much time should be devoted to each? If, to use another example, he is given a mobile/digital terminal and increases his "hit" rate on wanted vehicles and persons by a factor of eight, is this, per se, an indication of increased effectiveness on his part? What are the measures of effectiveness for mobile/digital systems? This question has not been answered.

The third question can only be answered by conducting a well designed experiment. The manufacturers will not provide sufficient data in the detail required for analysis of system performance. In addition, there are no data available for error statistics on VHF and UHF channels. Therefore, system technical performance can only be determined by conducting a data collection program on an operational system. To date, no such program has been performed. Finally, cost/benefit ratios require quantification of the term benefit. This cannot be accomplished until the first three questions are answered. It should be apparent that the questions listed above should be answered before mobile/digital systems are implemented on a large scale.

The system overviews presented in this section (and the more detailed descriptions presented in the appendices) concentrate on the basic system configurations offered by each of the four manufacturers. Many variations and extensions of these basic configurations (particularly as regards system software) are possible, some of which are described in the appendices. The overviews are intended to give the reader a general idea of each system and its capabilities. Readers who are interested in more detail should consult the appropriate appendix.

3.2 System Cost Data

3.2.1 Introduction

The cost data which have been made available to IITRI for the four mobile/digital systems studied are presented below. These data are somewhat sketchy and reflect the desires of all the manufacturers to quote system prices rather than individual component prices. Further, the systems are all sufficiently different from one another to make direct cost comparisons difficult. The reader should therefore exercise care in making comparisons and IITRI has attempted to clearly label all cost data in order to enable the system differences to be clearly noted.

3.2.2 Estimate of System Costs

3.2.2.1 Mobile Unit Costs

The costs of the four available mobile data terminals are as follows:

- Kustom Electronics MCT-10 Mobile Terminal: $3320 each, including MM-10 mobile mounting kit.
- IBM 2976 Mobile Terminal: $3750 each
- Motorola Alphanumeric Terminal: $2495 each, including tunnel mounting kit
- Atlantic Research ARCOM Terminal: $1800 each.

These prices all include mobile encoder/decoder units. If the systems all are used on dedicated channels then a separate mobile radio may be required. The IBM system requires that a separate mobile radio be purchased for use with the terminal, because of the polling technique used. In the other three systems, which operate on a contention basis, a multi-channel radio might suffice, one channel being used for voice and one channel for data. Thus, if multi-channel radios were already in the patrol vehicles then no extra expense would be required. But if only single channel radios were available, or the system design required a separate radio, then the other three systems would also require the purchase of new mobile radios.

A mobile radio costs approximately $1000 to $1200 each. The cost per vehicle (excluding base station equipment) for the IBM terminal is then $4950 each. The cost per vehicle for the other three systems would be:

- Kustom MCT-10: $3320 or $4520 each
- Motorola Alphanumeric Terminal: $2495 or $3695 each.
- ARCOM Terminal: $1800 or $3000 each.

Kustom Electronics gives quantity discounts. If 10 to 24 terminals are purchased Kustom gives a five percent discount on each terminal, if 25 to 49 terminals are purchased the discount is eight percent, if 50 to 99 terminals are purchased the discount is ten percent and if more than 100 terminals are purchased, a twelve percent discount is given.

The only manufacturer to quote a price for an optional mobile printer was Motorola, who quoted the cost of a mobile printer at $1500 each.

3.2.2.2 Base Station Costs

3.2.2.2.1 Base Station Encoder/Decoder

The cost of a base station encoder/decoder unit is:

- Kustom ED-10-1: $6400, including telephone line interface and control modules.
- IBM Signal Converter: $5200
- Motorola Base Logic Unit: $2000 - $3000
- ARCOM Base Radio Interface: not specified.

3.2.2.2.2 Base Station Computer

Computer costs are the most difficult to compare because each manufacturer uses a different size memory and different peripherals. In addition, the IBM 2976 System requires that the user have (or purchase) a 360 or 370 series time-sharing computer. The cost of such a computer cannot be estimated because many different models are available and the cost should be shared among all the users.

IITRI can only list the data it received:

- Kustom Electronics supplies the following units with a 10 mobile terminal RADCOM-1 system, at a total cost of $50,190.

  1 - TC10-1 Terminal Controller with 16K memory
  1 - DK-10-1 Disk Controller
  1 - DK-10-1A Disk Drive
  1 - DK-10-1A1 Disk Pack
  1 - LP-10-1 Line Printer

1 - TT-10-1 Controller Console
2 - DT-10-2 Dispatcher Display Terminal
1 - DT-10-3 Status Monitor Terminal
1 - LI-10 Line Interface

A cost breakdown for this equipment was not furnished but an estimate can be obtained by noting that the TC-10-1 Terminal Controller is a PDP-11/05 minicomputer and the DT-10 Data Terminal is a Super Bee Data Terminal. The list price of the Super Bee is $3000 and the list price of the PDP-11/05 minicomputer with 16K of core memory is $9895. Each block of 4K core memory is an additional $1700. Costs for the other devices are not available. It should be noted that in larger systems Kustom Electronics uses the PDP 11/45 minicomputer. Depending on the exact model, a PDP-11/45 can cost between $25,950 (for a unit with 16K of core memory) and $45,470 (for a unit with 32K of core memory). The system costs would increase accordingly.

- In the IBM 2976 Mobile Terminal System the user is required to purchase the following equipment, which is added to his System/360 or System/370:

  1 - Transmission Control Unit @ $125,000 each.
  (includes one Link Adapter)
  A second Link Adapter costs $10,000.
  A third Link Adapter costs $7500.

The cost of CRT Data Terminals, line printers and other peripherals must be added to the above costs.

- A Motorola MDP-2000 Data Processor, including base station interface, encoder/decoder and logic units costs $30,000. This figure does not include the cost of CRT data terminals, line printers and other peripherals.

- ARCOM supplies the following equipment with a 20 terminal ARCOM system, at a cost of $30,000:

  1 - General Automation SPC-16/40 minicomputer
  1 - Centronics Model 306 Line Printer
  1 - Super Bee CRT Data Terminal
  1 - Communication Line Interface

The list price of an SPC-16/40 minicomputer with 8K of core memory is $7000, and each additional 4K of core memory is an additional $1500. A Super Bee Data Terminal costs $3000 each.

3.2.2.2.3 Software Costs

The software package costs which IITRI has obtained are:

- Kustom RADCOM-1 System Software, $15,000 for a 10 terminal system.
- IBM System software must be furnished by the user.
- Motorola MODAT Application Software, $30,000
- ARCOM System Software, $30,000 for a 20 terminal system.

3.2.2.3 Installation Costs

Kustom Electronics quotes the installation costs for a ten terminal RADCOM-1 system as $10,800. No other manufacturers quoted installation costs.

3.2.2.4 Maintenance Costs

None of the manufacturers quoted maintenance costs. Kustom Electronics provide a one year warranty.

3.2.2.5 Lease Plans

Kustom Electronics provides a leasing plan, typically with fifty percent of the lease monies applied to the purchase price of the system, after the second year.

IBM provides extended term leasing plans, with maintenance included in the cost of the lease. For example, on a two year leasing plan, the system components would cost:

Mobile/Digital Terminal: $150/month/terminal

Signal Converter: $150/month

Transmission Control Unit with 1 Link Adapter: $3000/month

Second Link Adapter: $250/month

Third Link Adapter: $187/month

Lease/purchase options are also available, typically with 55 percent of the lease monies applied to the cost of the TCU and 60 percent of the lease monies applied to the cost of the mobile terminals.

Motorola and ARCOM provide leasing plans that are tailored to the needs of the user, but no details were furnished.

3.2.3 System Cost Comparisons

The Kustom, Motorola and ARCOM systems are basically similar, allowing cost comparisons to be made. Table 1 compares the estimated costs of these systems for 10, 20 and 50 terminal systems. It is assumed that existing base station and mobile radio equipment are used. These costs are estimates only. Note that for large numbers of terminals, the system costs are dominated by the terminal costs.

The IBM 2976 System cannot be compared to the other three systems, because its design philosophy is so completely different. It is a very expensive system, however, even when the costs associated with the host computer are not included. For example, a ten terminal system would cost approximately $190,000, assuming that a new base station and new mobile radios were required, and a 100 terminal system would cost approximately $640,000, excluding software costs in both cases. It is therefore a system appropriate for large cities, not smaller departments.

Table 1

COMPARISON OF SYSTEM COSTS FOR LOCAL PROCESSOR MOBILE/DIGITAL SYSTEMS

Number of Mobile Terminals	ESTIMATED SYSTEM COST (1)		
	Kustom	Motorola (5)	ARCOM (6)
10	$104,790 (2)	$ 92,950	$ 79,500 (7)
20	137,870 (3)	117,900	99,000 (8)
50	226,090 (4)	192,750	159,000 (9)

(1) System cost does not include installation.

(2) 16K of core memory.

(3) 20K of core memory.

(4) 28K of core memory.

(5) Prices include 2 CRT data terminals at $3000 each and 1 line printer at $2000.

(6) Prices include an assumed base station encoder/decoder cost of $3000.

(7) 8K of core memory.

(8) 12K of core memory.

(9) 28K of core memory.

3.3 Existing Mobile/Digital System Overviews

3.3.1 Kustom Electronics RADCOM-1 Mobile/Digital System

3.3.1.1 Introduction

The philosophy behind Kustom Electronics' mobile/digital communication system appears to be modularity and flexibility. Thus, while the RADCOM-1 System (described below) represents what might be termed their "standard package", it is possible to either simplify or expand this system, depending upon the user's requirements and budget. The simplest conceivable system would consist of mobile terminals and a minicomputer (with necessary interfaces). Such a system would only permit inquiry/response functions to a remote data base. At the other end of the scale, the RADCOM-1 plus an additional minicomputer and appropriate software would permit the performance of such functions as automated records, message switching for non-mobile terminals, and mobile unit report writing.

The versatility of the Kustom Electronics System will emerge from the following overview of the RADCOM-1 system. It should be kept in mind, however that the only products manufactured by Kustom are the mobile terminal, the mobile printer and the encoder/decoder interface. All other hardware is purchased equipment, which in some cases is modified to Kustom specifications.

3.3.1.2 General Description

The RADCOM-1 system, a block diagram of which is shown in Figure 7 , was designed by Kustom Electronics to provide law enforcement agencies with a turn-key digital communication system which would interface with existing voice radio systems. The system design permits digital messages to be mixed with voice messages on an existing channel,or a separate channel can be dedicated to digital traffic. Further, the system is compatible with simplex, duplex or half-duplex channels .

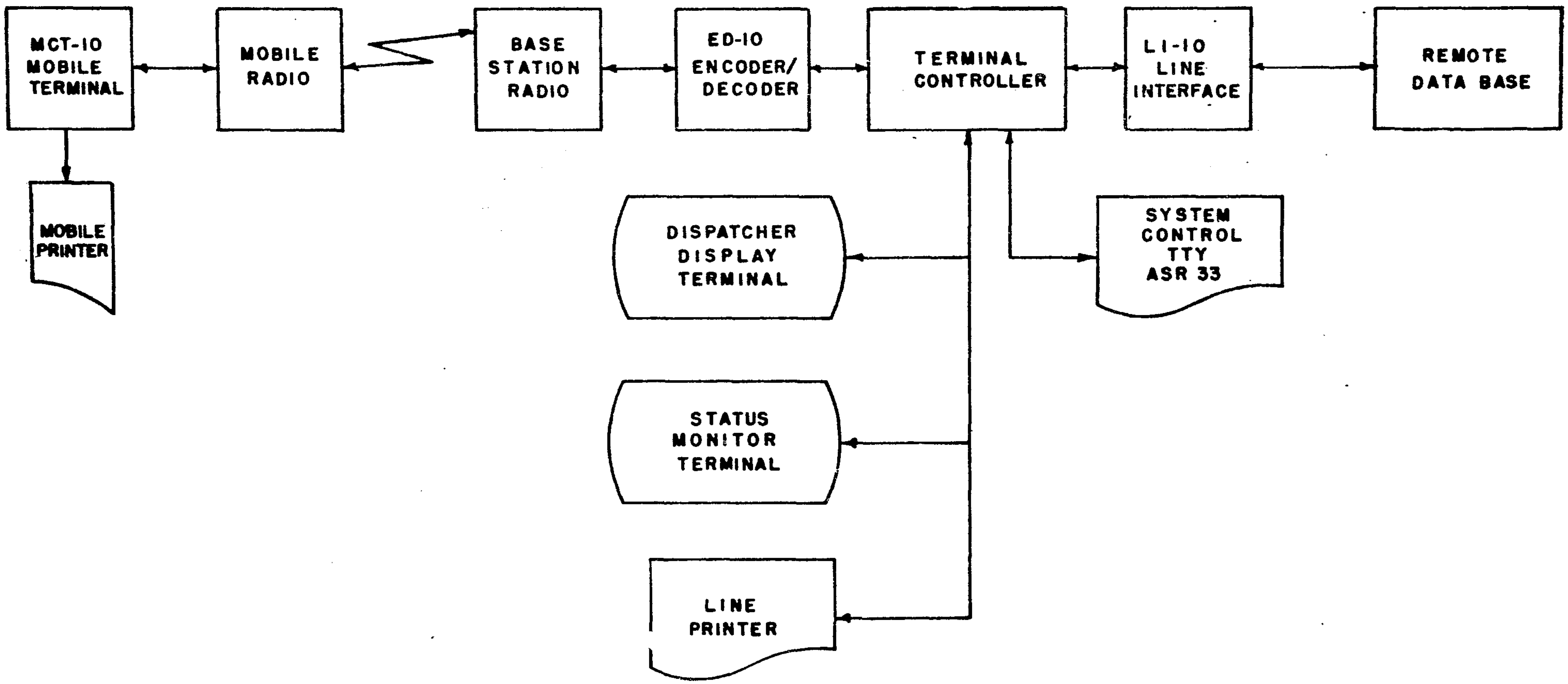


Fig. 7 RADCOM-I SYSTEM BLOCK DIAGRAM

By providing a network of mobile/digital terminals connected by radio to a minicomputer at the base station, the RADCOM-1 system provides a law enforcement agency with three major capabilities:

1) Direct data base inquiry and response,

2) Mobile unit status maintenance, and

3) Terminal-to-terminal digital communication.

Since both the hardware and the software systems are modular, additional functions may be added at any time, as the user's requirements dictate.

The basic RADCOM-1 system consists of the following hardware units:

1) MCT-10 Mobile Terminal
2) TC-10 Terminal Controller (including DK-10 Disk Unit)
3) ED-10 Encoder/Decoder
4) LI-10 Line Interface
5) DT-10-2 Dispatcher Display Terminal
6) DT-10-3 Status Monitor Terminal
7) LP-10 Line Printer
8) TT-10-1 Teletype Console
9) MP-10 Mobile Printer (Extra Cost Option)

The software available with this basic system will support 10 MCT-10 mobile terminals, one Dispatcher Display Terminal and one Status Monitor Terminal. The system is expandable however, by adding software modules, to support up to 80 mobile terminals, six radio channels, four data base communication links and six CRT (Cathode Ray Tube) terminals. Software is available in two forms,

1) OS-10 Operations Software, and
2) AS-10 Applications Software.

The system design necessary in a particular case is determined by the requirements of the user.

At the mobile unit, data entry is made by means of a manual keyboard, and message reception is made on a 256 character alphanumeric display. At the base station, data entry is also done on a manual keyboard, but message output is either by means of an alphanumeric display or printed copy. The system provides for transmission of messages between mobile units, between mobile units and the base station, and between either and a remote data base.

3.3.1.3 RADCOM-1 System Functions

3.3.1.3.1 Data Base Inquiry/Response

Direct field inquiries into remote data bases are made using the MCT-10 mobile terminal. The complete communication link consists of the mobile terminal, the radio system, the base station encoder/decoder, the Terminal Controller, the Line Interface and the telephone circuit that connects the RADCOM-1 system to a line interface (modem) at the remote computer.

Seven function keys are provided on the mobile terminal keyboard. Their purpose is to reduce the amount of information which must be entered into the system by a field officer. He is required to enter only the information necessary for the inquiry desired, press the proper function key, and then press the Transmit key. The unit then automatically transmits the inquiry to the Terminal Controller via the voice radio link and the Encoder/Decoder Interface. The Terminal Controller performs any reformatting required in order to access the remote data base, and transmits the reformatted inquiry automatically, via the Line Interface. The response returned by the remote data base is passed, through the Terminal Controller, back to the requesting terminal. Should the response indicate a "hit" (stolen vehicle, wanted person, etc.), the base station dispatcher is notified on the Dispatcher Display Terminal and the message is automatically logged by the Line Printer. Assignments of the seven function keys by a user agency will correspond to the requirements and capabilities of the various remote data bases accessible to that agency.

3.3.1.3.2 Mobile Unit Status Maintenance

Four status keys and a special emergency key are available for assignment by the user agency. The definition of each assignment is recorded in the Applications Software, and indicates the particular mobile unit status information required by that law enforcement agency. When the status of a mobile unit changes, the field officer presses the appropriate status key, followed by the Transmit key. The change of status information is then automatically transmitted to the Terminal Controller for storage and display at the Status Monitor Terminal. Status information for any mobile unit is retrievable by the dispatcher and by any designated mobile command units. Two levels of mobile unit status information are available. Available Vehicle Status is provided in list form, usually by unit or vehicle number, and indicates those mobile units available for dispatch. Detailed Status contains all information pertinent to the status of a particular mobile unit. Detailed Status might include, for example, the vehicle number, field officer ID's, beat number, time of last status change, and the current status of the mobile unit.

All status changes are displayed on the Status Monitor Terminal, and status changes may also be logged on the Line Printer or routed to a local computer file system for later historical and statistical analysis.

3.3.1.3.3 Terminal-to-Terminal Digital Communications

Terminal-to-terminal communcations are permitted within the RADCOM-1 system. The Terminal Controller will route correctly addressed messages between mobile terminals, as well as route inbound messages from the mobile terminals to the Dispatcher Display Terminal and to remote data bases, and outbound messages addressed to mobile terminals.

3.3.1.4 RADCOM-1 Hardware Units

The RADCOM-1 system is composed of nine primary hardware units. A brief description of each unit is provided below. Detailed discussions and unit specifications will be found in Appendix A.

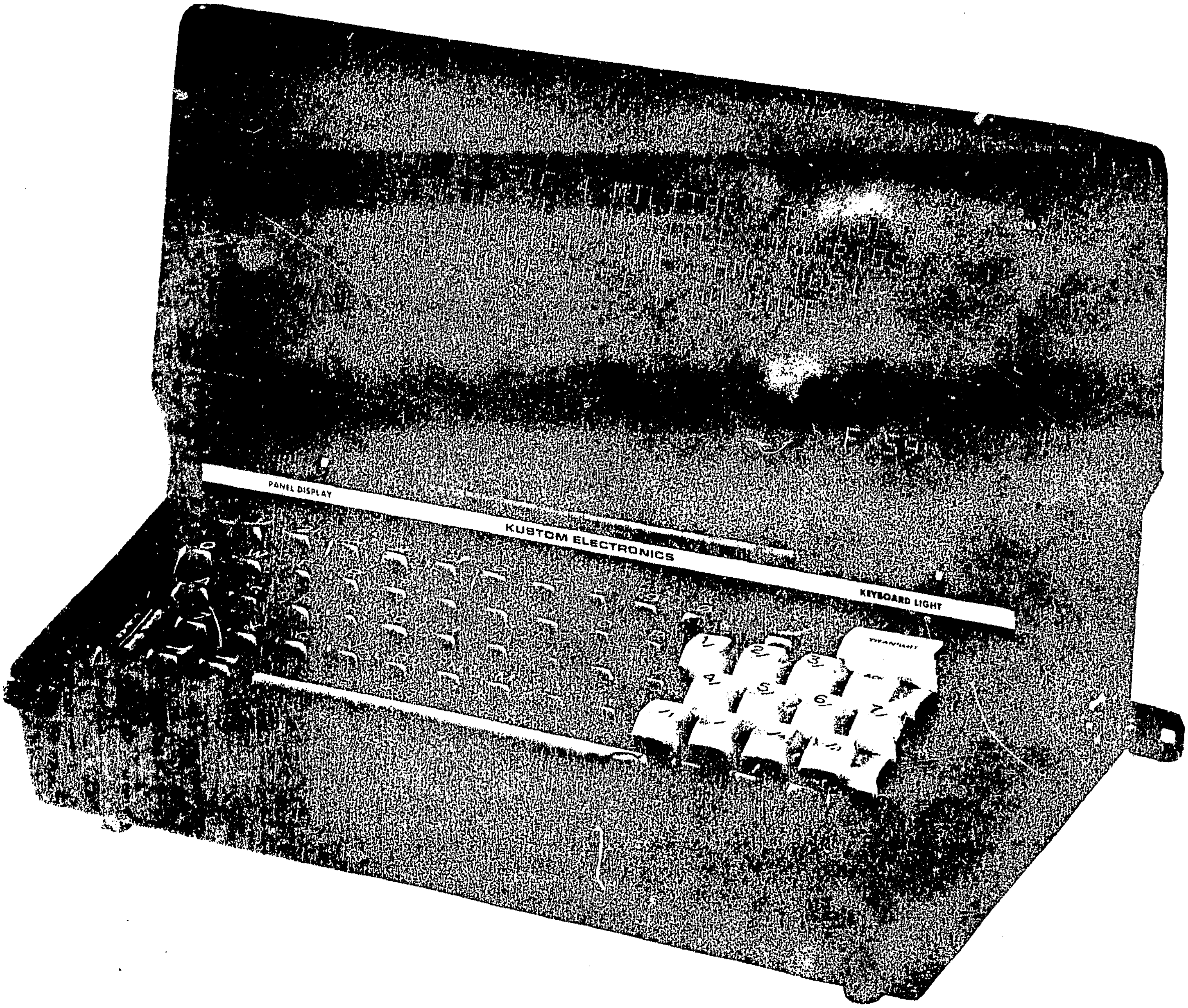
3.3.1.4.1 MCT-10 Mobile Communication Terminal

The MCT-10, shown in Figure 8, allows a field officer to communicate with the TC-10 Terminal Controller, in digital form, directly from his car. Data entry is accomplished using the terminal keyboard. Responses are received on a 256 character alphanumeric display. Function keys simplify the data entry for certain fixed format messages and assignable status keys allow semi-automatic status entry and update. Prior messages and dispatches may be recalled at will from the Terminal Controller. More advanced functions, such as report form generation, automatic vehicle monitoring, and extended information recall are anticipated.

3.3.1.4.2 TC-10 Terminal Controller and DK-10 Disk Unit

A programmable communications processor (minicomputer) is the essential sub-unit of the RADCOM-1 Terminal Controller. Kustom Electronics have developed both operating and applications software packages which enable the Terminal Controller to exercise total control over the mobile/digital system operation. Features of this processor/software combination are:

1) formation of a communications interface capable of adapting to all law enforcement data bases, such as NCIC and FCIC.
2) power-fail/restart capability, enabling the TC-10 to maintain operation despite minor power fluctuations and providing an orderly shutdown and recovery in case of total power failure.



MCT 10
Mobile Communications Terminal

Fig. 8

3) time and date stamping of all appropriate messages and status changes handled by the processor.

4) on-line error detection for inbound messages from the mobile terminals, and retry logic to establish an absolute response to all outbound messages.

Extended memory for the Terminal Controller is provided by the DK-10 Disk Unit, a moving head, removable cartridge, disk device with a capacity of 2.4 million data characters. The Disk Unit is an integral part of the Terminal Controller, and is housed in the same cabinet as the TC-10. The storage provided by the Disk Unit is used for program loading, program overlays and message queueing. The Disk Unit provides sufficient storage capability for later expansion of the RADCOM-1 system. Thus, the addition of new capabilities, as well as additional mobile and dispatcher terminals, does not necessarily require additions to the Terminal Controller.

3.3.1.4.3 ED-10 Encoder/Decoder

The Encoder/Decoder is required to connect the Terminal Controller to the base station radio. The output signal from the TC-10 is a bi-level (binary) d.c. signal with one level representing a logical 1 and the other level representing a logical 0. The encoder, or modulator, converts this series of pulses to an audio signal of constant frequency (1950 Hz) whose phase, as a function of time, assumes two values. One value represents a logical 1 and the other a logical 0. The time of occurrence of phase changes corresponds exactly to the level changes of the d.c. signal. This process, called phase-shift-keying (PSK) adapts the d.c. signal from the Terminal Controller to the 3kHz audio input bandwidth of the base station transmitter. Each level (or phase value) in this signal persists for a fixed time before it either changes to the other level, or remains the same. These time durations (which may have one of two amplitudes) are called bits and are generated and transmitted at the rate of 1300 per second. Thus, the data rate in the Kustom Electronics mobile/digital system is 1300 bits/sec.

The decoder, or demodulator, does the reverse of the above process, converting the audio PSK signal received from a mobile terminal to a d.c. signal which can be processed by the Terminal Controller.

In the Kustom system, the above modulation process is synchronous, which means that the decoder extracts information from the received signal which enables it to tell when each bit within a message occurs. Thus, the decoder cannot mistake one bit for another or miss a bit because it has adjusted the time at which it looks at the incoming signal to correspond to the times at which the signal changes level. The information which enables the decoder to synchronize itself to the incoming signal is contained in a low level subcarrier which is transmitted along with the PSK signal. This sub-carrier has an amplitude only one-one hundredth that of the PSK signal.

3.3.1.4.4 LI-10 Line Interface

In order to connect the Terminal Controller to remote computers (data bases), telephone lines are used. These lines are similar in many respects to the radio system in that they transmit audio signals of 3kHz maximum bandwidth. In general, telephone lines cannot transmit d.c. signals. Therefore, a device similar to the Encoder/Decoder is required to connect the Terminal Controller to a telephone line. In this application, these devices are generally called modems (modulator-demodulator), but Kustom uses the term Line Interface. The operation of the Line Interface is controlled by an Operating Software module in the TC-10, and any format conversions which are required to convert the language used in the TC-10 to the language used in the remote computer are done by a programming module in the Application Software.

Line Interfaces are available to handle transmission rates varying between 110 bits/sec and 9600 bits/sec, and synchronous (including bi-synchronous) or asynchronous detection can be used, depending upon the interface requirements of the particular computer.

3.3.1.4.5 DT-10-2 Dispatcher Display Terminal

Resource allocation is effected by means of the Dispatcher Display Terminal which is located in the communication center of the user agency. This device is a cathode ray tube (CRT) terminal, with the majority of the 2,000 character screen used to display the current status of mobile units in the system. The display is continuously updated by the Terminal Controller as new status information is received from the mobile terminals. The balance of the display can be used by the dispatcher for composition of messages, assignment of mobile units, retrieval of detailed status from the Terminal Controller, and dispatcher inquiry into the available data bases, in a manner analogous to a mobile terminal.

3.3.1.4.6 DT-10-3 Status Monitor Terminal

The Status Monitor Terminal is physically identical to the DT-10-2 Dispatcher Display Terminal, and is used to display the status of available mobile units. The terminal also serves as a backup unit for the Dispatcher Display Terminal. Changes in status are automatically updated and displayed for use by the dispatcher in resource allocation. It is not necessary for the dispatcher to request a display of the status of a unit unless detailed status information is required.

3.3.1.4.7 LP-10 Line Printer

A 100/165 character per second, dot matrix, serial impact line printer, the LP-10, is used for message logging and documentation. Normally it is located adjacent to the dispatcher's console. Alternately, it may be used in the computer center for programming functions and management information reporting.

The printer produces an original plus up to four carbon copies. Various character sets are available. The printer is self-contained, including mechanical and electro-mechanical components, control logic, character pattern generator, a single line (80 characters/line) buffer, and power supply. In the RADCOM-1 system, the line printer is used for logging items such as potential inquiry "hits" and status changes. Information displayed on the dispatcher's CRT can also be printed, at the operator's command.

3.3.1.4.8 TT-10-1 Teletype Console

The Teletype Console is an input/output device for the TC-10 Terminal Controller. It is used for performing maintenance and control operations within the RADCOM-1 system. A low-speed device, it is intended for use by maintenance and system personnel only. During normal system operation it is not used, and may be located out of the main communication center area, along with the TC-10 Terminal Controller.

3.3.1.4.9 MP-10 Mobile Printer

The MP-10 Mobile Printer is a solid-state, silent head optional printing attachment for the MCT-10 Mobile Terminal. The Mobile Printer provides hard copy at the demand of the field officer or upon command from the base station. Printing is done directly from the Mobile Terminal's display memory, requiring no additional air time.

3.3.1.5 RADCOM-1 Software Systems

Two software systems are required to implement and operate the RADCOM-1 system. The Operating Software (OS-10) system includes modules which perform interrupt and device handling, task scheduling, and memory and disk allocation. Applications Software (AS-10) modules are tailored to fit the demands of individual agencies, providing data base interfacing and status and function key utilization. Design and programming of the Applications Software system was done in open-ended fashion, using standard linkages (sub-routine calling sequences), modifiable tables, and generalized routines, in an attempt to permit later expansion of the software system.

3.3.2 The IBM 2976 Mobile Terminal System

3.3.2.1 Introduction

The IBM 2976 Mobile Terminal System is a digital communication system which introduces novel concepts into law enforcement radio communications. These novel concepts include installation of a keyboard and line printer in patrol vehicles, use of polling techniques for network control, and use of an existing IBM System/360 or System/370 to provide the data processing necessary for system operation.

A block diagram of the system is shown in Figure 9. The mobile terminal is linked to the user's local data system through a signal converter, which provides an interface with the radio system, and a transmission control unit (TCU), a device which controls the flow of data between the network of mobile terminals and an IBM System/360 or System/370 central processing unit.

The Mobile Terminal System enables a patrol officer to communicate directly with local and remote computers, thereby giving him access to law enforcement data bases without the necessity of dispatcher intervention. The system provides a direct data link from the keyboard of the mobile terminal to the central data system. The use of a polling technique establishes a fixed channel discipline, allowing a patrol officer to make numerous inquiries without suffering excessive delays due to radio channel congestion, especially since a dedicated half-duplex radio channel is required, eliminating voice traffic entirely. Information concerning events which occur within the law enforcement system is available to all mobile terminals as soon as it is placed into the computer data files. The mobile

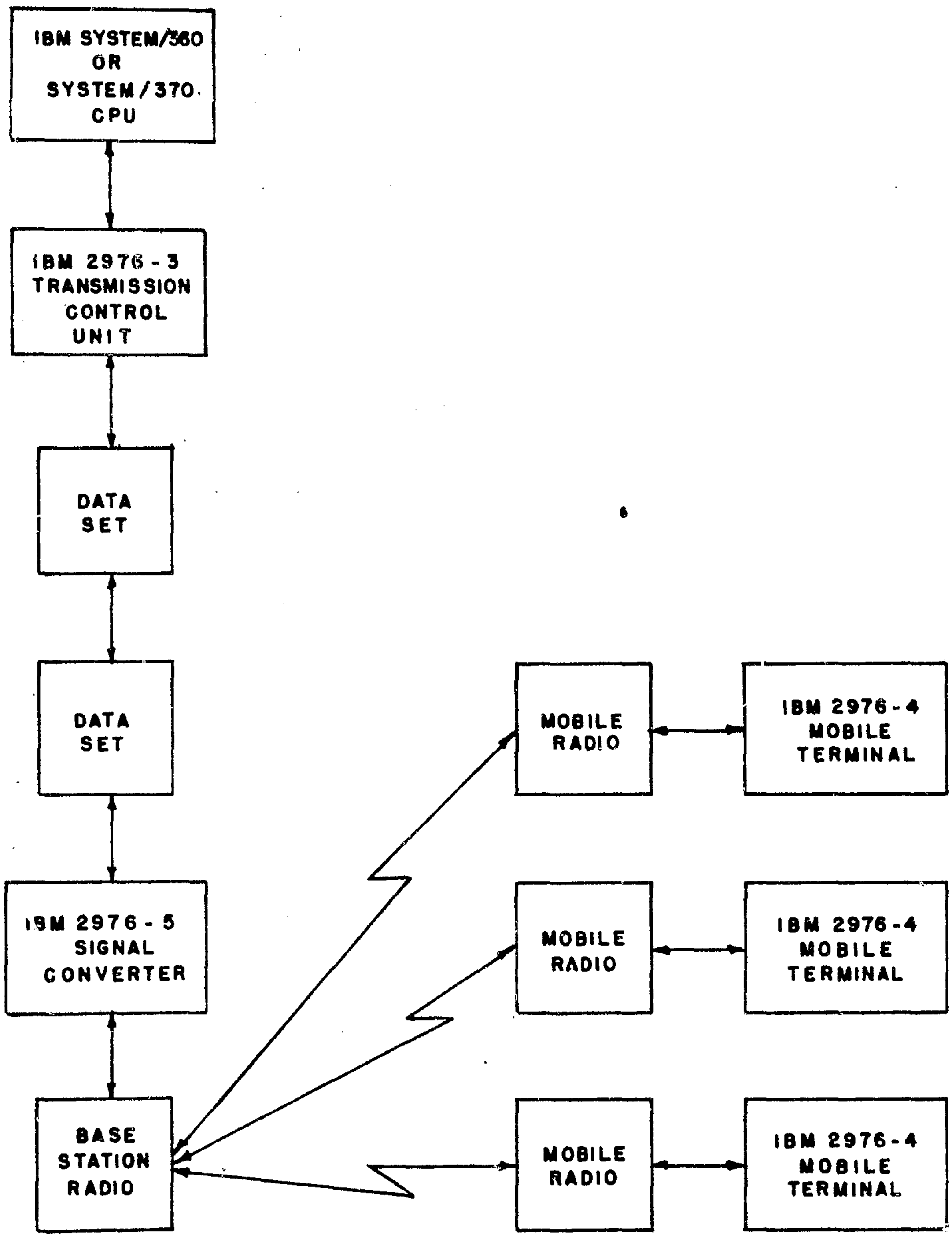


Fig. 9 IBM 2976 MOBILE TERMINAL SYSTEM

terminal provides a hard-copy printed response to all inquiries, and maintains a continuous printed record of all messages transmitted or received by the mobile terminal.

3.3.2.2 Application of the Mobile Terminal System

The IBM 2976 Mobile Terminal System provides a means for field units to make inquiries into local and remote data bases, permits the implementation of computer-aided dispatching, allows incidents to be quickly reported to the computer file, and provides system security and private communication of law enforcement data.

3.3.2.2.1 Data Base Inquiry

The Mobile Terminal System allows a field officer to make inquiries directly into a law enforcement data base without dispatcher intervention. IBM estimates that responses will generally be obtained within 11 or 12 seconds. Multiple inquiries on an individual, using names, driver's license number, social security number, or other identifiers, can all be made in a short time. Inquiries can also be made using license plate number, vehicle identification number, address or complaint/warrant numbers. For any inquiry, the data to be entered and the response obtained depend on both the extent of the application programming done for the central processing unit, and the interface requirements of local and remote data bases.

3.3.2.2.2 Computer Assisted Dispatching

The IBM Mobile Terminal System allows the dispatcher to enter information concerning the type of complaint, the complainant, and its location or address into the central computer by means of a keyboard or video display terminal. The computer then correlates the received information with beat assignments and mobile unit status, while monitoring the situation. Using complaint type and mobile unit status, the computer makes a decision to either dispatch a unit immediately, or delay dispatching until more mobile units are available, thus maintaining a reserve of unassigned mobile units to handle high-priority calls.

3.3.2.2.3 Incident Report Generation

Field reports may be entered directly into the central computer system. A field officer may enter an incident or case number, which is assigned by the computer, and add additional data as necessary or as requested, thereby avoiding unnecessary duplication. Once the operator enters the report type, he is led by the central computer through a question and answer sequence, supplying the correct responses to fill out the report.

3.3.2.2.4 Statistical Reports

All data sent to mobile terminals from the central data base is automatically logged by the data processing system. Data entered by mobile terminals is also logged at the central processing unit. These data are then available for statistical and geographic service analysis. IBM has developed a Program Product labeled Law Enforcement Manpower Resource Allocation System (LEMRAS), which produces up to 142 different reports, all derived from basic dispatch data.

3.3.2.3 System Security

IBM emphasizes the importance of the system security and privacy of communication obtained by users of the Mobile Terminal System. Digital transmission insures the privacy of all messages transmitted between the mobile terminal and the data base. Each mobile terminal is identified by an address within the system, and accepts only messages labeled with its address.

A keylock-switch is available for the mobile terminal. If a mobile terminal were lost, or stolen, the corresponding address would be deleted from the list of available addresses, and no further inquiries would be accepted for, nor messages transmitted to, that terminal.

Finally, a system of procedural controls has been developed to prevent human errors.

3.3.2.4 <u>IBM 2976 Mobile Terminal System Components</u>

3.3.2.4.1 <u>Introduction</u>

The Mobile Terminal System has three major components which form a data communication link between the patrol officer and the central computer system. The first component is the mobile terminal, which allows entry of messages into the data system, and provides hard-copy responses. The second component is the transmission control unit, which provides the interface to the radio channel. The third component is the transmission control unit, which controls the mobile terminal network.

3.3.2.4.2 <u>The IBM 2976 Model 4 Mobile Terminal Unit</u>

The Mobile Terminal Unit shown in Figure 10, is a specially designed terminal with a familiar typewriter keyboard plus function keys and guidance lights. The mobile terminal provides printed message output only, and records all messages entered into it or transmitted to it. The terminal is designed to be strapped to the front seat next to the officer. The mobile terminal may be interchanged between vehicles, and the printer and keyboard unit swivels so that either the driver or a passenger may use the device.

The base of the terminal contains all attachments to the mobile radio, buffer storage, the power supply and the mobile processor, which controls the terminal's operation.

3.3.2.4.2.1 <u>Mobile Terminal Features</u>

The mobile terminal has the following features:

- Output device is a line printer with a maximum printing rate of 150 lines per minute using pressure sensitive paper, and printing 16 characters per line.

