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Security Communication Systems for Nuclear Fixed Site Facilities

Prepared by L. C. Howington, L. L. Taylor

Union Carbide Corporation
Oak Ridge Y-12 Plant

Bernard Johnson, Incorporated

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ABSTRACT

This report presents a basic discussion of communication techniques and factors relevant to designing communication systems for nuclear fixed site facility security systems.

The reader is provided communication fundamentals, design considerations, and specification techniques. Copious references and an annotated bibliography are provided for individuals who desire to delve deeper than the limits and areas of study of this report.

Ease of reading and use of this report are enhanced by relegating detailed communication design treatise to the Appendices. Sample procurement specifications are provided throughout the report for various communication system components and are distinguished from the regular text by using a smaller type.

CONTENTS

	Page
ABSTRACT	iii
CONTENTS	v
LIST OF FIGURES	ix
PREFACE	xi
1. INTRODUCTION	1
1.1 Objective	1
1.2 Uses	1
1.3 General Description	4
2. THE COMMUNICATIONS SYSTEM: REQUIREMENTS, CONSTRAINTS, AND LIMITATIONS	9
2.1 Requirements of the Code of Federal Regulations	9
2.2 FCC Rules and Regulations	10
2.3 Nuclear Facility Communications	12
2.4 System Types	17
2.5 Equipment Considerations	17
2.6 Security	20
2.7 Message Confirmation	22
3. WIRELINE COMMUNICATIONS	24
3.1 Wireline Voice Systems	24
3.2 Wireline Data Systems	28
3.3 Obtaining Service from Franchised Company	29
3.4 Obtaining Service from Private Company	29
4. RADIO COMMUNICATIONS	33
4.1 Radio Voice Systems	33
4.1.1 Mobile radio systems and equipment	33
4.1.2 Paging systems	38
4.1.3 Point-to-point radio systems and equipment	40
4.1.4 Changing technology	46
4.2 Radio Data Systems	52
4.3 Radio System Types	55
4.4 Radio System Components	59
4.4.1 Repeaters	67
4.4.2 Base stations	74
4.4.3 Control stations	80
4.4.4 Mobile transceivers	84
4.4.5 Portable transceivers	91
4.4.6 Paging receivers	94
4.4.7 Antenna towers	96
4.4.8 Lightning protection	100

4.5 Radio System Accessories 104
4.5.1 Emergency power 105
4.5.2 Status signaling 105
4.5.3 Digital messages 106
4.5.4 Remote control 106
4.5.5 Microphones, speakers, and other items 106

5. HYBRID AND COMBINATION SYSTEMS 108

5.1 Hybrid Systems 108
5.1.1 Point-to-point communications by means of control stations 108
5.1.2 Interconnection 108
5.2 Combination Systems 108

6. COMMAND AND CONTROL CENTERS 110

6.1 Command and Control Center Designs 110
6.1.1 General specifications 111
6.1.2 Mechanical characteristics 112
6.1.3 Electrical characteristics 112
6.2 Methods of Improving Reliability 114

7. SYSTEM APPROACH 116

7.1 System Procurement and Implementation 116
7.1.1 Sole source procurement 116
7.1.2 Design and implementation contractor selected through bidding 116
7.1.3 Owner design and build 117
7.1.4 Owner design and contractor build 117
7.1.5 Consultant design and contractor implementation 117
7.2 Legal 118
7.3 Technological 118
7.4 Economics 118
7.5 Natural 119
7.6 System Implementation 119
7.7 System Support 119
7.7.1 Personnel training 120
7.7.2 Operating and expendable spares 121
7.7.3 Maintenance spares 121
7.7.4 System documentation 123
7.7.5 System updating and replacement 124
7.7.6 System retirement and replacement 124

8. REFERENCES 125

9. GLOSSARY 130

10. BIBLIOGRAPHY 143

APPENDIX I	Propagation Path Considerations	150
APPENDIX II	Interference	163
APPENDIX III	System Engineering	168
APPENDIX IV	Total System Life Cost	170
APPENDIX V	Future Systems	175
APPENDIX VI	Applicable Electronic Industires Association Specifications	177
APPENDIX VII	Applicable NILECJ Standards	179

LIST OF FIGURES

Figure		Page
1.	A communication system transfers information between two (or more) people	2
2.	Communication subsystem	4
3.	Radio communication with one paging channel and two repeater channels, one of which uses voting receivers	5
4.	Required communication links	13
5.	Access to law enforcement via control stations in nuclear facility	15
6.	Types of communication links	18
7.	Use of encryption	21
8.	Effect of line compensation	30
9.	Telephone system with private interconnect system	31
10.	Simplex versus duplex operation	34
11.	Basic voting comparator circuit	36
12.	Depiction of point-to-point communication systems	41
13.	Operational fixed vhf or uhf	42
14.	Types of operational fixed microwave hops	43
15.	Base-to-base communications	45
16.	Amplitude modulation	48
17.	Frequency domain of FM signals of the same peak frequency deviation with different modulating frequencies	49
18.	Single-sideband modulation waveforms	50
19.	Use of satellites	53
20.	Exemplary radio system types	56
21.	Vehicular repeater techniques	58
22.	Typical mobile radio communication system	60
23.	Block diagram of mobile transceiver	85
24.	Vehicular repeater	88
25.	Lightning protection system	101
26.	Tone pad button configuration for 16-button pad showing tones for each row and column	107
27.	Radiation divergence	152
28.	6 dB per octave fall-off	153
29.	Four-thirds earth profile propagation plot	154
30.	Earth curvature loss: $L_1 + L_2 + L_3$	157
31.	Calculating knife edge gain and obstruction loss	160
32.	Measured versus calculated propagation attenuation	161
33.	Measured field strength recording	162
34.	Block diagrams of typical transmitter and receiver	164
35.	Diagram of antenna site illustrating use of interference rejection techniques	166
36.	Total system life cost (TSLC) plotted against cost of the system	170
37.	Total system life cost versus reliability of the system	171
38.	Total system life cost versus maintenance expenditures	171
39.	Repair cost versus preventive maintenance	172

40.	Training expenditures	172
41.	Reliability cost as part of initial cost of the system, versus maintenance cost for constant system availability	173
42.	Initial system costs for automaticity and human factors considerations	173
43.	Expenditure for backup provisions	174

PREFACE

The preparation of a report on the subject of communication systems is an awesome, if not impossible, task because such systems are complex, diverse, and subject to endless changes. It becomes important to place the objectives of this report into perspective.

A "cookbook" document that could transform a person not well versed in communication engineering disciplines into a communication expert would be a panacea; however, this concept is unrealistic in that no document of this type could provide enough information in the proper forms to enable the tyro to design and implement an effective communication system suited to any conceivable environment.

This document is primarily for supervisors, noncommunication engineers, and technicians who have limited experience in the field of communication, and should provide an understanding of basic communication system fundamentals, terminology, requirements, and factors that must be considered in designing a communication system. The goal of the report is to create an awareness of the tools available to those who must become involved in implementing a communication system rather than to provide the skill to use these tools.

The report discusses interactions between communication system components and contains exemplary procurement specifications (printed in smaller type) for these components. The values and limits used in the exemplary specifications represent the current state of the art, not typical values; therefore, the specifications should be used as models and must not be used in their present form to create a procurement document. Readers must realize that communication systems come in all sizes, from those necessary to provide the security for a small industrial plant to multifaceted systems for a geographically dispersed complex. Although only the largest communication systems would require most of the components and features discussed in this report, the designers of smaller systems should also find useful information.

In anticipation that this report will stimulate further reading and investigation, abundant references, an annotated bibliography, and several appendices concerning significant communication topics are included. Detailed discussions in the appendices and the extensive glossary both serve to acquaint those unfamiliar with communication system engineering with the intricacies of communication system design, implementation, and operation.

The design of a communication system can be very complex and involved, perhaps making some discussions appear too complicated to the novice. However, the authors feared that oversimplifying the design might give the reader a false confidence which could lead to his attempting a system design with the aid of this report only. Every attempt was made to keep the discussion simple; but where these attempts appear to fail, it is hoped that the reader will still grasp some concept or "feel" for the principles and problems involved. Care should be taken to use equations and formulas in the report only within the stated context.

Although the report is primarily aimed toward the beginner or intermediate, it should serve as a refresher in some areas and as a source of references to the communications professional. It is hoped that this middle-of-the-road approach will benefit the maximum number of people.

Criticism is often given that a document which attempts to describe the fast-paced and time-variant field of communication systems (or any other semiconductor-oriented discipline) will be outdated within a few years. This argument is valid to an extent; however, the counterargument is twofold. Many innovations undoubtedly will be developed, but communication fundamentals will remain inviolate. This point is strengthened by the fact that dramatic new developments filter slowly into the routine industrial environment. If this argument is too weak, the second is stronger and supersedes the first. The understanding and use of current technology of communications systems are needed now, even if the design later becomes outdated.

The authors wish to express their appreciation to the numerous individuals, both of the commercial community and of the nuclear community, who aided in the assimilation and organization of the material in this report by allowing visits to their facilities, by providing information on commercial hardware, and by proofreading the original text. Although every suggestion could not be included per sē, each was considered, and each contributed to the final product.

1. INTRODUCTION

1.1 Objective

The objective of this report is to provide information to assist in developing a communication system for a particular application. Special emphasis is placed upon the use of communication systems as part of security systems in nuclear fixed site facilities. Much of this report consists of information on characteristics of communication systems, capabilities and limitations of communication system components and configurations, economic considerations, and other factors that influence the design and performance of communication systems.

When designing a communication system, the engineer must be familiar with components of typical systems; their relationship to other components; and the options, design variables, and tradeoffs available to the designer. The design engineer must know the environmental constraints on the system, the information load that must be carried by the system, the locations for information input and output, the permissible waiting time for users of the system, and the factors that affect total system life cost. This report furnishes the reader with basic information to aid in understanding, designing, and implementing a communication system once the requirements for the system have been established.

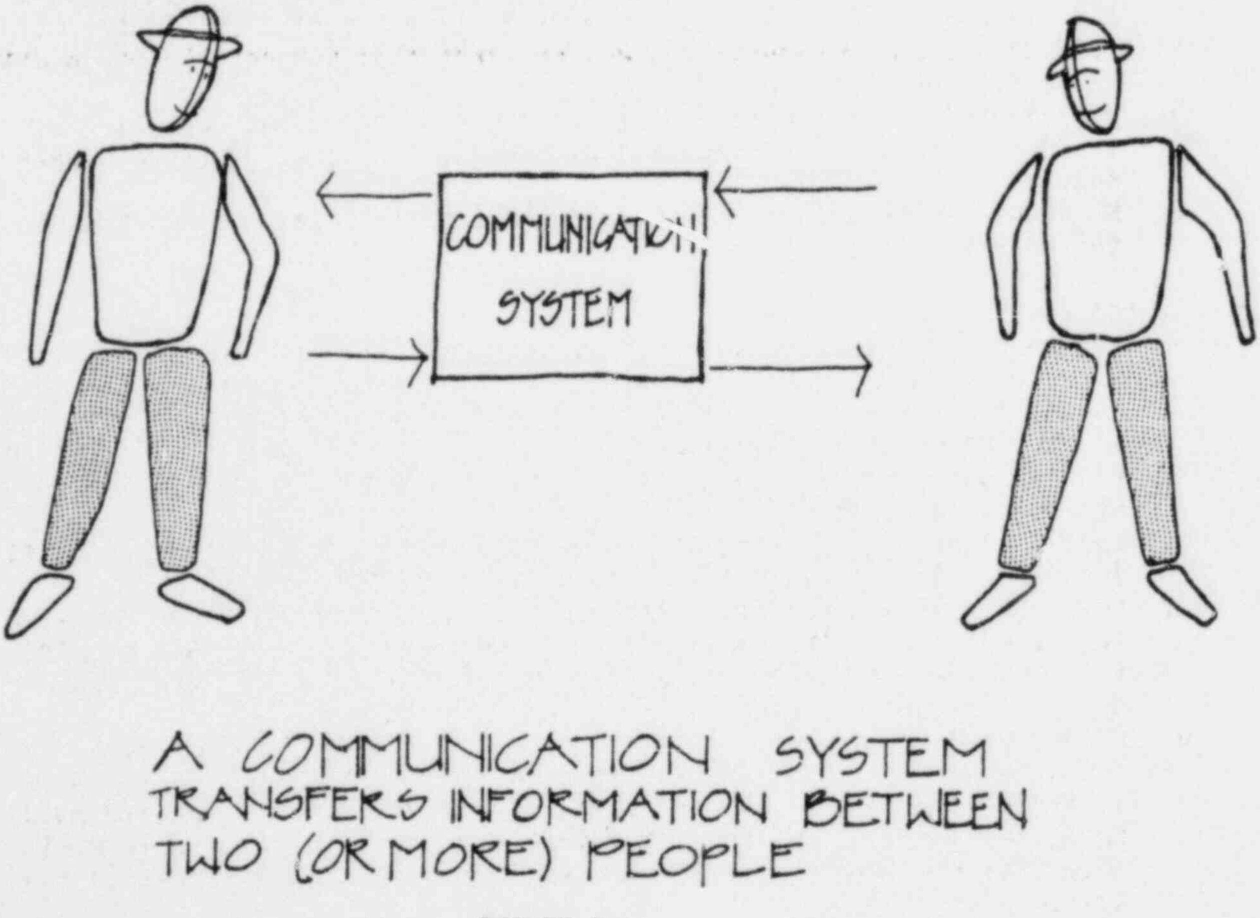
1.2 Uses

As illustrated in Fig. 1, a communication system is necessary to provide a communication medium[1] for transferring information in real time between two or more locations that cannot be practically interconnected by human audio or visual signaling. The information conveyed can be a simple call for help, orders and instructions, a visual scene, the actuation of a sensor, a command to a mechanical or electrical device, data from one computer to another, printed or pictorial material, etc.

The following basic information is required to develop a communication system design:

1. Locations for access to the communication system
    a. Fixed - control points, computer terminals, guard stations, etc.
    b. Mobile - supervisors' vehicles, mobile guards, etc.
    c. Portable - guards on foot, pagers, personnel in offices, etc.

2. Bandwidth requirements of common communication devices
    a. Telegraph - 300 Hz
    b. Telephone - 3000 Hz
    c. Compressed voice - 100 Hz to 300 Hz, depending on the speech compression method employed
    d. Computer terminal operating at 9600 bits/second - 3000 Hz
    e. Mobile voice radio - 3000-Hz audio spectrum, 15,000-Hz FM radio-frequency spectrum, or 3000-Hz AM single-sideband radio-frequency spectrum



A COMMUNICATION SYSTEM
TRANSFERS INFORMATION BETWEEN
TWO (OR MORE) PEOPLE

FIGURE 1

f. Broadcast radio (AM) - 10,000-Hz radio-frequency spectrum
g. Broadcast radio (FM) - 200,000-Hz radio-frequency spectrum
h. Television broadcasting - 6,000,000-Hz radio-frequency spectrum

3. Increased system reliability and performance
   a. More complex, and therefore more expensive, equipment and installations will be required as reliability requirements are increased and/or additional system performance (e.g., additional control points, additional range, alternate modes of operation, additional functional features, such as selective-calling and automatic identification) is required.

4. Environments in which the system must operate
   a. Special physical environments that are more extreme than anticipated by the normal design requirements of standard production equipment: explosive environments which must meet one of the intrinsically safe requirements of the National Fire Protection Association;[2] extremely cold or hot environments; and environments that subject the equipment to severe shock or vibration
   b. Operational environment: remote unattended operation, operation by trained personnel, or operation of emergency devices by unknown persons
   c. Maintenance and support services (self-test features, monitoring of the need for contract maintenance)

5. System design restrictions
   a. Economic - cost overruns in system implementation and operation through some combination of the following: (1) including features not absolutely necessary, (2) developing instead of buying system components already commercially available, (3) not using stringent specifications, (4) not using the simplest possible system, and (5) establishing unnecessary requirements
   b. Legal - thorough checking of system components and operations against local, state, and federal laws to prevent any illegality
   c. Coverage area and terrain - factors that determine the types of systems used to meet the requirements: the coverage area required, terrain, number and configuration of communication channels required, and the frequencies available (see Appendix I)
   d. Policy procedures - personnel, maintenance, supply, capital acquisition, and other policies that limit many design options (for example, if trained operators are not available, the system will require automatic features and the type of maintenance personnel available will determine the extent of self-checking that should be included in the system design)
   e. Interference to the system and by the system to others - recognition crucial during the system design process (see Appendix II).

1.3 General Description

All communication systems can be divided into three basic components as Fig. 2 shows:

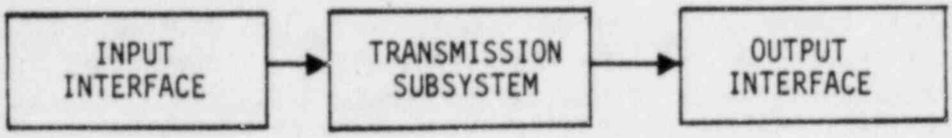


Fig. 2. Communication subsystem

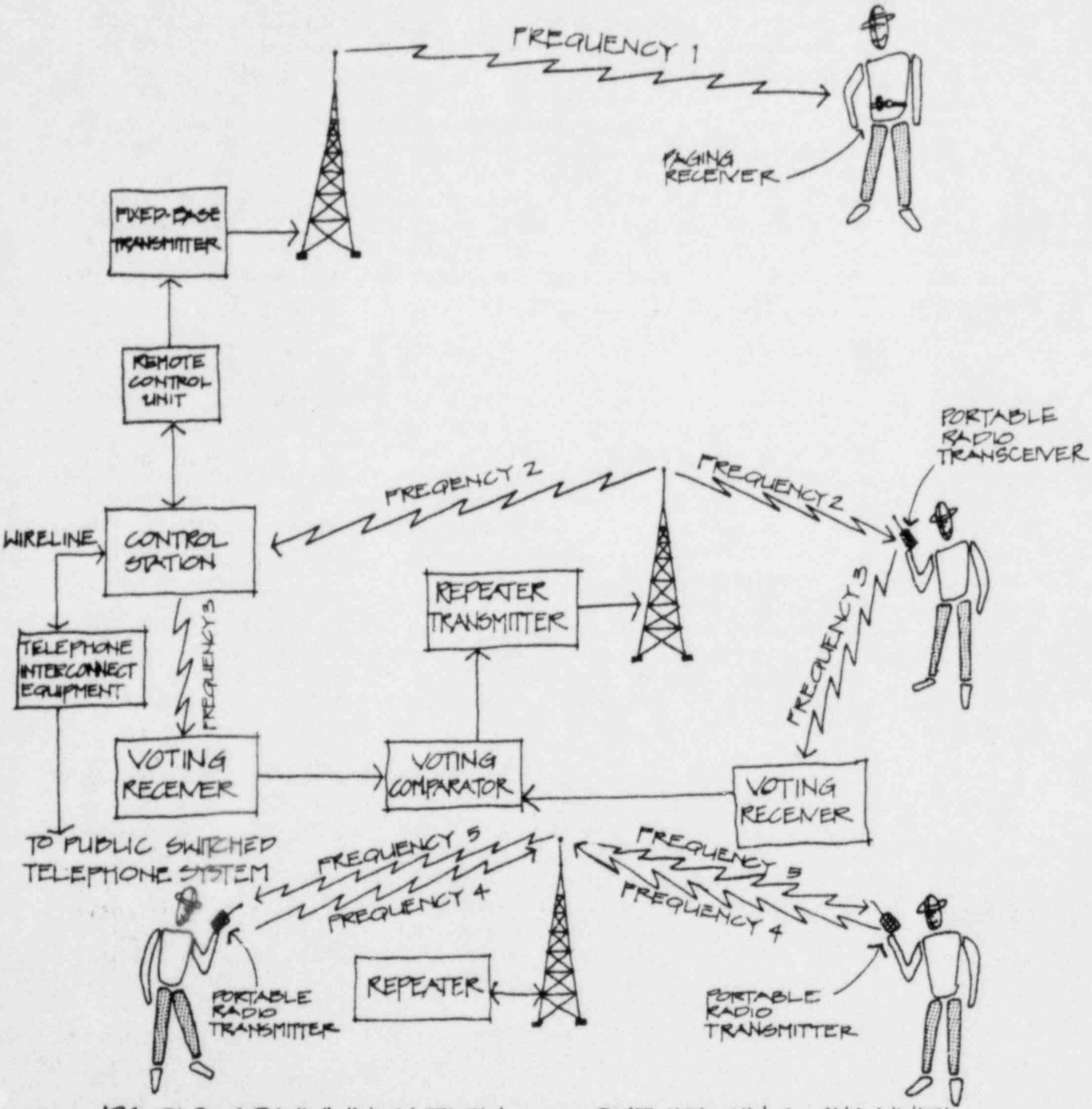
The input interface will be a microphone, computer modem, television camera, or other device that converts incoming information conveyed by modulated acoustical, electrical, mechanical, video, or other energy into a modulated form of energy that can be conveyed by the transmission subsystem. The transmission subsystem will be a radio, wireline, seismic, optical, mechanical, nuclear, or acoustical device. The output interface will be a loudspeaker, cathode-ray tube (CRT), recorder, modem, or other device that will convert the modulations of the transmitted energy into a form that can be utilized by a person directly or indirectly.

