Law Enforcement Equipment Technology

COMMUNICATION SYSTEMS GUIDE

A User Guide from the National Bureau of Standards

ACKNOWLEDGMENTS

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COMMUNICATION SYSTEMS GUIDE

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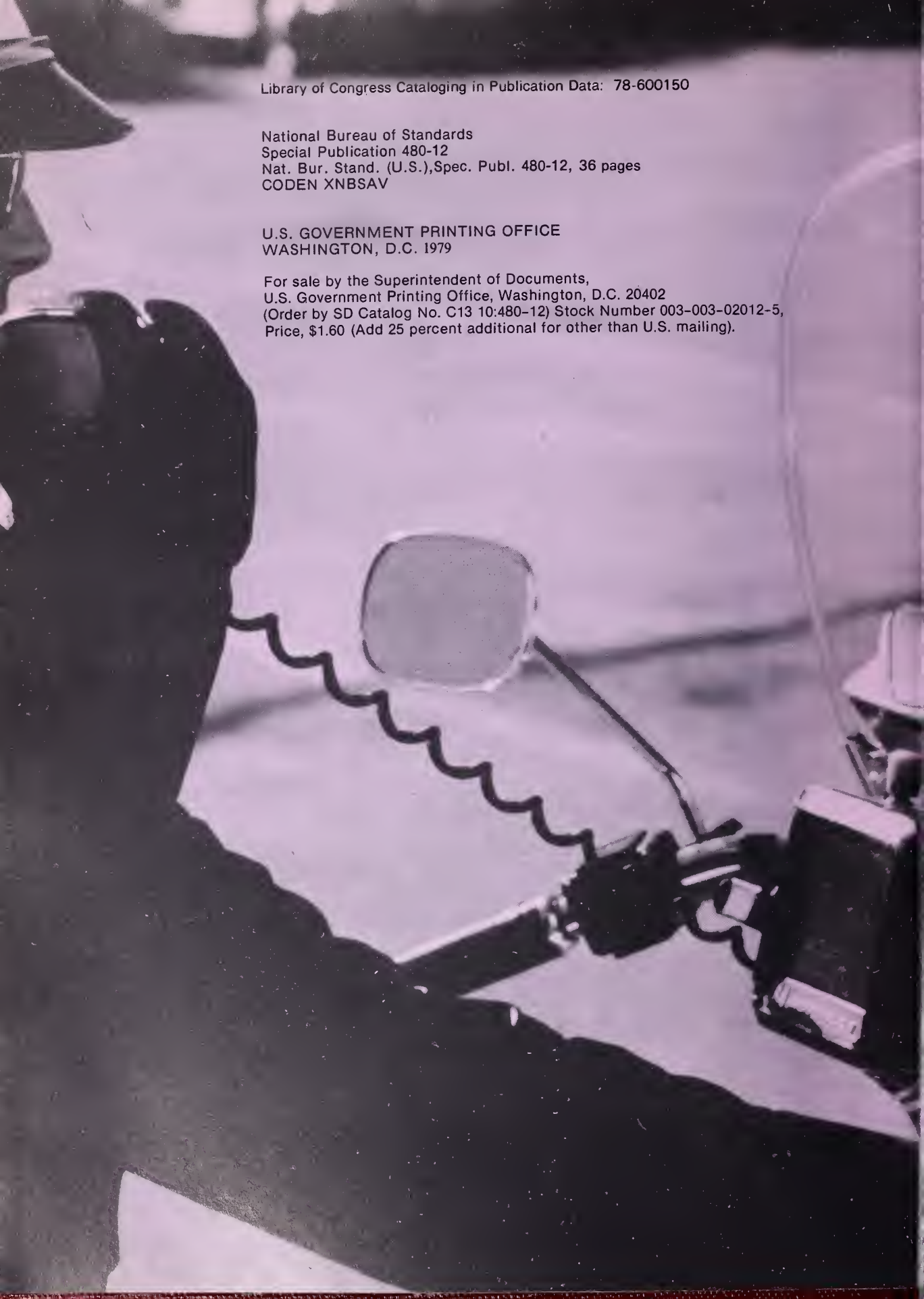

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FOREWORD

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

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

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

Technical comments and suggestions concerning this guide are invited from all interested parties. They may be addressed to the author or to the Law Enforcement Standards Laboratory, National Bureau of Standards, Washington, D.C. 20234.

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INTRODUCTION

Communication organizations in public safety and law enforcement in particular are rapidly expanding and improving their services. Authorized base station transmitters in public safety communications have increased from about 63,000 in 1968 to about 114,000 in 1977 [1]*. Funding for law enforcement equipment and programs by Federal, State, and local law enforcement agencies is currently estimated at over 15 billion dollars and predicted to increase to 25 billion in 1980 [2].

Many law enforcement agencies have found additional funding sources for communications—such as those funding 911, the national .emergency telephone number, and Emergency Medical Service (EMS). Since the communication needs of these services are common to law enforcement, there may be advantages in centralizing efforts [3].

The intent of this guideline is to inform and aid the reader in the selection of subsystems used in law enforcement communications. Included is a general discussion of both complex and relatively simple operational and support subsystems. Sections on principal equipment, cost considerations, and purchasing suggestions are also included to assist the potential purchaser and user of the equipment.

COMMUNICATION SYSTEMS

The increase in population throughout this country has brought with it an increase in the demand for services, particularly law enforcement services. To comply with this demand, law enforcement facilities have been expanded and become more sophisticated. With added facilities, greater numbers of personnel and increased responsibilities, more departments are improving their communication systems to deal with the increased requirements imposed on them.

To provide for orderly growth, it has been found advisable to initiate early planning of new communications and electronic facilities and equipment [4]. A communications manager needs to be aware of the latest Federal Communications Commission (FCC) rules and regulations. Existing assigned radio frequencies need protection from the effects of new intermodulation products, many public buildings and institutions need adequate communication facilities, and new equipment needs to be properly installed and operated. Properly planned systems help promote increased manpower efficiency and savings of public funds.

Recent Developments

As law enforcement departments have grown, the need for a centralized facility for dispatching vehicles and personnel has been recognized and recommended by many large agencies. Dispatchers use radio communications to communicate with officers in the field. The functions of telecommunications can be categorized into three areas:

- Communications with the department (telephone).
- Communications within the department (telephone and radio).
- Communications with other agencies (telephone, radio, facsimile, high speed digital).

Each category is essential for the protection of a community and its citizens.

With the increasing emphasis on reducing crime, there has been more financial support for all phases of law enforcement, including communications. This increase in support has enabled some departments to consider purchasing more elaborate and improved communication systems. Communications have improved considerably since the days of one-way broadcast band dispatching. Recent developments include the application of the computer to such things as information storage, retrieval, and comparison. The use of terminals equipped with keyboards and display screens operating with the computer can be a valuable aid to the dispatcher. Integrated circuits have made possible relatively inexpensive and compact teleprinters. Tone-coded squelch and digital-coding techniques allow the listener to be more selective in the messages he hears, thus enabling him to cope with the excessive traffic on some channels. Personal and portable transceivers have become more compact and lighter; the battery is now the limiting factor in size and weight reduction. In an effort to conserve battery power as well as reduce interference, digital techniques have been developed to allow the receiving station to judge the quality of the incoming signal and to automatically cause the personal transmitter to increase (or decrease) the radiated power.

Frequency congestion exists today for many reasons, but proper planning can reduce unnecessary congestion. Joint planning among municipal departments in a city and among adjacent suburban governments is often a valuable approach [5]. Such efforts usually reduce redundant actions and improve the information flow between such groups.

A System Overview

One way to study communication systems is to look at a very complex system and then break it

into sub-systems consisting of smaller amounts of equipment. The complex communication system in *figure 1* is shown as an illustrative example, and is not an operational system in use by any specific law enforcement agency. Specific systems must be carefully planned around the needs and limitations imposed by population and local area topography.

Figure 1 is divided into two major parts. To the left are control center functions; to the right are field functions. This communication system functions as follows: The public reports an incident by telephone (911 or direct dial) or, in limited locations, by radio (public transportation safety channels or CB radio). Law enforcement officials have access through several telecommunication media to a variety of information files. Officers on foot or in vehicles have a variety of means to communicate with the command center. These include the telephone for routine reports, and the radio for more

