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Technology Assessment Program

Guide to Base Station Communications Equipment

204-83

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a program of the **National Institute of Justice**

About the Technology Assessment Program

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.

The program operates through:

The *Technology Assessment Program Advisory Council* (TAPAC) consisting of nationally recognized criminal justice practitioners from Federal, State, and local agencies, which assesses technological needs and sets priorities for research programs and items to be evaluated and tested.

The *Law Enforcement Standards Laboratory* (LESL) at the National Bureau of Standards, which develops voluntary National performance standards for compliance testing to ensure that individual items of equipment are suitable for use by criminal justice agencies. The standards are based upon laboratory testing and evaluation of representative samples of each item of equipment to determine the key attributes, develop test methods, and establish minimum performance requirements for each essential attribute. In addition to the highly technical standards, LESL also produces user guides that explain in nontechnical terms the capabilities of available equipment.

The *Technology Assessment Program Information Center* (TAPIC) operated by the International Association of Chiefs of Police (IACP), which supervises a national compliance testing program conducted by independent agencies. The standards developed by LESL serve as performance bench marks against which commercial equipment is measured. The facilities, personnel, and testing capabilities of the independent laboratories are evaluated by LESL prior to testing each item of equipment, and LESL helps the Information Center staff review and analyze data. Test results are published in Consumer Product Reports designed to help justice system procurement officials make informed purchasing decisions.

All publications issued by the National Institute of Justice, including those of the Technology Assessment Program, are available from the National Criminal Justice Reference Service (NCJRS), which serves as a central information and reference source for the Nation's criminal justice community. For further information, or to register with NCJRS, write to the National Institute of Justice, National Criminal Justice Reference Service, Washington, DC 20531.

James K. Stewart
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National Institute of Justice

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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) Technology Assessment Program to strengthen law enforcement and criminal justice in the United States. The overall NIJ Technology Assessment Program is briefly described on the inside front cover of this guide. 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. The standards that are developed by LESL, following review by the Technology Assessment Program Advisory Council, are adopted by the International Association of Chiefs of Police (IACP) and recommended for use by its membership. These standards are also used by the IACP Technology Assessment Program Information Center (TAPIC) as the basis for testing commercial equipment, and the results of that testing are published in the TAPIC Consumer Product information report series.

This document is a law enforcement equipment 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 Law Enforcement Standards Laboratory, National Bureau of Standards, Gaithersburg, MD 20899.

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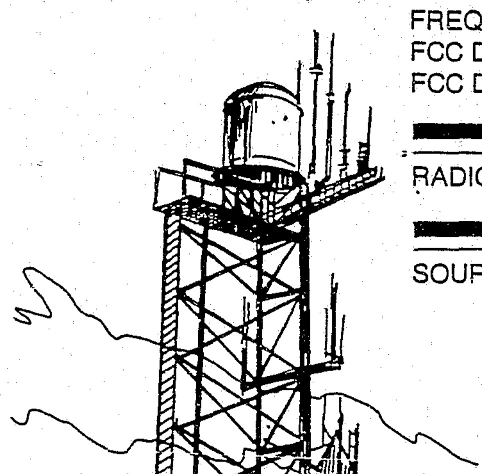
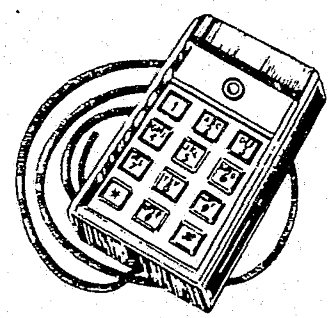




Introduction

Base station equipment performs an important function in the law enforcement communications system. Its primary purpose is to provide reliable communications between the control center and field units, be they equipped with mobile or personal radios[1] or a combination thereof. In its simplest form, base station equipment includes a transmitter, a receiver, and an antenna with associated control equipment and transmission lines (see fig. 1). This basic equipment, together with peripheral devices such as control consoles, displays, and computers, comprises the base station portion of the overall communications system.

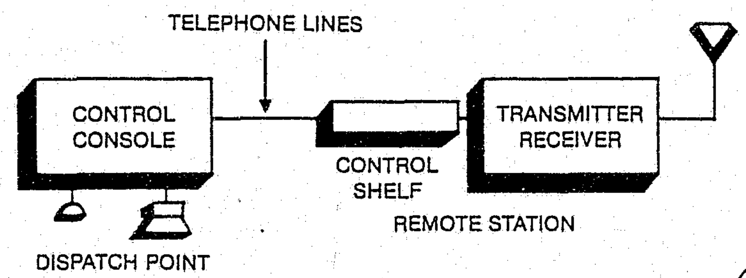
This guide is directed towards law enforcement officials who understand daily police operations and who desire assistance in the selection and use of base station communications equipment. It is one in a series of four guides covering police communications equipment. The other three guides cover mobile radios, personal radios, and overall communication systems, respectively [1–3].[2] Readers needing assistance should refer to the appropriate documents. The communication systems guide should be consulted by anyone who is designing a communication system or purchasing equipment for an existing system. Persons desiring assistance in developing procurement specifications should consult the appropriate guide and the necessary performance standards.

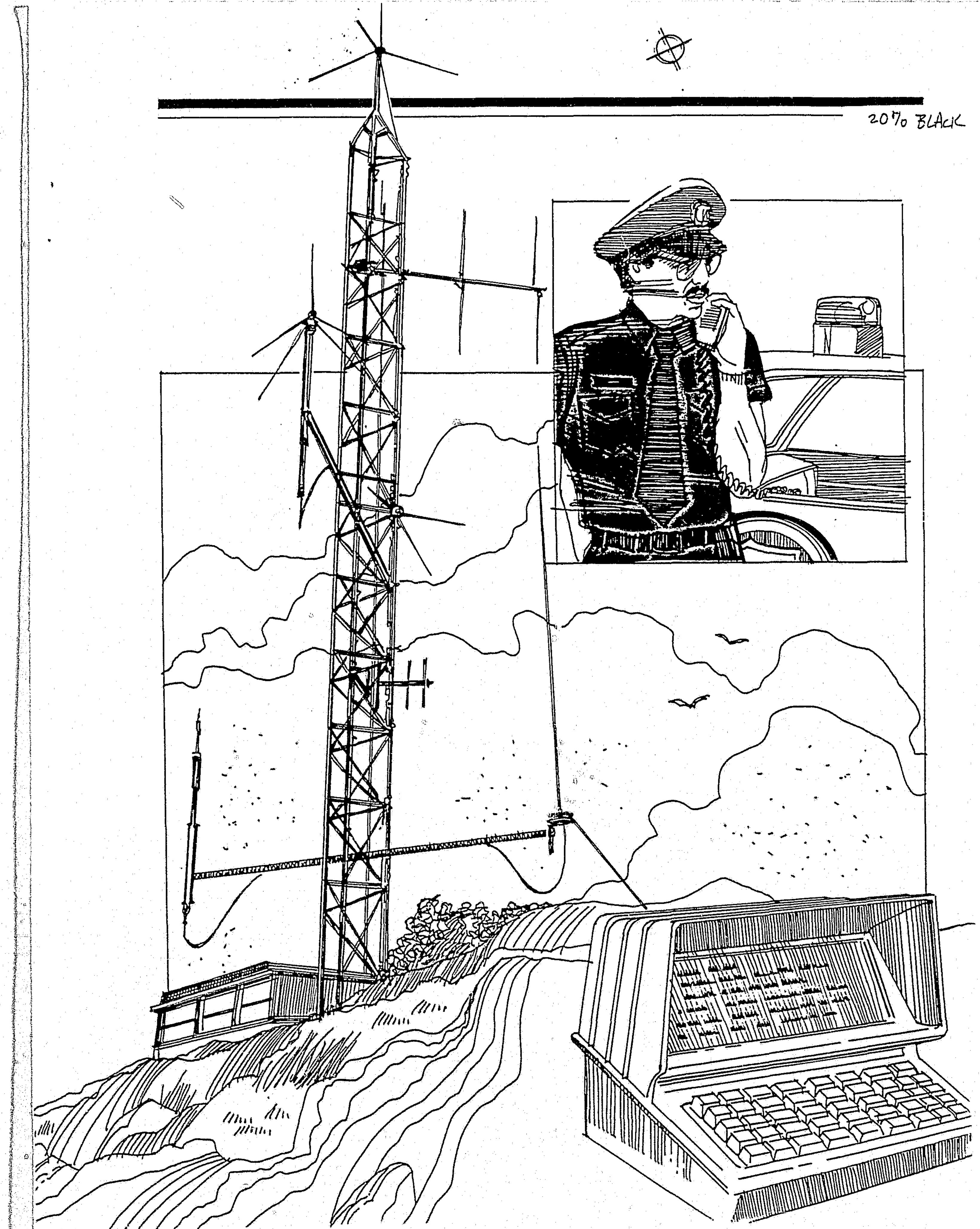
[1] Although they are really transceivers, i.e., having the capability of both transmitting and receiving messages, the devices are commonly called radios.

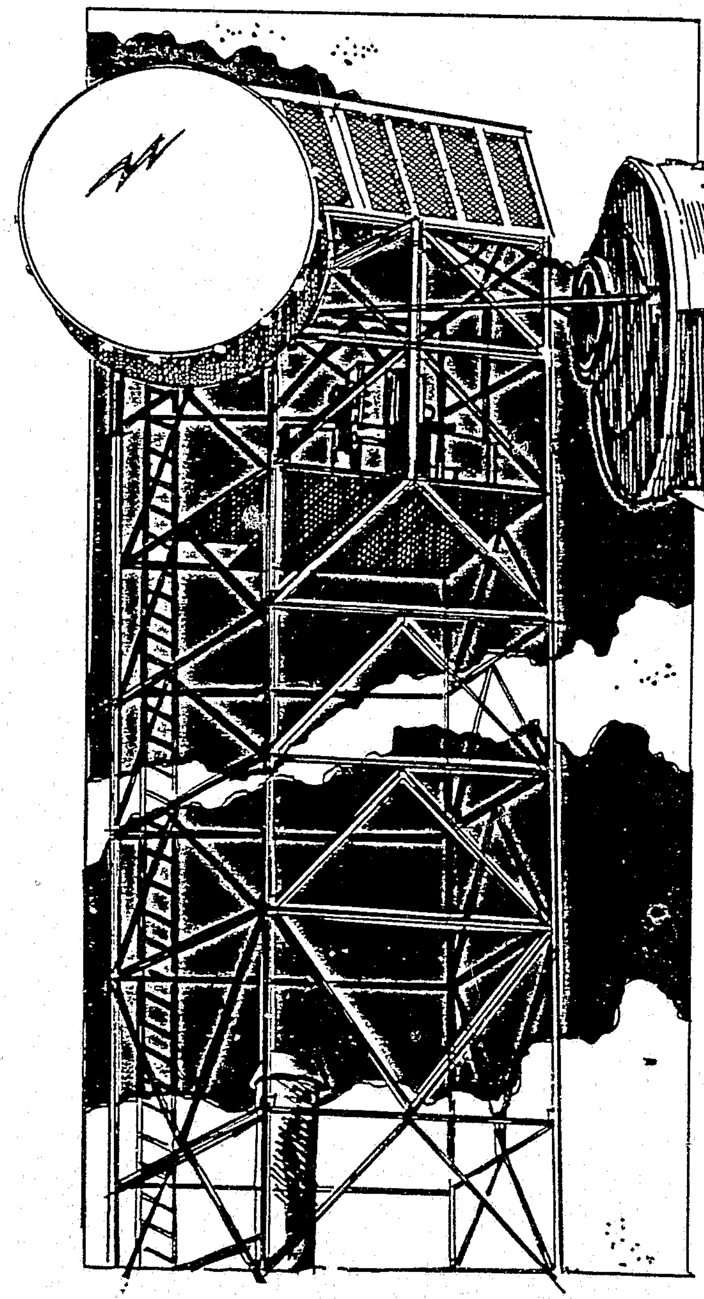
[2] Numbers in brackets refer to references in appendix A.