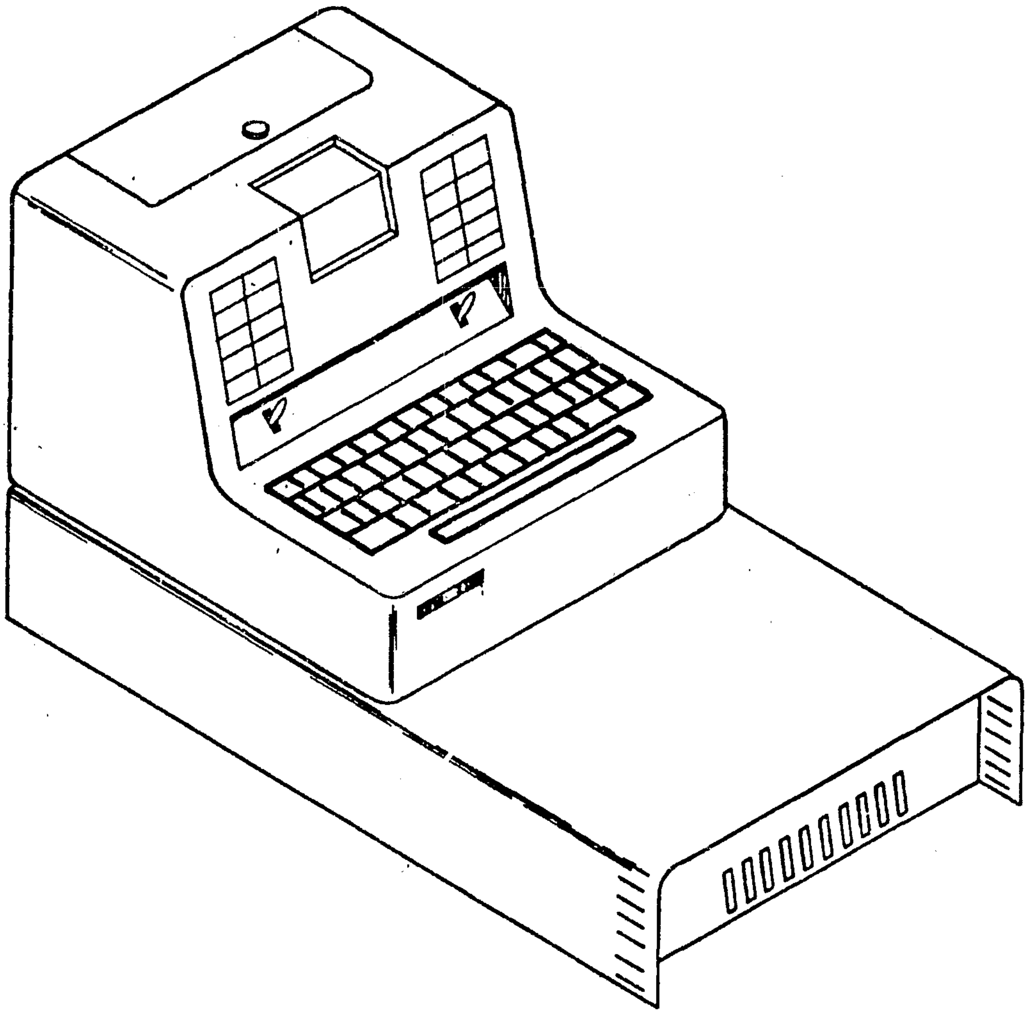


Fig. 10 - IBM 2976 Model 4 Mobile Terminal

- 48 active key non-mechanical keyboard
- Operator guidance panel with terminal hardware status lights and 8 programmable guidance lights, selectable by the user
- Illumination controls for day/night operation
- Forward error correction code for detection and correction of certain channel errors without retransmission.
- Non-print mode, allowing private entry of security codes
- Compact size, 19"L x 11 3/4" W x 14"H
- Operating temperative range, 32° to 110° F.
- Optional keylock switch, prohibiting unauthorized terminal usage.

3.3.2.4.2.2 The Terminal Keyboard

The terminal keyboard contains the standard alpha-numeric characters for data entry, plus other special characters. Keys are also provided for terminal control. The control keys are ENTER, NON-PRINT, SPACE, BACKSPACE, RESET, SEND, NEW-LINE, PAPERFEED, and TEST.

The numeric keys are used for entering numbers during inquiry composition. In addition, they provide single key status input, with status labeling assigned by the user.

The operator guidance panel contains lights which assist and direct the operator in entering data. The guidance lights are labeled READ, ENTER, RESP, RED, REENTER and BUFFER FULL.

Eight program-controlled lights are furnished which are also labeled by the user. These provide special indicators for the operator.

3.3.2.4.3 The IBM 2976 Model 3 Transmission Control Unit

The IBM 2976 Transmission Control Unit performs the following tasks:

1) Accepts messages from the central processing unit and transmits them to the specific terminal or terminals designated.

2) Requests transmission of messages from the mobile terminals, and accumulates these inbound messages for transfer to the central processor.

3) Checks message transmission, detecting and correcting certain errors, and initiating retransmissions as required.

4) Logs error conditions within the Mobile Terminal System and transmits them to the central processor.

5) Transmits and receives data using a forward error correction technique that detects and corrects data errors due to interference on leased lines or the radio channel, without retransmission.

6) Manages the network, establishing network discipline, and giving all terminals the opportunity to transmit, even during hours of high activity.

3.3.2.4.4 The IBM 2976 Model 5 Signal Converter

The IBM 2976 Signal Converter provides the data link between the Transmission Control Unit and the mobile terminal network. The Signal Converter accepts digital data, normally from a data set, and converts it into an audio signal using frequency-shift-keying. This audio signal is then transmitted to the mobile terminals by the base station transmitter. Audio signals are also accepted by the Signal Converter from the base station receiver. The Signal Converter recreates the digital data signal, and transmits it to the Transmission Control Unit.

3.3.3 The Motorola MODAT Alphanumeric Terminal System

3.3.3.1 Introduction

The MODAT Alphanumeric Terminal System is currently under development by Motorola. Many details of the system operation, including modulation and coding techniques, have not yet been released.

Conceptually, the Alphanumeric Terminal System is an extension of the basic Motorola MODAT Status and Message Display System, which provides mobile unit status and canned message

CONTINUED

2 OF 4

display only, together with voice identification and selective calling. The addition of alphanumeric terminals and rather sophisticated software packages should make the entire system much more versatile.

Motorola is prepared to supply a complete turnkey communication system, including the necessary voice radio equipment and control center furnishings.

3.3.3.2 General Description

Motorola is developing the MODAT Alphanumeric Terminal System to enable law enforcement field officers to send and receive critical information in a manner that is faster and more efficient than voice communication. The entire MODAT system will be provided by Motorola, including the mobile terminals, mobile and base logic units, radio equipment, dispatch center displays and controls, and a minicomputer with full peripherals and software support that has been developed specifically for public safety data systems.

The MODAT System is designed to provide field officers with the means for accessing local and remote law enforcement data bases, maintaining mobile unit status, and, as an option, obtaining hard copy output of all messages received at the mobile terminal. These features, and other software options, will permit the MODAT system to perform the functions required for both computer-assisted dispatching and eventual computerized dispatching with manual complaint entry.

A block diagram of the MODAT Alphanumeric Terminal System is shown in Figure 11. The system consists of the following hardware units:

1) MODAT Alphanumeric Terminal
2) MODAT Mobile Logic Unit
3) MODAT Base Logic Unit

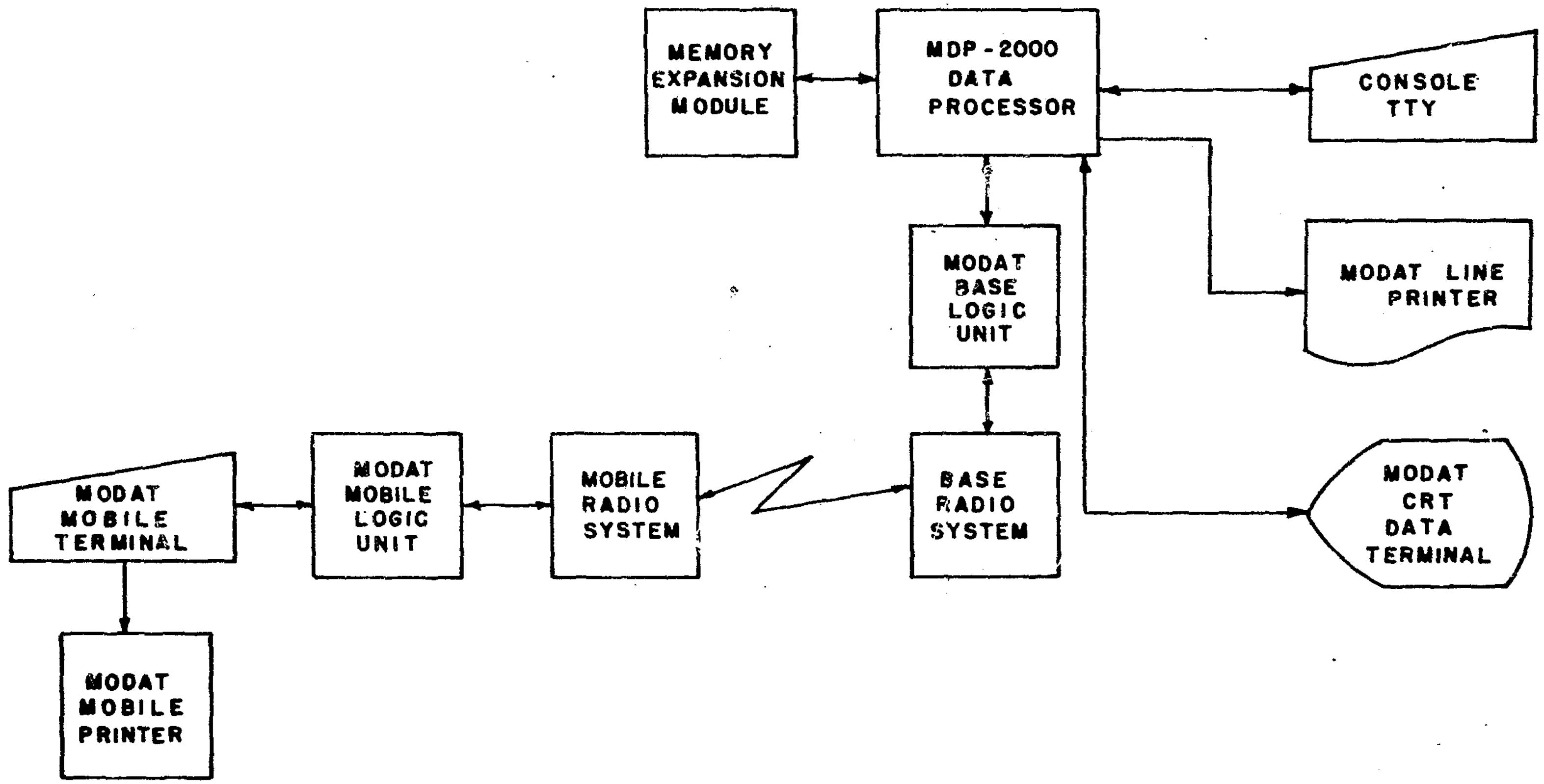


Fig. 11 MOTOROLA MODAT ALPHANUMERIC TERMINAL SYSTEM

4) MDP-2000 Processor
5) MDP-2000 CRT Data Terminal
6) MDP-2000 Line Printer
7) MODAT Mobile Printer

Software support for the MODAT Alphanumeric Terminal System has been developed by Motorola and will be provided in two packages, the RTMOSC-2000 Real-Time Multiprogramming Operating System, and the Motorola Command and Control Software System. In addition, Motorola's Data Management System, designed to run on a separate MDP-2000 Processor, is available to perform necessary data base functions.

The proposed MODAT system design is flexible, with an easily expandable hardware system, a variety of command and control software modules, and many possible display and control center configurations, all tailored to the requirements of the individual law enforcement agency.

3.3.3.3 <u>MODAT System Functions</u>

3.3.3.3.1 <u>Data Base Inquiry and Response</u>

The MODAT system permits inquiries to be made into a remote law enforcement data base directly from the mobile terminal. As designed, the mobile terminal keyboard contains function keys for license checks (LIC CHK) and wanted person checks (WNT CHK). In addition, three keys are available for assignment by the user agency as either function or status keys. Inquiries can thus be made by referencing a variety of identifiers.

In order to perform an inquiry, the operator presses the proper inquiry function key, enters the necessary identifiers using a simple preassigned format, and presses the transmit (XMIT) key. The terminal then automatically initiates transmission of the inquiry message to the MDP-2000 Processor.

The processor performs any reformatting necessary to access the remote data base. The inquiry may also be transmitted to a separate Data Management System processor for filing or later analysis. When a reply is obtained from the remote data base, the processor reformats the response and initiates its transmission to the mobile terminal which originally requested the information. If the reply indicates a "hit", a message is displayed simultaneously at the mobile terminal and at the dispatcher, complaint and supervisory CRT data terminals. "No hits" are displayed only at the terminal which initiated the inquiry.

3.3.3.3.2 Mobile Unit Status Maintenance

Five status entry keys with illuminated indicators are provided on the MODAT Alphanumeric Terminal. At the start of a working day, the operator switches on the mobile terminal, and all five indicators flash in unison to notify the operator that his status must be entered into the system.

Single keystroke status entry is provided. When a status is entered, the associated indicator remains lighted to display the current status of the unit. It is not necessary to press the XMIT key following a status entry. As noted earlier, three keys are unassigned and thus are available for assignment by the user agency as either additional status or function keys.

3.3.3.4 MODAT System Hardware Units

A MODAT system is configured from seven primary components. A brief description of each component is given below. Additional available details and specifications will be found in Appendix C.

3.3.3.4.1 MODAT Alphanumeric Terminal

The alphanumeric terminal enables a field officer to access remote data bases and enter mobile unit status changes in a simple manner. Using the keyboard, a data base inquiry is made directly from the mobile unit through the MDP-2000 Data Processor, bypassing the dispatcher.

An inquiry message or its response may contain up to 64 characters of text, of which 32 may be displayed at any one time. Display control keys are used to scan through a message that is longer than 32 characters.

Five status keys allow single keystroke status entry. Three additional keys may be assigned by the user agency as either status or function keys.

Five fixed-message keys are provided to perform functions such as limited data base inquiry, manual message acknowledgement and message repeat request.

Applications programming for the MDP-2000 Processor permits the alphanumeric terminal to be used for a wide variety of law enforcement and public safety functions.

3.3.3.4.2 MODAT Mobile Logic Unit

The Mobile Logic Unit is the hardware interface between the MODAT Alphanumeric Terminal and the user's mobile radio. This unit converts digital signals from the mobile terminal into audio signals for transmission to the MDP-2000 Data Processor, via the existing voice radio system.

Audio digital signals received by the mobile radio are also accepted by the Mobile Logic Unit and converted to digital form for processing by the alphanumeric terminal.

Details of the audio modulation method used in the Mobile Logic Unit have not been released by Motorola except for a statement that differential phase-shift-keying will be used. The entire MODAT system will, however, be designed to operate with the user's Motorola radio equipment.

3.3.3.4.3 MODAT Base Logic Unit

The Base Logic Unit serves as the hardware interface between the base station radio and the MDP-2000 Data Processor. Outbound d.c. digital messages are accepted by the Base Logic Unit from the MDP-2000 Processor and converted to audio signals for transmission by the base station. Inbound messages are similarly converted from audio signals to d.c. digital signals for processing by the MDP-2000.

Design details of the Base and Mobile Logic Units are similar but have not been released by Motorola. The coding scheme used to reduce the effects of transmission errors has also not been defined.

3.3.3.4.4 MDP-2000 Data Processor

The MDP-2000 Data Processor is a minicomputer designed by Motorola specifically for communication systems applications. Up to 248 input/output channels can be controlled by the MDP-2000. These channels are used to connect the processor to mass storage and input/output devices such as disk and tape drives, teletypes, CRT data terminals, paper tape readers and punches, line printers, MODAT systems, and vehicular printer control terminals.

Each channel may handle inbound or outbound data, but can not handle both simultaneously. If a duplex channel is required, two single channels must be used. The processor may send or receive data on each of the 248 channels simultaneously.

Features of the MDP-2000 Processor are:

1) Real Time Clock, 1/960 second standard time interval
2) Power Fail Protect/Automatic Restart, which senses power loss, saves the contents of important registers, and prevents destruction of data stored in the core memory. When power is returned, program control is restored.
3) Teletype Controller, used for loading, assembling, debugging and system logging functions. No input/output channel or controller is required.
4) 650 nanosecond cycle time required for the processor to read or write the contents of a memory location.

The standard memory of the MDP-2000 is 8K words, of 16 bits each. The memory may be expanded to 32K words using plug-in memory expansion modules. Self-test capability is provided on the memory chassis, enabling a complete test without connecting the memory to the processor.

3.3.3.4.5 MDP-2000 CRT Data Terminal

The CRT Data Terminal is an input/output device which uses a keyboard for input and control, and a television-like cathode ray tube (CRT) for display. In the MODAT system, CRT terminals are used for complaint entry and dispatcher display, both being operations where data input is slow, but rapid response and display are desired.

Both serial and parallel data input/output CRT terminals are available. Parallel operation permits high-speed data output, but the terminal must be located within 1,000 feet of the MDP-2000. Serial operation is permitted at data rates up to 9600 baud, but remote operation is possible using conditioned telephone lines and data sets. At 300 baud, or 30 characters per second, operation is permitted over standard telephone lines using acoustic couplers.

When the control center console is provided by Motorola, the CRT terminals may be premounted in the console.

3.3.3.4.6 MDP-2000 Line Printer

Motorola supplies a line printer to provide high-speed printed output from the MDP-2000 Processor for applications where the 10 character per second speed of a teletype is inadequate. Two models are available, operating at 135 or 300 lines per minute, each with 80 characters per line.

3.3.3.4.7 MODAT Mobile Printer

A mobile teleprinter may be located in the patrol vehicle adjacent to the alphanumeric terminal. This option allows hard copy output at the mobile unit. Printer operation may be either automatic on receipt of a message, or on the demand of the terminal operator. The teleprinter will be mechanically identical to the VP-100 teleprinter now available from Motorola.

3.3.3.5 MODAT Software Systems

Motorola has developed both operating and applications software systems for the MDP-2000 Data Processor. Operations software includes the RTMOSC-2000 Real Time Multiprogramming Operating System, a Symbolic Assembler, and a Utility Package.

Applications software includes the Command and Control Packages and the Motorola Data Management System.

3.3.3.5.1 RTMOSC-2000 Operating System

The RTMOSC-2000 is a multiprogramming operating system which allows a variable number of application programs, resident in the core memory, to operate concurrently within a fixed priority system.

The following functions are provided:

1) Real time in milliseconds, seconds, hours and days,
2) Scheduling of program tasks for real time execution,
3) Scheduling and execution of program input/output requests,
4) Interrupt handling for all 248 input/output channels,
5) Memory protection management,
6) On-line control of operating system tasks, and
7) Control of re-entrant system subroutines.

3.3.3.5.2 Symbolic Assembler

A Symbolic Assembler allows the programmer to write direct or relative addressed source program codes for the MDP-2000. The assembly program then translates between the source codes, in a mnemonic form of the machine language, and the machine language itself, generally in a one-to-one instruction manner. This feature enables a programmer to assign a label to statements or data variables for use anywhere in a program.

3.3.3.5.3 Utility Package

This operating package is required to load and verify other programs, to punch and print "dumps" of the contents of core memory, and to provide debugging aids to the system programmer.

3.3.3.5.4 Command and Control Packages

Many modules are available for assembly into an applications software package to implement a MODAT system. Modules available include:

1) Complaint Entry
2) Dispatcher Display
3) Automatic Complaint Routing
4) Street-to-Crime District
5) Incident Status
6) Adjacent Incident Display
7) Status of Forces
8) Vehicle Recommendation
9) Vehicle Location
10) Mobile Digital Keyboard
11) NCIC Interconnect
12) ANI-CNA Interface
13) Automatic Frequency Switching
14) Terminal-to-Terminal Dialogue
15) Remote Computer Interface
16) Traffic Hazard File
17) Premise Information File
18) General Display
19) Activity Logging
20) Statistical Summary
21) Automatic Pre-Dispatch and Early Mobile Alert
22) Automatic Telephone-to-Mobile

These modules are described in Appendix C.

3.3.3.5.5 Motorola Data Management System

For those applications where high data base activity is required, in addition to the command and control functions, Motorola has developed a software package labeled the Data Management System. This system provides the means for arranging, storing, and retrieving data on disk files.

The Data Management System is designed to run on a dedicated MDP-2000 Processor, since data base functions such as retrieval, entry and display can become a major source of activity in larger, more complex systems. This dual-processor structure enables rather slow data base activities to proceed simultaneously with more rapid command and control operations.

3.3.4 The ARCOM Mobile Data Communications System

3.3.4.1 Introduction

The ARCOM Mobile/Digital System is designed to provide law enforcement agencies with a means for allowing mobile units to directly access computer data files. In addition, the system provides automated mobile unit status reporting and makes it possible to implement other operational and administrative functions.

Economic considerations played an important role in the design of the ARCOM System and its mobile terminal. Atlantic Research Corp. has attempted to provide a data communication system capable of meeting the requirements of most law enforcement agencies, while maintaining reasonable system costs.

A compact mobile terminal, the MCT-16, was designed specifically for use in a law enforcement mobile unit environment. The ARCOM System operates over the user's existing two-way radio system, allowing data to time-share the radio channel with voice communications.

3.3.4.2 General Description

The ARCOM System is designed to provide field officers with direct access to law enforcement data bases, permit automation of mobile unit status maintenance, and allow transmission of terminal-to-terminal text messages.

A block diagram of the ARCOM System is shown in Figure 12. The system operates in conjunction with the user's existing two-way radio equipment. Digital data messages time-share the radio channel with voice traffic.

An ARCOM System is configured from the following hardware units:

1) MCT-16 Mobile Communications Terminal
2) ARCOM Mobile Radio Interface
3) ARCOM Base Radio Interface
4) General Automation SPC-16 Minicomputer
5) Super-Bee CRT Data Terminal
6) Centronics Model 306 Line Printer.

The specially designed mobile terminal, the MCT-16, contains a full keyboard, with numerals, alphabet and special purpose keys, and a 16 character LED display. Messages sent from the MCT-16 may contain up to 80 characters of text. Received messages are limited to 16 characters of text. Only 16 characters can be displayed at the terminal at any one time.

All messages handled by the ARCOM System are logged on the Centronics Model 306 printer, providing a permanent record of mobile unit and data base activity.

3.3.4.3 ARCOM System Functions

3.3.4.3.1 Data Base Inquiry and Response

Inquiries into local and remote data bases can be made from the MCT-16 Mobile Terminal. Messages are directed from the mobile unit to the data base via the ARCOM Mobile Radio Interface,

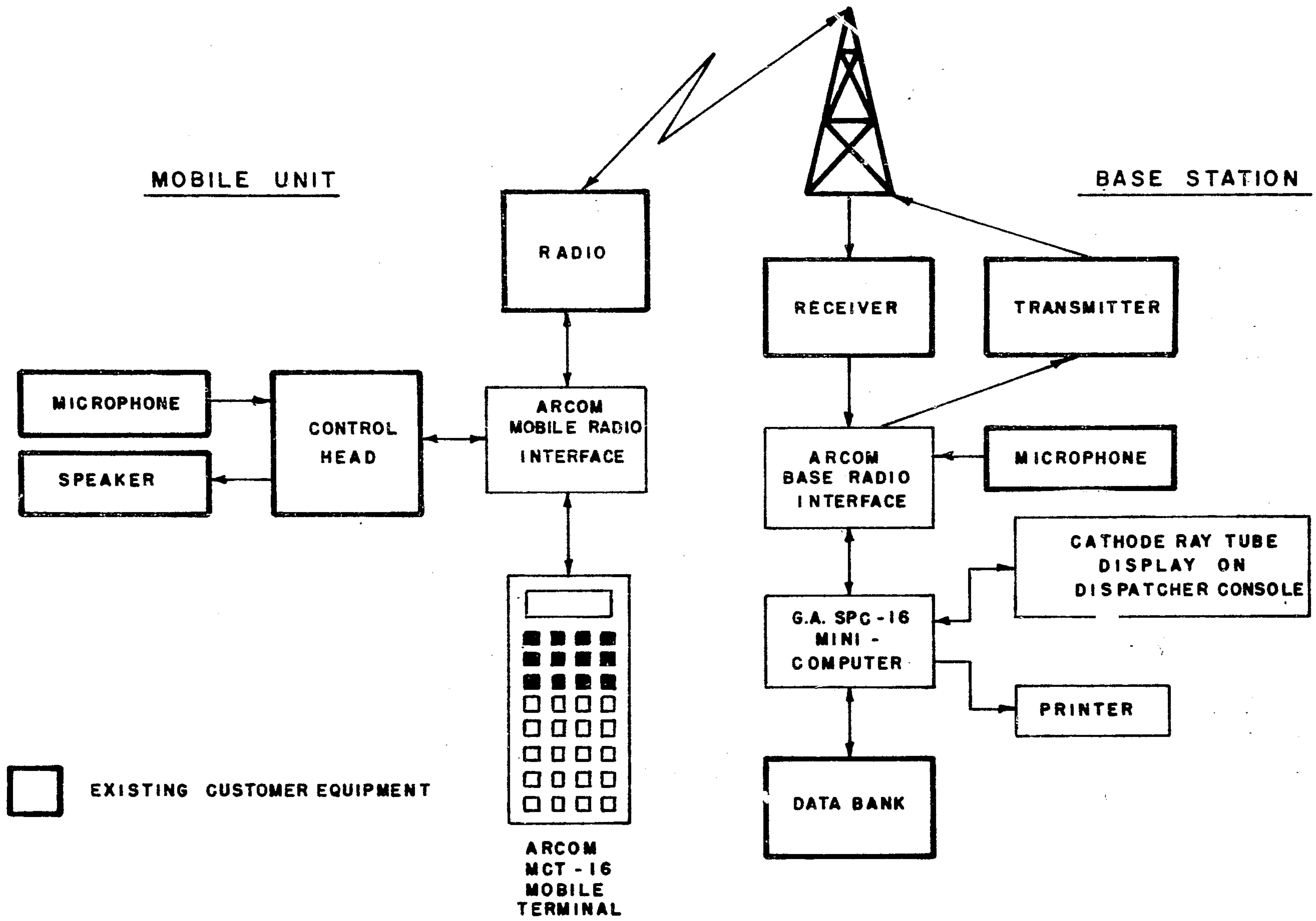


Fig. 12 ARCOM SYSTEM BLOCK DIAGRAM

the SPC-16 minicomputer, and any telecommunications equipment necessary to connect to the remote data system.

Identifiers such as name, address, vehicle identification number, driver's license number, social security number, vehicle registration number, or license plate number may typically be selected as the basis for inquiries into the law enforcement data base. To initiate such an inquiry, the operator must erase the display, press the selected function key, enter the associated identifier, and press the Transmit key. The SPC-16 minicomputer performs the reformatting necessary to access the data base, and forwards the inquiry message.

The response obtained from the data base is returned to the requesting mobile terminal, generally in an abbreviated form, with simple indications for "hit" or "clear". The use of abbreviated formats and a 16 character display are designed to minimize the amount of data entry required on the part of the terminal operator, and reduce the required length of data messages transmitted to the mobile units.

Inquiry messages may contain up to 80 characters of text. As an inquiry is entered by the operator, only the last 16 characters entered are displayed on the MCT-16. Responses are received in blocks of 16 characters, so that the entire message can be displayed for the operator. Space and Back-Space keys are provided for shifting the remainder of longer messages into view.

The user may specify the designations for the seven inquiry function keys provided by Atlantic Research if other special functions need to be implemented.

3.3.4.3.2 Mobile Unit and Emergency Status Entry

The ability to maintain mobile unit status is available in the ARCOM System. To enter a new status, the terminal operator erases the display, presses the special purpose TEN key, enters the appropriate numerical status code, and presses the TRANSMIT key.

A special red EMERGENCY key is provided. To enter Emergency status, the operator erases the display, presses the EMERGENCY key, enters any additional data he desires, and presses the TRANSMIT key. This initiates the transmission of a priority emergency message to the dispatcher.

All status changes, dispatches, and Emergency calls can be logged on the Centronics Model 306 Line Printer. Unit status information is displayed for the dispatcher's use on the Super Bee CRT Data Terminal.

3.3.4.3.3 Terminal-to-Terminal Messages

Messages may be transmitted between terminals in the ARCOM System. To send a message to the dispatcher the terminal operator erases the display, presses a preassigned function key, enters up to 79 characters of text, and presses the TRANSMIT key. To address another mobile terminal, the operator must include an address in the message text, for interpretation by the SPC-16 minicomputer which then forwards the message text to the addressed destination.

In the ARCOM System, the dispatcher's Super Bee CRT Data Terminal is able to duplicate the functions of the MCT-16 Mobile Terminal, although the keyboard and message formats used vary. The dispatcher may address messages to single units, groups of mobile units, or to all mobile units under his control. Applications programming for the SPC-16 minicomputer will be tailored to the requirements of each user agency, including function key assignment and dispatcher terminal operation.

3.3.4.4 ARCOM System Hardware Units

An ARCOM System is configured from six primary hardware components. A brief description of each unit is provided below.

Detailed discussions and available unit specifications will be found in Appendix D.

3.3.4.4.1 MCT-16 Mobile Communications Terminal

The MCT-16 Mobile Terminal enables a field officer to send and receive messages to and from the SPC-16 minicomputer, permitting direct communication with local and remote data bases, the system dispatcher and other MCT-16 terminals in the same system.

Data entry is performed using the unique alphanumeric keyboard, containing numerals, the alphabet, and special purpose keys. Seven function keys may be assigned by the user to simplify data base inquiries. Unit status reporting is accomplished by entering a ten code message.

Messages generated at the terminal may be up to 80 characters long, 79 text characters plus one control character. A 16 character 5 x 7 dot matrix LED display is provided. Display control keys are used to view messages longer than 16 characters. One character is required in each message to identify the message type.

3.3.4.4.2 ARCOM Mobile Radio Interface

The Mobile Radio Interface allows the MCT-16 Mobile Terminal to send and receive messages over the user's existing two-way voice radio system. The Interface serves as an encoder/decoder to convert messages represented by bi-level D.C. signals within the MCT-16 Mobile Terminal into audio frequency-shift-keyed signals for use within the user's mobile radio system. The Mobile Radio Interface also performs other functions, such as controlling the transmission of messages initiated by the MCT-16 Mobile Terminal, and reception of messages from the two-way voice radio system.

3.3.4.4.3 ARCOM Base Radio Interface

Just as the Mobile Radio Interface connects the MCT-16 Mobile Communications Terminal to the user's mobile radio equipment, the Base Radio Interface serves as the encoder/decoder between the SPC-16 minicomputer and the base station radio system.

The Base Radio Interface uses the same audio frequency-shift-keying modulation method as the Mobile Radio Interface. The transmission data rate is 600 bits per second.

3.3.4.4.4 SPC-16 Minicomputer

A General Automation SPC-16 Minicomputer is the essential controlling element in an ARCOM System. Software packages are currently being developed by Computer Sciences Corporation which will permit the operation and application of the SPC-16 minicomputer, within the ARCOM System, to be tailored to user requirements.

The SPC-16 minicomputer is responsible for maintaining operational interfaces between the ARCOM system and remote or local data bases, control of the network of MCT-16 and Super Bee data terminals, and processing of messages within the ARCOM system, including generation of printed output on the Centronics Line Printer.

Input/output controllers required to connect the Super Bee CRT Data Terminal, the Line Printer, and the Base Radio Interface to the SPC-16 minicomputer's internal input/output system are considered to be a part of the SPC-16 supplied by Atlantic Research, simplifying the system configuration.

The SPC-16 minicomputer maintains the mobile unit status information display on the dispatcher's Super Bee CRT Data Terminal. Since the ARCOM system is designed for use with fleets of approximately twenty mobile units, sufficient memory capacity is expected to be available within the SPC-16 to permit the addition of advanced application programs as further system requirements are developed by the user agency.

3.3.4.4.5 Centronics Model 306 Line Printer

The Line Printer supplied by Atlantic Research with the ARCOM System is the Centronics Model 306, manufactured by Centronics Data Computer Corporation. The Line Printer is used for selective logging of messages transmitted within the ARCOM System, including data base inquiries and responses, status and emergency messages, and terminal-to-terminal calls.

Normally the Line Printer is located in the communications control center, near the dispatcher's terminal.

A standard 5 x 7 dot matrix format is used for print character generation. The model 306 printer operates at a print rate of 100 characters per second, with a line width of 80 characters. The average speed is 60 lines per minute for full 80 character lines, or 150 lines per minute for shorter 20 or 30 character lines.

3.3.4.4.6 Super Bee CRT Data Terminal

The ARCOM System uses a Super Bee CRT Data Terminal as a mobile unit status monitor and dispatcher position keyboard. At all times, the status of every mobile unit in the system is available to the dispatcher. In addition, the dispatcher may initiate data base inquiries and terminal-to-terminal messages. The functions provided by the CRT Data Terminal are under applications program control, and the required programs will be developed to meet user specifications by Computer Sciences Corporation.

A CRT Data Terminal contains a typewriter-like keyboard for data entry and a television-like cathode-ray tube (CRT) for display of entered and received information. These terminals are well suited to applications where a slow data entry rate is allowed, but a rapid response is required.

The Super Bee terminal is one of a new class of commercially available data terminals, containing an internal microprocessor and read-only memory, simplifying the operation of the data terminal, and permitting more efficient interfacing to the SPC-16 minicomputer in the ARCOM System.

3.3.4.5 ARCOM Software Systems

Software support, both operating and applications, for the ARCOM System is currently being developed for Atlantic Research by Computer Sciences Corporation. Since the ARCOM System is not yet operational, no documentation is available describing the packages to be made available to ARCOM System users.

Demonstrations of the ARCOM System have been made using simulations of the final program. In general, special application and operating routines will be assembled to satisfy the requirements and wishes of each user agency, including function key assignment, dispatcher display and message formats, and printer output specifications.

3.4 ANALYSIS OF EACH CURRENT MOBILE/DIGITAL SYSTEM

3.4.1 Introduction

This section presents IITRI's evaluation of each of the four mobile/digital systems investigated. Unfortunately, none of the manufacturers will release sufficient data to enable any quantitative analysis to be undertaken. Therefore, only operational attributes can really be discussed. An experimental program should be conducted to evaluate the technical operation of each system. This program would measure system error rates, actual message throughput rate, channel occupancy and other quantities which indicate the basic worth of the system design.

3.4.2 Kustom Electronics RADCOM-1 System

The Kustom Electronics RADCOM-1 System currently has one definite advantage over its rivals; it is the only system operational in law enforcement environments. None of the other manufacturers have delivered operating systems. Unfortunately, IITRI does not have enough information to state how well it works, in the technical sense.

The basic design of the RADCOM-1 System is modular, permitting the addition of software routines as the need develops and allowing mobile terminals and communication center equipment to be added without making major system changes. Again, IITRI has not been able to obtain sufficient information to evaluate the efficiency of the RADCOM-1 computer system design. The basic RADCOM-1 system is delivered with 28 K of core memory but there is no indication as to how it is allocated. If a user should require on the order of 60 mobile terminals, several CRT data terminals and many software modules, Kustom Electronics will replace the PDP-11/05 with a PDP-11/45, a larger and faster minicomputer.

The Kustom RADCOM-1 System is designed to operate on radio channels that are shared with voice traffic. IITRI has suggested in Section 2.0, and further discussion appears in Section 4, that if there is a fair amount of voice traffic on a channel, the access delay for digital messages may be greater than is desirable. If sufficient transmission errors occur to require that messages be repeated, then the channel can saturate very quickly. For any substantial number of mobile terminals, therefore, IITRI also recommends using channels that carry digital traffic only.

Kustom Electronics claims that its PSK modulation technique yields a 6 db improvement in required signal-to-noise-ratio compared to FSK techniques, for the same error rate. This is true, theoretically, for ideal channels corrupted only by white, Gaussian noise. In reality, however, the noise on VHF and UHF radio channels is not white, Gaussian noise but consists chiefly of impulse noise and fades. The theoretical advantage of PSK over FSK therefore may not carry over into practice. One cannot say which modulation technique is superior without a knowledge of the channel error statistics and a knowledge of the modulation technique used. Neither is available, to date. The analysis is complicated by the fact that the modulation technique is really either PM-FM or FM-FM. Such dual modulation techniques must be analyzed to determine the exact manner in which noise enters the system.

The MCT-10 mobile terminal contains all the equipment required to support digital communications in the mobile unit. There are no units in the trunk of the vehicle. Yet the terminal is compact and relatively lightweight, the size basically being determined by the sizes of the display and keyboard. The terminal is also well padded, to reduce the possibility of operator injury, and special attention has been given to the display in order to reduce glare. However, the terminal generates a fair amount of heat which requires that there be louvers in the case. The circuit boards are coated to protect against salt spray environments but the unit can still potentially be damaged if certain fluids are spilled on the terminal. The terminal design is such that maintenance and repair are quite simple, and the terminal can operate over the range of temperatures which are likely to be encountered in police vehicles.

The amount of display provided by Kustom is an advantage if the user department requires report generation from the field, transmission of fairly lengthy messages, or uses the terminal for mobile command and control functions. Otherwise, it is IITRI's opinion that more display area is provided than will normally be used.

Kustom Electronics has also simplified terminal installation and replacement by using a special cable to connect the terminal to the mobile radio. This cable contains active devices so that the cable can be adjusted to allow proper operation of the terminal. Since the terminals are all essentially identical, this cable compensates for each particular mobile radio and allows terminals to be moved from car to car without having to make any adjustments to the mobile radio. The cable stays with the mobile radio it has been adjusted for, and only the terminals are moved. It is not clear whether Kustom requires internal access to the mobile radio. If this were required, the connection would be to the discriminator output. Normally, only the squelch output is available at the control head, and the signal level is a function of the setting of the squelch control. Therefore, most manufacturers like to connect to the discriminater output, because the signal level is not influenced by the setting of the squelch control.

From a human engineering standpoint, except for points noted above, IITRI would rate the design of the Kustom Electronics MCT-10 mobile terminal as good. The overall system design is also good.

3.4.3 IBM 2976 Mobile Terminal System

The IBM 2976 Mobile Terminal System is well designed from a data processing and communications standpoint, but is rather poorly designed from a human engineering standpoint. The system is obviously oriented toward large police departments. This is indicated both by the requirement that the user have a System/360 or System/370 computer and by the availability of the two data-dedicated duplex channels to only the police departments in the 30 largest metropolitan areas in the country. Further, all the other manufacturers talk in terms of systems consisting of less than 100 units; IBM talks in terms of 250 to 750 units.

