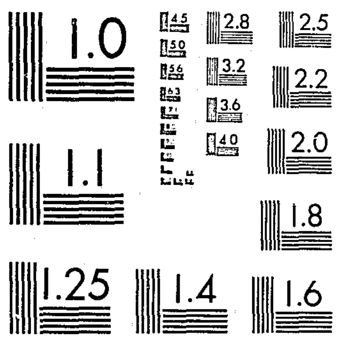

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NIJ

Technology Assessment Program Standards Laboratory

Mobile Radio Guide

202-83

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The Technology Assessment Program is sponsored by the Office of Development, Testing, and Dissemination of the National Institute of Justice (NIJ), U.S. Department of Justice. The program responds to the mandate of the Justice System Improvement Act of 1979, which created NIJ and directed it to encourage research and development to improve the criminal justice system and to disseminate the results to Federal, State, and local agencies.

The Technology Assessment Program is an applied research effort that determines the technological needs of justice system agencies, sets minimum performance standards for specific devices, tests commercially available equipment against those standards, and disseminates the standards and the test results to criminal justice agencies nationwide and internationally.

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James K. Stewart,
Director, National Institute of Justice

Technology Assessment Program
Standards Laboratory

Mobile Radio Guide

202-83

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National Institute of Justice
James K. Stewart
Director

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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 Justice (NIJ) 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 technology guide developed by LESL under the sponsorship of NIJ. 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, DC 20234.

James K. Stewart *Director*

National Institute of Justice

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INTRODUCTION

In recent years there has been a steady expansion of communications services and many significant technological improvements of existing equipment. Surveys predicted that land-mobile communications would more than double in the 10-year period from 1973–1982 [28]*. Accordingly, most police departments have purchased more mobile radios** than they have retired in recent years [16,21].

This guide has been written for the benefit of law enforcement officials and others who are interested in the selection and use of mobile communications equipment. It is one in a series of four guides. The other three cover personal radios, base station equipment, and complete communications systems [18–20]. Those who plan to prepare procurement specifications should consult the appropriate guide and the related performance standard or standards.

TABLE 1. AVAILABLE DOCUMENTS

Application	Applicable documents
Communications system planning	NBS Special Publication 480-12, Communication Systems Guide Any or all of the others listed in this table
Mobile transceiver procurement	NILECJ-STD-0202.00 Mobile FM Transmitters NILECJ-STD-0205.00 Mobile Antennas NILECJ-STD-0207.00 Mobile FM Receivers NILECJ-STD-0212.00 RF Coaxial Cable Assemblies for Mobile Transceivers NBS Special Publication 480-9, Mobile Radio Guide
Personal/portable transceiver procurement	NILECJ-STD-0209.00 Personal FM Transceivers NILECJ-STD-0211.00 Batteries for Personal/Portable Transceivers NBS Special Publication 480-10, Personal Radio Guide
Base station equipment procurement	NILECJ-STD-0201.00 Fixed and Base Station FM Transmitters NILECJ-STD-0204.01 Fixed and Base Station Antennas NILECJ-STD-0206.00 Fixed and Base Station FM Receivers NBS Special Publication 480-11, A Guide to Base Station Communications Equipment
Accessory equipment procurement	NBS Special Publication 480-8, A Guide to Voice Scramblers for Law Enforcement Agencies NBS Special Publications 480-9, 480-10, 480-11 and 480-12 References 6, 10, 12, 32, and 35

These have been developed for a wide variety of communications equipment. Although they have been tailored specifically for law enforcement application, they are obviously suitable for other public-safety and land-mobile use. They are listed in table 1, grouped by subject area, and are detailed in the list of references [23–25]. In addition to those listed in the table, standards are now being developed for mobile digital equipment, microphone cable and connectors, control heads, microphones, logging devices, and selective signaling equipment.

This guide is intended to provide background information for the choice of mobile radio equipment. It points out most of the factors that purchasers of such equipment should consider. Some test results are provided, and tradeoffs in system and equipment performance are identified. Federal Communications Commission (FCC) regulations, safety, and purchasing considerations are also discussed.

Many of the technical terms used in this guide are defined in "Technical Terms and Definitions Used with Law Enforcement Communications Equipment" [8].

*Numbers in brackets refer to references.

**Although they are really transceivers, i.e., having the capability of both transmitting and receiving, the devices are commonly called radios.

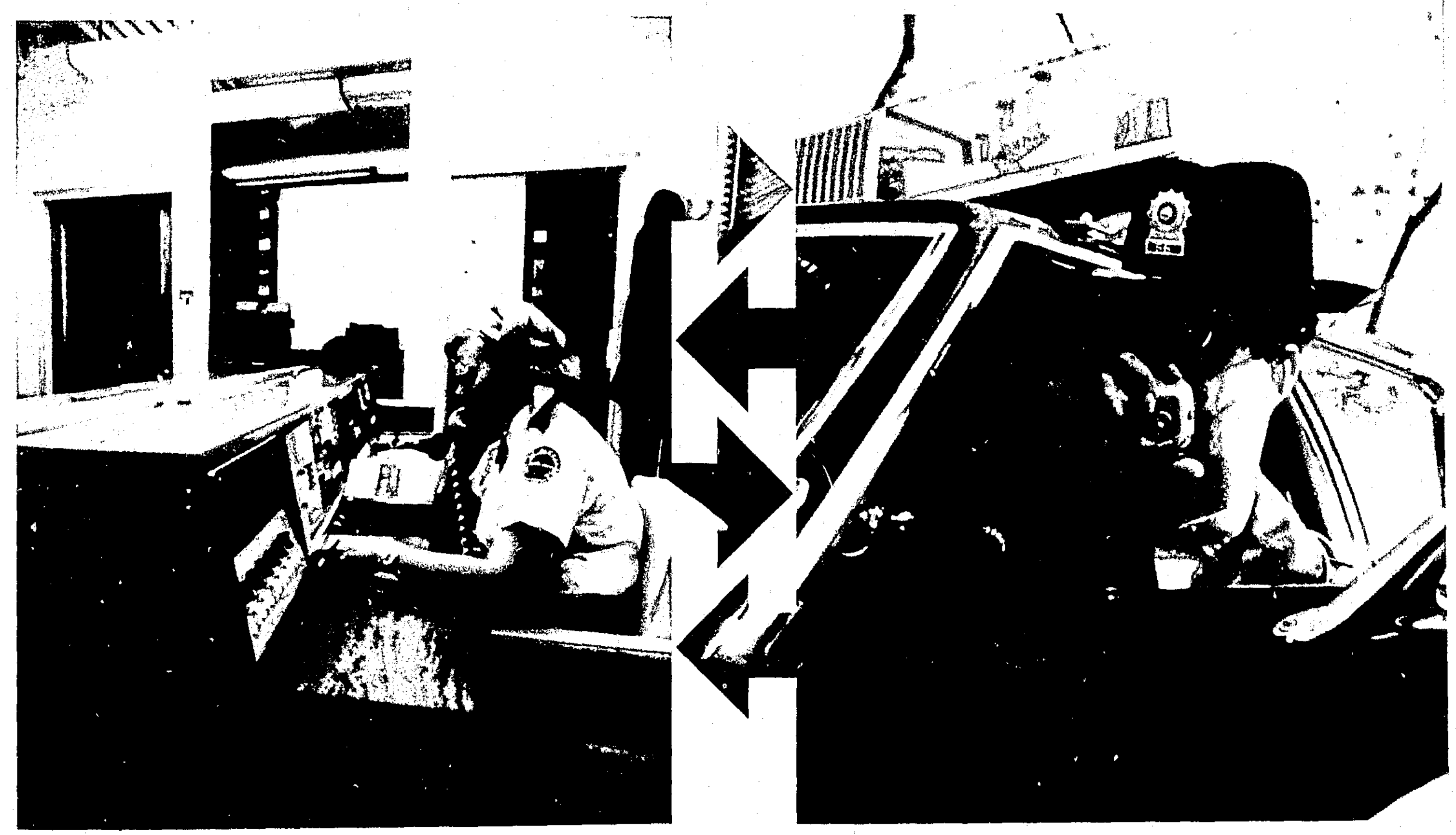
BACKGROUND

Law enforcement communication requires a two-way exchange of information between a command officer and law enforcement personnel within an area of operation. The ability to communicate with other law enforcement agencies and national or regional information storage facilities is also essential.

Regardless of department size, most systems consist of the same types of equipment: field transceivers, base station equipment, and accessory equipment. The amount of equipment is determined by the complexity of the operation and the extent of the need for communications. If either personnel or area of jurisdiction is limited, only one base station may be required. This base station needs only to be located at a convenient site that allows all mobile stations to communicate effectively with it. It does not necessarily have to be devoted to the needs of one organization; it can be shared by several local agencies. Large departments or those with large areas of jurisdiction may operate two or more base stations.

Fifty years ago only one-way communication was attempted. Messages were transmitted from police headquarters to mobile units in the field. Eventually, two-way communication between vehicles and headquarters became common. Then, in 1938, the advantages of FM mobile communication were demonstrated. The first repeater was installed in 1939 [1] and, being ideally located on top of a mountain, dramatically improved the area coverage. Mobile communication has grown steadily since, becoming increasingly complex and costly in the last several decades, but service to the public has improved as a result. As the usefulness of mobile communications has increased, a large variety of functions are being performed.

Frequency modulation (FM) systems gained popularity early in the development of police communications because of essentially static-free reception which provided a more effective radius of communication than previously used systems. FM systems have since proved to be reliable and relatively economical in operation and maintenance.



SYSTEM TECHNICAL ASPECTS

Frequency Considerations

There are four frequency bands now in use. These are the 25-50 MHz (VHF low-band, commonly called low-band), 150-174 MHz (VHF high-band, commonly called high-band), 400-512 MHz (UHF band), and the 806-960 MHz (UHF band, commonly called the 800 or 900 MHz band).

Today, most police departments operate on high-band and UHF, in contrast to 25 years ago, when almost all mobile police communication was on low-band. A shortage of available low-band frequencies started the move to high-band. Just as equipment had been developed to facilitate the move to high-band, so was the process repeated for movement to the UHF band and for the same reasons—crowded spectrum, interference, and growing man-made noise. Now UHF frequencies are being more heavily used. As systems and equipment are developed for the new 806-960 MHz band, the move to those frequencies by more jurisdictions will undoubtedly start.

Coverage

In mobile communications, coverage is defined as the area surrounding the base station within which reliable mobile transmission and reception occurs. A primary objective of any communications system is to provide adequate coverage. There are several factors, listed in table 2, which influence coverage. The dependence of some of these factors on frequency is shown in table 3 [13]. Although table 3 does not include the 806-960 MHz band, performance at these higher UHF frequencies will be similar to operation in the 400-512 MHz band.

Low-band propagation has the characteristics of greater direct range capability. Mobile-to-mobile communications can be conducted at reasonable ranges in this band even with low output power. In this band, the terrain and building losses are low, and multipath reception by mobiles is usually not a factor. However, man-made noise has a large effect and there are occasional interference problems from co-channel stations hundreds or thousands of miles distant (skip propagation).

TABLE 2. FACTORS WHICH AFFECT COMMUNICATIONS COVERAGE BETWEEN A MOBILE STATION AND A BASE STATION

1. Antenna height and placement.
2. Type of terrain.
3. Frequency.
4. Transmitter power.
5. Antenna gain.
6. Transmission line loss (primarily base stations).
7. Man-made noise at receiving locations.
8. Interference at receiving locations.
9. Receiver sensitivity.
10. Propagation path losses.

High-band transmissions have limited range compared to low-band, but usually have fewer interference problems. Elevation of the base station antenna is important to improve communications range. On this band, multipath propagation involving reflections from buildings is noticeable, and received signals may vary by 10 to more than 20 dB in just a few vehicle lengths of travel.

Transmissions at UHF frequencies usually have slightly less range than at high-band. Equipment costs are slightly higher for both original purchase and maintenance. There are rather rapid and extreme amplitude fluctuations due to multipath propagation. Such things as street orientation, foliage, and irregular terrain are significant at these frequencies. However, there is often much better coverage inside buildings and beneath underpasses. Because of the limited transmission range in this band, repeaters are commonly used for mobile relay operations.

Mobile communications in the 806-960 MHz band are more dependent on repeater operation than those at lower frequency bands, particularly in urban environments. Propagation characteristics are quite similar to those at the lower UHF frequencies.

Mobile radios must cope with two phenomena that adversely affect coverage: man-made electrical noise and interference.

Man-Made Electrical Noise

Man-made noise is of interest to law enforcement personnel because it often interferes with mobile radio reception.

Effective communication in the presence of electrical noise becomes more difficult as communication systems are expanded in complexity, and as vehicle usage and concentration grow in a given locality. The effects of electrical noise in mobile communications can be reduced by increasing transmitter power, choosing a better antenna site, improving vehicle noise suppression features and/or replacing a receiver with another of better design. Although vehicles in general are becoming more quiet electrically, electromagnetic man-made noise has been doubling about every 10 years. Sources of man-made noise include electrical appliances, motors, fluorescent lights, and even small hand-held calculators.

TABLE 3.
FACTORS AFFECTING COVERAGE AS FUNCTIONS OF FREQUENCY [38]