FIGURE 1.

The interconnection of units comprising a base station installation under remote control.







Performance standards have been developed for a variety of communications equipment. Although these standards have been tailored specifically for law enforcement application, they are obviously suitable for other public-safety and land-mobile use. Table 1 illustrates the suggested utilization of these documents in the communications planning and equipment procurement process.

The purpose of this guide is to provide general background information that will help law enforcement agencies analyze their base station equipment needs and select superior equipment to meet those needs. It also provides a description of presently available equipment. A brief summary of the more important peripheral equipment for base station communications, such as repeaters, satellite receivers, and scanning receivers, also has been included.

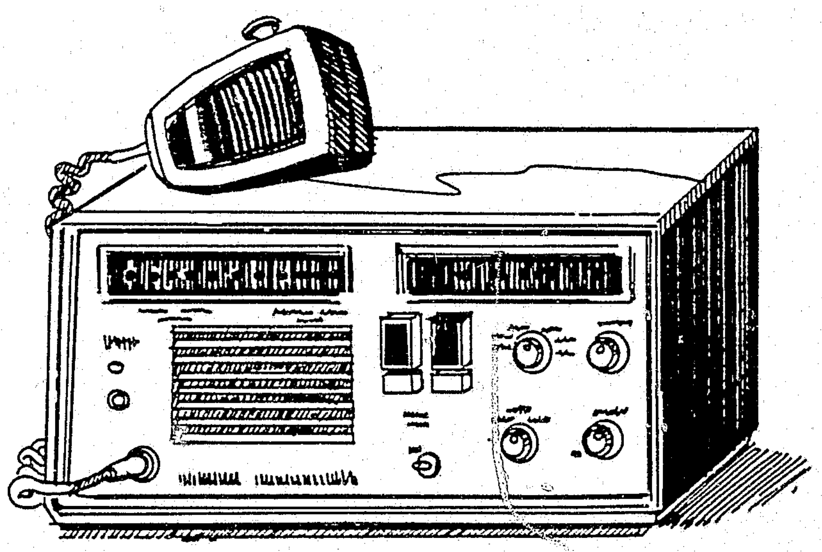


Table 1. Use of Documents.

Application	Applicable Documents
Communications 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 NIJ Standard-0216.00, Control Heads and Cable Assemblies for Mobile FM Transceivers NIJ Standard-0217.00, Microphone Cable Assemblies for Mobile FM Transceivers NIJ Guide 202-83, Mobile Radio Guide
Personal/Portable Transceiver Procurement	NIJ Standard-0209.01, Personal FM Transceivers NILECJ-STD-0211.00, Batteries for Personal/Portable Transceivers NIJ Guide 203-83, Personal Radio Guide
Base Station Equipment Procurement	NILECJ-STD-0201.00, Fixed and Base Station FM Transmitters NIJ Standard-0204.01, Fixed and Base Station Antennas NILECJ-STD-0206.00, Fixed and Base Station FM Receivers NIJ Guide 204-83, Guide to Base Station Communications Equipment
Accessory Equipment Procurement	NBS Special Publication 480-8, A Guide to Voice Scramblers for Law Enforcement Agencies NIJ Standard-0215.00, Mobile Digital Equipment NIJ Standard-0219.00, Continuous Signal-Controlled Selective Signaling LESP-RPT-0206.00, Repeaters for Law Enforcement Communication Systems LESP-RPT-0207.00, Electronic Eavesdropping Techniques and Equipment NIJ Guide 202-83, Mobile Radio Guide NIJ Guide 203-83, Personal Radio Guide NIJ Guide 204-83, Guide to Base Station Communications Equipment

Frequency Bands

Law enforcement frequency modulation (FM) communications for base and mobile stations occupy 226 dedicated channels in the very high frequency (VHF) low-band from 37 to 46 MHz, the VHF high-band from 154 to 159 MHz, and the ultra-high frequency (UHF) band from 453 to 466 MHz. They also share 32 channels with other services within these bands. In addition, selected frequencies between 470 and 512 MHz have been allocated by the Federal Communications Commission (FCC) to help relieve the presently crowded spectrum in certain heavily populated urban areas. A portion of the UHF band between 806 and 896 MHz is also available for public-safety use.

FCC DOCKET 18261

The FCC proposed in 1970 that a 42 MHz band of frequencies from 470 to 512 MHz, which are the UHF-TV channels 14 through 20, be shared with the land-mobile radio services in the 13 largest urban areas in the United States. As a result, portions of these frequencies have been allocated to Public Safety Radio Services, which includes law enforcement. In 1971, the Electronic Industries Association showed that 50 percent of all land mobile transmitters in the United States were concentrated in less than 8 percent of the country. The additional channels from the UHF-TV band should help to ease some of this spectrum congestion.

FCC DOCKET 18262

Simultaneously with Docket 18261, the FCC proposed that additional channels in a band of frequencies of approximately 40 MHz within the 806-896 MHz band be reassigned for land-mobile services and this has been done. This band offers significant advantages in lower noise, greater building penetration, and shorter antennas.

Radio Coverage

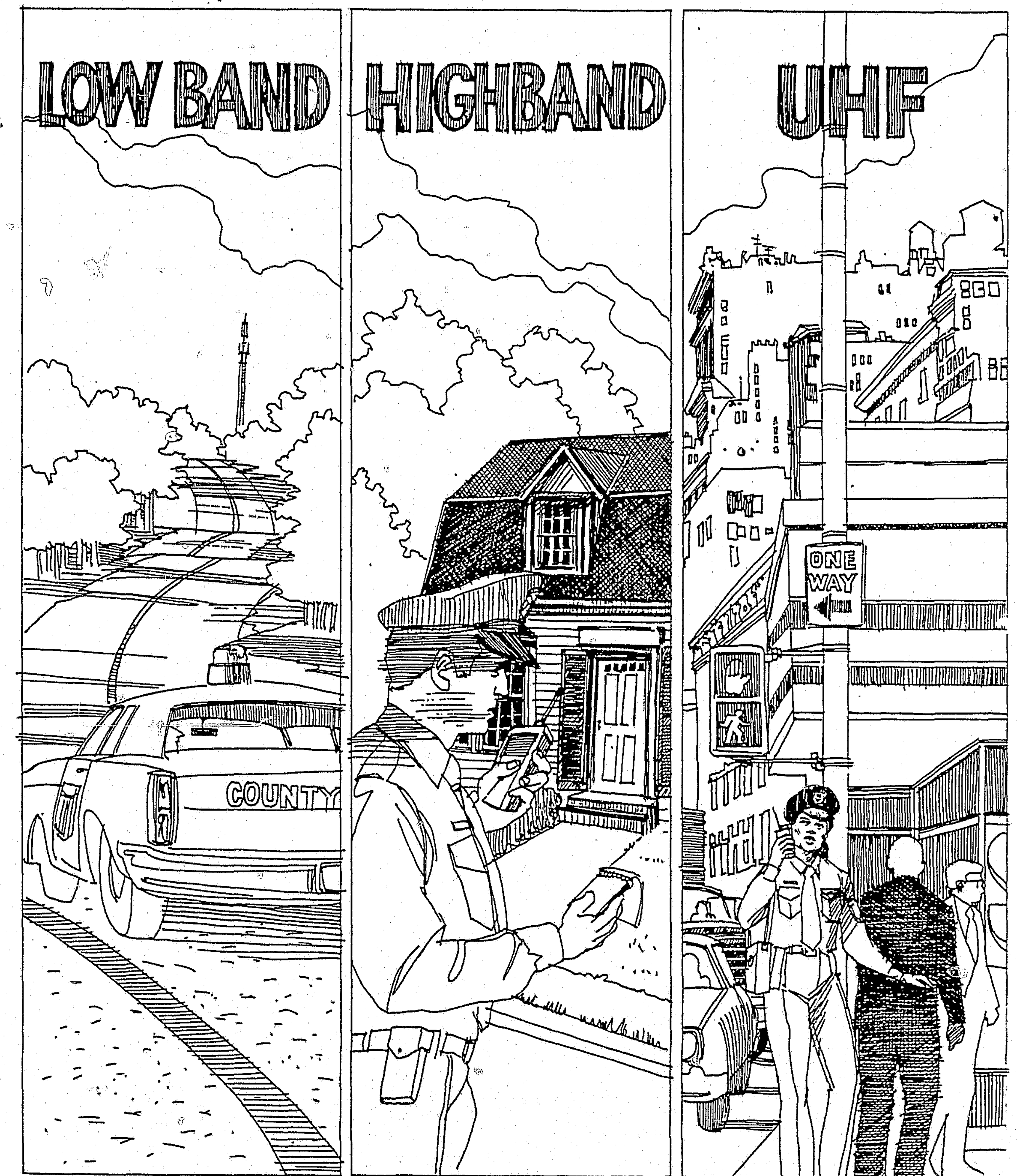
The primary goal when designing a communication system is to provide adequate coverage. This coverage is influenced by the factors listed in table 2, many of which are frequency dependent. Table 3 illustrates this dependency for three of the frequency bands available to law enforcement.

TABLE 2.

Factors which affect coverage in communications between base and mobile stations.

- Antenna height and placement (base station and mobile).
- Antenna gain (base station and mobile).
- Frequency.
- Type of topography.
- Transmitter power (base station and mobile).
- Man-made noise and interference at receiving locations.
- Transmission line loss.
- Receiver sensitivity.
- Propagation path loss.

Of all the law enforcement frequency bands, low-band has the greatest range capability. Direct mobile-to-mobile communication has reasonable range at these frequencies. Topographic and building losses are low; multipath interference, the interference between direct and reflected signals from the same nearby source, is rarely noticed. However, co-channel interference will occur occasionally from stations many miles away when atmospheric conditions permit long range propagation (commonly called skip).



Transmission range in high-band is somewhat less than in low-band; therefore, base station antenna height assumes greater importance. Although interference from strong distant signals is less common, co-channel interference from nearby stations can be serious because of the crowded spectrum. Multipath interference caused primarily by signals reflected from buildings becomes more noticeable at the shorter wavelengths of high-band and UHF. The signal strength for mobile receivers may vary from 10 to 20 dB within a few car lengths under multipath interference conditions.

Transmission range at UHF frequencies is somewhat less than for high-band. Antenna positioning becomes extremely important to maximize range and minimize multipath interference. Mobile receivers are subjected to rapid and extreme signal fluctuations when multipath interference occurs. Foliage can also cause appreciable attenuation at these frequencies. On the plus side for this band, penetration into buildings and through underpasses is usually better than for the lower bands.

Further comparisons of the law enforcement frequency bands are made in table 3.

TABLE 3.

Factors affecting coverage as functions of frequency. (Adapted from material originally published in Vol. I, Proceedings of the International Communications Association Telecommunications System Management Seminar, Boulder, CO, June 11-12, 1973.)