System definition, in terms of base station equipment and software routines, is left to the user. IBM does not include applications programming as part of its system price and CRT data terminals, line printers and other base station peripherals are also not included. Therefore, the user must either utilize his own personnel to design the communication center and write applications programs, or execute a separate contract with IBM to obtain these services. Again, the orientation is to large city police departments.

The communication system design, however, is quite good. Not only is forward error correction used but indicators are provided at the terminal to advise the operator when he is in a weak signal area and thus not likely to be able to send or receive messages. The system status and diagnostic indicators provided at the terminal are thus of considerable help to the operator. IITRI should point out that the forward error correction code is only useful if the errors that occur are correctable by the code. Thus, IBM can correct burst errors up to five bits in length. If longer error bursts typically occur, the code is useless and the data rate has been halved to no purpose. Since no error statistics are available, IITRI cannot say whether IBM's code is useful or not, but the point should be kept in mind when and if error statistics are determined.

IITRI also has some reservations concerning the use of a time sharing computer to control the network of mobile terminals. If another user of the computer causes the system to fail, then the mobile terminals fail also. This is largely a matter of operating system design and insuring that the computer is "up" most of the time.

It is in the design of the mobile terminal where IITRI feels that IBM has not taken full advantage of the capabilities of the 2976 System. One can argue the merits or demerits of providing only hard copy output; the final decision rests with the user. However, the terminal is too large and heavy, and it cannot operate over the temperature range likely to be encountered in police environments. The mobile terminal itself is mounted on an electronics unit which is attached to the front seat of the vehicle by the vehicle seat belts. This electronics package is, in IITRI's opinion, too large and takes up too much valuable front seat room in the patrol vehicle. Logically, it belongs in the trunk of the vehicle. Ambient temperatures inside a police vehicle can easily exceed 110°F or be below 32°F, when the officer is out of his vehicle and the engine is turned off. Under these conditions the IBM unit is not operable and no messages can be received. When the officer returns to his vehicle, he must wait until the ambient temperature is between 32° and 110°F before he can send or receive messages using the terminal.

Finally, the terminal has no padding or means to protect the front seat occupants from injury in the event of an accident. Also, under certain conditions the combination of the contrast of the printed output and glare off the plexiglass covering over the paper renders messages hard to read.

3.4.4 Motorola MODAT Alphanumeric Terminal System

Motorola's alphanumeric terminal has not, as yet, been delivered to a law enforcement agency and many system details have not been released. However, the system, as described, appears to be well planned and a level of software support is available which will enable users to choose among functions as simple as inquiry/response and as sophisticated as computer-assisted dispatching. Motorola's library of software routines seems extensive and the system design is modular, enabling a separate Data Management System to be implemented, if the user so desires.

The alphanumeric terminal itself is well designed, being compact, lightweight and completely sealed. Terminal-associated electronics are located in the trunk of the vehicle. The terminal display consists of 32 characters, which may not be adequate for longer messages or for mobile unit report generation. The terminal display might, in fact, limit the capability of the more sophisticated systems, although this will depend to a large extent upon the software implementation.

The system is designed to share voice channels and can also operate with current satellite receiver voting systems. Beyond this, not much more is known about the details of the modulation and coding techniques which will be used. It would appear (if a 64 character message requires 1.5 seconds for transmission) that the effective data rate is fairly low. This may not be desirable in systems consisting of many terminals.

3.4.5 Atlantic Research Corp. ARCOM Mobile Communication System

The design philosophy used in the development of the ARCOM system stresses economy and simplicity. The mobile terminal itself is the smallest and lightest one currently available. ARCOM software support appears adequate to provide such basic functions as inquiry response and status, but does not appear oriented toward transmission of dispatch messages or mobile report entry.

The mobile terminal was designed to be easily interfaced to any existing mobile radio. The terminal-associated electronics are mounted in the trunk. The terminal is not padded but is small enough so that impact protection is probably not required. ARCOM does not appear to have standardized a mount for the MCT-16 terminal. The terminal uses a non-standard keyboard. The advantages or disadvantages of this design cannot be determined without user reaction.

In IITRI's opinion, the weak points of the ARCOM system design lie in the use of a 16 character display and in a very low effective data rate (300 baud). The use of a 16 character display means that only very short messages can be displayed in their entirety, an operational disadvantage. Composition and editing of long messages would be tedious. The low effective data rate means that the FCC two-second rule is violated if a full 80 character message is transmitted. It also tends to increase access delays on channels shared with voice communications and to limit the maximum number of terminals which can be used on a dedicated channel. The ARCOM system appears to be designed for a maximum of 30 terminals on a single channel. This is also about the maximum number of terminals for which status information can be displayed at the base station CRT terminal, in the existing system configuration.

In short, the ARCOM system appears to be intended for smaller departments who are mainly interested in the inquiry/response and status maintenance functions.

4.0 APPLICATION OF MOBILE/DIGITAL COMMUNICATION SYSTEMS TO THE STATE OF FLORIDA

Mobile/digital communication system design in the State of Florida is constrained by the structure of state criminal justice data processing (FCIC) on the one hand, and communication system design on the other. In both cases, the county is the governmental unit viewed as fundamental to the system design. Since there is a wide variation in the population of Florida counties, county size becomes a third parameter which merits discussion.

4.1 Structure of the Florida Criminal Justice Information System

In Florida, there are criminal justice information systems at the state, county and local levels. The county is the interface between the state and local level and, in fact, consolidation of local criminal justice systems at the county level is being encouraged. For this discussion, the nature of the data in the system is not as important as the means used to process and disseminate it. Accordingly, the structure of the processing and communication system at the state level is shown in Figure 13. Within the FCIC system, the Data Communications Processor (DCP) provides switching for all incoming and outgoing messages to and from the central computer system (CCS). The DCP interfaces the CCS to other systems (and terminals) at the federal, state and local levels.

At the federal level, FCIC interfaces to NCIC and NLETS (National Law Enforcement Telecommunications System). The link to NCIC is a single high speed line, the noteworthy fact about which is that it operates on a "one-in, one-out" basis. That is, FCIC can send only one message at a time up to NCIC, and that message must be completely processed before another message will be accepted. Even if the response time per message is short, multiple messages must be queued at FCIC, and the overall response time for FCIC inquiries which are also passed on to

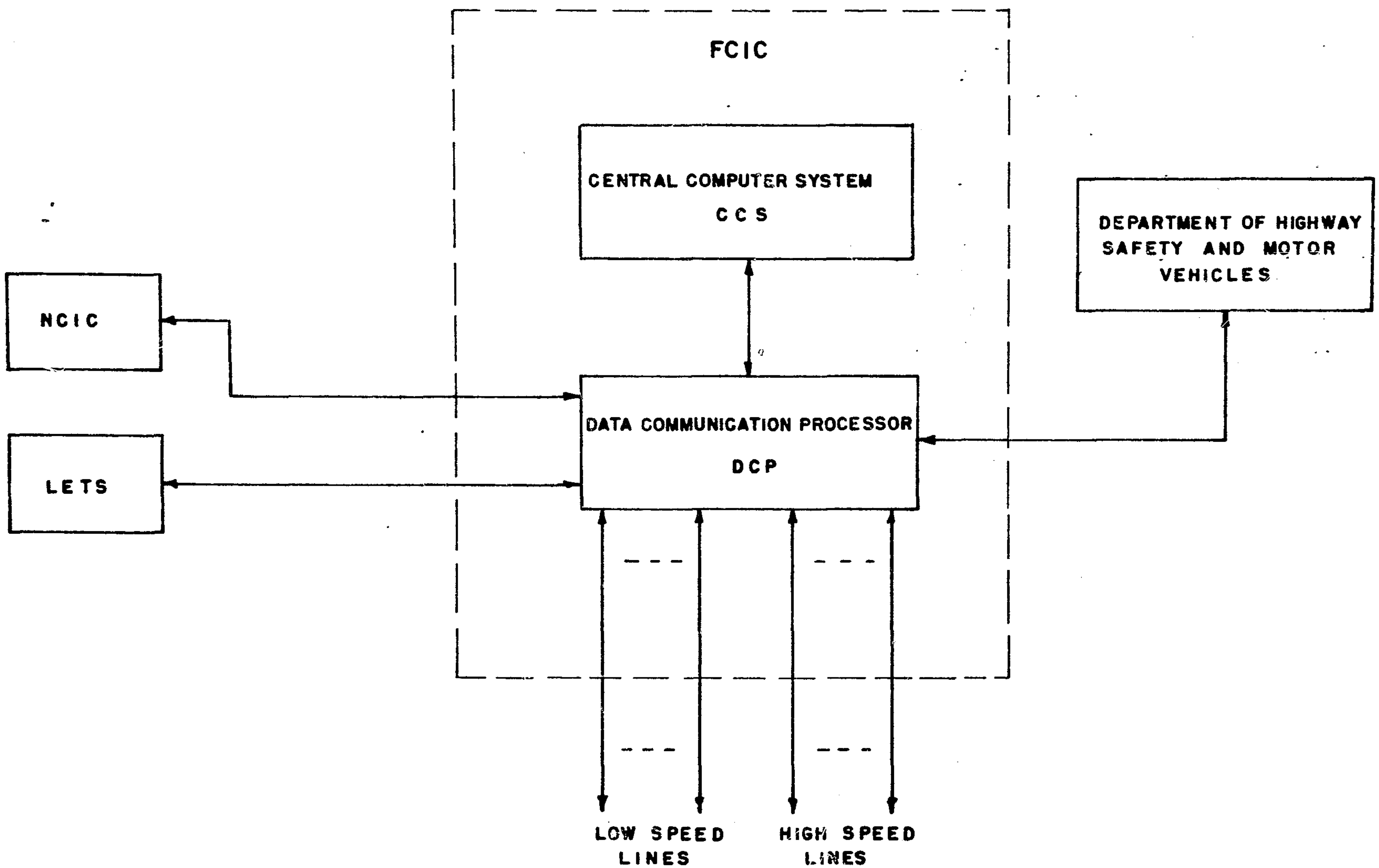


Fig. 13 STRUCTURE OF THE FCIC SYSTEM

NCIC will increase. The link from FCIC to NLETS is a low speed teletype line. Response times on the NLETS system are sufficiently long that the system is not worthy of consideration in this discussion.

Within the state, FCIC is connected, at the state level, to the Department of Highway Safety and Motor Vehicles. At the local level, connection to FCIC can be by means of terminals, or computer-to-computer connections. Terminals are connected, presently, by means of low speed lines (150, 600 and 1200 baud). Computer to computer lines are dedicated, 2400 baud high speed lines. The low speed lines are multidrop lines, operated asynchronously, using polling of field terminals. This requires buffering at the field terminals. The high speed lines are operated synchronously (on a message basis) in a half-duplex mode. Users within the state are not limited to a "one-in, one-out" mode of operation in accessing FCIC; input and output queues are formed in the FCIC processor.

Presently, the bulk of the users of FCIC have IBM 2740-2 terminals connected to the DCP by means of 600 baud lines. There are 297 of these low speed terminals in operation. Only two high speed lines are utilized, one to Dade County and one to Palm Beach County (for its mobile/digital communication system). For mobile/digital communication systems, only these high speed lines are of interest.

The interface requirements at the terminals of one of these high speed, 2400 baud, duplex lines are well defined by the Florida Department of Law Enforcement. Messages are transmitted asynchronously, using three sync characters at the start of each message. Transmission is accomplished serially, by character and by bit, with the least significant bit transmitted first. The character code is the ASCII 8 bit code, consisting of 7 data bits and one odd parity bit per character. Message formats, error control and addressing are all well defined.

Each terminal has two identifiers, a two (ASCII) digit terminal number and a five character mnemonic.

Criminal justice data systems, at the county level or below, therefore have a fixed message structure and format requirement in order to interface to FCIC. The only other interface requirements at this level involve security and privacy. The objective of the system in Florida is for any terminal to be able to address any other terminal in the system. Each terminal (or local system) therefore must determine which other users are to be allowed access to local data, and which data each user is entitled to know. Such questions become even more important when mobile data terminals are admitted to the system.

With the state/county interface being well defined, the structure of the system within a county needs to be examined. Within a county, there are five classes of agency that require access to criminal justice information: law enforcement, courts, corrections, prosecution, public defender and probation/parole. Each agency, in general, requires different types of information, at different rates. As defined in the "Master Plan for Criminal Justice Information Systems for the State of Florida," the most stringent time requirements are for data retrieval in one to three minutes. These times are probably not realistic for police mobile units in certain situations. Information may be required in this case within 10 seconds. Certainly, the response time of the FCIC system is compatible with a 10 second retrieval time.

At present, in all but two of Florida's counties, the criminal justice agencies within a county have separate terminals, connected to FCIC by low speed, multidrop lines. The goal of state planning is to replace this system by a network of high speed lines, one to each county. A message switcher would then be located within each county to connect the local terminals to this high speed line. In any reasonably populous county (population greater than 200,000) there will be more than one sizable law enforcement agency, each of which will require a terminal, and all the other criminal justice agencies will be represented. The number of terminals, the possible variety of terminal types, and the amount of message traffic, will require that the message switcher be a separate mini-computer, with capability to buffer lines of varying data rate (150 to 2400 baud). A diagram of such a system is shown in Figure 14.

However, only 10 of the 67 counties in Florida have populations greater than 200,000. Thirteen counties have populations of less than 10,000 persons. Therefore, it is unlikely that 67 high speed lines, one per county, would be required. If an average message length of 500 characters is assumed, with four second spaces between messages, 432,000 messages per month can be handled over a 2400 baud line. Monthly volume on the Dade County high speed line is currently less than 200,000 messages per month. Terminal message volumes are all less than 30,000 messages per month. Therefore, the possibility of forming networks of counties, similar to the proposed radio networks, should be investigated. Such a network would be formed by a group of small counties, the number determined from the message traffic generated by each county. These counties would then jointly purchase a minicomputer which would be the connection point for a 2400 baud line to FCIC. Lines would then run from the minicomputer (message switcher) to terminals in each of the counties. These lines could be 2400 baud lines, or lower speed lines, depending upon the requirements of criminal justice agencies in the counties. Such a structure would be more economical than one with 67 high speed lines, and offer comparable capability.

Therefore, the structure of the criminal justice information system envisioned in the "Florida Master Plan" implies a network of high speed lines connected to message switching

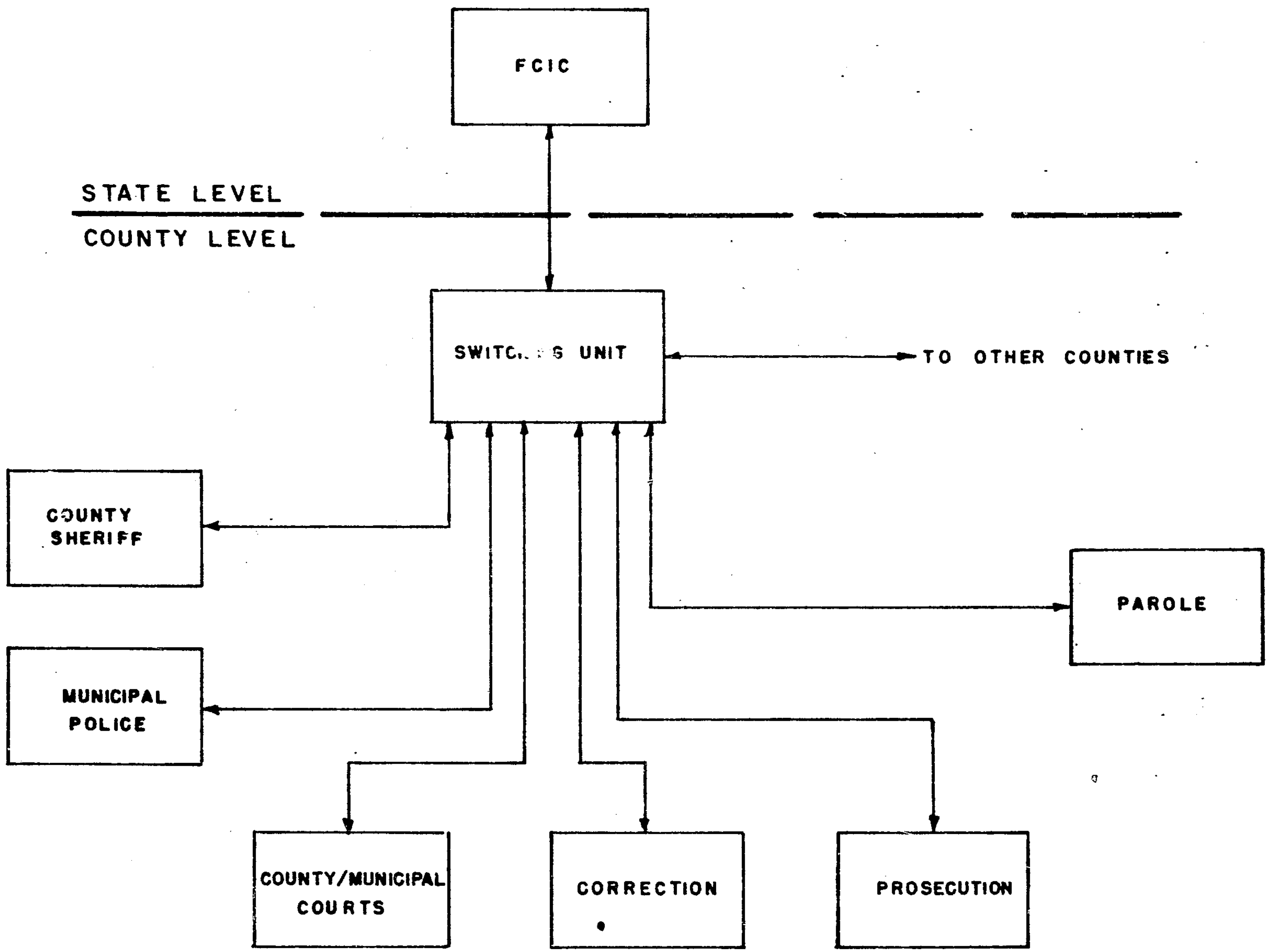


Fig. 14 INTRA-COUNTY CRIMINAL JUSTICE INFORMATION SYSTEM STRUCTURE

devices in each county or group of counties. Each message switching device is connected to terminals or systems at the criminal justice agencies within that county or counties. These terminals or systems may consist of various types of low speed terminals or other computers, such as those required in mobile/digital communication systems. Since different types of terminals and systems are likely to be encountered, especially in the more populous counties, the message switching device should only do switching, buffering, and format conversions. No editing or other processing should be performed at this level.

4.2 Communication System Factors

There are more than 380 county and local law enforcement agencies in the State of Florida. To support the radio communication requirements of these agencies, 97 channels are provided in the VHF and UHF regions of the spectrum by the FCC, not all of which may be used in Florida. Two UHF channels are set aside for non-voice traffic, but these may only be used by the Miami Police Department. Therefore, there are theoretically 95 channels available to 380 departments, which must support both the existing and future voice traffic, as well as digital traffic generated as the result of the introduction of the mobile/digital communication systems discussed in this report.

The "Preliminary Plan for County and Municipal Law Enforcement Communications in the State of Florida" prepared by Atlantic Research Corp. recommended the use of two frequency channels in the VHF high band as well as in the UHF band, with the exception of the simplex point-to-point channel on 155.370 MHz. This reduces the theoretical number of available channels from 95 to 66, and the Atlantic Research report states that only 53 channels are available for use in Florida. Even though these channels may be re-used, with geographical separation, the point is that all channels will be in use somewhere in the state and that there are likely to be few, if any, additional channels in an area which could be used. This means that the channels required for mobile/digital communication systems must expect to either share the channel with voice traffic from the same department or suffer co-channel interference from other voice traffic, or both. Furthermore, it is likely that co-channel digital interference will occur.

The UHF channels are really usable only by agencies operating in a relatively small area. Typical county areas are such that VHF systems are required. Therefore, if county sheriffs install mobile/digital systems, they will be using VHF channels. Only relatively large cities will be able to use UHF channels for mobile/digital systems.

Therefore, mobile/digital communication systems installed in the State of Florida, at the county and municipal level, will be required to operate on two frequency channels, and will require channel sensing devices, since co-channel interference can be expected. This will be especially true as the number of systems in operation increases. The city of Miami can utilize the two UHF channels that the FCC has allocated for non-voice traffic. County sheriff's systems will operate in the VHF high band and metropolitan police department systems will operate on UHF and VHF high band channels.

4.3 Influence of County Population on Mobile/Digital Communication System Design

IITRI is required, in this project, to consider counties with populations of approximately 250,000 persons or more. Of the 67 counties in Florida, only 10 have populations greater than 200,000 persons. Of these 10 counties, 5 have populations less than 350,000 persons, 4 have populations between 400,000 and 650,000 persons, and only one county has a population that exceeds 1,000,000 persons. For these ten counties, a list of the current and projected future numbers of mobile units belonging to law enforcement agencies is given in Table 2.

Table 2:

Mobile and Portable Units in Florida Counties
With Populations Exceeding 200,000 Persons

County	1970 Population	Sheriff Mobile Units 1972	Sheriff Mobile Units 1982	Sheriff Portable Units 1972	Sheriff Portable Units 1982	All Other Police Mobile Units 1972	All Other Police Mobile Units 1982	All Other Police Portable Units 1972	All Other Police Portable Units 1982
Escambia	205,334	64	74	3	4	54	63	20	24
Polk	227,222	68	86	20	25	87	112	51	66
Brevard	230,006	48	52	8	29	99	107	34	37
Orange	344,311	105	160	21	32	34	54	178	272
Palm Beach	348,753								
Hillsborough	490,265	225	259	32	37	346	398	105	106
Pinellas	522,329	118	142	14	17	180	216	189	225
Duval	528,865	707	811	145	166	28	32	37	41
Broward	620,100								
Dade	1,267,792								

These data are taken from the Atlantic Research Corp. report mentioned earlier. Considering that some departments provide field officers with both mobile and portable radios, an estimate of the number of field units expected to be available in 1982 is given in Table 3 , for the seven counties for which data are available.

In all of these counties, the total number of police field units exceeds 150. In Duval County, almost 900 units will be available by 1982. If every unit were given a mobile/digital data terminal, the systems required would be quite large in all cases. The procurement philosophy for mobile/digital terminals is therefore very important.

Currently operational mobile/digital systems utilize only small numbers of units. The system in Palm Beach County comprises 30 units, one for each of the Sheriff's Department patrol cars. All the units listed in Table 3 are not patrol units, in fact, typically only about one third of the units are patrol units. Therefore, one might expect these counties to require 50 to 300 mobile/digital terminals each. However, there may be a requirement to equip non-patrol cars (detective cars, for example) with mobile/digital terminals as well, so whatever system is installed should be capable of growth by at least a factor of two.

Based on the data presented, IITRI suggests that the following size mobile/digital systems should be considered for the State of Florida:

County Population	Number of Mobile/Digital Terminals
250,000	50-100
500,000	200-300
1,000,000	750-1000

Each system should be expandable by a factor of two, as department resources and requirements emerge.

Table 3
Police Field Units in Seven Florida Counties
With Populations Exceeding 200,000 Persons

County	1970 Population	1982 Field Units	
		Sheriff	All Other Police
Escambia	205,334	74	80
Polk	227,222	86	112
Brevard	230,006	52	107
Orange	334,311	160	277
Hillsborough	490,265	259	398
Pinellas	522,329	142	305
Duval	528,865	811	37

4.4 System Requirements

The preceding three sections have discussed the constraints imposed upon mobile/digital communication system design by the particular conditions existing in the State of Florida. Three different size systems were defined, based on three sizes of county, requiring systems with approximately 75, 250 and 900 units, respectively. The interface between these mobile/digital systems and FCIC has been defined, and the intra-county structure has been defined.

The number of radio channels required in the three different size systems can be estimated, based on the following analysis. The result of the mobile/digital system evaluation conducted by the New York State Police yielded the following results: 0.05 messages per minute per terminal, 3.55 transmissions/message, and 0.89 seconds per transmission. A message is a complete one way message, inbound or outbound. If these average numbers are applied to the three sizes of system applicable to Florida, the message rates obtained are:

Number of Terminals	Message Rate
75	3.75/min.
250	12.5/min.
900	45/min.

The number of transmissions/message measured in New York showed that that system had a high uncorrectable error rate. Retaining this rate, in order to derive conservative estimates, and applying a single server queueing model, the expected waiting times on a single duplex channel, assuming a contention system and a channel used only for digital traffic, are

Number of Terminals	Average Access Time	Channel Occupancy
75	0.778 sec	0.2 min/min
250	6.06 sec	0.66 min/min
900	channel saturated	2.38 min/min

If it is assumed that the response time for an inquiry should be 10 seconds on the average, then the access time to the channel should be no more than 0.84 seconds, for a retransmission rate of 3.5 and a data base response time of 2 seconds. This means that one duplex channel can support only 4 messages per minute. Thus, although a single channel is sufficient for a 75 unit system, 3 channels are required for a 250 unit system, and 11 channels are required for a 900 unit system. This assumes that access to the channel is on a contention basis.

The preceding results were derived assuming that, on the average, a message had to be transmitted 3.5 times before it was successfully received. If the system were error-free, requiring only one transmission per message, and the transmission length remained at an average of 0.89 seconds, then a single channel could support 52.5 messages per minute and a terminal would still obtain responses to inquiries within 10 seconds. An errorless system would then allow 1050 terminals to share a single channel.

It is difficult to draw any firm conclusions based upon such limited data. For example, IITRI has seen some data from Palm Beach County which indicates that the message generation rate per terminal could be 0.2 to 0.4 messages per minute. For such a message generation rate, 75 terminals would generate at least 15 messages per minute and 250 terminals would generate at least 50 messages per minute. The Palm Beach County data covered only inquiries to local and remote data bases.

Until more, and better, data are available it is impossible to state, categorically, how many terminals a single radio channel can support. IITRI would like to state the following guide lines, however:

1) All experience to date has shown that technological advances have resulted in increased message generation rates. This has been demonstrated in tests of both personal portable

transceivers and mobile/digital data terminals.

2) The preceding example indicated that errors that cause retransmissions markedly reduce the number of terminals which a single channel can support. It is therefore imperative that the design of a mobile/digital system result in an operational error rate which keeps the number of transmissions per message close to unity. For a response time of 10 seconds, a message generation rate of 0.2 per minute per terminal, and a transmission length of 0.89 seconds, one channel can support (theoretically) 262 terminals if there is one transmission per message, 93 terminals if there are two transmissions per message and 37 terminals if there are three transmissions per message. Since radio channels are scarce, the system design should reduce retransmissions to a very low level.

3) There are insufficient data to compare contention and polling techniques for channel control. This assumes that contention systems are designed to eliminate interference between messages. If messages are allowed to interfere with each other, then polling would be a more efficient channel control technique.

5.0 MOBILE/DIGITAL SYSTEM SPECIFICATIONS

5.1 Introduction

Development of a set of "general" specifications for mobile/ digital systems for three sizes of county in Florida is very difficult, especially at the system level. IITRI's philosophy as regards specifications is to prepare performance specifications which do not unduly constrain the bidder while allowing the purchaser to obtain proof that the delivered system meets his requirements. A more rigorous specification, one that defines the system and equipment in detail, places the burden of proof upon the organization that prepares the specification. If the system, when installed, does not meet the requirements, then the vendor is not at fault. A performance specification places the responsibility on the vendor, providing the purchaser with an effective means for obtaining the required performance without escalations in system cost.

IITRI, following this philosophy, has prepared a performance specification for the mobile/digital terminal, which is common to all county sizes. Although some parameters, such as size of display, might vary from system to system, the specification allows for this and the purchaser has only to specify the functions that he wishes to perform and this will place sufficient restriction on the bidders.

In the case of the base station equipment, and the overall system design, the situation is highly ambiguous. IITRI is in no position to tell any county how to structure its criminal justice data processing or to specify the functions which should be performed with a mobile/digital system. These functions have been clearly discussed in Section 2.0 of this report and it is up to the agencies themselves to determine which they require.

Some general guidelines can be stated, however, and the discussion will proceed in this direction.

The three sizes of county specified, (250,000, 500,000 and 1,000,000 populations) are not sensitive to the overall system design. All these counties are large enough to use a complete system that performs all the available functions, if they so desire. All are large enough to have their own data processing systems, as in Palm Beach County, which has a PALMS system that provides, on a county wide basis, what FCIC provides on a state-wide basis. Therefore, the following comments will be made:

1) Each county will have one 2400 baud high speed line to FCIC. The interface requirements at this line are well defined in FCIC documentation.

2) Each county will have a sufficient criminal justice agency structure to require that the message switching function be separate from other functions, including mobile/digital system control. Therefore, either a minicomputer should be devoted to this function or an existing large timesharing computer should be modified to handle it.

3) Each criminal justice agency in the county with its own computer should be connected to this message switcher with a single 2400 baud line. A higher speed line is clearly not appropriate, nor is a lower speed line. This will tend to standardize criminal justice computer-to-computer links at 2400 baud. Character codes and message structures should be standardized also, to those used by FCIC.

4) Inter-county high speed (2400 baud) lines should terminate at the message switcher. Low speed intra-county lines, from low speed terminals at criminal justice agencies, should terminate at the message switcher. Multi-drop lines could be

used for such terminals. The result is that there is one, and only one, message switcher in the county.

5) The message switcher will be responsible for all criminal justice message traffic passing between terminals or systems in the county and between these terminals and all points outside the county. The message switcher must accomplish addressing, routing and need-to-know. The latter is important. This is the logical place in the system to determine whether a terminal has access to other terminals or certain classes of information.

6) Each criminal justice agency within the county will have its own terminal or computer system. If the county has no large cities (greater than 50,000 population) the county sheriff can provide criminal justice information to all police departments via a mobile/digital system with remote dispatch terminals. Large cities could have their own mobile/digital systems, separate from the Sheriff, increasing the number of computer-to-computer links in the county. All counties in Florida with populations greater than 250,000 have city police departments large enough to justify their own mobile/digital systems. However, in the interests of spectrum conversation and efficiency IITRI recommends the following:

a) Digital data traffic should be separated from voice traffic if the number of terminals in the system is 75 or more. It was shown in Section 2.3.4.5 that a moderately loaded voice channel could support about ten digital messages per minute with a ten second response time. This assumed no retransmissions due to error. It was shown in Section 4.4 that a 75 terminal system might generate anywhere between 4 and 15 or more messages per minute. Therefore, system sizes in the neighborhood of 75 terminals appear to justify a channel dedicated to digital data, especially if functions are added to the inquiry/response function.

b) It would appear that one dedicated digital data channel is adequate to serve 250 to 500 mobile data terminals. This is a crude guideline, however, suggested by the examples in Section 4.4.

c) Networks can be operated in either polling or contention modes. The choice depends on the details of the system, the number of terminals to be served and traffic statistics, none of which are available at this time. If polling techniques are used, mobile/digital systems should be centralized at the county level.

7) In designing a mobile/digital system with a large number of terminals, it has been shown in a preceding section that the cost of the base station equipment soon becomes a minor portion of the cost of the entire system. System cost, given the current state-of-the art, is determined, in other words, by the cost of the mobile terminals. This fact argues strongly for obtaining as much performance from such systems as is possible, given the desires of the agency implementing the system. Such a procedure minimizes the cost/benefit ratio. Therefore IITRI recommends imple-

mentation of as many functions as an agency feels that it can accomodate without seriously disrupting its organization.

The above comments serve to define the broad structure of mobile/digital systems which IITRI feels is appropriate to large counties in Florida. Three general types of system are compatible with this structure. One is centralization of all communications at the county level. Another possible implementation would be for each law enforcement agency to have its own mobile/digital system, but all would share a common channel. Voice communications would be de-centralized. The third implementation would centralize mobile/digital systems at the county level but continue with decentralized voice communications. Each agency would then have a CRT terminal(s) connected by telephone lines to the county computer.

The nature of the computer system used to support mobile/digital terminals is also variable. Either a large, time-shared computer or a minicomputer system could be used. The choice would be determined by the expected message traffic on the mobile/digital system and the existing data processing load in the county.

5.2 Mobile/Digital System Specifications

5.2.1 System Specifications

5.2.1.1 Computer System Structure

The structure of the computing system associated with mobile/digital systems in a county has been defined in Sections 5.1 and 4.0. Briefly, message switching, queueing and "need-to-know" are to be performed by one minicomputer, which serves all the criminal justice agencies in a county. This minicomputer is to be connected to FCIC by a single 2400 baud dedicated telephone line. The interface requirements defined by FCIC shall be met.

Within the county, computer-to-computer links are to be 2400 baud lines; terminal to message switcher links are to be appropriate to each terminal.

The structure of the mobile/digital systm or systems in the county is defined by the functional description accompanying this specification (to be furnished on a county by county basis) but there shall be at least one computer which serves the mobile/digital terminals and provides the communication center functions required by the user. This computer may be either a minicomputer or a time-sharing large computer, as appropriate.

The bidder shall supply all operating and applications software packages that are required to enable the mobile/digital terminals to perform the data base inquiry/response function and that provide all the other reporting, status and dispatching functions required by the user. The bidder is required to deliver an operating system which meets the purchaser's requirements, including any extra programming and debugging required to adapt the bidder's software routines to the specific application.

5.2.1.2 Communication System Requirements

The bidder is required to deliver an operating system that meets the purchaser's functional requirements. This responsibility includes the communication link between individual mobile data terminals and the computer at the base station. Therefore, the bidder shall supply any required radio equipment or modify the existing radio equipment, to insure that digital data traffic can be handled with a bit error rate (over the actual channel, from end to end) that is less than 1 in 10^5. The bidder is responsible for providing system signal-to-noise ratios adequate to support this error rate and for providing any necessary channel sensing devices required to combat co-channel interference. The bidder shall clearly state, in his proposal, any changes he intends to make to the radio system in order to provide the specified performance.

5.2.1.3 Equipment to be Supplied

The equipment to be supplied by the bidder in connection with this specification shall include at least the following:

- 1 minicomputer system to perform intra- and inter-county message switching
- ___ mobile/digital data terminals
- ___ base station minicomputer systems (as appropriate)
- ___ CRT data terminals
- ___ Line printers
- ___ mobile radios (as appropriate)
- all necessary operations and applications programming and support

and all modems, interconnecting cables and telephone lines, teletypewriters, data storage units and radio equipment required to provide the specified functional capability.

5.2.2 Mobile/Digital Terminal Specifications

5.2.2.1 General Description

The mobile/digital terminal shall enable an authorized operator to transmit and receive messages in the following categories: data base inquiries, status, dispatch information, report information and data, and messages of a general nature. Such messages shall be able to be transmitted to or received from other mobile terminals and the communication center.

The mobile terminal shall contain a keyboard for message entry, a display for message reception and message composition, indicators to describe system status as well as mobile terminal status, and all necessary modulators and demodulators to enable the unit to interface with a mobile radio. The mobile/digital terminal and its associated equipment shall be designed to interface to the battery power supply of the vehicle, to a standard mobile radio, and its design shall allow its efficient use by a police officer.

5.2.2.2 Physical Design

The mobile/digital terminal shall be designed so that the keyboard, display and indicators are part of a single unit, mounted in the front seat area of the patrol vehicle. The size of this unit shall be sufficient to house the components mentioned but it is required that the size, weight and power dissipation be minimized. Therefore, modulator/demodulator equipment and other electronics not associated with the keyboard, display and indicators should be separately housed and located in the trunk. The front seat unit should be designed to minimize the interference which it causes to other systems in the vehicle, as well as minimizing interference with the operation of the vehicle itself.

The mobile/digital terminal should be easily accessible to the driver and a front seat passenger, and the display shall be easily read under normal ambient lighting conditions. This requires that glare be minimized in daylight and that illumination be provided at night. The keyboard shall be illuminated at night, also.

The terminal shall be so designed and mounted as to minimize the impact hazard to the driver and front seat passenger in the patrol vehicle.

5.2.2.3 Environmental Requirements

The unit shall be operable over an ambient temperature range of -20°F to +150°F.

The unit shall be completely sealed to provide immunity to water, dust and hazardous chemicals.

The unit shall meet the humidity, vibration stability and shock stability standards developed by the EIA for land-mobile communication receivers (EIA RS-204).

5.2.2.4 Electrical Requirements

The unit shall operate with a nominal input voltage of 12 volts d.c., but be operable over an input voltage range of +10 to +15 volts d.c. without measurable degradation in performance.

The current consumption of the unit shall not exceed 5 amperes.

The unit shall interface to a standard mobile radio. No internal modifications to this radio shall be required.

5.2.2.5 Construction

The mobile terminal shall be a completely solid state unit, using devices that are resistant to electrical noise interference. The construction of the unit shall be modular, using plug-in, replaceable circuit borads, so that troubleshooting and service can be provided by any competent land-mobile communications service agency.

5.2.2.6 Service

The vendor shall provide spare parts service for his equipment for a period of ten (10) years from the date of system acceptance. Spare circuit boards shall be available within 24 hours after placement of an emergency order.

5.2.2.7 Mobile/Digital Terminal Requirements

5.2.2.7.1 Keyboard

The keyboard shall be completely sealed against dirt and moisture and shall provide full alphanumeric (numbers 0 to 9 and letters A to Z) capability plus any additional symbols and keys required by the vendor to enable his system to provide the necessary capability and performance. The keyboard shall consist of alphanumeric keys, status keys and function keys. The number of status and function keys shall be consistent with the defined requirements of the purchaser. The grouping of the alphanumeric, status and function keys shall enable the terminal

CONTINUED

3 OF 4

operator to clearly distinguish between them. If an emergency key is provided, it should be designed to guard against inadvertant operation. The keyboard shall be illuminated for operation at night or in the dark.

To the maximum extent possible, operation of the keyboard shall be a one key operation. Therefore, messages with clearly defined (or fixed) formats should be simplified by using function keys, and status keys should not require the use of a transmit key. Reports or similar long messages should be entered in accordance with a format defined by the vendor in his software and displayed at the terminal.

5.2.2.7.2 Display

The display should provide adequate contrast for any ambient lighting conditions likely to be encountered and should be designed to minimize the effects of glare. The display shall be alphanumeric, with enough characters to enable frequently used message formats to be completely displayed. Thus, data base inquiries, such as license, VIN and persons checks, shall be able to be completely displayed. Only information shall be displayed, no control characters or other internal message components are to be visible. It is left to the vendor to define trade-offs between display size and software complexity subject to the above constraint.