Voice radio systems that transmit information between two or more people are the principal communication systems this report discusses. Components for implementing such systems are listed below.

1. Fixed-base transmitters (see Fig. 3) can be used for paging and other one-way communications and can be equipped with companion receivers and used for two-way communication with mobile and portable radio units. Fixed-base transmitters usually are controlled by wirelines or radio links from remote locations but may be controlled from a location near the transmitter.

2. Remote control units (Fig. 3) may be used to control one or more transmitters and associated receivers. Wirelines, usually telephone lines, are used to connect the remote control unit with the associated transmitter(s) and receiver(s). In special isolated instances, radio control links operating in the 72-, 450-, 960-MHz, or higher frequency range can be used for this purpose if wirelines are unobtainable. Control functions such as transmitter actuation and frequency selection are sent to the controlled station by either direct-current signals or audio tones over the wirelines or audio tones over the radio control link. The use of direct-current signals is simpler and less expensive but necessitates continuous copper circuits that do not employ transformers or audio frequency amplifiers other than direct-coupled amplifiers, but this method is not practical over distances greater than 15 or 30 miles.

3. Repeater transmitters consist of fixed-base transmitters that receive audio input signals from associated receivers for automatic retransmission. The retransmission is usually on a frequency that differs from the receiving frequency. The repeater transmitter shown in Fig. 3 receives audio input from two voting receivers via a voting comparator by means of wireline circuits.



RADIO COMMUNICATION WITH ONE PAGING CHANNEL & TWO REPEATER CHANNELS, ONE OF WHICH USES VOTING RECEIVERS

FIGURE 3

4. A repeater is a combination of a repeater transmitter and an associated receiver that retransmits on one frequency, communications received on another frequency. The FCC Rules and Regulations define two types of repeaters. One is a fixed-base station "authorized primarily to retransmit automatically on a mobile service frequency communications originated by mobile stations." This type of repeater is identified by the FCC as a "mobile relay station." The second type of repeater is identified by the FCC as a "mobile repeater station" and is basically a repeater station, as defined above, mounted in a vehicle. Repeater transmitters can function automatically under the control of the associated receiver(s) or can be controlled by a remote control unit. If a remote control unit is employed, the repeater transmitter can be used to originate communications in addition to functioning as a component of the repeater.

5. Control stations are fixed stations used to communicate with mobile and portable stations via a repeater. As shown in Fig. 3, the control station transmits on the input, that is, the receive frequency of the repeater, and receives on the repeater's transmitting frequency in the same manner as a mobile unit.

6. Voting receivers are remotely located and are used to receive communications from mobiles, portables, and control stations for subsequent input to the associated repeater transmitter. Voting receivers are usually located at a number of sites to provide a reception coverage area from the lower powered mobile and portable units, an area that coincides with the area of coverage provided from the greater power and antenna height of the repeater transmitter. Voting receivers manufactured by most communication equipment companies send a signal indicative of the level of the communications received, along with the audio component of the communications via wireline or radio control link to the voting comparator.

7. Voting comparators receive input signals (audio communications and an indication of received signal level at the receiver) from two or more voting receivers, select the best signal upon the basis of a preestablished criterion, and connect the voting receiver with the best signal to the associated repeater transmitter.

8. Mobile radio transceivers, also called "mobile units," "mobile transmitters," and simply "mobiles," consist of an integral transmitter and receiver mounted in a convenient location in the vehicle; a control head used to select frequency, audio output level, and other functions of the unit; a microphone; and a loudspeaker. Mobile units used for some purposes, like a mobile radio-telephone, may contain duplexers to permit simultaneous reception and transmission, known as "duplex operation." The output power of mobile unit transmitters will range from 15 W for units mounted under the dash to 100 or 150 W for trunk-mounted units. The maximum output power of mobile radiotelephones is limited to approximately 65 W due to the power-handling capabilities of the smaller mobile unit duplexers.

9. Portable radio transceivers, also called "portable radios," "handy talkies," "walkie talkies," "walky-talkys," and simply "portables," are similar to mobile radio transceivers except that the entire receiver, transmitter, and control portions of the unit are packaged into a single unit that may be

carried in the hand, fastened on the belt, or placed in a coat pocket. Each unit is powered by a self-contained battery. Full duplex portable units are not yet manufactured commercially. The options available from some manufacturers of portable units include separate speaker-microphones and antennas to enable keeping the portable unit on the belt while in use, rechargeable batteries, tone pads to originate commands for remote control purposes, automatic identification, and a secondary control to summon aid during an emergency.

10. Antenna support towers vary from simple masts attached to an existing building or water tower to 300-ft, 1000-ft, and higher steel constructions. Self-supporting towers, that is, towers with no guy wires, can be used to a height of approximately 400 ft. Self-supporting towers higher than this level usually are economically unfeasible.

11. Antennas are required for all receivers and transmitters. In pagers, the clip that holds the paging unit in the pocket serves as the antenna. The antennas on portable units are either telescoping tubular units or rubberized helical wire units. Compared with the helical units, the telescoping units have 2 to 4 dB higher gain and enable greater reception and transmission ranges but are less convenient to the user. The simplest antenna for mobile units is a quarter-wavelength whip mounted in the center of the roof or on the trunk lid of the vehicle. Coils are sometimes placed in series with the whip, either at the base or somewhere along its length, to reduce the overall length of the antenna, provide greater gain (up to 5 dB), or a combination of both. Directional antennas usually are used with control stations to minimize transmitter output power and antenna height requirements and to reduce interference from other radio-frequency sources. Antennas used for base transmitters, repeaters, and receivers will have 6 to 9 dB horizontal directivity to conserve power and 0 to 3 dB vertical directivity as required to overcome pattern distortion imposed by the antenna support structure and to provide the desired area of coverage.

12. Paging receivers are small units that can be carried in a coat or shirt pocket to enable calling the individual carrying the pager from some remote location. Three types of paging systems are commonly used. The simplest is a tone-only system that simply informs the paged individual that some prearranged action should be taken - usually a call to the office or home. A second type of pager permits as many as five or six predetermined messages to the individual paged. The third and most versatile pager, and the largest and most expensive, is the tone-and-voice pager, which alerts the paged individual and provides him with a voice message 10 to 45 seconds long from the individual originating the page. Paging systems can be implemented to enable a page to be originated from any telephone and from paging transmitter remote control units (also called paging encoders). More elaborate systems will store pages if the system is occupied with transmitting previously placed pages and will transmit the stored pages in sequence or in sequence by priority.

13. Telephone interconnect equipment is used to interconnect wireline telephone systems (public switched and private) to mobile radio systems. This equipment permits telephone calls to be received with and placed from a mobile or portable radio unit. The telephone interconnect equipment can be

configured to permit receiving and placing calls from the mobile and portable unit without assistance from an operator or individual at a remote control unit, or it can be configured so the control of the system is at a remote control unit and the remote control operator receives and places all calls and then interconnects them with the mobile and portable units.

14. Control consoles provide a convenient grouping of the controls necessary to operate a communication system. A control console will have one or more microphones, speakers, push-to-talk switches, mute switches, channel-select switches, and transmit lights; and, perhaps, some combination of the following controls, displays, and ancillary items, such as telephone, telephone-radio interconnect controls, clock, channel cross-connect control, call light(s), simultaneous-select switch, repeater disable switch, VU meter, headset jacks and headsets, alert tone annunciator, intercommunication control, recorder controls, and ac utility strip.

The following chapters discuss the functions these components fulfill in various types of communications systems; the trade-offs that must be made between the various objectives, requirements, and constraints to synthesize a communication system for a particular application; and the analyses, implementation steps, and support that must be considered to realize the desired communication system. Terms that are unique to communication disciplines or that have unique meanings in communication disciplines are defined in the Glossary of this report.

2. THE COMMUNICATIONS SYSTEM: REQUIREMENTS, CONSTRAINTS, AND LIMITATIONS

2.1 Requirements of the Code of Federal Regulations

The Code of Federal Regulations (CFR), Title 10, Part 73, enumerates the physical protection requirements imposed by the Nuclear Regulatory Commission (NRC) on licensed fixed-site facilities. For several years, a series of amendments have been proposed and refined to strengthen physical protection. Because these regulations are in a state of upgrade and probably will continue to be with new technological advances, the reader will be well advised to check with the NRC for current or probable changes in the regulations. The regulations listed below should become effective March 25, 1980, and deal primarily with voice communication systems.[3]

73.46(f) (1) Each guard, watchman, or armed response individual on duty shall be capable of maintaining continuous communication with an individual in each continuously manned alarm station ... who shall be capable of calling for assistance from other guards, watchmen, and armed response personnel and from law enforcement authorities.

73.46(f) (2) Each alarm station ... shall have both conventional telephone service and radio or microwave transmitted two-way voice communication, either directly or through an intermediary, for the capability of communication with the law enforcement authorities.

73.46(f) (3) Nonportable communications equipment controlled by the licensee and required by this section shall remain operable from independent power sources in the event of the loss of normal power.

73.46(g) (3) (ii) Testing of communications equipment required for communications onsite, including duress alarms, for performance not less frequently than once at the beginning of each security personnel work shift. Communications equipment required for communications offsite shall be tested for performance not less than once a day.

73.46(h) (2) The licensee shall establish and document response arrangements that have been made with local law enforcement authorities.

In addition to these specific requirements concerning voice communication, the NRC regulations also deal with tests and inspections during installation, preoperational tests, preventative maintenance, and breakdown maintenance of all physical protection subsystems in general. These new regulations also deal more extensively with alarm systems, especially duress alarms, and with closed-circuit television (CCTV) than ever before. Although either an alarm or CCTV system could qualify as a communication system under the definition given in Section 1.2, the scope of this report is limited primarily to voice and voice-related systems.

2.2 FCC Rules and Regulations

The Federal Communications Commission (FCC) establishes the rules and regulations,[4] which control the use of radio-frequency-emitting devices in the United States by other than federal organizations. The federal organizations (agencies and departments), like TVA, the military services, NFS, and DOE, obtain permission to use radio frequencies from the Interdepartmental Radio Advisory Committee of the Office of Telecommunications Policy, 1800 G Street N.W., Washington, D.C. 20504. The rules and regulations consist of ten volumes, two booklets, and four pamphlets, all of which are listed inside the front cover of each volume.

An engineer involved with the design of radio communication systems for use in nuclear fixed site facility security systems should be thoroughly familiar with Vols. I and V of the FCC Rules and Regulations. These documents are printed and distributed by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Volume I contains Part 0, Commission Organization; Part 1, Practice and Procedure; Part 13, Commercial Radio Operators; Part 17, Construction, Marking, and Lighting of Antenna Structures; and Part 19, Employee Responsibilities and Conduct. Volume V contains Part 87, Aviation Service; Part 89, Public Safety Radio Service; Part 91, Industrial Radio Service; Part 93, Land Transportation Radio Service; and Part 94, Private Operational-Fixed Microwave Service. Updates for each volume appear in the Federal Register and are sent automatically to purchasers of the volumes.

Part 0, Commission Organization, explains the organization of the FCC, the authority of the different offices in the organization, privacy act regulations, public access to FCC information, and other general information. Paragraph 0.433, for example, explains that lists of equipment acceptable for licensing by the FCC (i.e., type accepted equipment) are prepared periodically, are available for public inspection in the FCC field offices, and may be obtained from the Commission's duplicating contractor. Paragraph 0.465, for example, identifies the Commission's duplicating contractor and provides instructions concerning charges, address, and method of working with the duplicating contractor to obtain copies of material the FCC makes available to the public.

Part 1, Practice and Procedure, provides information concerning methods that may be used by members of the public to work with, apply to, or appeal to the FCC. This part provides the methods used by the FCC to make public their rule-making intentions and actions.

Part 13, Commercial Radio Operators, explains the various classes of radio operator licenses issued by the FCC, the functions that may be performed only by a licensee of each class, the rules and regulations governing the performance of licensed radio operators, and the method by which a person may obtain a particular class of commercial radio license.

Part 17, Construction, Marking, and Lighting of Antenna Structures, provides the criteria for determining whether an antenna structure (e.g., support tower) must have special painting and/or lighting and, if so, stipulates the painting and lighting that is required. This part contains the criteria for determining whether the FAA and/or the EPA must be contacted for approval to construct an antenna structure.

Part 19, Employee Responsibilities and Conduct, contains provisions covering the standards for the ethical and other conduct of FCC employees set forth in the civil service regulations of 5 CFR 735.201a through 5 CFR 735.210, the federal conflicts of interest statutes and the Federal Communications Act of 1934. This part should be understood by anyone who has social contact with FCC employees.

Part 87, Aviation Services, identifies the frequencies and establishes the rules and regulations governing licensing and use of airborne radio stations and ground stations associated primarily with airborne radio stations.

Part 89, Public Safety Radio Services, identifies the frequencies and establishes the rules and regulations governing licensing and use of radio stations for nonfederal governmental functions and for alleviating emergencies that endanger life or property. These radio stations include those used for the following:

1. local government communications by states, cities, and counties;
2. police operations;
3. fire prevention and control operations;
4. highway maintenance operations;
5. forestry conservation activities;
6. special emergency operations such as medical, rescue operations, disaster relief, school buses, beach patrols, and communications for isolated areas; and
7. state guard operations.

Parts 89, 81 and 93 were combined, effective January 2, 1979, into a new Part 90, which will be available in the fall of 1979 from the USGPO. The new Part 90 was published in the Nov. 20, 1978, issue of the Federal Register and updates will be published soon.

Part 91, Industrial Radio Services, is the part that identifies the frequencies and establishes the rules and regulations governing licensing and use of radio facilities by nongovernmental nuclear facilities. These include the following items of special interest to nuclear facilities:

1. power radio service - facilities used for generation, transmission, or distribution of electrical power;

2. special industrial radio service - a miscellaneous category that often serves industrial organizations that cannot qualify under other subparts of Part 91;
3. business radio service - any commercial activity, educational institutions, philanthropic institutions, ecclesiastical institutions, hospitals, clinics, and medical associations; and
4. manufacturers' radio service - activities involved in manufacturing or assembling components of manufactured articles.

Part 93, Land Transportation Radio Services, identifies the frequencies and establishes the rules and regulations governing licensing and use of radio stations by motor carriers, railroads, taxicab companies, and automobile emergency services (wrecker truck companies).

Part 94, Private Operational-Fixed Microwave Service, identifies the frequencies, available bandwidths, and permissible use and establishes the rules and regulations governing licensing and use of microwave frequencies (frequencies above 952 MHz) for all who desire to use these frequencies at fixed locations.

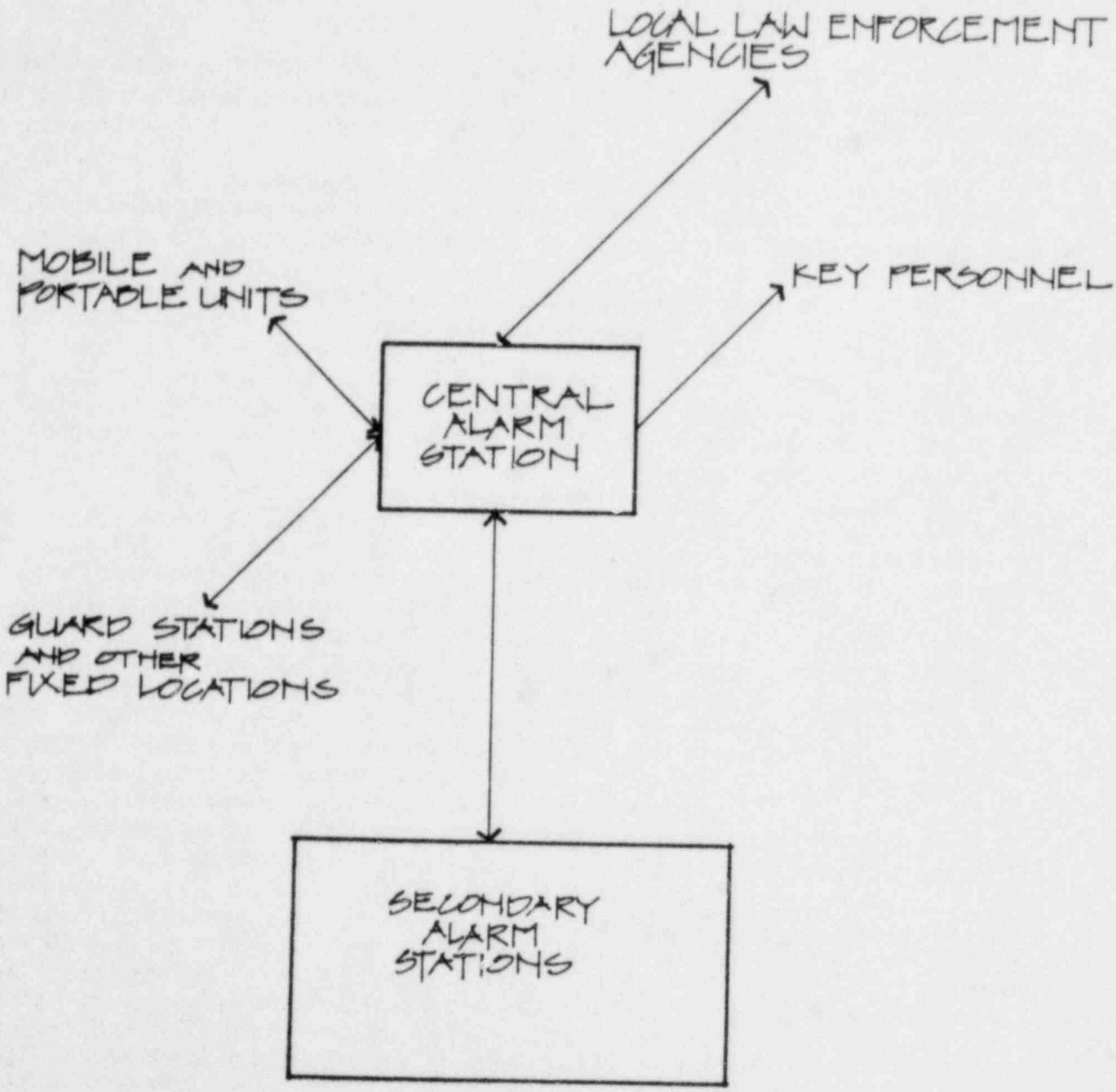
The document, FCC Two-Way Radio License Application Manual,[5] is an excellent aid to comprehending the FCC Rules and Regulations when individuals apply for radio station licenses.

2.3 Nuclear Facility Communications

The voice communication system required for a security system for a nuclear fixed site facility must provide the communication links[6] indicated in Fig. 4 for the central alarm station. Arrowhead symbols are used in the figure to differentiate between two- and one-way links. Duplicate, independent links are required for the secondary alarm station(s).

The use of the telephone could apply to all the links shown in Fig. 4, except communication with mobile and portable units. An in-plant telephone system, either leased from a local telephone company or owned outright by the licensee, could provide communications to the guard stations and other fixed locations. The links between the central alarm and secondary alarm stations could be a portion of the in-plant telephone system, even though the secondary alarm station is outside the protected area. If the secondary alarm station is located at some remote section of the site, this link could be a dedicated line leased from a telephone company or could be a telephone service line. As noted in Section 2.1, Part 73 of CRF, Title 10 requires that both two-way voice radio and a conventional telephone service line be used to link the facility with local law enforcement agencies. The one-way link necessary to notify key personnel of emergencies could be furnished by telephone service lines if the specific location of these personnel were known, or it could be furnished by a telephone-accessed public address system if the personnel were known to be within a particular area.