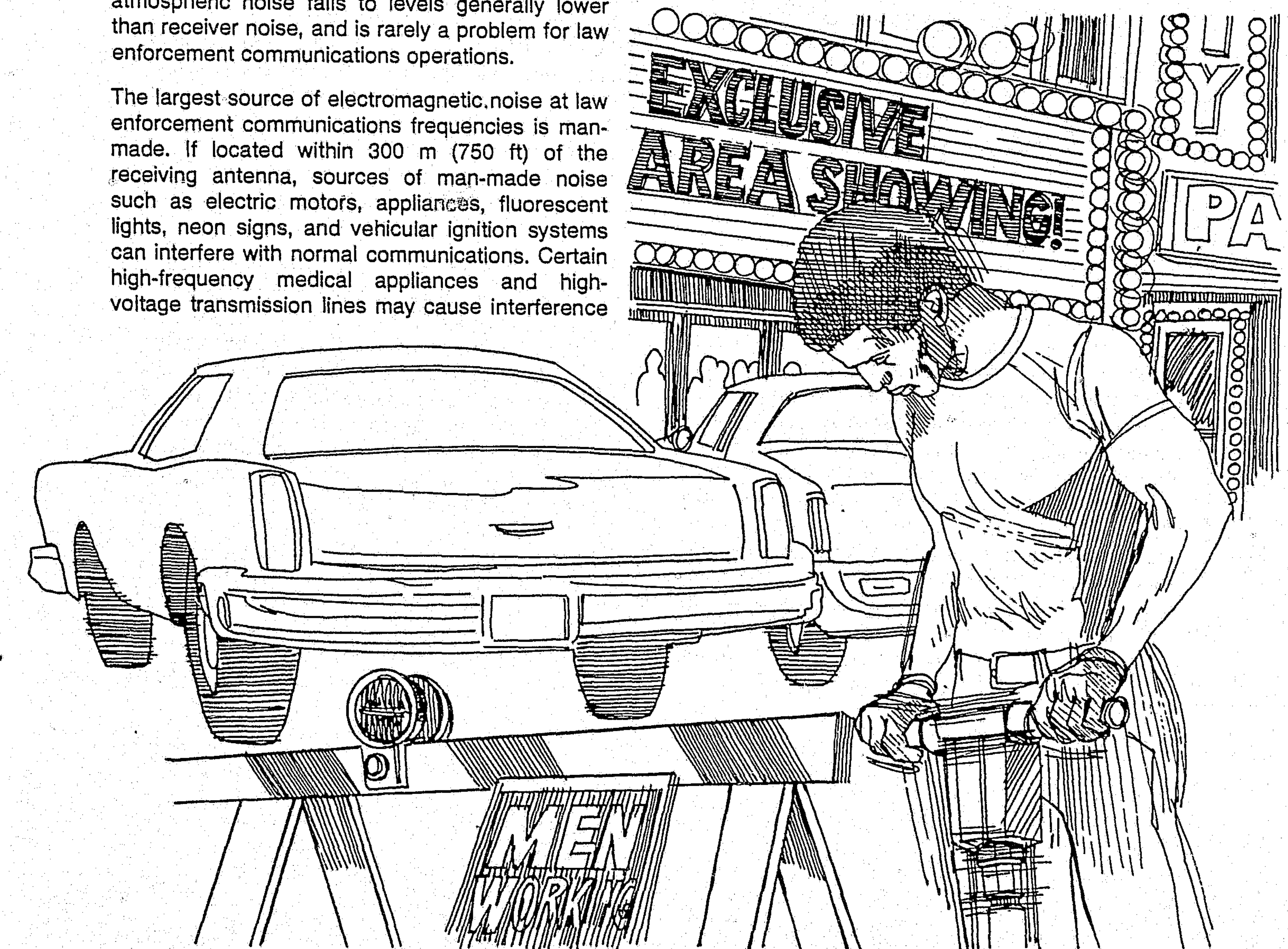
Factor	Low-Band (30–50 MHz)	High-Band (150–174 MHz)	UHF-Band (450–512 MHz)
General use category	Rural (State)	Suburban (County)	Suburban and urban
Comparative range, base-car	56 km (35 mi) Longest range	40 km (25 mi) Good range	37 km (23 mi) Good range
Comparative range car-car	21–48 km (13–30 mi)	8–16 km (5–10 mi) Repeater desirable	6–14 km (4–9 mi) Repeater desirable
Antenna elevation required	Minimum	Medium	Maximum
Terrain & bldg. losses	Lowest	Medium	Highest
Penetration into buildings	Least	Better	Best
Transmission line loss	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

Sources of Electronic Noise

Noise has been defined as any unwanted disturbance superimposed upon a desired signal that tends to obscure its information content. In FM communications, thermal noise generated by the transmitter or receiver is a primary source of interference. Atmospheric noise, produced mostly by lightning discharges in thunderstorms, is the principal deterrent to radio communications at the lower frequencies. However, above about 30 MHz, atmospheric noise falls to levels generally lower than receiver noise, and is rarely a problem for law enforcement communications operations.

The largest source of electromagnetic noise at law enforcement communications frequencies is man-made. If located within 300 m (750 ft) of the receiving antenna, sources of man-made noise such as electric motors, appliances, fluorescent lights, neon signs, and vehicular ignition systems can interfere with normal communications. Certain high-frequency medical appliances and high-voltage transmission lines may cause interference at much greater distances. Automotive ignition noise is usually the major source of receiver interference in urban areas [29].

The average level of man-made noise in urban areas can be higher than in suburban areas by 16 dB or more. In remote rural locations, the level may be 15 dB below that experienced in a typical suburban environment.



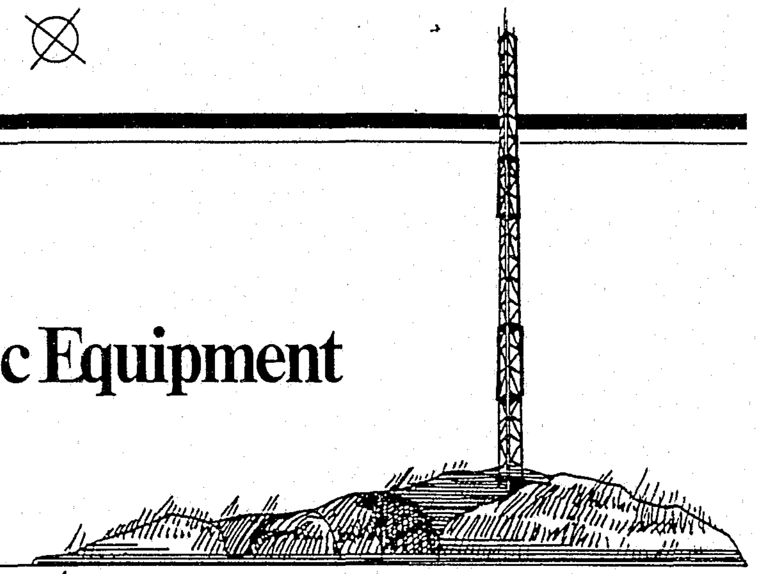
Radio Interference

Two of the problems that confront the two-way radio user can be simply stated as: "Either you don't hear what you want, or you hear what you don't want." Electromagnetic noise, discussed previously, and radio interference are usually the cause.

One type of radio interference is co-channel interference due to the assignment of another transmitter to the same channel. This can usually be prevented by changing frequencies or, if this option is not available, by relocating the base station transmitter(s). The problem can be minimized if proper coverage is designed for all users of a shared channel.

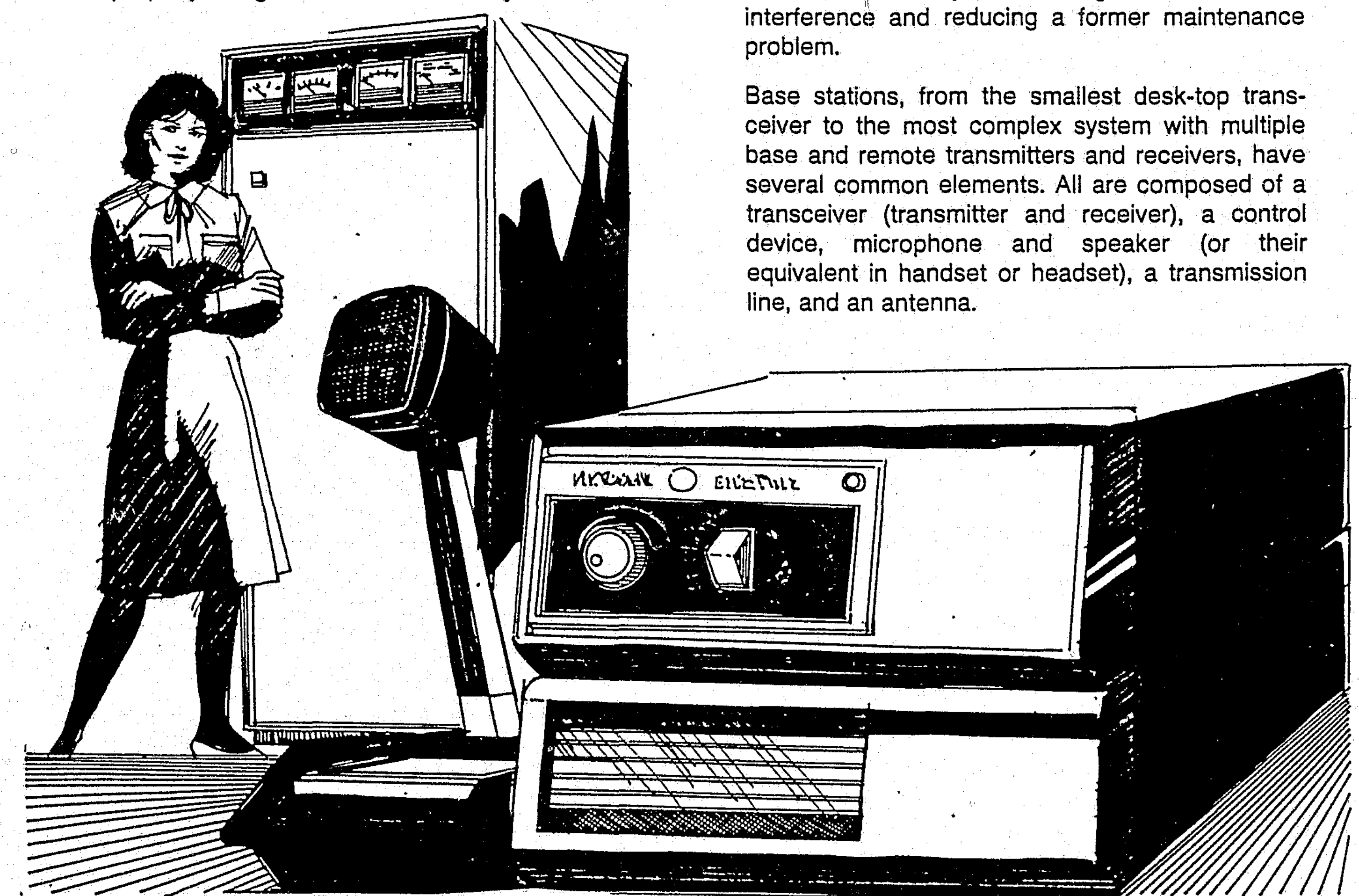
Other types of radio interference can usually be traced to equipment problems. One of these is transmitter spurious emissions in which the equipment transmits on another frequency in addition to its normal frequency, an input frequency of the receiver. Transmitter spurious emissions are not a serious problem beyond a mile or two from the interfering transmitter, since the minimum FCC performance requirement for both conducted and radiated emissions for base station transmitters is $43+10 \log_{10} P$ dB below the level of the transmitter output power, P, in watts.
Another type of interference is receiver spurious response, where a receiver responds to inputs at a frequency other than the frequency to which it is tuned. Again, the offending transmitter will not be a problem unless it is closer than a mile or two to the receiver. Also, a notch filter on the receiver input can be used to reduce most known receiver spurious response. To counter this type of interference, it is recommended that users incorporate the minimum performance requirement for spurious response attenuation (95 dB) and test method from NILECJ-STD-0206.00 [7] in any receiver procurement actions. Adjacent channel interference can also be a serious problem in urban areas, especially in high-band where adjacent channels may be separated by as little as 15 kHz. Use of the adjacent channel selectivity performance requirement (85 dB of attenuation) and test method given in reference [7] should provide substantial assistance in reducing this type of interference.

Intermodulation interference occurs when two or more signals combine in a nonlinear element to produce a frequency to which the receiver is sensitive. These nonlinearities occur most often in transmitter and receiver circuits, but they may also occur due to poor metal-to-metal contact in or near a transmitting antenna. However, if certain frequency combinations are avoided when channels are assigned, most intermodulation problems can be minimized.