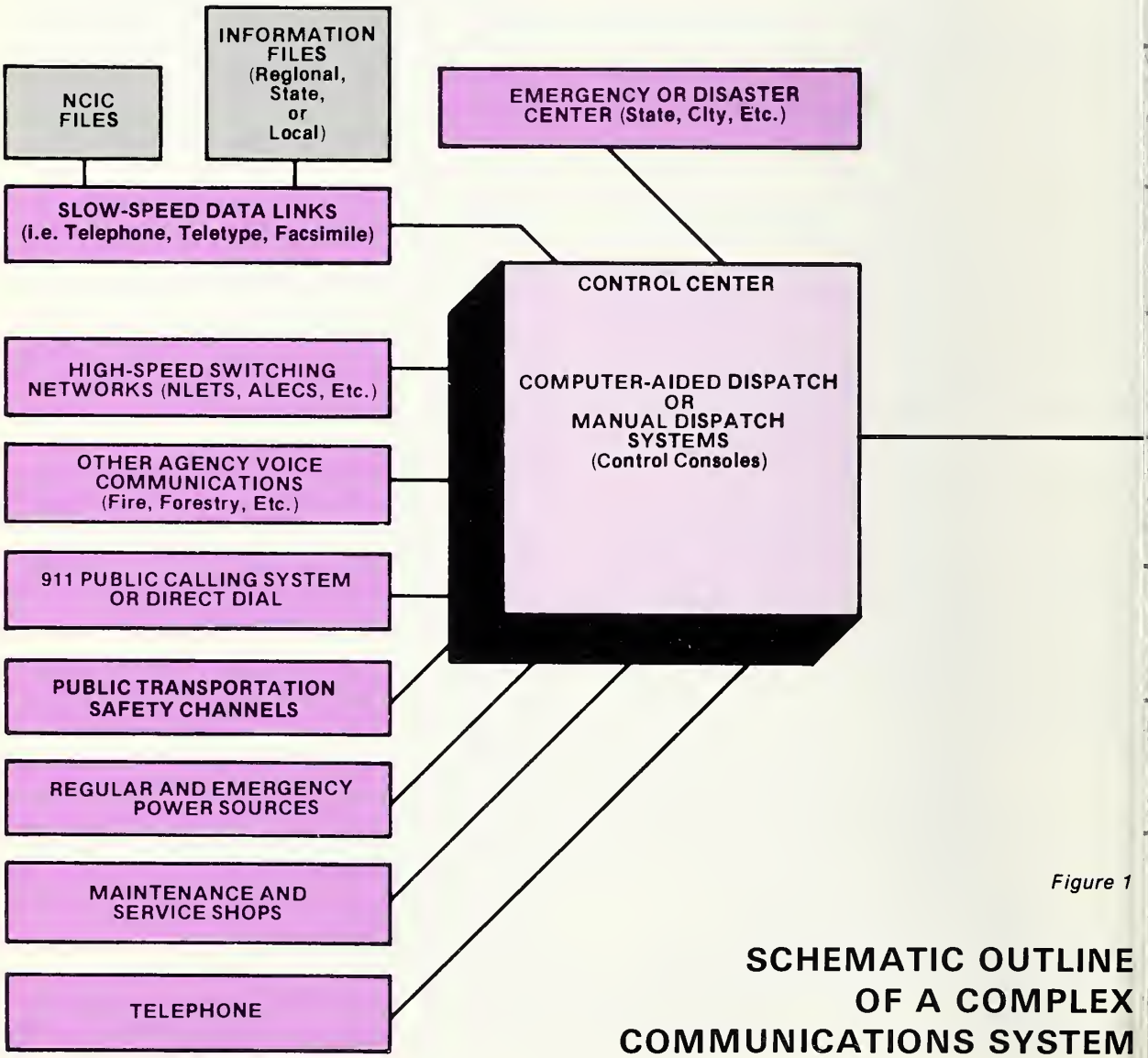


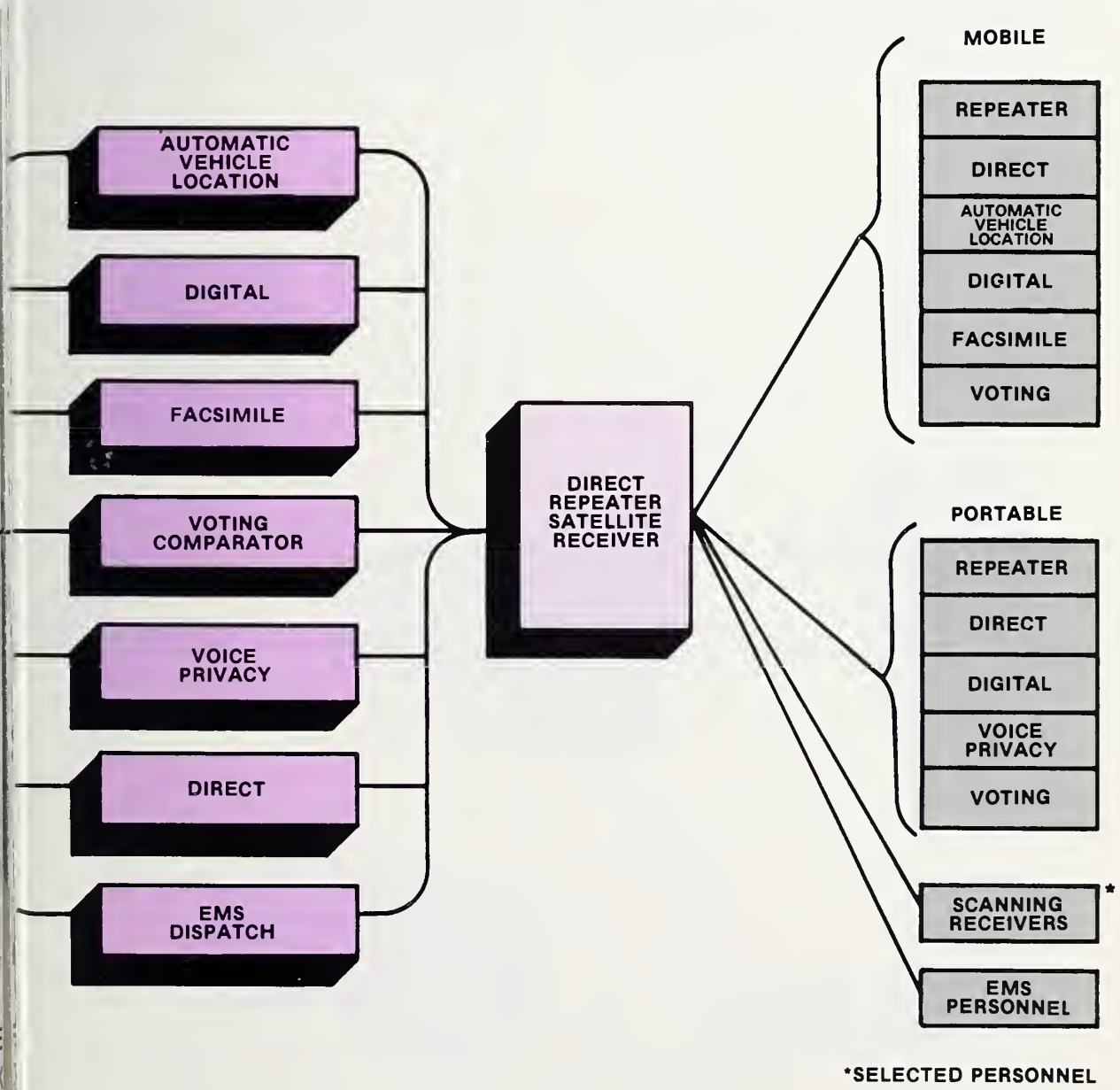
Figure 1

SCHEMATIC OUTLINE OF A COMPLEX COMMUNICATIONS SYSTEM

urgent voice or digital messages. Digital systems may include automatic vehicle location, communication terminals, printers, and status reporting. In order to improve transmission or reception quality, repeater or satellite receiver systems are often used. Most of the sub-systems shown will be discussed in further detail in subsequent sections.

Major Sub-Systems

There are several recent major innovations in systems affecting control, command, and communication operations. Computer and digital equipment are now available at reasonable prices, and as their use expands, it is expected that the resulting advantages of increased community service and personnel safety will be more apparent. Some of these sub-systems are described, along with the advantages and problems in their implementation and operational use.

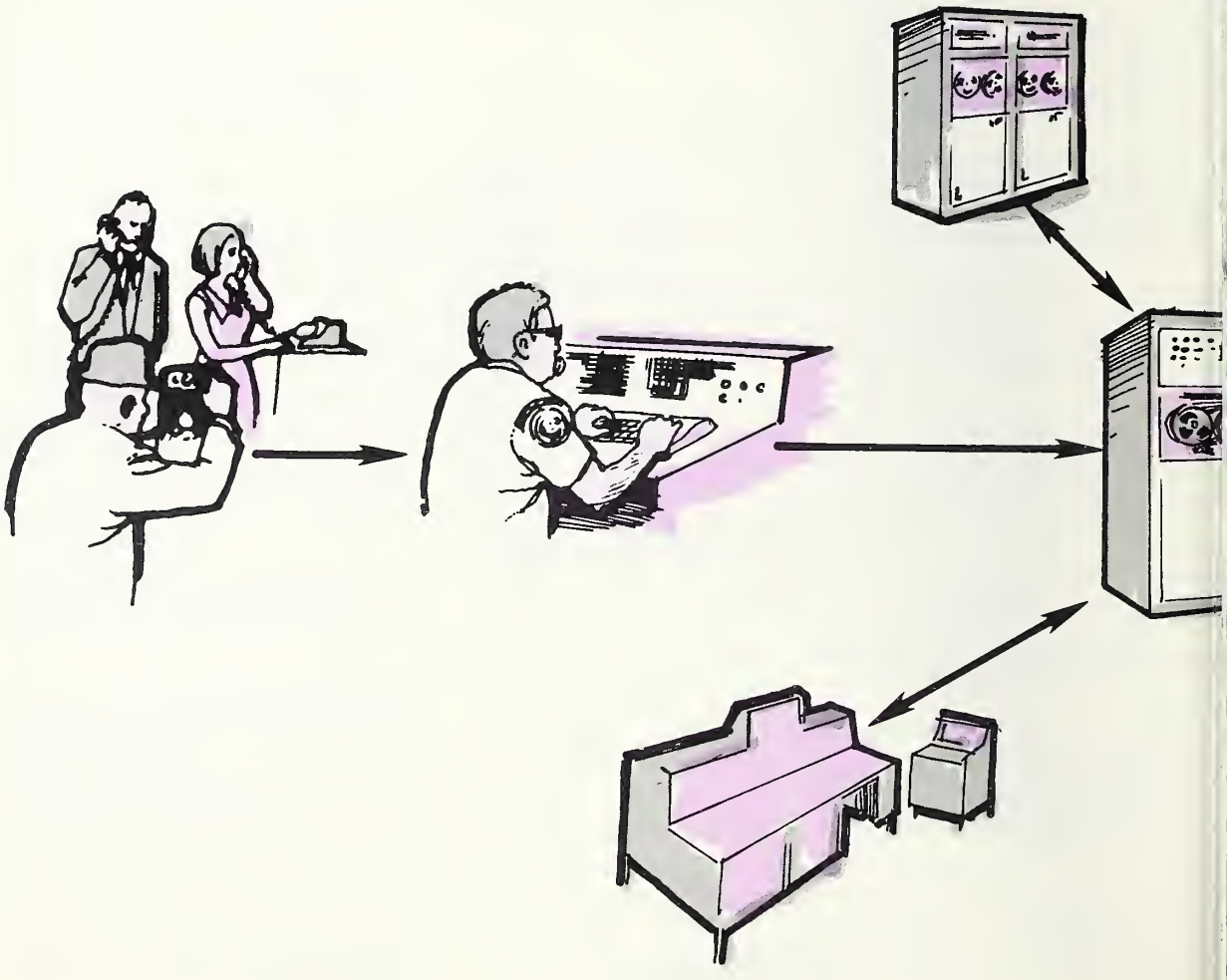


Computer-Aided Dispatch Centers

Computer-aided dispatch (CAD) is having a major impact in the solution of some of the chronic problems of command and control in law enforcement departments. A properly designed computer system allows a manually operated system to become one which is fast, accurate, and tireless.

Figure 2 illustrates the basic components of a computer-aided dispatch system. When a complaint is phoned in, the complaint-board operator keypunches information (such as name, address, telephone number, and complaint) into the computer. The complaint-board operator also assigns a priority number to indicate to the dispatcher the degree of urgency. The computer assigns a case number and records the time the complaint was received. It also verifies that the address exists and is within the jurisdiction of the agency. It determines the area of law enforcement responsibility and which police units are available for assignment. If there have been any prior complaints at that address or there is other relevant information, the computer recalls it and then places a one-line summary of the entire incident on the dispatcher's display screen. Acting upon the information displayed, the

Figure 2.



dispatcher assigns a police unit and relays essential information, either by voice or by digital communication. The computer-stored information is continually updated. For example, upon assignment, the police unit status file is updated by the dispatcher, and the time of assignment is logged automatically. Other information is also entered, such as time of arrival, classification, how the incident is disposed of, and the time the police unit is again available for assignment.