Radio communication links are necessary to extend person-to-person communications to locations that cannot be reached by fixed telephone facilities or public address facilities and to provide backup communications for telephone. Radio paging extends public address contact with individuals to any



REQUIRED COMMUNICATION LINKS

FIGURE 4

desired geographical area and provides privacy that is lacking in public address systems; however, it suffers from the restriction that it cannot provide two-way communications. Public address systems can be configured to provide two-way communications between the originator of the page and an individual at a selected speaker-microphone.

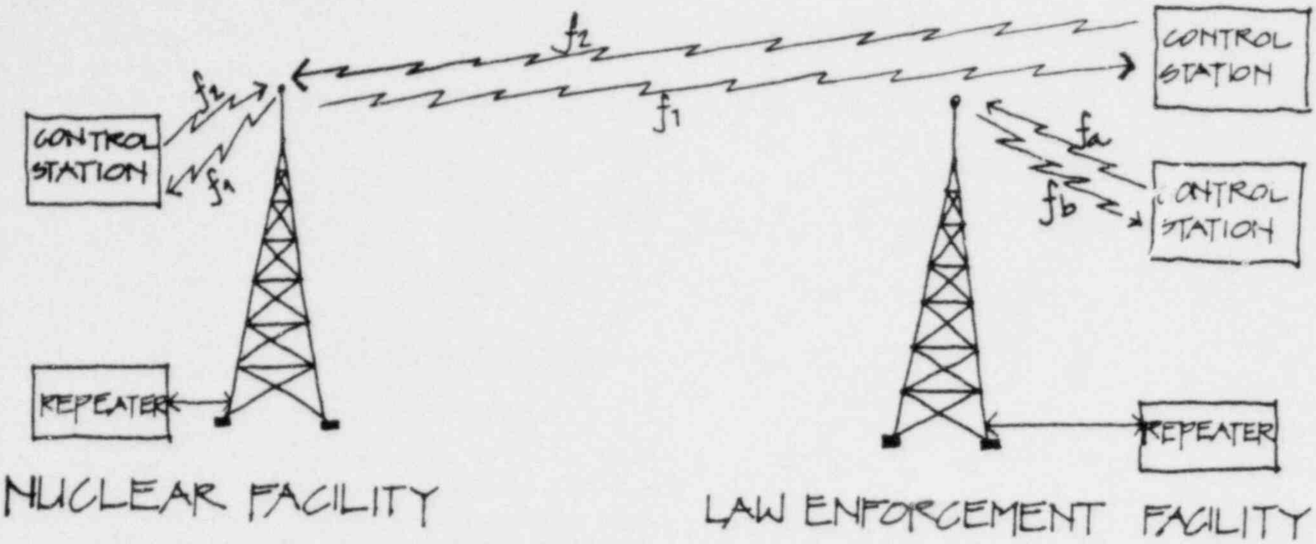
Key personnel can be assigned to monitor selected radio nets. Monitor receivers can be turned on by the listener or activated by a radio transmitter to alert the listener to a particular situation.

Radio could be used for all of the links shown in Fig. 4, but it is mandatory for the communications between the central alarm station and the mobile and portable units and local law enforcement agency.

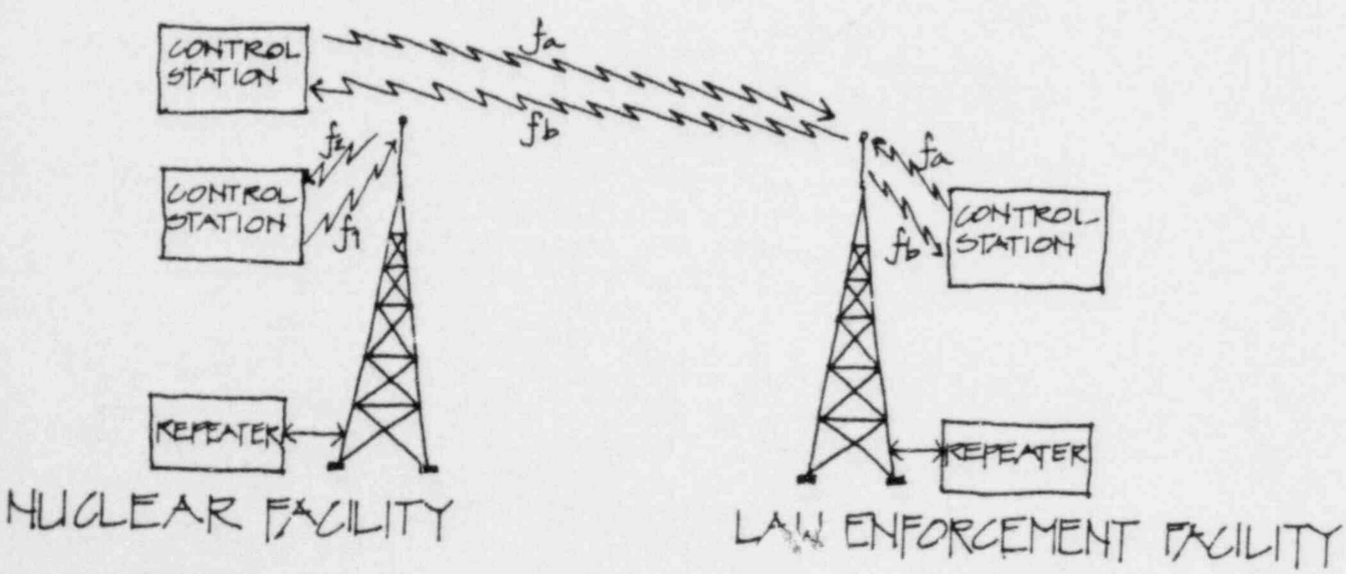
The link shown in Fig. 4 between the central alarm station and local law enforcement agencies represents several critical links for the protection of the facility.* Law enforcement agencies depend upon the telephone and radio for their operation, and the links with these agencies are more reliable when both radio and telephone are used, with each medium backing up the other. Generally, a single vhf or uhf radio voice communication channel can provide the radio link and the public-switched telephone system franchised in the area can provide the telephone link. Only if an analog CCTV link is established to the law enforcement agency will a coaxial cable or microwave link be required. Figure 5 shows the two methods whereby a uhf or vhf radio communication link can be established between a nuclear facility and the local law enforcement agency. One is to provide the law enforcement agency with a control station or base station on the facility's radio system. If this method is used, a special access code using CTCSS or digital signaling should be employed so the law enforcement radio dispatcher hears the channel only when there is traffic for the law enforcement agency. The other method is to provide the facility with a control station or base station on one of the law enforcement agency's channels. In this case, the volume may be kept low in the facility until the channel is used to call the law enforcement agency. This second method usually is preferable because it provides better access to the law enforcement agency's communication system by the nuclear facility.

The use of the link between the central and secondary alarm stations will vary widely from one nuclear facility to another, depending on the function and design of the facility. This link may be used for several voice channels plus data channels and certain alarm signals. Radio will usually be used to back up the telephone on this link. The basic design requirements must define the total number of communication channels needed, the intended use of each channel, and the communication reliability desired. The system must include the multiplexed channels and channel redundancy necessary to meet the requirements. A typical channel complement on this link could be the following:

*This link must be established through coordination and cooperation with local officials.



ACCESS to LAW ENFORCEMENT VIA CONTROL STATION IN LAW ENFORCEMENT FACILITY



ACCESS to LAW ENFORCEMENT VIA CONTROL STATION IN NUCLEAR FACILITY

FIGURE 5

1. local law enforcement agency interface channel,

2. paging transmitter control,

3. mobile radio net,

4. plant intercommunication system.

5. telephone circuit or extension on the plant telephone system, and

6. alarm circuit with individual alarms multiplexed on it.

Although each of these channels could be implemented several ways, it must be remembered that the secondary alarm station is required by CFR[3] to have the same communication links as the central alarm facility, instead of being extended from it. As an example, the station-to-station link might be limited to a multiplexed alarm channel and a voice telephone channel, with all other communications duplicated at the secondary alarm station. The alarm channel might be for the duress and intrusion alarms installed at each station, not to extend alarms received at one station to the other, as this situation would allow a failure at one station to prevent the second station from receiving the alarms. This duplication would entail a second paging transmitter, a mobile radio base station, and a facility for communicating with the local law enforcement agency at the secondary alarm station. This type of system should be designed to prevent conflict between the duplicated facilities. For example, a backup or secondary radio repeater must not be active at the same time the primary repeater is active or simultaneous transmission by the two stations will obliterate the radio transmission.

Communication with the guard stations would be more flexible and reliable if the guard stations were equipped with portable radios or fixed control stations on the net used by the mobile and portable units. This would enable the guard stations to contact portable and mobile units directly and would provide them an alternate means of communication with the central alarm station.

The design of the radio remote control units, telephone instruments, and consoles must take into consideration the interface requirements of the individuals who must use the equipment. Not uncommonly, failure to consider human factors in the design of interface equipment prevents the utilization of needed capabilities available within the system itself.

Emergencies bring about the most critical and intensive usage of communications. All communication links terminate at the central alarm station and the secondary alarm station. Consoles must be installed to provide the personnel manning these with simultaneous use of all communication links available to them.

2.4 System Types

Communication between two fixed points, usually called "point-to-point" communication, can be accomplished by wireline or radio techniques, as illustrated in Fig. 6. To conserve radio spectrum utilization, the FCC prohibits use of radio techniques in instances in which wireline techniques can provide the service needed. However, point-to-point radio communications are not restricted for radio stations licensed under Part 89 of the FCC Rules and Regulations.

Communication between fixed points and mobile units (point-to-mobile) and between mobile units (mobile-to-mobile), as shown in Fig. 6, necessitates use of radio techniques. Portable units are considered the same as mobile units in this context. The need to communicate with mobile units and the demands of the entertainment industry have both spurred the majority of the developments in the field of radio. A nuclear facility generally will use mobile-to-mobile and point-to-mobile communications for routine and emergency communications and point-to-point communications for emergency situations only.

2.5 Equipment Considerations

The communication system designer today is blessed with the availability of an extremely broad spectrum of equipment from which to choose components for his intended system.[7] In addition to buyers' guides,[8] numerous excellent trade journals are readily available for keeping engineers abreast of advances in technology. Typical trade journals that would be useful to a designer of communication systems for nuclear facilities are listed below:

1. Communications - Cardiff Publishing Company, 3900 S. Wadsworth Blvd., Denver, Colo. 80235.

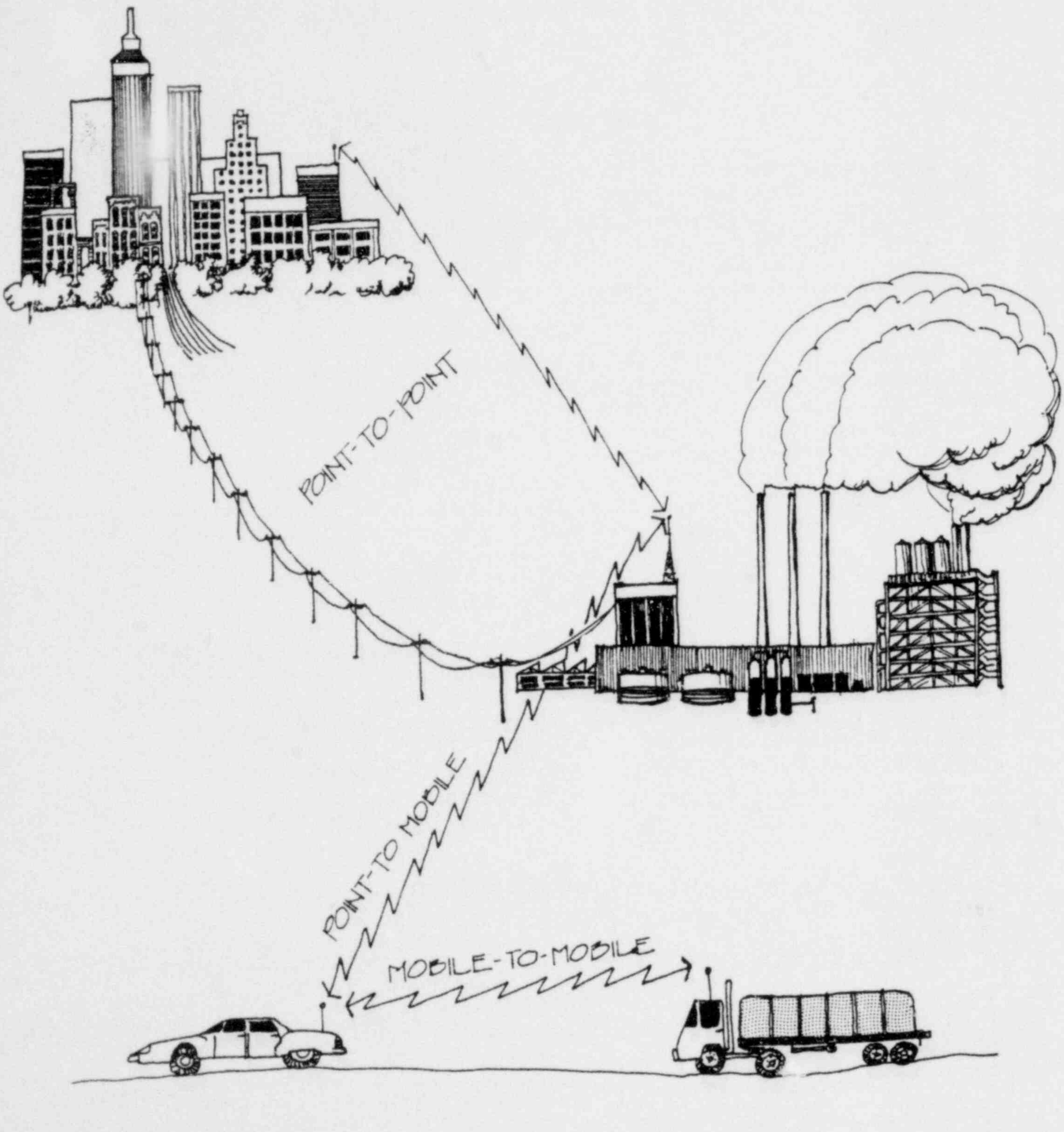
2. Communications News - Harcourt Brace Jovanovich Publications, 124 South First St., Geneva, Ill.

3. Computer Decisions - Hayden Publishing Co., Inc., 50 Essex St., Rochelle Park, N.J. 07662.

4. Data Communications - McGraw-Hill, Inc., 1221 Avenue of the Americas, New York, N.Y. 10020.

5. Electrical Communication - International Telephone & Telegraph Corp., 190 Strand, London, WCR1 RDU, England.

6. Electronic Engineering Times - CMP Publications, Inc., 333 East Shore Road, Manhasset, N.Y. 11030.



TYPES of COMMUNICATION LINKS

FIGURE 6

7. Electronic Products - United Technical Publications, Inc., 645 Stewart Avenue, Garden City, N.Y. 11530.

8. Electronics - McGraw-Hill, Inc., 1221 Avenue of the Americas, New York, N.Y. 10020.

9. Microwave Journal - Horizon House, 610 Washington Street, Dedham, Mass. 02026.

10. Microwave System News - Weber Publications, Inc., 3975 East Bayshore Road, Palo Alto, Calif. 94303.

11. Microwaves - Hayden Publishing Company, Inc., printed by Brown Printing Co., Waseca, Minn.

12. Mobile Times - Titsch Publishing, Inc., 1139 Delaware Plaza, P. O. Box 4305, Denver, Colo. 80204.

13. Personal Communications - Cowan Publishing Corporation, 14 Vanderventer Avenue, Port Washington, N.Y. 11050.

14. Satellite Communications - Cardiff Publishing Company, 3900 S. Wadsworth Blvd., Denver, Colo. 80235.

15. Telecommunications - Horizon House, 610 Washington St., Dedham, Mass. 02026.

16. Telephony - Telephony Publishing Corporation, 53 West Jackson Blvd., Chicago, Ill. 60604.

17. Two-Way Radio Dealer - Titsch Publishing, Inc., 1139 Delaware Plaza, P. O. Box 4305, Denver, Colo. 80204.

The mobile radio and microwave fields include manufacturers such as Aerotron, Inc.; Cardion Electronics; Farinon Electric; General Electric Co.; Granger Associates; Harris Corporation; E. F. Johnson Co.; GTE Lenkurt; Microwave Associates; Motorola, Inc.; Radio Corporation of America; Rockwell International; and Wescom, Inc. These companies manufacture and install mobile radio units, base stations, control stations, microwave terminals, microwave relay links, and complete radio communication systems. There are numerous other companies that provide such accessories as antennas, antenna support structures, tone-signaling modules, telephone system interconnect equipment, control consoles, weatherproof buildings, and lightning protection equipment. A few of these companies and the products for which they were noted at the time of this writing are included in the following list:

1. Antenna, Inc. - mobile antennas.
2. Larson Electronics, Inc. - mobile antennas.
3. Decibel Products, Inc. - mobile and base station antennas.
4. Andrew Corporation - base station and microwave antennas and transmission cables.
5. Rohn Manufacturing - antenna support structures.
6. Allied Tower Company, Inc. - antenna support structures.

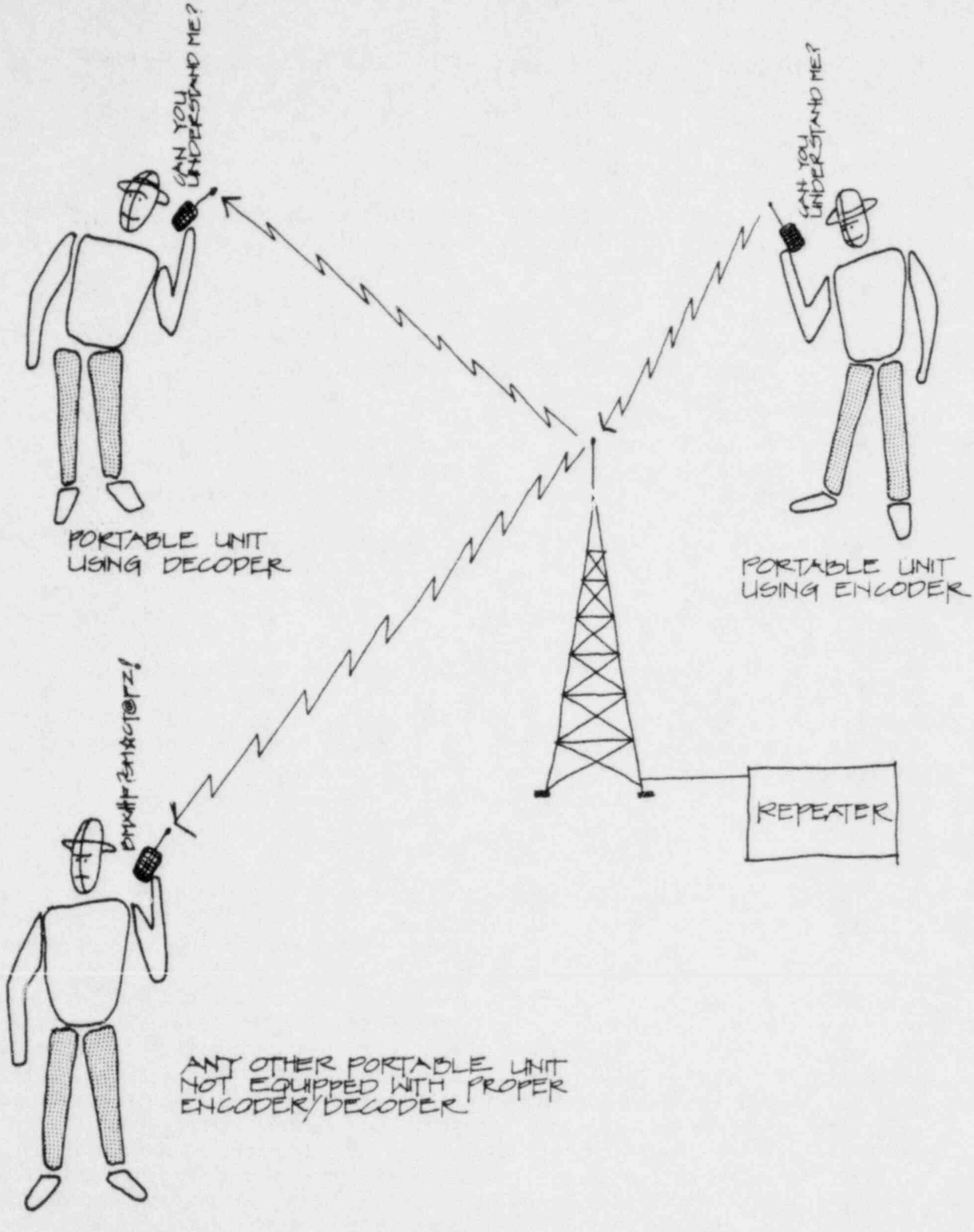
7. Union Metal Manufacturing Co. - antenna support structures that are self-supporting, that is, use no guy wires.
8. Alpha Wire Corporation - tone-signaling equipment.
9. Solid State Communications, Inc. - tone-signaling equipment.
10. Secode Electronics - tone-signaling equipment.
11. Ledex, Inc./Bramco Division - tone-signaling equipment.
12. Speedcall Corporation - tone-signaling equipment.
13. Data Signal, Inc. - tone-signaling equipment.
14. Reach Electronics, Inc. - tone-signaling equipment.
15. Fisk Electric Co. - telephone interconnect systems.
16. International Telephone & Telegraph Corp. - telephone interconnect systems.
17. SYT Corporation - telephone interconnect equipment.
18. Rolm Corporation - telephone interconnect equipment.
19. Digital Telephone Systems, Inc. - telephone interconnect equipment.
20. General Telephone & Electronics Corp. - telephone interconnect systems and equipment.
21. ComCenter Corporation - communication consoles.
22. Kustom Signals, Inc. - communication consoles, digital systems.
23. Fort Worth Tower Co., Inc. - antenna support structures, weatherproof buildings.
24. Thompson Lightning Protection, Inc. - lightning protection equipment.
25. Transtector Systems Division - lightning protection equipment.
26. Tx Rx Systems, Inc. - antenna combiners, receiver multicouplers, and filters.