Basic Equipment

Base station equipment for two-way FM communications is available in a variety of power ratings, cabinet styles, and methods of control, with various options to fit the user's requirements. The performance characteristics of the transmitter and receiver usually occupy a prominent position in the equipment catalogs of two-way radio manufacturers; however, the performance characteristics of the antenna, transmission line, and other ancillary system components are just as important in a properly designed communication system.



Solid-state circuitry is now used almost universally in transceiver design to increase reliability and reduce maintenance requirements. Transistors reduce failures caused by system-generated heat. They also minimize the gradual performance degradation associated with vacuum-tube systems. Transmitters are predominately solid state, with industrial-rated power tubes used by some manufacturers in the output stages of their units. Solid-state switching devices are now used as base station control relays, eliminating a source of radio interference and reducing a former maintenance problem.

Base stations, from the smallest desk-top transceiver to the most complex system with multiple base and remote transmitters and receivers, have several common elements. All are composed of a transceiver (transmitter and receiver), a control device, microphone and speaker (or their equivalent in handset or headset), a transmission line, and an antenna.

Transceiver control, which must be available to the dispatcher, may be local with the function switches within reach of the dispatcher, i.e., on the front panel of the transceiver cabinet. Extended local control, usually housed in a small console, provides control of the transceiver up to 60 m (200 ft) away, and also permits personnel provided with appropriate equipment the opportunity to communicate directly with the mobile transceivers via the base station transceiver. A remote control console must be provided when the base station is removed from the dispatch center area, usually to take advantage of a better antenna site. Control of the transceiver from the dispatch center is then usually accomplished over leased telephone lines. A radio link for remote control has proved to be economically sound where distance or terrain results in high telephone costs.

Base station equipment need not take up much space for moderate power output. A single desk-top unit may contain a transmitter, receiver, local control, and speaker, all in one cabinet measuring no more than 15×40×40 cm (6×16×16 in). A desk microphone and a coaxial cable connecting the transceiver to an outside antenna can complete a typical 5- to 100-W base station, in its most compact form, at a cost of $500 to $2000.

Base stations designed for larger output power are commonly mounted in cabinets approximately 55 cm (22 in) wide and 75 to 210 cm (30 to 84 in) high, depending on the transceiver requirements. Both indoor cabinets and outdoor, waterproof cabinets designed for pole-mounting, are available. Higher power and other options can bring the cost up to $3000 or more per location.

Antenna site selection and antenna mounting demand careful study. Normally, base station antennas are mounted as high above the ground as practicable to increase transmitting and receiving range. The top of the dispatch center is an economical site if it is high compared with surrounding buildings. The tallest centrally-located office building is a common site. A hill or

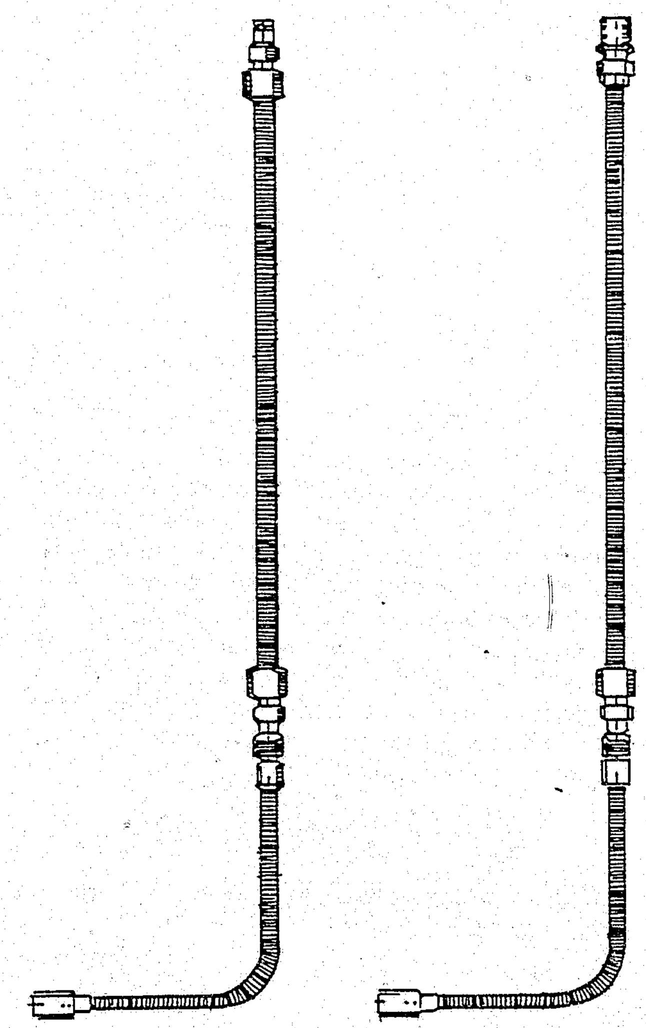


FIGURE 2.

Semirigid coaxial transmission lines for base-station installations are normally supplied with a short length of flexible cable for connecting the transmission line to the receiver.

mountaintop can provide the extra antenna height; however, some antenna pattern modification may be necessary at a remote site. A free-standing or guyed tower may often be the best antenna support available. A leased position on the side of a TV tower may be ideal for height, but the modification of the antenna pattern caused by the steel tower may be less desirable.

To minimize power loss, the radio frequency (rf) coaxial transmission line between the transceiver and the antenna should be as short as possible. A typical coaxial transmission line is shown in figure 2. For instance, the attenuation of RG-8/U, a

popular coaxial cable for base stations, is approximately 2.5 dB in 30 m (100 ft) for VHF high-band (150–174 MHz). Almost half the transmitter power would be lost in a cable of this length. The received signal is attenuated a like amount. Coaxial cables with lower attenuation are available at higher cost.

To shorten the transmission line, the transceiver may be located on the top floor of the building supporting the antenna, on the roof in a waterproof cabinet, or on the tower itself for tower-supported antennas. Maintenance requirements may also influence the final selection of the transceiver location.

DESK-TOP TRANSCEIVERS

Desk-top models are an economical choice as part of a medium-range communication system. They are available in powers of 5 to 100 W in low-band, 5 to 40 W in high-band, and 5 to 20 W at UHF. These moderate power levels allow all solid-state construction, thus eliminating the heat problem posed by tubes previously found in the output stages of higher power transmitters. Mechanical antenna relays have been replaced with solid-state switching devices in most desk-top models for more dependable operation.

Sensitivities of 0.5 μV or less are commonly available in narrow-band FM communications receivers. Of particular benefit to users in areas of low rf noise, preamplifiers can be installed in most receivers extending the sensitivity to 0.2 μV. The typical audio output of 5 W from these units is usually sufficient for clear reception. Models are available with one to four channels. Control of the operation can be local, extended local, or remote. Other popular options include a microphone foot switch for the transmitter, panel-mounted digital clock, panel-mounted VU meter for monitoring the modulation level, tone-coded squelch, and selective signaling.

For a given manufacturer, the transmitter and receiver sections of a desk-top transceiver are often identical to the corresponding sections of the mobile transceiver. This design permits substitution from a spare mobile unit to keep the base station on the air. This feature of interchangeability has been extended one step further by a number of medium-range base station users. A mobile transceiver and control head may serve as a base station with the conversion from a 120-V ac power supply to a 12-V dc power source. A 12-V automobile battery with charging circuitry may be used to provide service during brief power failures. Note, however, that the FCC requirement for transmitter frequency stability within the UHF band is more stringent for base stations than for mobile units. Not all UHF mobile transmitters can meet the base station requirement.

CABINET TRANSCEIVERS

Where greater transmitter power is necessary, cabinet models designed for indoor and outdoor installation are available for either floor or pole mounting. Ratings for rf power range from 100 to 330 W in low-band, 50 to 375 W in high-band, and 12 to 250 W at UHF. Generally, industrially-rated power tubes are used for the final stages in transmitters with power outputs above 100 W, in contrast with the all solid-state circuitry for 100 W and below. Electromechanical antenna switching relays and high-voltage interlock relays are also used in high-power transceivers. The transmitter is often rated for continuous duty rather than the 20 percent duty cycle often associated with desk-top models. Improved rf shielding and filtering is usually present in cabinet models, minimizing the possibility of interference problems.

Receiver sensitivities and selectivities are essentially identical with those of desk-top models; however, the larger cabinets can accommodate two or more receivers when necessary. Space can also be found for additional options such as multiple audio tone-control boards, special noise-limiting circuits, voting comparators for satellite (remotely located) receiver signals, and circuitry for automatically switching to battery operation when primary power fails.

TRANSMISSION LINES

Selection of a satisfactory transceiver-to-antenna transmission line is primarily a compromise between cost and power loss. Several types of coaxial cables are available, including single-shielded cable, double-shielded cable, cable with noncontaminating jackets, and low-loss cable. However, size, weight, and flexibility must also be considered. RG-8/U, a flexible, low-cost, polyethylene-insulated coaxial cable with an outer conductor consisting of a single layer of untinned copper braid, has been installed in many base stations with acceptable results. However, attenuation provided by this cable may be excessive at both high-band and the UHF-band for lengths exceeding a few meters. Regardless of length, the maximum average power handling capability of RG-8/U at an ambient temperature of 40 °C (104 °F) varies from 600 to 800 W in high-band and 300 to 400 W in the UHF-band, depending on the manufacturer. Note that these ratings are considerably greater than the output power of most base station transmitters. In general, the power handling capability of polyethylene-insulated cables must be derated for operation at ambient temperatures above 40 °C (104 °F), by 30 percent at 50 °C (122 °F), for example. A derating factor need only be considered if the rf power output of the transmitter approaches the cable rating.

For temperatures other than 20 °C (68 °F), the attenuation per unit length of coaxial cables as listed by cable manufacturers should also be modified by a correction factor. Elevated temperature increases cable attenuation by increasing the resistivity of the conductors and by increasing the power factor of the dielectric. The attenuation of braided cables can also increase with time. This change can be caused by corrosion of the braided shield, by contamination of the dielectric due to the migration of the plasticizers in certain types of polyvinyl chloride jacket material, and by moisture penetration through the jacket.

Seamless copper or aluminum outer conductors of semirigid cable can often reduce or eliminate the attenuation changes caused by aging. Because of the solid conductive materials and the use of foam dielectric or supporting strips of polyethylene or polytetrafluoroethylene in place of solid polyethylene, the attenuation characteristics of semirigid cable are lower than those of braided cable of the same diameter. Power-handling capabilities are also improved. Outer conductors may be corrugated to increase flexibility. Usually, semirigid cables are jacketed with polyethylene, primarily for protection against galvanic corrosion caused by contact with dissimilar metals. In addition, the jacket increases the crush resistance by distributing stresses over larger areas of the outer conductor, and protects the outer conductor from abrasion at points of contact with tower members and wire ties. Jacketed cables also are more suitable for burial. Semirigid cables are normally supplied with a short length of flexible cable for connecting the transmission line to the transceiver; occasionally a short flexible section is also used at the antenna end. Type N or UHF connectors are used to terminate the transmission line at most base station installations.