5.2.2.7.3 Indicators

Indicators shall be provided to enable the operator to determine the status of the system (whether his terminal is operable, whether the base station system is operable), the status of messages either being sent or received by his terminal, and his unit status, as last reported to the base station. These indicators should be clearly visible under all normal ambient lighting conditions.

5.2.2.7.4 Memory

The terminal shall be double buffered, or shall have separate transmit and receive (or read and write) memories. Each of these buffers, or local memories, shall have the capability to store at least 80 characters. If a large amount of display is provided (greater than 100 characters) the vendor need only provide a memory capable of storing the number of characters in the display.

5.2.2.7.5 Modulator/Demodulator

The modulator/demodulator is the device which encodes a terminal-to-base station message onto an audio carrier or decodes a base station (or other terminal)-to-terminal message from an audio signal to a d.c. signal. The modulator/demodulator shall output a signal which can be transmitted by any existing public safety mobile radio and shall accept as an input a properly modulated signal which is the output of any existing public-safety mobile radio. The modulator/demodulator shall be an audio signal in the 300 to 3000 Hz frequency range.

5.2.2.7.6 Other Circuitry

The terminal shall incorporate all circuitry required by the vendor to generate the necessary binary data streams, perform error control and/or correction and sense channel occupancy, if such is required.

5.2.2.8 Mobile/Digital Terminal Performance Requirements

5.2.2.8.1 Throughput Rate

The vendor's system design shall be such as to provide a throughput rate which enables one way transmission of a complete message (including repeats and acknowledgements) within 2 seconds after transmit initiation. Thus, for a terminal-to-base station message, the message, complete with control and error correction characters, repeats requested by the base station (or automatic repeats) and acknowledgement of receipt by the base station, must require less than 2 seconds. This two second time period thus might include transmissions by the base station. The transmission bit rate adopted by the vendor must be such as to allow the longest message normally transmitted in the system to be successfully transmitted within a two second period. The minimum acceptable transmission bit rate is 600 bits/sec.

5.2.2.8.2 Signal-to-Noise Ratio

The vendor is responsible for the performance of the complete system, including the two-way radio system which supports the digital traffic. The design of this system should be such as to ensure that the throughput rate defined in the previous section shall be maintained in the operable system. The vendor shall provide a combination of r.f. and audio signal-to-noise ratios and error control sufficient to guarantee the specified performance. The end-to-end bit error rate on the actual channel shall be no greater than 1 in 10^5.

5.2.2.8.3 Security

Means shall be provided to insure the security of each terminal, and the system as a whole. Each terminal shall be mounted in the car in such a manner that a key is required in order to remove the terminal from the car. The off-on switch for the terminal shall be operated by a key which is carried by the officer. A system of identification codes shall be utilized that identifies each terminal and each terminal operator and the data to which he has access. The vendor's system software shall record and maintain the ID status of each terminal and means shall be provided to flag and lock-out terminals which use unauthorized or incorrect identification numbers.

The system software shall also identify those terminals which have the capability for producing hard-copy output and require that any hard copy produced be turned in and checked off against the system records. If this is not done on a per shift basis, that terminal shall be automatically locked-out of the system.

The system software shall collect statistical data on each terminal in the system, consisting of numbers and types of messages generated and received. Such data shall be able to be printed out at intervals to be determined by the purchaser.

The number of valid identification codes usable in the system shall be at least three times the number of units purchased under this specification.

5.2.2.8.4 Squelch

If the channel used for the digital traffic generated by the mobile terminal is also used for voice transmissions, the vendor shall modify the mobile radios in the system so that the audio signals associated with digital messages are not audible at any receiver in the system.

5.2.2.8.5 Options

The bidder shall list his options for the mobile/digital terminal that he provides. Such options include printers, additional software packages, and control modules which activate other car systems upon command by the base station. Each option shall be clearly defined as to physical, environmental, electrical and performance characteristics.

APPENDIX A

Appendix A

A DETAILED DESCRIPTION OF THE KUSTOM ELECTRONICS RADCOM-1 MOBILE/DIGITAL SYSTEM

A.1 INTRODUCTION

The discussion of the available details of the RADCOM-1 system is divided into three parts, hardware, software, and design and error control philosophy. It is presumed that the system overview in section 3 has been read, so that the reader has a general idea of the purpose and functions of the system and an initial familiarity with the components which make it up.

A.2 RADCOM-1 SYSTEM COMPONENTS

A.2.1 The MCT-10 Mobile Communications Terminal

A.2.1.1 Introduction

Developed and assembled by Kustom Electronics, the MCT-10 Mobile Communication Terminal, shown in Figure A1, provides a means for messages to be transmitted and received in digital form, allows automated direct data base inquiry and response, and permits simple mobile unit status entry, update, and maintenance.

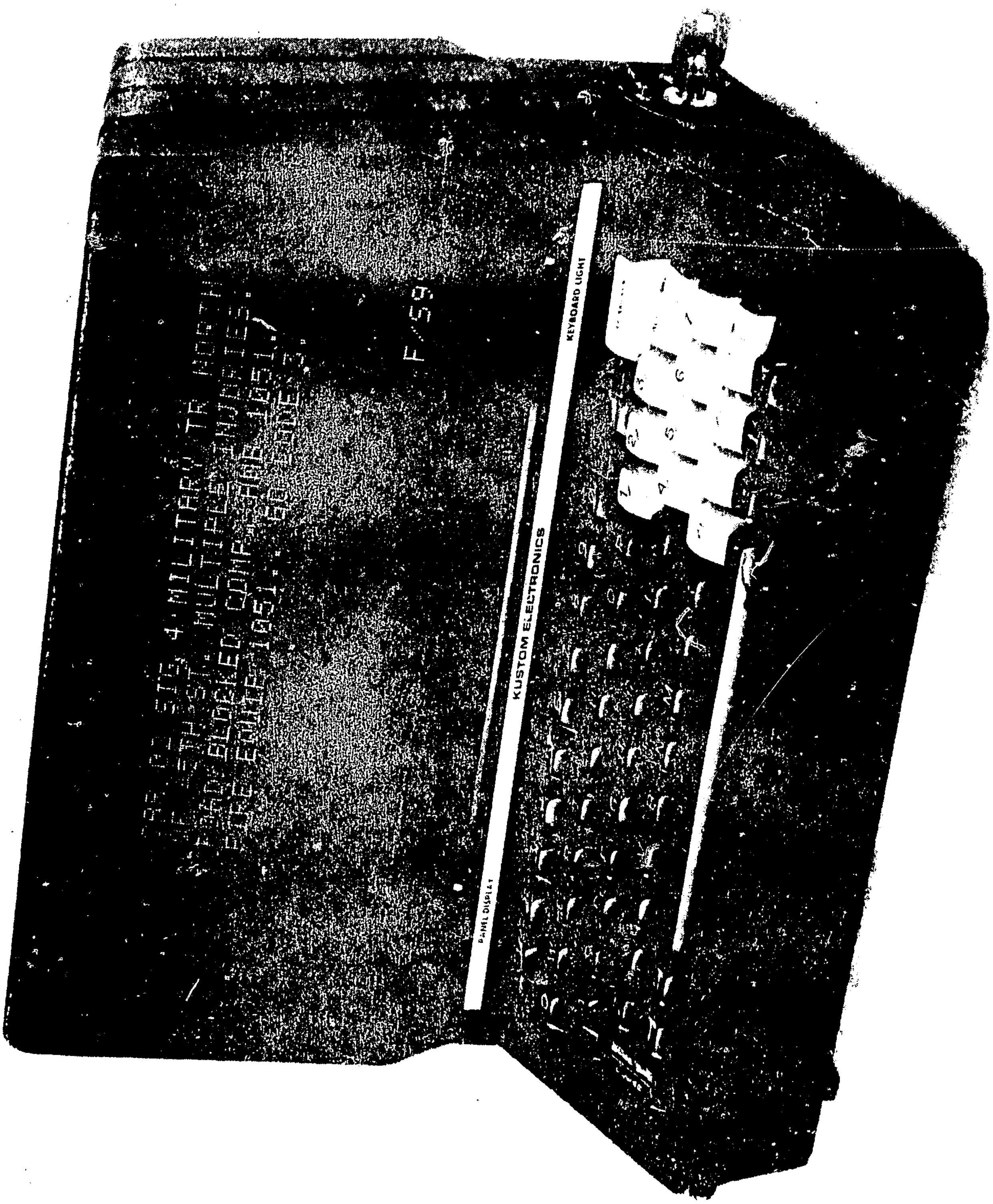
The main functional components of the mobile terminal are an alphanumeric keyboard, a solid-state alphanumeric display panel, receive and transmit message memories (called buffers), an internal power supply, and a specially designed modern (modulator/demodulator) for interfacing the terminal to the user's existing mobile radio.

A.2.1.2 Keyboard and Terminal Operation

Messages to be transmitted from the mobile unit are entered by the operator into the mobile terminal using the alphanumeric keyboard. Thirty-nine alphanumeric keys are provided (A-Z, 0-9, period, comma, slash). Messages entered into the terminal are displayed for the operator's verification; editing is done using the cursor controls (single space up, down, left, or right shifts). The next character to be printed appears in the position on the display indicated by the cursor.

After message composition and any required editing, transmission is initiated when the operator presses the TRANSMIT key.

A CLEAR/DISPLAY key allows the operator to clear any message no longer required to be displayed and to display a new message received by the mobile terminal. Received messages are not automatically displayed; the operator must request dis-



MCT 10
Mobile Communications Terminal

Fig. A-1

play of the received message by pressing the CLEAR/DISPLAY key. An exception occurs when a received message contains a remote action command from the TC-10 Terminal Controller. Then the received message can be displayed, or automatically duplicated on the Mobile Printer, or some other action, such as sounding the vehicle's horn, may occur. The message displayed on the mobile terminal will be duplicated on the mobile printer (if this option has been provided) when the operator presses the PRINT key. Received messages may be manually acknowledged by pressing the ACK key. Pressing either the TRANSMIT or the ACK key places the mobile terminal in an auto-transmit mode, and all operation of the terminal is then automatic. The auto-transmit mode permits a message to be transmitted, automatically, up to five times, if the message is not acknowledged by the TC-10 Terminal Controller within some pre-specified time, typically two seconds.

Controls are provided for varying the keyboard lighting and panel display intensity. A key-operated power switch prevents unauthorized operation of the terminal. All messages received by a mobile terminal contain information identifying single, group or all-unit calls. The unit identification number is set by inserting a hard-wired key into a slot in the rear of the terminal, and two thumb-wheels are used to set the two digit group code. Only messages containing the proper group and unit identifiers will be accepted by a mobile terminal and made available for display. Selective addressing is also possible for outbound messages from a mobile terminal. Seven FUNCTION keys, coded by the user, denote that the message which follows contains special text. To perform a name check, for example, the user presses the name check coded FUNCTION key, enters the name using a predefined format, and then presses the TRANSMIT key.

Four STATUS keys are available. When coded, simply pressing any one of the STATUS keys automatically enters that status into the mobile terminal and then pressing the TRANSMIT key initiates its transmission to the TC-10 Terminal Controller.

Pressing a double-size, two position, mechanically-locking EMERGENCY key automatically places the terminal in "emergency" status. The terminal operator may enter any additional data he desires and then, by pressing the TRANSMIT key, the emergency message is sent to the TC-10 Terminal Controller.

Upon receipt of any correctly addressed message by a mobile terminal, the message is verified by parity checks over each character. Only error-free messages are accepted and immediately acknowledged back to the TC-10 Terminal Controller. An incoming, error-free message is held in a receive message buffer until the operator requests its display. Dual buffering of input and output messages permits a message to be received and held even while another message is being entered using the keyboard.

Accepted messages are immediately and automatically acknowledged by the MCT-10 Mobile Terminal; no manual action is required. In some cases, the TC-10 Terminal Controller may issue a command to a mobile terminal requesting only internal status and control information. These interrogations are automatically acknowledged and answered by the MCT-10 Mobile terminal.

A.2.1.3 <u>Message and Status Display Panel</u>

The 256 character solid-state plasma panel display contains 8 lines, each with 32 characters. The upper seven lines provide a 224 character display for transmitted and received message texts. The eighth line presents 32 characters of status information, serving as a mobile unit status indicator. The status indicator also provides either a MESSAGE, TRANSMIT, or RETRANSMIT indication, along with the indication F/Sxx. MESSAGE indicates to the operator that a message has been received and accepted by the mobile terminal, is stored in the receive message buffer, and is available for display and/or printing. TRANSMIT indicates that the mobile terminal is in the auto-transmit mode, while RETRANSMIT indicates that the mobile terminal did not receive an acknowledgement within the five transmission limit, and it is necessary for the operator to repress the TRANSMIT key. F/Sxx indicates the present numerical function and numerical status code of the mobile terminal, which is automatically included as a part of each message transmitted. Each character in the display is 0.20" wide by 0.28" high, providing a panel viewing area 9.18" wide by 3.38" high.

A.2.1.4 Message Structure and Internal Modem

The character information code used by the MCT-10 Mobile Terminal for message transmission is the 7-bit ASCII code. Only a subset of that code is used, forming a 6-bit code with a seventh parity bit for each character. Transmitted messages may contain up to 224 characters of text, both unit and group codes, and control and status information.

Essentially a functional duplicate of the ED-10 Base Station Encoder/Decoder, the specially designed modem in the MCT-10 Mobile Terminal operates at a bit rate of either 1300 or 867 bits/second, depending on the frequency of the audio carrier, which is either 1950 or 1300 Hz. The modulation method used is synchronous audio phaseshift keying, with absolute phase referencing. Synchronization is obtained by including a pilot-tone reference sub-carrier on the audio signal.

Using a 1950 Hz audio carrier, with a bit rate of 1300 bits/second, a 224 character message requires approximately 1.5 seconds for transmission. At 867 bits/second, 2.25 seconds would be required. These times correspond, respectively, to effective data rates of 1045 bits/second or 149 characters per second, and 700 bits/second or 100 characters per second. Note that when the system operates at a rate of 867 bits/second it violates the FCC two-second rule, if a 224 character message is transmitted. A carrier sensing technique is used to test radio channel occupancy prior to transmission.

A.2.1.5 Mobile Radio and Power Supply Connections

A permanent interface cable is attached to the user's mobile radio, which provides the connections required to the audio portion of the mobile radio for data transmit and receive, as well as transmit control and carrier sense connections to the internal circuitry of the mobile radio. The interface cable is field-matched to the characteristics of the particular mobile radio, thus allowing any of the user's MCT-10 Mobile Terminals to be used in that vehicle. Connections to the automotive power supply which provides 12 volts DC and negative ground are also required; these leads are contained within the interface cable.

Physical and Environmental Specifications

Operating Voltage	10.5 to 15 VDC
Input Current Drawn	3.5 amp (Maximum)
Size	10 3/16" H x 13 1/2" W x 9 7/8" D
Weight	17 pounds
Color	black
Padding	Rubber padded enclosure
Temperature Range	-20°F to + 150° F (operational)
Humidity	0% to 85% at 150° F
Shock	18 G maximum
Interface to Vehicle power supply	Power cable to battery, 12 VDC (negative ground)
Interface to Mobile Radio	Data transmit (audio input), Data receive (audio output), Transmit control (carrier sense), Ground
Options	MP-10 Mobile Printer MM-10 Mounting Kit

A.2.2 The TC-10 Terminal Controller and DK-10 Disk Unit

A.2.2.1 Introduction

Control of the RADCOM-1 digital communications network is maintained by the principal subcomponent of the TC-10 Terminal

Controller, the central processor, a PDP-11/05 minicomputer manufactured by Digital Equipment Corp. Operating as a programmable communications processor, the PDP-11/05 provides the link between the MCT-10 Mobile Terminal network, the base station command and communications center, and local and remote data bases. The processor performs communications control, message format conversion, input/output buffering, and queueing of inquiry, response and command messages. The processor also handles status file management, logging and other administrative functions.

Programming for the central processor is provided by Kustom Electronics in its Operating Software (OS-10) and Applications Software (AS-10) packages, described elsewhere.

The central processor, through Encoder/Decoder (ED-10) and Line Interfaces (LI-10), maintains communication with both the MCT-10 Mobile Terminal network, through the user's base station radio system, and remote data bases.

Also contained in the TC-10 Terminal Controller is the Kustom supplied DK-10 Disk Cartridge System, which provides mass data storage for the central processor. The disk storage area is used to maintain the large volumes of programs and data generated within the communications network. The DK-10 System contains a disk controller and four disk drives with removable cartridges, each cartridge capable of storing 1,228,880 16-bit words (1.2 million words).

The basic modular design of the central processor permits addmitional interfaces and input/output devices to be easily added to the RADCOM-1 system, providing flexibility for functional growth and hardware expansion.

A.2.2.2 The PDP-11 Minicomputer

The basic RADCOM-1 system is equipped with a PDP-11/05 minicomputer, with a maximum of 28 K of 900 nonsecond cycle-time read/write core memory. Other versions of the PDP-11 machine are architecturally similar, and hardware and software upwards-compatible. This makes it possible for the RADCOM-1 system user to choose a central processor configuration which meets his initial requirements and to add-on or completely change the computer hardware later to satisfy changing needs or growth.

The main feature of any PDP-11 machine which makes it suited for communications applications is its UNIBUS structure. All PDP-11 minicomputer system components are connected to and communicate with each other on a single high-speed bus called the UNIBUS This structure enables all components, including the central processor, to communicate with each other in an identical manner. The central processor is thus provided with the same means for access to peripheral devices as it has for access to the core memory.

Communications on the UNIBUS are bidirectional and asynchronous, enabling all devices to send, receive or exchange data without intervention by the central processor. Since its operation is asynchronous, the UNIBUS enables the PDP-11, and hence the TC-10 Terminal Controller, to be compatible with input/output devices which operate over a wide range of speeds.

Interdevice communications on the UNIBUS are interlocked. The "master" device issues a command, and a response signal must be received from a "slave" device for completion of any data transfer. Device-to-device communication is independent of physical bus length and the response times of "master" and "slave" devices. All interfaces to the UNIBUS are time-dependent. The maximum data transfer rate on the UNIBUS is 2,500,000 words per second, or one 16-bit word every 400 nanoseconds.

Requests for input/output by devices transfering data directly to or from memory are given the highest priority by the central processor. Such devices may request bus mastership, stealing bus and memory cycles while the central processor is executing other instructions. The processor resumes control of the bus after the memory transfer. This feature enables multiple devices to simultaneously operate at maximum direct memory access (DMA) rates by "stealing" bus cycles from the central processor.

The central processor is connected to the UNIBUS as a unique subsystem, controlling priority allocation of the UNIBUS for the system's peripherals, and performing arithmetic, logical and instruction decoding operations. The processor contains high-speed, general purpose registers for temporary storage of data and instructions, and can perform data transfers between input/output devices and memory without disturbing the contents of the registers. The central processor accepts single and double-operand addressed instructions, handles both 16-bit words and 8-bit bytes, and allows nested interrupts and automatic rerentrant subroutine calling.

An instruction set containing over 400 hard-wired instructions is available to the programmer of a PDP-11 computer. This set relies on the UNIBUS structure, which allows peripheral device registers to be manipulated by the central processor as if they were core memory locations.

A multi-line priority interrupt system enables the central processor to respond automatically to conditions outside the computer system. Any number of separate input/output devices can be attached to each line. Each peripheral device connected to a PDP-11 system has a hardware pointer to its own pair of memory words. One word contains the starting location of the peripheral's service routine, and the other word contains the new processor status information. Interrupt servicing hardware thus selects and executes the appropriate device service routine, after saving the status of the interrupted program segment.

Each device's interrupt priority and service routine priority level are independent, allowing the system behavior to be adjusted to meet real-time conditions, by dynamically changing the service routine priority level.

The interrupt handling and subroutine call hardware facilitate writing re-entrant subroutines for the PDP-11. This allows a single stored copy of a subroutine or program to be shared by more than one process or task, reducing core memory requirements for applications such as concurrent servicing of many peripheral devices (as in the RADCOM-1 system).

The PDP-11's power fail/restart system protects memory contents when power fails, saving the existing program location and status, including the contents of the dynamic registers. This feature eliminates the need for reloading programs, and prevents harm to peripheral devices. When power returns, automatic restart is accomplished, allowing remote or unattended operation of a PDP-11 system.

Interfaces can be supplied for input/output devices such as alphanumeric terminals, line printers, paper tape readers and punches, teletypes, and synchronous and asynchronous communication lines.

A.2.2.3 The DK-10 Disk Unit

The DK-10 Disk Unit supplied by Kustom Electronics serves as a mass storage area for the TC-10's central processor, and consists of a disk controller with one to four disk drives having removable cartridges. Each cartridge has storage for 1,228,800 words (1.2 million words) of 16-bit length.

The disk unit is expandable, by adding disk drives, to a total capacity of 4.8 million words. Additional disk controllers may also be added to the RADCOM-1 system.

The average total access time is 70 milliseconds. On systems with multiple disk drives, operations may be overlapped for time efficiency; one drive may read or write while the others are seeking new head positions for their next transfer. All data transfers utilize the direct-memory-access (DMA) capability of the central processor.

A.2.3 ED-10 Encoder/Decoder Interface

Kustom Electronics supplies two versions of the ED-10 Encoder/Decoder Interface. The ED-10-1 interfaces the TC-10 Terminal Controller to the user's base station radio.

The ED-10-2 provides the necessary conversion from audio transmission to standard data set communications. For a RADCOM-1 network, the ED-10-2 is used to convert the audio signal received at the base station into a digital signal for data set operation at the base station site. This device is useful when telephone lines are of poor quality and/or when extreme line distances are required. It may also be used as a direct interface from the MCT-10 Mobile Terminal network to the user's existing central data system, allowing the RADCOM-1 system to assume a non-local processor configuration.

In some instances, a prospective user of the Kustom MCT-10 Mobile Terminal may have existing processor capability; the TC-10 Terminal Controller may then be unnecessary, and Kustom-supplied application software (AS-10) may be suitably modified to the user's specifications.

Both versions of the Encoder/Decoder consist functionally of a modulator and demodulator section. In the ED-10-1, the modulator accepts digital messages in serial form from the TC-10 Terminal Controller and converts them into a phase-shift-keyed (PSK) audio signal. This audio signal is then transmitted over an existing voice-grade radio communication channel, of 3 kHz audio bandwidth. The demodulator section of the ED-10-1 converts the PSK audio signal from the base station receiver into a digital signal for presentation to the TC-10 Terminal

Controller.

The frequency of the audio tone is either 1950 Hz or 1300 Hz. With a tone frequency of 1950 Hz the operating bit rate is 1300 bits/sec; a tone frequency of 1300 Hz yields an operating bit rate of 867 bits/sec.

The modulation method used is synchronous audio phase-shift-keying; synchronism is provided by the inclusion of a suitable pilot-tone, at an audio frequency different than that of the modulated audio tone. Absolute phase referencing is obtained from a comparison of the pilot tone and the header portion of the modulated audio tone.

The modulator section of the ED-10-2 Encoder/Decoder accepts digital messages via an RS-232-C standard interface device and converts them to a phase-shift-keyed audio signal for transmission over a voice-grade radio channel at a 1300 bit/sec. rate. The demodulator section converts the PSK audio signal received at the base station radio into a digital signal for transmission over a Bell 202 or equivalent data set.

The character information code used by both versions of the ED-10 Interface for communication with the TC-10 Terminal Controller and the MCT-10 Mobile Terminals is a subset of the ASCII 7-bit code. Digital messages are formatted by both the TC-10 Terminal Controller and the mobile terminal prior to transmission, and contain phase referencing information, start and end message signals, all-call, group, or unit address details, control and status information, and up to 224 characters of text.

Error detection is performed by means of character parity checks. Every seventh bit within a character is a parity check bit. The parity checks are performed by the ED-10 Encoder/Decoder interface, not by the system's central processor.

A.2.4 LI-10 Line Interface

Kustom Electronics manufactures two series of Line Interface units, allowing the TC-10 Terminal Controller to be connected to a variety of data communication channels.

A.2.4.1 LI-10-A Series

A.2.4.1.1 Description

LI-10-A series units provide interfaces to serial communications channels, typically local console teletype terminals, another local computer, or a remote data base system, using data sets on private line or switched public telephone facilities.

The UNIBUS structure of the PDP-11 central processor contained in the TC-10 Terminal Controller serves as a multiplexer for the addition of multiple LI-10-A's, up to a maximum of 31 units.

An LI-10-A unit may be connected to a local terminal whose data rate is between 50 and 9,600 baud, having a character code set of 5, 6, 7 or 8 data bits, with odd, even or no parity, and one, one-and-one-half or two stop bits. All necessary signals are provided to control Bell 103A, E and F, 113A, 202C and D, or equivalent datasets with RS-232-C standard connections.

A.2.4.1.2 LI-10-A Series Specifications

- Double character-buffered receiver and transmitter.
- Full or half-duplex operation under program control.
- Selectable standard data rate between 50 and 9,600 baud, or non-standard rates made-to-order
- Independent receive and transmit speeds, except for 110 and 134.5 baud units.
- Strap-selectable character size; 5, 6, 7 or 8-bits.
- Strap-selectable parity generation on transmit and checking on receive: even, odd or no parity.
- Strap-selectable stop-code length; 1,1.5, or 2 bits.
- Full dataset control option for Bell 103, 113, 202 or equivalent datasets.

A.2.4.1.3 Features

LI-10-A1 Features

- Full serial asynchronous line unit.
- Modem control features, Bell 103 or equivalent data set.
- Clock speeds of 110, 134.5, 150 and 300 baud.
- Includes 25 foot cable.

LI-10-A2 Features

- Full serial asynchronous line unit.
- Modem control features, Bell 202 or equivalent data set.
- Clock speeds of 110, 300, 1200 and 1800 baud.
- Includes 25 foot cable.

LI-10-A3 Features

- Allows direct connection of the TC-10 Terminal Controller to any peripheral with an EIA RS-232-C standard interface.
- Allows direct serial asynchronous computer-to-TC-10 data transfer.

A.2.4.2 LI-10-S Series

A.2.4.2.1 Description

LI-10-S series units provide interfaces to serial synchronous communication lines, and operate in either a full or half-duplex mode at speeds between 2000 and 50 K baud, with programmable 6, 7 or 8-bit character sizes. An option is available which enables the unit to interface with Bell 303 type data sets, using 10, 11 and 12-bit data characters. A null modem, with internal clocking, is available for direct connection to a local synchronous interface.

A.2.4.2.2 LI-10-S Series Specifications

- Double buffered receiver and transmitter.
- Full or half-duplex operation under program control

- 50 k bits per second maximum data rate.
- Character size is program controlled; 6, 7 or 8 bits with 10, 11 or 12 bits optional.
- Synchronous clock obtained from the data set, with internal clock optional.
- Programmable sync character, two successive sync characters required to activate the unit.
- Low order bit transmitted first.
- Parity check on incoming characters.

A.2.4.2.3 Features

LI-10-SA Features

- Full or half-duplex synchronous line unit.
- Double buffered; 6, 7 or 8-bit characters.
- RS-232-C connection for Bell 201 or equivalent data set.
- Include 25 foot cable.

LI-10-SB Features

- Full or half-duplex synchronous line unit.
- Double buffered; 10, 11 or 12 bit characters.
- RS-232-C connection for Bell 303 or equivalent data set.
- Includes 25 foot cable.

LI-10-SC Features

- Full or half-duplex synchronous null modem.
- Internal clocking, allows direct connection to a local synchronous computer interface.

A.2.5 The DT-10-2 Dispatcher Display Terminal

A.2.5.1 Introduction

In the RADCOM-1 system, the DT-10-2 Dispatcher Display Terminal is used for controlling the deployment of mobile units. It is an operator-controlled display terminal for transmitting and receiving information to and from the TC-10 Terminal Controller. The terminal consists of a detachable keyboard, a 12 inch (diagonal measurement/CRT display), and a character generator, memory, programmable input/output processor unit and power supply. This terminal is the SUPER BEE manufactured by Beeline Medical Electronics Corp.

The DT-10-2 displays the status of mobile units and other system resources, and is used by the dispatcher for routing information and dispatch messages to the operators of mobile units, via the MCT-10 Mobile Terminals. The dispatcher may also retrieve detailed status information for any mobile unit, and make inquiries into local and remote data bases in a manner similar to that of a mobile terminal.

A.2.5.2 Terminal Operation

The terminal is operated in a dual-screen mode, and up to nine fixed message formats are available to simplify data entry operations. One of the formats, Format 1, simulates the operation of an MCT-10 Mobile Terminal. The other eight are defined by the user, and depend on the system application.

A cursor is always visible on the CRT screen, indicating the next character position to be entered or transmitted. The cursor may be moved by entering a character, tabbing, or using the cursor control keys. When the operator initiates a transmission, the cursor will reposition itself to the beginning of the format area and move as the message is transmitted, until the end of the format area is reached. A transmission request will only deliver information from the format area of the message being sent, even if the cursor has been moved beyond the boundary of that area to some other portion of the CRT screen.

Control functions are used by the terminal operator to specify the area of the screen to be worked in. After choosing CONTROL A or CONTROL B, the cursor goes to the first working position of the appropriate area.

Transmission from the terminal to the central processor of the Terminal Controller is initiated by pressing the EOM (end of message) key, which causes all the text in the current format area to be transmitted. The operator may abort any operation at any time by pressing the ESC (Escape) key, which clears the format area, displays the MCT-10 format, and repositions the cursor.

Any message format in the system can be recalled by keying Lx, where x is the number (1 to 9) of the desired format.

A function request, obtained by typing Fx, where x is the number of the desired function, allows the operator to simulate MCT-10 Mobile Terminal operations. Function requests must be performed in Format 1. Text is entered exactly as for an MCT-10 terminal.

Status information is retrievable from an MCT-10 terminal which has been designated a command terminal using function 7. General status information for all system resources, including identification number and status code, can be obtained by keying ST. A ten character area is reserved for the display of the status of each system resource, including the unit ID number and its current numerical status. This information appears for each mobile unit or other resource which is logged on the system. Reverse video (white background with black letters) is used to indicate available resources, and units on emergency status have a blinking display.

Messages to be delivered to the DT-10-2 Dispatcher Display Terminal by the TC-10 Terminal Controller are held in a single queue. The queue discipline is first-in, first-out (FIFO). The next message to be displayed upon operator request, is brought into the area of the CRT screen in which the operator is working.

The presence of a message in the queue is indicated by a "bell" tone, which repeats every five seconds as long as a message is in the queue. The tone repeat time is modifiable.

All messages to be delivered to the DT-10-2 are queued except those which are responses to a request for general or detailed status. Those responses are returned immediately to the current working area, by-passing the message queue. Any input from the CRT terminal which occurs between receipt of a status request by the Terminal Controller and its response is ignored.

A.2.6 DT-10-3 Status Monitor Terminal

A.2.6.1 Monitor Terminal Operation

The DT-10-3 Status Monitor Terminal is physically identical to the DT-10-2 Dispatcher Display Terminal, but the keyboard is not normally used in the RADCOM-1 system. The CRT screen alone is used as a monitor by the dispatcher, and displays, on-line, the general status of all mobile units and other resources in the system.

General status information contains only each resource's number and numerical status. This information is updated automatically by the TC-10 Terminal Controller. Reverse video is used to indicate units available for assignment, and units on emergency status are represented by a blinking status identifier.

Since both the Dispatcher Display and the Status Monitor Terminals are identical, the DT-10-3 can serve as a backup unit for the DT-10-2. The main value of the DT-10-3 Status Monitor Terminal is its usefulness in continuously displaying status information eliminating the need for status recall by the dispatcher.

A.2.6.2 DT-10-2 and DT-10-3 Specifications

Display Size	12" diagonal
Display Area	Approximately 6" x 9"
Display Format	25 lines of 80 characters each

Display Refresh Rate	60/50 Hz
Display Memory	MOS shift registers
Character Type	5 x 7 dot matrix (7 x 9 scan)
Character Size	Approximately 0.1" x 0.2"
Character Set	224 displayable characters
	32 control codes (displayed in program entry mode only)
	64 upper case ASCII set
	32 lower case ASCII set (with decenders shifted down two scan lines)
	96 escape sequence control codes (display a detensified characters in program entry mode only)
	Upper case only 64 ASCII set switch selectable
Character Generation	MOS ROM (Read Only Memory)
Cursor Type	Blinking underscore
Cursor Controls	Cursor up
	Cursor down/line feed
	Cursor left
	Cursor right
	Cursor home
	Carriage return
	New line
	ETX (End of Text) search
	Format search
	Horizontal tab
Cursor Address	Positions by column character and line
Cursor Sense	Cursor positions transmitted
Memory Organization	Paging
Communication Interface	Serial RS232C
I/O Controller	Micro-processor
I/O Program	MOS ROM

Transmission Rate	1,200 bits per second
Baud Rate Selection	Switch selectable
Transmission Mode	Full duplex
Data Transmission	10 bits asynchronous
	8 bits synchronous (switch selection)
Parity	Even/non asynchronous
	Odd/non synchronous
	LRC (Longitudinal Redundancy Check) after EXT in block transmissions
Format	Protected fields
Erase Functions	Clear memory
	Erase to end of line
	Erase to end of memory
	Clear memory to delete codes
Alarm	Audible "bell" tone
Keyboard	Layout attached
	Detachable
	N key rollover
	ANSI logical paired
	Auto repeat
	Lighted mode indicator
Input Voltage	117 VAC ± 10%, 60 Hz
	230 VAC ± 15%, 50 Hz
Input Power	200 watts maximum
Environmental	Non-operating temperature 10°C-50°C
	Operating temperature 5°C-40°C
	Humidity 5%-80% non-condensing
	Altitude 0-10,000 ft.
Mechanical Dimensions	Display 20"Wx15"Hx15"D
	Keyboard 20"Wx3 1/2"Hx10"D
Weight	Display 25 pounds
	Keyboard 10 pounds

Options Available	
Edit	Insert character
	Delete character
	Insert line
	Delete line
	Page edit
Polling	Address up to 95 terminals (sequence as defined)
High Resolution	7 x 9 dot matrix
	15" diagonal monitor

A.2.7 LP-10 Line Printer

A.2.7.1 Introduction

Kustom Electronics will supply either a 100 character per second, LP-10-2, line printer or a 165 character per second, LP-10-1, line printer as a standard output device for the RADCOM-1 system.

The printer is used for logging and documentation, programming assistance, and management information reporting. Normally the printer is located adjacent to the dispatcher's display console.

Both line printers will produce an original document plus up to four carbon copies, and alternate character sets are available.

The LP-10-1 Line Printer is a 100 character per second dot matrix, serial impact printer, capable of printing up to 60 lines per minute, with 80 characters per line.

The LP-10-2 Line Printer is a 165 character per second, dot matrix, serial impact printer capable of printing up to 60 lines per minute, with 132 characters per line.

A.2.7.2 LP-10-1 Line Printer Specifications

Printing Rate:	
Characters	100 characters per second
Lines	60 lines per minute 150 lines per minute (short lines)
Character Structure	5 x 7 dot matrix 9 x 7 dot matrix optional
Input Data Code	7-bit ASCII, plus parity
Paper Requirements	Standard sprocketed paper, produces up to four carbon copies
Paper Feed	Sprocket feed, adjustable to 9 1/2" width
Printing Structure	80 characters per line 6 lines per inch
Character set	Full 64 ASCII characters
Dimensions	11" high, 20" deep, 20" wide
Weight	55 pounds
Standard Features	Form feed Audio alarm buzzer Vertical format control Paper memory control (10 sec.) Gated strobe pulse for data input Optional character set 50/60 cycle, multi-voltage operation
Terminal Controller Interface Options	Direct connect Store to remote CRT terminal
Electrical Requirements	117 VAC ± 10%, 60 Hz 117/234 VAC ± 10%, 50 Hz (optional)
Temperature	40-100° F, operating 40-160° F, storage
Humidity	5-90%, operating (no condensation) 0-95%, storage
Noise Dampener	LP-10-1B Noise Dampener (optional)

A.2.7.3 LP-10-2 Line Printer Specifications

Printing Rate:	
Characters	165 characters per second

Lines	60 lines per minute 200 lines per minute (short lines)
Character Structure	9 x 7 dot matrix
Input Data Code	7-bit ASCII, plus parity
Paper Requirements	Standard paper, produces up to four carbon copies
Paper Feed	Pin feed, adjustable up to 14" form
Printing Structure	132 characters per line 6 lines per inch
Character Set	Full ASCII 64 characters
Dimensions	11 1/4"H, 19 1/4"D, 27 1/2"W
Standard Features	Form feed Audio alarm buzz Vertical format control Paper memory control (6 sec.) Gated strobe pulse for data input Optional character set 50/60 cycle multi-voltage operation Elapsed time indicator
Terminal Controller Interface Options	Direct connect Store to remote CRT terminal
Noise Dampener	LP-10-2B Noise Dampener (optional)

A.2.8 <u>TT-10-1 Teletype Console</u>

The TT-10-1 Teletype Console is a standard ASR 33 Teletype used for maintenance and control operations by maintenance and system personnel only.

An ASR 35 Teletype is available as an option.

A.2.9 <u>MP-10 Mobile Printer</u>

A.2.9.1 <u>Introduction and Operation</u>

The MP-10 Mobile Printer is assembled by Kustom Electronics, and, as an optional attachment for the MCT-10 Mobile Terminal, provides a hard copy output of the text displayed at the mobile terminal.

The mobile printer is a solid-state, silent-head printing device which uses a 5 x 7 dot matrix print format. Messages may be printed by remote control from the base station, or the mobile terminal operator may press the PRINT key on the terminal keyboard to obtain a copy of the text displayed.

Within the RADCOM-1 System, remote control print, messages appear identical to data messages containing ordinary text. If the terminal operator desires printed copy, no retransmissions are required, since the printing is done directly from the terminal's memory.