Officers in the field may initiate computer processing by going through the dispatcher instead of the complaint console. Queries to the remote information files may be requested to check information such as vehicle status, wants and warrants. Depending on the amount of this activity, a separate console or even a separate operator may be justified.

The functioning of a particular CAD system may differ from this outline due to the type of equipment used, the allocation of duties among the various operators, or the number and extent of the data files used. But that reflects operational decisions by department managers and the equipment involved, rather than fundamental conceptual differences.

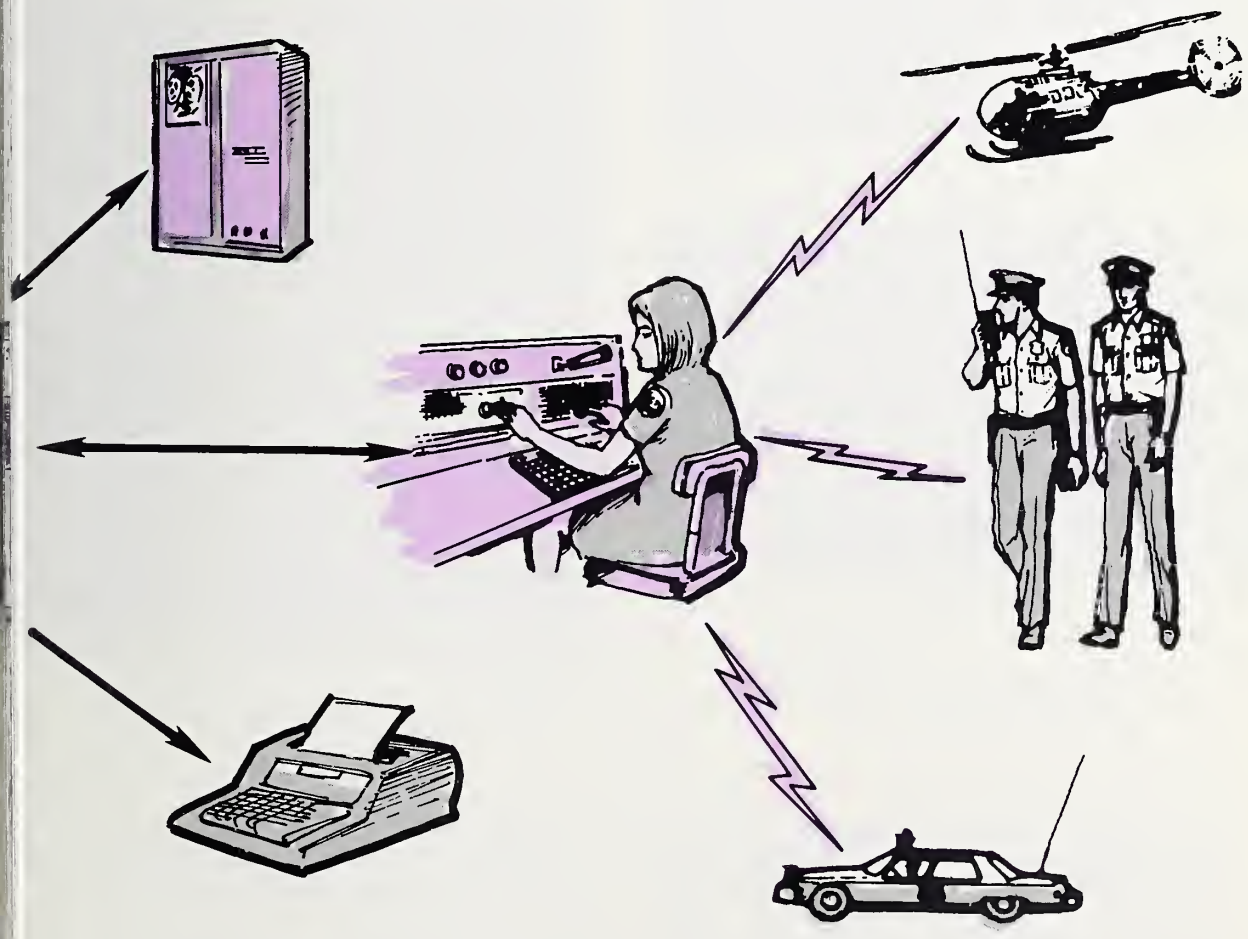


Table 1 lists some of the advantages and disadvantages of a CAD system. One of the major benefits is the near-real-time ability to generate management reports without the necessity of tedious manual data transfer from dispatch cards to computer tape. One major communication facility showed labor savings due to field and communication center operations of more than $29,000 in the first year of operation of their CAD system [6].

Another consideration is the ease with which mobile digital communication capability can be added. With this feature it is possible for the dispatcher, when making an assignment to a police unit by voice, to activate a printer in the vehicle. The receipt of hard copy in the vehicle minimizes the possibility of misunderstanding or error.

As more complex systems or components are procured, operational and maintenance problems are likely to increase. Good procurement practices and planning are obviously needed. It has been said that obtaining a new electronic capability is somewhat like becoming a parent [7]. It is an expensive, almost irreversible process and the joys of ownership are tempered by the problems that surface.

Table 1. *Summary of advantages and disadvantages of computer-aided dispatch systems*

ADVANTAGES	DISADVANTAGES
1. Replaces awkward manual system for keeping track of incident reports and status with computer memory and analysis.	1. Requires special selection and training of dispatchers for needed skills.
2. Ability to quickly and effortlessly compile management information.	2. Requires large initial funding and much planning to construct and initiate operations.
3. Automatic logging as items are typed into the system.	3. Additional physical facilities and maintenance arrangements may be required.
4. Interfaces easily with mobile digital communications.	4. Special uninterruptable power supplies are often required for the computer.
5. Improved overall service to public such as reduced response time and fewer handling errors.	5. Professional help is required to identify and debug problems within the computer and software systems.

Several surveys have been made to categorize CAD systems. One survey of ten operational systems gives data on population, calls for service, number of switchboard operators and dispatchers, types of internal information files, and extent of voice and digital communications with field units. Work-load measurements and analysis have also been performed for a major metropolitan police department in order to better understand dispatching requirements in a CAD system [8].

Figures 3-5 illustrate several types of communication centers which utilize computer assistance and typewriter keyboard terminals for the dispatchers and supervisors. *Figure 6* illustrates a typical computer system used in a CAD system.

Figure 3 Cooperative dispatch center located in the Broward County (Florida) Sheriff's Department.

Figure 4 Command and control center located in the Las Vegas Metropolitan Police Department.

Figure 5 Automated communications center located in the Hillsborough County (Florida) Sheriff's Department.

Figure 6. A typical computer system used in a computer-aided dispatch system.

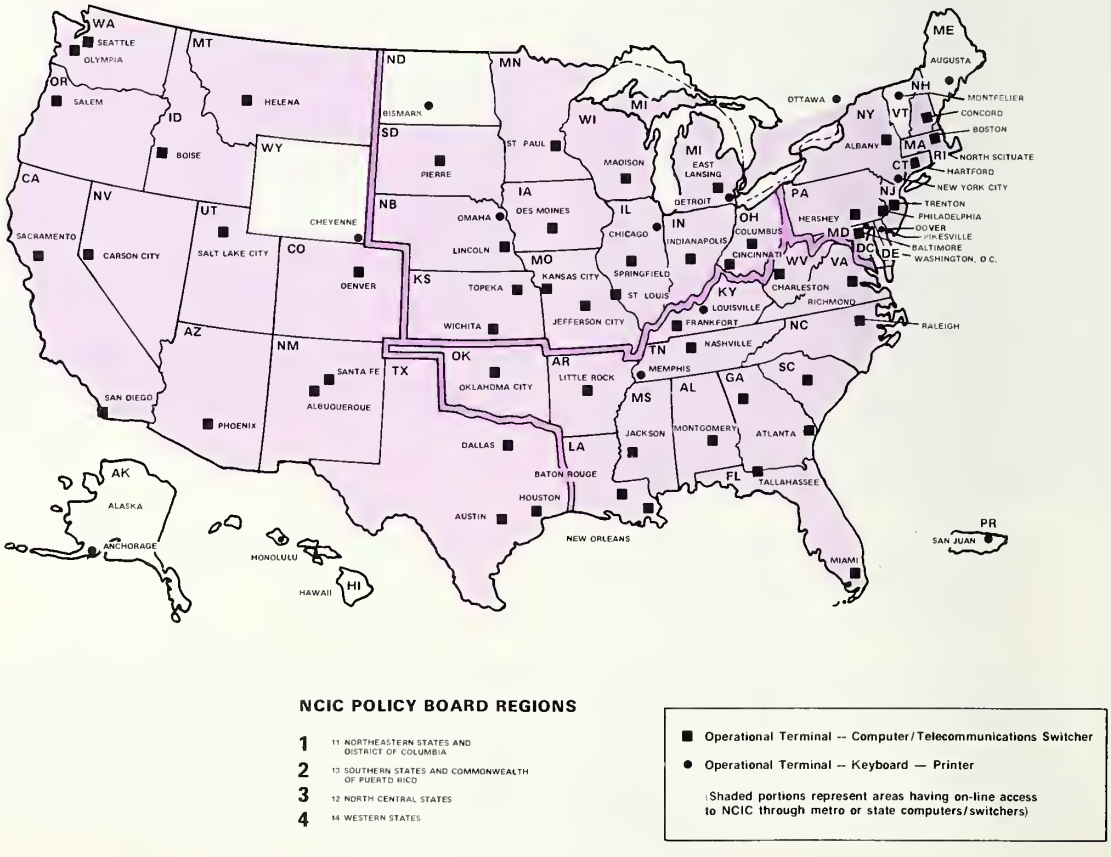
Computer-Controlled Communication Systems & Information Files

Computer technology has made possible the gathering of crime records into electronic storage units with provision for rapid recall as needed. There are a multiplicity of such systems in use by local, State, and Federal agencies. The National Crime Information Center (NCIC), one such organization, is administered by the Federal Bureau of Investigation. Serving a telecommunications network that involves all

50 states, the District of Columbia, Canada and Puerto Rico *(see fig. 7),* the NCIC computers process as many as 210,000 transactions per day, and yield about 1,000 positive responses (hits) [9]. There are ten computerized files: Wanted persons; stolen vehicles, license plates, guns, securities, aircraft, boats, snowmobiles, and miscellaneous identifiable articles; and offenders' criminal histories. The Computerized Criminal History (CCH) file is intended to be a national index of the criminal history records of individuals arrested for serious offenses. This file shares information among State and Federal jurisdictions in response to the substantial interstate travel of criminals.