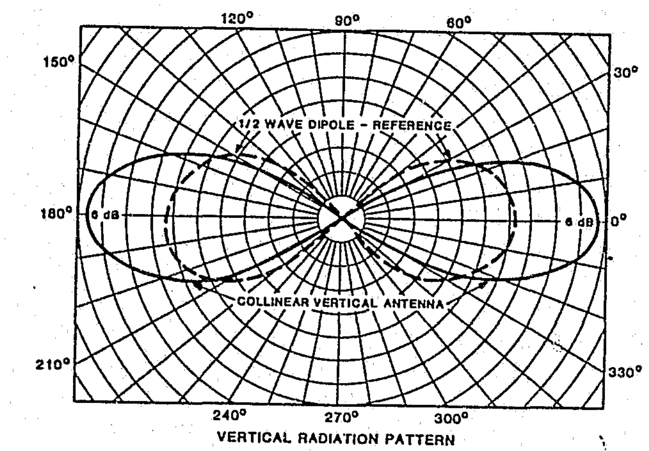
ANTENNAS

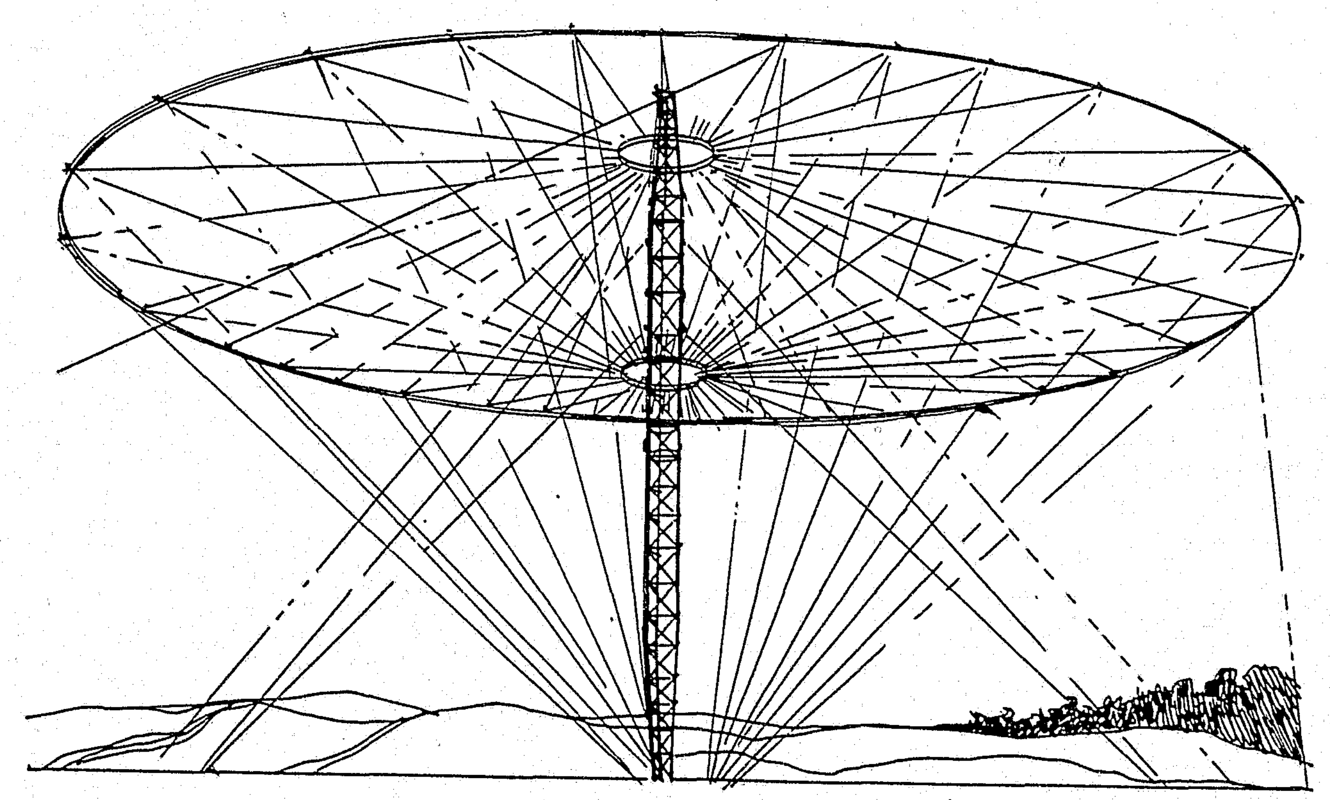
The antenna is a device for coupling transmitter power from the transmission line into space and from space into the transmission line, performing equally well for both purposes. Land-mobile antennas are usually vertically polarized, because of the ease of mounting a vertical antenna on a vehicle. However, point-to-point land-mobile communication systems often use horizontally-polarized antennas.

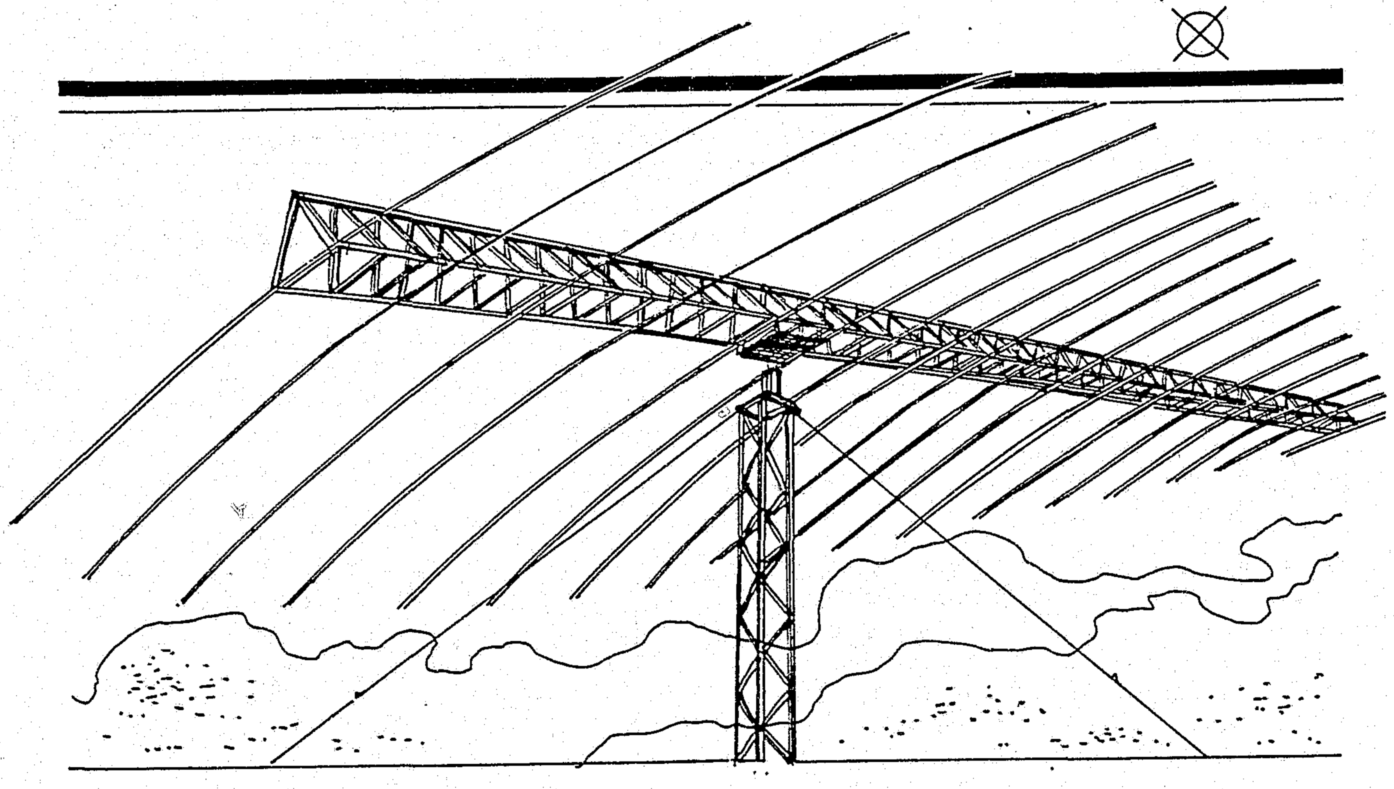
Antenna gain for base station omnidirectional antennas is typically 2 to 5 dB for low-band, 3 to 9 dB for high-band, and 3 to 10 dB for UHF-band. Gain is the measured ratio of the effective radiated power (ERP) from an antenna in the intended direction of propagation to the ERP from a standard reference antenna in that direction. An increase in gain results when power is concentrated in the desired direction and not radiated in unnecessary directions, such as high radiation angles. However, the vertical beamwidth of the antenna radiation must not be made too narrow, since the radiation must illuminate both hilltops and valleys in the service area. The minimum acceptable vertical beamwidth may vary in specific cases, but a minimum of 6 ° between the directions of half power might be typical for flat or gently undulating terrain. A typical vertical radiation pattern is shown in figure 3.

FIGURE 3.

The vertical radiation pattern of a collinear antenna is typical of base-station omnidirectional gain antennas.







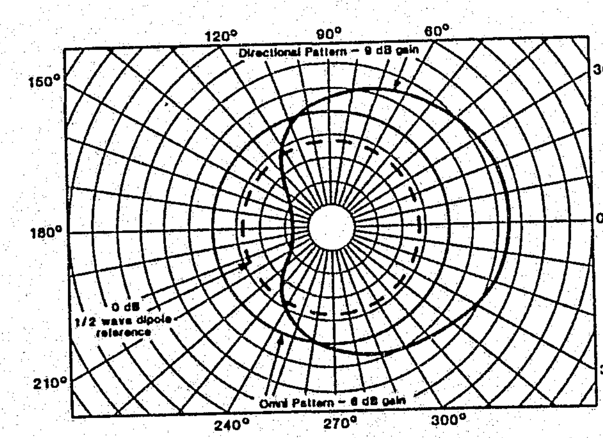
Base station antenna gain is omnidirectional as a rule; modification of this circular pattern can be achieved for many antennas when greater gain in a preferred direction is desired. If a base station antenna is not centrally located in its service area, the use of a directional antenna may be desirable. See figure 4. Additionally, a specific antenna pattern may be designed to minimize the gain in the direction of high ambient rf noise levels to provide improved receiver signal-to-noise ratio. For fixed station operation (transmitting and receiving in a specific direction only), corner-reflector and yagi antennas can provide even higher front-to-back ratios, 15 to 20 dB for high-band, and 15 to 30 dB for UHF, with forward gains of 8 to 10 dB, typically.

To maintain an omnidirectional pattern, an antenna must be positioned free of metallic obstructions. Usually it is mounted on the top of a mast. Side-mounting on a metallic tower produces a directional pattern that varies in shape depending on the space between the radiating elements of the antenna and the tower structure and on the location of tower guy wires, if any. Mounting hardware is commonly constructed of hot-dipped galvanized or stainless steel. Side mounting may also require insulated support arms.

When specifying base station antennas, gain and directivity are not the only electrical performance characteristics that should be considered. A typical antenna power rating is 100 to 500 W. It should

FIGURE 4.

Typical omnidirectional and cardioid horizontal radiation patterns that are possible in high-band by changing the orientation of the dipole elements of a four-dipole base station antenna.



equal or exceed the maximum intended rf output power of the transmitter. For efficient power transfer to and from modern transceivers, the standing wave ratio (SWR) of a base station antenna is typically less than 1.5, referenced to 50 Ω, within its design bandwidth. Certain antennas require field tuning for minimum SWR, a minor consideration. Because the bandwidths of base station antennas vary between 0.5 and 20 MHz or more depending on the design, transmitter and receiver frequencies may need to be stated as part of the antenna specifications.

Mechanical performance characteristics are also important. The design of an antenna affects its wind velocity rating, aptly called wind survival rating by some manufacturers. A rating of 160 to 200 km/h (100 to 125 mph) is typical for high-band base station antennas, and 112 to 160 km/h (70 to 100 mph) in low-band, both often derated for ice loading. Local meteorological stations should have a record of the maximum expected wind velocities for their areas. Lateral thrust or wind load at maximum rated wind velocity, a specification supplied by most manufacturers, helps define the requirements for mast or tower installations. See NIJ Standard-0204.01 [8] for assistance in determining the appropriate wind velocity rating for your area.