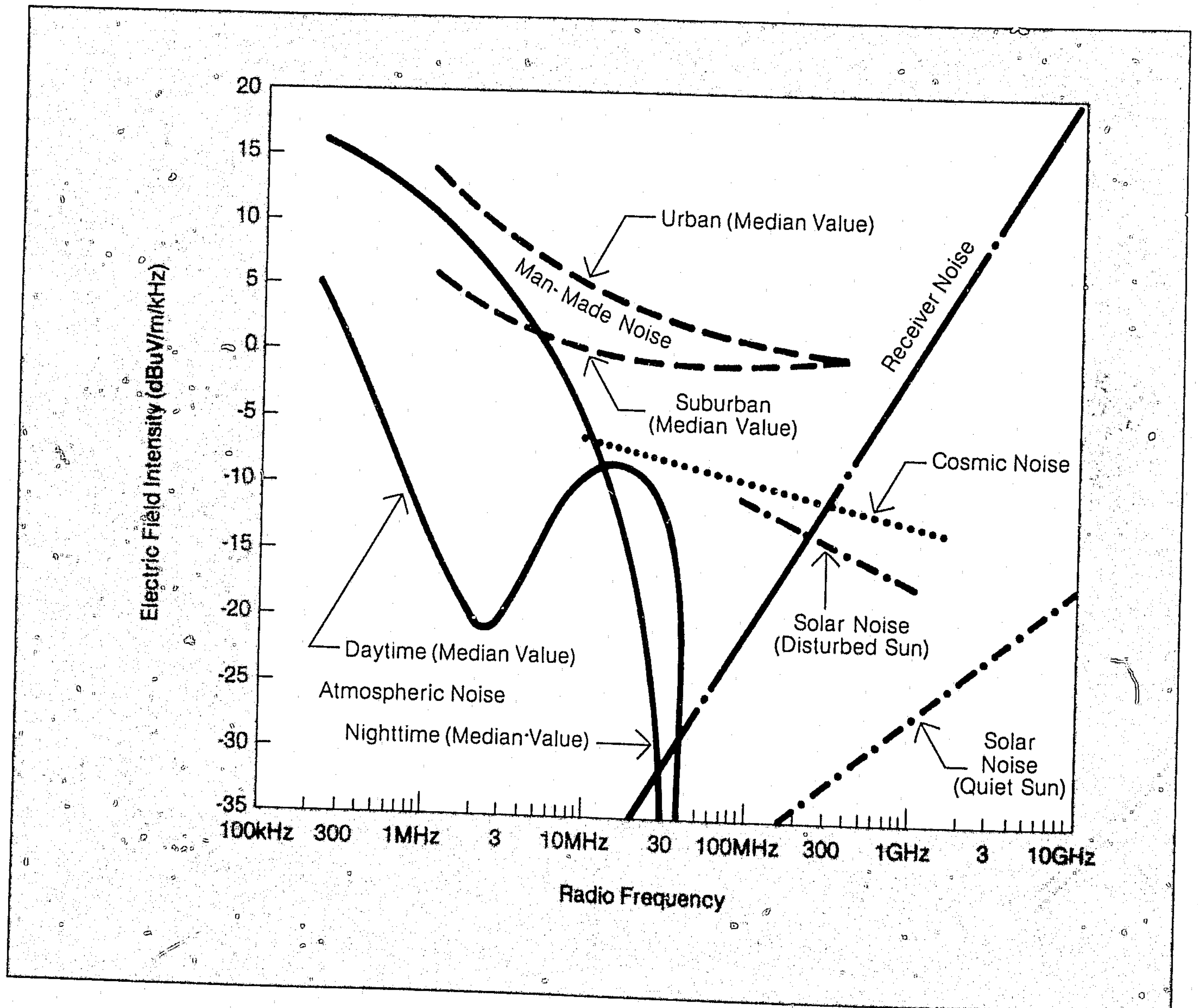
Factor	Low-band (25–50 MHz)	High-band (150–174 MHz)	UHF band (400–512 MHz)
General use category	Rural (State)	Suburban (County)	Suburban and urban
Range, base to car	56 kilometers (35 miles); longest range	40 kilometers (25 miles); good range	37 kilometers (23 miles); good range
Range, car to car	21–48 kilometers (13–30 miles)	8–16 kilometers (5–10 miles); repeater desirable	6–14 kilometers (4–9 miles); repeater desirable
Antenna elevation required	Minimum	Median	Maximum
Terrain and building shadowing	Lowest	Median	High
Penetration into building	Least	Better	Best
Transmission line losses	Least	(Increases with frequency)	
Leaf absorption	Least	Some	Becomes a factor
Multipath reception	Barely noticeable	Noticeable	Pronounced effect
Interference	Skip and co-channel	Co-channel	Good probability of clear channels
Noise	Most—can seriously limit range	10–12 dB less than low-band	20–22 dB less than low-band

Figure 1 illustrates the relative levels of electromagnetic noise from natural sources such as the sun, atmosphere, or cosmos [36]. Equipment design limitations, such as typical noise generated within a receiver, are shown. Note that man-made noise is the largest source of electromagnetic noise at frequencies of interest to law enforcement communications. The amount of urban and suburban noise may differ significantly from those shown, depending on factors such as strength of the noise source or distance separating the noise source and the receiver.

The problem of man-made noise gets progressively less important as the communication frequency increases. The 806-960 MHz band is least affected by man-made noise.

Probably the most common source of man-made noise affecting mobile communications is the ignition system of the motor vehicle. Noise generated by vehicles may range from severe to negligible. Measurements of receiver performance in common situations reveal that in almost every case, receiver degradation caused by automotive ignition noise becomes less as the frequency is increased [4].

FIGURE 1. TYPICAL SOURCES AND LEVELS OF ELECTROMAGNETIC NOISE FOUND IN NATURE, URBAN, AND SUBURBAN ENVIRONMENTS.



Interference

The radio spectrum has become more crowded each year because of the increased number of transmitters in use.

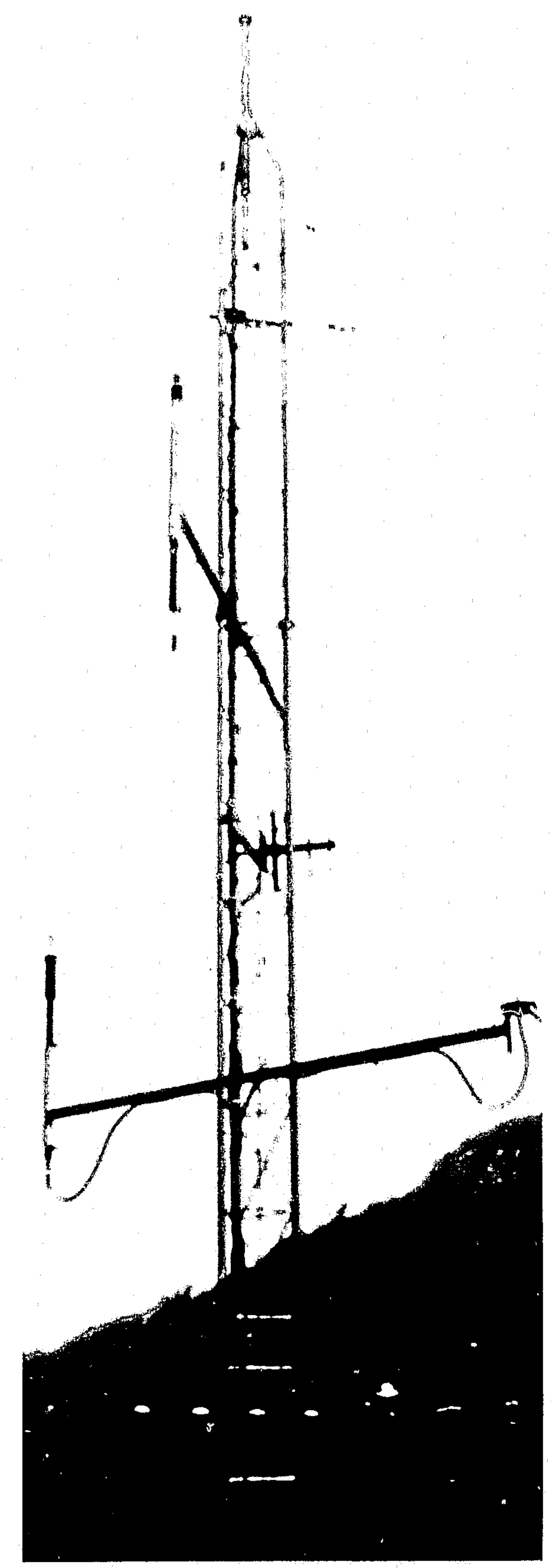
Of the four frequency bands used in law enforcement, low-band was the first to suffer from significant interference. It is not uncommon at these frequencies to have receivers interfered with by transmitters located several thousand kilometers away. This is one of the reasons that high-band became popular, and soon became crowded. In an effort to provide more communication channels within the high-band region, channel spacing was reduced from 30 kHz to 15 kHz by the FCC. This action alleviated one problem, but compounded the problems of adjacent channel interference, intermodulation, and spurious radiation. Table 4 lists the primary types of mobile radio interference.

Co-channel interference arises from more than one transmission simultaneously on the same frequency and can be reduced by the use of squelch systems. One type of system, tone-coded squelch, is used to prevent the opening of the squelch until the appropriate tone signaling occurs, thereby allowing the dispatcher to control the mobile receiver. The three types of common tone-coded squelch systems available are sub-audible tone-coding, audible tone-coding, and frequency-shift tone-coding.

An extensively used squelch system for mobile application is the sub-audible Continuous Tone-Coded Squelch System (CTCSS). The sub-audible tones, which are between 67 and 251 Hz, are used to open muted receivers. The tones are sufficiently low in frequency that a properly designed communication receiver does not allow them to be heard. The advantage of this system is that if a severe fade or drop-out of signal occurs, the continuous sub-audible tone will again unmute the receiver.

TABLE 4. TYPES OF INTERFERENCE OBSERVED BY A RECEIVER

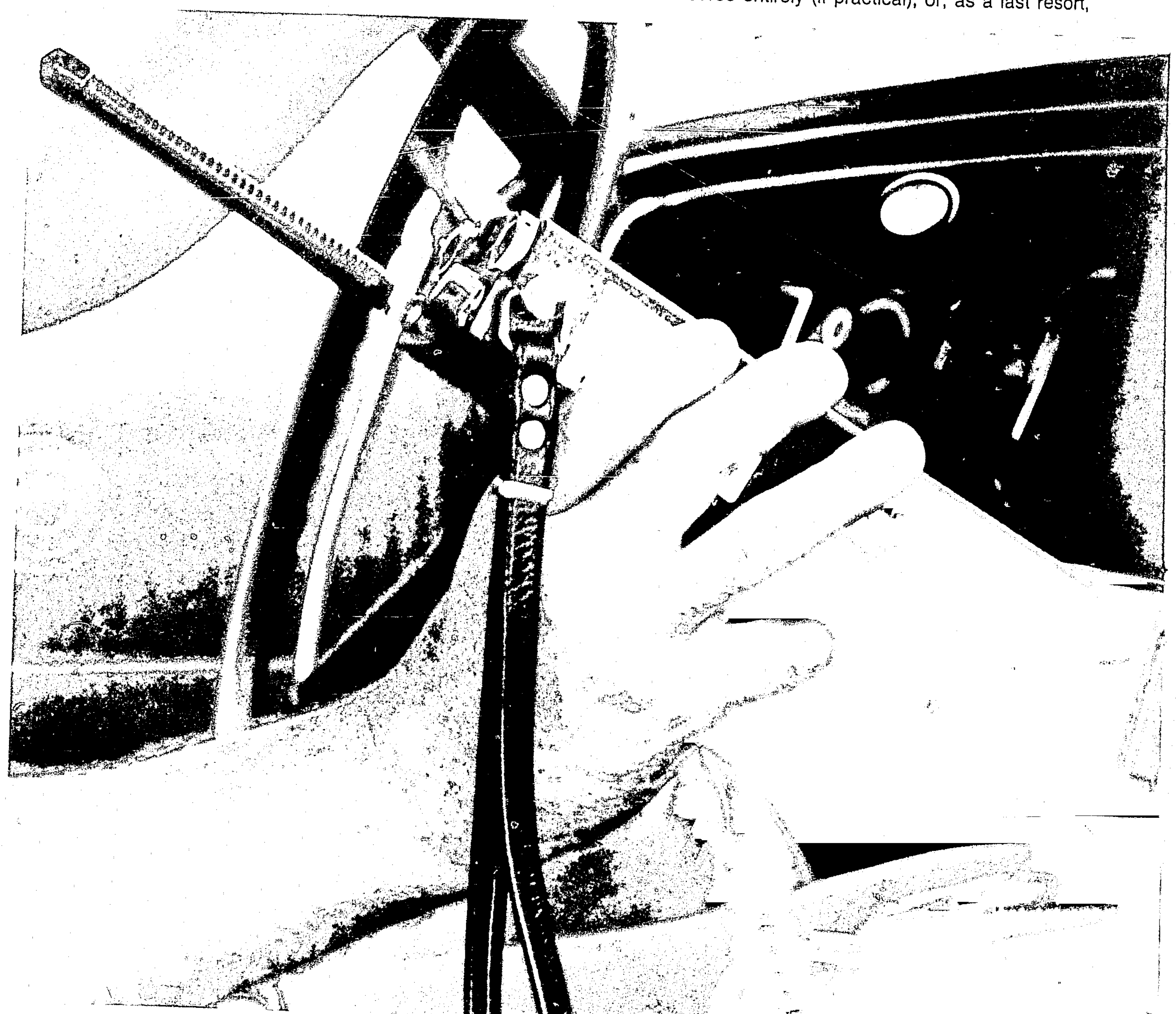
1. Co-channel interference.
2. Intermodulation.
3. Spurious radiation.
4. Spurious response.
5. Transmitter noise.
6. Adjacent channel interference.



Continuous audible tone-coding systems are not allowed by the FCC, although short non-voice tone-signaling operations are allowed. These "burst-tones" are heard during fades because of their high energy content. Audible tones are standardized at selected frequencies from 860 to 3000 Hz. Typical tones last from a few tenths of a second to about five seconds. The burst-tones are sent each time the transmitter push-to-talk switch is activated.

Frequency-shift tone-coding consists of a series of short tone bursts on two or more different audible frequencies. This forms a digital word which can be used for selective signaling, vehicle identification and status reports.

Intermodulation (IM) is another type of on-channel interference. Next to co-channel interference, it is the most serious type of interference in land mobile communications. When two or more signals of different frequencies are mixed in a non-linear element, IM signals are generated. If one of the IM signals falls in a receiver's passband, then IM interference results. Examples of non-linear elements where IM signals may be generated are the output circuitry of a transmitter, the input circuitry of a receiver, and in special circumstances, metallic objects near the transmitting or receiving antennas. Such interference can usually be reduced by use of filters, by removing the non-linear source entirely (if practical), or, as a last resort, by changing the frequency of the receiver or transmitter.



Transmitters sometimes generate spurious radiations which fall within a receiver's passband. This is largely a function of design, but the addition of filters and improved shielding at the source can reduce spurious emissions.

Occasionally a receiver may respond to a signal out of its passband. This is termed "receiver spurious response" and results when the receiver responds to one or more off-frequency signals. The solution may require the addition of filters and improving the shielding of the receiver.

Another kind of interference is transmitter noise, which is a problem mainly in the immediate area of the transmitting antenna. Its effect on a receiver tuned to another channel is to degrade the effective sensitivity. One solution is to increase the spacing between the transmitting and receiving antennas. Another is to place a selective filter at the transmitter output.

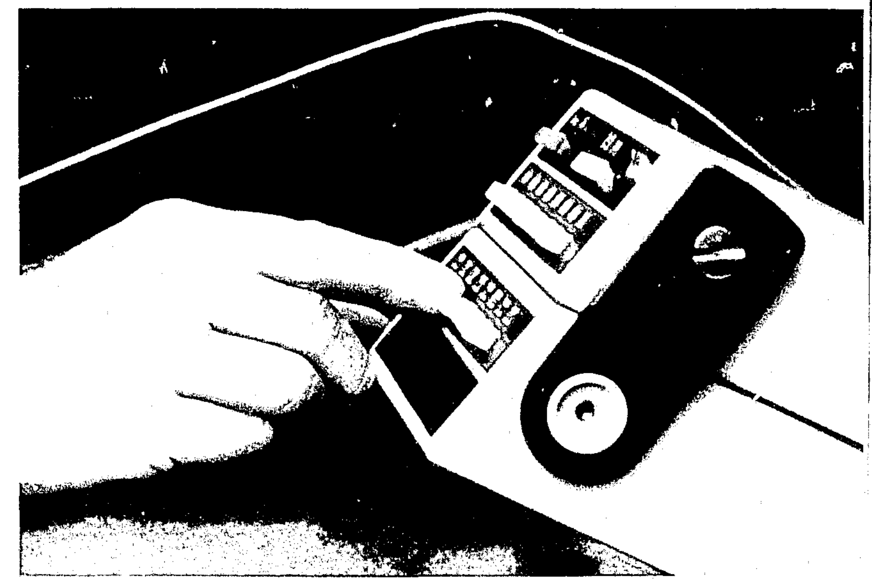
Adjacent channel interference is a common problem in some metropolitan areas. Most communications equipment is designed for a 30 kHz channel spacing although many law enforcement channels are authorized at 15 kHz spacings. Adjacent channel interference may become a primary problem when there is a strong signal in a nearby channel.