A.2.9.2 Specifications

Voltage Requirement	10.0-15.0 VDC
Input Current Drawn	1.1 amp (max.), stand-by 3.5 amp (max.), print
Print Speed	3 1/2 lines per sec., 16 characters per line
Print Time	4.5 sec. for a full 224 character message
Controls	Paper feed/advance Uses PRINT key on MCT-10
Print Format	16 characters per line Right margin justified 5 x 7 dot matrix 7 lines per inch
Dimensions	10" long, 6" high, 5" wide
Mounting	Adjacent to and below the MCT-10
Temperature	-20°F to +150°F, operational
Humidity	0-85% at 150°F
Paper Requirement	NCR 2 1/4" thermo roll (250' length)
Power and Signal Interface	Cable to MCT-10 supplied, with connector

A.2.10 MM-10 Mobile Terminal Mount

The MM-10 Mobile Terminal Mount is designed to secure the

MCT-10 Mobile Terminal to the front seat of a vehicle. The mount is portable, and installs by fastening to the seat with two standard seat belts.

The mount is made of 13 gauge aluminum with a plastic shell covering. The vehicle's seat serves as a cushion, or shock absorber, for the MCT-10 Mobile Terminal, and the optional MP-10 Mobile Printer. A swivel mount allows either the driver or a passenger to have access to the keyboard.

A.3 RADCOM-1 SYSTEM SOFTWARE

A.3.1 Introduction

A.3.1.1 Operating Software OS-10

For overall coordination and control of the RADCOM-1 system, Kustom Electronics provides the OS-10 Operating Software system. This software package was developed to furnish the PDP-11/05 central processor with the capabilities for handling interrupts and input/output devices, task scheduling, error recovery, and core memory and disk storage allocation. The OS-10 Operating Software system is standard for all RADCOM-1 systems, with a modular design permitting later enhancements to be incorporated as required.

A.3.1.2 Applications Software AS-10

A number of modules are contained in the AS-10 Applications Software system to enable a RADCOM-1 system to be adapted to the standards and requirements of a particular law enforcement agency. Modifications are normally required to satisfy specific demands for data base interfacing, and status and function key assignment and utilization. Additionally, an open-ended design using standard linkages, modifiable tables and generalized routines permits later enhancement. The AS-10 Applications Software system includes the modules assembled into the RADCOM-1 System Software package, as well as the modules available for further enhancement of the RADCOM-1 system.

A.3.2 The Complete RADCOM-1 System Applications Software Package, SRD-1

A.3.2.1 Modules Composing the SRD-1 Package

The SRD-1 package provides the programming support for the PDP-05, the central element in the TC-10 Terminal Controller, necessary to implement the complete RADCOM-1 system. Included in the SRD-1 package is the basic system package SIR-1, and the seven other modules listed below:

1) SIR-1 Inquiry/Response System, containing:
   1-SIR Inquiry/Response Module
   1-SRC Radio Channel Module
   1-SCC Data Base Communication Line Module
2) SDA Dispatcher Display Terminal Module
3) SSA Status Monitor Terminal Module
4) SFT DT-10-2 Format Layout Module
5) SMS Basic Message Switch Control Module
6) SSM Status Maintenance Module
7) SIL Inquiry/Response Logging Module
8) SML Comprehensive Logging Module

A.3.2.2 <u>SIR-1 Inquiry/Response System Capabilities</u>

The SIR-1 package will support the following:

1) 10 MCT-10 Mobile Terminals (expandable to eighty)
2) 1 Communication Line (to a remote data base)
3) 1 Radio Channel (two-frequency, half-duplex channel using one ED-10-1 Encoder/Decoder Interface)
4) Function key translation
5) Status key translation and status maintenance
6) Output message editing/paging (by the Terminal Controller)
7) Expanded input/output buffering with disk storage
8) Message switching
9) Hard-copy logging of selected inquiries and responses, such as ("hits"), car-to-car messages, and status changes.
10) One Dispatcher CRT Terminal with stored format retrieval, including a simulated MCT-10 format.
11) One Status Monitor Terminal

Each of these eight modules are discussed in more detail in the following section.

A.3.3 AS-10 Applications Software Modules

A.3.3.1 SIR-1 Inquiry/Response Module

SIR-1 is the basic system package for implementing digital communications capability. Mobile terminals are supported in an inquiry/response mode, with function keys utilized to initiate inquiries into a remote data base. Status key interpretation and maintenance, message switching, "hit" detection, and control of display terminals and line printers are not included in the SIR-1 module. Other modules must be added if these functions and capabilities are required.

The SIR-1 system package supports ten mobile terminals with memory buffering alone. Up to eighty mobile terminals can be supported as long as other enhancements (added modules and requirements) do not require a total system memory exceeding 28 K of usable core storage. Disk buffering capability is provided when module SMS is incorporated.

A.3.3.2 SRC-1 and SRC-2 Radio Channel Support Modules

Up to six half-duplex radio channels can be interfaced to a RADCOM-1 system, each radio channel requiring a separate SRC module.

The mobile terminals are associated with a radio channel based upon their most recent input to the RADCOM-1 system. Any output addressed to a mobile terminal is sent to that terminal via the radio channel currently associated with it. Normal retry procedures are following in the event of transmission errors or no response from the terminal.

A terminal is marked "down" if the retry procedures are unsuccessful. Once a terminal is "down", it remains so until a new input message is received from the terminal. All messages addressed to a "down" mobile terminal are rerouted to its designated alternate and "down" notification is sent to the message originator, if appropriate.

A terminal is marked "busy" if the retry procedures are unsuccessful. Once a terminal is "down", it remains so until a new input message is received from the terminal. All messages addressed to a "down" mobile terminal are rerouted to its designated alternate and "down" notification is sent to the message originator, if appropriate.

A terminal is marked "busy" if the retry procedures determine that a terminal's input buffer has been full for a predetermined length of time (indicating a probable non-manned mobile terminal) and the alternate routing procedures are followed. The system will attempt to continue to communicate with the busy terminal even after alternate routing has occurred, and when communication is reestablished, the mobile terminal is notified of the alternate routing.

The SRC-1 module supports the ED-10-1 Encoder/Decoder. The SRC-2 module supports the ED-10-2. Any combination of the two is allowed in a RADCOM-1 system, up to a total of six interfaces.

A.3.3.3 <u>SCC Data Base Communication Line Module</u>

Up to four data base communication lines, each requiring a separate SCC module, can be interfaced to a RADCOM-1 system. SCC modules require a detailed design effort to determine their required characteristics for a specific application, but general criteria can be defined. Each channel is considered by the system to be totally separate from the others. Each channel appears as a separate address to the message switch (SMS). Some filtering of messages can be accomplished to prevent certain messages from reaching the data base, eliminating unauthorized access to those files. The ability to detect "hits" and relate inquiries to responses is possible in certain instances, but in general there are no fixed rules for determining the occurrence of "hits" and the procedures to be followed if a "hit" does occur.

Message translation, reformatting, and line discipline are handled by the SCC module, along with error processing and "down" notification as appropriate. Whenever possible, the entire RADCOM-1 system will appear to the remote data base system as another input/output device, similar to all the others which it serves. The terminals within the RADCOM-1 system will be addressable through the remote data base system simply as additional addresses on its existing list; this capability permits terminals within multiple systems to communicate directly with each other.

A.3.3.4 SDA Dispatcher Display Terminal Module

The SDA module allows a CRT display terminal to operate in a split-screen mode, simulating a dual-screen terminal. Also, the operation of an MCT-10 Mobile Terminal may be simulated. In addition, general status information may be retrieved if the SSM module is also included, and formatted layouts may be retrieved if the SFT module is incorporated. The operation of the DT-10-2 Dispatcher Display Terminal has been detailed in the hardware descriptions. A total of six CRT terminals may be included in a RADCOM-1 system, each operated as either a Dispatcher Display Terminal or a Status Monitor Terminal. Each CRT Terminal requires an SDA or SSA module.

A.3.3.5 SSA Status Monitor Terminal Module

The CRT terminal supplied by Kustom Electronics, when supported by an SSA module, may be used as a Status Monitor Terminal, showing the general status of all mobile units in the system. The terminal itself is physically identical to the dispatcher's CRT terminal, permitting it to serve as a backup unit for the dispatcher's terminal.

A.3.3.6 SFT DT-10-2 Dispatcher Display Terminal Format Layout Module

The SDA (Dispatcher Display Terminal) module provides a single message layout, that of an MCT-10 screen, for use by the dispatcher. Up to nine message layouts may be contained in any system, however, and each SFT module provides one additional layout for the SDA module. The formats are variable, and subject to definition by the user agency, so long as each layout can be presented solely on the upper or lower half of the CRT screen.

Additional layouts may be used for formatted inquiries, dispatch or complaint forms, entry or display of "hot sheet" information, and various report forms. The layout provided by each SFT module is available for retrieval by all dispatcher terminals incorporated in the RADCOM-1 system.

A.3.3.7 SMS Basic Message Switch Control Module

All interfacing between different I/O devices and functional modules is provided by the SMS module. A prerequisite for most enhancements to the basic RADCOM-1 system, its operation is not visible to the users of the system. The SMS module also provides disk support and control for the RADCOM-1 system.

A.3.3.8 SSM Status Maintenance Module

This module allows assignment and use of the ACK key, emergency key, and four status keys. Through this module, the RADCOM-1 system monitors the status of the mobile units in the system, as well as the internal status of each terminal.

A log-on/log-off procedure must be established when the SSM module is utilized. After log-on, all status changes (including ACK and Emergency) associated with each mobile terminal are time-stamped, saved, and reported as required. This status information is retrievable for use by other modules in the system.

Status key assignments are designated by the user agency. One assignment feature worth noting is the ability to save information displayed at the MCT-10 Mobile Terminal for later retrieval.

Emergency status can be used to control the performance of special operations, such as notification to other MCT-10's, the Dispatcher Display Terminal, and the data base systems on a high-priority basis.

ACK (Acknowledgement) key utilization can include return notification to the originator of a message that has been manually acknowledged by a mobile terminal operator.

The SSM module is required in any RADCOM-1 system which attempts to handle more than just the inquiry/response function.

A.3.3.9 <u>SIL Inquiry/Response Logging Module</u>

The SIL module allows user selective logging of inquiry and response information, depending on various criteria. The messages to be logged are relayed through the SMS (Basic Message Switch Control) module to selected devices such as an MCT-10 Terminal, a CRT terminal, a line printer, or a data communication line.

The criteria for inquiries to be logged are selected on the basis of RADCOM-1 system operation and the message text generated by the terminals. Typical messages which may be logged include all inquiries containing text matching specified criteria, and inquiries routed to data bases such as NCIC and FCIC.

The criteria for responses to be logged depend on "hit" detection and local crime report code interpretation policies, which generally vary with each user agency. The particular format used by the data base system must be analyzed to determine these criteria.

A.3.3.10 SML Comprehensive Logging Module

Depending upon the operating procedures of the user law enforcement agency, various agency functions performed within the digital communication system may require logging. Information can be routed through the RADCOM-1 system to any designated input/output device. The criteria for messages to be logged is flexible, and may include car-to-car (or MCT-10-to-MCT-10) messages, status changes, ACK notifications, and log-on/log-off signatures.

A.3.4 Optional AS-10 Applications Software Modules

A.3.4.1 SAT MCT-10 Support Module

The RADCOM-1 system will support ten MCT-10 Mobile Terminals. Up to seventy mobile terminals may be added to the system, for a total of eighty, using SAT modules. Each SAT module provides the appropriate entries for status as well as routing, alternate routing and line service tables. One SAT module is required for each additional MCT-10 Mobile Terminal added to a basic RADCOM-1 system.

A.3.4.2 SRM Resource Maintenance Module

The SSM module (Status Maintenance Module) is required in order to automatically maintain status information for all MCT-10 terminals in the RADCOM-1 system. In some installations it may also be of value to maintain status information for non-terminal-equipped resources such as helicopters, motorcycles, and foot patrolmen. The SRM module provides this additional capability.

Changes in the status of non-terminal-equipped resources are entered manually by the dispatcher using the DT-10-2 Dispatcher Display Terminal, in a manner similar to the entry of status information from an MCT-10 Mobile Terminal. This status information is then maintained and displayed by the RADCOM-1 system.

Note that whether or not a specific resource (mobile or other unit) is equipped with an MCT-10 Mobile Terminal, the resource is allocated one position in the list of all resources within a RADCOM-1 system. If a system can support 20 resource units, there may be any combination of terminal equipped or non-equipped units, providing the memory requirements do not exceed the core storage available.

The SRM module provides only the capability for the RADCOM-1 system to maintain the added resource status; one SRA module per additional resource unit is required.

A.3.4.3 <u>SRA Non-Terminal-Equipped Resource Entry Module</u>

Each SRA module provides the ability to support one non-terminal-equipped resource unit in conjunction with the SRM (Resource Maintenance) module.

The SRA module provides the same ability for support of a non-terminal-equipped resource as the SAT module provides for an MCT-10. The SAT and the SRA modules are interchangeable from a memory requirement and price viewpoint. If a RADCOM-1 system is configured to support ten MCT-10 Mobile Terminals, it can be configured with ten SRA modules or any combination of SRA and SAT modules which total ten.

A.3.4.4 <u>SST Status Display CRT Module</u>

A Kustom Electronics supplied CRT terminal may be used as an additional status monitor to show the general status of all resource units in the system, when supported by the SST module.

This module is useful in cases where an agency desires to provide status information only, perhaps to supervisory or administrative personnel.

A.3.4.5 <u>SDT Dispatcher Terminal CRT Module</u>

This module is useful in those cases where an additional dispatcher's display terminal is desired. A Kustom Electronics supplied CRT data terminal is then capable of dual-screen operation, simulated MCT-10 Mobile Terminal display, and general status and retrieved layout display.

A.3.4.6 Hot Sheet System Module

This module provides a means for making information of an important, but general, nature available to all mobile terminal equipped vehicles. The information is maintained in a disk file and is available to all terminals for recall and report generation.

Up to 99 messages can be maintained within the system. Each message may be up to 9 pages long, with a maximum of 224 characters per page. Each message is uniquely identified, and any mobile terminal operator may recall any one of the 99 messages.

Message content is "free-form", and messages are maintained and displayed exactly as entered. Messages may be entered, deleted, updated, listed and retrieved, but only one designated CRT data terminal may perform those functions required for "hot sheet" maintenance.

A.4 SYSTEM DESIGN AND ERROR CONTROL PHILOSOPHY

A.4.1 Message Transmission

A.4.1.1 Messages Originating at the MCT-10 Mobile Terminal

In the RADCOM-1 system, a message which originates at the MCT-10 Mobile Terminal may be one of the several types listed below. An inbound message is composed and entered into the RADCOM-1 system by the operator of an MCT-10 terminal. Since one of the available formats for the Dispatcher Display Terminal simulates an MCT-10 terminal, the dispatcher may also originate the same message types as those originating at the MCT-10.

A.4.1.1.1 Remote Data Base Inquiries

The RADCOM-1 system permits one of the seven available FUNCTION keys on the MCT-10 to denote data base inquiries. The terminal operator presses the appropriate FUNCTION key, enters the necessary descriptive data, and presses the TRANSMIT key to initiate transmission of the message to the TC-10 Terminal Controller. A typical name check data entry would be:

JONES, J W M 110543

Similar text formats may be specified by the user agency for vehicle license number, vehicle identification number, address or complaint or warrant number checks. When the data base inquiry message is received by the TC-10 Terminal Controller, an applications program performs the necessary reformatting, and queues the resulting message for the remote data base.

A.4.1.1.2 FUNCTION Key Utilization and Fixed Format Message

All seven FUNCTION keys available on the MCT-10 Mobile Terminal are available for assignment by the user agency. All function keys are used by the terminal operator in the manner described above for remote data base inquiries. When possible, fixed formats for data entry are used; this is largely a matter left to the applications programs. The primary purpose of the

FUNCTION keys is to add a header to each FUNCTION message, signifying that the message contains special descriptive data. Text contained in any message in the RADCOM-1 system may be up to 224 characters long.

A.4.1.1.3 <u>Terminal-to-Terminal Messages</u>

Inter-terminal messages are handled by the Terminal Controller in the RADCOM-1 system. For this message type the address of the receiving terminal, or terminals, must be included and a fixed format is required to permit identification of the message destination by the TC-10 Terminal Controller.

A FUNCTION key may be used to provide this addressing, especially for mobile terminal-to-Dispatcher Display Terminal messages. This is generally a question of applications programming; message text, except for the destination address, is variable, and the total of address and text may be up to 224 characters long. Messages may, in general, be addressed to single mobile units, groups of mobile units, or all mobile units. MCT-10 terminals may be set to any two-digit group code, and a unit identification key is used to permit use of the terminal and access to the data base.

A.4.1.1.4 <u>Status Entry Messages</u>

Four STATUS keys are available on the MCT-10 Mobile Terminal. The RADCOM-1 system permits the user agency to specify the unit status which corresponds to each key. Formation of a resultant status entry message, containing no text, is automatically initiated when the terminal operator presses one of the STATUS keys. Transmission of the status message requires pressing the TRANSMIT key.

When a status entry message is received by the Terminal Controller, the applications programs maintain the newly entered status for use by the dispatcher.

A.4.1.1.5 Manual Message Acknowledgement and Emergency Key Operation

An acknowledge, or ACK, key is used by the mobile terminal operator to signal the dispatcher, through the Terminal Controller, that a message was received. Pressing the ACK key initiates message transmission just as in the case of pressing the TRANSMIT key.

Pressing the red emergency key, EMERG, sets the status of the mobile unit to "emergency". The terminal operator may then enter any additional data he desires, using the keyboard. To prevent accidental transmission of emergency messages, the operator must press the TRANSMIT key to initiate transmission of the message. If no additional data are entered by the operator, the emergency message will contain the mobile unit's identification code and an emergency status notification.

A.4.1.1.6 Report Format Retrieval

With an enhanced RADCOM-1 system, it is possible to retrieve report formats for use by the mobile terminal operator. Such retrieval messages may be generated using an assigned FUNCTION key, or a fixed-format mobile terminal-to-Terminal Controller message, with or without additional text.

A.4.1.1.7 Automatic Response to Interrogations

The Terminal Controller may issue an outbound message to a particular mobile terminal, requesting internal status and control information. These messages are decoded within the mobile terminal, and appropriate responses are automatically composed, after which transmission is automatically initiated. The terminal operator is not informed that the interrogation and response have occurred. The response message contains only terminal address, identification code, and control and status information.

A.4.1.1.8 Inbound Message Formats

All inbound messages in the RADCOM-1 system use the same general format. A preamble of binary zero's is used to permit system synchronization. Two start-of-message characters follow, identifying the presence of a message on the channel. Two address characters follow the start-of-message characters, defining the message address by number and type, either single unit, a group of units, or all units. This permits messages to be directed by the Terminal Controller to individually numbered terminals, numbered groups of terminals, or all mobile units within the RADCOM-1 system.

The next two characters in a message are special characters used by the RADCOM-1 system for control and status information. Following these characters, up to 224 characters of text can be inserted. A FUNCTION key operation sets control and status bits within the two special characters. A STATUS key operation sets the control and status bits, but does not permit additional text to be inserted. An end-of-message character terminates all messages.

The character string is held for transmission in a transmit message buffer. The status and text information are simultaneously available for display on the display panel of the mobile terminal. The characters are stored in binary form, using a modified subset of the 7-bit ASCII standard code. Only a 6-bit modified subset is required to represent those characters available on the MCT-10 keyboard. The seventh bit is used to check odd parity. The bit string which represents the message is transmitted in character-serial form, with the low-order bit of each character transmitted first. The bit string itself does not appear on the radio channel, but is used to modulate an audio carrier, producing a binary phase-shift-keyed audio tone, which then becomes the audio input to the mobile radio.

A.4.1.2 Outbound Terminal Controller-to-Mobile Terminal Messages

A.4.1.2.1 Introduction

Messages which originate at points other than the MCT-10 Mobile Terminals in a RADCOM-1 system become outbound messages to a mobile terminal. The Dispatcher Display Terminal may originate inbound messages while simulating MCT-10 operations, but it also originates outbound messages when performing dispatching and control operations. Outbound messages may be grouped into several of the types discussed below.

A.4.1.2.2 Responses to Remote Data Base Inquiries

After reformatting the information contained in a response from a data base, the Terminal Controller composes a message addressed to the mobile terminal which originated the inquiry. If the response message contains more than 224 characters of text, it must be "paged", or separated into two or more messages of 224 characters or less. This paging procedure is handled by an applications program.

A.4.1.2.3 Terminal-to-Terminal Messages and Dispatches

The dispatcher can originate terminal-to-terminal messages during normal system operation. All-call, vehicle group, and single mobile unit messages may be transmitted. Applications programs handle the message composition function, setting the proper address characters.

A.4.1.2.4 Interrogations for Obtaining Terminal Status

The dispatcher may initiate a message which automatically requests transmission of a particular mobile terminal's internal control and status information. The TC-10 Terminal Controller may also initiate such interrogations. Responses are handled automatically by the MCT-10 Mobile Terminal, without operator intervention. This operation and type of message forms the basis for a "polling" mode of operation of the RADCOM-1 system.

A.4.1.2.5 Remote Operations Messages

Messages may contain control information which requires that the MCT-10 Mobile Terminal automatically initiate some operation at the mobile unit. One typical example is the use of a control character to cause automatic printing of a received message. Users may also wish to permit vehicle lights, horns, sirens, etc. to be operated by remote control from the Dispatcher Display Terminal.

A.4.1.2.6 Outbound Message Format

Messages outbound from the Terminal Controller use the same format as described for inbound messages. A 7-bit modified ASCII subset code is used; the mobile terminal can decode all 64 ASCII characters, but the full set is not available at the Mobile Terminal keyboard.

A.4.2 Error Control

A.4.2.1 Error Control for Inbound Messages from the MCT-10 Terminal

Messages inbound from an MCT-10 Mobile Terminal contain characters from a subset of the ASCII 7-bit code. The seventh, or high-order, bit of each code character is an odd-parity check bit. In the RADCOM-1 system, these check bits are the primary error control mechanism.

When any message is transmitted from a mobile terminal, bit-errors may be introduced by radio channel conditions or hardware faults. At the base station, a binary string is extracted from the received phase-shift-keyed audio-signal. Start and end of message characters identify messages. The ED-10 Encoder/Decoder recomputes the value of the parity check bit, for each character within a message, and compares the result with the value of the received check bit. If any parity errors are found, no attempt at correction is made.

If an inbound message is found to be free of parity errors, the ED-10 assumes it to be a valid message. Programs resident within the TC-10 Terminal Controller then perform the decoding of the received character string. If an invalid message is found, again no attempt at correction is made.

Messages which are received incorrectly, whether the errors are discovered by either the ED-10 Encoder/Decoder or the Terminal Controller, are disregarded completely.

Messages which are received error-free, and contain valid text, control and status characters, are acknowledged by the TC-10 Terminal Controller. If no acknowledgement is received by a mobile terminal within a predefined time interval, typically 2 seconds, the entire message is retransmitted to the base station.

A maximum of five attempts are made by the MCT-10 Mobile Terminal to transmit a message and received an acknowledgement from the TC-10 Terminal Controller. If the unit does not receive an acknowledgement within five tries, the indication RETRANSMIT appears on the last line of the terminal display screen, indicating to the operator that he must re-initiate the auto-transmit cycle, or take another action.

A.4.2.2 Error Control for Outbound Messages from the Terminal Controller

The error control system used for outbound messages to the mobile terminals is identical to that used for inbound messages. It is important to note that all outbound messages are received by every terminal in the RADCOM-1 system. Every message must be parity checked, and then the group and unit address codes must be examined by every terminal. If a particular terminal address matches that of the message, then that terminal performs further processing of the message contents and acknowledges the message. Otherwise, the entire message is rejected,

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4 OF 4

and the mobile terminal waits for receipt of a new start-of-message sequence, signalling the appearance of a new message on the channel.

A.4.2.3 Message Transmission Technique

Since messages may be of variable length, containing no text for status messages, and up to 224 characters of text for other messages, an asynchronous transmission method is used.

Each message is prefaced with a double character start-of-message sequence. The ED-10 Encoder/Decoder, and the corresponding modem in the MCT-10 Mobile Terminal, continuously extract a binary string from the phase-shift-keyed audio signal. The decoder portion examines this bit string for the occurrence of a start-of-message sequence, followed by a message and an end-of-message character. This process permits message transmissions to be performed asynchronously over the voice radio channel.

A.4.3 Modulation Technique

A.4.3.1 Audio Modulation Method

The Kustom RADCOM-1 system uses a synchronous audio phase-shift-keying modulation technique for transmitting digital data over a voice radio channel.

The audio carrier frequency is either 1950 Hz or 1300 Hz, depending on the application and the characteristics of local telephone channels. An audio voice channel bandwidth of 3 KHz is required.

A synchronous detection method is used, with local synchronization (absolute phase referencing) obtained by adding a small amplitude (-20 db) coherent audio reference signal to the transmitted data signal. In addition, each data signal is preceded by approximately 150 milliseconds of pure audio tone, allowing local synchronization for absolute phase referencing.

A.4.3.2 Radio Channel Requirements

Kustom Electronics has designed the RADCOM-1 system to operate over existing simplex or two-frequency, half-duplex voice grade radio channels, with 3 KHz audio bandwidth.

In a two-frequency half-duplex system, one frequency is used for transmission by the base station and another is used for transmission by all the mobile units. At any time, the base station can both transmit and receive, allowing simultaneous inbound message transmission and outbound message transmission.

Full-duplex system operation is also possible. A full-duplex system would require two antennas or a duplexer in each mobile unit, as well as modifications to the system programs to permit simultaneous two-way data flow.

Systems using receiver voting techniques may be modified to operate with the RADCOM-1 system, by insuring that when a receiver is initially selected that it is used for the duration of the digital message. Only after the digital message has been completely received, typically two seconds later, may the voting system select another receiver.

A.4.4 Line Control

The RADCOM-1 system is normally operated in a contention mode with both inbound and outbound digital traffic competing with voice traffic for channel control.

Channel occupancy is tested by a carrier sensing technique. When the TRANSMIT key is pressed, RF carrier presence on the channel is electronically sensed. If no RF carrier is present, the digital transmission begins. This prevents pre-emption of a voice transmission by a digital message, and also prevents interference resulting from simultaneous digital transmissions.

Should a digital transmission be garbled or lost, the error control functions insure an eventual retransmission.

A.4.5 Throughput

Message throughput for a mobile digital communication system operating on a channel shared with voice traffic is difficult to calculate, due to a lack of statistical data with which to construct a satisfactory queueing model. In such a system, digital and voice traffic may be mixed, with both message types being generated at different rates, and both requiring different amounts of channel time. A numberical value for throughput in such a system cannot be determined at this time.

In the RADCOM-1 system, a full 224 character message requires about 1.5 seconds of channel time for transmission, assuming a bit rate of 1300 bps.

A total transmission time of 1.5 seconds yields an effective data rate of 149 characters, or 1043 bits, per second.

It must be emphasized that higher throughput alone does not imply a faster response time. Response time to data base inquiries, for example, depends to a great extent on the applications programming used within the TC-10 Terminal Controller, and on the interface procedures at the remote data base.

Appendix B

A Detailed Description of the IBM 2976 Mobile Terminal System

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A Detailed Description of the IBM 2976 Mobile Terminal System

B.1 INTRODUCTION

The IBM 2976 Mobile Terminal System is unique among current mobile/digital systems for the following reasons:

1) The display at the mobile terminal consists only of a printer and system condition indicators,

2) Network control is based upon a polling technique which requires a dedicated, duplex radio channel, and

3) A minicomputer is not used at the base station. A fixed-form, non-programmable Transmission Control Unit is used to interface the network of mobile terminals to the user's existing System/360 or System/370 central data processing system.

The IBM system is therefore restricted to agencies which possess a System/360 or a System/370 series computer and have access to a clear duplex radio channel.

The IBM 2976 System is therefore the only existing example of a remote processor mobile/digital system. The system hardware elements, design and error control philosophy, and the programming support required for the host computer are discussed in the following sections. The system overview in Section 3 should be read prior to this appendix, in order to obtain a feeling for the general nature of the system.

B.2 THE IBM 2976 MOBILE TERMINAL SYSTEM HARDWARE ELEMENTS

B.2.1 Introduction

The IBM 2976 Mobile Terminal System provides high-speed, two-way data communications between a centrally located IBM System/360 or System/370 central processing unit (CPU) and a network of IBM 2976 Mobile Terminals. The basic system is comprised of a central processing unit, an IBM 2976 Model 3 Transmission Control Unit (TCU), an IBM 2976 Model 5 Signal Converter, and up to 250 IBM 2976 Model 4 Mobile Terminals. The system design requires operation on a data-dedicated duplex radio channel. Two additional link adapters (LA) may be added to the Transmission Control Unit, each providing the capability for the system to handle an additional 250 mobile terminals. Each link adapter, or each block of 250 mobile terminals, requires a separate, dedicated duplex radio channel. The system thus has a total capacity of 750 mobile terminals, which would require three dedicated duplex radio channels.

The central processing unit, which is not included in the system and must be furnished by the user, is responsible for implementing the functions which the mobile/digital system performs and for providing overall system control. The user must therefore furnish operations and applications programs to provide for outbound message generation, remote data base inquiry and response, message addressing, routing and priority assignments, and control of the Transmission Control Unit (TCU).

The Transmission Control Unit (TCU) is a microprogrammed computer which is responsible for control of the network of mobile terminals. It therefore executes the polling function, transmits outbound messages upon command by the CPU and buffers inbound messages until the CPU can accept them. Error control and monitoring of the electronic status of the mobile terminals are both functions that are performed by the TCU.

The Signal Converter is a modulator/demodulator unit which converts between the d.c. binary signal required by the TCU and the audio FSK signal transmitted over the radio channel.

The Model 2976 Mobile Terminal provides an officer in a patrol vehicle with the input/output device necessary to interface with the digital communication system. Input is via a standard keyboard and output is provided by a printer unit.

B.2.2 The IBM 2976 Model 3 Transmission Control Unit

B.2.2.1 Introduction

A microprogrammed device, the Transmission Control Unit controls the flow of messages and other data between an IBM System/360 or System/370 Central Processing Unit and a network of mobile terminals.

The TCU accepts outbound messages from the CPU, via the multiplexer channel, and transmits them to the proper mobile terminal, automatically selecting the radio channel appropriate to that terminal. Inbound messages are accumulated at the TCU as the mobile terminals are polled, and are transferred to the CPU for further processing upon its command. The TCU also initiates the transmission of outbound messages and initiates retries as required.

The TCU communicates with the IBM System/360 or System 370 via a standard IBM multiplexer channel. A data-dedicated duplex transmission line and the necessary data sets are provided to interface the TCU to the base station radio.

The TCU consists of six functional elements; the system control unit, bridge storage memory, integral disk drive, disk adapter, multiplexer channel adapter, and up to three link adapters.

B.2.2.2 System Control Unit

The system control unit is the primary functional element of the TCU. It is a microprogrammed processor that provides the capability to operate and control the network of mobile terminals. The system control unit consists of hard-wired control logic, data flow paths and data registers.

B.2.2.3 Bridge Storage Memory

The bridge storage memory unit contains the resident control program as well as areas for temporary data storage. The total memory capacity is 32K bytes of 1.2 microsecond access time read/write core storage.

B.2.2.4 Integral Disk Drive Unit

A disk drive unit is housed within the TCU. This unit is designed to accept the 2315 Disk Cartridge, which has a capacity of approximately one million bytes. The disk cartridge stores the TCU control and diagnostic microprograms.

B.2.2.5 Disk Adapter

The disk adapter allows attachment of the disk drive unit to the system control unit. It permits the transfer of read and write operations between the 2315 Disk Cartridge and the core storage in the system control unit.

B.2.2.6 Multiplexer Channel Adapter

The multiplexer channel adapter permits the TCU to be connected to the multiplexer channel of a host IBM System/360 or System/370 Central Processing Unit. A microprogram-controlled adapter, it interfaces with the system control unit and coordinates sequencing commands and instruction buffering, as well as hardware data and status transfers.

B.2.2.7 Link Adapter

The TCU may control up to three link adapters, each of which interfaces with a duplex radio channel. Each link adapter allows the TCU to communicate with up to 250 mobile terminals. The interface between the link adapter and the Signal Converter at the base station radio is a dedicated 2400 baud duplex transmission line.

The link adapter buffers, serializes, and deserializes data, under the control of the operational microprogram. Automatic polling, output message sequencing, output and input message interleaving, input message checking, error status collection and error recovery logic are all performed within the microprogram routines of the radio channel control program.

Each link adapter contains the following functional components.

B.2.2.7.1 <u>Common Interface</u>

Three link adapters may be added to the Transmission Control Unit. The common interface contains controls and address decoding common to all link adapters.

It also provides clock signals for the link adapters and encodes and decodes control signals transferred to and from the operational microprogram.

B.2.2.7.2 <u>Transmit Adapter</u>

The transmit adapter operates synchronously at a speed of 2400 bits per second. A continuous character stream is transmitted by inserting sync characters into the output data stream when no other information is being sent.

B.2.2.7.3 <u>Receive Adapter</u>

The receiver adapter also operates synchronously at a speed of 2400 bits per second, recognizing sync character patterns and transferring data from the transmit section of the data transmission interface or the operational microprogram to the operation microprogram.

Messages from the mobile terminals are solicited either by polling, which is an invitation to send, or by an ENQ (inquiry) sequence, which is a request for status information. Channel service requests are coordinated by the operational microprogram on an individual receive adapter basis.

B.2.2.7.4 Data Transmission Interface

The data transmission interface contains the hardware necessary for operation with an RS-232-C standard interface connected to a data set operating at 2400 baud. The Signal Converter, at the base station, interfaces between the externally clocked data set and the base station radio.

B.2.2.7.5 Error Checking by the Link Adapter

A forward-error-correction (FEC) technique is used by the link adapter to detect and correct transmission channel errors.

A half-rate convolutional code (one error control bit for each data bit) is used to correct bursts of errors that occur on both the telephone lines and the radio channel. The effective data rate for such a code is only half of the bit rate, however, which in this case yields a data rate of 1200 bits per second. Parity check bits are inserted between data bits in such a way that error bursts are not likely to include more than one bit of a checked group. Typically these types of codes can correct bursts of errors of 6 bits or less, provided that there are 19 or more correct bits between the error bursts.

B.2.2.8 Physical Specifications

Dimensions (Installed)	60" High, 32" Wide, 62" Deep
Required Service Clearances	35" front, 41" rear 60" right, 42" left
Weight	1350 lbs.
Heat Output	9,600 BTU/Hr
Air Flow	240 CFM
Power Requirement	208/230 + 10% VAC 60 Hz 3.5 KVA, 3 Phase
Environment, Operating	60-90°F 8-80% Rel. Humidity 78°F Max. Wet Bulb

Environment, Non-Operating	50-110°F 8-80% Rel. Humidity 80°F Max. Wet Bulb

B.2.3 The IBM 2976 Model 5 Signal Converter

B.2.3.1 Introduction

The Signal Converter is located at the base radio station and interfaces between duplex radio channel and a data set or leased line link. The duplex radio channel must be dedicated to digital data traffic. The Signal Converter thus provides the data link between the Transmission Control Unit and the network of mobile terminals.

Digital signals that are received by the Signal Converter from the TCU (via the data set) are used to modulate two audio frequency tones to produce an audio frequency-shift-keyed signal. This audio signal is then broadcast by the base station radio.

In a similar manner, audio FSK signals received from mobile terminals are decoded by the Signal Converter, and the clock and data signals transmitted to the Transmission Control Unit.

B.2.3.2 Signal Converter Functional Elements

The Signal Converter contains three functional elements, a modulator, demodulator, and common section. The modulator element converts digital data to be transmitted over the radio channel from a d.c. to an audio signal, using audio frequency-shift-keying. The transmission rate is 2400 bits per second. The demodulator element converts received audio transmissions into d.c. form, for transmission to the Transmission Control Unit. The common section contains the logic circuitry necessary to control these functions.

For communication with the Transmission Control Unit, a data set is required. Connections are in accordance with the RS-232-C standard, synchronous, externally clocked, and at a rate of 2400 bits-per-second. The interface between the base station radio and the Signal Converter is the user's responsibility. Connections must be made to the microphone input jack of the transmitter, to the push-to-talk line, and to the discriminator output of the base station receiver. The transmitter must be equipped with a clipping circuit and low-pass filter, as required by the FCC Rules and Regulations, Part 89-109. The modulator relies on this low-pass filter for removal of undesired harmonics from the audio input signal.

B.2.3.3 Physical Specifications

Interface Line:	
Discriminator Output	0 to 5 volts, peak-to-peak, maximum voltage range 1.5 to 3 volts, peak-to-peak, nominal
Microphone Input	0.3 volts, peak-to-peak, nominal
Push-to-Talk	Open circuit voltage not greater than 30 volts. Short circuit current not greater than 0.5 amp.
Dimensions (installed)	6.75" high, 17.0" wide, 5.0" deep
Service Clearance	12" for each surface, obtainable with cable slack
Weight	12 lbs.
Heat Output	35 BTU hr.
Air Flow	Convection - minimum of 6" clearance (installed) at each end.
Power Requirements	115 VAC 60 Hz 0.012 KVA Single phase 0.1 ampere current
Environment, Operating	32°-110° F 8-80% Rel. Humidity 85°F Max. Wet Bulb

Environment	-40° to + 140° F 8-80% Rel. Humidity 85° F Max. Wet Bulb

B.2.3.4 Data Set Requirements

The Signal Converter interface meets the EIA RS-232-C standard. All data sets used must also meet this standard. The data set used at the Signal Converter location must be synchronous, have a 2400 bits per second transmission rate, and use an external clock (supplied by the Signal Converter). The data set used at the TCU location must also operate synchronously, at 2400 bits per second, but it should have an internal clock. Both data sets must use the four wire duplex option, and operate over standard voice grade (3kHz audio bandwidth) telephone lines.

B.2.3.5 Radio System Requirements

The IBM Mobile Terminal System requires one data dedicated, FM, two-way duplex radio channel for each 250 mobile terminals. The base station transmitter and receiver must be rated for continuous duty. Simultaneous transmit and receive capability is required, as is carrier controlled squelch.

The Mobile Terminal System may be operated on any currently available radio channels. IBM suggests, however, that the VHF low band (25 to 50 MHz) has too high a noise-level to yield efficient performance. The VHF high band (144 to 174 MHz) and the UHF band (450 to 470 MHz) both will provide satisfactory performance. UHF frequency assignments are made in pairs, fulfilling the duplex channel requirement, but in the VHF high band, two clear frequencies must be obtained. A clear frequency is one with no co-channel interference.