Some antenna designs offer better lightning protection than others, provided that the mast or tower is properly grounded. The radiating elements of many antennas are designed to operate at dc ground potential; others require a built-in spark gap between the radiator and dc ground. A top cap on the support mast for pole-mounted antennas can provide additional protection. Grounding of the outer conductor of the coaxial cable at the base of the tower and at the entrance to the station is recommended.

Two methods for connecting the antenna to the transmission lines are common in base station antenna design. Either the antenna is terminated in an rf coaxial connector, rigidly fixed in position, or the antenna is furnished with a short length of flexible coaxial cable terminated in a cable connector. The fixed connector method often employs a UHF-type connector, SO-239, to accept a UHF-type connector, PL-259. The flexible cable method uses a Type N or UHF male connector as a termination. Coaxial connectors may be provided with a waterproof housing, a worthwhile consideration. With proper assembly, the electrical performance of a Type N connector pair exceeds that of a UHF pair throughout the frequency range of law enforcement communication systems, especially above 300 MHz. With either type connector, a wrapping of waterproof electrical tape will help prevent moisture penetration.

Auxiliary Equipment

Most base stations can benefit from one or more auxiliary subsystems. Some form of emergency power to supply essential equipment during power failures is a necessity. Repeaters and satellite receivers may be needed to improve the coverage in those sections of a service area shadowed from the base station signal by intervening hills and buildings. Scanning receivers can simplify the monitoring of multi-channel systems by key personnel. Tone-coding will reduce the fatigue of listening to co-channel interference common in congested areas. Voice privacy equipment will reduce the problems caused by public monitoring of law enforcement channels. Digital systems, by providing such services for patrol officers as ready access to computer data files, can help increase the efficiency of a law enforcement agency.

EMERGENCY POWER SYSTEMS

Since radio communications are essential to law enforcement, some form of emergency power should be included for the base station. Emergency power is an independent reserve source of stored electrical energy which, upon failure of the prime power source, automatically provides reliable electric power to designated critical equipment. Transfer can be either automatic or manual.

The minimum emergency power system is probably a battery on trickle charge with enough reserve power to operate a receiver and a backup transmitter at reduced power. Because of the uncertainty of the duration of prime-power interruption, battery-provided emergency power may be insufficient for all but the smallest of base stations. Jurisdictions with larger facilities or those which want to provide acceptable quality power at all times, commonly employ engine-driven generators.

These generators are available with powers from one up to several thousand kilovolt-amperes (kVA). When properly maintained and kept warm, they dependably come on-line within 8 to 15 s.

Gasoline-engine generators are satisfactory for installations up to about 100-kVA output. They start rapidly and are low in initial cost. Their disadvantages include higher operating cost, greater fuel storage hazard, and a lower mean time between overhauls than diesel-engine generators.

A typical diesel-engine generator is rated at 500 kVA, although sizes vary from 2.5 to above 4000 kVA. Installed operating units will cost between $100 and $170 per kVA. Diesel engines are somewhat more costly and heavier than gasoline engines, but are both rugged and dependable. Diesel fuel cost is comparable to that of gasoline, and diesel fuel is less hazardous to store.

Natural gas and LP gas-engine generators are similar to gasoline-engine generators in cost. They are quick starting, and maintenance is reduced because of the clean burning fuel. However, consideration should be given to the possibility of losing both electricity and natural gas supplies at the same time.

A conservative schedule calls for weekly operation of the engine generator system to maintain reliability; preferably, the system should be run under load. To keep an engine in good condition, it should run sufficiently long each time it is started so that all parts reach their normal operating temperature. Thus, when emergency power is called for only briefly, it is desirable that the engine continue to run for a minimum of 15 min.

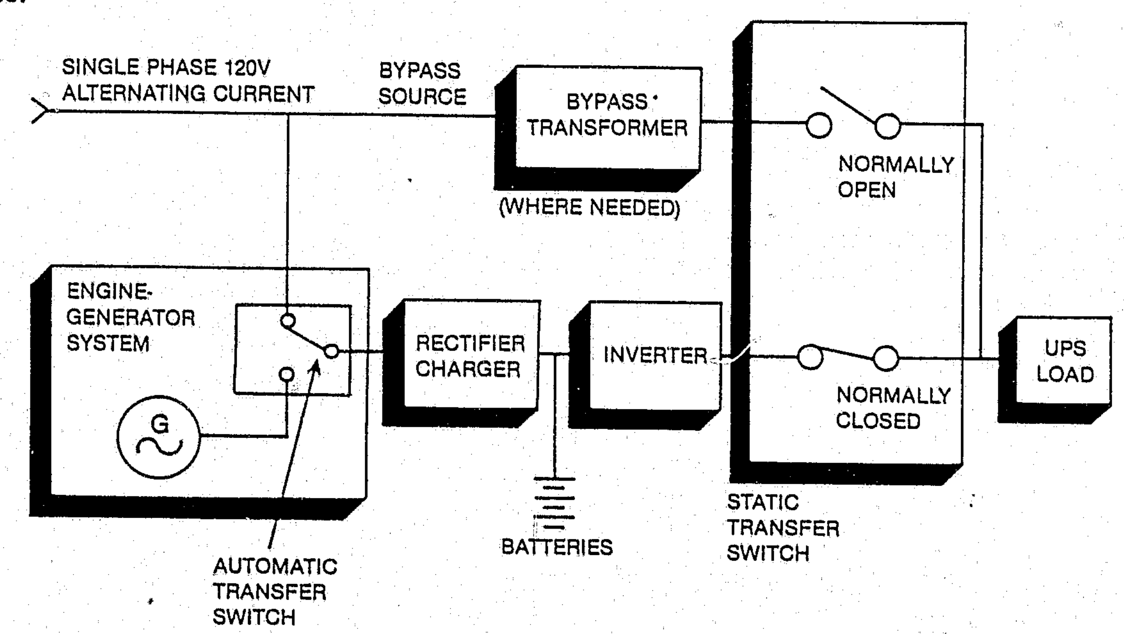
Since brief interruptions in power are usually not harmful to communications equipment, less elaborate, less expensive standby power systems are adequate for many law enforcement systems. The maximum allowable power interruption is about 10 s for communications equipment, but preferably not more than 3 s for emergency lighting circuits. However, if the base station complex includes computer systems, then emergency power may be required within milliseconds to prevent data loss. Computers are available with features that protect against such loss and which restart automatically when power returns. Better regulated, more expensive standby equipment is then unnecessary. For most communications equipment, 80 to 90 percent voltage dip protection is adequate; i.e., transfer to emergency power when the line voltage drops to 80 percent of normal and retransfer when it returns to 90 percent.

A prime power source, an engine-generator source, and a battery source may be combined to provide an uninterruptible power supply as in figure 5. During an interruption of normal utility power, a time delay prevents the engine from starting immediately. After a preset time, the engine starts automatically and, when the voltage stabilizes, the automatic transfer switch connects the generator to the uninterruptible load. This load is normally served by an inverter which is supplied by the prime source, the batteries, or the engine-driven generator; but, if any of the power supply equipment should fail, the load is readily transferred to the bypass source while repairs are being made.

Inverters require a minimum direct-current voltage to function properly, usually 75 to 80 percent of the nominal rated voltage. A typical inverter operates at 105 to 140 V dc input with a 120 V ac output. Therefore, uninterruptible power supplies should have a low dc voltage alarm.

FIGURE 5.

Block diagram of a typical uninterruptible power supply combining prime power source, engine-generator source, and bypass source.



Nearly all storage batteries used in emergency power supplies are either lead-acid or nickel-cadmium. Nickel-cadmium batteries have a longer life and are not usually damaged by deep discharge, but they are much more expensive than lead-acid batteries for the same W-h capacity, and it is very hard to determine their state of charge.

In addition to the minimum lighting circuits required for base station operation for which emergency or standby power will be supplied, battery-supplied emergency lighting should be installed in critical areas. The compartment that houses the standby power system is one such area. Repairs may have to be made under emergency conditions.

These emergency lighting units commonly contain a battery and a small charger to maintain a charge on the battery. In the event of power failure, the lamps switch on automatically. When external power is restored, the lamps switch off, and the batteries are automatically recharged. In extreme emergencies, an alternate source of power for battery-supplied emergency lighting can be the battery used to start the engine for an engine-generator system.

REPEATERS

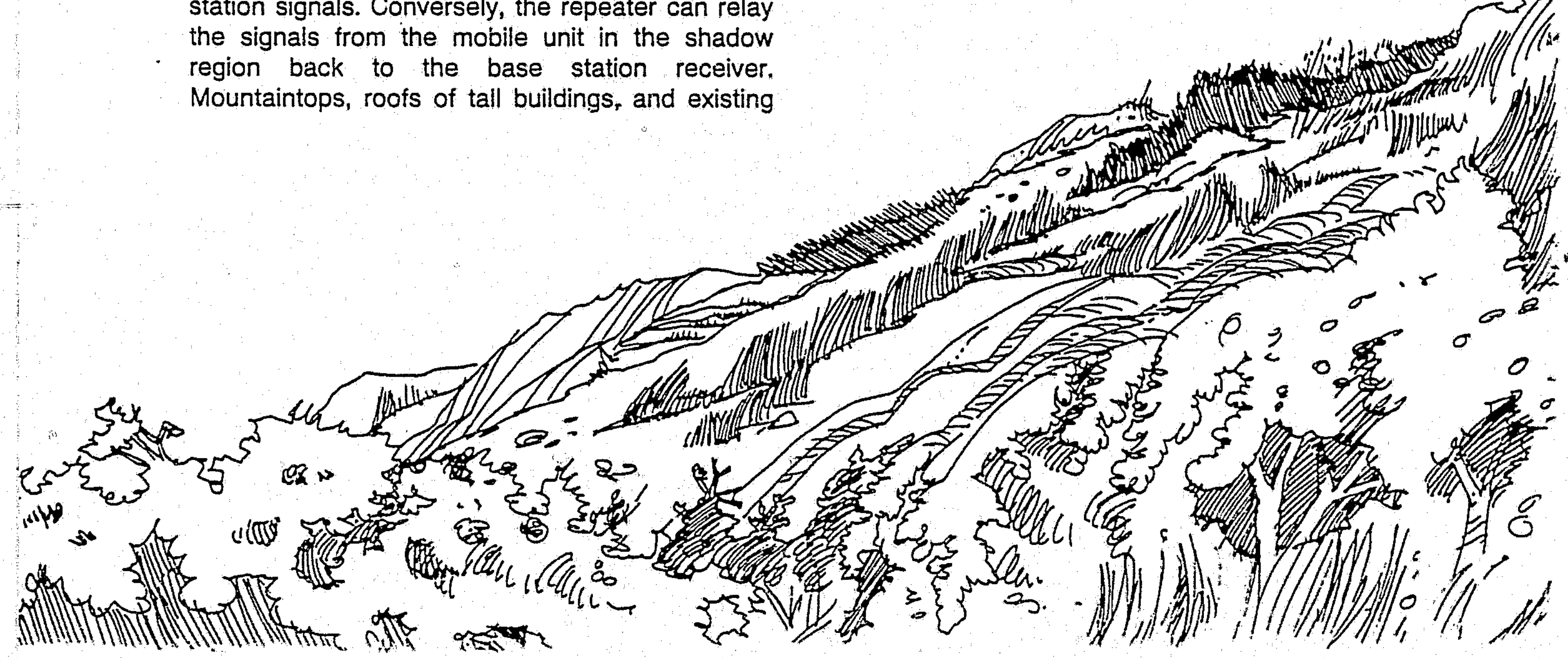
Even with a good base station antenna site, it is possible that a hill, a large building, or other obstruction can cause a shadow region where the signals received by a mobile transceiver are extremely weak. In such cases, rather than attempting to improve the signal strength by increasing the power radiated by the base station, a repeater station may be positioned outside the shadow region and used to retransmit the base station signals. Conversely, the repeater can relay the signals from the mobile unit in the shadow region back to the base station receiver. Mountaintops, roofs of tall buildings, and existing commercial broadcast towers provide excellent sites for repeaters when available. Otherwise, a special tower installation is necessary.