Design Considerations

Regardless of who designs a communication system, certain compromises or tradeoffs should be considered, because increasing the performance of one parameter may cause problems in other parts of the communication system. Typical examples of some of these tradeoffs are given in the following paragraphs.

Talking Range vs. Interference

In a base station-mobile station communication link, the weakest part is usually the inability of the mobile transmitter to be heard by the base station receiver. The effective radiated power (ERP) of base stations is generally greater than that of mobile units, and the base station dispatcher can usually be heard in the vehicles. However, the response of the officer in the vehicle may not be heard by the dispatcher. There are several solutions to this problem, depending on the particular situation. One is to increase coverage by raising the antenna or by increasing the ERP of a communications system by increasing the antenna gain, by reducing transmission line losses, or by increasing transmitter rf output power. However, these may not be desirable solutions if co-channel interference problems are created for other nearby communication systems. If interference is a problem, it may be better to change frequency or frequency bands or to use satellite receiver systems (see Accessory Equipment), although sometimes these add intermodulation problems.



Reducing interference by reducing transmitter power is common practice. There are systems being developed in which an exchange of information between the receiver and transmitter results in automatically reducing the transmitter power to a level just sufficient to maintain adequate communications. This meets the requirement stated in Part 90.205 of the FCC Rules and Regulations that the power used shall be the minimum required for satisfactory communication. Reducing transmitter power also results in reduced co-channel interference.

Receiver Sensitivity vs. Interference and Noise

A noisy environment places a severe burden on the performance of receivers. Although a highly sensitive receiver is usually desirable, it can be argued that, for high-noise areas, a receiver of relatively low sensitivity will usually out-perform one of exceptionally high sensitivity. In addition, receivers with the highest sensitivities often have reduced ability to attenuate intermodulation interference and spurious responses. High-noise levels can degrade the effective sensitivity of a receiver by several microvolts. Desensitization due to extensive co-channel, adjacent channel, and far-channel traffic along with the probability of large intermodulation effects and spurious receiver responses all may combine to make communications less than ideal for those using the system.

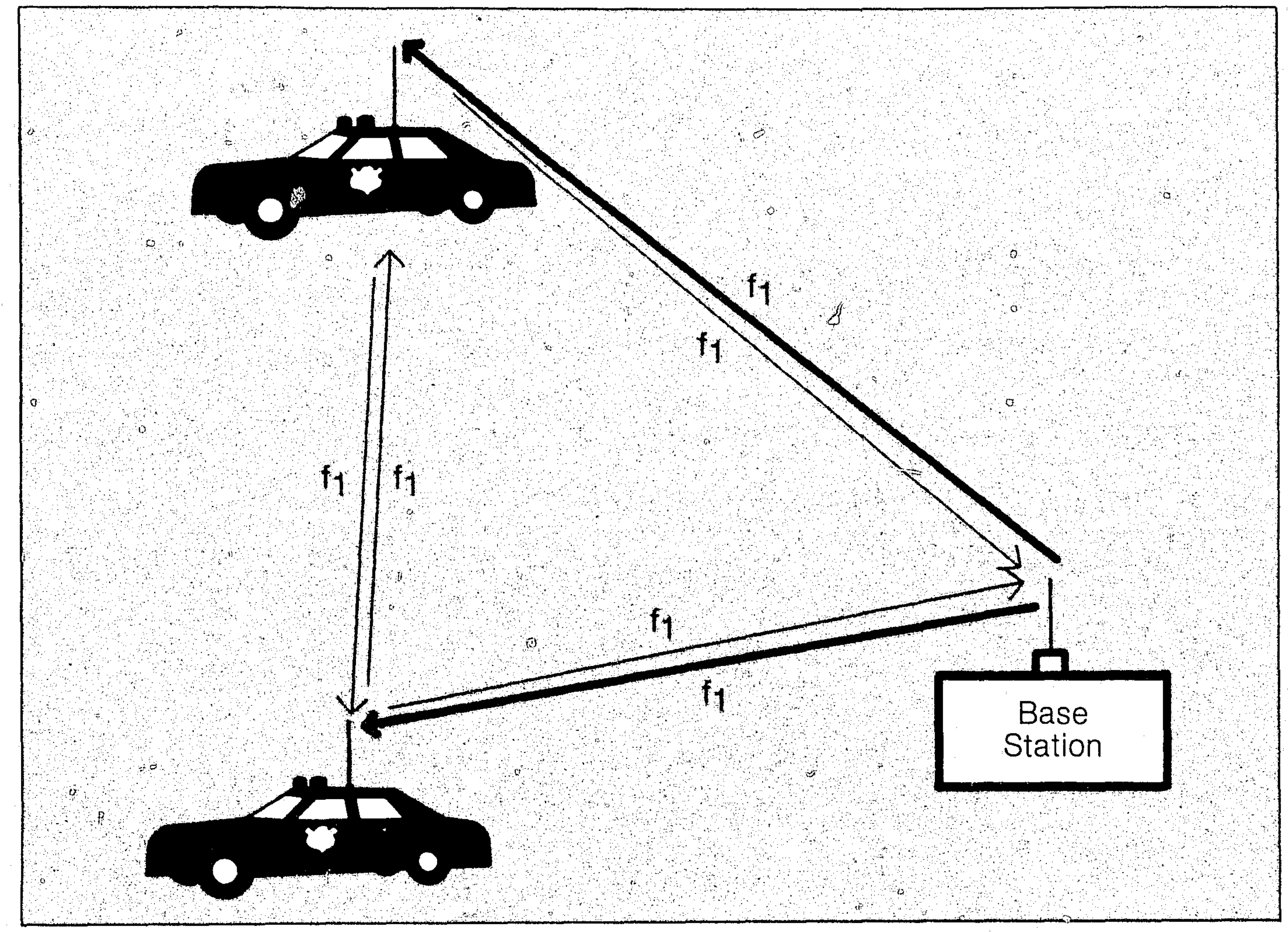
Simplex vs. Duplex Communications

There are a number of different types of communications systems possible which combine several mobile, portable, and base stations into an effective working unit. Each system has its advantages and disadvantages relating to problems in a given area. These pros and cons merit careful consideration, especially when a new communications network is being established.

The three most commonly used systems in law enforcement communications are single-frequency simplex (fig. 2), two-frequency simplex (fig. 3), and two-frequency half-duplex (fig.4).

Full-duplex systems, where simultaneous transmissions by both mobile and base stations occur (as in ordinary telephone systems), are rare in law enforcement communications. The single-frequency simplex system is commonly used and offers the advantages of reduced radio spectrum occupancy and least expensive equipment. As seen in figure 2, signals are transmitted on one frequency one at a time, with the other stations having to wait their turn. An obvious disadvantage is that any other transmissions will interfere with the one in progress. An advantage of this system is that all traffic on the channel can be heard by all the other receiv-

FIGURE 2. SINGLE-FREQUENCY SIMPLEX COMMUNICATIONS SYSTEM.



ers. This allows all participants to monitor both sides of the conversation and also helps them to determine when not to use their transmitters.

The two-frequency simplex system is particularly useful in areas where frequency sharing is necessary. Figure 3 shows that low-powered mobiles can use one common frequency in adjacent jurisdictions without the degree of interference that would exist if the powerful base stations in one jurisdiction competed with the mobiles of the other jurisdiction. This scheme is superior in performance to a single-frequency simplex system but not as effective as the two-frequency half-duplex system described below. However, a disadvantage is that mobiles in either jurisdiction will sometimes hear both base stations.

One solution to this problem is to use a two-frequency, half-duplex system as shown in figure 4. In this system, the base station can automatically relay mobile signals. The base station can both receive and transmit simultaneously at different frequencies, and the mobile stations can hear each other's transmissions when relayed by the base station.

More elaborate systems are commonly used where more than one channel is required, and transceivers such as four-channel receive, two-channel transmit are common. Elaborate com-

FIGURE 3. TWO-FREQUENCY SIMPLEX COMMUNICATIONS SYSTEM.

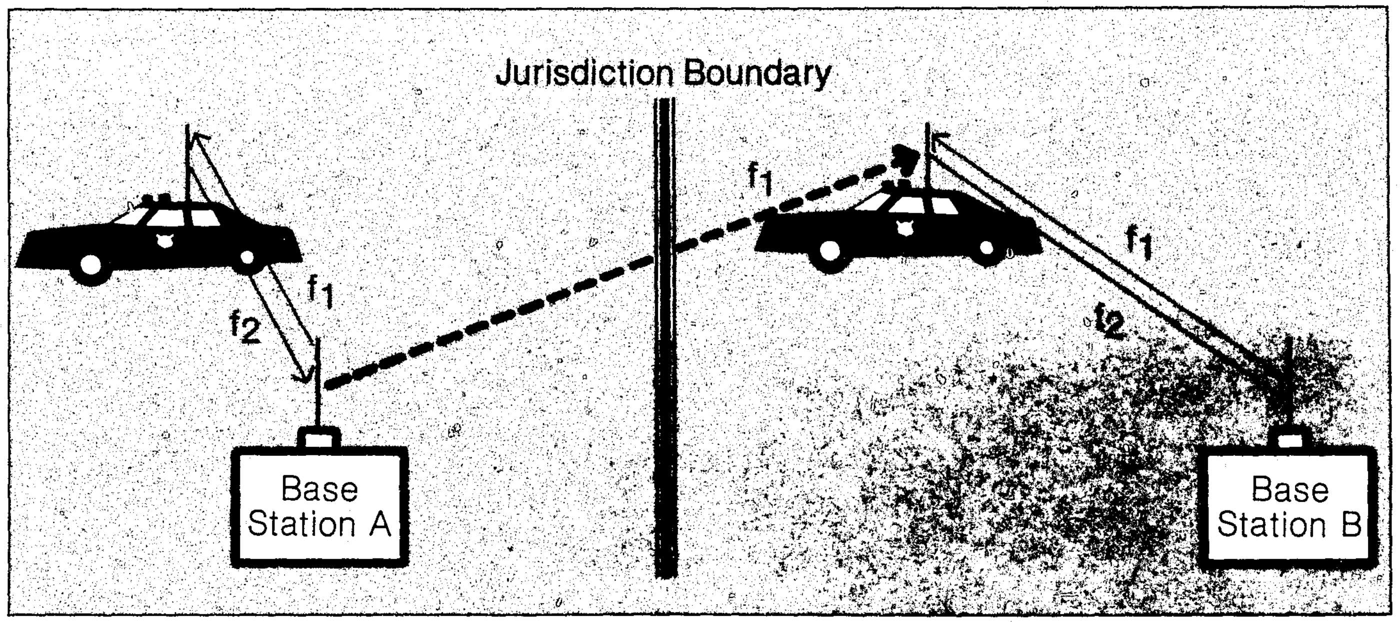
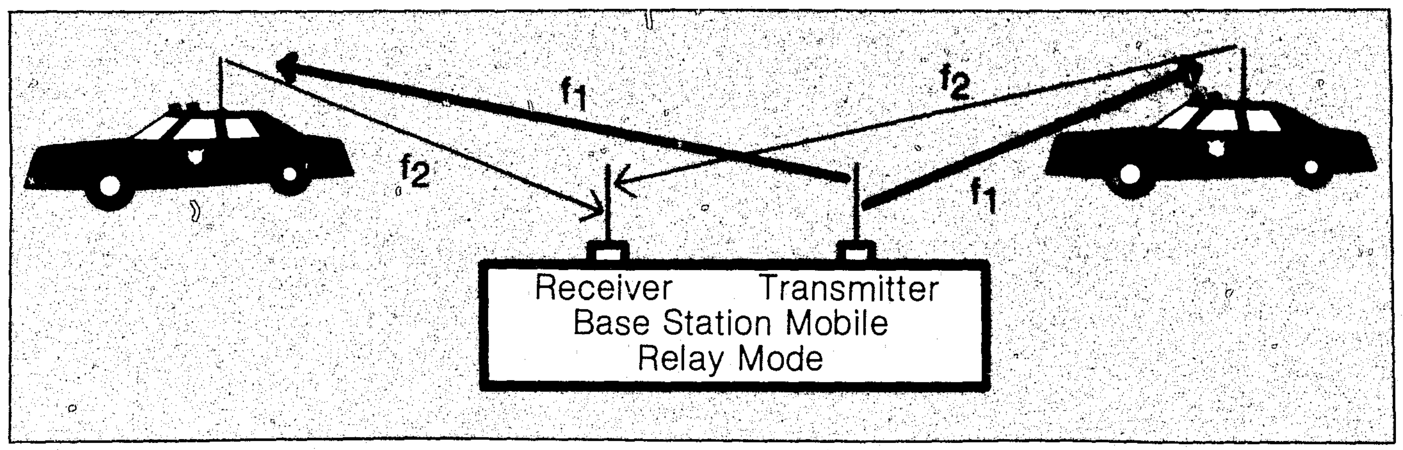


FIGURE 4. TWO-FREQUENCY, HALF DUPLEX COMMUNICATIONS SYSTEM IN THE MOBILE RELAY MODE.



munication networks can be tailored to fit special requirements of large congested areas. A full discussion of the possible types of networks, which may involve the use of several dispatchers, is beyond the scope of this guide, but good references are available for additional information [1,29].

FCC REGULATORY ASPECTS

FCC Frequency Allocation

State and local government law enforcement communications are regulated by the Federal Communications Commission (FCC) under Title 47 (Telecommunication) of the Code of Federal Regulations [2,3]. One objective of the FCC is to enable all communication users to be compatible in spectrum use, and to provide for maximum effective utilization of assigned frequencies.

Of special interest to those in law enforcement is Part 90 (Private Land Mobile Radio Services) which has several subparts of primary interest. Subpart A (General Information), Subpart B (Public Safety Radio Service), Subpart G (Applications and Authorizations), Subpart H (Policies Governing the Assignment of Frequencies), Subpart I (General Technical Standards), Subpart N (Operating Requirements), and Subpart Q (Development Operation) contain general rules applicable to all authorized stations. A section (90.17) of Subpart B entitled "Local Government Radio Service" applies to governmental subdivisions including States, counties, cities, towns, and districts. Often, the county sheriff frequencies are assigned under this section. However, control stations operating on some frequencies regulated by the rules of this section may also have to comply with additional requirements if they are located within 75 miles of urbanized areas of 200,000 or more population. The section (90.19) within Subpart B entitled "Police Radio Service" applies to similar governmental subdivisions, especially where that subdivision is authorized by law to provide police protection. The State patrol and cities usually have frequencies assigned under this subpart.

Before an organization constructs a new communications system or changes transmitter power, antenna, location, or frequency, it is necessary to make application to the FCC for modifications to the station license. It is helpful to the licensee, as well as the FCC, to work with the local frequency coordinator [29]. Frequency coordinators assist the FCC in an advisory capacity in the orderly assignment of frequencies. Frequency coordinators are selected for most user groups. One example of user group frequency coordination is the Public-Safety Communications Officers, Inc. (APCO) which provides police and fire radio coordinators for local government service. The goal is to select a frequency which will provide the required coverage, and at the same time avoid interference to other systems. After a frequency is chosen, the application for a new or modified station license (FCC Form 400), accompanied by a letter of recommendation from the local frequency coordinator, is sent to the FCC.

Each station is subject to inspections by the FCC for compliance with the rules and regulations. The inspector will insure that licenses are current and posted, and will be particularly interested in making certain that all conditions or limitations of the licenses are being complied with.