The National Law Enforcement Telecommunications System (NLETS) is a sophisticated computer-switched communications network linking all of the law enforcement agencies in the United States and Puerto Rico. Other State and Federal agencies are also members, including the Department of Corrections, Wild Life Management, Secret Service, and Internal Revenue Service. Besides the capability of quickly interconnecting law enforcement agencies for telecommunication, there is direct access for computer interrogation of driver's license and motor vehicle files within each state. NLETS is incorporated as a non-profit organization and is controlled by the participating states. The heart of the system is a pair of computers located in Phoenix, Arizona, which control interconnections among the individual State computer networks. The routing of messages over local networks within each State is a State responsibility. NLETS operates continuously, exchanging point-to-point administrative messages and regional and national all-points bulletins. It is important to realize that NLETS is only a routing and communication agency and maintains no data files. The NLETS governing board and each individual State determine which data files within the State can be

Figure 7. The National Crime Information Center (NCIC) telecommunications network.



NCIC POLICY BOARD REGIONS

1. 11 NORTHEASTERN STATES AND DISTRICT OF COLUMBIA
2. 13 SOUTHERN STATES AND COMMONWEALTH OF PUERTO RICO
3. 12 NORTH CENTRAL STATES
4. 14 WESTERN STATES

■ Operational Terminal -- Computer/Telecommunications Switcher

● Operational Terminal -- Keyboard — Printer

(Shaded portions represent areas having on-line access to NCIC through metro or state computers/switchers)

accessed by the system. The system, as now formed, is capable of handling a peak hourly load of 13,000 messages, but has the capability for expansion to 26,000 messages an hour [10].

There are many important regional and statewide communication switching systems. For example, the Automated Law Enforcement Communications System (ALECS) serves Illinois and seven other midwestern States [11], while the California Law Enforcement Telecommunications System (CLETS) serves California.

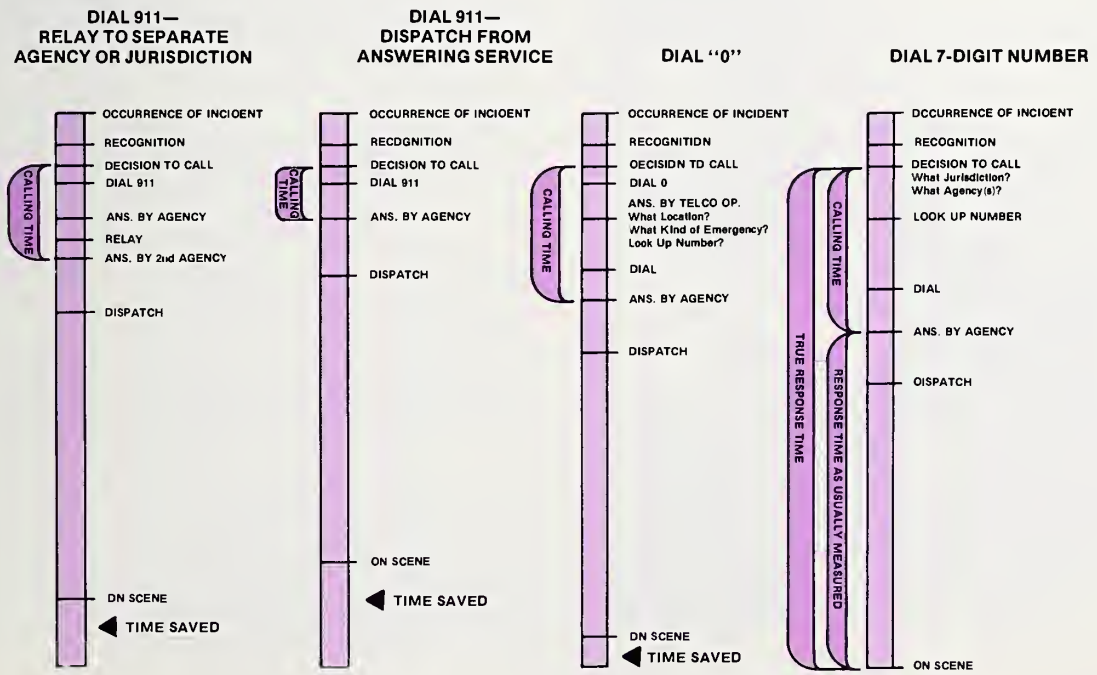
There are also many data-file systems maintained by the States. One example is the Law Enforcement Agencies Data System (LEADS) operational within Illinois. This system maintains files entitled Stolen Vehicles, Wanted and Missing Persons, Stolen and Recovered Guns, Stolen and Lost License Plates, Stolen Articles, Firearm Owners, Criminal Histories, Alias Names, Stolen Securities, Highway Conditions, Accident Victims, Stolen Boats, Towed or Impounded Vehicles, and Liquor License Owners. LEADS utilizes about 360 remote terminals located in State, county, and municipal offices within the State. The remote terminals are connected via communication lines to the central computer located in Springfield. Other State systems include the New York State Identification and Intelligence System (NYSIIS), the Iowa Traffic Records and Criminal Justice Information System (TRACIS), and the California Automated Jail Information System (AJIS) [12,13].

911 Public Calling System

Agencies are always striving to reduce the time period between receipt of a call and the time assistance arrives on the scene. In contrast, the 911 system reduces the time it takes a citizen to actually contact the agency. When 911 is the primary emergency number in a community, the citizen saves time in not looking up the correct seven digit number and dialing it *(see fig. 8).* In some cases, a telephone book may not be available or the caller may not be able to see the dial.

The 911 system requires considerable planning to efficiently receive, route, and dispatch calls. The fact that several agencies and several jurisdictions may be involved in any given 911 reception center usually raises questions of control and chain of command [14]. The degree of success in implementing a 911 system depends greatly upon the process chosen for

Figure 8. Comparison of times required to telephone for assistance.



handling calls for other agencies and jurisdictions.

The Federal and State Governments have committed themselves to the 911 emergency calling system. The Federal Government is actively encouraging local authorities to establish this system in both urban and rural areas [15]. Entering 1977, it had been established in 665 jurisdictions, representing communities of all sizes and serving slightly less than one-quarter of the total population of the United States [61]. However, in the 25 largest cities, those with populations greater than 500,000, more than one-half the population had 911 service.

Emergency Medical Service

Another public service which is rapidly growing and one which, it is predicted, will eventually rank in importance with law enforcement and fire, is emergency medical service (EMS) [16]. The statement has been made that "the greatest threat to the average citizen is not the fire in the home or the criminal in the street—the greatest threat to the average citizen is the inability to get emergency medical care at a time when minutes mean lives" [17]. With the anticipated growth in EMS will come a significant growth in communication needs. Some metropolitan areas will receive sixteen or more radio channels to handle the expected emergency traffic. Much planning is necessary to put such a system into operation, and it remains to be seen how the EMS system will interact with law enforcement communications.

Digital Systems

Digital systems, where messages are encoded into binary form prior to transmission and decoded at the destination, are of growing interest in law enforcement communication systems. Because digital systems use the language of the computer, they are very efficient when communicating with crime information files such as NCIC. A mobile unit can directly access computerized crime information files when suitable switching arrangements are made at the base station. Other advantages include the following:

- Digital communications offer a significant degree of privacy. Special equipment is necessary to decode these messages.

- Messages in digital format can be transmitted much faster than ordinary voice transmissions. Frequently used messages (including status reports and acknowledgments) can be sent by pressing a button.

- Unlike voice transmissions, which require an acoustically quiet environment, digital transmissions can be received and sent without phonetic errors. Messages can be automatically stored for a period of time until the officer has time to review them. Some equipment can check messages for errors in transmission.

Digital communications impose special requirements on the overall communication system [63]. To avoid significant interference with voice transmissions, it is recommended that digital transmission be via dedicated radio channels [8]. Also, electromagnetic interference can cause significant error rates, requiring either retransmission of messages or the use of error detection codes [64]. Adding digital terminals to older voice transmitters which have long warm-up requirements can produce delays in digital transmissions.

Reports and guidelines on digital communications are available to assist law enforcement agencies in selecting, evaluating, and developing operational plans for digital communications 18,63 . These documents provide further details on digital communications such as requirement analysis, system concept design, implementation planning, and performance and cost modeling. A standard providing minimum performance requirements and test procedures for mobile digital terminals has been developed [62].

Commercial systems often include provision for sending status messages from the vehicles, thereby saving time and radio channel usage. Since a vehicle identification code is automatically sent periodically to the dispatcher, it is a simple matter to include additional status messages, selected by push buttons in the vehicle. Typical status messages are AVAILABLE, ENROUTE, ACKNOWLEDGE, and AT SCENE. Also, certain alarm functions are possible, including an "officer in trouble" signal.

Mobile digital communication terminals allow the patrolman in the vehicle to visually receive the incoming message. *Figure 9* illustrates a mobile digital terminal which has eight lines with capability for 256 characters on a solid-state dot-matrix panel.

One system uses a programmable communications computer (also called a processor) at the base station facility to perform functions such as communications control, format conversions and buffering, in conjunction with the host

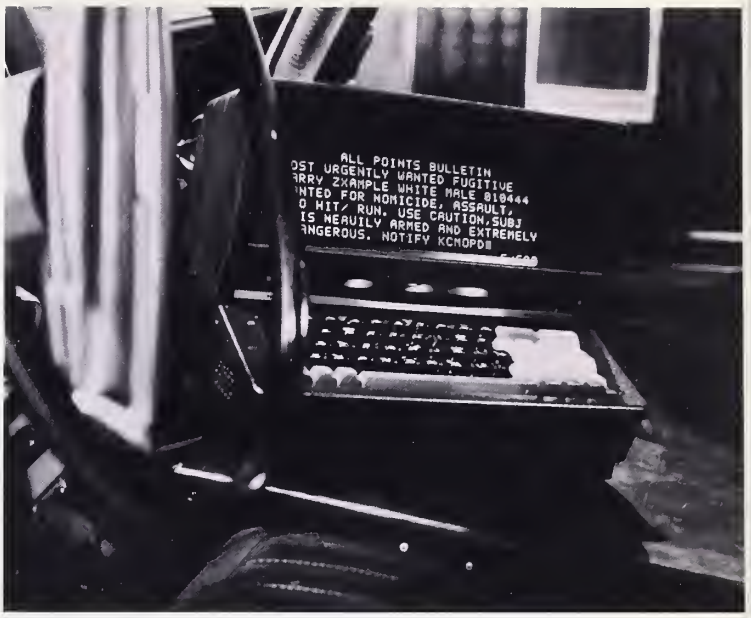


Figure 9. A typical mobile digital communications terminal.

computer. The processor is connected to the base station communications equipment through an appropriate encoder and decoder interface. The mobile terminal consists of a keyboard and display. The keyboard may include both alphanumeric capability and special function keys such as status, emergency and "canned" messages. The eight-line displays allow officers to view entire incoming messages at one time. One-line displays are available that are more compact [8]. The smaller displays require manual switching from line to line while reading or preparing a message. Attention should also be paid to display brightness and the likelihood of screen washout in daylight. Glossy surfaces, such as the keyboard, may reflect light directly onto the screen. The size of the keys and keyboard should be checked for adequate size and spacing.