The field of technology is changing so rapidly that the system designer must stay informed of the manufacturers supplying the latest equipment and of equipment that has become obsolete. The designer must be aware that many manufacturers supply two or three levels of quality, especially base, mobile, and portable radio stations. The two or three product levels of one company do not necessarily correspond in price and quality with the two or three product levels of other companies. The designer must be careful to specify only the level of quality actually required, to prevent either unnecessary expense or lack of competition resulting from specifications too high or too low.

2.6 Security

Security of information transmitted over a communication system can be considered from the standpoint of compromise of information vs time, as illustrated in Fig. 7. Increased security increases both the time and cost of compromising the information.[9] The best security is not to transmit the information in the first place. If the information must be transported from one location to another, and security is vital, it should be encrypted and sent by escorted and supervised couriers. Additional methods of transmitting information are listed below, ranked in the order of a general decrease in security:

1. escorted courier, encrypted information;
2. escorted courier, plain text information;
3. courier, encrypted information;
4. courier, plain text information;
5. supervised wire (or fiber optic) line, encrypted information;



USE of ENCRYPTION

FIGURE 7

6. supervised wire (or fiber optic) line, plain text information;
7. unsupervised wire (or fiber optic) line, encrypted information;
8. unsupervised wire (or fiber optic) line, plain text information;
9. radio link, encrypted information; and
10. radio link, plain text information.

Encrypting methods vary in security over a wide range. Some typical methods are listed below, ranked in the order of a general decrease in security:[10]

1. random code transposition, substitution, and/or masking;
2. pseudorandom code transposition, substitution, and/or masking;
3. rolling code transposition, substitution, and/or masking;
4. band splitting and transposition with frequency inversion;
5. band splitting and transposition;
6. frequency inversion;
7. use of unusual language known to the communicating parties; and
8. use of unusual words and symbols known to the communicating parties.

Another security technique that applies to all methods of transporting information is the use of route dispersal, that is, sending the information by two or more separate routes (or methods) and dividing the parts that are transported so the information cannot be extracted until the separated parts are reassembled. The MIT Laboratory for Computer Science has developed a digital encryption and decryption system wherein the encryption key can be public, because it does not reveal the decryption key.[11] This facilitates electronic mail, funds transfer, and similar communications because all potential senders of information can be provided with the encryption key, but only the recipient of the information can decipher it if he keeps his decryption key private.

2.7 Message Confirmation

The sender of a message needs confirmation that the message was received as sent, and the receiver of a message needs confirmation that the message receive is identical to the one transmitted. Confirmation poses no problem in a voice communication link in which two or more people are communicating interactively because each can obtain the desired confirmation by a series of remarks and questions; however, the problem is more difficult if the message is a digital or printed language message. The simplest method is an automatic indication from the receiving end to the originating end of a communication link that a message was received and displayed for use by the operator, but this technique provides no assurance that the received message duplicated the original message. The next simplest method of confirmation with digital messages is a parity check in which a single "zero" or a single "one" is added to each grouping of bits to make each grouping always contain either an even or an odd number of "ones," which helps ensure that the received message contains no errors. Formal message transmissions in encrypted or plain language usually contain a count of the total number of words in the message. In either case, if the parity check or the word count indicates an error, the receiver can request a repeat of the message. Reference 12 contains an extensive discussion of error-detecting and -correcting codes. The trade-off is always between the number of errors that can be detected or detected and corrected with the least reduction in data flow rate. The procedure that limits the data flow rate involves sending the message back to the sender for comparison with the original and, if any errors exist, repeating the process until the returned message coincides with the transmitted message.

3. WIRELINE COMMUNICATIONS

3.1 Wireline Voice Systems

Wireline voice communications systems are the standard means of enabling two individuals out of "earshot" of each other to communicate if they are at known fixed locations. The telephone system in a nuclear facility will provide the backbone communications for the facility, and all other communications will extend to locations for which telephone wireline service is impractical.

The method of franchisement of common carriers in the United States simplifies the design engineer's job of providing wireline voice communications. He either calls in the franchised public-switched telephone company's marketing representative and selects from the available tariffed options the services required, or he buys (or leases) and interconnects a private system for use in the facility interfaced with the franchised public-switched facility somewhere near the property boundary of the facility. In a given area, both the locally franchised, public-switched telephone company and those offering private interconnect systems are listed under "Telephone Companies" in the yellow pages of the area telephone book. Bell System companies dominate the franchised public-switched telephone field, followed by General Telephone and Electronics Corp. (GTE); United Telecommunications, Inc.; Continental Telephone Company; and others. The U.S. Department of Commerce/Office of Telecommunications (OT) Report 73-1 provides a map of each of the 50 states[13] and identifies the franchised public-switched telephone company serving each area of the state. International Telephone and Telegraph Communications Systems; Fisk Telephone Systems, Inc.; Communications Corporation of America; NEC Telephones, Inc.; RCA Service Company; and Stromberg-Carlson Communications, Inc. are a few of the larger suppliers of private telephone interconnect systems in the United States. Selection of the best systems approach is a trade-off between economics and requirements and should be based upon a comparison of the cost of the various features and services offered by the franchised company and the independent companies vs the need of the facility for each of the features and services offered. Occasionally, a new feature or service is tariffed ahead of its scheduled presentation by the carrier; however, selections and trade-offs are usually made from existing offerings.

The features and services normally considered for wireline service and a brief explanation of each are listed below.

1. An interconnect is made when service from other than the franchised public-switched telephone supplier in the area is obtained, that is, from a private system. The private system must be "interconnected" with the public-switched system to allow telephone calls to be sent and received. The franchised supplier will charge for each telephone line of the public-switched system that interconnects with the private system. The maximum number of telephone calls (or total of telephone calls, data lines, and control circuits) that can pass into and out of the facility simultaneously equals the total number of telephone lines obtained from the franchised supplier.

2. Maintenance and Modernization are services that the franchised public-switched telephone company will automatically supply, along with periodic telephone directories, equipment replacement in case of catastrophic loss, training of operators, and system expansion without renegotiation of the existing contract. Suppliers of private systems will not supply these services unless they are included in the contract for the equipment and services to be delivered.

3. Automatic Identification of Outward Dialing (AIOD) maintains an automatic record of every outbound long-distance call.

4. Automatic Call Routing (ACR) selects routing of outbound long-distance calls on the basis of priority of call and tariff charges to achieve the most economical long-distance call charges.

5. Wide Area Telephone Service (WATS) permits unlimited use of calling into or out of a designated area at a single monthly fee, independent of the number of times the service is used.

6. Call Forwarding is one of the many useful features available in the modern stored-program, electronic-switching telephone systems. Call forwarding enables an individual to dial instructions into a telephone instrument that will cause incoming calls to be forwarded automatically to any designated instrument in the system.

7. Call Forwarding Busy-Line forwards an incoming call directed to an instrument in use, that is, "busy", to a second designated instrument that is not busy.

8. Call Pickup passes an incoming call that is not answered to a second instrument when requested by command at the second instrument.

9. Trunk Cueing prevents having to dial repeatedly for an outside line, WATS line, or other trunk line by indicating to the calling party that all the lines requested are busy. Trunk cueing notifies the calling party when a line is available.

10. Automatic Call Back provides a method of automatically redialing a called party when the original call results in a busy signal.

11. Call Transfer enables an individual who has originated or received a telephone call to transfer the call to another instrument or to include in the telephone conversation an individual at another instrument. This feature is available in practically all modern onsite telephone systems without added hardware.

12. Priority Interrupt enables an individual who originates a telephone call and receives a busy signal to interrupt the existing telephone conversation for a message of higher priority than the existing conversation. This feature is obviously of potential use to nuclear security forces and should be in telephone installations for their use if for no other reason.

13. Consultation Hold permits holding a call temporarily while the telephone instrument is used to communicate with a third party.

14. Public Address may be included in a telephone system to permit access to a public address system from any telephone in a facility. Telephone-accessed public address systems can be supplied with priority override and/or two-way capability. A typical extensive system will enable any telephone to access any public address speaker, a combination of speakers, all speakers simultaneously, a radio paging system, or a two-way mobile radio system. When an individual speaker, a two-way paging system, or a mobile radio system is addressed, two-way communications can be established; but when a combination of speakers or a tone-only paging system is addressed, the communication provided is one-way only.

15. Call Waiting is a telephone feature that employs an audible signal to inform an individual who is talking over a telephone circuit that an incoming call is present. The individual may elect to terminate the first call and take the second call, ignore the second call, or place the first call in a hold mode and talk to the second caller.

16. Conference calls allow more than two telephone instruments to be used in a telephone conversation.

17. Music-on-Hold places music, voice announcements, or other entertainment on a telephone line that is placed in a hold mode. This feature reduces the frustration of being placed on hold and reduces the probability that a person placed on hold will prematurely terminate the call.

18. Automatic Dialing permits prearranged telephone numbers or code arrangements with up to 15 digits to be dialed automatically when a single button is depressed. This feature requires the installation of special addressable memory equipment.

19. Dedicated Line is a telephone circuit that is established permanently, or periodically at prearranged times, between two locations. This circuit will either be a simple voice or a "conditioned" circuit.

20. Key Sets are push buttons installed on a telephone instrument to permit answering one of several lines, to place a call on hold, or to access an intercommunication circuit by a central answering location or a secretary. The need to use key sets in a telephone system is obviated by the use of stored-program controlled PBX units. The stored-program controlled PBX units can perform all functions provided by the older key sets and many additional functions. Any of these functions may be accessed by depressing the hangup button momentarily and dialing the numbers representing the service desired.

21. Telephone instruments are available with other special features, such as built-in amplifiers for hard-of-hearing individuals, microphones for use in noisy areas, and mute switches for excluding the telephone from local conversations.

22. Speaker-phones are units that are connected to the telephone line in parallel with the usual telephone instrument; when turned on, they permit hands-off telephone operation and enable anyone near the instrument to join

in the telephone conversation. Each speaker-phone contains a sensitive microphone, an amplifier, a loudspeaker, and an off-on switch. The feedback from speaker to microphone causes speaker phones to sound quite different from telephone handsets.

23. Ring-down circuits are telephone circuits in which the instrument at the receiving end rings automatically when the instrument at the calling end is taken off the cradle. In security operations, ring-down circuits interconnect operation centers with locations of individuals required for command functions.

24. Sound-powered telephones are telephones containing dynamic microphones and narrow voice-spectrum passbands. They are constructed for interconnection and use without intervening amplifiers. Because sound-powered telephones require low power levels and no batteries or outside power source, they can be used in environments where intrinsically safe equipment is required.

25. Tone pads are 12 or 16 button switches found on many telephone instruments and are used also for control applications. The term "touch tone" is the registered trademark name for the tone pads of Western Electric. Touch dialing, enabled by tone pads, is faster than the manual dialing of older instruments and is an advantage in an emergency.

These features and services of a telephone system for a nuclear facility should be based on the overall needs of the facility and on the particular organizations and functions of its security operations. These features and services can be added to or deleted from a telephone system after it has been installed and operating; such changes often occur with changes in administration, management, and experience. The other features listed here are similarly available in some companies but require additional subassemblies.

The basic difference in implementing radio and telephone systems is that radio systems are specified by components and performance, while telephone systems are specified by functions and services. For example, if a mobile radiotelephone is implemented to enable certain facility personnel to originate and/or receive telephone calls in their vehicles, with the same service as a desk top telephone, this adjunct to the facility's communication system would be specified according to the source desired. If it is to be obtained from a local company franchised to provide this service, known as a radio common carrier (RCC), it will be specified by function and service. The local franchised public-switched telephone company may or may not be franchised also as an RCC. If it is to be provided along with the other radio systems and equipment used in the facility and interfaced with the public-switched telephone system at one of the control points of the base radio station, it will be specified by component and performance. Generally, implementing a mobile radiotelephone circuit for the exclusive use of a facility is very expensive, but it provides excellent service. To obtain this service through an RCC costs from $60.00 to $100.00 per unit per month, which is considerably less expensive than a privately owned system unless approximately 50 or more mobile units are used on the circuit. To obtain this service from an RCC may incur appreciable waiting time for access to a channel.

The high cost of mobile radiotelephone service will be found, in most cases, not to be commensurate with the slight advantages this service provides over a properly designed mobile radio (or paging) system that is interconnected with public-switched telephone service.

3.2 Wireline Data Systems

Telephone systems were developed to handle voice traffic, but their use for data transfer is increasing at a rapid pace. A telephone circuit designed specifically for voice traffic, often called a "voice grade" circuit, can handle data up to 2400 bits per second (bps) using frequency-shift keying (fsk) input and output modems, up to 4800 bps with quadraphase modems, and even higher rates using more complex modulation-demodulation techniques, depending on the length of the circuit. Any channel used for data communication can be subdivided, with the maximum data rate in the resultant subdivided channels proportional to their bandwidth. The narrowest channel width normally used is one/twenty-fourth of a voice channel, which can be used for data rates up to one/twenty-fourth of 2400 bps, or approximately 100 bps. American Telephone and Telegraph offers equipment and service capable of transmitting up to 4800 bps over dial-up service and 9600 bps over private lines. Higher rates than 9600 bps require special trunked circuits available from AT&T and other communication common carriers. Extremely high-speed (wideband) circuits can be provided by fiber optics, but use of this technology is not fully developed. The limiting bit rate of any circuit, as a function of circuit bandwidth (BW) and signal-to-noise ratio (S/N), is provided by the expression

$$BPS(max) = BW \times \ln (1 + S/N),$$

where ln is the natural logarithm.

Narrow-bandwidth telephone circuits, continuous-copper telephone circuits, and wide-band, "conditioned" telephone circuits can be obtained between locations if the locally franchised telephone company(ies) have the necessary facilities installed or are willing to install them. The narrower bandwidth telephone circuits are used often for signaling, teletype, alarms, and other special nonvoice applications. The wide-band circuits are useful for high-speed data and closed-circuit television[14] applications. Continuous-copper, also called "metallic pair" circuits, are used for direct-current control of remote devices such as radio transmitters.

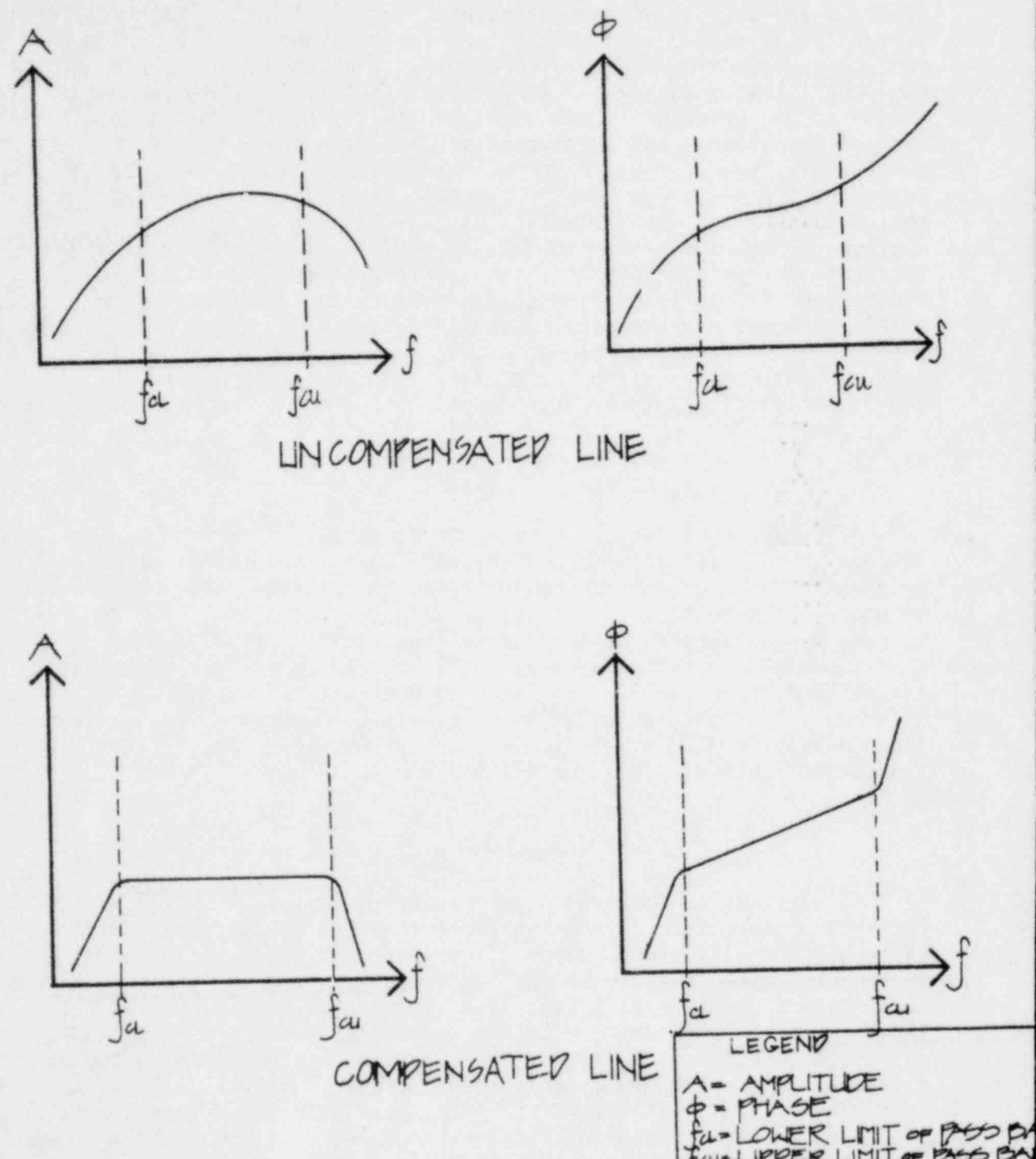
When selecting a circuit for wide-band use, a trade-off must be made between the monthly cost of the circuit, which is a function of length and characteristics of the line (bandwidth, phase distortion, and amplitude distortion) and the cost of the input and output modems. In some instances, dividing data into two or more streams and using less expensive circuits may be more economical than leasing one extremely broad-band circuit. Another trade-off is the use of broad-band analog television signals on a closed-circuit television circuit rather than digitized video. The digitized video uses more expensive terminal units but incurs a much lower circuit cost. Generally, as circuit length and period of use become longer, more money should be allocated to terminal units to decrease overall circuit cost. If the wireline is to be completely within a facility and installed by the facility, it can be installed with practically any characteristics desired and the cost of the modems can be reduced to the barest minimum. Coaxial cable can be used within a plant to provide extremely wideband circuits, but coaxial cables between facilities are usually so expensive that open wirelines of narrower bandwidth or multipair cables are used and the necessary bandwidth is provided electronically through use of circuits that compensate for or counteract phase and amplitude nonlinearities of the wireline cricuit - especially at the upper and lower limits of the passband of the circuit. Typical amplitude and phase characteristics of compensated and uncompensated lines are shown in Fig. 8. Note the wider useful spectrum of the compensated line. If the compensation is performed by the telephone company providing the line instead of by the owner of the equipment, the results will be similar, and it will be known as a "conditioned line." Reference 15 details Western Electric standards and methods of conditioning telephone lines to enable them to handle high-speed data. Electronic Industries Association Standard RS-232-C, "Interface Between Data Terminal Equipment and Data Communication Equipment Employing Serial Binary Data Interchange," is the accepted standard for equipment design that enables equipment manufactured by different companies to be interconnected by public service and other facilities to produce operating systems.