In choosing several frequencies in one band, the spacing between these frequencies is a significant consideration when specifying new equipment. Many multiple-channel receivers are designed to operate at a frequency spacing of no more than a half percent (i.e., 7.5 MHz at a frequency of 150 MHz), whereas multichannel transmitters often are capable of broadcasting over a frequency range of at least twice that value. For those who must have broader frequency spacings, manufacturers provide receivers with dual front ends, each tuned to the desired frequency. Some transceivers also have the capability to operate in a crossband (both low-band and high-band or both VHF and UHF) mode.

In choosing frequencies for the base-mobile communication system, it may be desirable to have wide frequency spacings. For example, if the transmitting antennas are on the same tower, or in close proximity to each other, as at a transmitter or repeater site, a wide spacing between operating frequencies is recommended to minimize interference.

The FCC requires that transmitters be type accepted to be certain that the equipment meets certain technical operating standards, as required by the Communications Act, international regulations, and treaties. For equipment to be type accepted by the FCC, the manufacturer must submit test data and a description of the equipment. Based on these representations the FCC will decide whether the model of equipment in question is to be type accepted.

To assist those who are interested in determining which model of a manufacturer is acceptable for licensing, the FCC publishes a list [30]. A copy may be viewed at the Washington, DC offices of the FCC, any of its field offices, or purchased from any publications vendor which sells FCC reports. The equipment list is in alphabetical order by manufacturer and type number and contains the following information:

(1) notes relating to transmitter usage;

(2) part numbers of the FCC rules in which the transmitter is acceptable for licensing;

(3) frequency range in MHz over which the equipment is acceptable;

(4) maximum input power in watts to final rf amplifier;

(5) rated rf output power in watts;

(6) frequency tolerance in percent;

(7) emission designator generally coded to indicate bandwidth occupied by the emission and modulation type; and

(8) effective date for type acceptance withdrawal.

Additional Radio Spectrum

The land-mobile radio service, which includes law enforcement activities, has petitioned for additional radio frequency spectrum to relieve both existing congestion and to provide for anticipated growth in mobile communications. In FCC Docket 18262 (1970), additional spectrum consisting of selected frequencies from 806 to 947 MHz were reallocated as additional land-mobile frequencies. Also, in FCC Docket 18261, shared use of a 42 MHz band from 470 to 512 MHz (UHF-TV channels 14 through 20) was authorized for land-mobile radio services within the 13 largest urbanized areas of the United States.

FCC Docket 18261

In the late 1940's, the FCC allocated approximately 40 MHz of frequencies between 25 and 890 MHz to the land-mobile radio service. The land-mobile radio service at that time had about 155,000 radio transmitters. By 1970, it had grown to 4 million transmitters, made possible by extensive co-channel sharing and improved equipment which allowed more intensive utilization of the available spectrum. The Electronic Industries Association (EIA) showed that 50 percent of all land-mobile transmitters were being operated in less than 8 percent of the country's land areas. This concentration limited the possibility of more extensive frequency usage. It was predicted that land-mobile communications transmitters would more than double from 3 million in 1968 to 7.3 million in 1980. It was for these and other reasons that selective use of these frequencies was conditionally allowed in the largest urban centers of the country.

FCC Docket 18262

At the same time that a decision was made regarding Docket 18261, additional frequencies in the 806–960 MHz band were reallocated, with 40 MHz (825–845 MHz and 870–890 MHz) allocated for common carrier land-mobile communications systems and 30 MHz (806–821 MHz and 851–866 MHz) allocated for private land-mobile systems.

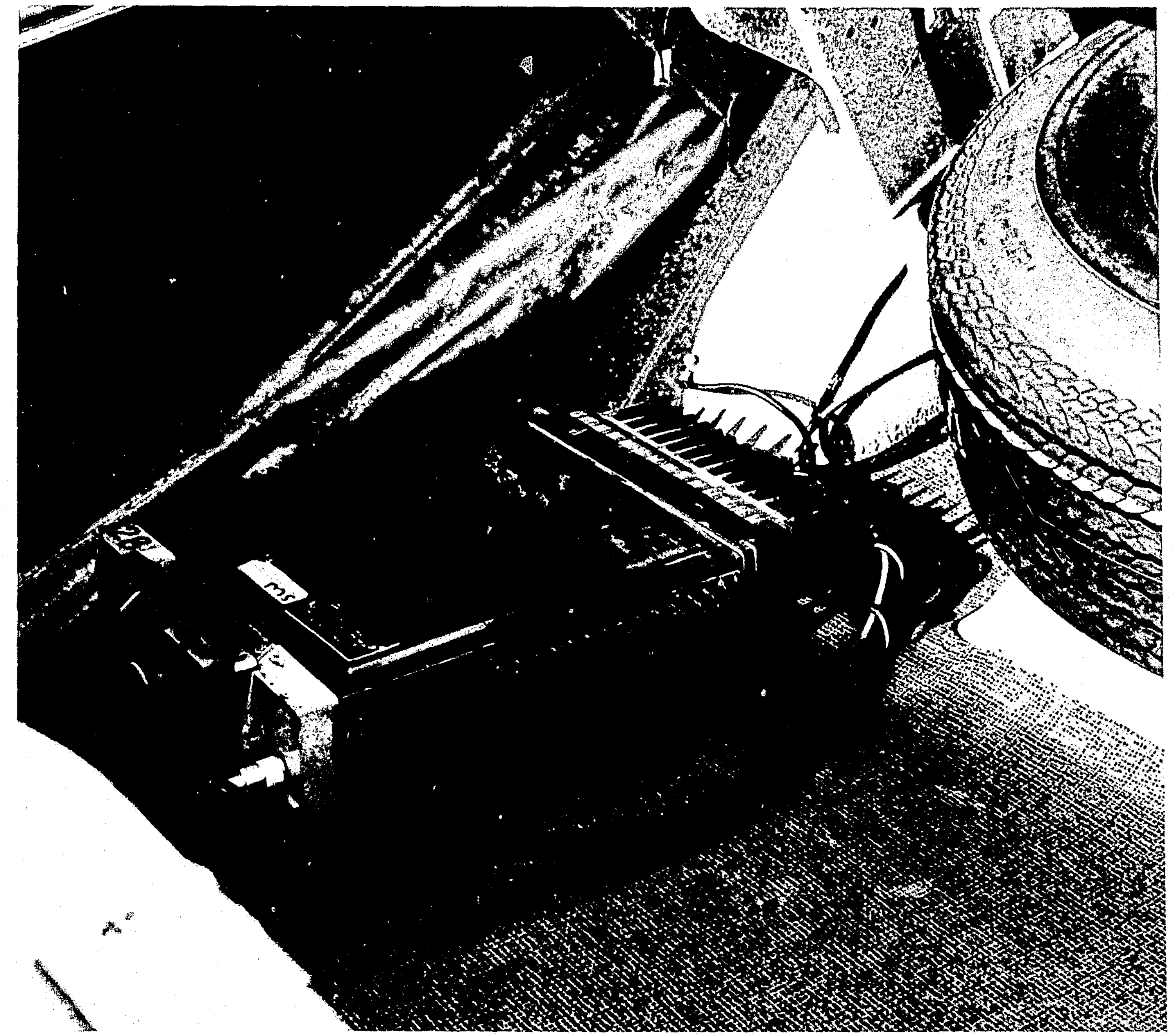
In general, the 806–960 MHz band is more limited in coverage than the lower bands, the range of communications being about 8 to 24 kilometers (5 to 15 miles). Because this is a new band, equipment development time and associated high initial costs to develop new systems have combined to hold back the immediate use of these frequencies by public safety users. However, this band offers significant advantages in lower noise, greater building penetration, and smaller antenna size. There is great potential in law enforcement communications for short-range high-density services.

EQUIPMENT TECHNICAL ASPECTS

Mobile Radios

Radios are usually designed specifically for each frequency band to counter the technical problems presented by component integration, propagation, noise and interference. Mobile FM

FIGURE 5. A TYPICAL TRUNK-MOUNTED TRANSCEIVER INSTALLATION.



systems are commercially available for operation in all four frequency bands (see Frequency Considerations). Tuning of this equipment is usually by fixed, crystal-controlled means that allows operation only on selected channels. Units with up to a 12-channel capability are available. The multichannel radios are used for both mobile-to-base station and mobile-to-mobile communications.

A wide variety of commercially available mobile radios exist. Some can be trunk-mounted with control heads at the dash while others can be located entirely at the dash. By far the most common equipment is trunk-mounted radios (see figs. 5 and 6). The transmitter of the radio is usually rated according to its output power which may range from 1 to 110 watts. Although equipment with vacuum tube circuitry is still available, most radios sold today are solid-state (transistorized) units. These are selected because of significant reductions in both physical size and dc power requirements and improvement in reliability. The authorized bandwidth for public safety communication is limited to 20 kHz by FCC regulations. Maximum frequency deviation limits are ±5 kHz.

The receiver of the radio usually has adjacent channel selectivities in the order of 80 to 90 dB and the on-channel sensitivity is usually lower than 0.5 μV for 12 dB **SI**gnal to **N**oise **a**nd **D**istortion (SINAD) ratio. Audio output powers of 2 to 15 watts are available for mobile equipment.

Most mobile receivers used in law enforcement communications are double-conversion receivers. Recently, improved single-conversion receivers have become available, made possible through monolithic technology. Single conversion units offer small size, good reliability, simple construction, low chance of spurious responses, and little desensitizing with strong interfering signals. However, with the necessarily high intermediate frequency (IF) in single conversion receivers, some commercial test equipment cannot be used satisfactorily because of interaction problems.

Mobile communication systems are continually being modified to reduce size, weight, and power requirements, to improve the quality of reception and ease of use, thus reducing demands on the user. One attempt in this area is in the development of the portable-mobile concept. With this concept, a personal radio is connected to the electrical system of the vehicle and provides most of the functions of a regular mobile radio. The personal radio is usually connected to the vehicle battery, which not only powers the radio but also charges the radio internal battery. The vehicle antenna, speaker, and microphone systems are connected. Usually an rf power amplifier is provided in the vehicle to increase the radiated power. The personal radio can be quickly removed from its mounting frame and handcarried to provide communications while on foot. In this mode, the antenna, loudspeaker, microphone, and dc power source are switched automatically as the unit is withdrawn. One advantage of this portable-mobile concept is that the radio always remains with the officer.

It may be argued that purchase of such equipment will provide significant savings on the part of the police department in terms of initial investment. For instance, instead of purchasing two radios, one portable and one mobile, to do the job, one portable-mobile will suffice. However, there are some disadvantages. For example, if the portable is dropped and damaged, the officer is without communications even when in the vehicle. The connectors of the portable that interface with the mobile unit often become damaged or corroded and cause intermittent operation. This is due to plugging and unplugging the radio from the mobile mount or the environmental extremes of dust, dirt, rain, and salt. Increased maintenance costs over ordinary installations can be expected. Also, such a communication system is usually not compatible with certain accessory equipment, such as a digital system.

FIGURE 6. A TRANSCEIVER CONTROL HEAD INCLUDING SWITCHES FOR LIGHTS AND SIREN.

Antennas

Transmitters and receivers need effective antenna systems to provide efficient and reliable communications. The type of antenna and its location on the vehicle are important to the performance of a mobile system. Figure 7 illustrates possible vehicle antenna locations. Table 5 shows the length of a quarter-wave whip antenna at selected frequencies. When the antenna is mounted in the center of the vehicle roof, the antenna pattern is most uniform regardless of vehicle heading, because the roof provides a uniform and symmetrical ground plane. Note that a 3 decibel (dB) improvement in antenna gain is equivalent to doubling the mobile transmitter power or improving the receiver sensitivity by 3 dB.

Figure 8 illustrates two antenna patterns measured at 162 MHz with a quarter-wave monopole mounted in the center of the roof on a 1966 standard sedan and also on a 1974 compact sedan. Note that the antenna on the standard vehicle produces a pattern uniform within 2 decibels of the reference value at 0°. The same antennas mounted on a compact vehicle produce a pattern that is uniform to within only 4 to 5 decibels because of the smaller ground plane.

Lights and sirens located in close proximity to the roof-mounted antenna can affect antenna performance. Figure 9 illustrates two antenna patterns measured at 162 MHz with a quarter-wave monopole mounted in the center of the roof of the standard-sized sedan. One pattern was plotted with a large rotating light (and two sirens on either side of it) located 38 cm (15 in) in front of the monopole. The second pattern was taken with light and sirens removed. Note that the maximum difference between patterns is approximately 5.5 decibels. Figure 10 illustrates the same tests using 417 MHz as the test frequency. Note that the maximum difference in the two patterns is 8 decibels and the pattern with no light or siren is uniform within 2.5 decibels.

There are other possible locations for the antenna. Figure 11 illustrates an antenna pattern measurement at 417 MHz with a quarter-wave monopole mounted in the center of the trunk lid of a standard-sized sedan. Note that its pattern exhibits a non-uniformity of 10 decibels and has several deep nulls. Figure 12 illustrates an antenna pattern measurement at 417 MHz with a quarter-wave monopole mounted on the left front fender. Note that it has several deep nulls also, with one a particularly deep 19 decibels. This is to be expected from the lack of ground plane symmetry and the nearby reflective surfaces. The front fender antenna location is of particular interest to those responsible for providing communications equipment for undercover vehicles. A quarter-wave whip antenna for the VHF band can be made to resemble a standard broadcast receiving antenna. Another antenna used in undercover work is the broadcast receiving antenna imbedded in the windshield of many late model vehicles. As seen in figure 13, the nulls obtained were numerous and severe in amplitude.

In summary, the location of the antenna on the vehicle is critical to antenna performance. Further, massive lights and sirens mounted near a roof-mounted antenna may degrade antenna performance.