The FCC requires that digital transmissions on voice channels be less than two seconds in length and that such transmissions not interrupt voice communications. Channel sensing equipment to accomplish this latter task is available on all equipment marketed for this purpose. An alternative is to use dedicated "digital-only" radio channels in lieu of voice channels already assigned.

Other equipment available for use in the vehicle is a printer which provides a permanent copy. Some printers are capable of being controlled from the base station such that even if unattended, messages will be printed out. Very quiet print heads are available.

Typical complaints against printers are that they are slow and wasteful of radio transmission time, and that the resulting received audio is highly distracting without tone-coded squelch. Also, printers usually do not have acknowledgment features, meaning that the sender doesn't know whether the message was received correctly (or at all). Probably for these reasons, mobile printers have not been too popular for use in law enforcement systems. However, at least one manufacturer includes as an option with its mobile digital terminal a printer that effectively gets around these objections. For example, by using the buffer in the mobile digital terminal, the "air time" is only 1.5 seconds maximum for 224 characters, and error detection is provided.

Other accessories include devices for the facsimile transmission of messages and documents such as maps and photographs. Equipment of this type can be produced in compact and lightweight models suitable for mobile installation. A typical system receives at a rate of 10 cm per minute (four inches per minute) with a resolution of 35 lines per cm (90 lines per inch). This equipment can be operated automatically when controlled by signals from the transmitter.

Facsimile can play a vital role in disseminating information within a complex communication system. For example, a telephoned complaint received at a central facility and written on a card can be transmitted by facsimile transmitter directly to appropriate district stations [20]. This method is fast and accurate, when compared with other systems such as teletype. Further information on performance characteristics and purchasing hints for facsimile systems are available [21].

Automatic Vehicle Location Systems

Dispatchers, in order to dispatch patrol vehicles efficiently, must have some knowledge of where the vehicles are located. There are systems that do this automatically, with a high degree of precision, known as Automatic Vehicle Monitoring (AVM) or Automatic Vehicle Location (AVL) systems. There are many different kinds of vehicle location techniques [22]. One method, a dead-reckoning system, makes use of the odometer to measure distance traveled and a gyrocompass to measure travel direction. A computer processes this information and displays the vehicle's location on a computer-drawn map. The degree of accuracy may be as good as 15 meters (50 feet) with this system. *See figures 10 and 11.*

Proximity systems use specially equipped "signposts," located throughout the area to be covered. Each signpost contains a low-powered microwave transmitter which transmits its location continuously. A vehicle passing by receives the signal, stores it, and tranmits to the dispatcher, on request, the location of the most recently passed signpost. Claimed accuracy is 90 to 180 meters (300 to 600 feet) at a 95 percent confidence level. *See figures 12 and 13.*

Figure 10. In a dead-reckoning system, a data processor (left) is used in conjunction with a transceiver (right) to send location information to the computer at the base station. (Photograph courtesy of the Boeing Co.).

Figure 11. Computer processed location information is presented at the control position on a computer generated map. (Photograph courtesy of the Boeing Co.).

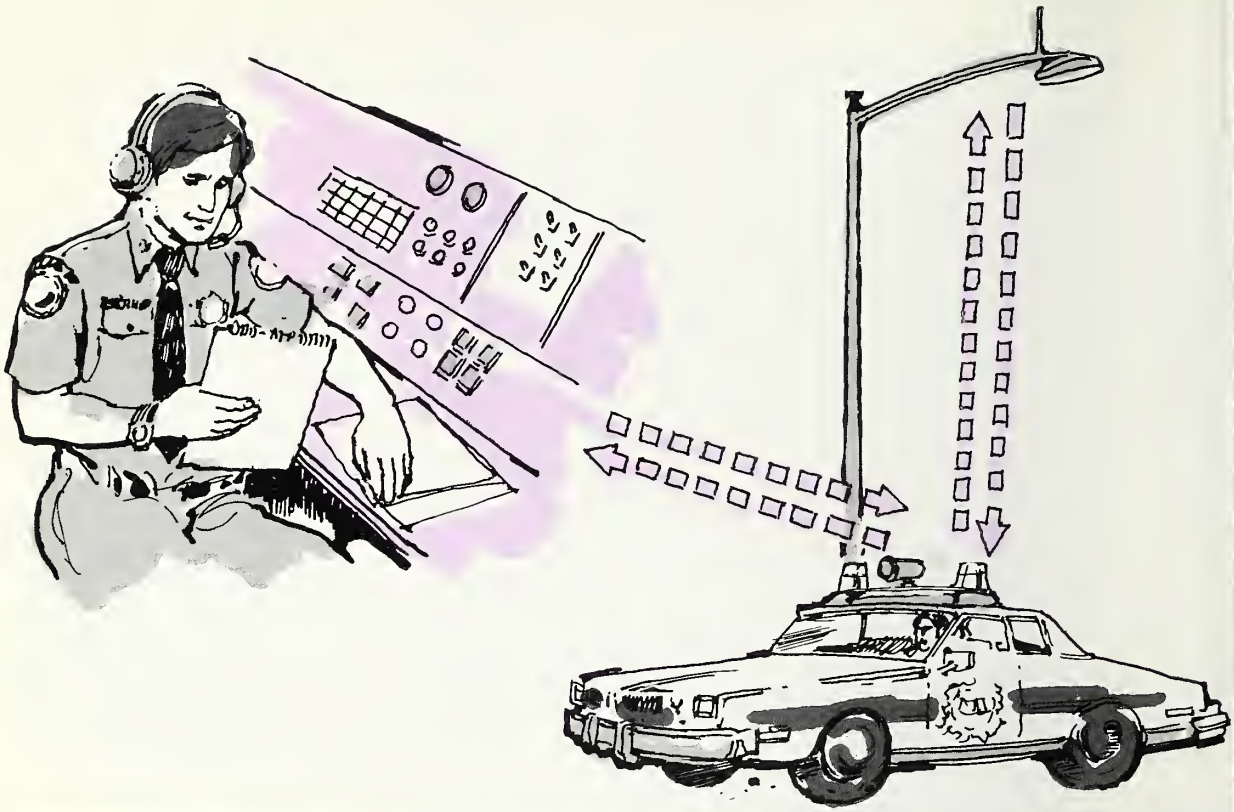


Figure 12. A representation of a law enforcement vehicle receiving a weak signal from a transmitter mounted on a signpost and retransmitting the vehicle location to the dispatcher. (Photograph courtesy of Hoffman Electronics Corp.)

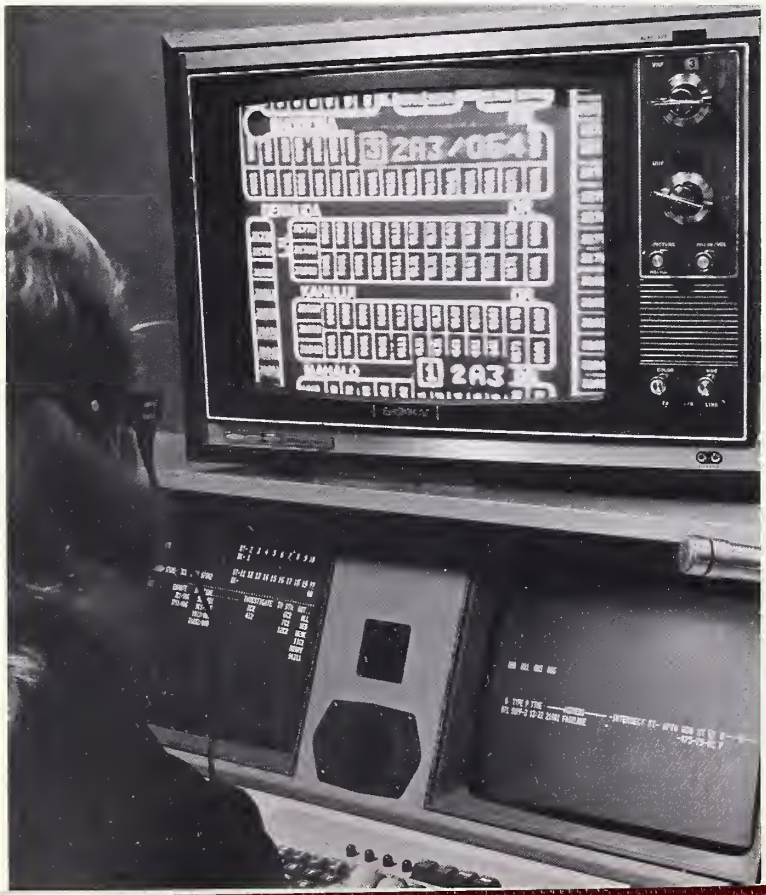


Figure 13. A view of the dispatcher position showing vehicle location and status for a proximity system. (Photograph courtesy of Hoffman Electronics Corp.)

Voice Privacy Systems

The availability of low-cost receivers has encouraged public listening to law enforcement communications. Unfortunately, there are some individuals who misuse the information obtained from such eavesdropping. One method used to discourage such listening is to add voice privacy equipment to the police communications system. These systems encode the voice at the transmitting end and decode it at the receiving end. It is desirable that the coding technique chosen have adequate voice security, minimum degradation of received voice clarity, and reasonable compatibility with other equipment. *Figure 14* illustrates a typical voice privacy system in operation.

The cost of voice privacy equipment depends on factors such as the technique used for scrambling and the number of codes available. Voice privacy systems are available from a number of manufacturers at costs ranging from $250 to over $6,000. For advice in selecting voice privacy systems, the reader is referred to another guideline [23].

Incompatibility among the scramblers of different manufacturers and even different models of the same manufacturer is not unusual [24]. Scramblers must often be tailored to work with specific communications equipment. The additional electronics adds complexity, bulk and weight, and has a tendency to reduce system reliability and increase maintenance requirements. On portable equipment especially, it is usually desirable to reduce bulk and weight as much as possible.

Figure 14

Repeater and Voting Receiver Systems

Each police officer in the field expects to have reliable communications with the dispatcher. The police officer on foot patrol utilizes hand-held, battery-operated transceivers. These devices are low-power units (usually 2 1/2 watts or less) of limited range. They can normally hear the dispatcher because of the high-power base station transmitter, but the dispatcher may have difficulty hearing the lower-power hand-held transmitter. In some cases even a mobile unit may have difficulty talking to the dispatcher because of irregular terrain or long distances. One method of solving this problem is to use a voting receiver system.