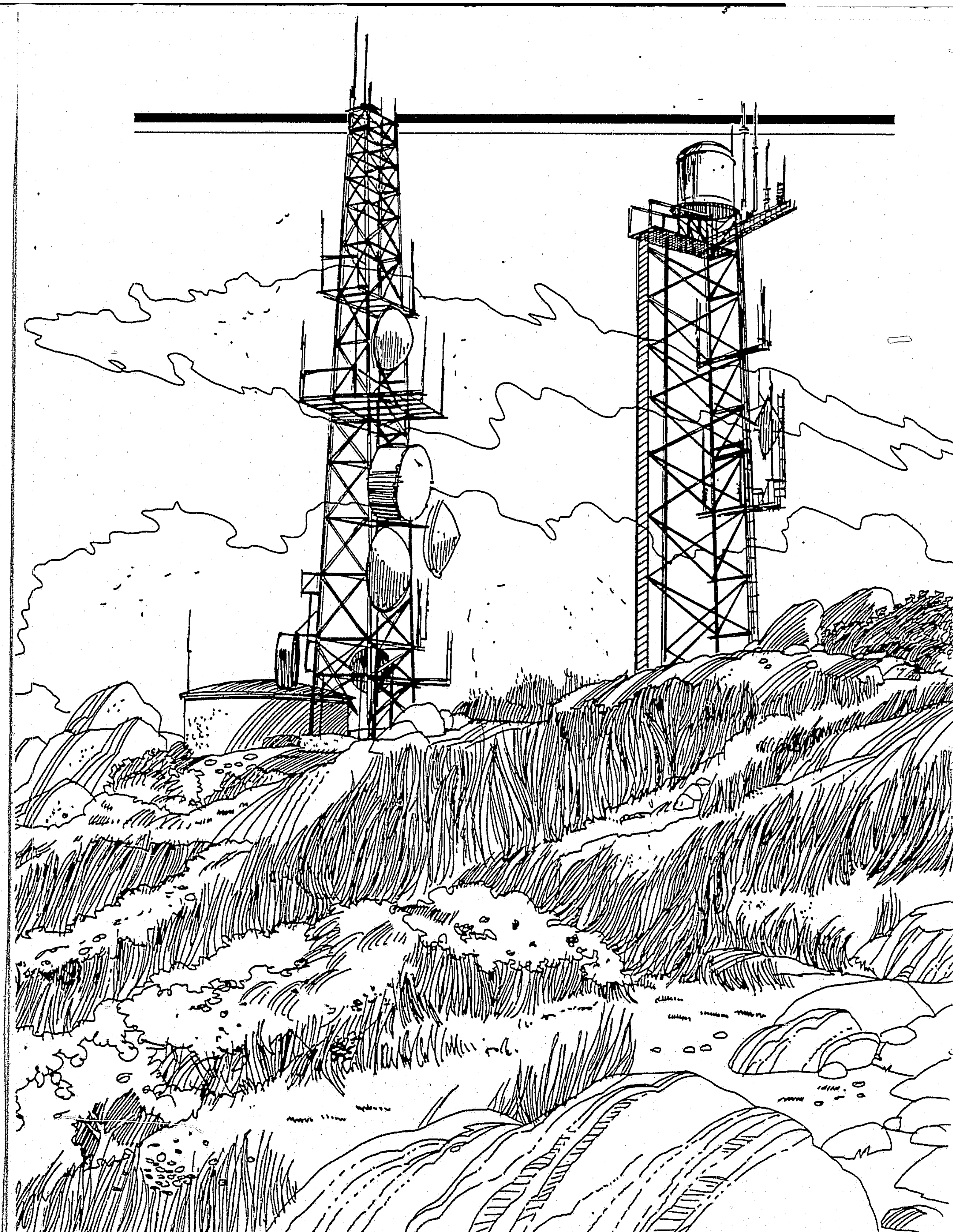
In its simplest form, a repeater consists of a receiver on one frequency with its audio output connected to the audio input of a transmitter usually operating on a second frequency. For most law enforcement systems, the first frequency differs from the second by an amount ranging from a few hundred kilohertz to a few megahertz. In an extremely small number of cases, the second frequency is the same as the first. An operational system requires additional control features which include carrier delays, failure-mode protection, and positive repeater control. Because of the close frequency spacing between received and transmitted signals, specialized antenna transmission-line components such as duplexers and notch filters are required.

The cost of a repeater is approximately the same as that of a base station transceiver of the same rf output power. In addition, users must consider the additional cost of the extra control features and the receiver-transmitter interface hardware. See LESP-RPT-0206.00 [6] and NILECJ-STD-0213.00 [9] for more information on the selection and use of repeaters.

SATELLITE RECEIVERS

Both repeater receivers and base station receivers can often be out of the useful range of the relatively weak transmitted signal from a personal transceiver. This is especially true when a field officer must transmit from an urban environment





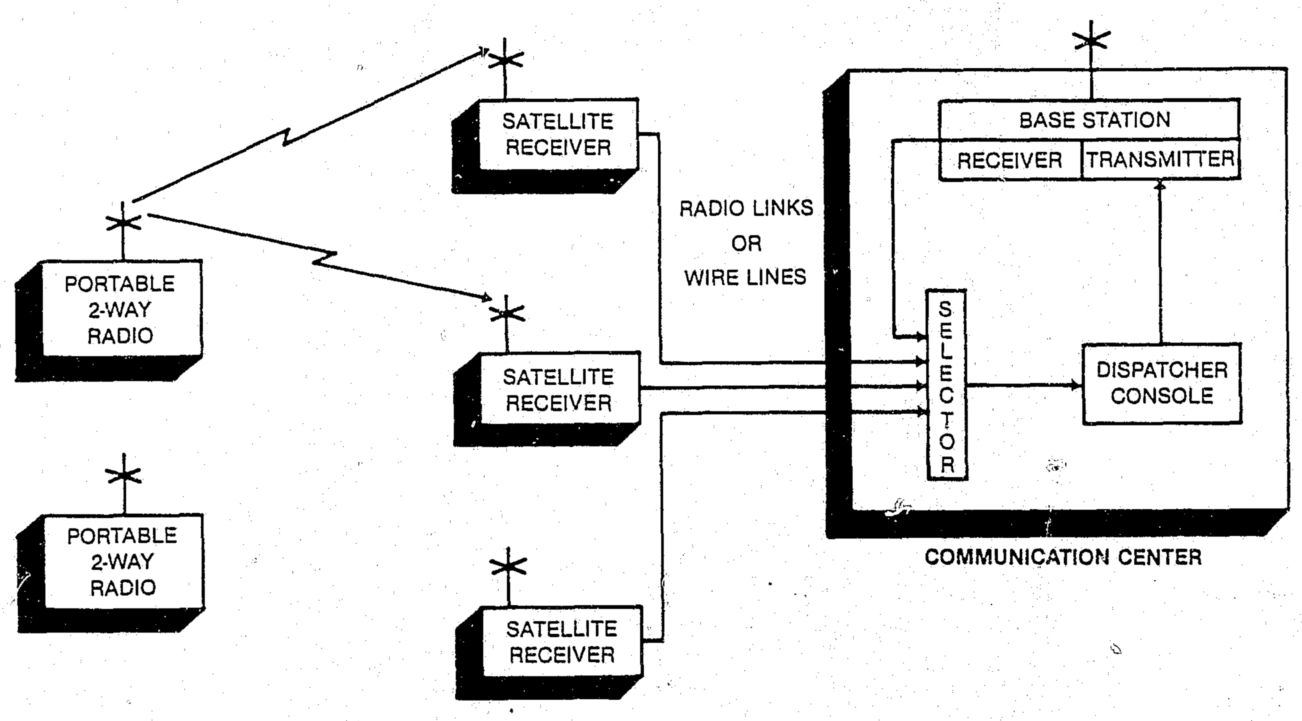


FIGURE 6.

In a satellite receiver voting system, the selector at the communication center will compare the signals relayed from the satellite receivers and select the signal with the highest quality.

such as a building or narrow alley. An arrangement of several remotely located (satellite) receivers for each channel, placed at selected locations throughout the service area, can help compensate for the weak transmitted signal by being closer to the personal transceiver. See figure 6. One or more of the satellite receivers may receive signals from a transmitter at any location in the service area. The signals are relayed to a repeater site or a base station by telephone lines or radio links, where a comparator selects the signal with the highest quality using a voting process. Voting may take place at the beginning of the transmission, periodically, or continually, depending on the comparator design. Three selection techniques used are audio quality selection, rf signal level selection, and quieting level selection [6].

SCANNING RECEIVERS

Scanning receivers that monitor from 8 to 50 channels automatically are available (see fig. 7) for low-band, high-band, and the UHF-band. Scanning rates of 10 to 20 channels per second are typical, and most models also permit manual scanning. Some models allow scanning in any combination in more than one band. Front panel switches are usually provided to allow the operator to bypass individual channels in the scanning sequence. By this means, one can hear the two sides of a two-way communication when the stations are on different frequencies.

Some models, with a multichannel capacity, feature priority scanning, a useful option if one particular channel should be given precedence over others. Channel 1 is usually designated as the priority channel. If a signal appears on channel 1, the scanning receiver will automatically switch to that channel even if it is currently monitoring a … another channel. Scanning is then resumed when the signal on channel …

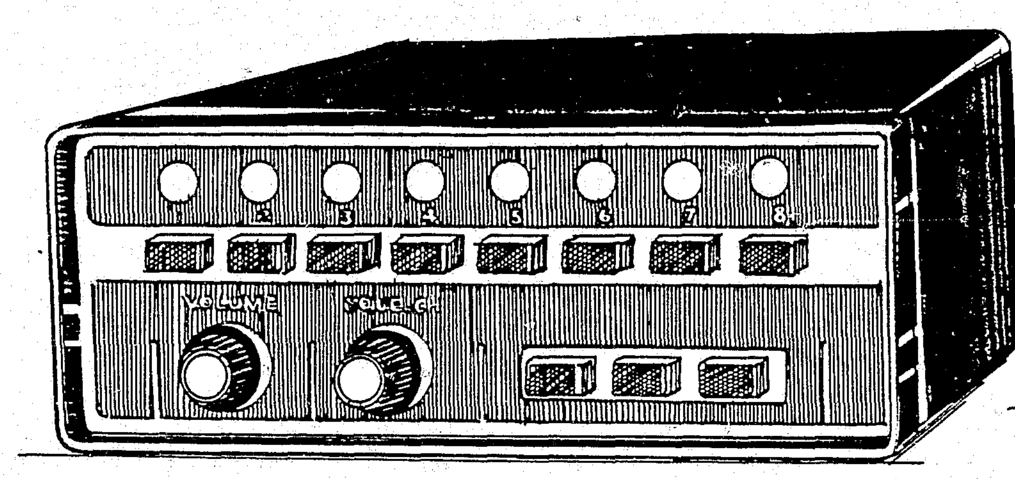


FIGURE 7.