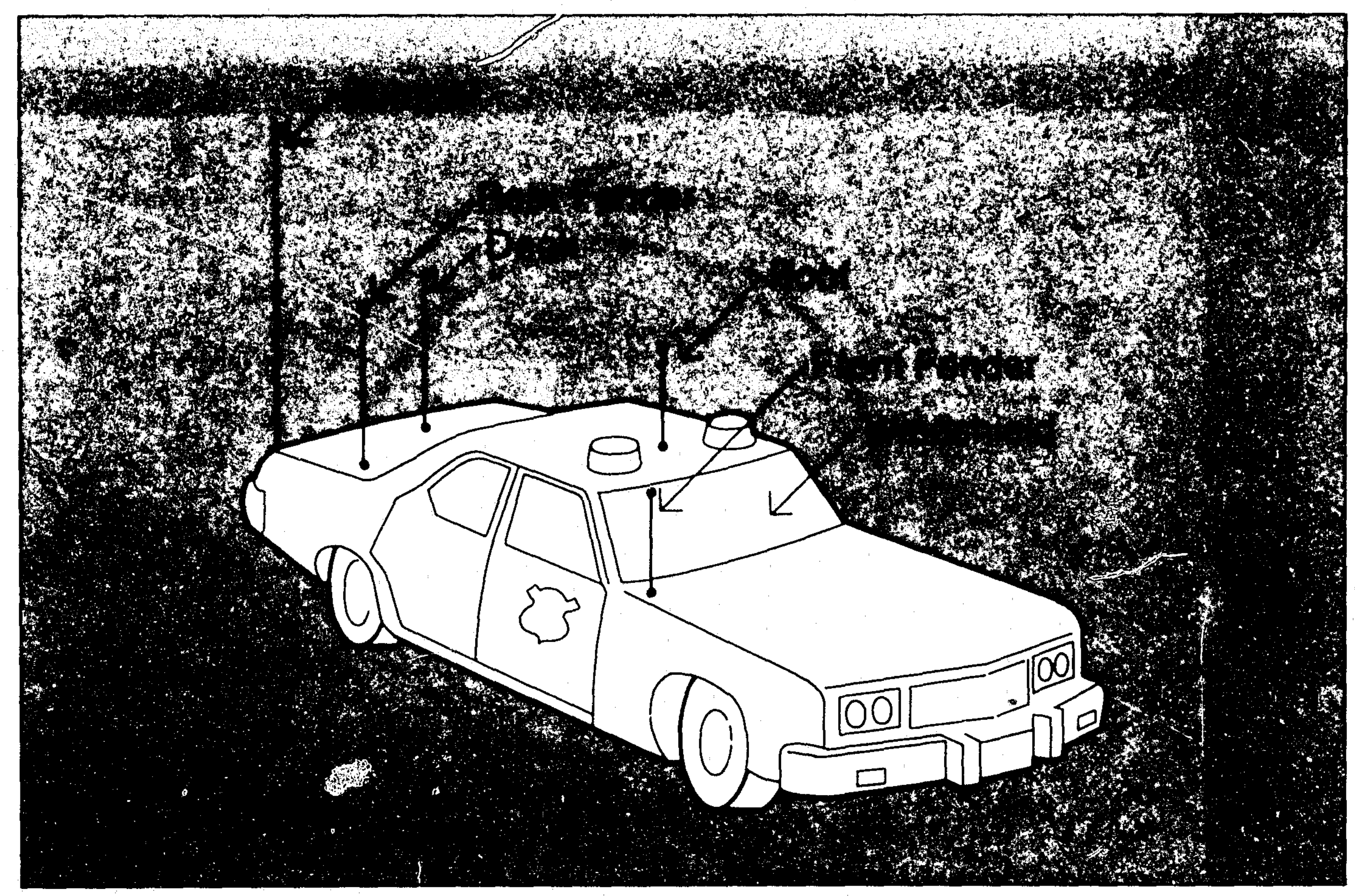
Using gain antennas to increase radiated power is an effective means of improving system performance. Gain antennas are very practical for the VHF and UHF bands, because the shorter wavelengths at these frequencies permit the design of a gain antenna that is physically short

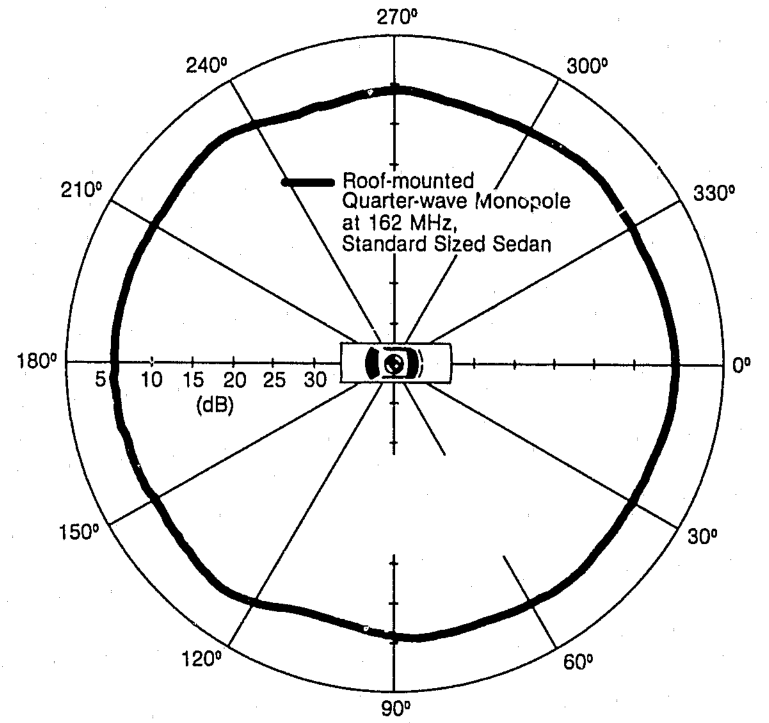
TABLE 5. TYPICAL QUARTER-WAVE ANTENNA LENGTHS USED IN LAW ENFORCEMENT COMMUNICATIONS

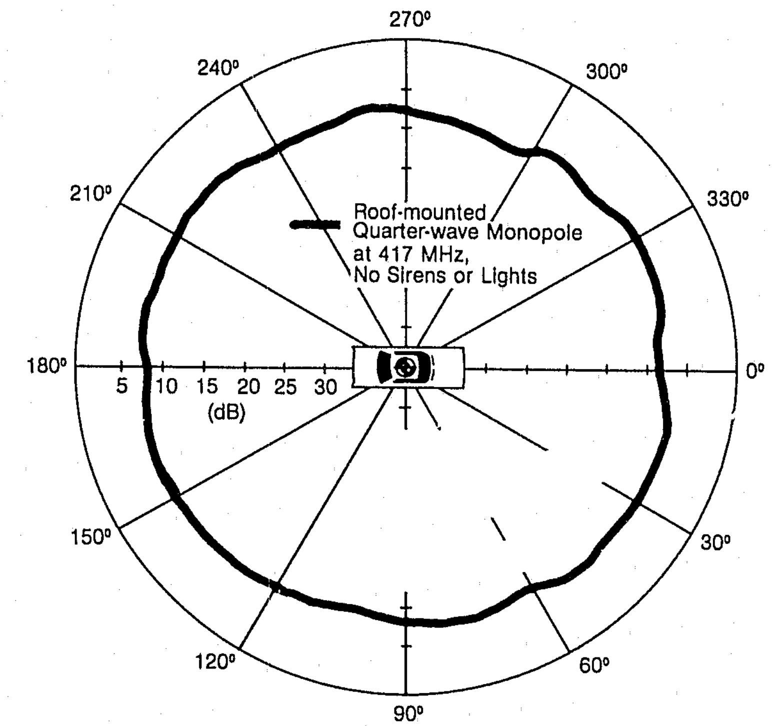
Law enforcement band	Nominal frequency MHz	Quarter-wave antenna* Inches	Meters
1. Very high frequency low-band (25 to 50 MHz)	30 50	93 56	2.4 1.4
2. Very high frequency high-band (152 to 174 MHz)	155	18	0.45
3. Ultra high frequency band (450 to 512 MHz)	455	6	0.15
4. Ultra high frequency band (806 to 896 MHz)	851	3.2	0.08

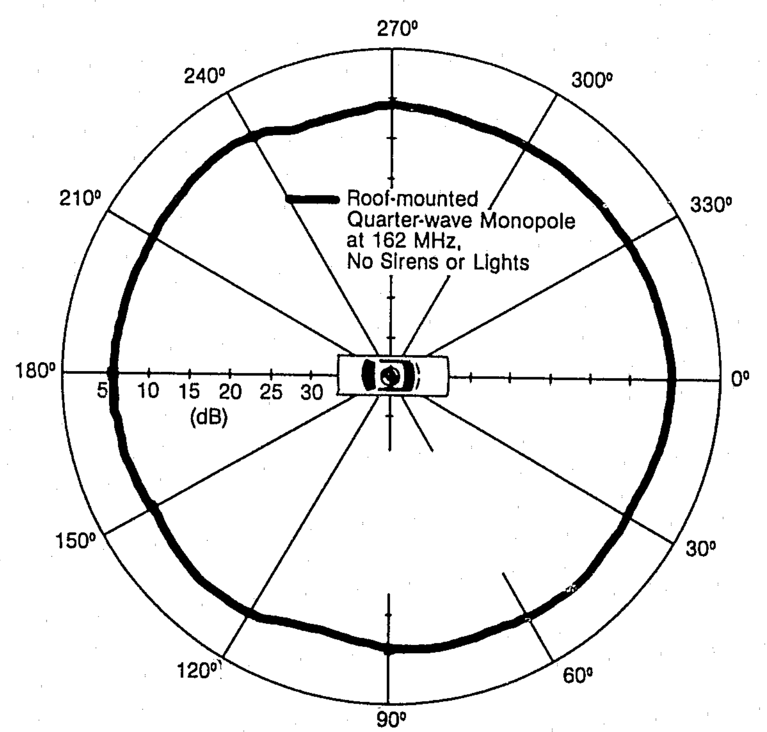
*It is suggested that a "cutting guide," provided by the antenna manufacturer, be used to compensate for certain variables in actual installation, such as variable base-insulator heights. The low-band and high-band antenna lengths shown are shortened by several percent to account for effects such as limited ground plane availability in mobile application.

FIGURE 7. VEHICLE ANTENNA LOCATIONS.




270°
240°
300°
210°
330°
180°
0°
150°
30°
120°
60°
90°
5 10 15 20 25 30
(dB)
Roof-mounted
Quarter-wave Monopole
at 162 MHz,
Standard Sized Sedan


270°
240°
300°
210°
330°
180°
0°
150°
30°
120°
60°
90°
5 10 15 20 25 30
(dB)
Roof-mounted
Quarter-wave Monopole
at 417 MHz,
No Sirens or Lights


270°
240°
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210°
330°
180°
0°
150°
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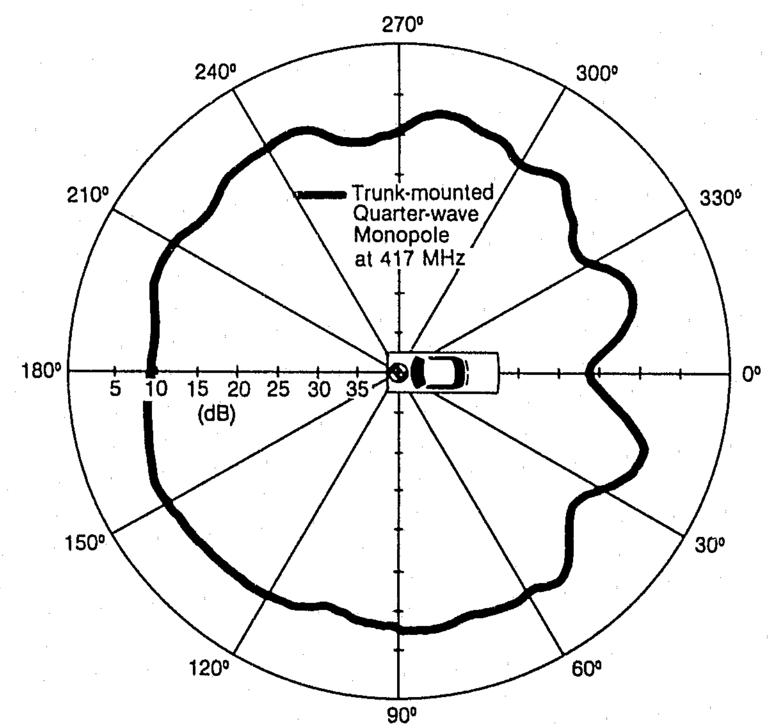
60°
90°
5 10 15 20 25 30
(dB)
Roof-mounted
Quarter-wave Monopole
at 162 MHz,
No Sirens or Lights


270°
240°
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90°
5 10 15 20 25 30 35
(dB)
Trunk-mounted
Quarter-wave
Monopole
at 417 MHz

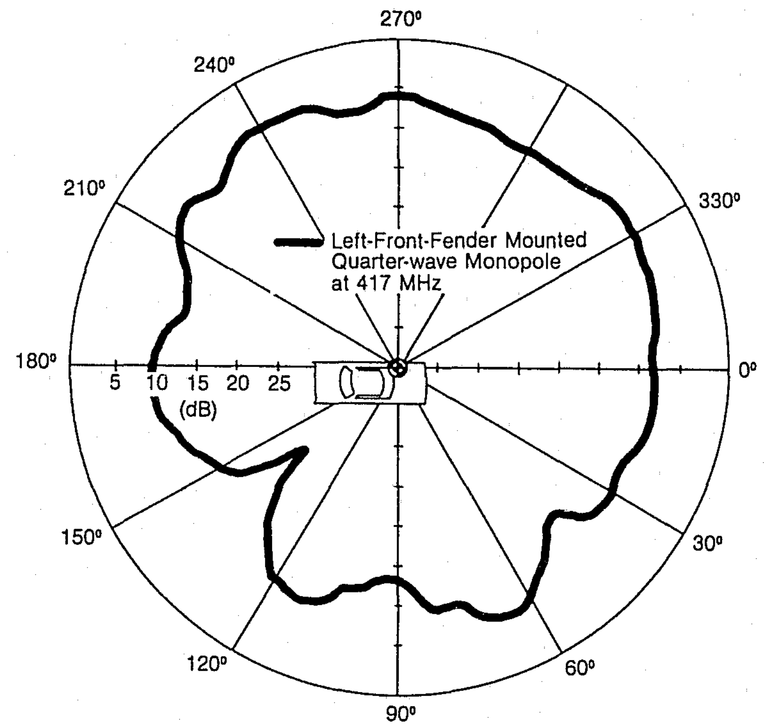
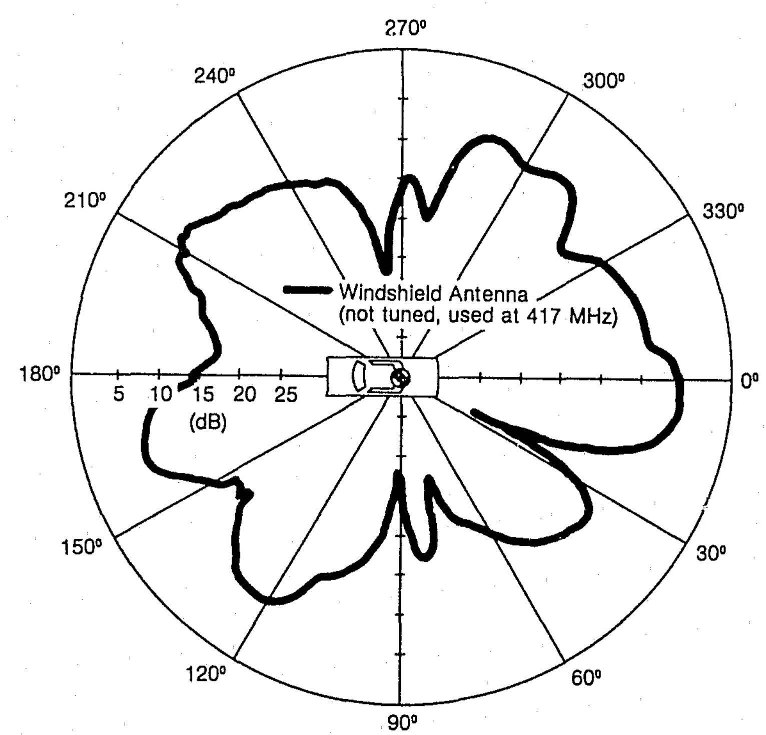