A voting receiver system consists of a number of "satellite" receivers and a comparator. The satellite receivers are located at carefully selected locations within the desired area of coverage. A low-power field unit then has a better chance of being heard by one of the satellite receivers because of the shorter distances involved. If several receivers hear the signal from the field unit, the comparator selects the best signal for the dispatcher. The satellite receivers are usually connected to the comparator by wire, but radio links can also be used. *Figure 15* is a photograph of voting equipment at a large facility.

A field transceiver, either hand-held or mobile, may have difficulty at a particular locality in both receiving from and transmitting to a given base station. Possible solutions to the problem include relocating the base-station antenna, increasing the antenna gain, increasing the transmitter power, or installing a repeater system. The latter is often the best choice for reasons of effectiveness. A repeater is essentially an intermediary receiving and re-transmitting station designed to automatically relay communications between base-station and field units. A desirable repeater site is generally one which has power already available, few powerful nearby transmitters, few radiofrequency noise sources, controlled road access, and good height and "overlook" for the area to be served. Control of the repeater can be either by wire lines or radio links.

Figure 15.

Figure 16.

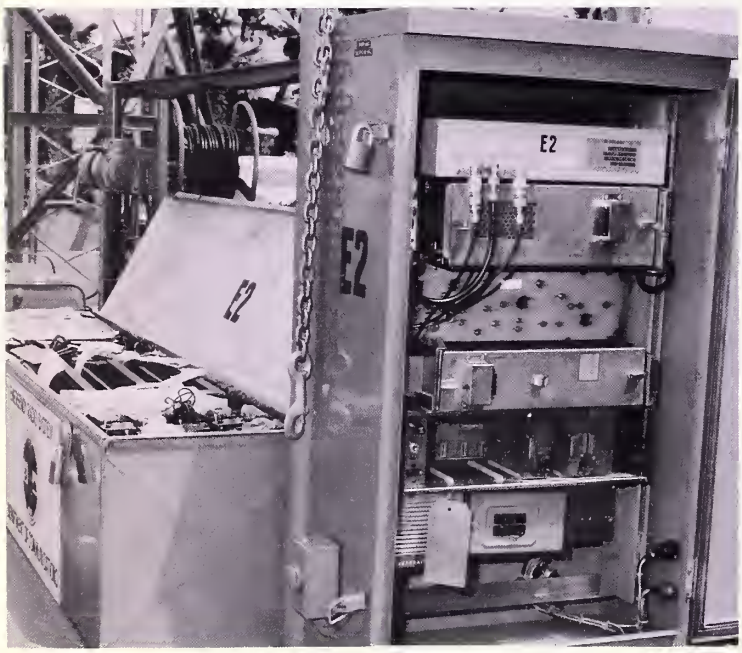


Figure 15. Receiver voting equipment including amplifiers, controls, and patching arrangements at the Los Angeles County Communications Radio Center.

Figure 16. Part of the portable emergency radio system in the Los Angeles County Sheriff's Department. (Photograph courtesy of L.A. County Communications Department.)

Repeaters need not be fixed permanently in location to be of service to a community. For example, emergencies may require additional communications on very short notice. *Figure 16* illustrates a trailer-mounted system consisting of a repeater with control console for local base-station use and a 12 meter (40 foot) crank-up tower for the antenna system. Additional equipment with the trailer includes an auxiliary generator as well as mobile transceivers and personal transceivers arranged for two-frequency operation in the 450 MHz band. Six mobiles and twelve portables, complete with antennas and batteries are provided, although twice that number can be handled with the repeater if needed.

Additional information for those who are contemplating purchasing repeater systems is available in a report and a standard [25,26].

Scanning Receiver Systems

Scanning receivers provide a relatively inexpensive means for monitoring traffic on several channels. Equipment of this type is priced from approximately $100 to $250 or more. Crystals (if used) for the desired channels are additional and may total more than $100. A scanning receiver can be used at fixed locations or for mobile operation. The receiver typically scans selected channels in rapid sequence until a signal is detected. At that point the receiver stops scanning and that channel is heard until the signal ends. Then the receiver starts scanning again.

Options available include variable scanning rates, and channels that can be locked out and not routinely scanned. A priority channel can be designated such that traffic on it will supersede all other listening, even to the point of interrupting a lock on another busy channel. Units are available with frequency synthesizers that are programmable by coded punched cards. Hand-held, portable scanning receivers are also available. A word of caution: do not expect the same performance from these receivers that would be expected from more expensive fixed frequency receivers. Do not expect the same reliability, freedom of overload from nearby transmitting sources, and lack of spurious responses that the more expensive communication receivers provide. Perhaps the proper place for scanning receivers is for situations where information of a general nature is desired and not where critical reliance is sought.

Public Transportation Safety Channels

In order to improve the safety of the traveling public there is presently a proposal before the Federal Communications Commission (FCC) to provide three frequencies in the standard AM broadcast band for the transmission of information to the traveling public by "Traveler Information Stations" [27].

In addition, an ad hoc committee has recently studied whether the Department of Transportation (DoT) should allow, fund, or encourage law enforcement and other public safety organizations to use citizens band (CB) radio to augment their present communication systems [28]. The committee supported the use of CB Channel 9 as a national emergency and motorist-aid channel. It also supported the encouragement of cooperation between CB users and the emergency response agencies.

The FCC has estimated that there are fifteen million citizens band transmitters now in use in the United States. Many of these stations are located in vehicles, and several law enforcement agencies have found that communications with trucks, for example, can be advantageous [11]. The misuse and abuse of CB equipment, overcrowding, and the technically inferior quality of some CB communications are problems, however. Careful planning is needed before any such concept can become workable and practical.

Planning and Management

In order to assure an effective and smoothly operating communication system, a great deal of early planning and continuing good management is required. In the limited space available here, we can only hope to point out typical problem areas and refer the reader to some excellent references that deal more completely with the subject.

Special problems exist in making major modifications to existing communication systems, as opposed to implementing entirely new systems. For example, that part of the system which is changed or added must be integrated with the rest of the system so that total system performance is enhanced. Usually the entire system cannot be shut down during modification. The process of modification must satisfy both old and new systems.

It is essential that someone has a thorough grasp of the communication needs of the law enforcement agency. Someone continually needs to match needs with the means by which the desired result may be accomplished. The best results in new system design or modification can then be achieved. In designing a new system, however, there is broader scope for integrated planning of all operational and support systems [20].

New public buildings and facilities should be planned with adequate conduit systems provided to allow future deployment of communications systems. This illustrates the need for early planning of communication facilities. It is important that management recognize the need for someone to keep abreast of Federal Communication Commission (FCC) Rules and Regulations; to be aware of and utilize current state-of-the-art communications; to effectively use existing assigned frequencies; and to assure proper operation and utilization of the equipment [4].

Most communication system managers have many areas of responsibility. For example, the manager usually consults with department heads to review and monitor their communication needs, and to provide recommendations. He may need to determine that all systems and equipment meet the needs of the department, not only economically, but with good engineering and operational procedures. He may design new or additional communication systems and plan long-range programs. The manager needs to make certain that the terms of the FCC licenses are met and that the Rules and Regulations are followed [4]. System managers should keep supportive data, not only to ascertain personnel requirements, but also to provide accurate inputs affecting budget decisions for those in the administration who have fiscal responsibilities [30].

PRINCIPAL COMPONENTS

Once a communication plan has been developed, there is need to identify the kinds of equipment necessary to accomplish those goals. The following sections discuss many types of communications equipment available for use in law enforcement. New equipment is continually being developed, and readers should query the various manufacturers for the latest developments.

Transceivers

Detailed descriptions of the principal types of law enforcement transceivers are given in three companion guidelines [31-33]. These discuss personal/portable, base station and mobile transceivers, and give information relating to the various available options and suggestions for proper placement in service.

Antennas and Combiners

The antenna system is an important link in any communications chain. A well designed and deployed antenna system, with low transmission line losses and low standing wave ratios (SWR), will often make the difference between good and poor communications. Usually the same antenna system is used to transmit and receive, since antenna switching is often performed within the communications transceiver. Therefore the time, trouble, and expense taken to improve the antenna system will pay dividends in improved performance for both transmitting and receiving. Additional information on antennas is available in other guidelines [31-33].

Multifrequency operation in a given band is not at all uncommon in busy urban areas. What then can be done to assure satisfactory operation at a given location when reception is desired a few megahertz or even a few tens of kilohertz away from the frequency of an active transmitter? The problem is one of providing receiver protection from transmitter noise and receiver desensitization. In addition, if two or more transmitters are sharing a common antenna, there must be provision to reduce transmitter intermodulation. The most commonly used type of equipment to reduce these effects is a combiner. The type of combiner chosen depends upon a number of system factors including frequency separation, number of transmitters and/or receivers, and antenna system gain [34].

When transmitters and receivers share a single antenna and are in operation simultaneously, a duplexer is commonly used to provide the necessary isolation. The duplexer usually consists of high Q filters combined so as to achieve the desired isolation. The filters may be placed in series to act as a bandpass filter, or in parallel to act as notch (band-reject) filters, or in combination. A typical filter installation is shown in *figure 17.*

Figure 17. A cavity resonator installation for 39 MHz. (Photograph courtesy of Los Angeles County Communications Department.)

Ferrite isolators in combination with bandpass cavities are commonly used at VHF and UHF to reduce transmitter-produced intermodulation when the frequency separation between trans-

mitter frequencies are at adjacent channels. A ferrite isolator is a three port circulator with a matched resistive load connected to port #3. It passes transmitter power from its input (port #1) to its output (port #2) with a typical loss of 0.5 dB, but attenuates rf energy in the opposite direction by typically 20 or 25 dB. One disadvantage is that a ferrite isolator may itself generate harmonics and other noise. Therefore harmonic low-pass filters are usually placed between the isolator and the following system component. This device has an added advantage in protecting the transmitters from open or shorted transmission line or antenna conditions.

Control Consoles

A control console usually consists of a desk-mounted, enclosed panel containing a number of controls used to operate a radio station. The control consoles can be combined in various ways to form a communication control center of almost any desired level of complexity and sophistication. A communication control center is of prime importance in law enforcement. Incoming information in the form of citizen complaints is processed and dispatched at this location. Activities of the field personnel are also monitored, coordinated, and directed from the control center. *Figure 18* illustrates typical control consoles within such a communication control center.

Typical features of a control console include audio controls (microphone, loudspeaker or earphones, volume control, compression amplifier, telephone line balance control, tape record controls), and rf controls (transmit-receive switch or voice operated control, selective-calling controls for individual mobile units, and frequency selector). Indicators include a transmit indicator, and volume unit meter. Useful accessories include card files for frequently used information, automatic time clock, and automatic dialing controls for telephones. In general, there is a lot of interest in well-designed control consoles and many manufacturers offer consoles that are both pleasing to the eye and human engineered for use in law enforcement communications.