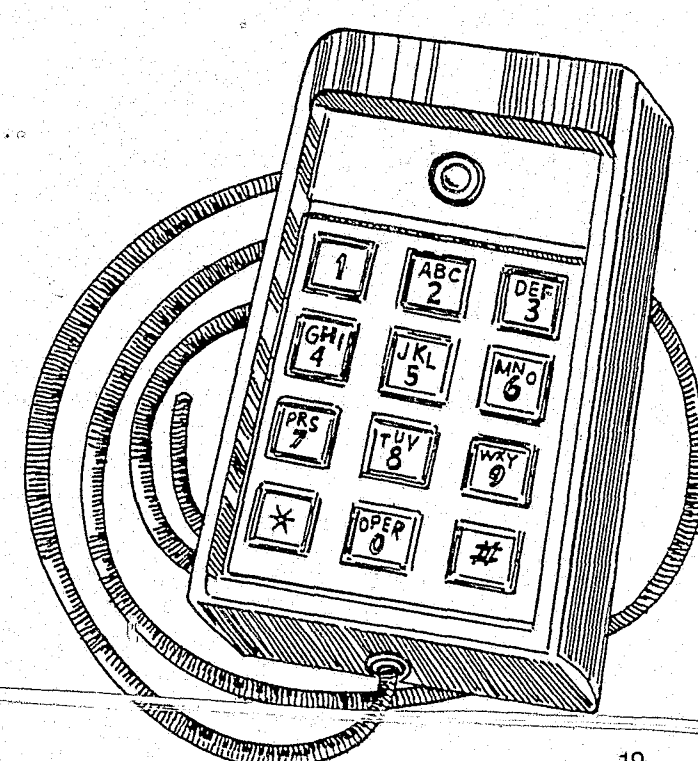
An eight-channel scanning receiver featuring a priority channel.

Until recently, the majority of scanning receivers were crystal-controlled, employing the common 10.7-MHz intermediate frequency for which standard receiver crystals are used. A recent innovation is digital frequency synthesis. By eliminating standard receiver crystals and using one frequency-synthesized scanning receiver, the user can digitally program up to 16 channels from the 6000 frequencies covering five public service bands for under $350. Also offered are 50-channel scanning receivers for under $600. All programmed frequencies are retained permanently unless reprogrammed. No external battery or other power source is needed to prevent loss of memory.

While scanning receivers are usually as sensitive as their equivalent in fixed frequency receivers, scanning receivers have less rejection of spurious responses and tend to be 30 to 50 dB less selective for adjacent channel rejection, a possible problem in areas of high channel density. Carrier squelch is a standard feature, although some two- to four-channel models are on the market with tone-coded squelch. Audio outputs are typically 2 to 5 W. All have internal speakers, and many have external speaker terminals also. Most scanning receivers are designed for both 13.8 V dc and 117 V ac operation; some are battery operated with built-in charging circuits. Most receivers are provided with both a telescopic antenna and a coaxial-connector jack on the rear panel to which a mobile or base station antenna may be connected for improved reception.

TONE-CODING SYSTEMS

The addition of audible or subaudible tones to a two-way radio system equipped with tone encoders and decoders allows a number of functions to be performed which are unobtainable with voice alone. In present equipment, both encoders (the tone generators) and decoders (the frequency-operated switches) are reliable solid state devices. Most forms of tone-coding can be applied to any unit of the system. Tone-coded squelch, selective signaling and recall, automatic mobile identification, remote transmitter keying, and remote control of repeaters are examples of the application of tone-coding.



Tone-coded squelch has one well known advantage: it eliminates the fatigue of listening to unwanted signals on a monitored channel. An undesired signal, although too weak to override a desired signal, may still be sufficiently strong to open the receiver squelch circuit in the absence of a desired signal if the receiver is not equipped with coded squelch. Others on your channel not equipped with coded squelch can hear your signal, but you will not hear theirs.

Both audible and subaudible tones can be employed in coded-squelch systems. Continuous tone-coded squelch systems (CTCSS) are most often used for unmuting receivers and keying repeaters using subaudible tones in the range of 20 to 300 Hz. Industry has standardized on 27 subaudible tones ranging from 67.0 to 203.5 Hz. Commercial equipment using 42 other frequencies in the range from 100 to 251.9 Hz are available also. These tones are called "subaudible" only because the audio characteristics of the receivers used in two-way communication systems are designed to filter out audio frequencies below 300 Hz. In fact, those tones near the upper end of the group (approaching 300 Hz) may be noticeable in the speaker output. Additional filtering in the audio stages of the receiver will minimize this problem without disturbing the voice intelligibility. Selection of the tones must be coordinated with others who also use coded squelch and share your channel. A performance standard for assistance in procuring these systems is available [10].

Continuous subaudible tones are recommended for remote keying applications where fading is likely, since under such conditions a continuous tone will automatically reinstate keying after fading is past.

On the other hand, audible tone bursts are often recommended for paging applications and for remote keying where fading is rare. Encoders and decoders for audible frequencies are less expensive and easier to install than those for subaudible frequencies. The FCC prohibits continuous tones in the audible range on voice radio transmissions; however, they do allow audible tone bursts.

In two-way radio applications, there are at least six different signaling systems that might be called typical. Each is designed for a different communication density level as well as system cost.

1) Dispatcher alert: The dispatcher mutes his receiver with a switch. A call switch in each mobile unit will turn on a light and sound an audible alarm in the dispatcher's console to have the dispatcher take a call.

2) One-way protection: While all mobile units may receive all calls on the channel, including co-channel users, the dispatcher does not. Only calls with the assigned CTCSS tone are received by the dispatcher.

3) Two-way protection: Both dispatcher and mobile units receive only those calls with their own CTCSS tone; all others on the channel are silenced.

4) Three-way protection: This system is essentially like two-way protection with the added feature that dispatcher and mobile operators hear all page calls, but need not hear the actual message unless they choose to do so. Tone burst techniques are used. When the dispatcher or mobile operator closes a switch, a tone burst will key a repeater and open all receivers for a 6-s page call and then automatically close. The person paged switches to monitor position to override muting and to take the call.

5) Individual unit or group select: All receivers in the user's system are muted. A tone signal will unmute a receiver, activate an indicator light, or sound an audible alarm to alert the dispatcher, a single mobile unit, or a group of particular units to take a call.

6) Digital select and identification: All receivers in the user's system are muted. A digitally coded pulse will not only select the called party, but identify the calling unit on a numerical display. A logging system may be included.

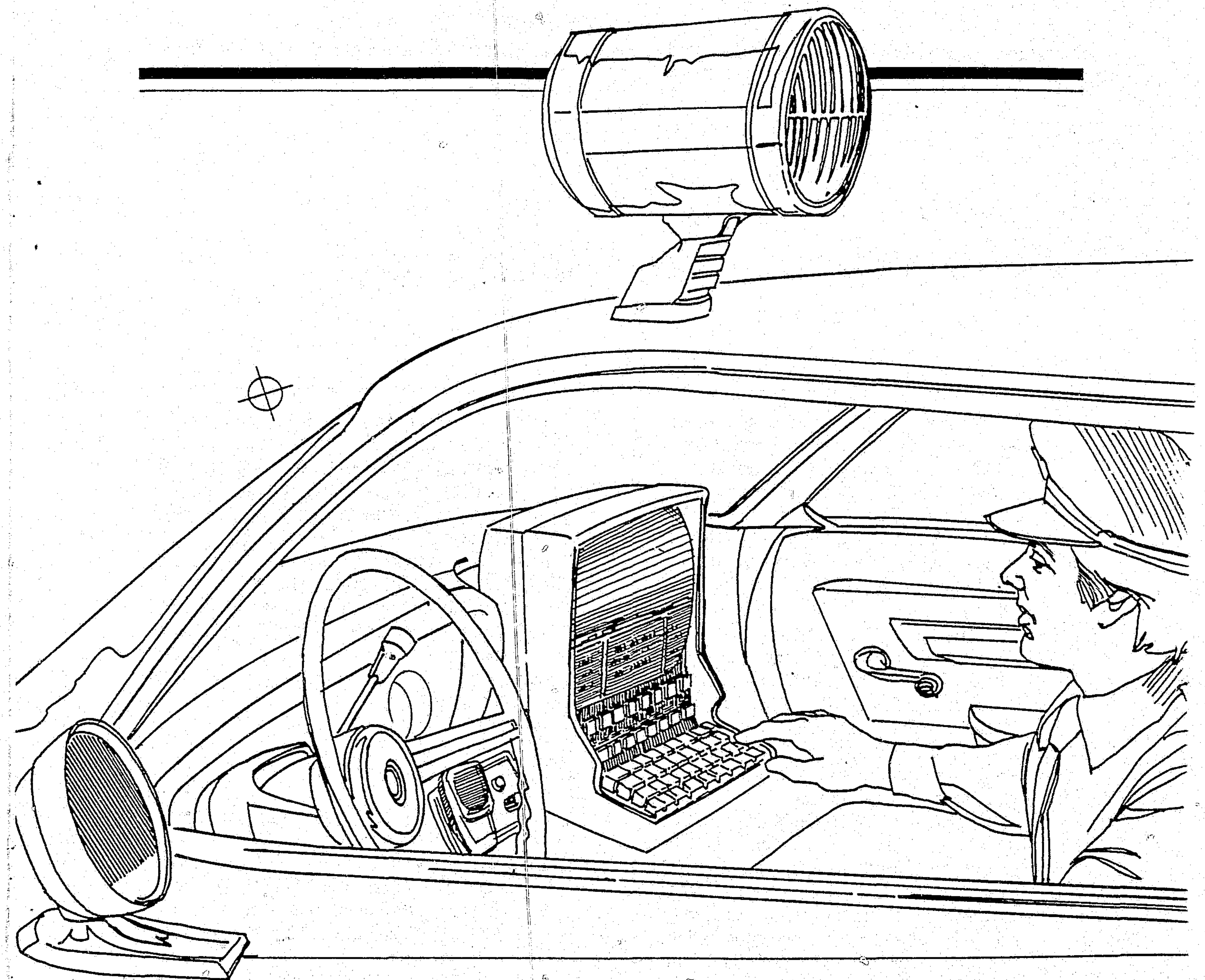
Other variations and combinations of coded squelch are available; however, one limitation should be mentioned. Only one subaudible tone may be used in conjunction with audible tones as well as voice. Two simultaneous subaudible tones, because of the deviation limit, tend to saturate the modulator of a narrow-band FM transmitter.

A distinct disadvantage comes with the use of coded squelch. If the strength of an undesired signal on a shared channel exceeds the strength of the desired tone-coded signal, the undesired signal may block the receiver so that it cannot respond. This process is commonly called "capture." Without tone-coding the operator of the receiver would hear the undesired signal, but the operator would then know that desired messages might not be heard. With coded squelch the channel would be silent, and the operator would have no way of knowing that a desired message was missed.

Another slight disadvantage to operating with coded squelch on shared channels is the requirement to monitor the channel prior to transmitting on it. This monitoring may consist of viewing the state of the channel (busy lamp) or listening to the channel prior to transmitting. Tone-coding does not remove any messages from the channel; it just reduces the fatigue of listening to them. Without tone-coded squelch, channel monitoring is automatic, provided the volume is turned up.

Selective signaling and recall employ audible tones to alert one or more receivers at a time from the base station rather than all simultaneously. The base station is equipped with a tone-encoder console capable of generating a number of different code combinations. The desired code is selected by one or more switches. Particular receivers are provided with decoders corresponding to the selectable codes. The recall feature alerts an officer to a message for him when he is away from the vehicle. A properly coded signal will activate a call indicator light, the horn, headlights, or the dome light to inform the officer that the base station called.

Automatic mobile identification is an application of tone-coding which identifies each mobile unit



DIGITAL EQUIPMENT

In law enforcement communications, digital equipment in the form of mobile teleprinters and mobile and base station video displays are used to complement voice communications. Teleprinters are most helpful in conveying lengthy, descriptive messages to patrol vehicles. They reduce the errors in writing out long messages and they can be equipped to record messages unattended. Because signals are transmitted in digital form, security is greater than for voice transmissions. Teleprinters as well as video displays are well suited for the direct reception of information from computers and electronic data-processing equipment, a timesaver for both dispatcher and patrol officer. Since digital signals are similar to tone-coded signals, the advantages of tone-coded squelch and selective signaling can be used in digital systems. Some disadvantages exist in the use of digital equipment. Costs are considered high. When they are used on voice channels, digital transmissions produce an irritating noise. Some types of messages may require considerable time at a teleprinter or video keyboard. Additional material on digital communications for law enforcement use is available [12–15].

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