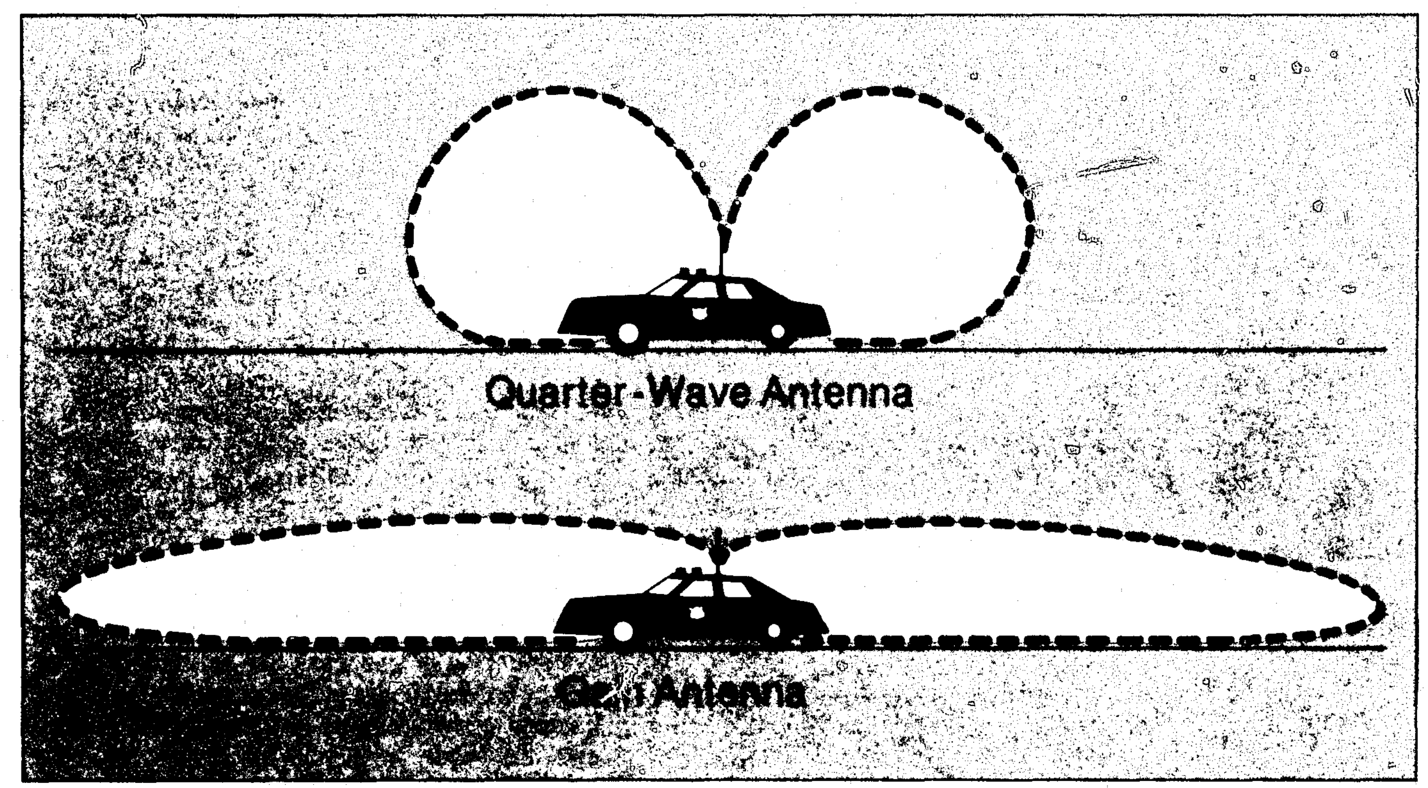
FIGURE 13. ANTENNA PATTERNS



in length. For example, a 5/8-wavelength gain antenna at 455 MHz is approximately 37 cm (14 in) long. A mobile collinear antenna consisting of two 5/8-wavelength radiators co-phased with a helical phasing coil is approximately 81 cm (32 in) long. It is reported that at 455 MHz, the roof mount collinear antenna provided a 5-dB improvement over the quarter-wave, while at 155 MHz, a 5/8-wavelength antenna used in place of the quarter-wave provided a 3-dB signal improvement [9].

A gain antenna provides more gain than a quarter-wave antenna because of its electrical design, which causes the pattern to be stretched horizontally when viewed in vertical profile. Figure 14 illustrates this point. Energy formerly sent at high angles from the quarter-wave antenna is now re-directed into the lower angles by the gain antenna. Gain antennas are usually considered more effective in flat terrain than quarter-wave antennas. In mountainous terrain, however, gain antennas may not outperform quarter-wave antennas. The collinear roof-mounted gain antenna has a tendency to bend temporarily from the vertical during high-speed vehicle operation, thereby decreasing antenna effectiveness. These factors need to be considered when making a choice between gain and quarter-wave antennas.

FIGURE 14. VERTICAL PROFILE COMPARISON OF GAIN ANTENNA AND QUARTER-WAVE ANTENNA WHEN MOUNTED ON A VEHICLE.

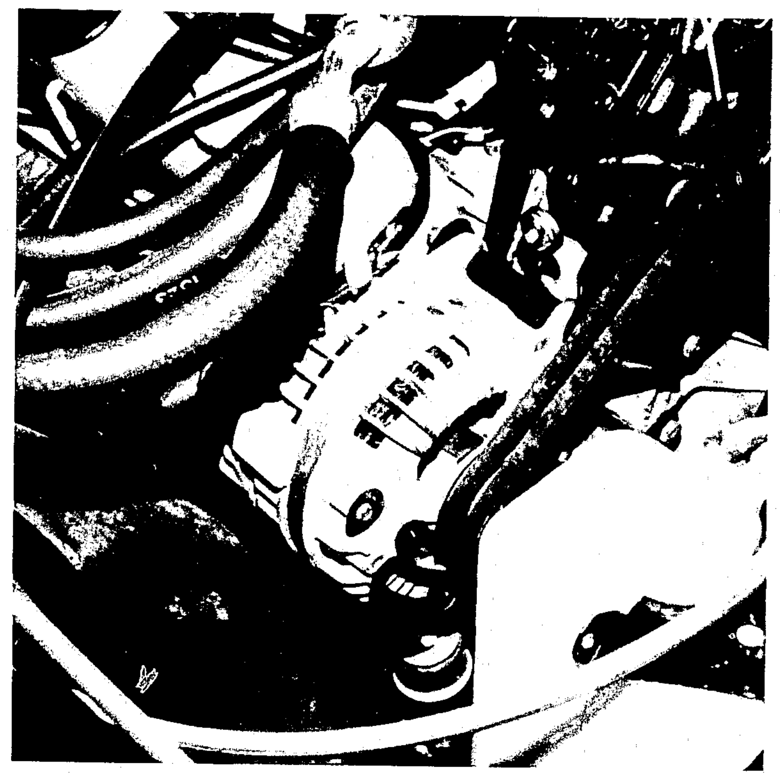


Power Sources

The alternator, regulator, and battery system of a vehicle are often used as the power source for mobile communication systems. In special cases, such as in communication vans, several batteries may be used. These may be either recharged from a high-ampere rated alternator or from a motor-generator unit. The low horsepower motor-generator unit is more efficient than using the more powerful mobile van engine to power an alternator for extended periods of time.

Most vehicles used in law enforcement activities have the negative terminal of the vehicle battery grounded to the vehicle chassis. Accordingly, most transceivers are designed for use with negative-ground vehicle systems, but, on occasion, communications equipment is needed for vehicles which require positive-ground connections. In order to adapt negative-ground equipment to positive-ground vehicles, an electronic converter must be used to effectively change the chassis reference voltage from negative to positive.

Some manufacturers build the transmitter and receiver in modular form with good electrical isolation from the chassis so that connections may be made to either terminal with the appropriate internal changes.



Microphones and Speakers

Most microphones used with mobile radios are supplied by the radio manufacturer. Controlled reluctance (magnetic) microphones are used extensively for mobile units. Since these microphones have a low audio output voltage, a transistor amplifier is often built into the microphone. Special noise cancelling microphones are available for use in noisy locations. Handsets are used occasionally for mobile use and offer some degree of in-car privacy in that only the user hears replies from the dispatcher. Headsets are generally not used with mobile systems, in spite of the obvious advantage of not having to hold the microphone during communications. Headsets do have a tendency to cut down on the user's ability to discern outside noises. In some states, it is against the law to use headsets in highway vehicles. On the other hand, helmets which contain earphones and bone-conductance microphones are sometimes used by operators of motorcycles, thus leaving both hands free for driving.

Push-to-talk switches are normally located on the microphones, although special circumstances, such as surveillance work, may dictate a foot-operated switch. Electronic voice-operated (VOX) switches which respond to human speech are available, but they may also respond to other noises and activate the transmitter. Also, the VOX takes a fraction of a second to function when voice transmission starts, with some danger of losing the first word or two of a transmission. Another type of switch is an automatic hang-up switch that is used to disable a decoder in a typical selective calling system. This allows the user to monitor other traffic on the channel between the time the handset or microphone is lifted from its holder and the user is ready to speak into the mouthpiece.

Speakers are usually of the permanent magnet type and may include either a transistorized amplifier or an attenuator as needed to provide for proper audio levels. Speakers inside the vehicle range in power from 4 to 15 watts, while horn speakers located outside the vehicle are often 15 to 50 watts or more. Speakers may be mounted on the firewall, under the dash, on the steering column or in more than one of these locations. Some have provision for temporary mounting outside the window for use in hearing messages at some distance from the vehicle.

Accessory Equipment

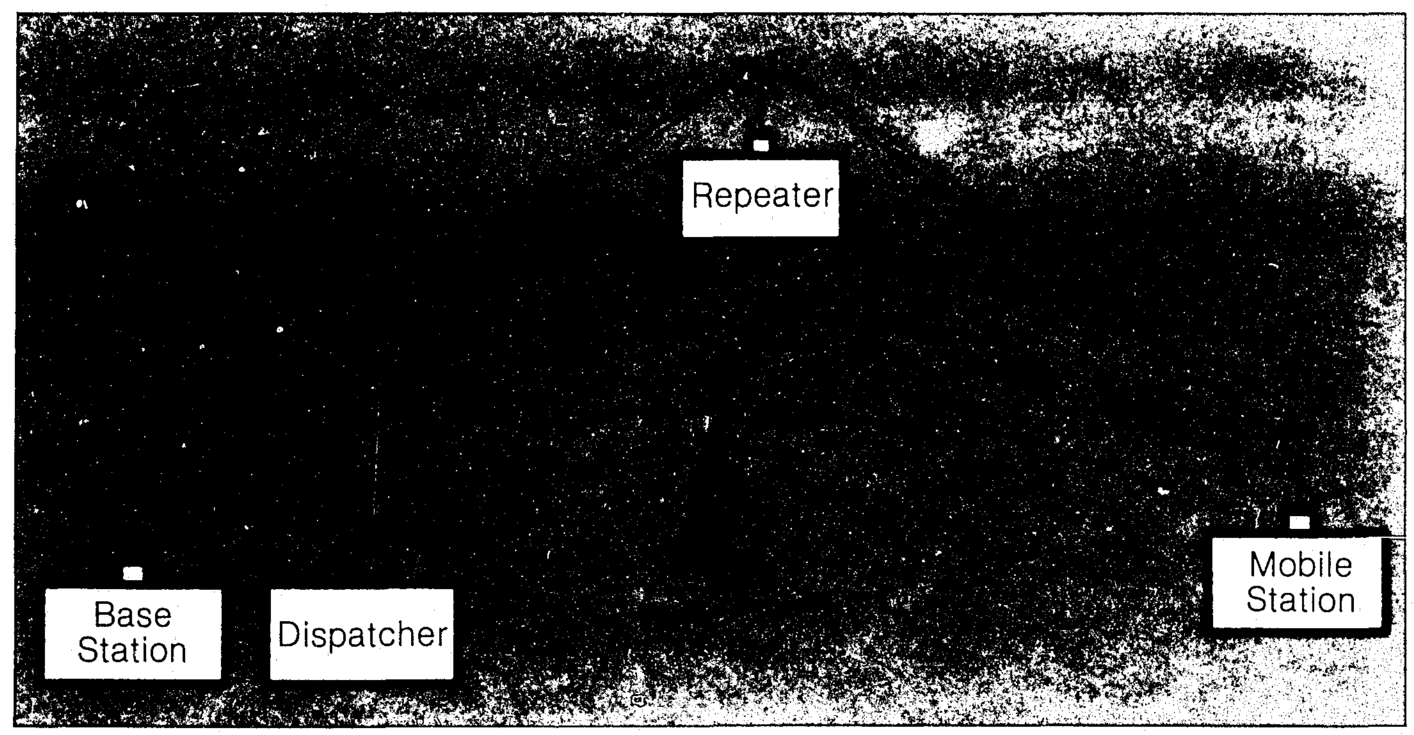
Accessory equipment that enables mobile radios to perform specialized tasks can take many forms. For example, repeaters, voting systems, voice privacy systems, digital systems, automatic vehicle location systems, scanning receivers and others are available. Several of these are discussed in more detail in the following paragraphs.

Repeater Systems

Unmanned repeater stations are used to improve coverage in irregular terrain, large service areas, or locales where extended coverage is required. Because a repeater is a relay system which boosts the power of signals by receiving, amplifying, and retransmitting them, these systems usually require two frequencies (see fig. 15).

It is not unusual for mountains, hills, or other large obstructions to create shadow regions in which received radio signals are very weak. Rather than attempting to increase signal strength by increasing transmitting power, some agencies use strategically placed repeaters to

FIGURE 15. A REMOTE REPEATER SYSTEM.



amplify signals between mobiles and a base station.

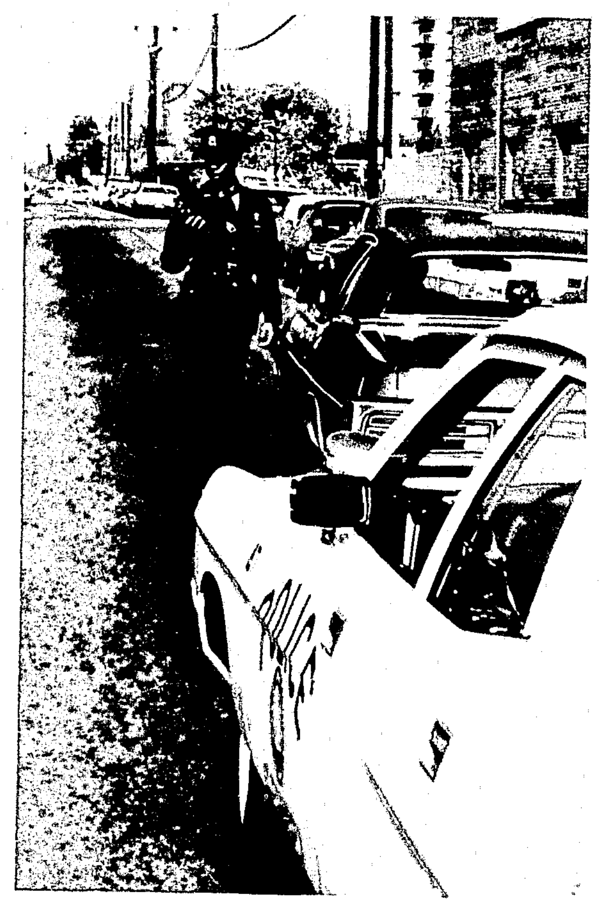
Repeaters usually consist of a transmitter isolated from a receiver in an enclosure, connected to an antenna. They can be placed on a pole, building, mountain or almost anywhere that power is available. Their output power ranges up to 300 watts. Besides being needed in irregular terrain or large areas, repeaters are also used routinely by agencies on the UHF band to boost its range.

Mobile radios themselves can act as repeaters for personal radios. If an officer must leave the vehicle and depend on a low-powered personal radio, he or she may be unable to transmit satisfactorily to the base station. When designed as a repeater, the mobile radios can be used to amplify and retransmit the signal of the personal radio. Additional information on repeaters is available [10].