Power Sources

Power sources for communication equipment vary over a broad spectrum. Base stations primarily use power from the commercial power lines. Mobile units use power from the vehicle alternator and battery. Personal and portable transceivers use either primary or secondary batteries. These power sources are well described in the literature and will not be discussed further here [35,36]. However, special power sources are occasionally needed. For example, a remote repeater site may not have commercial power available, and base stations

are subject to occasional power outages, often just when service is needed to handle a critical situation.

Equipment used in emergency situations include battery and inverter systems and engine-driven generators. A battery-inverter system offers the advantages of instant availability, low maintenance (no moving parts), easy installation, high reliability, and good performance and efficiency. Unfortunately, a battery is limited in the amount of energy it can deliver, and a power failure of sufficient duration will cause such a system to fail. If it is suspected that the outage time or current demand may exceed the capacity of an existing emergency batter, the purchase of a small supplemental engine-generator system rather than a larger battery should be considered. The engine-generator system may be programmed to start automatically after a given time interval in order to recharge the battery or supplement the battery power [37].

Engine-generator systems are relatively expensive, and to assure reliability must be regularly inspected. They are not capable of providing instantaneous power and require some time (seconds or even minutes) before they can be safely used. The selection of the engine depends upon various factors. Diesel engines are heavier and more costly than the other choices, but are more rugged and dependable and are often the choice for continuous operation. Fuel costs and fire danger are lower than for gasoline engines. Gasoline engines are useful for output powers up to 100 kw; they start quickly and are relatively low in initial cost. However, their higher operating costs, due to fuel cost and short time between overhaul, work to their disadvantage. The storage and handling of gasoline involves great hazard, and the user must be cautious. Natural gas and LP gas engines are perhaps the most reliable after long shutdown periods, because these fuels do not deteriorate with time as do gasoline and diesel fuel. Also, because of cleaner burning, engine life is longer and maintenance is less. Initial costs are comparable with gasoline engines. The local situation should be studied relative to the availability and dependability of alternative fuel supplies, especially in emergency situations.

Figure 18. Adams City (Colorado) Dispatch Control Center.

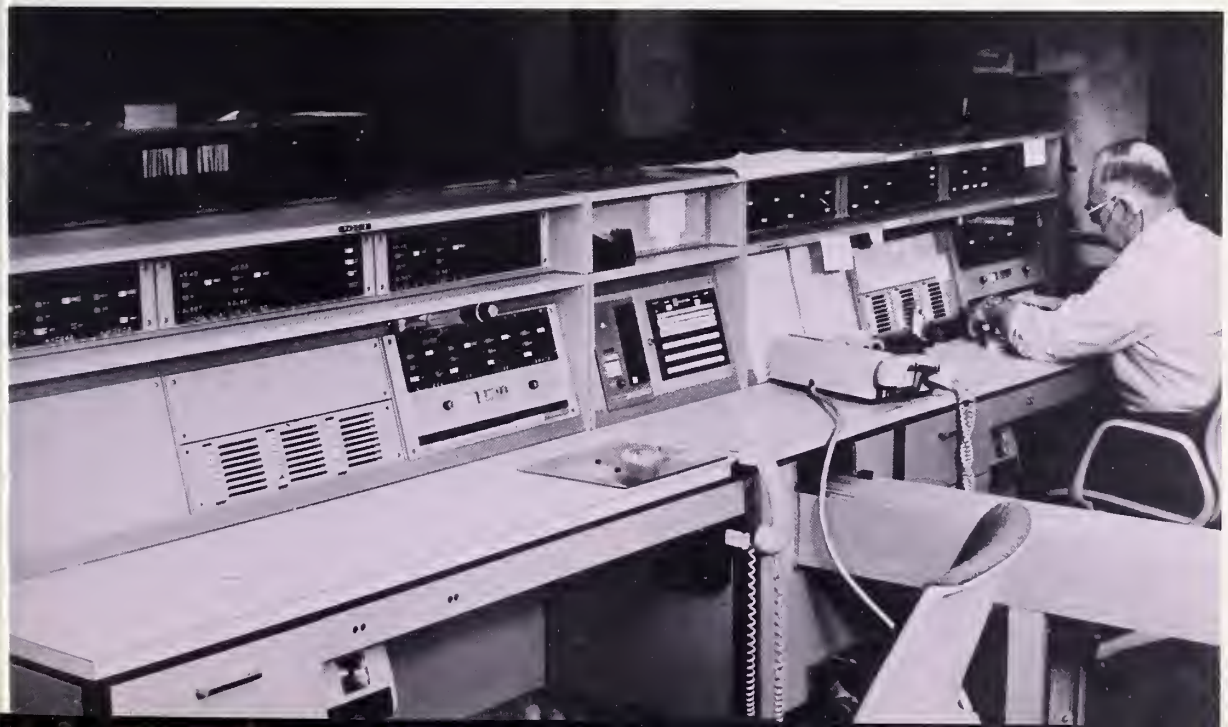


Figure 19

Another source of power is the thermoelectric generator. This system converts heat energy to electrical energy by the use of a thermopile. Electrical energy is produced by burning propane or butane and heating the hot junctions of the thermopile. Models are available that supply from 10 to several hundred watts. Prices range from one to over three thousand dollars. Special enclosures are available for better corrosion, insect, and environmental control in hostile climates. *Figures 19-21* illustrate examples of the power sources mentioned above.

Figure 19. A remote communications site with propane supplying a thermoelectric generator that is mounted on a portable building (arrow points to generator). (Photograph courtesy of U.S. Geological Survey.)

Figure 20. A nickel-iron (or Edison) battery installation for standby power for the computers in a computer-aided dispatch center.

Figure 21. A standby motor-generator installation for a remote communications site.

Figure 20

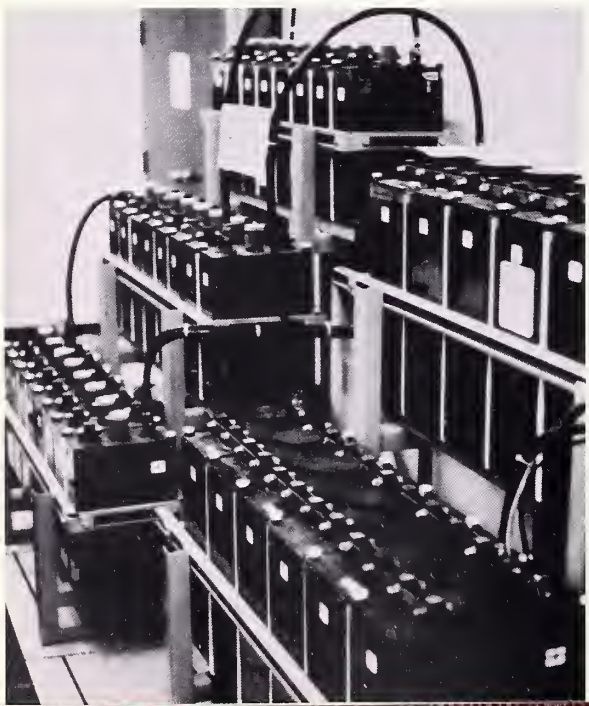


Figure 21

Other sources of electrical energy that are presently being developed which may soon fill the needs of emergency and standby power systems include the following [38]:

- Fuel cells which convert the energy of chemical reactions such as the burning of hydrogen into electrical energy. High initial costs and the lack of long-term reliability are the major disadvantages of these cells.

- Photovoltaic cells which convert radiant energy from the sun into electrical energy. These cells have very high reliability, which makes them attractive for remote unattended locations. The major disadvantages are high cost and the large surface area required for even modest voltage and power levels. A practical system would include batteries for use during cloudy days and at night.

Standard Interfaces

There are several problems due to the lack of standardization of law enforcement communications equipment. For example, the control head made by one manufacturer has a squelch control and a channel selector which operate counterclockwise, while another manufacturer uses the opposite rotation. One manufacturer has chosen the left side of the control panel for the squelch control and the right side for the volume control, while another manufacturer has these reversed. The result is that an officer who must use patrol cars equipped with different types of equipment may make unnecessary mistakes in critical situations. These and similar standardizing problems are being resolved [39,40].

Standardization at the local level has been attempted for many years, and items such as cable connectors, mounting hardware, and control heads used in mobile transceivers have been prime candidates [41]. It is expensive and difficult to change from the equipment of one manufacturer to that of another. Not only do cables and similar accessories not interchange, but entire subsystems usually are not electronically compatible. This dissimilarity of circuitry and parts among manufacturers places additional training and inventory requirements upon maintenance personnel.

While there would be significant advantages in the standardizing of certain equipment interfaces, there could well be disadvantages in the standardization of the equipment itself. Manufacturers frequently claim that the standardization of equipment would decrease their ability to provide improved products [42]. For that reason, equipment standards should, whenever possible, be performance standards rather than design standards.

Telephone Interfaces

A large expenditure in the annual budget of nearly every large law enforcement agency is for telephone service. The telephone is used conventionally for interoffice and external communications. In addition, dedicated telephone lines are often used with base stations and repeaters, and with satellite receivers spaced advantageously within a community and connected in a voting arrangement to the base station communication equipment.

Adequate service is a necessity, and it is important that the telephone equipment be sufficient to perform the mission of the department as economically as possible, while at the same time providing a good "telephone image" to the public. There is nothing as disturbing to a caller as to be forced to wait for an extended period for a line to clear. One agency improved its service by adopting the following guidelines [43]:

- Sixty seconds was to be the average talk time for primary operators,

- Ninety percent of all incoming calls were to be answered within twenty seconds.

In order to accomplish the first goal, additional training was provided in telephone answering procedures and questioning techniques. Tele-

phoned reports and other calls expected to take longer than sixty seconds were transferred to secondary operators. The second guideline helped to determine the number of telephone lines and operators required.

Many law enforcement agencies use a Private Branch Exchange (PBX). A PBX is a switching system for interconnecting telephones with other telephones on the same premises. The older PBX's are manually operated; a switchboard attendant makes the connections and controls the bell ringing. Dial PBX systems make use of dial operated equipment to establish connections between stations while a switchboard controls "external" connnections to the system. With another type of Private Branch Exchange called CENTREX, incoming calls can dial directly to any extension without the assistance of an operator. Outgoing and internal lines are dialed directly by the extension users.

A PBX can be either telephone company or customer owned. If telephone company owned, there are certain monthly fees to be paid. If the PBX is privately owned, the appropriate connection arrangements are furnished, installed, and maintained by the telephone company [44]. A monthly charge is made for the interface. Although a privately owned PBX often has a very attractive initial cost and may offer otherwise unobtainable features, one should carefully consider the alternatives before renting or purchasing. Local experience should be sought out and questions asked relating to local servicing of both the PBX and the interface. Because of the high costs involved, the specifier of such a system should also study the available equipment options from the several suppliers, training programs for the operators, and the expansion capabilities of the systems [45-47].