An agency's existing radio equipment may be used if it meets the above requirements. Continuous transmission is required from the base station transmitter because, when no data are being transmitted, sync signals are transmitted to provide system status signals to the mobile terminals, as well as to provide the means for polling and message transmission. Design and procurement of the radio system, including the necessary FCC licenses, is the responsibility of the user.

B.2.4 The IBM 2976 Model 4 Mobile Terminal

B.2.4.1 Introduction

The 2976 Mobile Terminal, shown in Figure B-1, has been designed to interface with a standard two-way FM radio mobile. The terminal provides direct access to local and remote data bases, and permits controlled transmission of data to and from the Transmission Control Unit.

Keyboard entry and transmission of alphanumeric data are permitted, and a hard copy record of all messages, transmitted and received, is provided by the built-in line printer. The line printer is the only message display device provided in the terminal. However, a lighted guidance panel is provided which displays terminal and system status, provides keyboard entry guidance, and provides application-oriented alerts to the terminal operator. Mobile unit status is entered by a single keystroke. A transmitted message may contain up to 90 characters of text.

The mobile terminal requires that the mobile radio operate on a dedicated duplex channel, with one frequency used for transmission and the other for reception. Voice communications are not permitted on the data channel, but the mobile radio may be provided with a switch to allow voice communication on an alternate channel. In such a case, the radio is switched to the data channel when data are being transmitted, and to the voice channel when the microphone and speaker are used.

An optional two position keylock protects the terminal from unauthorized use. The OFF position completely removes power from the terminal. The ON position permits the terminal to be controlled by the panel mounted ON/OFF switch.

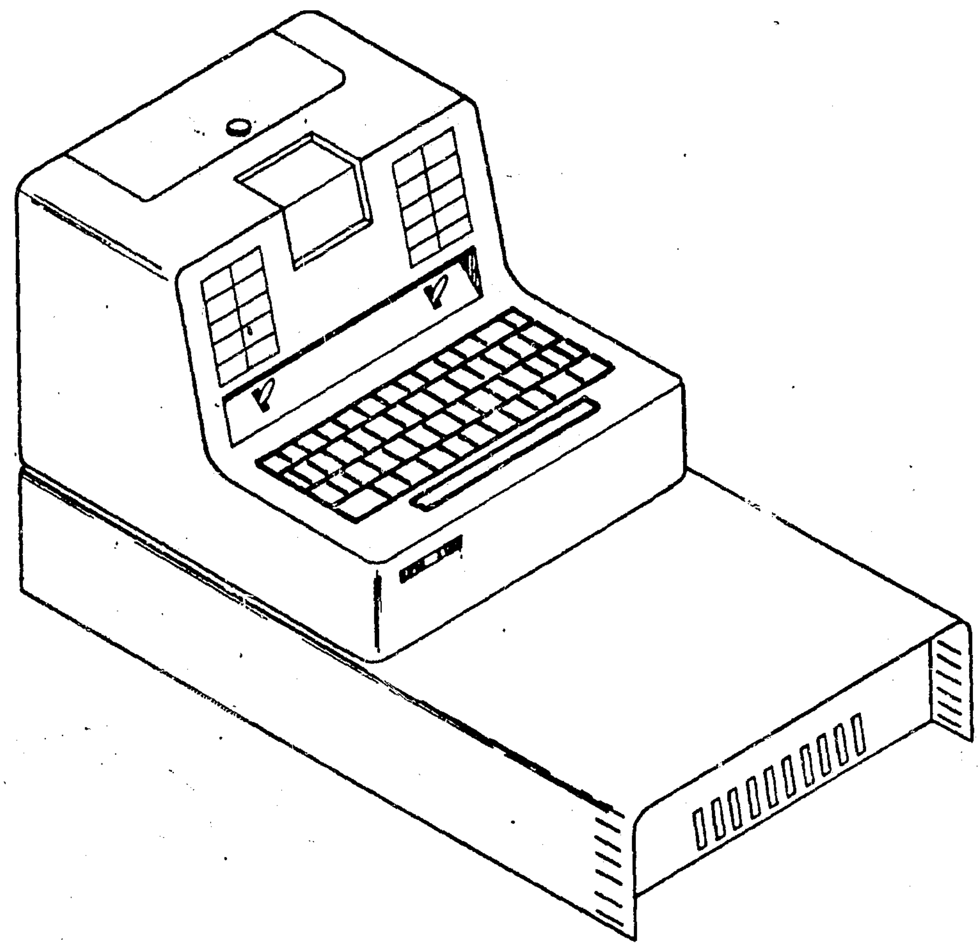


Fig. B-1 - IBM 2976 Model 4 Mobile Terminal

B.2.4.2 Mobile Terminal Functional Elements

The Mobile Terminal consists of the eight functional elements described below.

B.2.4.2.1 Control Logic

The control logic element is a multiple-register hardware device which controls the terminal by means of a stored program maintained in an internal read-only storage area. Data transfer to and from the control logic is by means of the I/O Adapters.

B.2.4.2.2 Storage Areas

Storage areas within the mobile terminal are dedicated to the control logic and contain the operating microprogram required by the control logic, the printer and keyboard translation tables, and I/O buffer and program save areas.

B.2.4.2.3 I/O Adapter

The I/O adapters are the interfaces between the control logic and the terminal input/output devices. Interfaces are required for the internal signal converter, printer, keyboard, and guidance panel, as well as for the terminal address and its link identification.

B.2.4.2.4 Signal Converter (Internal)

The internal signal converter is the interface between the mobile radio and the mobile terminal. In the receive mode, the audio FSK signal received from the mobile receiver is converted to a d.c. signal. In the transmit mode, the signal is converted from a d.c. to a frequency-shift-keyed audio signal.

Functionally, the internal signal converter is identical to the base station Signal Converter. The interface lines to the mobile terminal must meet the same specification as those for the Signal Converter. All such interfaces are the user's responsibility.

B.2.4.2.5 Keyboard

The mobile terminal keyboard has 49 keys. These permit the entry of alphanumeric data and provide additional keys for terminal control, special functions and special characters. The numeric keys, 0 to 9, provide single keystroke status entry. This operation does not require that the ENTER key be pressed prior to message entry or that the SEND key be pressed to initiate message transmission.

B.2.4.2.6 Printer

The terminal printer employs a continuously rotating print drum and uses a segment printing technique. The drum has 16 print positions around itself which generate a print segment matrix, and characters are formed by striking the appropriate segments as the drum revolves.

The printer prints up to 2-1/2 lines per second, with a maximum of 21 characters per line. In addition to the alphanumerics and the control characters, the printer can print an apostrophe, slash, a "less than" sign, a "greater than" sign, a dollar character, an open parenthesis sign, a closed parenthesis sign, plus sign, and an underscore sign.

B.2.4.2.7 Guidance Panel

The guidance panel provides visual guidance for the terminal operator. The left section contains 10 terminal status lights. The right section contains 10 user function lights which may be labelled with user specified names. The user function lights are set and reset by special guidance characters. These guidance characters may be included in the text of messages sent to the terminal by the CPU.

B.2.4.2.8 Power Supply

The power supply for the mobile terminal is housed in the base of the terminal. The terminal requires a maximum of 6 amperes at 12 to 18 VDC. The vehicle power supply furnishes this input power.

An optional ignition interlock is available. The interlock controls all power supplied to the terminal. No power is available when the ignition key switch is in the off or starting position. This feature reduces the chance of terminal failure due to low voltage when the vehicle is being started. When the ignition switch is in the ON position, power is supplied to the terminal.

B.2.4.3 Mobile Terminal States

Nine states are maintained by the terminal, which, together with the control characters, sequence numbers and display guidance lights, control the functions of the terminal. Within the TCU a record is kept of these states. An inquiry to this record can determine the terminal state and message sequence numbers. From this internal information, the TCU determines whether the mobile terminal received the last message sent out by the TCU and whether the TCU received the last message sent in by the mobile terminal.

B.2.4.4 Mobile Terminal Physical Specification

Dimensions (Installed)	4.0" high, 11.75" wide, 19.0" deep
Service Clearances	The Mobile Terminal must be removed from the vehicle for servicing.
Weight	45 lbs.
Heat Output	180 BTU/hr.
Airflow	Ventilation requirements are normally met by the vehicle environment, but the terminal logic box louvers should not be obstructed.
Power Requirements	12 to 18 VDC 6 amperes maximum current Negative ground system 4.5 amperes nominal 0.072 KVA

Environment, Operating	32-110°F 8-80% Rel. Humidity 85°F Max. Wet bulb
Environment, Non-operating	-40 to +140°F 5-100% Rel. Humidity 85°F. Max. Wet bulb

B.3 PROGRAM SUPPORT FOR THE IBM 2976 MOBILE TERMINAL SYSTEM

B.3.1 Introduction

The IBM 2976 Model 3 Transmission Control Unit (TCU) is a microprogrammed device which controls the flow of data between an IBM System/360 or System/370 Central Processor and a network of IBM 2976 Model 4 Mobile Terminals. The TCU accepts messages from the CPU and transmits them to the addressed terminals, and accumulates messages from the mobile terminals and transfers them, on request, to the CPU. The TCU also performs message checking and initiates retries as required.

The system programming (both operating and applications)for the System/360 or System/370 Central Processor that is required in order to operate the Mobile Terminal System is the responsibility of the user. IBM assumes that a Central Processor is available and that the user has the capability to do the necessary programming. System Engineering Services (SES) contracts with IBM are available, however, but this is an extra cost option. System diagnostics for maintenance purposes are provided by IBM.

From a practical viewpoint, the entire mobile communications system functions as a local input/output (I/O) device for the host System/360 or System/370 CPU. A software-oriented description of the system operation can be described in terms of two data interfaces, one between the TCU and the host CPU multiplexer channel, and a second between the TCU and the radio data link.

Although the Transmission Control Unit is a microprogrammed device, and, as such, may be considered to be a fixed-form contoller, the TCU does possess several important parameters whose settings may be modified to improve system performance. Typically these parameters specify the minimum number of buffers allowed in a buffer pool, the number of transmission retries before time-out occurs, and the minimum time delay acceptable before a re-inquiry is attempted.

B.3.2 TCU/CPU Multiplexer Channel Interface

B.3.2.1 Introduction

Functionally, the TCU provides an additional operational I/O interface to the host CPU. The resulting data communication system is described as automatic, buffered, and controlled. The microprogrammed TCU performs all functions relevant to communication system network management, such as polling of mobile terminals, checking of both in-and-out-bound messages, and initiation of retries for non-received messages. The system is thus automatic. In order to transmit a message to a mobile terminal, the CPU issues a WRITE command. In order to receive buffered inbound terminal-to-CPU messages, the CPU issues a READ command, but only when a sufficient number of inbound messages have accumulated.

Each inbound or outbound message is entirely buffered in the TCU before any attempt is made to transmit it to either the terminal addressed by a previously received WRITE command, or to transfer it to the host CPU following receipt of a READ command. A number of messages may also be buffered in the transmit (outbound) and receive (inbound) directions by each Link Adapter.

Control of the data communication system is delegated to the host CPU and its resident support programs. The TCU is designed (microprogrammed) so that the host CPU activates each Link Adapter, deactivates each Link Adapter, starts and stops the polling within each Link Adapter and regulates the rate at which inbound data are transferred to the host CPU.

B.3.2.2 Acceptable Multiplexer Channel Commands

The host CPU Multiplexer Channel uses the following commands to communicate with, and control, the TCU:

WRITE - Executes byte mode data transfer from the multiplexer channel to the TCU.

READ - Inbound data stored in the TCU data buffers are sent to the multiplexer channel

PREPARE - Used to effect a system status change when data are available to be input to the CPU. No immediate data transfer occurs.

SENSE - Obtains information from two sense bytes defining a previously detected error condition.

NO OP - The TCU returns a Channel End (CE) and Device End (DE) signal in the initial status byte.

TEST I/O - The TCU responds with:

All-Zero Status, indicating a command free TCU state with no pending or stacked messages, or Busy Status, indicating non-completion of the previous command.

ENABLE/DISABLE/SET MODE - The TCU accepts these commands. However, no action is taken and CE and DE signals are returned in the status byte.

HALT I/O - The control register is set to indicate the present conditions, and any command in progress is terminated.

B.3.2.3 Sense Bytes and Initial Selection

In addition to the above commands, certain logical information concerning the system state is necessary. This logical information is recorded in two TCU Sense Bytes. One byte is bit-significant and pertains to multiplexer channel operations. The second is applications oriented and describes CPU to TCU message format checking.

Execution of any I/O instruction or command chaining within the multiplexer channel generates initial device selection sequences which determine the channel-connected I/O device to be used. When the TCU responds to an initial selection sequence, a command byte is transferred to the TCU from the multiplexer channel. Chained commands are treated as if each had resulted from a START I/O command within the multiplexer channel.

B.3.2.4 Channel Command Responses of the TCU

In response to a valid channel command, the TCU performs the following basic operations:

WRITE - The TCU accepts and stores data presented by the multiplexer channel until an end-write transaction is processed or until an error is detected. The receive buffer pool count parameter specifies the maximum data which may be accepted.

READ - If inbound read data are queried within the TCU when a read command is issued by the host CPU, the waiting read transactions are transferred to the channel until (1) the data are exhausted, (2) a previous read transaction causes the amount of data read to exceed the TCU's maximum read count limit parameter, or (3) a HALT I/O is issued by the CPU.

PREPARE - After accepting this command, the TCU presents an ending status only when sufficient read data becomes queued or when a HALT I/O command is issued.

SENSE - Two bytes of TCU maintained sense information are transferred to the multiplexer channel during this command's operation.

NO-OP - This command results in no formal execution, but CE and DE status are returned in the initial status byte.

ENABLE/DISABLE/SET MODE - The operation is the same as that for a NO-OP command.

B.3.2.5 Write Transactions

The TCU is controlled by the host CPU through the transfer of units of data called write transactions. These write transactions are contained in WRITE command data streams. A write operation can consist of the transfer by the multiplexer channel to the TCU of one or a series of write transactions, terminated by a special end-write transaction. There are two functional types of write transactions, transmit and control.

A transmit write transaction or "transmit transaction" is the term applied to a message data string which must be transmitted over the radio data link to a mobile terminal. These are host CPU-to-mobile terminal messages. A transmit transaction may vary in length, but always consists of a terminal address list and a message data block. The TCU provides seven buffers per Link Adapter for storing transmit transactions. The CPU supporting program must specify, by a buffer address, the buffer to be used for each transmit transaction. The TCU then returns the buffer address to the CPU within the read data when the transmission has been completed and the buffer is free. In practice, the number of operating buffers is kept less than seven, to provide buffer availability for unexpected priority output.

The CPU indicates to the TCU the type of message that will follow by inserting appropriate bits in the write transaction control byte. The number of data characters to be transmitted appears in the write transaction count byte. Whether each output message is to receive normal or priority handling is also indicated. The TCU delivers CPU-indicated priority messages to the appropriate base station transmit adapter first, followed by CPU-indicated normal priority messages.

Control write transactions have a fixed length of two bytes and deal with TCU functions other than CPU-to-mobile terminal message transmission. Each control transaction instructs the TCU to perform a specific function. Link control write transactions are used to control the Link Adapter. End-write transactions appear at the end of all write operation data streams, and signal the end of the current write operation.

B.3.2.6 Read Transactions

When operational, the TCU requires periodic read command service by the CPU for the transfer of mobile terminal-to-CPU messages and the return of write transaction responses to the CPU via the multiplexer channel. Such service also frees the buffers allocated to these queued transactions. If a read service is not provided when required, the TCU may become unavailable for write command operation, if insufficient buffers are available, and further polling of all Link Adapters may be suspended, halting terminal-to-CPU message input. Such an event could occur if, for some reason, the CPU halted processing of the host support program without suspending TCU operations.

The TCU transfers all available inbound data to the CPU during read operations, in the form of fixed or variable length read transactions. If one or more complete transactions are queued when a read command is issued by the multiplexer channel, the read data stream consists of one or more read transactions, terminated by an end-read transaction. The first byte of any read transaction is a transaction identifier which denotes the type of transaction and its format. Four types of read transaction are possible: (1) received data, (2) transmit (write) response, (3) unsolicited status and (4) control response.

Received data read transactions are accumulated and queued by the TCU as the result of polling the mobile terminals through the Link Adapter. Transmit response read transactions are formed by the TCU after a write transmit transaction has been completed. For any TCU-initiated action on a Link Transmit Adapter, the TCU builds a response message and queues it for transmission to the CPU. Unsolicited status read transactions are originated by the TCU whenever abnormal conditions are detected. These inform the CPU, allowing the host program to take appropriate action. Control response read transactions are formed when write control transactions are completed, and can also include information requested by the CPU.

B.3.3 TCU/Mobile Terminal Data Link Interface

B.3.3.1 Introduction

Network control in the Mobile Terminal System is maintained by the TCU. Inbound terminal-to-CPU messages are solicited by polling the terminals through the Link Adapter. Outbound messages to terminals consist of select, ENQ or inquiry, and poll messages.

B.3.3.2 Outbound Messages and Mobile Terminal Control

Select messages contain data text which may be printed only, or may cause guidance lights to be turned on while also being printed, or may only cause guidance lights to be turned on. An ENQ or inquiry message from the TCU to a terminal solicits a response to confirm the integrity of the previous message. A poll message from the TCU solicits terminal-to-CPU data messages.

An outbound select (or data) message on the radio channel may be prefaced with any one of eight select-type characters denoting some logical combination of checked-function, override-function or message-incomplete properties of that particular message. A checked-function select character indicates that an ENQ message will also be transmitted to the terminal, to determine if the present message was received. Conversely, a message may be of the unchecked type. The override-function select characters allow the CPU to transmit an important message on an interrupt basis, overriding the operation of a terminal on which an operator is either keying in a message, ready to transmit a composed message, or seeking a response to some previously input message. Override-function select messages may also be of the checked or unchecked type.

Message-incomplete-function select characters are used for the transmission of multi-block messages to mobile terminals. As long as the terminal receives incomplete message blocks, it will not return to the ready state; thus, the terminal cannot interrupt the input data stream by entering a new message. This feature permits continuity within multi-block messages. A message-complete-function select character signifies the transmission of the block, allowing the terminal to return to the ready state.

The TCU buffers and holds a checked-function select output message and retransmits it upon receipt of a negative acknowledgement from the addressed terminal. No response is required for an unchecked message; this type is transmitted only once and therefore is not held. The number of transmissions which the TCU will attempt before freeing the associated transmit buffer is controlled by the pre-set retry parameter.

After a checked type message has been transmitted to a terminal, and if the associated Link Receive Adapter is not busy, an ENQ sequence is transmitted to the terminal asking for terminal status in order to verify whether or not the checked output message was received. If a response sequence is received but the sending terminal address cannot be recognized due to radio channel problems, the TCU waits for a short time (specified by a TCU parameter) and retransmits the ENQ sequence. If no response is recognized within the assigned response time, the TCU retransmits the ENQ sequence in the next available output time interval.

If the retry count is fully depleted before any response is detected from the terminal, indicating a timeout, or if the responses are garbled, or if there is an indication of a hardware error, the temporarily-out-of communication (TOC) bit is set in the terminal control word and retained in the TCU. When the retry count is depleted and the the terminal address TOC bit is set, the transmit buffer associated with that terminal is returned to the available state, and the CPU is notified of this abnormal condition.

B.3.3.3 Inbound Messages

Mobile terminal-to-TCU inbound messages are of two types, data messages and responses to TCU inquiry (ENQ) requests. Data messages include normal terminal-to-CPU inquiries, entries and so forth, and may also include test message requests, which may be either for a "canned" response or for a "wrapback" of the text portion of the test request. Test messages are handled by the TCU alone, and no notification of the CPU is required.

Response messages to a TCU inquiry request are transmitted automatically by the terminal to the TCU, immediately upon receipt of an ENQ status request sequence.

B.4 DESIGN AND ERROR CONTROL PHILOSOPHY

B.4.1 Message Transmission

Messages transmitted and received by the mobile terminals in the IBM 2976 system are similar in structure to the read and write transactions which are transferred between the CPU and the Transmission Control Unit. Outbound messages to the terminals consist of select, ENQ or inquiry, and poll messages.

Select messages contain data text. The text may be printed, may be printed and cause a guidance light to be turned on, or may only cause a guidance light to be turned on. A select character indicates whether such a message is to be checked, or is to override terminal operations, or is the last message block in a logically continuous message.

Poll messages solicit terminal-to-CPU inbound data transmissions. All transmissions from the mobile terminal are the results of poll messages received by the mobile terminals.

An ENQ, or inquiry message from the TCU to a mobile terminal solicits a response to confirm the reception of the previous message transmitted to that mobile terminal.

Sync characters are transmitted on the outbound frequency (TCU-to-mobile terminal) when no messages are being transmitted. These sync characters also serve as message frames, and provide bit-interval synchronization.

B.4.1.1 General Outbound Message Structure

A typical outbound message consists of a header containing control and address characters, an intermediate block check character which is formed by a cyclic redundancy check performed on the header, a text message of up to 90 characters, and a final block check character which is formed over the entire message. The character set used is the same as that used by the Transmission Control Unit, a special 8-bit code containing alphanumeric and control characters. Certain control characters are used to set and reset the guidance indicators.

The select character is an 8-bit character, and bit combinations are also used to designate ENQ and poll messages.

The address portion of the message may also contain the eight bit link adapter and mobile terminal addresses. A sequence number may also be added, and if present, is associated with the previous terminal address. Sequence numbers are only relevant for checked messages.

B.4.1.2 Outbound Select Messages - Single Terminal Address

The message structure is the following:

FRAMER
SELECT CHARACTER
LINK ADAPTER IDENTIFIER
TERMINAL ADDRESS
SEQUENCE NUMBER
INTERMEDIATE BLOCK CHECK CHARACTER
TEXT CHARACTERS (1-90)
BLOCK CHECK CHARACTER

B.4.1.3 Outbound Select Messages - Multiple Terminal Addresses

The message structure for these messages is as follows:

FRAMER
SELECT CHARACTER
LINK ADAPTER IDENTIFIER
TERMINAL NO. 1 ADDRESS
SEQUENCE NO. 1
TERMINAL NO. 2 ADDRESS
SEQUENCE NO. 2
....
....
INTERMEDIATE BLOCK CHECK CHARACTER

TEXT CHARACTERS (1-90)

BLOCK CHECK CHARACTER

B. 4.1.4 Outbound Select Message - All Unit Addressing

The message structure used for a message addressed to all terminals is the same as that used for a single terminal address message, but the terminal address is one used to denote an all unit message, and the sequence number is that associated with the all unit address.

B.4.1.5 Outbound Poll Message - Single Terminal Address

The poll message header structure is as follows:

FRAMER

POLL (SELECT) CHARACTER

LINK ADAPTER IDENTIFIER

TERMINAL ADDRESS

No check characters are added to a poll message.

B.4.1.6 Outbound Poll Message - Multiple Terminal Address

The message structure for messages to multiple terminals is the same as that used for a single terminal, except that the terminal address is replaced by a terminal address list of up to 31 terminals. No checking is performed.

B.4.1.7 Outbound ENQ Message Structure

The outbound ENQ message verifies that a mobile terminal has received a previous message. The message structure is the following:

FRAMER

ENQ (SELECT) CHARACTER

LINK ADAPTER IDENTIFIER

TERMINAL ADDRESS

SEQUENCE NUMBER

BLOCK CHECK CHARACTER

Note that the block check character, rather than the intermediate block check character, is included.

B.4.1.8 Inbound Poll Response Messages

The message structure used is:

FRAMER

TERMINAL ADDRESS

TERMINAL STATUS BYTE NO. 1

TERMINAL STATUS BYTE NO. 2

INTERMEDIATE BLOCK CHECK CHARACTER

TEXT CHARACTERS (1-90)

BLOCK CHECK CHARACTER

B.4.1.9 Inbound ENQ Response Messages

The message structure used is:

FRAMER

TERMINAL ADDRESS

TERMINAL STATUS BYTE NO. 1

TERMINAL STATUS BYTE NO. 2

BLOCK CHECK CHARACTER

B.4.1.10 Terminal Status Bytes

Two eight bit bytes of internal status information are maintained by the terminal and stored in the TCU. Both are bit-significant. Status Byte No. 1 records:

Terminal state hardware error

Terminal sequence number hardware error

Received IBC (Intermediate Block Check Character) error

Received BCC (Block Check Character) error

Invalid Terminal Address received

Invalid Data character received

Format error during receive

Terminal reset by reset control character

Status Byte No. 2 records:

- Terminal FEC (Forward Error Correction) error
- Terminal temporarily out of communication (TOC)
- Terminal CRC (Cyclic Redundancy Check) error
- Terminal message abort
- Terminal in broadcast incomplete state
- Terminal intervention required
- Terminal in keying state
- Terminal sending message.

B.4.2 Error Control Scheme

Error control in the IBM 2976 Mobile Terminal System functions at two levels. First, messages are parity checked, on an individual basis. Second, system errors are controlled by a sophisticated polling scheme.

B.4.2.1 Message Error Control

In general, each select message transmitted over the radio channel contains at least one parity check character. Poll messages are not parity checked. The parity check may be an intermediate block check, over only the address and control header, or it may be a block check over the entire message. These check characters are obtained by a cyclic redundancy check.

All messages are checked for errors by a half-rate convolutional code which interleaves parity check and data bits as the message is transmitted. This code has the capability to detect and correct all single bursts of five or fewer errors within a span of 19 bits. This means that if a burst of five errors occurs, 14 error free bits must pass before any other errors are able to be corrected. This code results in a doubling of the message length, and an effective data rate that is only half of the transmission rate of 2400 bits per second.

B.4.2.2 System Error Control

Details of the polling scheme used by IBM in the 2976 system have not yet been made available. A general description of the method follows.

Terminal addresses are arranged to form a polling list. The TCU performs all polling with reference to this list.

Outbound messages may be poll, ENQ or select types. These messages are transmitted in a message-interleaved manner, to permit time-spacing of mobile terminal responses. Since the radio channel is a duplex channel it is possible to transmit poll or ENQ messages to some terminals while receiving responses from others, thus conserving time, and increasing efficiency.

Strict discipline is maintained by the TCU on the outbound link. At all times only one message, which may be addressed to multiple terminals, is present on the outbound link.

On the inbound link, contention between terminals is possible. Two terminals may attempt to transmit responses nearly simultaneously. If this occurs, the TCU will receive an invalid response. Normal list polling is therefore suspended, while the TCU reviews the list to determine which terminals were in the process of transmitting responses. These terminals, which were contending for the channel are then repolled on a one at a time basis, after which the TCU resumes normal polling. The polling rate is thus variable, and is adjusted to meet system operating conditions.

The FEC (forward error correction) code enables a check to be made for sync-error-abort, which occurs if there is excessive noise on the channel, or if the carrier signal strength drops below a predetermined minimum. If this happens, inbound transmissions are neglected, and the polling scheme is switched to a slow-poll in order to recover the lost messages. Inbound messages must be received within a preset, but adjustable, time after the transmission of a poll or ENQ message. A number of retries, the maximum number being adjustable, will be made if necessary.

B.4.3 Modulation Technique

The modulation technique used to conver the d.c. digital data into audio signals that can be transmitted over the radio channel is audio frequency-shift-keying (AFSK). Two audio frequencies are used, 1200 Hz corresponding to a logical "1" and 2400 Hz corresponding to a logical "0". The transmission rate is 2400 bits per second and transmission is synchronous within a message but asynchronous between messages.

B.4.4 Line Control

IBM has adopted a polling technique for line control in the IBM 2976 system. Outbound messages are transmitted on a strictly controlled basis, according to a dynamically changing polling list. Terminals with a high message generation rate require and receive priority service by being more frequently polled than terminals exhibiting only limited activity.

The basic polling rate is variable and depends on outbound select message traffic and other system parameters, including the number of active terminals.

Contention may occur on the inbound link if two or more terminals which have recently received poll or ENQ messages attempt to simultaneously transmit their responses. Two steps have been taken to reduce the probability of such a condition. First, outbound poll and ENQ messages are interleaved with select messages to provide limited response timing. Second, a slow-poll mode enables the TCU to recover inbound messages that were received in error, or not received at all.

B.4.5 Throughput Capability

The IBM 2976 System uses a data transmission rate of 2400 bits per second. Since a half-rate code is used, the effective transmission rate is 1200 bits per second.

A single character is eight bits long, and an outbound message block may contain as many as 196 or as few as three characters. Message transmission times then vary between about 20 milliseconds and 1.5 seconds on the outbound data link. No extra time is required for synchronization on the outbound link. Inbound messages require additional time for transmission of a header which contains sync characters.

Inbound message blocks contain between four and 95 characters, which require transmission times ranging between 25 milliseconds and 0.635 seconds, excluding synchronization time.

Appendix C

A Detailed Description of the Motorola

MODAT Alphanumeric Terminal System

APPENDIX C

A DETAILED DESCRIPTION OF THE MOTOROLA MODAT ALPHANUMERIC TERMINAL SYSTEM

C.1 Introduction

This appendix contains as much information as IITRI has been able to collect on the design and operation of the Motorola MODAT Alphanumeric Terminal System. Motorola's position is that full details cannot be released until operating systems have been delivered, and none have been delivered to date. Therefore, many design parameters are not available and no description of the error control technique or transmitted signal structure can be included. The reader is cautioned that the MODAT Alphanumeric Terminal design is different from other MODAT devices (status entry units, line printer, etc.) and that the signal structure and error control technique used in these other devices may not be used for the alphanumeric terminal. Much confusion has been generated on this point and due caution is indicated.

The Motorola Alphanumeric Terminal System is, structurally, a typical local processor mobile/digital system. A base station minicomputer and CRT data terminals are employed as in other available systems. The reader is referred to the system overview in Section 3 before this detailed description is read.

C.2 MODAT System Hardware Units

C.2.1 The MODAT Alphanumeric Terminal

C.2.1.1 Introduction

The MODAT Alphanumeric Terminal was developed by Motorola to provide field officers with a means for rapidly accessing law enforcement data bases, maintaining the status of their mobile unit, and using an optional mobile printer, obtaining a hard copy output of all messages received at the mobile unit.

The terminal is compact, weighs only five pounds, and is mounted on an adjustable trunnion. The unit may be raised, lowered or swiveled for use by either the driver or front seat passenger. The unit can be tilted to reduce glare.

C.2.1.2 Keyboard and Terminal Operation

The mobile terminal keyboard is used by the operator to enter messages into the MODAT system. Forty alphanumeric keys are available for message composition (0-9, A-Z, -, ., /, space). Inquiries and other messages are composed using these forty keys and simple, preassigned message formats. As a message is entered, it appears on the display panel. When the operator is ready to transmit a message, he presses the Transmit (XMIT) key.

Five status keys are also provided to enable transmission of the following mobile unit conditions: Available (AVL), En Route (EN RTE), At Scene (AT SCN), Out of Vehicle (OUT VEH) and Out of Service (OUT SVC).

In addition, five "canned" message keys have been assigned by Motorola. These enable the operator to transmit the following messages with a minimum amount of data entry: 10-4, Repeat (RPT), License Check (LIC CHK), Wanted Person Check (WNT CHK), and Call (CALL).

Three keys are unassigned, and the user may designate these for either status or fixed message functions.

Six terminal control keys are used by the operator to alter the display and control the terminal's operation. A WRITE key causes the contents of the mobile terminal display to be printed by the optional mobile teleprinter. An on-standby (ON STD BY) key places the terminal in an operational mode or in a holding mode which allows no messages to be received or transmitted. SHIFT LEFT and SHIFT RIGHT display control keys (←,→) are used by the operator to scan through a received message, or to edit a message prior to transmission. Any message presently displayed at the mobile terminal may be discarded by pressing the clear (CLR) key. Messages not cleared are held until the operator presses the READ key, which causes a new message received from the base station to be displayed.

C.2.1.3 Message Display

A 32 character, 5 x 7 dot matrix, plasma display panel is used to present the first 32 characters of a received message or a message being composed. Messages may contain up to 64 characters of text, the last 32 characters being held by the terminal in its display memory. The entire 64 character message may be shifted through the display in a circular manner, enabling the operator to read messages longer than 32 characters without destroying any of the message.

Messages being composed by the operator appear on the display as the characters are entered. New characters enter the display at the right-hand side of the panel. To correct a character, or edit a composed message, the shift keys are used to place the desired character at the right-most position of the display. A new character or a space may then be entered automatically erasing the old character.

C.2.1.4 Status Indicators

An illuminated indicator is provided for each of the five preassigned status keys. Whenever the terminal is turned on, the five status indicators rapidly blink, to notify the operator that he must enter his mobile unit's status into the MODAT Command and Control System.

Status entry requires only a single keystroke, and the status light that corresponds to the status entered remains lit until a new status is entered.

C.2.1.5 Message Received Indicator

Whenever a message is received by a mobile terminal, it is held in a received message memory. At the time of reception, the message received (MSG RCVD) indicator lights, requesting the terminal operator to display the message. In order to do this, the operator must press the READ key and he then obtains a display of the first 32 characters of the message.

If a message has been received and stored in the received message memory, but has not yet been read, and a second message is transmitted to and received by the terminal, the MSG RCVD indicator flashes as a warning to the terminal operator. In addition, a reply message is automatically sent back to the processor, indicating that the second message cannot be accepted by the terminal. The processor may then store the second message until the mobile terminal is able to accept it. An audio alert option is also available which provides a tone signal whenever the terminal accepts a message.

C.2.1.6 Acknowledge Indicator

In order to transmit a message which he has composed, the terminal operator must press the XMIT key. The Acknowledge Indicator (ACK) then lights, as a signal that a message transmission has been initiated and that the unit is either waiting for the radio channel to clear, prior to transmission, or has transmitted the message and is waiting for a proper acknowledgment from the base station.

When the ACK indicator goes out, it is an indication that the last message sent was correctly received and automatically acknowledged by the base station.

If the ACK indicator is flashing, it denotes that the terminal has automatically transmitted the message five times without receiving an acknowledgment, and that the terminal operator must press the XMIT key again or take some alternate action, perhaps resorting to a voice transmission.

C.2.1.7 Message Structure

Details of the information code and specific message structure used by the MODAT Alphanumeric Terminal have not yet been released by Motorola.

A typical message transmitted from a mobile terminal can be expected to contain the vehicle address, terminal address, terminal status and control characters, and up to 64 text characters. Messages received by a mobile terminal may or may not contain text characters.

Motorola describes the vehicle address as composed of four alphanumeric characters, combinations of which yield 65,000 different identification codes. The terminal address also consists of four characters, and will be programmable to provide identification of the terminal operator.

C.2.1.8 Error Control

Only a general description of the error control technique used with the alphanumeric terminal is currently available from Motorola. Several levels of error detection are available, and the final method to be used in an actual system depends on the requirements of the particular agency.

Messages transmitted from the mobile terminal are checked for errors by the MODAT Base Logic Unit. All messages, both inbound and outbound, contain parity check bits at the character level and longitudinal parity check characters at the message level. Further, an interleaved code will be used during transmission that will enable the system to tolerate up to a 10 millisecond dropout of the radio channel due to noise or the action of a receiver voting system.

Status messages and "canned" messages will be compared to fixed formats by the MODAT Base Logic Unit. If the message is acceptable, a simple ACK message will be returned to the mobile terminal.

Variable text messages require that a sample of the inbound message be returned to the mobile terminal. The ACK message in this case will contain that sample. The mobile terminal verifies that the sample is correct, in which case the ACK indicator goes out. If the sample is not acceptable, the mobile terminal will retransmit the entire message, just as if no ACK had been received.

If no ACK message is received from the base station, the mobile terminal will automatically retransmit the message up to four times.

Outbound messages that are destined for a mobile terminal may be checked in any of several ways. First, no checking may be done. Verification of receipt of a correct message then requires that the mobile terminal operator take action and that this action be observed by the dispatcher. If the operator does not take the appropriate action, the message will be retransmitted by the dispatcher. Errors in a message must then be detected by the terminal operator. Of course, parity checks and interleaved codes will be employed and these may reduce the effects of transmission errors.

A second method for checking outbound messages involves checking the message destination address, and returning a simple ACK message to the base station if it is correct. In this case, message receipt is automatically verified by the mobile terminal.

A third method includes checking the outbound message destination address, and, if it is correct, automatically returning a sample of the text to the base station along with the ACK message.

The level of checking required, for each application, will depend on the demands and requirements of the particular user agency.

C.2.1.9 Data Rates

Motorola has not specified the exact data rates to be used in the MODAT Alphanumeric Terminal System.

A 64 character message is expected to require 1.5 seconds for transmission. A status or "canned" message, containing no text, should require 0.3 seconds of air time. These figures correspond to an effective character rate of 53 characters per second. Thus, approximately 18 characters are required for a status or "canned" message. Since eight characters are used as vehicle and terminal identifiers, five characters are available to use for control, status and synchronization.

The modulation technique used in the MODAT system has only been specified as differential audio phase-shift-keying. No details have been released describing the detection methods used.

C.2.2 MODAT Mobile Logic Unit

The Mobile Logic Unit is the hardware interface between the Alphanumeric Terminal and the mobile radio. Functionally, the Mobile Logic Unit serves as an encoder/decoder for messages transferred between the voice radio channel and the mobile terminal. As a decoder, the Mobile Logic Unit accepts an audio differential phase-shift-keyed signal from the mobile radio and converts it to a D.C. signal. This D.C. bit string can then be operated upon by the mobile terminal.

Messages to be transmitted from an Alphanumeric Terminal are also represented by bit strings, and these are encoded by the Mobile Logic Unit onto an audio carrier for transmission by the mobile radio, using differential phase-shift-keying.

The Mobile Logic Unit also controls the transmission and reception of messages by the Alphanumeric Terminal. Received messages are compared to fixed formats after decoding. Any retransmissions that are required for acknowledgments or verification are made automatically. Before a message can be transmitted, the channel occupancy must be sensed. The Mobile Logic Unit performs this function, and also controls the automatic retransmission of messages when acknowledgments are not received from the base station.

Vehicle identification is provided by a hardwired coded address within the Mobile Logic Unit. Operator identification can be provided by a programmable ID or variable ID key.