3.3 Obtaining Service from Franchised Company

All franchised public service companies have a marketing department or individuals who fulfill the functions of a marketing department. The business telephone number of this group is listed in the local telephone book, and a telephone call to them will initiate action by the franchised company contacted to provide the service desired. The franchised company probably will attempt to include all possible services and functions in the service it sells. An analysis of operational worth vs. cost trade-off of each service and function offered will result in selection of a better, cheaper system. Figure 9 presents a generic diagram of the interaction between a public-switched telephone system and a private interconnect system.

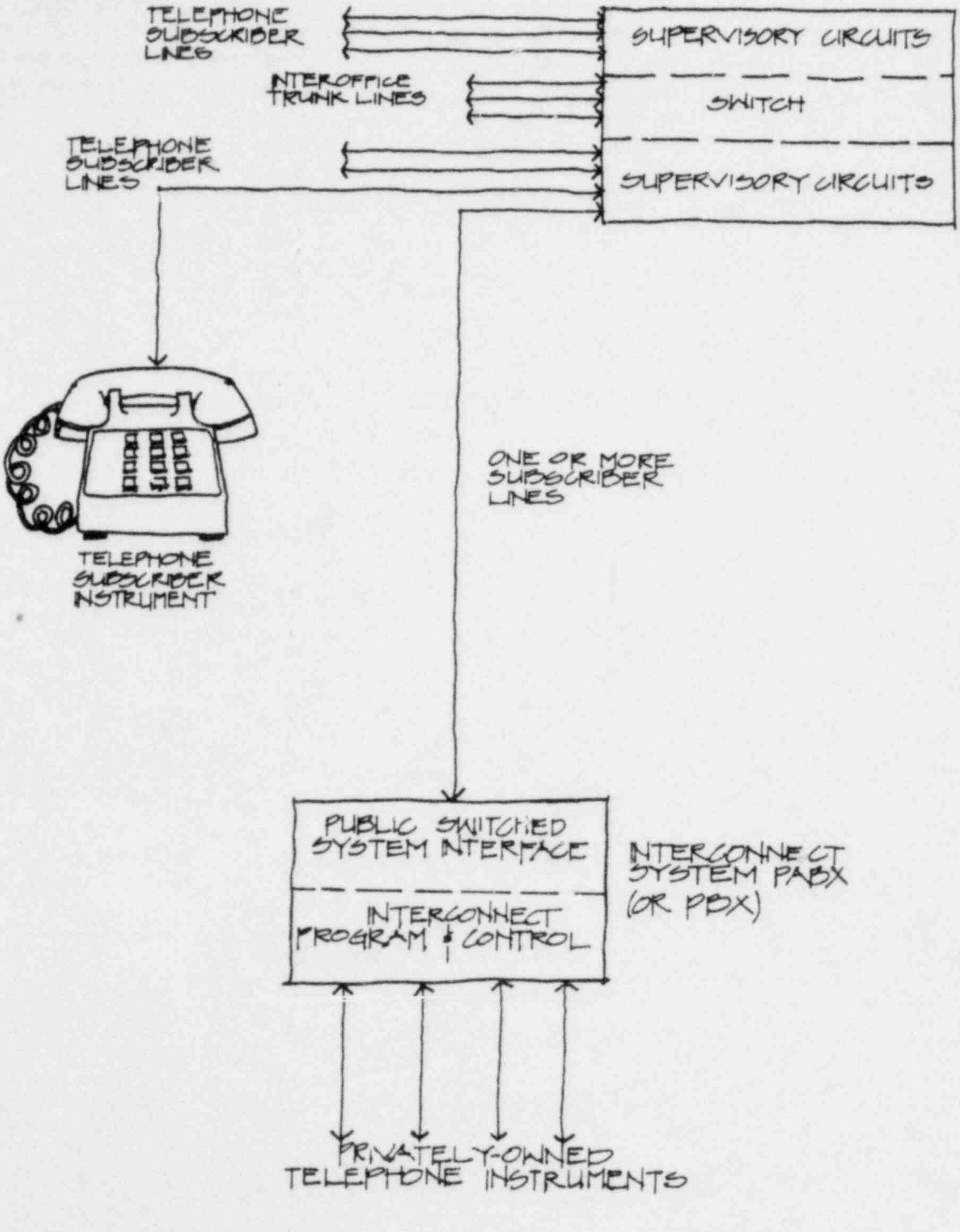
3.4 Obtaining Service from Private Company

Service may be obtained from private companies through a variety of procurement procedures. The most effective method is through competitive bidding based upon specifications carefully prepared to reflect the operational requirements to be fulfilled. The specifications should succinctly state the services and hardware to be supplied. Care should be exercised to ensure that two or more concerns can bid on the specifications with equal opportunity. The usual practice is to permit the companies concerned to review the specifications before bidding commences and to make suggestions for changes to enhance fairness. If this practice is adopted, the suggestions must be carefully evaluated to distinguish the changes requested to improve one's competitive position from the changes requested to improve the system as a function of cost, time, or other factors. The items most often overlooked in obtaining



EFFECT OF LINE COMPENSATION

FIGURE 8



TELEPHONE SYSTEM WITH PRIVATE INTERCONNECT SYSTEM

FIGURE 9

service from nonfranchised concerns are renewal of outmoded equipment, replacement of equipment lost through catastrophic events such as fire or flood, maintenance and training of operating personnel, and periodic furnishing of up-to-date telephone directories for the local dialing area. Rather significant costs are associated with these items, and these costs must be considered in evaluating franchised companies vs. private companies. The cost of money at the time the trade-offs are made must be considered to help decide whether to pay monthly for franchised service, to lease equipment, or to purchase equipment as a capital expense.

4. RADIO COMMUNICATIONS

4.1 Radio Voice Systems

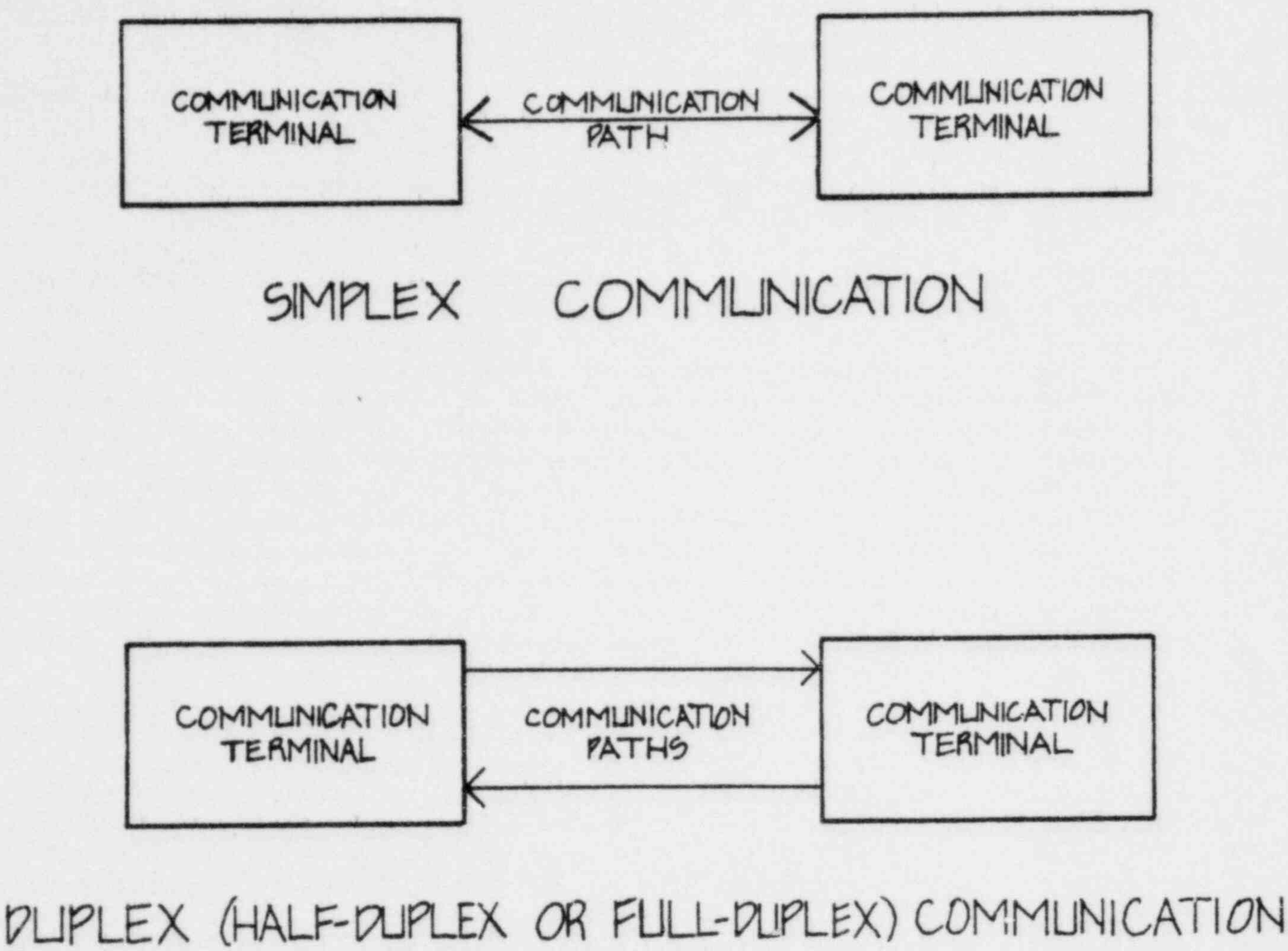
4.1.1 Mobile radio systems and equipment

A basic mobile radio system consists of a fixed-base radio receiver-transmitter (transceiver) and mobile (or portable) radio transceivers. The fixed-base transceiver may be a repeater, which enables portable and mobile units to communicate with each other when out of direct radio range of each other but still within radio range of the fixed-base stations.[16]

Use of a single frequency to transmit and receive at the fixed-base transceiver, as shown in the upper portion of Fig. 10, is known as "simplex operation." If the fixed-base transmitting frequency differs from the receiving frequency, the operation is known as "half-duplex operation." Repeater operation requires either half-duplex or full-duplex operation, as illustrated in the lower portion of Fig. 10. Full-duplex operation resembles half-duplex operation but has the added capability of the mobile transceivers to receive and transmit simultaneously, as in normal wireline telephone service. This is accomplished by using a duplexer instead of an antenna switch between the transceiver and the antenna and by not disabling the receiver when the transmitter is keyed. If there are several base stations in a mobile radio system, the use of half-duplex or full-duplex operation offers the advantage over simplex operation that the lower power mobile units do not compete for channel access[17] with a taller, higher power base station.

Base station transmitter power levels can approach 375 W at vhf high band, 275 W at uhf, and 125 W at 800 MHz. This power output is multiplied by antenna gains that can be as high as 12 dB over isotropic radiators.* On the other hand, the power output of mobile radios is seldom more and usually much less than 100 W, and the gain of mobile antennas is 0 to 4 dB over that of isotropic radiators. The transmitter power output of the small hand-held portables that can be carried in a coat pocket or hung from a belt varies from 0.5 to 5 W. The larger portables, often called "lunch pail portables" because of their similarity in shape, size, and carrying method to a lunch pail, have a maximum power output of 20 W. Antennas used with portable radio units are very inefficent for the following reasons: the small radio unit provides poor ground plane; the radio unit with its antenna may be used in different spatial orientations; and the physical size of the antennas is small for the convenience of the user. The result is 0 to -10 dB gain. A basic criterion that should be used in radio system design is that the "talk-out" range from the base station (or repeater) to the mobile units should approximately equal the "talk-back" range from the mobile unit to the base station. This is accomplished by the proper choice of power levels and antenna gain, and sometimes by the use of voting receivers.

*The term "isotropic radiators" is defined in the Glossary and discussed in Appendix I.



SIMPLEX VS. DUPLEX OPERATION

FIGURE 10

Voting receivers are used in radio systems that employ portable radios over an extensive area. Voting receivers allow portable radios to be used in locations too distant from the base station (repeater) for their signals to be received by providing reception locations within the limited range of the portable units. All voting receivers on a channel serving a particular geographical area, not necessarily conterminous, are connected to a voting comparator, which selects the voting receiver that is producing the best output audio signal. Figure 11 presents functional block diagrams of a basic receiver, transmitter, and voting comparator.

Currently available receiver sensitivities, transmitter power outputs, transmission line capabilities, and antenna gains coupled with normally available antenna support towers produce maximum base-mobile ranges on the order of 25 to 35 miles. Appendix I discusses in detail these propagation factors, and presents techniques for determining the range for a particular set of system parameters. Quite often, terrain and/or demographic features prevent siting a base station and antenna in a location that will provide the desired coverage area. In this case, multiple transmission sites may be employed for the desired coverage. The use of this technique requires that the transmitter be sited within range of the desired mobile or portable unit or that all transmitters be arranged in parallel or in sequence. A variety of techniques may be employed to perform these tasks, and all of them involve compromises. If an automatic vehicle location (AVL) system is employed,[18] the dispatcher knows the location of the desired unit and can be provided with controls to direct the desired transmitter to broadcast his message. If the dispatcher is replying to a previous transmission from the mobile unit (the reply can be to a simple "request to talk"), displays on the dispatcher's console can indicate which receiver provided the best signal (i.e., which receiver was selected by the voting system), and the transmitter covering the corresponding area can be selected by the dispatcher. Another method is to use either sequential or simulcast transmission[19] to contact the mobile or portable unit and, after the called unit responds, to select the transmitter that covers the area in which the called unit is located. None of these methods is suitable for mobile-to-mobile, portable-to-portable, or mobile-to-portable operation without some modification. Reference 20 discusses the problems with wide-area use of repeaters and methods that can be used for repeater selection. Generally, the methods used include manual selection from the mobile unit by use of subaudible or Continuous Tone Code Squelch System (CTCSS) tones[21]* or by use of selective address delay techniques for controlling the repeaters. Other selective address techniques are starting to appear, the most notable of which is Motorola's Digital Coded Squelch Technique,[22] which provides much greater flexibility and operating convenience than CTCSS tones.

Because the radio spectrum is crowded, the FCC discourages the exclusive use of a frequency or a pair of frequencies in a duplex mode for a system that does not utilize them fully. A general rule of thumb is that approximately 50 units are normal loading for a half-duplex channel. A unit is defined as one mobile or two portable transceivers. If a licensee is not going to load a channel to this capacity, he is encouraged and sometimes forced to share the channel with one or more other users. Separate facilities employing the same frequencies and use of a community repeater both permit shared-frequency use. A community repeater simplifies the system, reduces

*A list of EIA specifications applicable to communication systems is contained in Appendix VI.

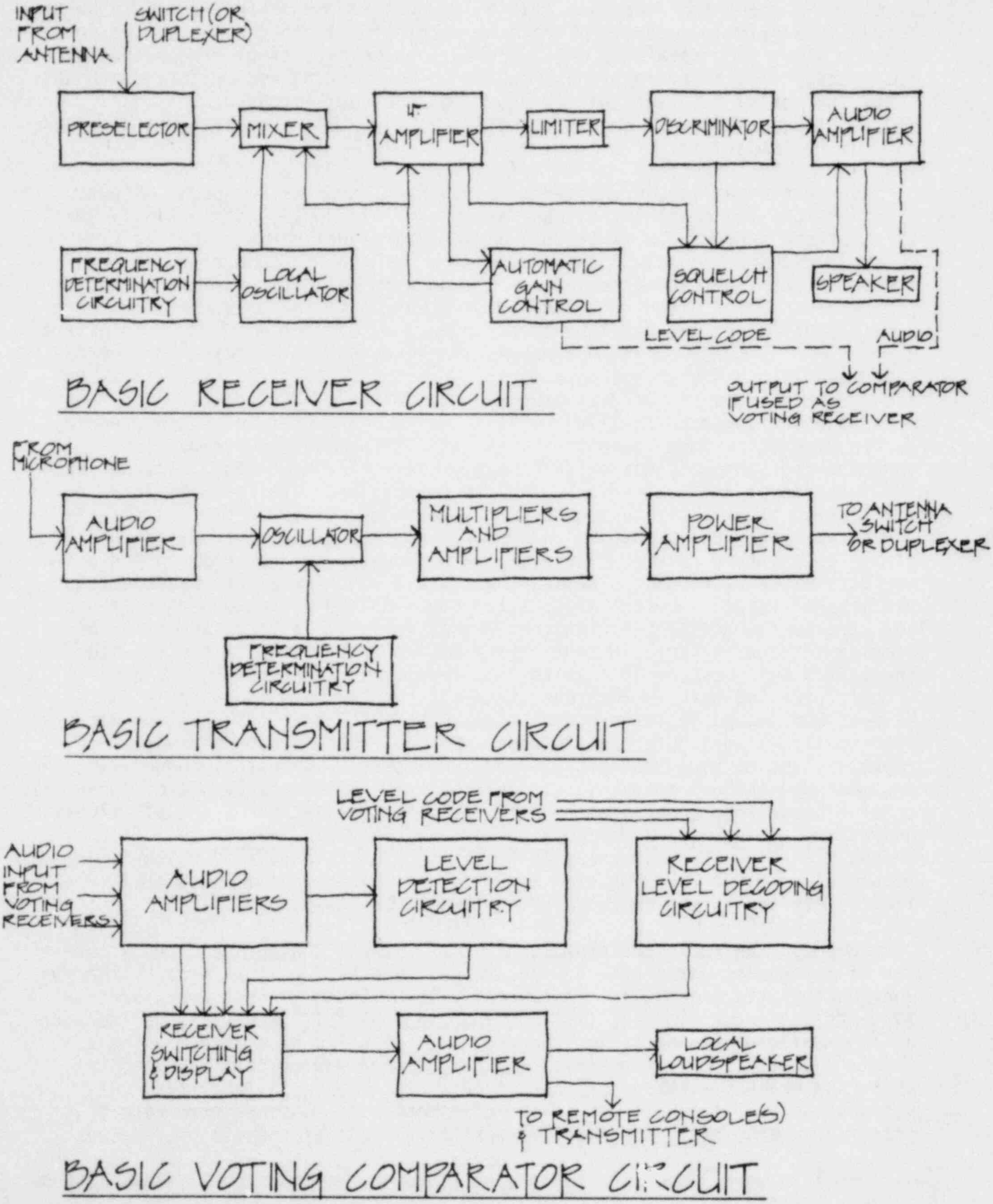

INPUT FROM ANTENNA
SWITCH (OR DUPLEXER)
PRESELECTOR
MIXER
IF AMPLIFIER
LIMITER
DISCRIMINATOR
AUDIO AMPLIFIER
FREQUENCY DETERMINATION CIRCUITRY
LOCAL OSCILLATOR
AUTOMATIC GAIN CONTROL
SQUELCH CONTROL
SPEAKER
LEVEL CODE
AUDIO
OUTPUT TO COMPARATOR IF USED AS VOTING RECEIVER
BASIC RECEIVER CIRCUIT
FROM MICROPHONE
AUDIO AMPLIFIER
OSCILLATOR
MULTIPLIERS AND AMPLIFIERS
POWER AMPLIFIER
TO ANTENNA SWITCH OR DUPLEXER
FREQUENCY DETERMINATION CIRCUITRY
BASIC TRANSMITTER CIRCUIT
LEVEL CODE FROM VOTING RECEIVERS
AUDIO INPUT FROM VOTING RECEIVERS
AUDIO AMPLIFIERS
LEVEL DETECTION CIRCUITRY
RECEIVER LEVEL DECODING CIRCUITRY
RECEIVER SWITCHING & DISPLAY
AUDIO AMPLIFIER
LOCAL LOUDSPEAKER
TO REMOTE CONSOLE(S) & TRANSMITTER
BASIC VOTING COMPARATOR CIRCUIT

FIGURE 11

interference, and reduces the overall cost of the system for the various users. Community repeaters employ CTCSS or other coded squelch techniques to prevent radio operators of one user from hearing radio operators of another user. Usually, a community repeater is located conveniently for all users, and it is actuated by wireline, control stations, or a combination of both. A control station is a fixed-base station that operates a repeater the same way a mobile unit operates a repeater: it transmits on the repeater's receiver (or input) frequency and receives on the repeater's transmit (or output) frequency* and thus allows communication with mobile and portable transceivers within range of the repeater that employs the same CTCSS frequency as the control station. A community repeater or any other radio system can use selective-calling techniques to enable the control point (see Glossary) to communicate with one or all radio stations (mobile, portable, or fixed) with which the control point is associated. The speakers of all radio stations using the community repeater will be muted until they receive a call. The exception to this rule, as required by the FCC Rules and Regulations, occurs when a radio station starts to access the community repeater while it is already in use by other stations. In this instance, the station attempting to access the repeater will hear all other traffic on the repeater when the microphone is removed from its hanger or when a listen switch (required by the FCC) is depressed. The reason for this exception is the basic limitation of community repeaters: they can handle only one message at a time, and if two stations try to access the repeater simultaneously, interference will result.