Lightning Suppression

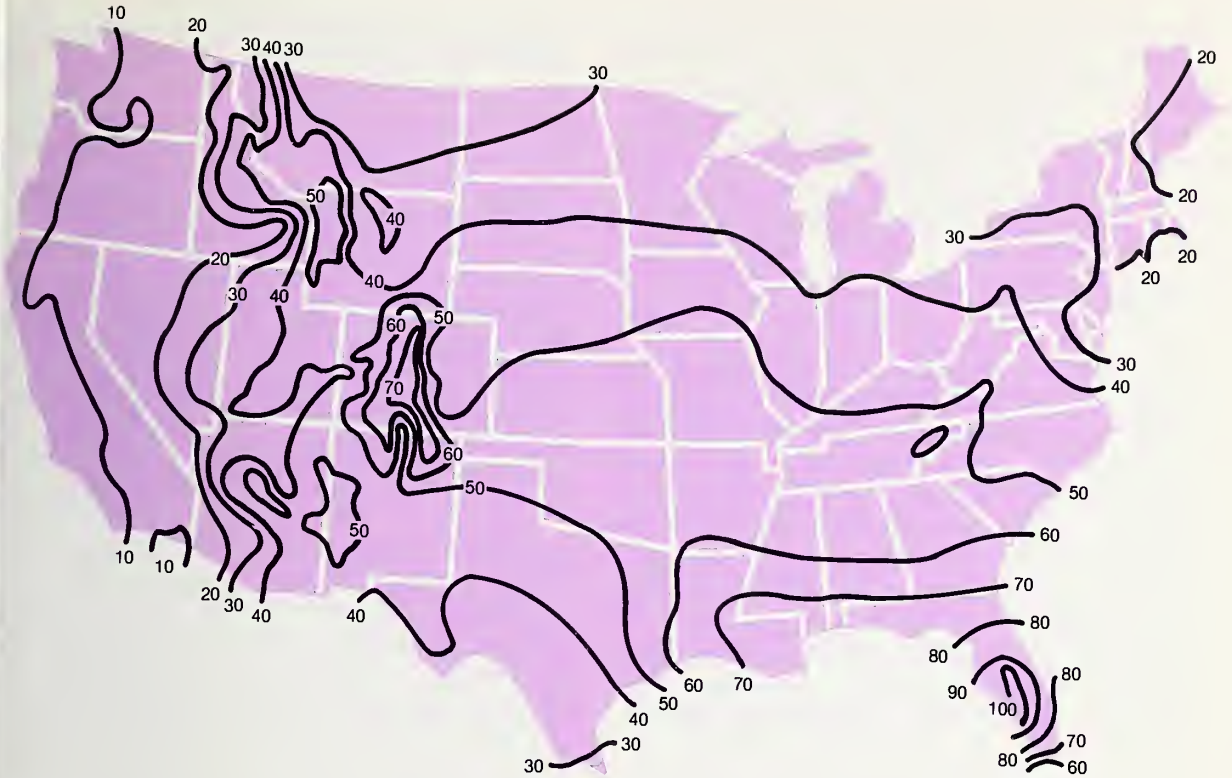
Lightning is one of the hazards to which communication facilities are subjected. *Figure 22* shows the average frequency of occurrence of thunderstorms within the United States. The most active area is in Florida. There, one communication facility was knocked off the air six times in one summer [48]. Also, one wild night there were 19 base stations and repeaters struck by lightning.

Fixed antenna systems are usually placed at high locations, such as a hilltop or the roof of a tall building, and are thus highly susceptible to lightning strikes. While there is little that can be done to reduce the occurrence of lightning, there is much that can be done to minimize the effects of a lightning strike. The physical damage (and shock hazard) can often be greatly reduced by the proper design and installation of the tower and antenna system.

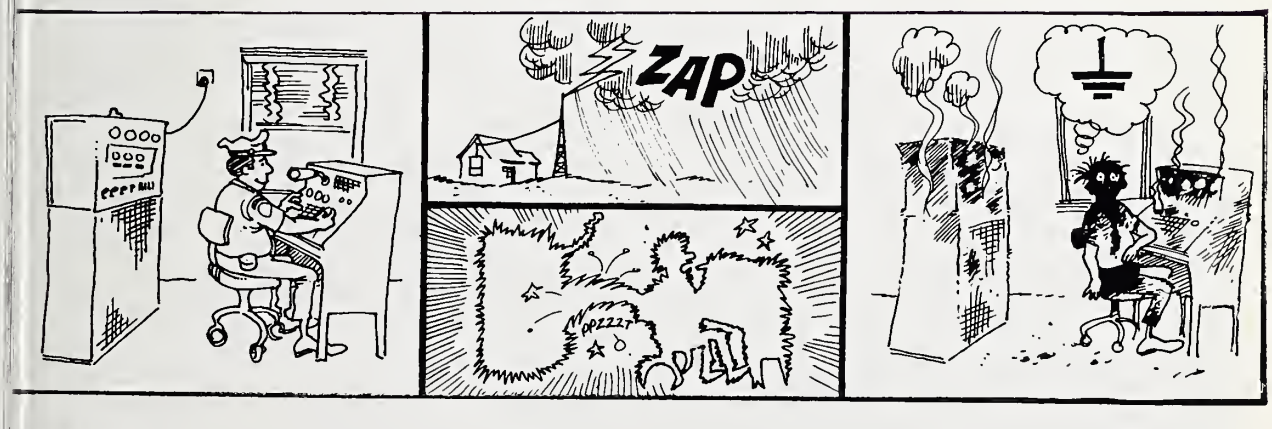
A lightning strike may involve several hundred thousand volts and currents increasing at the rate of several thousand amperes per microsecond. These rapidly changing currents can create hazardous inductive voltages between nearby equipment cabinets and other metallic objects *(see fig. 23)*. Proper bonding and grounding can greatly reduce this type of shock hazard to personnel. A variety of protection measures can be applied to help assure the uninterrupted operation of communications equipment. The following parts of a communication facility are usually the most vulnerable:

- Antennas, towers, and supporting hardware,
- Transmission lines from transmitter to antenna,
- Communications equipment and attendant buildings, and
- Power lines, telephone lines, and control cables.

For basic lightning protection and the automatic reduction of smaller voltage discharges through communications equipment, the use of "dc-grounded" antennas is recommended. Exam-



igure 22.



igure 23.

ples of these are folded dipoles and colinear verticals. High gain antennas use multiple elements but still are essentially self-protecting. Details on the proper methods of grounding and connecting arrestors, protectors, and suppressors are already available and need not be repeated here [49].

Test Equipment

A visit to a maintenance area where work on communication equipment is performed may tell one a lot about the operational success of a communication system. Such success is dependent not only on knowledgeable and dedicated personnel but also on adequate test equipment. A well-equipped and modern shop saves a great deal of labor and even frustration at times. Much emphasis has been placed on obtaining modern communication systems and operational equipment. But too often the tendency is to stay with the old familiar test equipment which may no longer be adequate.

For example, there has recently been a significant improvement in frequency-modulated (FM) signal generators used to test receivers. All-solid-state generators are available that provide digital readout of frequency. The more expensive ones (in the region of 4-5 thousand dollars), offer output frequency stabilization in the order of 1-5 ppm using special phase-locked circuits and very stable crystal references. In addition, signal generators can now be built that have very low noise output. Some generators are available that operate with such characteristics to slightly above 1 GHz. The interested reader is referred for details to a rather extensive discussion comparing available models and listing manufacturers [50].

In the testing of transmitters, a spectrum analyzer can be a very useful tool. A spectrum analyzer uses a frequency-domain presentation instead of the time-domain presentation that an oscilloscope uses. As a result, certain measurements and information can be more readily obtained. For example, certain characteristics of signal sources (such as the signal generators discussed above) can be readily studied. Because of typically large dynamic range—often exceeding 70 dB—measurements comparing spurious responses and harmonics with the fundamental frequency may be readily seen at a glance. Spectrum analyzers are also useful to identify certain modulation problems of transmitters, to compare relative signal levels in a large spectrum of frequencies, and (with a tracking generator) to adjust filters for desired frequency rolloffs. Spectrum analyzers typically cost from about 4 to 8 thousand dollars.

For suggestions as to where to purchase general test equipment, the reader is referred to the section below entitled Purchase of Communications Equipment.

COST CONSIDERATIONS

In public-safety communications there is an obligation, indeed a requirement, to carry out the tasks with reasonable efficiency and minimal costs to the taxpayers. Grants are available, but these often require feasibility studies and system designs which may be too complex and technical for the smaller communities who have limited staffs [51]. In such cases a communications consultant may be necessary.

Poor planning and procurement practices can result in a waste of purchasing dollars. Equipment costs can generally be best determined by competitive bids. It has been charged that the "lowest bidder" procedure results in waste, delay, inefficiency, and unnecessary expense [52]. However, most governments require a low-bid system to avoid the abuses inherent in no bidding system at all [53].

After the initial purchase of communications equipment, the user is faced with other costs including training, maintenance, and test equipment. As more fully discussed in another guideline, maintenance costs can be high [51]. Some communication officers figure maintenance to entail a yearly cost of 10 to 20 percent of the fixed investment [4]. Test equipment for the aligning or testing of communications gear can, in itself, run into a significant investment. Some precision signal generators, for example, cost $10,000 or more.

PURCHASE OF COMMUNICATIONS EQUIPMENT

According to the Electronic Industries Association (EIA), there will be more emphasis on the part of law enforcement agencies in improving communications equipment [54]. Much of the support will come from LEAA grants. Not only will older equipment be replaced with more modern state-of-the-art equipment using established radio frequencies, but the recent allocation of frequencies in the 900 MHz band is expected to encourage greater use of sophisticated communication systems. With the increase in the use of communications equipment, maintenance, alignment, and testing of communications equipment can also be expected to increase. A corresponding need would also exist for more specialized communications test equipment and service aids. What resources are available to help the prospective purchaser?

There are several buyers' guides for the general electronic market that cover products from "A" to "Z" [55-57]. Buyers' guides that specialize in telecommunications are also available [58-60]. However, none comprehensively and accurately cover only the law enforcement communications market.

The reader should query manufacturers that advertise in trade magazines and journals. Trade shows and conferences are a popular and convenient way of getting acquainted with some of the larger manufacturers in the field.

One extremely important source of information is the Equipment Technology Center of the International Association of Chiefs of Police. The IACP, with the technical support of the NBS Law Enforcement Standards Laboratory, has started a program to test important items of law enforcement equipment for compliance with the NILECJ/LESL or other appropriate standards. Handheld transceivers are among the first items to be tested under that program.

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