As far as the system is concerned, the mobile terminal and mobile logic unit are simply an input/output device and buffer between the terminal operator and the MODAT system. Motorola has designed these two elements so that much of the necessary electronic hardware can be placed in the trunk of the vehicle, reducing the size and weight of the Alphanumeric Terminal.

C.2.3 <u>MODAT Base Logic Unit</u>

The MODAT Base Logic Unit serves as the hardware interface between the MDP-2000 Data Processor and the base station radio. This device performs transmission control, message encoding and decoding, and received message error control for all inbound and outbound messages. Messages outbound from the Data Processor are PSK modulated onto an audio tone, and can be transmitted up to a maximum of four times, if no acknowledgment is received from the mobile terminal.

Inbound messages are decoded, checked for errors and verified. Acknowledgment messages are automatically issued to the mobile terminal by the Base Logic Unit.

Functionally, the Base and Mobile Logic Units are identical. Details of the character code, message structure, and modulation technique used by these units for transmission of digital messages over a voice radio channel have not yet been released by Motorola.

A description of the error correction code used, as well as a full description of the error control and message verification process, have also not yet been released.

C.2.4 MDP-2000 Data Processor

C.2.4.1 Introduction

The MDP-2000 Data Processor is a parallel logic digital minicomputer designed and manufactured by Motorola, Inc. specifically for communication system control applications.

In the MODAT Alphanumeric Terminal System, the MDP-2000 is the link between the network of mobile terminals and the base station complaint entry and dispatch center on the one hand, and the remote data base and Data Management System on the other. The Data Processor performs communications control, input/output buffering and message format conversion, and queueing of messages prior to their transmission to mobile terminals. The Motorola Data Management System uses the MDP-2000 Data Processor as a data base controller, performing information storage and retrieval functions.

A 16-bit data word is used by the processor. Up to 248 single input/output channels may be implemented. Direct memory access is available to all peripheral input/output devices, and cycle-stealing operation is used, permitting input/output between the main memory and any peripheral device without interference by the central processor unit. This feature frees the central processor unit to perform simultaneous non-input/output functions, increasing the overall operating speed of the Data Processor.

The Data Processor is mounted in a cabinet which has sufficient space to house the other computer-related components of a typical communication control system. Both the central processor unit and the basic input/output controller are built on plug-in printed circuit boards, and these are mounted in a cage which has space for six additional input/output controllers. Two more card cages may be added, each on providing space for an additional eight input/output controllers. Space is also provided for implementing up to 32K words of

16-bit core memory.

The MDP-2000 Data Processor is equipped with a power fail/automatic restart protection system, and is provided with an operator's console and a console teletype controller. The available instruction set contains 61 instructions, and 19 addressing modes are possible.

C.2.4.2 Central Processor Unit

The central processor unit operates in either the Executive Program State (EPS) or in the Functional Program State (FPS). While it is in EPS, the operation of the processor may not be interrupted. This state enables the processor to handle previous interrupts, and execute operating software system instructions. While in FPS, the processor executes applications programs.

A single interrupt port is available for placing the central processor in the Execute Program State. Interrupt service priorities are pre-wired and are ordered as follows:

Power Fail - The program location counter and processor status are saved, and memory contents are protected, in the event of a power failure.

Data Request - An application program calls for data transfer between one of the input/output channels and main memory.

Protection Trap - The processor is automatically switched to the Executive State when illegal instructions or program boundary violations occur.

Executive Call - This is a programmable interrupt which switches the processor from the Functional to the Executive State.

Console Panel Interrupt - This is a manual transfer to the Executive State, actuated from the operator's console.

Sixteen program-addressable registers, each with a capacity of 16 bits, are implemented in the main memory of the MDP-2000. Eight registers are dedicated to each of the two programming states.

A single program counter is used to record the execution of both operating and applications programs. When an interrupt occurs and the processor changes state, the program counter contents and processor status data are automatically saved, and these are restored when a return is made to the current state.

Instructions are formatted from one or two 16-bit words, permitting extended addressing. Nineteen addressing modes are available for accessing main memory and register contents, including register-to-register, indexed, indirect, immediate, register and program counter relative, and other combinations with both auto-increment and auto-decrement capabilities. The instruction set contains 61types, consisting of nine arithmetic, fourteen logical, eighteen branch, twelve shift and eight special purpose instructions.

C.2.4.3 Main Core Memory

A random access, magnetic core memory is used in the MDP-2000 Data Processor. The memory has a 650 nanosecond cycle time for either a read or a write operation. Memory contents may be addressed directly, either as a 16-bit word or an eight-bit byte. Parity checks are performed at both the byte and word levels. Memory protection is based on units of 128 words and is monitored by the operating software system.

The minimum memory size available is 8K words, but expansion is possible up to a maximum of 32K words, in increments of 8K.

CONTINUED

1 OF 3

PART II

C.2.4.4 Input/Output Systems

Up to 248 input/output channels may be implemented on the MDP-2000 Data Processor. To each channel may be attached a variable number of peripheral input/output devices, but only one device may use a channel at any given time. Data may only be transferred in one direction on a channel; that is, simultaneous single channel input/output is not possible. If a peripheral device requires simultaneous input and output, two channels must be used to support that device.

Each channel may transfer data directly into or out of the main memory, over a 16-bit parallel data path, at a rate of 180K words per second.

Many peripheral input/output devices are available for the MDP-2000. Each device requires an individual Input/Output Controller. Possible devices include:

- Console Teletype
- RS-232-C Standard Data Set
- Line Printer
- Paper Tape Reader/Punch
- CRT Data Terminal
- Magnetic Tape Drive
- MODAT Alphanumeric Terminal System
- Vehicular Printer Control Terminal

C.2.5 MDP-2000 CRT Data Terminal

C.2.5.1 Introduction

The CRT Data Terminal is an input/output device which uses a typewriter-like keyboard for manual data entry and terminal control, and has a television-like cathode ray tube (CRT) for an output display.

In the MODAT System, CRT Data Terminals serve as hardware interfaces between the MDP-2000 Data Processor and both the system dispatcher and complaint entry operator. The system dispatcher uses a CRT Data Terminal primarily for display of mobile unit status information and backlogged complaint data. The dispatcher may also make direct inquiries into the data base. A second CRT Data Terminal is used by the complaint entry operator to enter complaint data into the MODAT System and make direct data base inquiries. Both the dispatcher and the complaint entry operator may initiate terminal-to-terminal messages for delivery within the MODAT System.

A CRT Data Terminal is generally used for these types of computer-interactive operations because manual data input is normally rather slow, yet a rapid response is desired by the terminal operator.

C.2.5.2 Operating Features

CRT Data Terminals are available which communicate with the MDP-2000 Data Processor in either a serial or parallel mode. Parallel operation allows high speed, local operation because all bits in a character are simultaneously transferred into or out of the terminal. Serial operation may be used for local operation, or for remote operation with telephone data sets. In the serial mode only one bit of a character is transferred at a time.

Data Terminals may be supplied as free-standing units, or they may be factory installed in control center consoles supplied by Motorola as part of a MODAT Command and Control System.

Four models are available:

D1037A - Parallel operation, free-standing
D1038A - Parallel operation, factory installed
D1039A - Serial operation, free-standing
D1040A - Serial operation, factory installed.

C.2.5.3 Specifications

Display:	12" direct view CRT 74 sq. in. viewing area TV-type horizontal raster scan P4 (white) phosphor, standard
Refresh Rate:	60 Hz, crystal controlled
Character Generations:	5 x 7 dot matrix
Cursor:	Blinking underline, 4 Hz rate
Character Code:	7 bit ASCII standard
Hard Copy Output:	Connector available on rear panel
Remote Monitor:	Connector available on rear panel
Power Requirement:	115 VAC, 60 Hz, 120 watts maximum
Environmental:	Operating, +10°C to +40°C, 80% Relative Humidity Storage, -40°C to +65°C, 80% Relative Humidity
Dimensions and Shipping Weight:	Desk top with monitor: 17 1/8" w x 19 3/4" d x 13" h 68 pounds, including keyboard Rack mount without monitor: 19" w x 8 3/8" d x 10" h 39 pounds, including keyboard
Display Format:	1920 character positions 80 characters per line 24 lines
I/O Interface:	RS-232-C standard
Transmission Rates:	Serial: 110-9600 bits per second, switch selectable Parallel: 0-1000 characters per second 10,000 characters per second 900,000 characters per second

Serial Transmit Mode:	Half or full duplex, switch selectable
Transmission Format:	Parallel: 7 bit
	Serial: 10 or 11 bit start-stop code
Memory:	MOS Semiconductor,
	2048 characters capacity

C.2.6 MDP-2000 Line Printer

C.2.6.1 Introduction

In a MODAT System, a high-speed line printer can be supplied by Motorola in order to obtain printed output from the MDP-2000 Data Processor. The MDP-2000 Line Printer is required for those applications where the 10 character per second printing rate of a teletypewriter is inadequate. The Line Printer may typically be used to log "hits" resulting from data base inquiries, record mobile unit status changes, or to provide daily statistical records. Generally, the extent of the printing done depends on the requirements of the particular agency.

C.2.6.2 Operating Features

Two models of the MDP-2000 Line Printer are available, one printing at a rate of 135 lines per minute, the other printing at 300 lines per minute. Both models print up to 80 columns, use a 64 character code set, and provide single or multiple copies.

C.2.6.3 Specifications

Print Speeds	135 lines per minute, 300 characters per second
	300 lines per minute, 660 characters per second
Number of Characters	64 standard
Characters per Line	80 standard
Character Type	5 x 7 Dot matrix
Line Spacing	6 Lines per inch

Character Size	0.070 w x 0.100 h, nominal
Buffer Storage	Full line (80 characters)
Data Rate	Synchronous data entry, 33 KHz maximum
Code	6 bit ASCII standard
Interface Levels	Logical "0", +5 VDC
	Logical "1", 0 VDC
	DTL-TTL compatible
Input Voltage	115 VAC, 60 Hz, single phase
Power Consumption	900 watts maximum, 135 lines per minute unit
	1100 watts maximum, 300 lines per minute unit
Environment	Operating: 50°F to 105°F, 90% Relative Humidity
	Storage: -50°F to 150°F, 95% Relative Humidity
Physical	Size: 31" w x 27" d x 41" h, pedestal mounted
	Weight: Approximately 275 pounds.

C.2.7 MODAT Mobile Printer

An optional mobile teleprinter is available for use with the MODAT Alphanumeric Terminal System. Essentially, the teleprinter is mechanically identical to the VP-100 Teleprinter now available from Motorola. The MODAT Mobile Printer, however, will print directly from the Alphanumeric Terminal, rather than independently. When added to the MODAT system, this teleprinter will not require a printer control terminal to enable message transmission.

The Alphanumeric Terminal operator may print out any message displayed on the terminal simply by pressing a PRINT key. An internal hardware option will also be available that will enable messages to be printed remotely upon command from the base station, when the operator is not in the vehicle.

C.3 MODAT Alphanumeric Terminal System Design

C.3.1 System Software

Motorola has developed a full line of operating and applications software packages for the MDP-2000 Processor. The amount of applications software required depends on the functional requirements of each user. Certain software modules require other modules as a prerequisite for their application. A brief discussion of both the operating and applications software available is provided below.

C.3.2 RTMOSC-2000 Operating System

The RTMOSC-2000 real time multiprogramming operating system allows the MDP-2000 Processor to function as the central system component in the MODAT Alphanumeric Terminal System. As an executive monitor program, the RTMOSC-2000 allows a variable number of core-resident applications programs to operate on a multiprogrammed basis within a fixed relative priority system. The operating system keeps track of time in milliseconds, seconds, hours and days, schedules tasks for real time execution, schedules and executes input/output requests from the application programs, handles program interrupts, manages core memory protection, controls system tasks on-line, and handles reentrant subroutines.

In a multiprogramming system, each core-resident program is considered to be a task with a fixed priority for execution. Each task requires execution based either on time or on the occurrence of some event. Conversely, there are time intervals during which each task requires no execution. At any time, a given task may or may not be in the executable mode. In a multiprogramming system, a high priority task must be removed from the execution mode to permit execution of a lower priority task which is in the executable mode. Through calls on the executive monitor, execution of a task currently in the executable mode may be halted, and execution of another task also in the executable mode may be resumed. Once placed in the non-executable mode, a task's mode may change only by the passage of time, or at a predetermined time, or by the occurrence of an event which causes another task to change the mode of the now non-executable task. Certain tasks may be denied execution due to a program malfunction, and must be placed in the executable mode manually by an operator using the control console teletype. Other tasks may be waiting for some input/output completion, and may not be placed in the executable mode.

At any given time, the MDP-2000 Processor will be in either the Executive Processing State (EPS) or the Functional Processing State (FPS). All application tasks are executed while the machine is in the FPS. The RTMOSC-2000 operating system operates primarily in the EPS. Eight EPS registers are available to implement tasks. Whenever a task is interrupted and placed in the non-executable mode, the contents of the eight registers, the status indicator, and the program location are stored in the core memory.

An Input/Output Control System (IOCS) is a part of the RTMOSC-2000. Software drivers are included for all the peripheral I/O devices available from Motorola. As new or special devices become necessary, software drivers are added to the system, rather than special hardware interfaces.

Three levels of memory protection are provided by the RTMOSC-2000. These are (1) write memory protection only, (2) write memory and privileged instruction protection, and (3) read and write memory and privileged instruction protection.

Each functional task, or application program, is represented by a table entry in the main core memory. The fixed priority of a task is determined by the position of its table entry relative to all other table entries. The executive monitor maintains the next time of execution of each task. System time units are fixed at either 1/960 or 1/60 second, (1.05 or 16.67 ms). After the passage of each time unit, the executive performs a search for work to be done, and determines the highest priority task which is in the executable mode. If this task is an interrupted task, control is returned to it. If a higher priority task is executable, the register contents, status and program location are saved, the new executable task is restored, and control is passed to it.

C.3.3 Symbolic Assembler

A Symbolic Assembler is provided which enables programmers to write source code programs using a mnemonic form of the basic machine language. This permits the use of symbolic names and numbers for program variables and statements which are referred to throughout the program. Both direct and relative addressing is permitted, and both one and two-pass versions are available for translating the source code into acceptable machine instructions.

C.3.4 Utility Package

A Utility Package is provided to handle the routine functions of program loading, verification, punch, and print dump output. The Utility Package also provides debugging aids, in conjunction with program verification.

C.3.5 Motorola Command and Control Software System Modules

C.3.5.1 Introduction

Functional programming for a MODAT Alphanumeric Terminal System is obtained by configuring an application system from the various modules made available by Motorola. It is also possible for a user agency to develop its own modules, but Motorola provides modules that have sufficient flexibility to handle most requirements within the framework of Motorola's Command and Control System structure.

Motorola's general approach is to use terminal control routines which pass information on to larger standard modules.

The standard modules communicate with each other and are controlled by the RTMOSC-2000 operating system, described in Section C.3.2. Some modules require one or more other modules as a prerequisite to their operation.

It should be noted that nearly all data management functions are performed by the Motorola Data Management System, not by the applications programs.

C.3.5.2 Complaint Entry Module

The Complaint Entry Module provides a means for entry of complaint information into the system, as well as maintenance of complaint records in file. Complaint data are entered by a complaint operator on a CRT data terminal keyboard. Complaints may be entered at special complaint entry terminals, dispatcher terminals or supervisory terminals. Record control information is then added automatically. This module also furnishes complaint record queueing and recall capabilities for other modules in the system.

Any data terminal can be allowed or denied any privilege available to terminals in the MODAT system. Complaint entry terminals are normally allowed to enter and display complaint data using a predefined form. They may also display information received from the user's ANI (automatic number identification) service, enter and compose messages destined for other terminals, display complaints in a "hold" status, and display complaints waiting to be dispatched.

C.3.5.3 Dispatcher Display Module

This module allows a CRT data terminal to provide the interface between a dispatcher and the other application modules.

If the dispatch terminal is separate from the complaint entry terminal, the Automatic Complaint Routing Module is required to determine which complaints are to be handled by each dispatching position. The Dispatcher Display Module permits the dispatcher to queue and recall complaints, dispatch a computer-recommended mobile unit or select an alternate mobile unit, and assign backup units to a specific incident. The dispatcher may also enter operators' badge numbers, and assign priorities to complaints to be dispatched.

C.3.5.4 Automatic Complaint Routing Module

The Complaint Routing Module logically transfers complaints, which have been entered by a complaint operator, to a dispatcher.

In some small-scale systems, the dispatcher may also be the complaint operator. This module is still required in order to maintain the software interfaces necessary to logically separate the complaint entry and dispatching functions.

The Complaint Routing Module provides terminal identification and queueing for entered complaints, provides a selected routing algorithm, and provides displays for both the complaint entry operator and the dispatcher showing complaints awaiting dispatch. Only those complaints assigned to a dispatcher position are shown at that position.

Four standard routing algorithms are available from Motorola. These are (1) manual, with dispatch position entered by the complaint entry operator, (2) specified, with all complaints entered at one position transferred to a pre-specified dispatch position, (3) location dependent, using the Street-to-Crime District Module or (4) shortest line, with entered complaints automatically transferred to the dispatcher with the shortest queue of complaints waiting for dispatch. Once an algorithm is selected, supervisory terminals may alter the specified assignments on-line.

Other customer specified algorithms may be implemented as a special system product.

C.3.5.5 Street-to-Crime-District Module

Automatic conversion of incident location to crime district code is provided by this module. It accepts a number and street address from another module and determines the crime district code or X4 coordinates. The module requires random access to a file containing city map-to-crime district data. This data file is not included in the module, and is provided at extra cost. The Data Management System is a prerequisite for this module.

Generally, some error checking and operator diagnostics are also required, but only elementary checking and diagnostics are provided by this module.

C.3.5.6 Incident Status Module

This module tracks the status of incidents as they pass through the data system. Three states are used: complaint entered, complaint dispatched, and field actions taken. The module provides various information in response to a keyboard entered status request.

If processing of an incident requires that system limits be exceeded, displays and other warnings are generated. Such a situation could occur if a complaint were not dispatched within some preset time limit.

C.3.5.7 Adjacent Incident Display Module

This module allows all incidents which occur in the vicinity of some particular incident to be displayed on a CRT data terminal. Multiple responses to a single incident can thus be avoided.

This module performs a table look-up function, searching for recently entered complaints with common information such as type, location, calling person, etc. Possible mistakes are then displayed to the dispatcher, along with the status of the previous similar incident.

C.3.5.8 Status of Forces Module

This module enables the status of mobile units and other terminal-equipped resources to be stored, updated and displayed for use by the dispatcher. Status changes are accepted manually from the dispatcher keyboard, or automatically upon entry at MODAT alphanumeric terminals.

Status information may be displayed using a scoreboard listing, or using a single item display, either of which is available to the dispatcher on request.

C.3.5.9 Vehicle Recommendation Module

Status information from the Vehicle Status Module is available to the Vehicle Recommendation Module. This module will recommend an available vehicle in whichever crime district is manually entered by the dispatcher.

If the Street-to-Crime District module is included in the system, it is possible to recommend a vehicle for dispatch based on the original information entered by the complaint operator.

The addition of a Vehicle Location Module permits the system to recommend the closest available vehicle to the location of an incident.

If there are no available vehicles in the crime district corresponding to the incident location, a vehicle from an adjacent district may be assigned.

C.3.5.10 Vehicle Location Module

An automatic random vehicle location procedure can be implemented within the Motorola Command and Control system. This procedure would enable the dispatcher to assign an available vehicle closest to the location of an incident.

This module would accept vehicle geographic coordinate information either manually from the dispatcher, or automatically from a separate electronic vehicle location system.

Location information would then be continuously stored for each vehicle and would be available for display to the dispatcher and for use by other modules in the system.

C.3.5.11 Mobile Digital Keyboard Modules

Software interfacing of the alphanumeric terminals to the Command and Control System is provided by the Mobile Digital Keyboard module, which permits on-line information to be retrieved directly by mobile units. Normally, the NCIC Interconnect module would be included in such a law enforcement system.

C.3.5.12 NCIC Interconnect Module

When an agency has an interface to the National Crime Information Center (NCIC), this module will accept abbreviated inquiry messages from local CRT data terminals and other modules in the Command and Control System. These messages are then forwarded, using a standard message format, over the NCIC interface. The use of abbreviated message formats simplifies the input task of terminal operators.

Entry into a terminal of any vehicle license number, name/social security number, name/sex/race/DOB, or name/miscellaneous identification number will result in the generation of an NCIC wanted/stolen check. "Hits" are displayed simultaneously at dispatcher, complaint, and supervisory CRT terminals. "No-hits" are displayed only at the inquiring terminal.

C.3.5.13 ANI-CNA Interface Module

If the necessary telephone company equipment is available, the ANI-CNA Interface module allows the name and street address of the calling party to be forwarded to the police department along with each incoming phone call. The ANI-CNA Interface Module allows this identifying information to enter the Command and Control System, eliminating the requirement that the complaint entry operator manually obtain and enter this information.

C.3.5.14 Automatic Frequency Switching Module

This module permits the microphone at a dispatcher position to be switched to the appropriate mobile unit voice radio frequency, either manually by keyboard entry of the vehicle's identification number, or automatically if the Vehicle Recommendation module is part of the system.

C.3.5.15 Terminal-to-Terminal Dialogue Module

Any terminal operator in the system may enter a message and direct it to any other terminal in the system when this module is included. The originating operator must specify an address or terminal number as the message destination.

C.3.5.16 Remote Computer Interface Module

This module provides software capability for the Command and Control System, enabling it to communicate with a remote data base using industry standard serial data communication techniques. Any asynchronous data rate up to 9600 bits per second can be accommodated.

The hardware interface of the MDP-2000 is compatible with the RS-232-C standard. When the Activity Logging module is also used, transactions generated by the Command and Control System may be "batched" prior to data transfer. The Command and Control System can then be polled by the remote source, and all transactions accumulated since the last poll can be transferred in or out of the MODAT system. This module must be included if communications with a remote computer are required.

C.3.5.17 Traffic Hazard File Module

This module maintains a file of temporary highway hazards such as road closures, detours, and street work. This information can be used to determine alternate vehicle routings as well as to provide public traffic information.

C.3.5.18 Premise Information File Module

Any location which can be identified by a unique street address can be recorded in a file containing information on buildings, lots, and residences. Location history information is recorded in narrative form, and may include previous incidents at that address, building owner information, unusual contents or layout, and alarm system data. Before responding to a dispatch, the field officer would request location information and receive any information presently on file.

The Premise Information Module requires the use of the General Display Data Management, Terminal-to-Terminal and Street-to-Crime District modules.

C.3.5.19 General Display Module

This module is a generalized text editor which allows the terminal operator to create, edit or display data available in on-line files. The operator may append a specified file by entering new text at the terminal, change only a specified line of text, write and store a new file, delete and remove a file currently in storage, and display a specified page of text to other selected terminals. A page of text is defined as the maximum number of lines displayable on the user's terminal, minus one line.

If on-line storage requirements exceed more than two pages of text, the Data Management System must be included in the overall system.

C.3.5.20 Activity Logging Module

Information from the other system modules is accepted by the Activity Logging Module, and transactions containing this information are written on magnetic tape for off-line processing by a separate computer.

Motorola can supply magnetic tape systems compatible with most major computer systems. Stored information formats vary, and depend on the overall system configuration and other software modules included in the MODAT System.

C.3.5.21 Statistical Summary Module

This module provides a hard copy of statistical summary data on a specified line printer, and an abbreviated summary at a requesting CRT data terminal.

Statistical data can describe the number of calls per district, the average mobile unit response time per district, the average dispatcher response time per district, the average call service time per district, and the total number of calls per district.

Additional data can also be obtained, such as the number of calls per unit, and the number of personal calls and their average duration. These statistics are compiled on a daily basis, with a new record starting with the first shift on each day.

C.3.5.22 Automatic Pre-dispatch and Mobile Alert Module

As a preliminary step toward a computerized dispatching system, this module forwards information about complaints to mobile units in or near the appropriate district, providing an early alert prior to a manual dispatch.

As the complaint is entered into the system, the ANI-CNA Interconnect module forwards the phone number, name, and address of the calling party to the MODAT System.

The Vehicle Recommendation module identifies the available mobile units near the incident location, and the complaint information is forwarded to these units by the Mobile Alert module while the complaint operator is receiving the remainder of the call. Also, an alert tone may sound at the mobile units, advising the field officers that they may expect to be dispatched to the described location.

C.3.5.23 Automatic Telephone-to-Mobile Module

This module enables the calling party to talk directly to the operator of a mobile unit. Prerequisites for this module include the Vehicle Status, Vehicle Recommendation, Street-to-Crime District, Automatic Pre-dispatch and Early Mobile Alert and Automatic Frequency Switching Modules.

C.3.6 The Motorola Data Management System

The Data Management System has been designed to run on a dedicated MDP-2000 Processor, separate from the Command and Control application modules. This system provides a means for arranging, storing, and retrieving data from disk files.

Operation of the Data Management System depends on the hierarchical nature and use of most administrative data. Data are thus stored in a hierarchical structure, and disk space is conserved when certain types of information are not present. If specific information classes do not pertain to a particular incident, no unnecessary space is consumed or reserved.

Interfaces to the Data Management System from the applications programs are performed by simple calling statements. New data types may be added to existing files without changing existing applications programs. This feature insures that certain programs never "see" particular types of data, insuring system privacy.

In a sophisticated Command and Control system, data base activity can be expected to become a major activity. For this reason, a dedicated processor is used by the Data Management System, enabling data entry and display, and data base activities, to proceed simultaneously, minimizing deleterious effects on response times.

C.4 MODAT SYSTEM DESIGN AND ERROR CONTROL PHILOSOPHY

C.4.1 Introduction

Since Motorola does not yet have a MODAT Alphanumeric Terminal System operating in an actual law enforcement environment, all design details of the system are considered to be proprietary information. No details will be released by Motorola until a system is in actual operation. For this reason, only a general description of the MODAT Alphanumeric Terminal system design can be presented here.

C.4.2 Message Transmission

C.4.2.1 Messages Originating at the Alphanumeric Terminal

C.4.2.1.1 Introduction

The MODAT Alphanumeric Terminal system is designed to provide field officers with access to law enforcement data bases, maintain mobile unit status information, and facilitate terminal-to-terminal message transmission. Generally, a message originating at a mobile terminal will be either a data base inquiry, a status message, or a terminal-to-terminal text message.

C.4.2.1.2 Remote Data Base Inquiries

Keys are available on the mobile terminal keyboard for initiating license checks (LIC CHK) and wanted person checks (WNT CHK). To perform such data base inquiry, the operator presses the appropriate function key, enters the required identifiers, and then presses the transmit (XMIT) key.

For a license check, only the license number, followed by a slash and the state, need be entered. The year may be optionally entered, and the state need not be included for in-state license checks.

Wanted persons checks are similarly performed. Identifiers such as sex, race, date of birth, and social security number may be added to the entered name. In all cases, the inquiry operation requires minimum effort from the terminal operator.

Using the three available unassigned keys, other types of inquiry may be generated. Any inquiry message may be up to 64 characters long, which is the maximum message length permitted for any message generated by a mobile terminal.

C.4.2.1.3 Status Key Utilization

Five mobile unit status keys are provided on the Alphanumeric Terminal keyboard: AVL, EN RTE, AT SCN, OUT VEH, OUT SVC. Status entry is a single-keystroke operation, not requiring the use of the transmit key. A status message contains no text, and is one of the shortest messages originating at the mobile terminal.

C.4.2.1.4 Terminal-to-Terminal Messages and Function Keys

Three keys are provided for fixed-format terminal-to-base station messages. A manual acknowledgment (10-4) key is used by the mobile terminal operator to indicate receipt of a message from the base station. A call (CALL) key requests the base station to establish voice contact with the mobile unit. A repeat (RPT) key requests retransmission of the previous data message by the base station. Unlike status keys, these three keys require the operator to first press the appropriate fixed message key and then the transmit key.

Terminal-to-terminal messages may also be sent by using a pre-assigned terminal address format. The operator enters the destination address, followed by a text message. A total of 64 characters may be used for both the address and the message text.

C.4.2.1.5 Inbound Message Formats

Details of the inbound message formats used in the MODAT Alphanumeric Terminal system have not been released by Motorola.

It may be anticipated that inbound messages will contain start-of-message characters, vehicle and terminal address characters, control and status characters, up to 64 characters of text, and end-of-message characters.

C.4.2.2 Messages Outbound from the MDP-2000 Data Processor

In the MODAT System outbound messages for delivery to an Alphanumeric Terminal originate either within the MDP-2000 Data Processor, or at other points in the system, such as dispatcher or complaint entry terminals. In all cases, these messages must pass through the MDP-2000 Data Processor prior to their transmission over the radio channel.

Outbound messages may contain responses to data base inquiries, terminal-to-terminal text, or control information (such as mobile printer operate commands). Generally, these messages will share a common format, which can be expected to be similar to the format described for inbound messages. Messages are limited to 64 characters of text. For longer messages, a paging technique must be used. The entire message may also be printed, 64 characters at a time, on the optional mobile printer.

C.4.3 Error Control

C.4.3.1 Error Control for Inbound Messages from the MODAT Alphanumeric Terminals

C.4.3.1.1 Introduction

Inbound messages in the Alphanumeric Terminal system will be protected by parity error checks at both the character and message levels, the use of a forward-error-correcting (FEC) code for message transmission, and automatic retry procedures if the above techniques fail.

In some instances, error correction techniques may fail to correct all the errors which exist in a received message. In this case, Motorola relies on both the dispatcher's and/or the terminal operator's ability to pick out message errors, eliminating the need for some retransmissions.

C.4.3.1.2 Coding Techniques

The character code to be used with the Alphanumeric Terminal system has not yet been released by Motorola. It can be expected that at least one parity check bit per character will be included. A single parity bit can detect any odd number of bit errors, but does not permit error correction. This scheme can, however, be extended to error detection and correction over an entire message block, using cyclic-redundancy-check techniques.

During message transmission, an interleaved code will be used to insert parity check bits between message bits. This code promises to allow channel dropouts or error bursts up to 10 msec in duration, during a 1.5 second transmission, without affecting the quality of message reception. This will enable the system to operate with some existing receiver voting systems without modification of the voting equipment.

C.4.3.1.3 Retransmission Features for Inbound Messages

When message transmission is initiated at a mobile terminal, the ACK indicator lights. The mobile terminal must receive an acknowledgment from the base station in order to extinquish this indicator. Up to four retransmissions will be made automatically, at two second intervals, if an acknowledgment is not received. If the message has still not been acknowledged, the ACK indicator flashes to notify the terminal operator of a transmission failure.

At the base station, coding techniques are used to detect and correct errors. Inquiries to the data base are not allowed to contain errors. Inquiries with errors will not be acknowledged, and retransmissions will automatically occur. Other messages, such as terminal-to-terminal types, are presented to the addressed location with a special "error character" inserted in any required locations. The operator must then manually decipher the message and take the appropriate action. The ACK message returned to the mobile terminal will contain the unit address, control and status information, and a sample of the received message for automatic verification by the terminal.

C.4.3.2 Techniques for Outbound Error Control

Parity checks and the forward-error-correcting code will be used for outbound as well as for inbound message error control. In addition, three levels of error control, which may be operator dependent, will be used. The extent of the error control that is provided will depend on the requirements of the user agency.

At the first level, outbound messages are checked and verified by the terminal operator. Data base inquiry responses, for example, will contain the data received at the base station. The operator must verify that the data included in the original inquiry matches that which has been returned. Special error characters are inserted when required. No acknowledgment is required to be returned to the base station.

A second level of error control requires only the return of the address of the receiving terminal to the base station, indicating that the message was received in some form. The operator must manually acknowledge such messages if verification is required.

Finally, messages may be sampled, and an acknowledgment which contains the receiving address, plus the sampled message, may be returned to the base station. This provides an indication of near-correct reception, but not of the response of the terminal operator.

The MODAT system relies on the ability of the human elements in the system to perceive and correct minor transmission errors. In some non-critical cases, this can improve overall system performance.

C.4.4 Modulation Technique

The modulation method to be used by Motorola in the MODAT Alphanumeric Terminal System has only been described as an audio differential phase-shift-keying. No details of the audio carrier frequency, bit transmission rate, or character code used have been released. However, the method used will enable the Alphanumeric Terminal System to be compatible with existing Motorola voice radio communication systems.

C.4.5 Line Control

The MODAT Alphanumeric Terminal System will be designed to share existing voice radio channels, operating in a contention mode. Carrier sensing techniques will be used to prevent digital traffic from overriding voice traffic on such a shared channel. Limited error control techniques reduce the effects of voice traffic on digital traffic, but precedence must always be yielded to voice traffic. The MODAT system can operate with either half-duplex or full-duplex radio systems.

Operation with systems which utilize receiver voting systems is also possible. Modification of the voting systems will not be required if the channel dropout errors introduced are correctable by the forward-error-correcting code.

C.4.6 Throughput Capability

The only details released concerning the message throughput capability of the MODAT Alphanumeric Terminal System are that a message containing a full 64 characters of text will require about 1.5 seconds for transmission, excluding verification. An address and status type message will require about 0.3 seconds for transmission.

These figures indicate that the text portion of a message requires about 1.2 seconds, for a 64 character message, indicating a transmission rate of 53 characters per second. From this it can be inferred that during the remaining 0.3 seconds about 18 characters may be transmitted. Some time will be required for channel sensing and synchronization; the remainder can be used for address, control and status information.

APPENDIX D

APPENDIX D

A DETAILED DESCRIPTION OF THE ATLANTIC RESEARCH CORP. ARCOM SYSTEM

D.1 Introduction

The following sections describe the design operation of the ARCOM Mobile/Digital Communications System. Since Atlantic Research Corp. does not, as of this date, have an ARCOM System operating in an actual law enforcement environment, many features of the system, especially the required software support, have not been documented. Certain design details are also considered proprietary information and are thus not available for this report. This appendix does, however, contain all the information which IITRI was able to collect concerning the ARCOM system. It is assumed that the reader has read the overview of the ARCOM system in Section 3, so that he has some general familiarity with the composition and operation of the system.

D.2 ARCOM System Hardware Units

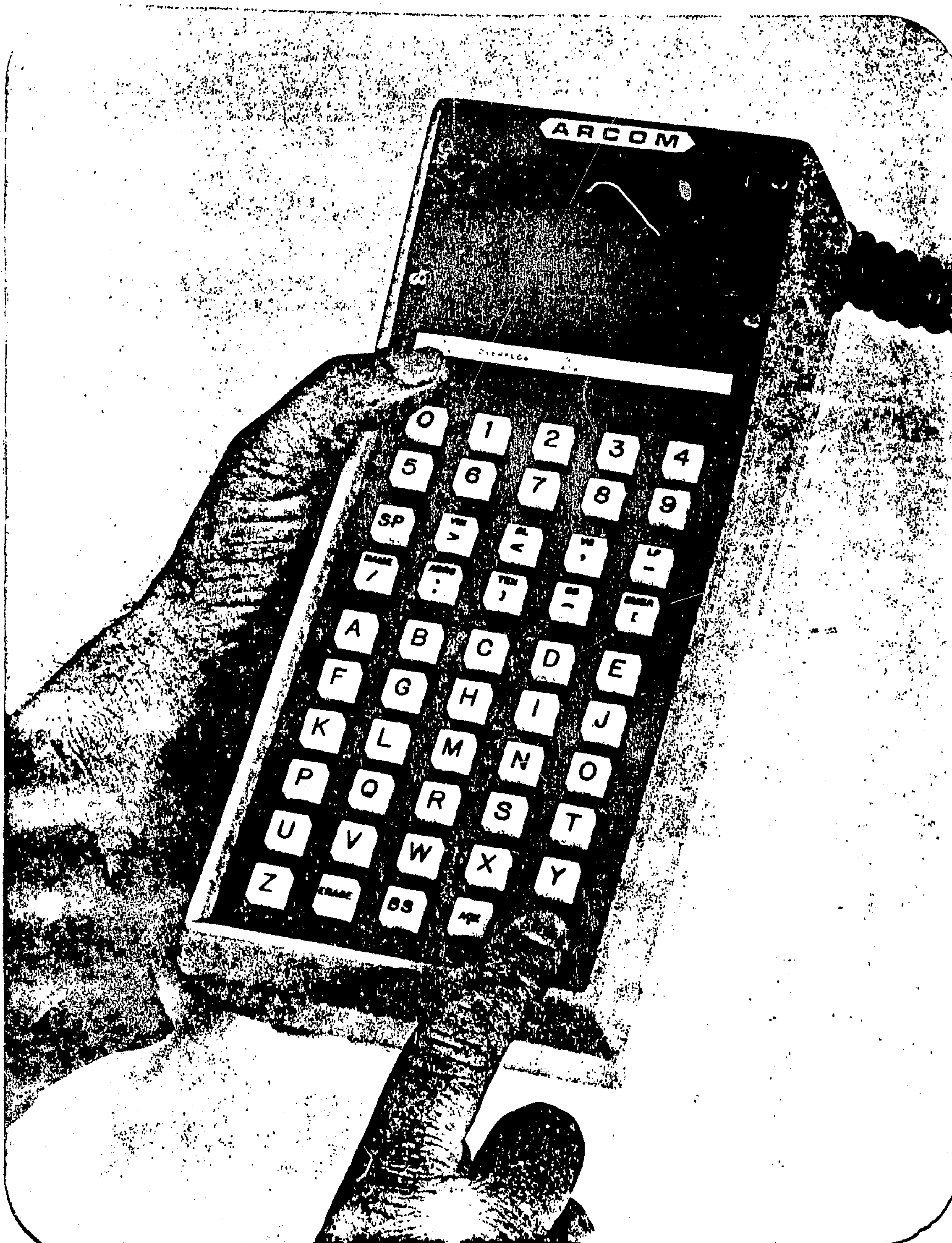
D.2.1 The MCT-16 Mobile Communications Terminal

D.2.1.1 Introduction

The MCT-16 Mobile Terminal, shown in Fig. D.1, was designed by Atlantic Research Corp. specifically for use in a law enforcement data communication system. The Mobile Terminal allows an operator to directly access remote law enforcement data bases, enter mobile unit status changes in a simple manner, and send messages to and receive messages from other properly equipped units in the same ARCOM System, including the system dispatcher.

One interesting aspect of the terminal's design is its novel keyboard arrangement, which is simple, but non-standard, and designed to permit easy use of the terminal by operators not familiar with typewriter-like keyboard arrangements.