Voting Receiver Systems

Voting receiver systems (multiple satellite receivers with comparators to select the one receiving the best signal) are useful in improving the "talkback" ability of the low power radio in the field. In contrast to the base station, where a large amount of transmitting power and a high gain antenna system are usually available, the mobile or portable radio is obviously limited in "talkback" ability, especially in poor signal areas such as hilly terrain, buildings, or alleys.

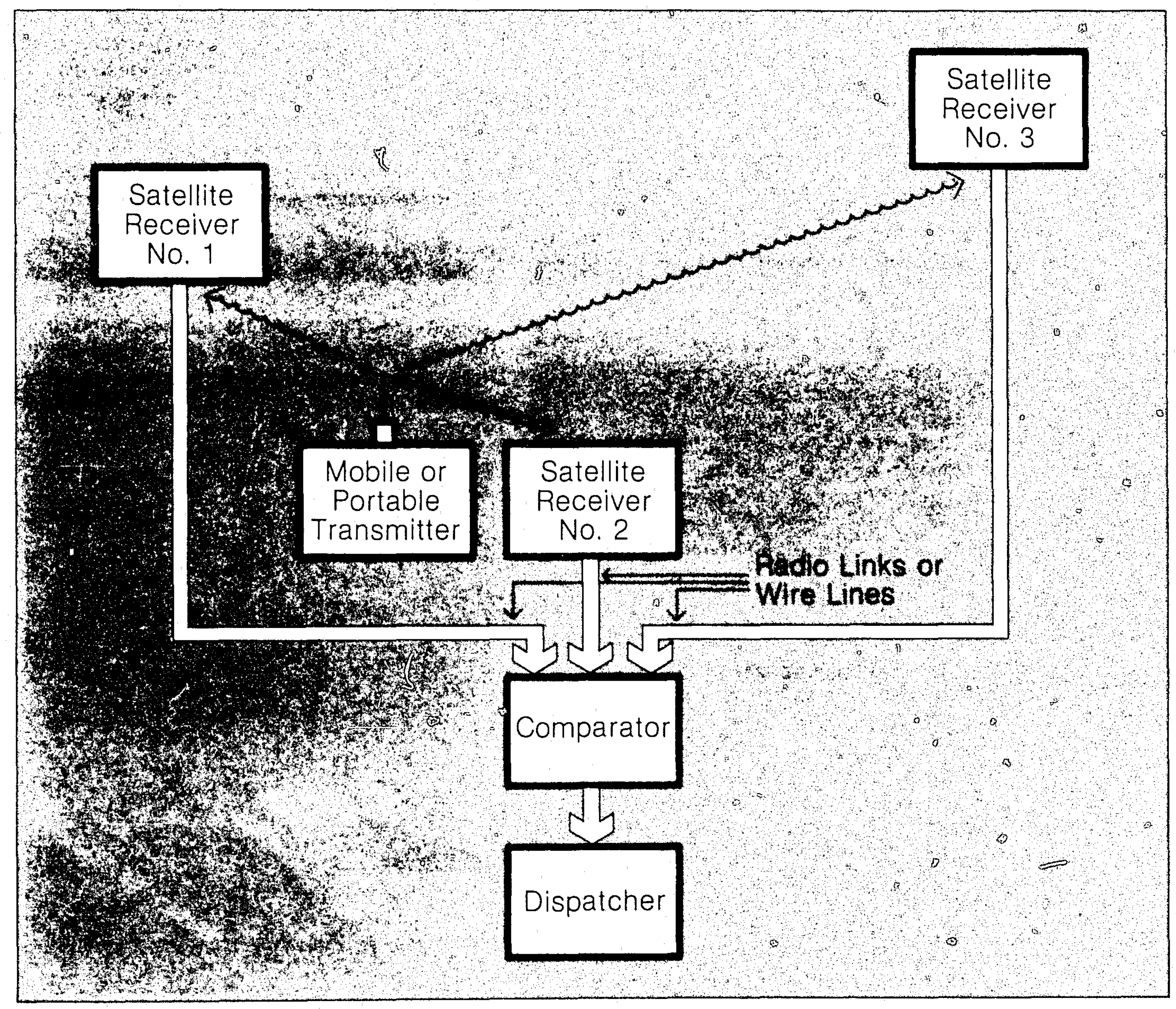
Several satellite receivers are usually installed at selected fixed locations within the desired area of coverage. This arrangement decreases the distance from the mobile or portable unit to the nearest receiver and thus helps compensate for the limited transmitting power of the field units. Either radio links or wire lines can be used to carry the received audio signals from each satellite receiver to a central location where a comparator selects the best signal (see fig. 16). Several types of comparators are available. Some are faster acting, some require receiver selection after the officer starts speaking, some will sample and select every few moments, while others will select just once at the beginning of the transmission.



Voice Privacy Systems

Scramblers are available which provide privacy in communications by encoding the voice at the transmitter and decoding it at the receiver. Many techniques are used for scrambling, differing not only in effectiveness (that is, degree of difficulty for the unauthorized person to decode) but also in cost. As the encoding and decoding process is made more complex in order to achieve better security, the purchase price usually increases. Both the encoder and decoder must be compatible with each other and designed to operate within the bandwidth limitations used in public-safety communication systems. Properly designed scrambler systems can be added to most radios and can be switched in and out as needed. However, one voice privacy system is usually incompatible with another. More information on this and on performance characteristics and purchasing hints for voice privacy systems can be found [17,32].

FIGURE 16. SATELLITE RECEIVER VOTING SYSTEM.



Digital Systems

Digital systems, which utilize coded combinations of pulses to convey information, are being utilized in law enforcement communications to reduce the amount of voice channel usage, and improve the efficiency of the patrol officer. Other major benefits include better protection against unauthorized message interception, no phonetic errors, unattended reception, permanent written records, operation in acoustically noisy environments, and direct field access to computer data banks.

Messages indicating status can be sent to the dispatcher through use of appropriately marked push buttons or selector switches. These messages can be in the form of "ten code" or other prepared messages.

Mobile digital displays present information received from the base station, such as results of computer inquiries. These results are usually displayed only in a designated vehicle in the mobile system. Some systems provide positive verification that the digital data transmission has been received without error.

Digital systems, including mobile teleprinters, are of greatest use in communities with severe frequency congestion. Unfortunately, this environment also harbors impulse noise, fading and multipath radio propagation effects that occasionally produce errors [11,36]. Additional information on applications of digital communications equipment for law enforcement use is available [22,35], and a standard for use in purchasing mobile digital terminals has been written [26].

Automatic Vehicle Location Systems

Automatic vehicle location (AVL) systems are used to locate patrol cars moving randomly. With this system, the dispatcher will know at all times the location of each patrol and supervisory vehicle. Such a system has many potential benefits. One of these is to reduce the response time between the dispatcher's receipt of a complaint call and the arrival of a patrol car at the scene of the incident. AVL also improves resource allocation and increases officer safety. Because the system identifies the location of each vehicle, assistance can be dispatched to the officer in danger. In addition, the current status of each vehicle (for example, "in service") can be provided.

One criterion by which AVL systems are judged is accuracy, i.e., how precisely does the system indicate where the car is. Generally, the more accurate a system is, the more expensive it is. Details and further discussion of these features are provided in [6] and [37].

Scanning Receivers

Scanning receivers are useful to both base stations and mobile units when several channels need to be monitored, and where a separate receiver for each channel is impractical. A scanning receiver samples each channel in sequence until a signal is detected. The receiver stops scanning and audio is heard from that channel until the signal ends, whereupon it starts scanning again. If the scanning receiver has a priority channel selection feature, the audio from that channel is presented to the operator when received even if it has to interrupt reception from another channel.

Additional options for scanning receivers include push-button selection for manual or automatic selection and for programming selection of channels to be scanned. A mixture of several frequency bands are available, with 8 to 16 channel selections being common. Typical scanning rates are 15 to 20 channels per second.

SERVICE AND SAFETY ASPECTS

Equipment Maintenance

Before purchasing mobile radios, the amount of maintenance required should be considered. Mobile radios are subject to severe physical and electrical wear and there is need for both preventive and "fix-it" maintenance. Improved reliability will probably continue to be an important consideration for users of communications equipment. In addition, the FCC requires that performance checks be made on licensed transmitters when any changes are made to the transmitter that might affect its performance. This information must be properly documented.

Maintenance Services

There are three basic approaches to maintenance services. They are in-house maintenance, local contract maintenance, and factory maintenance.

The two general goals in establishing an in-house maintenance capability are to reduce failure rate in operational equipment by preventive maintenance and to reduce the time required to repair the equipment when it does fail. The advantages of in-house maintenance are apparent. However, the costs of stocking spare parts, obtaining maintenance equipment, providing an area to work, and hiring qualified personnel may be greater than the cost of providing the same service using contract maintenance companies. Generally, only large organizations can afford to maintain their own equipment. Smaller organizations usually have to contract out to satisfy their needs. Often, several departments in a given area join together to operate a maintenance facility as part of a more extensive joint operation of communication facilities.

Contracting for maintenance services has the advantage that payment is made only for the work done, either on a pre-scheduled per item basis or on an hourly rate. The contractor has a place of business and must maintain test equipment and replacement parts and hire and train employees. To repair radios, the contractor may choose to bring service equipment to your facility.

Factory maintenance differs from local contract maintenance only in that the company that supplies the major items of equipment also maintains them, either locally or at a central (i.e., factory) location.

As equipment becomes more complicated, every service facility experiences the need to have its technicians become familiar with the latest service techniques for new types of equipment. Many manufacturers provide audio-visual self-instruction guides and courses for updating technical staff members. The important thing to realize in deciding whether maintenance should be performed in-house or purchased elsewhere is that quality, convenience, speed, and reliability are just as important as relative cost in deciding between the alternatives.

Maintenance Costs

Many engineers acquainted with the maintenance of mobile radios will agree that the cost of maintaining such equipment often equals the original purchase cost. This is undoubtedly true considering the long years of service some of this equipment experiences. Many maintenance shops, because of the nature of law enforcement communication needs, operate 24 hours a day, thus increasing maintenance costs.

Labor costs are a major expense in any service organization's budget. Some equipment is designed to attempt to reduce turnaround time for repair by modular construction. The service area maintains a stock of modules and the radio can be returned to service as quickly as the faulty module can be identified and replaced. The faulty module can be thrown away (if it is inexpensive) or repaired as time allows. Because modules require many connections, there is the possibility of connector problems, but manufacturers are still considering modular construction for the obvious advantages it offers.

For large maintenance facilities, managers may find it beneficial to determine optimum staffing. One study which discusses future personnel needs is available [7].

Safety

As with any other product that emits energy, mobile radios can be hazardous. Most users are aware that radio frequency burns result from touching the antenna of an active transmitter, but they may not be aware of the danger of extended close exposure to high rf fields. The user may also be aware of the possibility of detonating nearby electric blasting caps by keying a transmitter, but he or she may not be aware of the hazards of transmitting while in an atmosphere heavy with gasoline, liquid petroleum gas, or other explosive mixture. In addition, the service technician may unknowingly place users and others in danger by breaking open certain rf power transistors or wirewound resistors that contain beryllium oxide (BeO), which is potentially dangerous if inhaled, ingested, or absorbed into the body through the skin. These and other hazards relating to the improper installation of mobile radios are discussed in the literature [14].

The Williams-Steiger Occupational Safety and Health Act (OSHA) of 1970 brings force of law to many areas involving safety for employees. In law enforcement communications, one area of particular interest to operators and repair technicians of base station, mobile, or personal/portable transmitting equipment is that of non-ionizing radiation. Section 1910.97 of OSHA's Occupational Safety and Health Standards specifies rf radiation levels that should not be exceeded without careful consideration of the reasons for doing so [5]. The Radiation Protection Guide (RPG) contained in OSHA's standards, limits maximum exposure to either a power density of 10 mW/cm^2 averaged over any 0.1-hour period or more, or an energy density of 1 $mW\text{-}h/cm^2$ during any 0.1-hour period. The RPG applies to incident electromagnetic fields of frequencies between 10 MHz and 100 GHz and also is applicable whether the radiation is continuous or intermittent. The RPG is customarily interpreted as follows [31].

> A worker can be exposed to a radiation level of 10 mW/cm^2 for 0.1 hour (6 minutes) or more per hour and not exceed the RPG limit. If exposed to a radiation level of 100 mW/cm^2 for 0.01 hour (36 seconds) every 6 minutes, the worker still would not exceed the RPG limit. The RPG limit would be exceeded if the worker were exposed to this level for any time longer than 0.01 hour, or more than once every 6 minutes.

The RPG applies both to whole body and partial body irradiation. The critical parts of the body are the eyes and genitals, and medical evidence indicates that medical effects can be additive for repeated exposure of these areas.

The RPG has certain implications to those interested in the practical application for law enforcement communications. Table 6 summarizes results obtained using far-field calculations for selected transmitters, but the reader is cautioned that certain assumptions were used [33]. However, in near-field situations (in the immediate vicinity of the transmitting antenna), such as a passenger in a mobile unit with transmitter on board, the field is perturbed by the metal of the vehicle and unusually high field strengths may occur due to resonances or other abnormal conditions [14]. The intent is not to compute precise values for the table, but rather to provide values that can reasonably be considered to meet OSHA requirements.

TABLE 6. SUMMARY OF RADIATION-PROTECTION GUIDE MINIMUM DISTANCES

Transmitter service	Estimated maximum power	Estimated maximum ant. gain	RPG minimum body to antenna distance	
Personal	5 watts	0.5 dB	0.066 meter	(2.6")
Portable	22	0.5	0.139	(5.5")
Mobile	180	4.2	0.609	(2.0')
Base Station	330	12.0	2.02	(6.6')

Note that the RPG minimum body-to-antenna distance is dependent upon the power applied to the antenna terminals and the antenna gain. For example, if the powers listed in the table are halved, or if the antenna gains are reduced by 3 dB, then the RPG minimum distance is divided by 1.4 to obtain the new RPG minimum distance.

The listed RPG minimum distances in table 6 are for worst case situations in power and antenna gain and are to be applied for a continuous generation of the electromagnetic field. The possibility of a person accumulating a significant dose even at the listed RPG minimum distances in the variable situations found in law enforcement is probably remote. But this data is provided to indicate the extent of the problem in worst case situations.

The precise nature of the biologic effects of microwave radiation is not clearly understood at this time, although most experimental evidence indicates that the effects are primarily due to local or general heating of the tissues (hyperthermia) [15].

PURCHASING CONSIDERATIONS

Cost

In general, the more sophisticated and extensive a communications system is, the greater the cost. Maintaining sophisticated equipment may also require additional training for technicians. Another consideration is the point at which older and obsolete equipment should be replaced with newer equipment to improve efficiency, serviceability, and performance. Decisions regarding the selection and purchasing of equipment should only be made after a thorough analysis of the needs for improved community services.

Competitive Bidding

Most law enforcement agencies purchase equipment by competitive bidding. Pre-bid conferences or other information exchanges with prospective suppliers may be useful when preparing the equipment specifications. It is advantageous to find out what is currently available, what is the present state-of-the-art, and what problems, if any, can be identified for the equipment under consideration for purchase.

It is important to be complete in the original specifications. Quite often, it is found later that some significant feature or requirement was left out and the very nature of the bidding process requires that service be cut as low as possible by the competitive bidder to realize the lowest bid price. There may also be difficulty in getting the contractor to provide additional service later.