Community repeaters often are owned by Radio Common Carrier (RCC) companies, who lease access to the repeater and mobile, portable, and control station equipment for use on the repeater channel. The RCC companies usually are franchised as common carriers to provide certain services in the area; however, RCC companies have no exclusive right to the use of repeaters. Therefore, a facility may install a community repeater for its own use and permit different departments or operations in the facility to operate independently of each other through the repeater.

Channel trunking is another interesting technique that conserves the frequency spectrum by utilizing channels more efficiently. Channels may be trunked if two or more channels of a facility cover the same geographical area and if the frequency spacing between these channels is less than the maximum frequency capabilities of the mobile and/or portable radio units to be used. Two basic methods can be used. One is to have all the mobiles and/or portables scan the channels constantly until they detect their address on a particular channel; at this point, they stop scanning and monitor that channel for a message to them. The reply can be on the same channel, on a channel to which a code contained in the address directs them, or it can be the message. A second method is to have all the mobiles and/or portables monitor a command channel upon which instructions are sent telling the individual units which channel to monitor for a forthcoming message. Again, the reply can be on the channel on which the message is received or on one to which a code contained in the message directs them. Communications

*Note uses of control stations illustrated in Figs. 3 and 5.

initiated by a mobile or portable unit are handled similarly; that is, the mobile or portable unit sends a request to talk on the command channel and is directed to a particular channel for the exchange, or it sends the initiating transmission on any channel that is not in use and the base station constantly monitors all channels.

The IMTS (Improved Mobile Telephone System), which is available throughout the United States through franchised companies, is a trunked system in which the command channel (in this case called the "idle channel") does not stay on one designated frequency channel but moves from channel to channel. All the mobile radiotelephone receivers not being used on a telephone call monitor the idle channel, which is designated by the transmission of a 2000-Hz idle tone. The next incoming call appears on the idle channel, the recipient of the call acknowledges the call with an answering signal, and all other units move on to the next idle channel. Channel trunking is being considered for Special Mobile Radio (SMR) systems and cellular systems.[23] Channel trunking should be considered for mobile radio systems that must load the available radio channels with more mobile and portable units per channel than can be accommodated with conventional techniques.

4.1.2 Paging systems

There are three basic types of radio paging systems: tone only, tone and message, and tone and voice. The simplest tone-only paging system provides the greatest capacity of pages per channel, because only a fraction of a second is needed to transmit a tone signal to a pager, while a digital and voice message will take up to the maximum allowable time for a voice transmission. Most paging systems limit this time to between 10 and 45 sec. Paging systems using tone-only techniques can employ pagers with very narrow bandwidth, while paging systems using tone and voice must pass sufficient bandwidth for voice intelligibility, usually about 3.5 KHz. Therefore, for a given transmitter output power, antenna height, etc., a tone-only paging system provides greater paging area coverage than a tone-and-voice paging system due to the lower gain-bandwidth product.[24] Manufacturers of paging equipment include: Motorola; General Electric; RCA; NEC America, Inc.; Standard Communications; IWATA Electronics Co., Ltd.; IEC Electronics Corp.; Harris Corporation; and others. These companies sell pagers for approximately $200 to $400 per unit, 1978 dollars.

There are other specialized types of paging systems that have limited application. ITT Terryphone Corp. offers a wired system that is used in many hospitals and airports and in some industrial and manufacturing installations. This system issues an audio page through loudspeakers located throughout the area of coverage, and the paged individual can step to one of the paging stations to talk to the individual originating the page. Autophone AG of Switzerland offers another type which employs a wire loop around the paged area to produce a very low-frequency (20 to 40 KHz) and low-power electromagnetic field. The pagers operate anywhere within the loop and are of the tone-and-message type. Note that paging systems that use a wired system, such as ITT Terryphone, or a low-power loop, such as used by Autophone AG, do not occupy radio-frequency spectrum space and require no FCC authorization. Their general disadvantages are that they are restricted to an area of operation that is served by one PBX (for Terryphone) or to an area of approximately one city block (Autophone) and do not provide good coverage within an area that is effectively shielded by metal.

To operate tone-only paging, the user activates the paging transmitter from a paging terminal or a telephone interconnected with the paging system. Most paging systems are equipped to signal all pagers in the system (all-call), groups of pagers (group-call), or an individual (individual-call, also known as selective-call). The pager(s) called produces a sound or a vibration to signify that the person carrying the pager is to telephone a prearranged number, come to a prearranged location, or perform some other act. The method used to signal a group or an individual pager, known as selective signaling,[25] varies among suppliers of paging equipment; however, most manufacturers of paging receivers produce them for any selective signaling desired. In the simplest method of selective signaling, the sequence of two audio tones, which is specific to a particular paging receiver, activates a squelch circuit. The receiver may respond to two sequences, one for itself and the other for the group of receivers of which it is a member, that is, a group call or all call. This method of addressing pagers, usually known as the "two-tone sequential" method, is limited to approximately 3000 paging receivers per radio frequency channel due to the number of discrete tone frequencies that can be used in the audio spectrum. Systems of higher capacity use five-tone sequences and digital schemes with addresses having as many as 23 digits. This enables a paging system to have up to 100,000 paging receivers with several different indications (messages) for each receiver. Reference 26 presents a comprehensive discussion of signaling techniques used in modern paging systems.

Tone-and-message pagers operate in a manner similar to tone-only pagers, except that a choice of five or seven (depending on the manufacturer of the paging system) messages can be transmitted digitally along with the address of the pager. Each transmission presents a prearranged letter or number displayed on the pager to indicate the message.

Tone-and-voice pagers operate similarly to each of the above, except that after the tone or tactile message is received, the individual carrying the pager listens while the individual originating the page speaks his message. Individuals originating pages receive a tone or visual signal to indicate the beginning and near end of the message time.

Paging systems may include a telephone interconnection to permit access to the system from a telephone. Storage systems may be incorporated into paging systems to enable pages made simultaneously to be stored and automatically transmitted in the proper sequence. This technique is rather expensive since it increases the cost of a paging system from $30,000 to $75,000, but it does prevent other callers who attempt to access a paging system simultaneously from getting busy signals or being denied access to the paging transmitter and it greatly increases the capacity of a paging system.

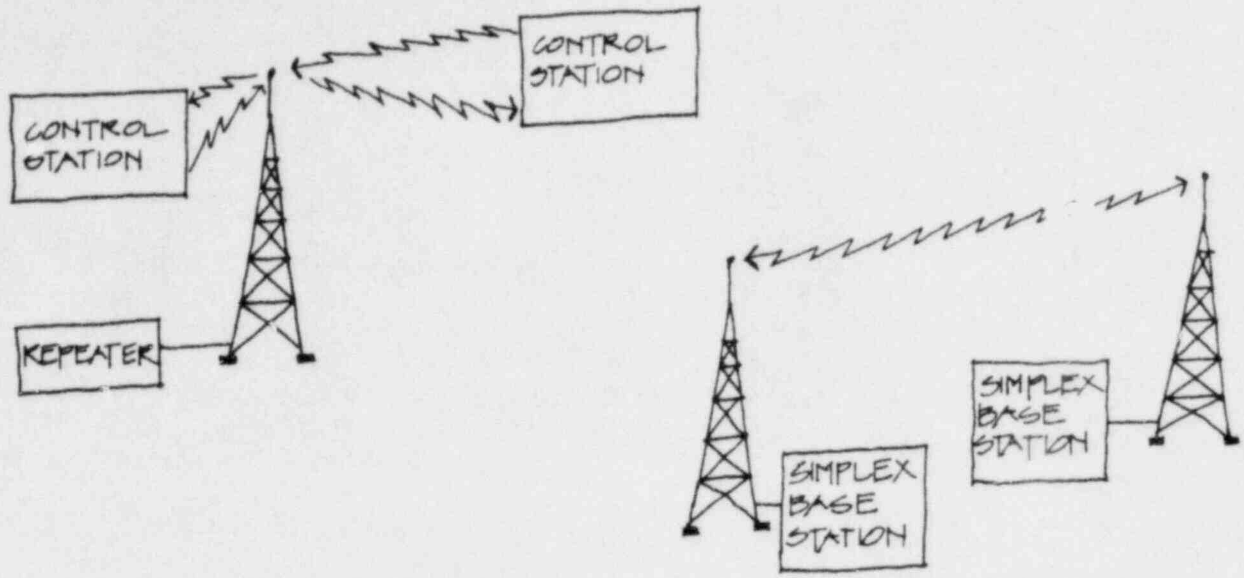
Some pager units have optional mute switches to silence the tone signal of the pager while in any environment unsuitable for an audible page. If a page is received during the time a mute switch is actuated, the pager will display a visual signal. An option available on some models greatly increases battery life both by operating the paging receiver for only short durations to sample for incoming pages and by operating the receiver continuously only while a page is being received.

Although many combinations of options are available for paging systems, the user saves money on pagers containing only the required functions. In general, the smaller and more rugged receivers have better selectivity and cost more. Section 4.4.6 presents parameters that should be defined in paging receiver specifications and lists some of the trade-offs that should be made when the values for these parameters are selected.

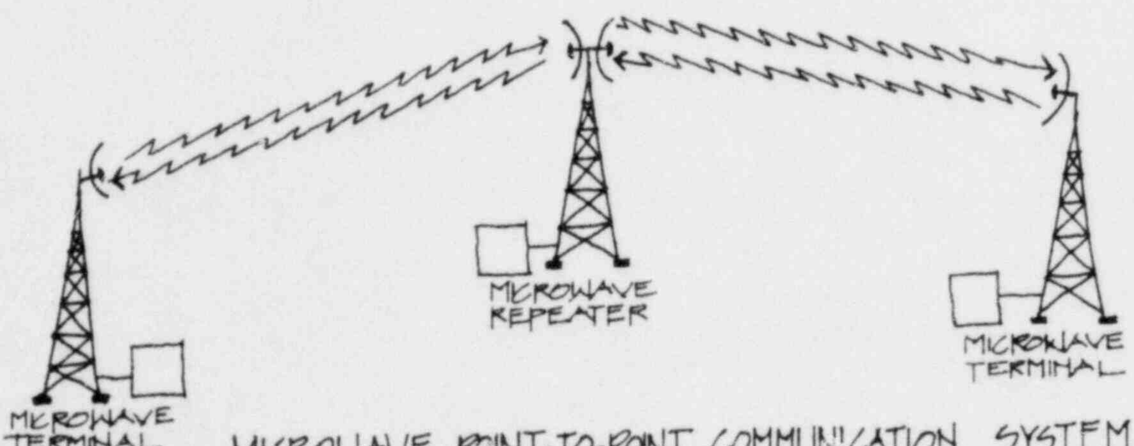
4.1.3 Point-to-point radio systems and equipment

Fixed point-to-point radio systems are required for communication between locations when franchised common carrier circuits (usually wireline) do not exist or cannot supply the needed service. Radio frequencies are licensed by the FCC for point-to-point use based on need and intended use and may be arbitrarily divided into three general categories: operational fixed microwave communications; and base-to-base communications, as illustrated in Fig. 12; and operational fixed vhf or uhf, as illustrated in Fig. 13.

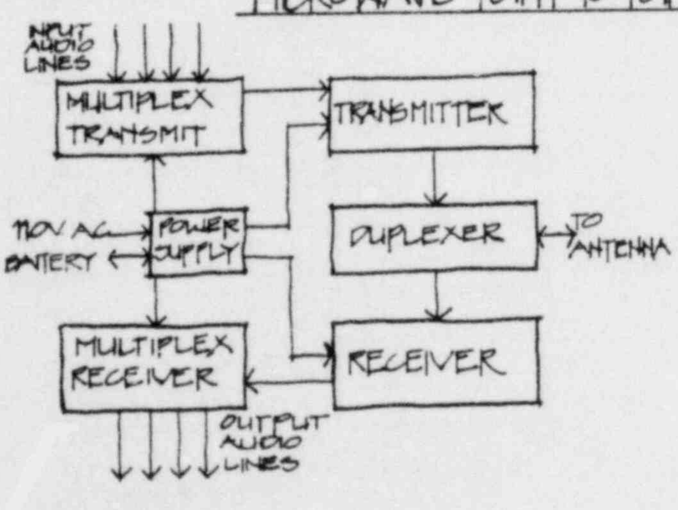
4.1.3.1 Operational fixed microwave. Volume V, Part 94 (Private Operational Fixed Microwave Service), of the FCC Rules and Regulations provides an annotated table of frequency bands, maximum output power, frequency tolerance, maximum bandwidth, and maximum antenna beamwidth that may be used for operational fixed stations in the microwave region (above 952 MHz). Each microwave frequency assignment may be used for a number of voice, voice and data, or (in the assignments above 6 GHz) voice, data, and/or video channels. In the 900-MHz region the maximum permissible bandwidth is 100 KHz, which with today's technology will provide a maximum of about six voice channels. The lowest region in which sufficient bandwidth usage is permitted to handle video (television) signals is 6 GHz. Generally, as frequency is increased, the frequency availability increases, the permissible bandwidth increases, the cost of the equipment increases, and the distance allowed between a receiver and a transmitter for a given fade margin decreases (the obtainable hop length decreases). Figure 14 shows a four-hop operational fixed microwave system with a different equipment configuration at each site. Site 1 is a typical terminal: the multiplexer combines the information received over the local wireline circuits into a composite signal to be transmitted over the microwave system and separates the similar composite signal from the microwave system into a voice or data signal for each interconnecting wireline circuit. The distance between sites, the hop length, is determined by terrain, economics, and desired system characteristics. The radio-frequency (rf) power levels used in operational fixed microwave systems require that a clear line of sight be used for the propagation paths for each hop. Earth curvature and terrain dictate that antenna heights and output power be increased as hop length increases; therefore, the economically optimum hop length is a trade-off between the cost of real estate and electronic equipment and the exponential cost increase of towers as a function of tower height. Another major factor influencing hop length is signal-to-noise ratio. If the hop is too long, the signal at the receivers has a low signal-to-noise ratio, which makes the signal difficult to use. If the hop is too short and there are many hops in the system, the signal-to-noise ratio decreases as the equipment at each repeater inadvertently injects some noise into the signal. Typical hop lengths for nonmountainous areas are 8 to 15 miles for 12-GHz systems, 12 to 25 miles for 6-GHz systems, and 20 to 35 miles for 2-GHz systems. In mountains, the hops are usually dictated by topography, which



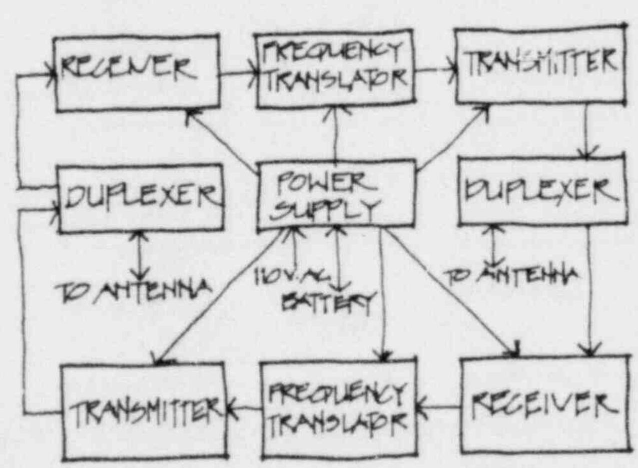
TWO POINT-TO-POINT COMMUNICATION SYSTEMS