Fig. D-1


ARCOM
0 1 2 3 4
5 6 7 8 9
SP
A B C D E
F G H I J
K L M N O
P Q R S T
U V W X Y
Z
ERASE
BS

D.2.1.2 Keyboard and Terminal Operation

Inquiries and data to be transmitted from the mobile unit are entered into the MCT-16 Mobile Terminal by its operator, using the terminal's keyboard which consists of 50 keys. The 50 keys are arranged into 5 columns and 10 rows, 5 keys per row. The numerals (0-9) occupy the top two rows, running from left to right and top to bottom. Next, two rows are devoted to 10 special purpose keys, nine color-coded blue, and a red Emergency (EMER) key. The 26 alphabetical characters occupy most of the remaining 6 rows, running (A-Z) from left to right, and top to bottom. In the bottom row, the final four keys are ERASE, BS, ACK and XMIT.

Thirty-seven alphanumeric characters are available (A-Z, 0-9, SPACE). Messages are composed using these characters, and entered into the terminal by pressing the appropriate keys.

Ten keys are provided for special purposes. One key is a SPACE key. The other nine are used for inquiry functions, status entry and manual acknowledgment. The inquiry function keys are normally used to initiate data base checks, and may be labeled to correspond to such inquiries as vehicle identification number (VIN), driver's license (DL), vehicle registration (VR), license plate (LP), name (NAME), address (ADR), and Social Security number (SS).

Status entries are performed using the ten-code (TEN) key, and a special emergency key (EMER) is available to initiate a priority message. An acknowledge (ACK) message may also be manually initiated.

The designations of the seven inquiry function keys (VIN, DL, VR, LP, NAME, ADR, SS) may be modified to meet the user's data base requirements.

Two display control keys, backspace (BS) and erase (ERASE) are used to shift and clear the contents of the display. Transmission of all messages from the MCT-16 Mobile Terminal is initiated by pressing the transmit (XMIT) key.

To perform, for example, a name inquiry, the operator first presses the ERASE key to clear the display, then presses the NAME key, and then enters the name to be checked, following a simple format which does not require punctuation marks. Transmission of the inquiry is initiated when the operator presses the XMIT key.

A single eighty character display memory is provided. The first character of any message will always be a special character which corresponds to the code used for that function key. This permits up to 79 text characters to be entered. Before entry of any message, the ERASE key must be pressed to clear the contents of the display memory.

To enter the status of a mobile unit, the operator presses, in sequence, the ERASE key, the TEN key enters the proper numeric status code, and then presses the XMIT key.

Terminal-to-terminal messages require the addition of necessary software at the base station, and assignment of a function key for this message type. To enter a terminal-to-terminal message, the operator presses the ERASE key and then the assigned function key. He then enters the destination address and the message, and presses the XMIT key. The applications programs in the SPC-16 Computer at the base station then re-address and re-route the message to its proper destination.

The Emergency key (EMER) enters a special priority message character into the terminal. Prior to pressing the EMER key, the operator must press the ERASE key. After pressing the EMER key, the operator must press the XMIT key before transmission will be initiated.

Once the display has been erased, and either a special function, TEN, EMER or ACK key has been pressed, up to 79 text characters may be entered before pressing the XMIT key.

D.2.1.3 Message Display

A 16 character 5 x 7 dot matrix LED (light emitting diode) display panel is used to present the first 16 characters of a received message, or the last 16 entered characters of a message to be transmitted. The display is arranged in two rows of eight characters each. Messages transmitted from the Mobile terminal may contain up to 80 text characters. The entire message may be circularly shifted through the display using the space (SP) or backspace (BS) keys; this enables the operator to read messages longer than 16 characters.

As new characters of a message are entered by the operator, they appear in the lower right-hand position of the display. When the ninth character is entered, the first-entered character appears in the upper right-hand position, and moves across the upper 8-character row to the left until the sixteenth character is entered. Then, as new characters are added, the oldest characters disappear, one by one, and only the last entered 16 characters are visible to the operator. No characters have been lost, however; they are stored in the terminal memory but cannot be displayed because of the 16 character limitation.

The character last entered can be erased by pressing the backspace (BS) key to shift the character back one position and out of view, and then entering a new character over the old one. Backspacing alone does not erase old characters.

When a message has been received, it must be erased by pressing the ERASE key prior to entering a new message.

D.2.1.4 Special Indicators

Three special indicators are used to alert the terminal operator to error conditions.

The INVALID ENTRY indicator lights if the operator improperly enters a character, for example, if he starts to enter message text before pressing a special function key.

The operator must then press the ERASE key and begin the entry again.

An OVERFLOW indicator signals that more than 80 characters have been entered into the terminal memory. It is still possible, however, to transmit the first 80 characters of the message by pressing the XMIT key.

Failure of the base station to acknowledge receipt of a message is signalled by the NO ACK indicator. The operator must either retransmit his message or resort to voice communication.

When the XMIT key is pressed, the keyboard locks, and an automatic transmission cycle begins. The mobile terminal initiates a transmission of the message, and waits for a reply ACK from the base station. If no reply is received within approximately three seconds, a retransmission is initiated; up to three retransmissions are performed, for a total of four tries. If no reply is ever received, the NO-ACK indicator lights, and the keyboard is released. ACK's are displayed on the MCT-16 in the same manner as a received message.

D.2.1.5 Message Structure

Messages transmitted from the MCT-16 Mobile Terminal may be up to 80 characters long. Characters are drawn from the standard 8-bit ASCII code. Each character contains a parity check bit and seven information bits.

An inbound message to the SPC-16 computer in the ARCOM System consists of a series of two ASCII SYNC characters, a four-character ID and header word, either a special function character (one of ten) or up to 80 characters of text, and an ASCII end-of-message (EOM) character. This message block is transmitted twice, without interruption. No coding scheme is used other than this redundant transmission.

Messages received by the MCT-16 Mobile Terminal are of the same form, except that in the basic ARCOM System a fixed length, 16 character, variable text message is always transmitted to the mobile unit, eliminating the need for the operator to scan through a received message.

D.2.1.6 Operational Features and Options

The keyboard is internally illuminated, and an ON/OFF/INTENSITY switch is provided for day/night use. The intensity control enables the display brightness to be adjusted for ambient lighting conditions.

The keyboard is constructed from sealed mercury switches, which are water, dust and jam proof. An optional mobile printer may be used with the terminal. The printer has not yet been specified by Atlantic Research, but should be available in the near future.

D.2.1.7 Physical and Environmental Specifications

Size:	5 1/4" W x 11 1/2" L x 3 5/8" H
Weight:	4 pounds
Color:	Blue
Power Requirements:	13 VDC (nominal) at 750 milliamps (nominal) 2.5 amps (maximum)
Display:	16 character 5 x 7 Dot Matrix LED
Controls:	Keyboard Light Switch LED Display Intensity
Character Code:	8-bit ASCII standard
Memory:	80 characters, single buffer

D.2.2 ARCOM Mobile Radio Interface

The Mobile Radio Interface is the hardware unit which allows the MCT-16 Mobile Terminal to be connected to the user's mobile radio. The existing radio control head is disconnected from the mobile radio, and the Mobile Radio Interface is connected to the radio in its place. The control head is then re-connected to the Mobile Radio Interface, along with the MCT-16 Mobile Terminal. The Mobile Radio Interface is located in the trunk of the vehicle.

In addition to assigning transmission control to either the mobile voice or digital system, the Mobile Radio Interface functions as an encoder/decoder for signals flowing between the MCT-16 Mobile Terminal and the mobile transceiver. The decoder function requires the Interface to convert frequency-shift-keyed (FSK) audio signals received from the mobile receiver into bi-level DC signals acceptable by the MCT-16. As an encoder, the Interface converts bi-level DC signals from the MCT-16 into frequency-shift-keyed audio signals suitable for transmission over the user's voice radio communication system. Within the MCT-16 Mobile Terminal, a character is digitally represented by a series of ones and zeroes, using the standard ASCII 8-bit code.

Electronically, a character is represented by a series of high and low DC voltage values. To transmit such a digital character, it is necessary to send this series of voltage values over a channel. One way of transmitting such information is to use a technique called frequency-shift-keying. A low DC value will be made to correspond to one audio frequency, and a high DC value will correspond to a second. Messages are thus represented by a series of audio tones of two different frequencies, which are capable of transmission over a voice radio channel.

The Mobile Radio Interface also controls the reception of digital messages, by decoding received signals and checking the format and address of the message before passing the message on to the MCT-16. Thumb-wheels are provided to change the address of the terminal, at the Mobile Radio Interface.

Although the MCT-16 Mobile Terminal contains keys to control both display and transmission, the Mobile Radio Interface is designed to allow ARCOM to place most of the required hardware in the trunk of the vehicle, thereby reducing the size and weight of the MCT-16 unit.

Full details of the frequency-shift keying modulation scheme used in the ARCOM System have not yet been made available. Information that is required includes the tone audio frequency assignments and the method used for obtaining a coherent local signal for detection.

The Mobile Radio Interface relies on a carrier sensing technique to determine channel occupancy before transmissions are initiated. The signal that indicates the presence of a carrier on the channel is obtained from the user's existing voice mobile radio.

D.2.3 ARCOM Base Radio Interface

The ARCOM Base Radio Interface serves as the connection between the existing base station voice radio communication system and the SPC-16 Mini computer, which is the processor in the ARCOM System. The Interface performs transmission control, message decoding and encoding, and received message error control.

A frequency-shift-keyed modulation technique is used to encode digital signals for transmission by the base station radio.

Messages are transmitted until an acknowledgment is received from the mobile unit, or until a maximum of four transmissions are made. Retransmissions, when required, are separated by about three second intervals.

Inbound messages are checked for errors, and if acceptable by the SPC-16 Mini computer, are acknowledged to the mobile unit via the Base Radio Interface.

D.2.4 SPC-16 Computer

D.2.4.1 Introduction

Atlantic Research Corp. has selected the General Automation SPC-16 Mini computer as the local processor communications controller for the basic ARCOM System.

Inbound messages from the MCT-16 Mobile Terminals are presented to the SPC-16 Mini computer by the ARCOM Base Radio Interface. The SPC-16 must recognize and accept input messages, perform a parity check on each character within a message, and, relying on the redundant message structure, re olve parity errors. If a message is acceptable, the SPC-16 Mini computer initiates transmission of a simple reply (ACK) message to the mobile terminal. Non-acceptable messages are simply denied acknowledgment.

Display and input-output by the dispatcher's CRT Data Terminal and the Line Printer are also controlled by the SPC-16 Mini computer.

Applications and operating software, developed by Computer Sciences Corporation, enables the functions of the SPC-16 Mini computer, the input/output formats for its various peripheral devices, and the type and amount of received output to be adjusted to the requirements of each user agency.

Inquiry messages received from the MCT-16 Mobile Terminals must normally be reformatted to meet existing data base standards. The SPC-16 Mini computer is assigned responsibility for this task and for the forwarding of reformatted inquiries to the local and remote data base systems.

Occasionally, a message must be queued until a communications link is available, or held for further processing by the SPC-16 Mini computer. The Mini computer therefore provides a storage system for internal message queueing and input/output buffering.

Outbound messages addressed to the mobile units must be reformatted and redundantly blocked prior to transmission. After an outbound message transmission is completed, the SPC-16 Mini computer waits for an acknowledgment from the mobile terminal. If an acknowledgment is not received, a retry is initiated, up to a maximum of four transmissions. Upon failure to receive an acknowledgment within a specified time period, the SPC-16 Mini computer notifies the dispatcher that an abnormal system condition exists.

D.2.4.2 SPC-16 Mini computer Organization

The General Automation SPC-16 Mini computer is a stored-program digital computer with a 16-bit word length organization, a high-speed memory, an arithmetic and control unit, and a versatile instruction set.

Core memory modules are available on a single printed circuit board in 4096 (4K) and 8192 (8K) word sizes. Instructions and data are stored in the memory. Eleven addressing modes are available for use with memory reference instructions. Nine instruction groups are used, providing 78 standard instructions.

D.2.4.3 Instruction Set Special Features

The instruction set includes several special operations:

1. Bit instruction to test, set or reset any bit in memory.
2. Byte instructions to load or store any byte in memory, or interchange the contents of any two byte locations. This simplifies character data handling.
3. Compare memory with register instruction, reflecting results in status indicators.
4. Ability to load an instruction into a register and execute it, facilitating the use of Read-Only Memory.
5. Jump to a subroutine and return via an address pre-stored in a designated register.
6. Load all registers and status, or save all registers and status; simplifying coding of

interruptable and re-entrant programs.

D.2.4.4 Addressing Modes

Eleven addressing modes are used with instructions that address the core memory. Two-word instructions may use literal addressing where the second word of the instruction contains the operant. Other modes are absolute, program relative (or relative to the location of the instruction itself), or base relative. All these modes are either direct or indirect. Some instructions may reference one of three designated index registers, and use their contents as a byte or word index to the addressed location.

D.2.4.5 General Purpose Register

Eight general purpose registers are provided. A Foreground/Background option includes an additional set of eight registers, and the facility to switch from one set to another, thus selecting the operational mode. The general purpose registers may be used as accumulators for arithmetic and logical operations, program counters, and data input/output buffers.

D.2.4.6 Input/Output System

Data are transferred between the SPC-16 Mini computer and the peripheral input/output devices either under program control or automatically via the Direct Memory Access feature. A stored program may poll devices to determine if they are ready to be serviced or the devices may interrupt the processor's operation, indicating their need for immediate service.

Input/output instructions permit a program to communicate with the peripheral devices. Four types of instructions are available for data input, data output, control and test functions. An input/output instruction may address any one of sixty-four I/O controllers. Two of these controllers are internal to the processor, a standard teletype controller and an internal interrupt controller.

A priority interrupt system is used to control response time. Each controller is referenced by a dedicated memory location containing the starting address of that controller's interrupt service routine. When the processor acknowledges an interrupt, control is transferred to the addressed routine.

Direct Memory Access allows automatic, rapid transfer of blocks of data between the SPC-16's core memory and the peripheral devices. When a controller indicates that it is ready to send or receive data, it "steals" a memory cycle from the running program, and then the input/output sequence runs to completion. The "stolen" cycles do not affect the execution of the running program.

D.2.4.7 <u>Peripheral Controllers</u>

General Automation provides a full line of peripheral device controllers for the SPC-16 Mini computer, enabling it to be interfaced with a wide selection of standard input/output devices.

Available peripheral controllers include:

1. Teletype
2. High-speed Paper Tape Reader/Punch
3. Line Printer
4. CRT Display Terminal
5. Disk Storage Drive
6. Drum Storage Drive
7. Communications Peripheral

D.2.4.8 <u>Special Features</u>

The following special features enable operation in unattended environments:

1. Power Fail Detection - insures that the contents of the memory are protected in the event of a power failure.

2. Real Time Clock - provides an interrupt every 1000 memory cycles when the Relative Time Clock interrupt level is enabled under program control. This feature permits multi-programming, and may be used to detect unusual conditions.

3. Operations Monitor Alarm - protects the system from abnormal operation, and provides for both controlling an audio-visual alarm and an orderly execution halt.

4. Power Fail Interrupt - issues a warning to the running program if the supply voltage drops below a pre-set limit. Control is transferred to an interrupt routine, saving register contents and status, and providing an orderly shutdown.

5. Auto Restart Interrupt - causes an orderly start up when power is restored following a power failure.

D.2.4.9 <u>SPC-16 Mini computer Specifications</u>

Memory:	Random access 16-bit word organization Expandable to 32K 16-bit words
Addressing:	Single and double word Eleven modes: Direct Direct Indexed Indirect Indirect Indexed Program Relative Program Relative Indirect Base Relative Base Relative Indexed

Base Relative Indirect
Base Relative Indirect Indexed
Literal

Arithmetic:	Bit, byte and word operation, both logical and arithmetic Parallel, binary, fixed-point two's complement
Instructions:	Nine standard instruction groups: Memory Reference, 4 instructions Memory Reference, indexed, 12 instructions Skip, ± 256 locations, 8 conditions, 8 instructions Register Operate and Compare 11 instructions Register Operate Literal and Compare, 11 instructions Register Change, 16 instructions Shift, 0 to 16 bits, 4 instructions Control, 9 instructions Input/Output, 64 possible devices, single word addressing, 6 instructions
Instruction Execution Time:	Multiple of memory cycle time, 1440 ns
Input/Output:	16-bit parallel bus Programmed I/O transfer rates, 347.2 KHz Direct Memory Access, 694.4 KHz 16 data channels, with dedicated memory locations

System Interrupts:	Power Fail memory protection Real Time Clock Operative Monitor Alarm Power Fail Interrupt Auto Restart Interrupt
Other Interrupts:	Block Memory Protect Teletype Operator's Console External Input/Output

D.2.4.10 SPC-16 Physical and Environmental Specifications

Console Panel:	Operator's console 16 data switches and indicators Register select switches Console lock-out switch, key operated Operations monitor alarm Console interrupt
Dimensions:	10.5" H x 19.0" W x 21.6" D
Weight:	55 pounds
Environment:	0°C to +50°C 90% Relative Humidity (maximum, no condensation)
Power Requirements:	115 VAC, ± 10% 47 to 63 Hz, single phase 220 VAC, ± 10% 47 to 63 Hz 700 watts power consumption with 4K core memory 40 watts additional consumption per additional 4K memory

D.2.5 Super Bee CRT Data Terminal

D.2.5.1 Introduction

The Super Bee CRT Data Terminal is a self-contained, operator or computer controlled remote display terminal with a detached standard keyboard. In the ARCOM System, the terminal serves as a dispatcher input-status output monitor. The terminal is designed to send and receive data serially with an inter-connected data source, like the SPC-16 Mini computer, and operates at any of several transmission rates, to a maximum rate of 9600 bits per second.

A 12-inch (diagonally measured) rectangular television CRT type monitor is used to display up to 25 lines of data, each with 8 characters per line, and the terminal has a total memory capacity of 2048 characters. Each character is drawn from a 5 x 7 dot matrix format, with two dot spacing between adjoining characters.

D.2.5.2 Super Bee General Specifications

Display Size:	
Standard	12" rectangular
Optional	15" rectangular
Active Display Size:	
Standard	6-1/2" x 7-1/2" (Approx.)
Optional	8" x 10" (Approx.)
Display Format:	25 lines of 80 characters each
Character Type:	
Standard	5 x 7 dot matrix (7 x 10 scan) Approximately .08 x .20 inches size
Optional	7 x 9 dot matrix (9 x 12 scan) Approximately .11 x .22 inches size

Character Set:	224 displayable as follows: 32 control characters 64 upper case ASCII set 32 lower case ASCII set 96 escape sequence control codes
Bell:	Audible alarm when control is received and on the 72nd character of a line when keyboard data are being entered
Cursor Type:	Non-destructive blinking underscore
Cursor Controls:	Horizontal tab (forward and back) Cursor up Cursor down Cursor right Home Carriage return Line Feed New line Format tab (forward and back)
Operator Controls:	
Keyboard	Brightness Control (thumb wheel) FDX/HDX Switch (full/half-duplex) Lower Case Character inhibit switch I/O Baud Rate Switch Contrast Control Power Switch
Function Keys	PRINT ENTER ERM EOL PREV PAGE NEXT PAGE SCROLL UP

	SCROLL DOWN
	TAB
	TAB SET
	TAB CLEAR
Function keys (Optional)	8 special function keys (F1 through F8)
Erase Functions	Clear Memory
	Erase to end of line
	Erase to end of memory
Edit (Optional)	Page Mode or Line Mode
	Insert Line
	Delete Line
	Insert Character
	Delete Character
Operation Modes:	CHARACTER
	FORMAT
	ON-LINE
	PROGRAM ENTRY
	PRINT-ON-LINE
	PAGE/LINE EDIT (Optional)
	INSERT CHARACTER (Optional)
Printer Interface:	Per EIA Standard RS-232-C
Transmission Rates:	
11 bit	110, 220, 440, 880, 1760, 3520 & 7040 baud
10 bit	150, 300, 600, 1200, 2400, 4800 & 9600 baud
Transmission Code:	8 bit ASCII
Baud Selection:	Switch selectable
Refresh Rate:	60 Hz. (50 Hz. optional)
I/O Controller:	Microprocessor
Video:	Standard, Blinking, Reversed and Blinking Reversed

Input Voltage Options:	117 VAC ± 10%, 60 Hz (Standard)
	220 VAC ± 10%, 50 Hz (Optional)
	240 VAC ± 10%, 50 Hz (Standard)
	260 VAC ± 10%, 50 Hz (Optional)
Power Consumption:	180 watts maximum
Operating Temperature:	+10° to +40° C (+50°F to +104°F)

D.2.5.3 SUPER BEE Physical Specifications

Dimensions:

Width	20 inches
Height	16 inches
Depth w/keyboard	26-1/2 inches
Depth less keyboard	17-1/4 inches
Depth of keyboard only	12-1/2 inches

Weight:

Monitor	Approx. 55 lbs.
Keyboard	Approx. 10 lbs.

D.2.5.4 SUPER BEE Environmental Specifications

Temperature:	Non-operating temperature: +10°C to +50°C Operating temperature: +10°C to +40°C (Allow five minutes warm-up time)
Humidity:	5% to 80% non-condensing

D.2.5.5 SUPER BEE Power Requirements

The input voltage is strap selectable for any of the following:

117 VAC ± 10%, 60 Hz, single phase
220 VAC ± 10%, 50 Hz, single phase
240 VAC ± 10%, 50 Hz, single phase
260 VAC ± 10%, 50 Hz, single phase

The power consumption is 180 watts maximum, 225 volt-amperes maximum.

D.2.6 Centronics Model 306 Line Printer

D.2.6.1 Introduction

In the ARCOM System, a line printer is used to selectively log messages and other data at the base station. The printer is normally located in the communications control center, near the dispatcher's CRT terminal.

Atlantic Research has chosen the Centronics Model 306 Line Printer for use in the basic ARCOM System. The Model 306 printer is a medium speed, serial impact printer, using a 5 x 7 dot matrix for character generation, with an optional 9 x 7 dot matrix format available. The model 306 is a low-cost, slightly slower, smaller version of the Centronics Series 100 high performance printers.

The print rate is 100 characters per second, with a maximum line width of 80 characters. The average speed is 60 lines per minute for full 80 character lines and 150 lines per minute for short 20 to 30 character lines.

A print format of 10 characters per inch horizontally, 6 lines per inch vertically is used. Up to 9 1/2 inch wide sprocket-fed paper can be used; special paper is not required. An original and up to four carbon copies may be produced. Optional character sets are available, and elongated boldface characters can be printed under software control.

The printer is self-contained and light weight. Both the control logic and power supplies are contained on a single printed circuit board. Vertical form movement is normally software controlled by means of line count pulses.

The maximum form width is 9 1/2 inches. Paper can be loaded from behind or from the printer bottom with an optional stand.

The Model 306 uses a special 1-inch fabric ribbon on 3-inch diameter spools, which is available in black, red, green or blue color. The ribbon is angled across the platen face, allowing use of the entire ribbon, and an automatic reverse mechanism changes the feed direction whenever the end of the ribbon is reached.

D.2.6.2 Centronics Model 306 Line Printer Specifications

Printing Method:	Impact, character-by-character, one line at a time
Printing Rate:	
Characters	100 characters per second
Full Lines	60 lines per minute (80 character line)
Short Lines	150 lines per minute (20-30 characters)
Transmission Rate:	
Serial	100 to 9600 Baud (with Serial option)
Parallel	Up to 75,000 characters per second
Data Input:	Parallel (Serial Option available)
Character Structure:	5 x 7 dot matrix, 10 point type equivalent
	9 x 7 dot matrix (option) 10 point type equivalent
Input Language Code:	USASCII - 64 characters printed, lower case characters recognized and printed as upper case equivalent
Paper Feed:	Sprocket feed, adjustable to 9 1/2" paper width
Paper:	Standard sprocketed paper
Number of Copies:	Original and up to four carbon copies
Switch Controls:	ON/OFF, SELECT, FORMS OVERRIDE;
	Options: LINE FEED, SINGLE/DOUBLE, LINE FEED, TOP OF FORM
Indicators:	SELECT, PAPER OUT

Manual Controls:	Forms Thickness, Paper Advance Knob
Character Buffer:	80-character buffer (1 line)
Format:	80 characters maximum per line, 6 lines per inch
Dimensions:	12" high, 19" deep, 23" wide
Weight:	66 pounds
Electrical Requirements:	117 VAC ± 10%, 60 Hz
	117/234 VAC ± 10%, 50 Hz (option)
Temperature:	
Operating	+40° to +100° F
Storage	-40° to +160° F
Humidity (%RH)	
Operating	5% to 90% (no condensation)
Storage	0% to 95%

CONTINUED

2 OF 3

PART II

D.3 ARCOM SYSTEM SOFTWARE

D.3.1 Introduction

Software support for the ARCOM System, including applications and operations programming, is under development by Computer Sciences Corporation. The software is not yet complete, and no full documentation is yet available.

An actual operating ARCOM system has not yet been assembled in a true law enforcement environment. Demonstrations of the ARCOM System have operated successfully, using a "simulation" of the final programs.

It is expected that final versions of the special operating and applications routines will be available in the near future, tailoring the ARCOM System to a user agency's requirements, including function key assignment, dispatcher display, message formats, and printer output.

A brief description of the software soon to be available for the ARCOM system is provided below. The software is organized into a system supervisor and a set of applications modules, and both will be entirely core resident. The descriptions are taken from literature furnished by Atlantic Research Corp.

D.3.2 Operating Software - The System Supervisor

The supervisor will perform five basic types of functions: system scheduling and control, communications interfacing, system status monitoring, and error detection, and log.

D.3.2.1 System Scheduling and Control

The scheduler and control module will organize the flow of information through the various system components. It will pass both data and controls from one applications program to the next and will coordinate the data transfer into and out of the system. The scheduler will use the real-time clock to provide periodic processes, alarms and system time-outs. This module also will control the dynamic allocation of buffer memory space to ensure effective use of the computer resources.

D.3.2.2 Communications Interface

Two reentrant line handlers will provide all communications interfacing for the ARCOM system. The use of reentrant code means that additional devices can be added to the system with no change to the software. The asynchronous line handler will control all asynchronous data communications and will be used in the system to control the dispatcher displays, the line printers, and the ARCOM base radio interfaces, with data rates varying from 600 to 9600 baud. In those areas where the non-local data banks are not programmed for high-speed synchronous communications, the asynchronous communications handler will be used to make the ARCOM GA/SPC-16 minicomputer simulate a low-speed terminal. The synchronous line handler will be used for high-speed synchronous communications in those instances where large amounts of data must be transferred. This type of transfer is typically used for computer to computer communications.

D.3.2.3 System Status Monitor

The status of all equipment interacting with the system will constantly be checked by the system status monitor. This capability will provide for notification of the proper authority in the case of a detected failure and for graceful degradation to ensure that the system continues to function in spite of the failure of any of its individual components. One significant capability is known as failsafe, which, in the event of a detected power failure, ensures that the entire system will be reset into the proper configuration so as to protect the electronic equipment.

D.3.2.4 Error Detection Processing

The error detection portion of the supervisor will provide the capability for detecting data transfer errors (using such techniques as parity, block check, forward error correcting codes) and taking appropriate action. In some cases, this action is rejection or retransmission of the message. In other cases, the messages may have the capability for self-correction.

D.3.2.5 Log

All information passing through the system may be logged on a designated device or devices, such as a hard copy printer.

D.3.3 Applications Software Modules

Each individual applications program operates on the data passed to it by the schedule and control module and provides a specific functional capability to the user.

D.3.3.1 Query/Response Control Module

This module will provide the interface between the ARCOM generated message and the fixed format of the state or local data base system. In particular, it will perform any code translation, header and trailer generation, and insertion of appropriate special characters and punctuation that is required. This module also will monitor the status of the query and process the information returned by the queried data base systems.

D.3.3.2 Message Control Module

This module will be responsible for the two-way data communication between the dispatcher and the ARCOM terminal. This will include both normal and emergency messages. If status reporting capability is included in the system, the recognition of an emergency message from a unit will also provide the last status and location reported by that unit.

D.3.3.3 Voice Identification Module

This module will recognize that a voice communication has occurred and will display (and log) the identification number of the mobile unit participating in the conversation.

D.3.3.4 Status Reporting Module

This module will record the status of all units in the system and make that information available to the dispatcher. The option will be provided to expand this capability to include a message (such as a location) that is associated with the status of a particular unit. In addition, this module will provide for dispatcher notification in the event that an expected status report has not been received.

D.3.3.5 Configuration Control Module

This module will allow the dispatcher to change the unit numbers and authorized capabilities available through the system. For example, the dispatcher can control the types of queries that can originate from certain units and the type of information which will then be made available to that unit.

D.3.3.6 Dispatcher Command Interpreter Module

This module will interpret the requests originating at the dispatcher's console(s) and will perform the indicated functions.

D.3.3.7 Car-to-Car Communication Module

This module will control car-to-car communications by re-formatting the incoming message from a car and controlling its outbound transmission to another car (or cars).

D.4 SYSTEM DESIGN AND ERROR CONTROL PHILOSOPHY

D.4.1 Message Transmission

D.4.1.1 Messages Originating at the MCT-16 Mobile Terminal

Inbound messages, originating at the MCT-16 Mobile Terminals in an ARCOM system, can be grouped into several classes, which are described below.

The SUPER BEE CRT Data Terminal, used by the dispatcher, is also a source of similar messages, which must be processed by the SPC-16 minicomputer, but these messages do not appear on the radio channel.

D.4.1.1.1 Remote Data Base Inquiries

In the ARCOM System, seven special function keys, color-coded blue, are available on the MCT-16 Mobile Terminal. These keys are presently labeled VIN, DL, VR, LP, NAME, ADDR, and SS. They are used to initiate data base inquiries for vehicle identification numbers, driver's licenses, vehicle registrations, license plates, names, addresses and Social Security numbers, respectively.

To perform an inquiry, the terminal operator presses the ERASE key to clear the terminal, presses the desired inquiry function key, enters the required identifier using a simple format without punctuation marks, and presses the XMIT key.

The assignment of the function keys described above may be altered to suit the particular data base requirements of a user agency. The SPC-16 minicomputer is programmed to reformat the inquiries to meet existing data base interface requirements.

The principal purpose of the function key is to add a single-character header to each message. Each key is associated with a special character of the ASCII set. This character is printed on the key below the boldfaced function assignment, and is displayed whenever the associated function key is pressed.

D.4.1.1.2 <u>Status Entry Messages</u>

Status entry is provided by a function key labeled TEN. To enter a mobile unit's status, the operator first presses the ERASE, then the TEN key. Next, the operator enters a numerical status code, and presses the XMIT key. A text message may be entered after the status code, if desired.

The TEN key adds a unique single-character preface to a status message. The application programs enable the SPC-16 minicomputer to recognize status messages and display mobile unit status on the dispatcher's CRT terminal.

D.4.1.1.3 <u>Emergency Messages</u>

A special red color-coded emergency key (EMER), is used to enter priority emergency messages.

To enter an emergency message, the operator presses the ERASE key, then the EMER key. Next he enters any text, if necessary, and presses the XMIT key. At the base station, the message, when received, may, at the user's option, cause an alarm to sound, or a special display to appear on the dispatcher's CRT Data Terminal.

D.4.1.1.4 <u>Manual Message Acknowledgment</u>

An ACK key is provided, enabling the terminal operator to send a manual message acknowledgement to the base station. This ability is important, because it ensures that the dispatcher is aware that a message has been received and displayed at the mobile terminal.

To perform an acknowledgment, the operator presses the ERASE key, then the ACK key, followed by any desired text, and finally the XMIT key is pressed.

Acknowledgements may be displayed to the dispatcher or logged on the Centronics Model 306 Line Printer.

D.4.1.1.5 Automatic Response

The MCT-16 Mobile Terminal automatically issues an acknowledgment to the base station for every message received. This acknowledgment must be received by the SPC-16 minicomputer if an automatically timed retransmission of the original message from the base station is to be prevented. This does not mean, however, that the terminal operator has seen (and read) the message; hence, the manual ACK key.

D.4.1.1.6 Inbound Message Format

All inbound messages in the ARCOM System use the same message format. A single message block consists of two ASCII Sync characters, a four-character identifying header (containing control, status and address information), a special function character, and up to 79 characters of text. An ASCII EOM (end-of-message) character terminates each block.

Messages are transmitted redundantly, that is, each message consists of two identical message blocks. The two blocks are used at the base station for error correction purposes.

D.4.1.2 Outbound Messages from the SPC-16 Minicomputer

Messages originating at the dispatcher's terminal and at mobile terminals in an ARCOM system may become outbound messages to an MCT-16 Mobile Terminal. Outbound messages may be grouped into several classes, which are described below.

D.4.1.2.1 Responses to Data Base Inquiries

The SPC-16 minicomputer reformats the information contained in a response from the local or remote data base, and composes a response message addressed to the inquiring mobile terminal. In a basic ARCOM system, responses, and in fact all outbound messages, are fixed length messages with 16 characters of text. Since the MCT-16 displays the first 16 characters of a message, the entire received message is displayed for the operator.

Messages whose lengths are greater than 16 characters are sent as multiple 16 character messages.

Outbound messages "override" messages displayed on the MCT-16. If an operator is entering a message, the keyboard locks and the received message appears on the display. The operator must press ERASE to remove the displayed message and free the keyboard.

D.4.1.2.2 Terminal-to-Terminal Messages

The dispatcher and other mobile terminals may originate outbound messages addressed to an MCT-16 Mobile Terminal.

The four-character header permits single unit, group or all-call messages. All outbound messages are 16 characters long in a basic ARCOM system.

D.4.1.2.3 Outbound Message Format

Messages outbound from the SPC-16 minicomputer use the same format described for inbound messages, with the exception that, in a basic ARCOM system, outbound messages are limited to 16 characters of text.

The standard ASCII 8-bit code is used. All 64 characters may appear in outbound messages. Only the characters A-2 and 0-9 are available on the MCT-16 keyboard.

D.4.2 Error Control

D.4.2.1 Inbound Message Error Control

Error control in the ARCOM system is provided by a combination of parity checks, redundancy and an automatic-repeat-request scheme.

During transmission of an inbound message, bit errors may be introduced by radio channel conditions or hardware errors at either the base station or mobile unit. At the base station, a binary message string is recovered from the received audio frequency-shift-keyed signal.

Sync and EOM characters identify the start and end of message blocks. Each character in a message is drawn from a modified ASCII 8-bit code. The eighth bit of each character is an odd-parity check over that character. The ASCII code is "modified", since certain characters are used for control, rather than message purposes.

All messages are transmitted redundantly. Each message block is sent twice. At the receiving station, each character is checked for parity. When a parity error within one character of the first message block is discovered, the same character in the second block is examined. If no parity error is found, the second block's character is assumed to be correct and is accepted in place of the incorrect character of the first block.

If both characters are in error, two actions are possible. First, if the message is not to be forwarded to another computer, which requires absolute accuracy, a special error symbol is inserted, replacing the character. Second, if no replacement is allowed, the message is disregarded.

Each message accepted by the SPC-16 minicomputer is acknowledged by the transmission of a simple ACK message back to the mobile terminal.

D.4.2.2 Outbound Messages Error Control

The procedure for error control in outbound messages is essentially identical to that used for inbound messages. At the mobile terminal, a special error symbol, @ , is inserted in place of any message character with unresolvable parity errors. This feature enables many messages to be correctly interpreted by the operator, even though they contain errors, thus reducing the number of retransmissions.

D.4.2.3 Asynchronous Message Transmission

In general, messages in the ARCOM System may be of variable lengths, containing 1 to 80 characters of control or data text. An asynchronous message transmission technique is thus used for both in- and out-bound messages.

Each message block begins with two ASCII SOM (start-of-message) characters. A continuous bit string is extracted from the frequency-shift-keyed audio signal received from the radio system. This bit string is examined for these SOM characters, which are followed by the message text and an EOM (end-of-message) character. Since blocks always appear in pairs, and are identified by SOM and EOM characters, asynchronous operation is possible.

D.4.3 Modulation Technique

D.4.3.1 Audio Modulation Method

The ARCOM System uses a coherent audio frequency-shift-keying technique for transmitting digital data over an audio bandwidth radio channel. No details of the tone frequencies used, or of the method for obtaining coherent detection have yet been provided by Atlantic Research.

The ARCOM system does require that a voice-grade radio link be made available by the user agency.

A data rate of 600 baud, or 600 bits per second, is claimed for the ARCOM System. This yields a character rate of 75 characters per second using an 8-bit ASCII code.

D.4.3.2 Radio Channel Requirements

The ARCOM system is designed to operate over the user's existing voice-grade radio communication system. Simplex, half-duplex or full-duplex channels may be used with the ARCOM System.

In demonstrations, the ARCOM system has successfully operated over repeater networks. Operation with existing receiver voting systems will require modification of the voting process.

D.4.4 Line Control

The ARCOM System operates in a contention mode; inbound and outbound digital traffic both compete with voice communications for channel control.

To prevent interruption of a voice communication by digital traffic, a channel busy, or carrier sense detection scheme is used. When a digital data transmission is initiated, the presence of an RF carrier on the channel is electronically sensed. If the channel is occupied, either by voice or digital traffic, no transmission occurs. When the channel clears, transmission begins, after a small, random time delay. This method yields the channel to current voice traffic, but a data message will generally "beat-out" an operator waiting to begin a voice communication. Digital messages, however, will usually be short enough so that they will occupy less time than the reaction time of an operator, reducing this problem.

D.4.5 Throughput

In an operating ARCOM system, digital and voice traffic are mixed on the same radio channel. Each type of message requires a different amount of air time for transmission. Various length messages, both inbound and outbout, are generated at various rates. Message throughput for such a system in terms of continuous digital operation, is virtually meaningless when expressed in numerical form.

Digital messages typically may vary between 16 (1 character of text) and 174 (80 characters of text) characters in length, including control characters and redundancy. At a bit rate of 600 bits per second, or 75 characters per second, a one-way message requires approximately 0.2 to 2.3 seconds for transmission, not including the time required for system delays and synchronization. It should be noted that the effective data rate is only 300 baud, because of the redundant transmission scheme used.

It should be emphasized that fast data rates alone do not imply a faster response time within a digital communications system. For example, the response time for a data base inquiry may well be limited by the times required internally to access, search and receive a reply from the remote data base.

END