Purchasing Hints

It is important that the mobile radios be a supportive part of the overall communications system. The designer of an overall communications system is concerned with questions such as geographic area, type of communication needs, and the level of performance needed [20]. There exists adequate guidance to advise the system designer in step-by-step procedures to select the best communications plan to fit the given constraints [29].

This section lists some general questions that should be answered before purchasing mobile communications equipment.

1. What frequency band and how many channels are you planning for?
2. How many frequencies are needed for each channel?
3. What type of simplex or duplex system have you chosen?
4. Is there agreement with the frequency coordinator for the choice of frequencies?
5. Has an optimum base station location been chosen?
6. Will a repeater or satellite receiver system be needed for adequate communication coverage?
7. Has the type of antenna and its placement on the vehicle been considered?
8. Have the transceiver options been specified, such as tone squelch frequency and transmitter output power?
9. Have the pros and cons of a conventional mobile system versus a portable-mobile system been considered?
10. Is the alternator, regulator, and battery system of the vehicle of sufficient rating to adequately power the equipment?
11. Are there any unusually strong noise sources in the vicinity of the base station?
12. Is the proposed transmitting equipment type-accepted for use under Part 90 of the FCC rules and regulations?
13. Are those involved with transmitting equipment sufficiently aware of the safety considerations?
14. What arrangements have been made to maintain the equipment?
15. Have the correct control cable lengths been specified for the vehicle in which the transceiver is to be installed?

There are hundreds of different models of mobile radios available with uncounted options which permit a large variety of tailor-made communication systems. Trade magazines and journals are a good source for current model advertising. Trade shows and conferences are a popular and convenient way of getting acquainted with some of the manufacturers. There are also several buyers guides published yearly that summarize available models [27,34,39].

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To better understand the problems and issues discussed herein, this short listing of annotated bibliographic material is included. This material should provide useful information to the reader, such as how to cope with intermodulation interference or how to suppress vehicle noise.

B-1 The Communications Problem

1.1 Noble, D. E., "Police Radio Origin: Past, Present and Future," The APCO Bulletin, Vol. 37, No. 3, p. 38, March 1971.

The history of mobile police communications is traced from about 1916 to 1971. Early FCC rules, as well as specific pieces of equipment and the people that designed and installed the equipment, are mentioned. It is predicted that great changes in police communication systems will occur in the next 50 years, with emphasis not only in size and weight reduction, but also in philosophy.

1.2 Shrader, R. L., "Electronic Communication," McGraw-Hill Book Company, New York, Second Edition, p. 686, 1971.

This book presents a rather complete course of instruction on electronics and radio communications with the goal of allowing the reader to successfully complete the FCC examinations. The chapter on frequency modulation presents fundamentals including descriptions of discriminators, limiters, pre-emphasis and de-emphasis circuits and includes a broad discussion of the Public Safety Radio Service.

B-2 The Equipment

2.1 Giles, O. S., "Single Conversion VHF/UHF Receiver Design and the Impact of Monolithic Technology," IEEE Transactions on Vehicular Technology, Vol. VT-23, No. 1, February 1974.

Single-conversion receivers are discussed in terms of performance and reliability. Advantages over the usual double-conversion design approach are listed. The size reduction possible for single-conversion receivers is attributed to the development of monolithic crystal filters and integrated circuits.

2.2 Leece Neville Company, "Do's and Don'ts for Emergency Alternators," The APCO Bulletin, Vol. 37, No. 2, p. 20, February 1971.

This is a guide of do's and don'ts for those who are concerned with troubleshooting alternators. Symptoms that are common with faulty alternators are given, and possible causes are suggested to aid the troubleshooter.

2.3 Davidson, A., "Mobile Antenna Gain at 900 MHz," IEEE Transactions on Vehicular Technology, Vol. VT-24, No. 4, November 1975.

Results of pattern range measurements and supporting computations are presented for several mobile antennas (quarter-wave and gain antennas) for the 900 MHz band. Actual antenna gain for increasing antenna heights and decreasing primary pattern beamwidth are also given.

B-3 Coverage

3.1 Gans, M. J., "A Power-Spectral Theory of Propagation in the Mobile-Radio Environment," IEEE Transactions on Vehicular Technology, Vol. VT-21, No. 1, February 1972.

The propagation between base station and mobile station is not only by direct line-of-sight route, but by many paths of reflection and diffraction off buildings and terrain. This paper derives the statistical properties of the resulting propagation and discusses the techniques of communication in their presence.

3.2 Shortall, W. E., "A Switched Diversity Receiving System for Mobile Radio," IEEE Transactions on Vehicular Technology, Vol. VT-22, No. 4, November 1973.

The input of a single receiver is switched back and forth between two antennas upon command from a single level-sensing logic circuit. The system was measured on simulated Rayleigh fading channels and was found to give a significant improvement to both voice and data signals.

3.3 Reudink, D. O. and Wazowic, M. F., "Some Propagation Experiments Relating Foliage Loss and Diffraction Loss at X-Band and UHF Frequencies," IEEE Transactions on Vehicular Technology, Vol. VT-22, No. 4, November 1973.

Measurements of signal attenuation were made from a suburban hilltop base station to a mobile vehicle on several streets in the surrounding countryside. Signal strengths were measured at 836 MHz and 11.2 GHz in both winter and summer to determine the effect of foliage. Observed results were compared with those predicted by theory with good agreement.

3.4 Rustako, A. J., Jr., et al., "Performance of Feedback and Switch Space Diversity 900 MHz FM Mobile Radio Systems with Rayleigh Fading," IEEE Transactions on Vehicular Technology, Vol. VT-22, No. 4, November 1973.

A theoretical and experimental comparison of performance has been made between two types of space-diversity mobile radio systems. This comparison was made at a frequency of 840 MHz using simulated Rayleigh fading for a vehicle speed of about 80 mph.

3.5 Nylund, H. W., "Characteristics of Small-Area Signal Fading on Mobile Circuits in the 150 MHz Band," IEEE Transactions on Vehicular Technology, Vol. VT-17, No. 1, October 1968.

Transmission on mobile radio circuits is often affected by "standing-wave breakup" resulting from spatial variations in rf signal amplitude, which to the moving mobile unit appear as rapid fades. Measurements and statistical distributions were determined for the depths and widths of fades in rural, suburban, and urban situations.

3.6 Reudink, D. O., "Properties of Mobile Radio Propagation Above 400 MHz," IEEE Transactions on Vehicular Technology, Vol. VT-23, No. 4, November 1974.

This paper reviews mobile radio transmission in frequency ranges above 400 MHz. The rapid and extreme amplitude fluctuations of the mobile signal are discussed, as well as factors which affect transmission, such as diffraction, rain, and the atmosphere. Other subjects such as base station antenna height, mobile antenna height, correction factors for suburban and open areas, effects of street orientation, foliage, irregular terrain, sloping terrain, and land-sea paths are discussed.

3.7 Cox, D. C., "910 MHz Urban Mobile Radio Propagation: Multi-path Characteristics in New York City," IEEE Transactions on Vehicular Technology, Vol. VT-22, No. 4, November 1973.

This paper describes some measured characteristics of multipath propagation at 910 MHz in New York City. The data presented describe the "local" statistics of multipath propagation which cover mobile vehicle travel distances on the order of 30 meters.

B-4 The Man-Made Electrical Noise Problem

4.1 Skomal, E. N., "The Range and Frequency Dependence of VHF-UHF Man-Made Radio Noise In and Above Metropolitan Areas," IEEE Transactions on Vehicular Technology, Vol. VT-19, No. 2, May 1970.

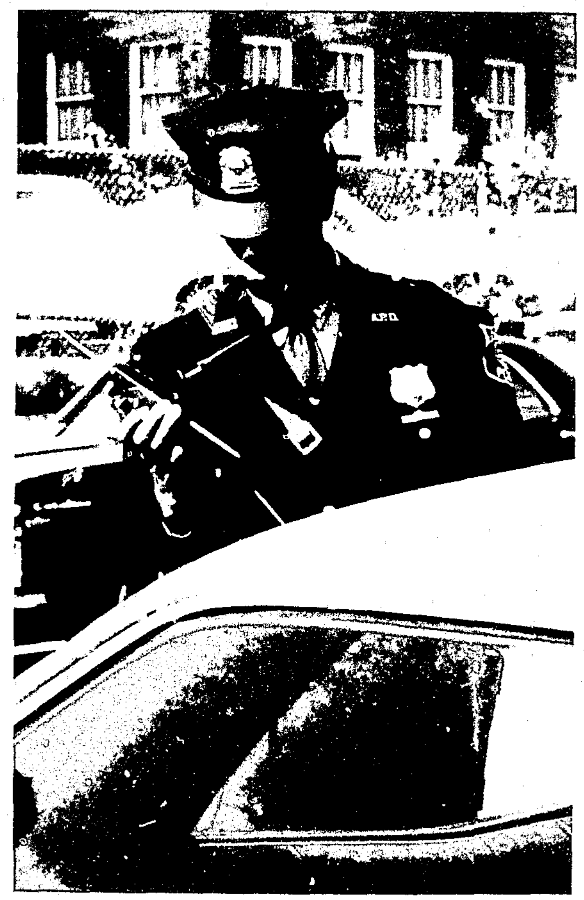
Sources of incidental man-made noise are discussed, such as from automobile ignition, power transmission lines, rf arc welders, and fluorescent and other gaseous discharge lighting devices. Their extent and relative importance are discussed for the metropolitan areas.

4.2 Bauer, F., "Vehicular Radio Frequency Interference—Accomplishment and Challenge," IEEE Transactions on Vehicular Technology, Vol. VT-16, No. 1, October 1967.

Although written for the engineer, the advanced technician is likely to find some useful pointers in applying the listed methods of suppression of vehicular rf noise. A multiplicity of standards to control vehicular interference adopted by countries throughout the world are also listed and compared.

4.3 Shepherd, R. A., "Measurements of Amplitude Probability Distributions and Power of Automobile Ignition Noise at HF," IEEE Transactions on Vehicular Technology, Vol. VT-23, No. 3, August 1974.

Measurements of the amplitude probability distribution (APD) of the envelope of automotive ignition noise were made at frequencies 24 to 30 MHz. Measurements were made with vehicles at idle, and at locations near a freeway with both light and heavy traffic densities.



B-5 The Interference Problem

5.1 "Tone Control Signaling Applications and Techniques," April 1972, available from Vega Electronics, 3000 West Warner, Santa Ana, Calif. 92704.

Several different methods of tone control signaling are described including sub-audible, audible, and frequency shift. Also discussed are the selection of a signaling method, sub-audible and audible frequency selection for tone control signaling, and predictions of future technology.

5.2 Chaney, W. G. and Myers, R. T., "Squelch Systems—New Designs for High Performance," IEEE Transactions on Vehicular Communications, Vol. VC-14, No. 1, March 1965.

The paper defines squelch and discusses some of the problems that noise squelch circuits generally experience, including problems caused by supply voltage variations, temperature variations, variable squelch closing time, and voice blocking or clipping. A new approach to a noise operated squelch is described that minimizes the effects of many of these problems.

5.3 Giles, O. S. and Paul, S., "Multipath-Frequency Reception With a Priority Channel," IEEE Transactions on Vehicular Technology, Vol. VT-18, No. 3, November 1969.

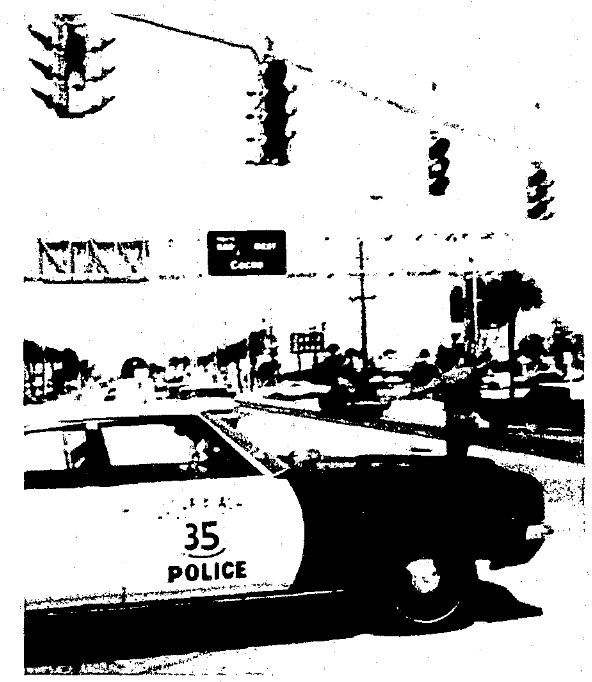
One can use separate receivers tuned to different frequencies to receive signals in a multi-frequency situation; however, the disadvantages of this approach can be avoided through use of the described priority search-lock monitor circuitry.

5.4 "Intermodulation Interference in Radio Systems," Bell System Technical Reference PUB 43302, p. 27, November 1972. Order from American Telephone and Telegraph Company, Supervisor-Information Distribution Center, 195 Broadway, Room 208, New York, N.Y. 10007.

This technical reference represents current views on the problems of intermodulation interference and offers some possible solutions. The objective is to provide assistance with diagnosis, prevention, and remedial treatment of this form of interference. Theoretical aspects are included only to offer aid in understanding and handling practical situations.

5.5 "Giving Two-Way Radio Its Voice," Champion Spark Plug Company, p. 15, 1969. Available from Automotive Technical Services Dept., Champion Spark Plug Company, P.O. Box 910, Toledo, Ohio 43601.

This booklet presents recommended procedures for obtaining optimum RFI suppression. Basic components and techniques include use of capacitors, bonding, routing of wiring, and high voltage suppressors. Clues are given to help identify the source of interference by its characteristic sound.



B-6 The FCC Frequency Allocation Problem

6.1 Mitchell, B. A. and Cullen, F. P., "Modulation Techniques Investigation to Enhance Communication Channel Utilization," Proc. Third National Symposium on Law Enforcement Science and Technology, Vol. 3, pp. 129-137, 1970.

As emphasized in studies for the FCC, frequency mismanagement and inefficient channel utilization of spectrum allocations is a critical problem in land mobile operations. Different techniques intended to increase the efficiency of present channels are discussed. The article summarizes for each technique the major technical and cost considerations.

B-7 Safety Considerations

7.1 Bodle, D., "Electrical Protection Guide for Land-Based Radio Facilities," Joslyn Electronic Systems, p. 67, 1971. Available from Joslyn Electronic Systems, Santa Barbara Research Park, P.O. Box 817, Goleta, Calif. 93107.

This booklet deals with the exposure of communications facilities to lightning and measures to protect personnel and plant against associated hazards. Emphasis is placed on specific problems related to mobile and microwave radio stations and associated landline facilities. Much basic information is provided on the general grounding problem and protection of structures.

7.2 Cory, W. E. and Frederick, C. L., "Environmental Health Effects Caused by Non-Ionizing Electromagnetic Energy," 1974 Earth Environment and Resources Conference Record, Philadelphia, Pa., p. 2, September 1974.

The purpose of this paper is to focus public attention on the need to control the use of electromagnetic energy to prevent potentially harmful effects on environmental health. In some cases, these effects are so insidious that they cannot be seen, felt, smelled, tasted, or heard by human sense organs until damage has occurred. Briefly considered are radiation sources, transportation and absorption of EM energy, and typical health effects including those on the nervous and endocrine systems.

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