MICROWAVE POINT-TO-POINT COMMUNICATION SYSTEM

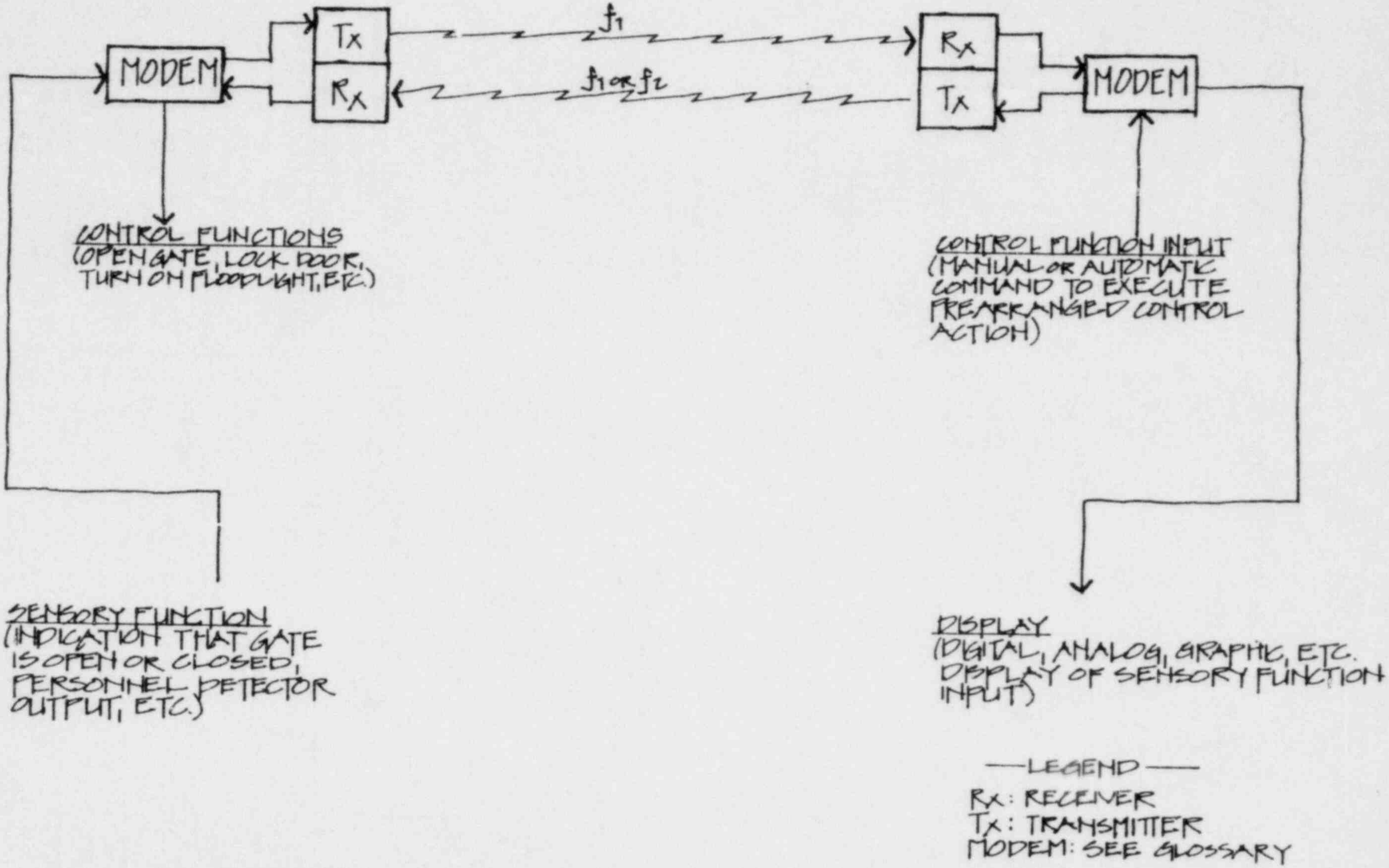


MICROWAVE TERMINAL



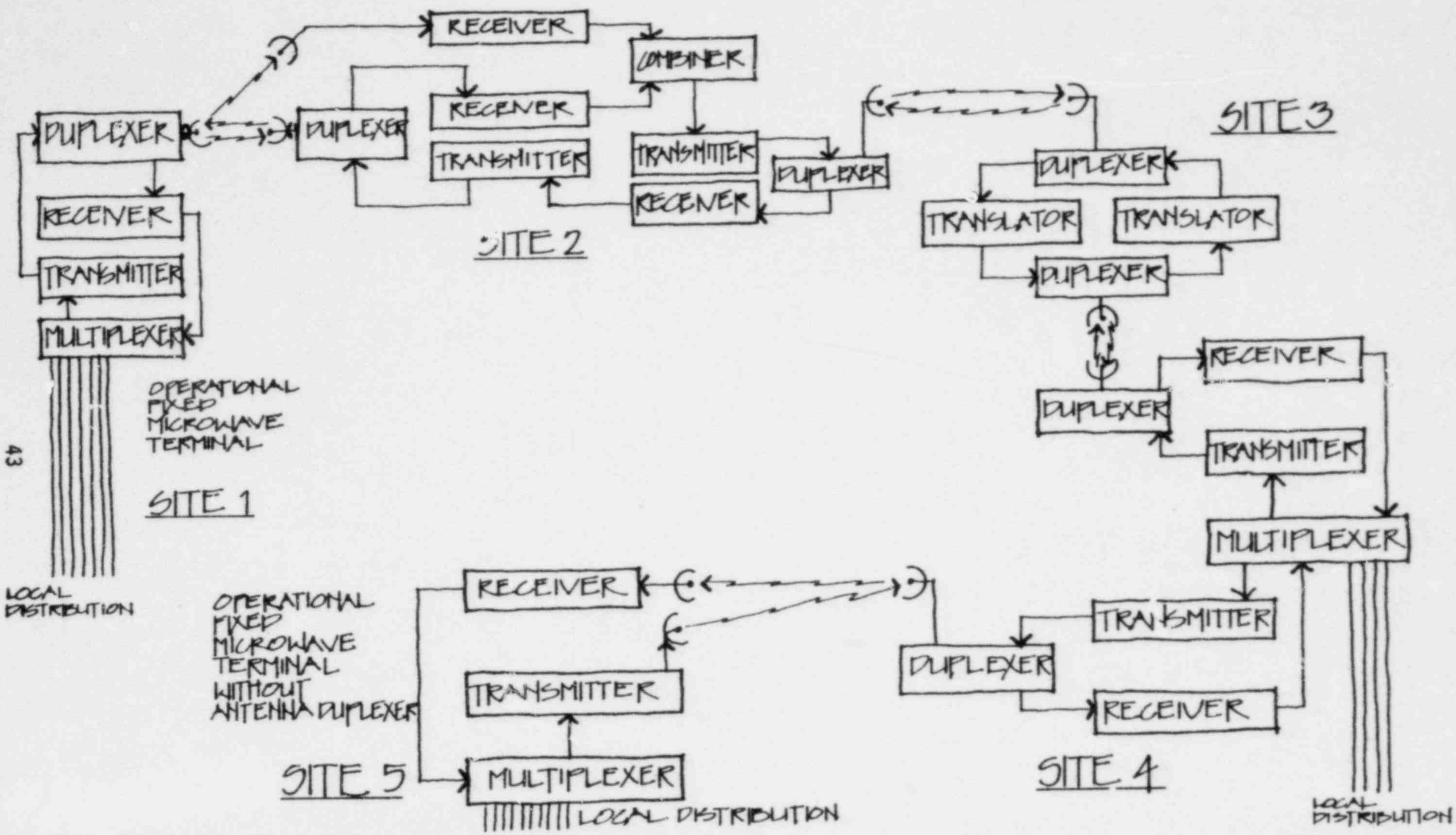
MICROWAVE REPEATER

FIGURE 12



OPERATIONAL FIXED VHF OR UHF

FIGURE 13

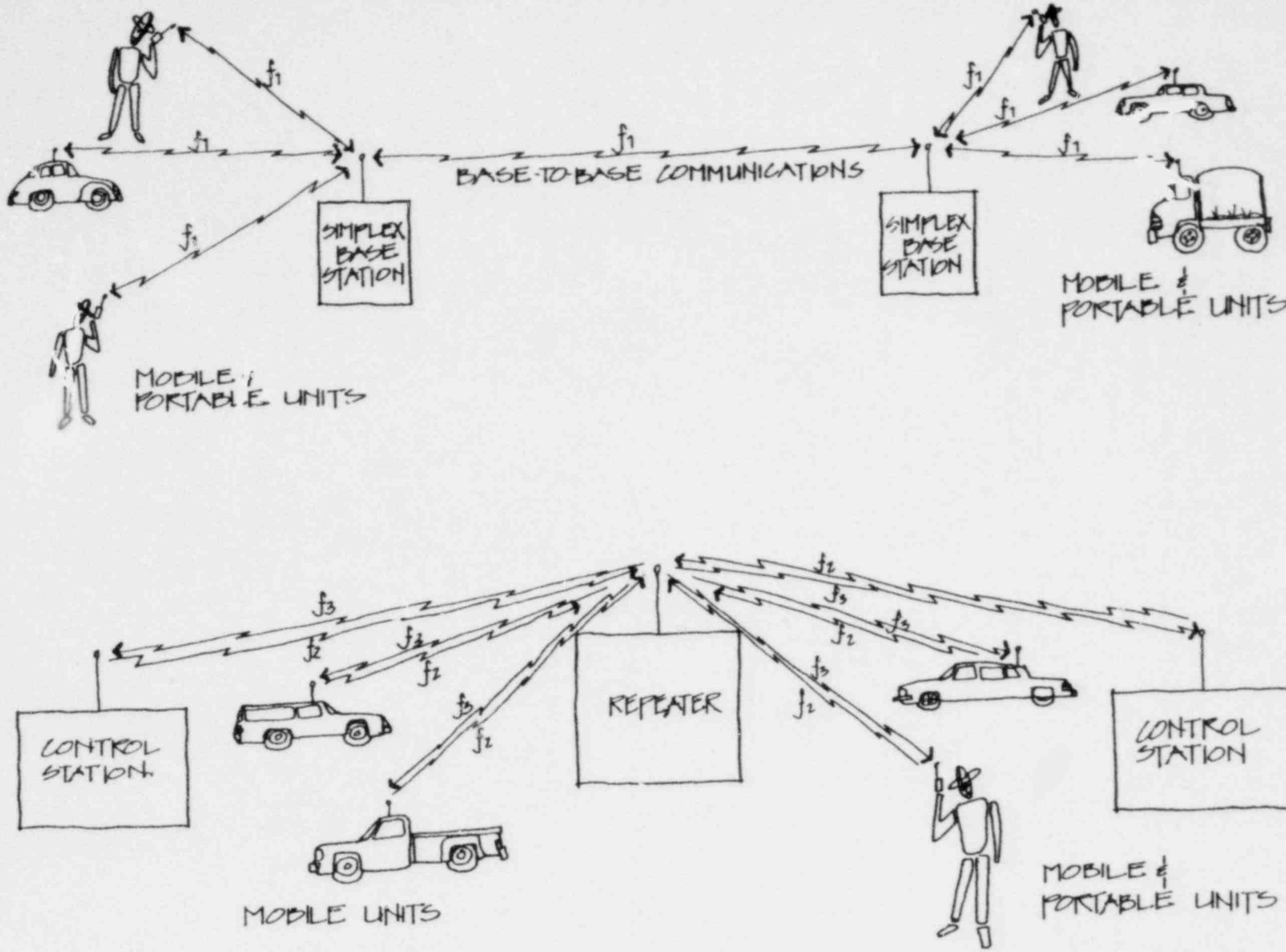


TYPES of OPERATIONAL FIXED MICROWAVE HOPS

FIGURE 14

results in hops longer and shorter than these typical figures. When difficult propagation conditions are encountered or when increased reliability is required, a technique called propagation diversity may be used, as shown on the path from site 1 to site 2 in Fig. 14. In this application, dual receivers and receiving antennas are used, and the output of the two receivers is combined and fed into the associated transmitter. The two receiving antennas are spaced so that a strong signal is received at one of them when a weak signal is received at the other. This spacing is determined by the intervening terrain and the physical distance between Fresnel zones (see Glossary). Site 2 shows an equipment configuration typical of older systems and used when no local distribution of the communication traffic going over the system is required. The equipment at site 3 is used for the same purpose, but at site 2 the equipment is composed basically of receivers driving transmitters to amplify the outgoing signal. The transmitted signal at a repeater, or translator, is of a different frequency than the received signal. If this were not the case, the receiver would receive the signal transmitted at its own site instead of that transmitted from the adjacent sites in the system. The translators at site 3 receive the incoming signal, amplify it, and translate it into the new frequency. The disadvantage of a translator is that it cannot be used, as can a companion receiver-transmitter-repeater system, to drop and/or insert signals for local distribution, as shown in the figure for site 4. Two advantages of a translator are that the signal is not demodulated to audio or video and that less noise is injected into the signal since the demodulation-modulation process is absent. The terminal at site 5 resembles the one at site 1, except that dual antennas are used in place of an antenna duplexer. References 27 and 28 are compendia of tables, charts, and formulas that are extremely useful for designing an operational fixed microwave system.

4.1.3.2 Base-to-base communications. Two simplex base stations within range of each other and operating on the same frequency can communicate with each other. In the same context, two control stations using the same repeater can communicate with each other. Such communications are illustrated in Fig. 15. The two base stations shown in the top half of the figure can communicate with each other (base-to-base communications) and with the mobile and portable units on the simplex frequency *f*1. The two control stations in the bottom half of the figure can communicate with each other (base-to-base communications) and with the portable units on the duplex pair *f*2 and *f*3. Base-to-base communication is legal for any station licensed under Part 89 (The Public Safety Radio Services) but is legal only under certain conditions for base stations licensed under Part 91 (Industrial Radio Services) and most of the other parts of the FCC Rules and Regulations. The permissible base-to-base communications and the conditions under which they are permissible are given in paragraph 91.151 of the FCC Rules and Regulations. Generally, this paragraph states that base-to-base communications are permitted when necessary to save life or property, when wireline facilities are unavailable, and when necessary to provide information of immediate importance to associated mobile units.



BASE-TO-BASE COMMUNICATIONS

FIGURE 15

4.1.3.3 Operational fixed vhf and uhf. Four of the services authorized in Part 91 of the FCC Rules and Regulations (Power Radio Service, Special Industrial Radio Service, Business Radio Service, and Manufacturers Radio Service), all of which can be used to protect a nuclear facility, have frequencies listed between 72.02 and 75.98 MHz, which can be assigned for operational fixed use. In addition, Parts 89 and 91 list some frequencies in the 150- and 450-MHz regions for operational fixed use under special circumstances - particularly for locations beyond a specified distance from metropolitan areas of certain sizes. These vhf and uhf frequencies are generally used for data communications, especially telemetry and remote-control applications, as illustrated in Fig. 13.

4.1.4 Changing technology

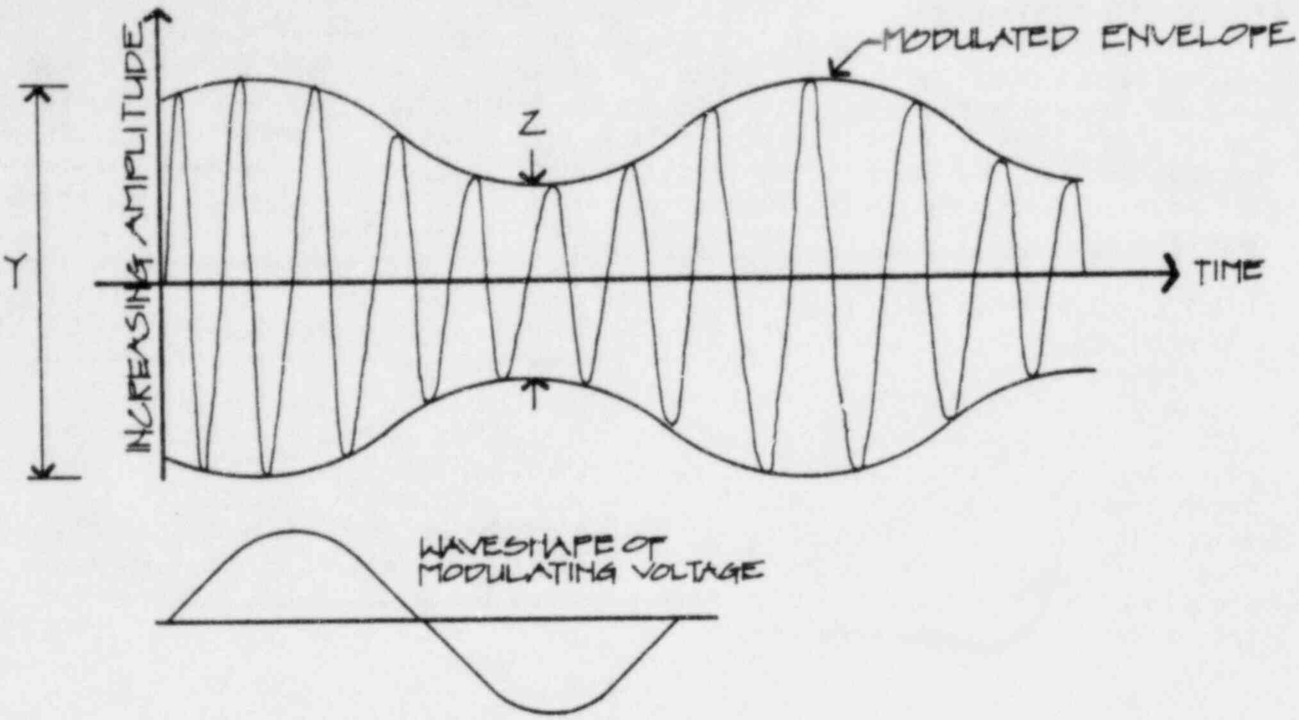
The state of the art of radio systems and equipment is being improved constantly due to the competition among equipment manufacturers. Before the development of frequency-modulation (FM) techniques, voice radio systems employed amplitude modulation (AM). Because FM provided superior noise-rejection characteristics, this technique was adopted to support the tremendous increase in mobile radio communications immediately after World War II. Channel spacing of early FM systems was established by the FCC at 50 KHz, and as crystal frequency-control devices improved in stability and demand for additional frequencies increased, the channel spacing was decreased to 30 KHz and later to 15 KHz in the vhf low- and high-band regions. Channel spacing in some services has been reduced to 7.5 KHz. Channel spacing in the uhf and 900-MHz region is standardized now by the FCC at 25 KHz.* There is increasing pressure among manufacturers and users of mobile radio equipment to change the FCC Rules and Regulations to permit the use of single-sideband (SSB) modulation to convey voice information. The present Rules and Regulations for public safety and industrial licensees, provided in the "Technical Standards" portions of Parts 89 and 91, respectively, permits double-sideband (DSB) amplitude modulation (6A3) and up to 20-KHz bandwidth frequency modulation (20F3). (The designations used for types of modulation and bandwidths are provided in Part 2 of the FCC Rules and Regulations. Generally, the letter "A" designates amplitude modulation, "F" frequency modulation, and "P" pulse modulation. The number in front of the letter indicates the overall modulating frequency in kilohertz and the number after the letter indicates the maximum modulating frequency in kilohertz. Single-sideband modulation is designated by a suffix "A"; therefore, 3A3A, the most common SSB modulation used in the vhf and uhf regions, would occupy a bandwidth of 3 KHz and have a maximum modulating frequency of 3 KHz.) The designation for SSB modulation indicates that it occupies half the AM bandwidth for a given maximum modulating frequency, and the designation for AM indicates a more efficient use of bandwidth than FM. Each of these modulation methods is discussed below along with its advantages and disadvantages.

*30 KHz for cellular 800-MHz systems.

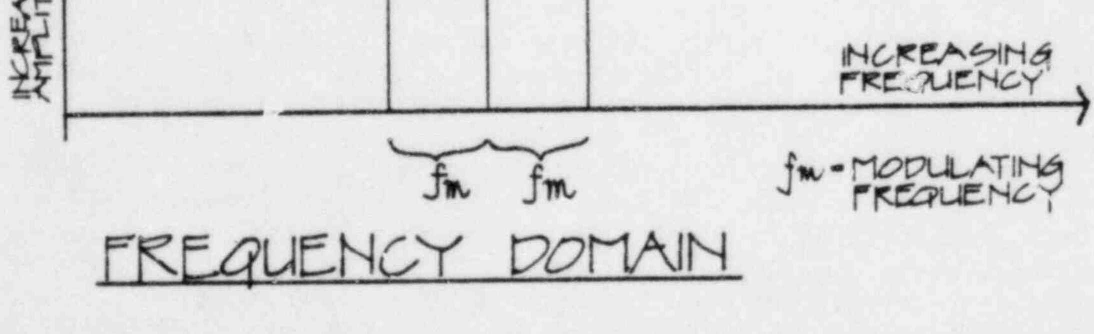
Amplitude modulation, varying the amplitude of a carrier frequency in relation to the modulating signal, was the first technique used to convey voice information via a radio carrier. It was preceded only by A1 modulation, which turns a carrier off and on, as in Morse Code, to convey information. In the process for 6A3 modulation, the voice frequencies are mixed (heterodyned) with the carrier frequency of the transmitter. The time domain plot for a single audio tone modulating an rf carrier frequency is shown in the top half of Fig. 16. The commonly used measures of modulation are called the modulation index and the modulation percentage. The modulation index is $(Y - Z)/Y$ and the modulation percentage is 100 times the modulation index, where Y is the average amplitude of the modulated signal and Z is the minimum. The frequency domain plot corresponding to this same example is shown in the lower half of Fig. 16. Amplitude modulation is the easiest voice modulation to create and receive. It is highly subject to atmospheric and man-made interference because the noise created by interfering signals appears on the modulated envelope just as an intended signal does and cannot be removed in the receiving process if it is in the same frequency range as the desired voice signal. A problem with AM is that it occupies a spectrum bandwidth twice the width of the highest modulating frequency.

Frequency modulation, varying the frequency of a carrier in relation to the modulating signal, is even more wasteful of spectrum space than AM is, but it provides a signal relatively immune from the amplitude variations caused by noise. Even if two signals are transmitted on the same frequency, one of them may be heard because of the phenomenon called "capture effect." Figure 17 illustrates frequency and time domain plots of a carrier frequency being modulated by a single audio tone. Notice the increased density of spectral lines as the modulating frequency is decreased. An infinite spectral density is approached as the input approaches 0 KHz. The usual measures of frequency modulation are the maximum modulating frequency and the maximum frequency deviation. Early FM mobile radio systems used frequency deviations of 100 KHz and above, while today the maximum allowable frequency deviation in the Public Safety and the Industrial Radio Services is 5 KHz for voice radio systems. Figures 16 and 17 illustrate the effect of a single audio-frequency modulating an rf carrier via an AM and FM modulation system. References 29 and 30 contain abundant information about modulation theory.

Single-sideband modulation resembles the AM technique described above, except that it removes one of the two sidebands and most of the carrier from the signal (Fig. 16). Figure 18 illustrates time and frequency domain plots of five SSB-modulated signals. A radio receiver must reinsert a signal equivalent to the original carrier frequency to demodulate the SSB-modulated signal received and produce an intelligible audio output. The greatest difficulty with SSB band systems is that unless the reinserted frequency is within a few cycles of the original carrier frequency, the resulting signal will be very distorted by a "Donald Duck" effect. Crystal manufacturers have struggled to achieve the necessary frequency stability for the reinserted carrier. A compromise solution is to put a fine-frequency adjustment control on the receivers, as is done with popular citizen's band SSB units under the guise of "phasing control" or "fine tuning." An obvious advantage of SSB modulation is that it uses less spectrum space than conventional AM. Another advantage is that the narrow bandwidth of the signal permits very selective



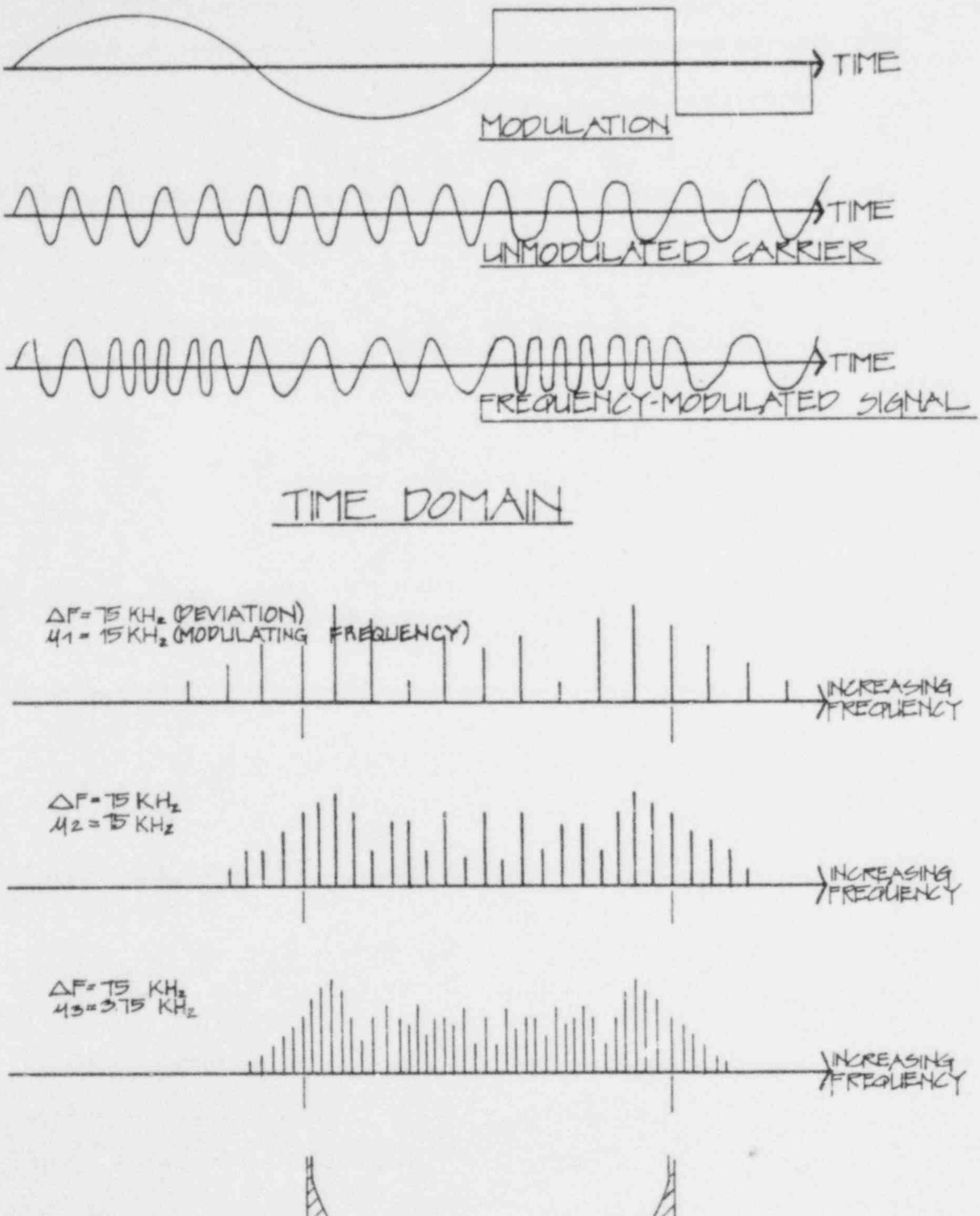
TIME DOMAIN



FREQUENCY DOMAIN

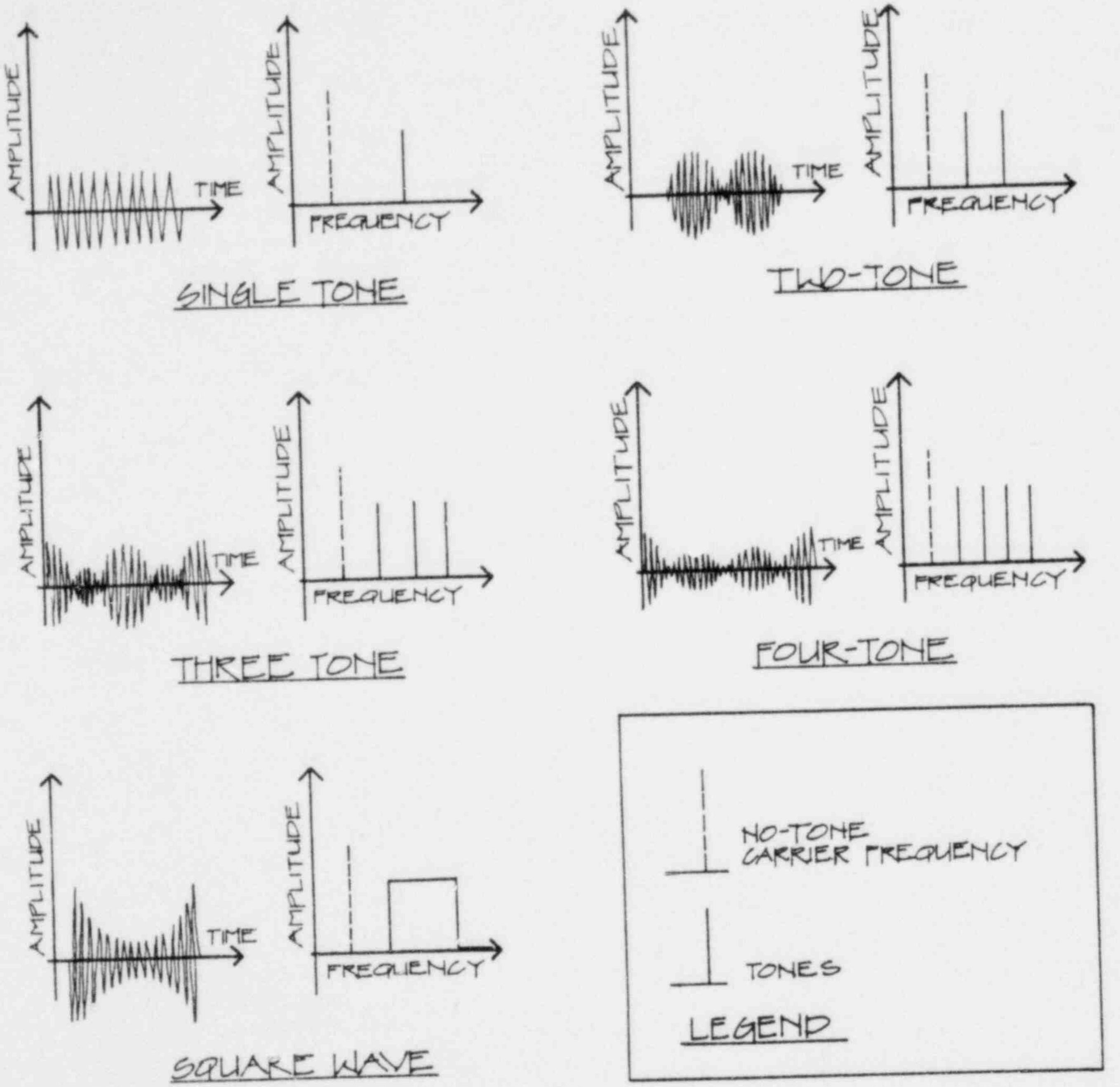
AMPLITUDE MODULATION

FIGURE 16



FREQUENCY DOMAIN OF FM SIGNALS OF THE SAME PEAK FREQUENCY DEVIATION WITH DIFFERENT MODULATING FREQUENCIES

FIGURE 17



SINGLE-SIDEBAND MODULATION WAVEFORMS

FIGURE 18

receivers to be used to produce audio signal output with less input rf signal power than conventional AM systems require. The growing use of SSB modulation has stimulated its improvement by amplitude and frequency compandors.[31]

When transmitting, an amplitude compandor reduces the amplitude of loud syllables and prevents large modulation excursions. When receiving, it reconstitutes the original amplitude excursions of the input audio signal. Amplitude compandors narrow frequency deviations when used with FM systems and conserve power when used with AM systems. For an existing system, amplitude compandors improve the signal-to-noise ratio by 10 to 20 dB or maintain the signal-to-noise ratio with 10 to 20 dB less power or effective deviation. A frequency compandor compresses the input audio-frequency excursions when transmitting and reconstitutes the original audio-frequency spectrum when receiving. Frequency compandors are especially useful in any AM system, since the spectrum occupancy is directly proportional to the highest modulating frequency and reduction in spectrum occupancy permits use of narrower bandwidth receivers which, in turn, produces higher signal-to-noise ratios.

The use of SSB in conjunction with amplitude and frequency compandors will permit a bandwidth of approximately 1.7 KHz for one voice-frequency radio channel with channel spacing of 2.0 KHz, which is an obvious saving over the present 15-KHz spacing in the vhf spectrum and 25 KHz in the uhf spectrum. Two factors will delay the adoption of these spectrum-saving techniques[32] for probably 10 to 15 years. Mobile equipment employing SSB and compandors costs more than the simpler FM equipment now in use. Furthermore, shifting the mobile radio services to SSB operation will create tremendous upheaval.

Digital modulation has advantages and disadvantages in mobile radio communication systems.[33, 34] Its main advantage is the ease of encrypting and decrypting voice messages and of conveying information that is basically digital, like status messages and identification information. Its principle disadvantage is that broader bandwidth is required when analog information is transformed into a digital format at a high sampling rate. Conversely, analog information with much redundancy, such as human speech, can be digitized and transmitted with a conservation in bandwidth but a higher cost due to increased complexity.[35]

Fiber optics, the use of glass fibers as waveguides to interconnect transmitters and receivers operating on frequencies near visual light frequencies, can be used to replace coaxial cable transmission systems and provide extremely wide-band communication channels. The use of fiber optics is in its infancy but is growing rapidly.[36] Fiber optics should be considered for new installations where many very wide-band (10-MHz and higher) channels are required, especially in areas of high ambient rf noise.

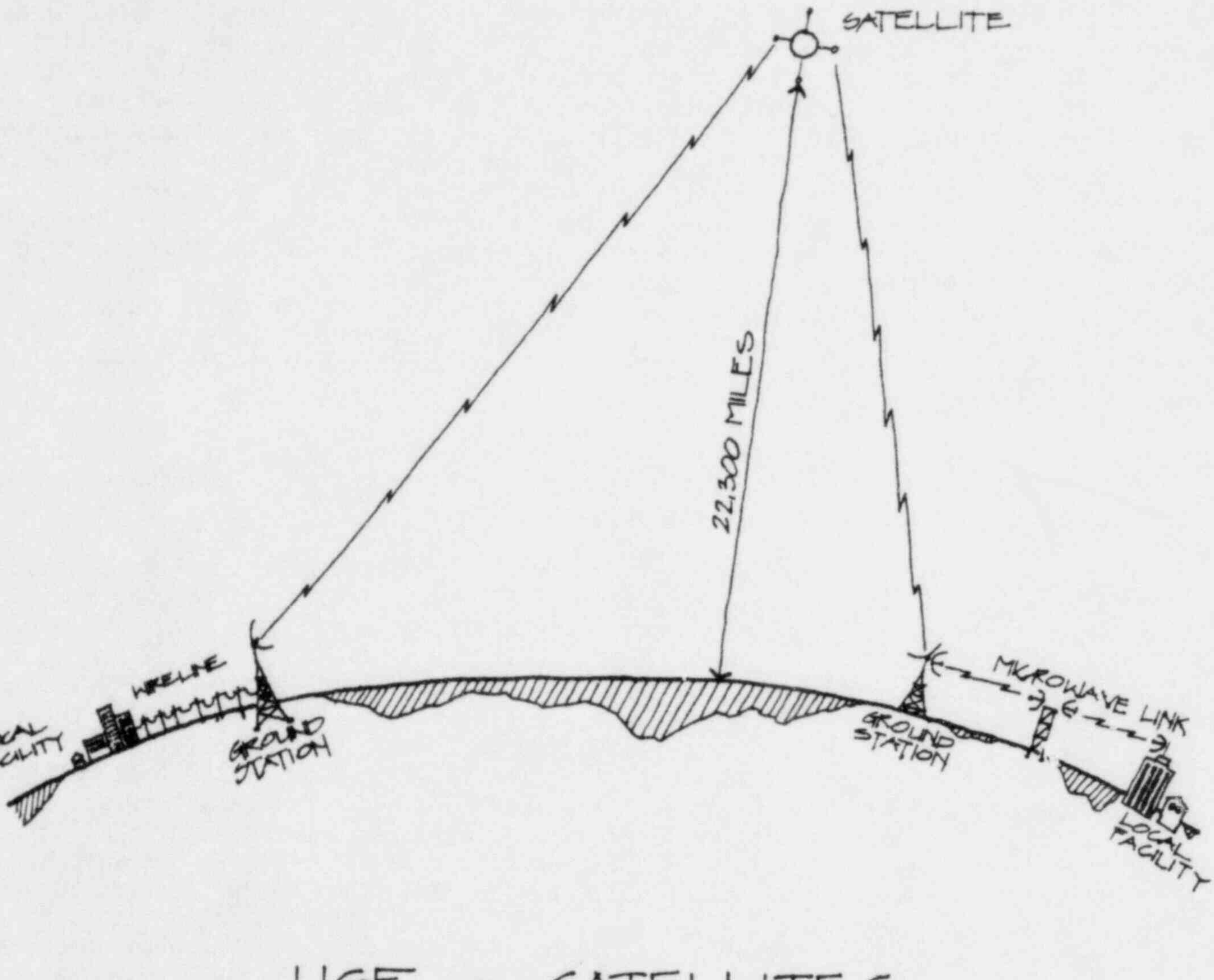
Spread-spectrum modulation techniques employ extremely wide-band and low-power level radiation and were originally used for secure communication systems. Spread-spectrum modulation uses an extremely wide frequency dispersion of the transmitted modulated signal with a matching spectrum characteristic in the associated receiver(s). Since the transmitted rf power is spread over such a wide spectrum, the average power within spectrum width is extremely low, and a spread-spectrum signal would be practically imperceptible to a conventional receiver. Spread-spectrum techniques are being considered for high-capacity cellular (see Glossary) mobile radio systems[37] and may apply in the design of high-density mobile radio systems that require several transmitting sites.

Communication systems can use satellites when wide bandwidths (6 MHz, 36 MHz, and higher) must be transmitted over long distances and other communication facilities do not exist. A satellite communication system for terrestrial use is illustrated in Fig. 19. The satellites usually orbit above the earth's equator at a height of 22,300 miles. At this height, the satellite's orbital velocity matches that of the earth's rotation, and the satellite is said to be in a synchronous orbit because it remains constantly above one point on the earth's equator. A communication satellite is a multistation transponder: it has several transponders, each of which operates in a manner similar to terrestrial microwave translators. Satellites have several wide-band translators (usually at least 6 MHz wide) that provide tremendous channel capability and enable them to serve many users; therefore, each ground station should be suitably located to communicate with the satellite (normally, far from the high radio noise of a metropolitan area) and connected to the users by wireline, radio, or microwave links. The cost of satellite communication service is the sum of the user's share of the ground stations ($250,000 to $500,000 each), the cost of the local distribution, and the user's share of the satellite cost (cost of replacing the satellite divided by the satellite's life expectancy). The cost of satellite service is decreasing very rapidly. At the time of this writing, 1978, a transponder on a satellite with suitable channels and bandwidth for two-color television and several audio channels (of approximately 36-MHz bandwidth) could be leased for $1,000,000 per year.[38] Commercial communication companies capitalize on leasing transponders on satellites and subleasing time and channel space on the transponders to others. If a company has several nuclear facilities it wishes to interconnect by satellite because of lack of other service or because of special data channel requirements that can be satisfied only by satellite, then subleasing of transponder space should be considered. RCA American Communications, Inc. and Communication Satellite Corporation (COMSAT) are two of the foremost concerns providing such service.

The expected use of this new technology in future communication systems is discussed in Appendix V.

4.2 Radio Data Systems

Any link that can be used for voice communications can be used for data communications, and many links unsatisfactory for voice communications can be used successfully for data communications. For example, a noisy radio circuit over which voice communication is impossible can convey Morse Code or digital data. On the other hand, data transmitted at rates above 9600 bits per second require greater bandwidth than does voice transmission. Radio usually transmits data when wireline and other common carrier facilities are not available or when data transmission is an adjunct to voice communications, such as in vehicle identification and status messages or in data communications with mobile or portable units. The relative merits of radio, wireline, or other common carrier facilities for data transmission should be based on the factors given below.



USE OF SATELLITES

FIGURE 19

1. Speed. If wide-band data circuits are required between two locations and no facilities exist to provide the needed service, radio techniques usually provide it more easily than wireline if the distances involved are more than a few thousand feet or if the wireline is routed over territory out of the control of the owner of the communication facility.

2. Reliability. Radio and wireline circuits can be made as reliable as desired, but the quantum jumps in cost for increases in reliability usually come at different points in the hypothetical reliability curves for the two methods. Wireline circuit costs increase most when dual circuit routing becomes necessary. Radio circuit costs increase most when hot standby equipment is required, that is, standby equipment kept ready to be switched into the communication link if the communication equipment being used fails. Reliability in either system can be improved by use of reliable equipment. Radio circuit reliability increases with increased fade margin, that is, the difference between the normal signal level and the practical threshold signal level. Wireline circuit reliability increases with physical hardening of the circuit, which is the degree to which the circuit resists interruption by physical damage from outside causes. Appendix IV further discusses system cost versus reliability.

3. Security. The security of wireline circuits (especially fiber optics) is far better than that of radio circuits, but encryption is necessary for much security with either communication medium.

4. Cost. The cost of wireline circuits consists of a small fixed cost plus a linear cost increase proportional to length, while the cost of radio circuits is a fixed cost per receiver-transmitter "hop."

Voice and data can be combined in a single channel in several ways. One of the most common for low-speed data is to transmit it in the portion of the spectrum that lies below the frequencies used to convey audio information to humans and above the minimum frequency of the circuit being used. With this method, a spectrum bandwidth of 50 to 400 Hz can be obtained for data transmission, depending on the type and length of circuit employed and the word intelligibility loss that is tolerable.[39] Extremely narrow-band data can be sent by filtering a small "notch" of up to 75 or 100 Hz in the central portion (around 1500 to 2000 Hz) of the audio spectrum and transmitting the data in this narrow spectrum. These techniques are known by several names. "Voice plus data" is the most widely used term, and "data under voice" and "data over voice" are commonly applied to the techniques of transmitting narrow-bandwidth data below and above the voice spectrum, respectively. Wider data bandwidths can be made available, depending on the circuit characteristics, between the top of the audio spectrum needed to convey audio information and the top of the useful passband of the circuit being used. Voice and data streams can also be interlaced so that digital data is transmitted in the interstices in the voice stream. This method is often used on several voice circuits simultaneously and can produce a fairly wide-band data channel. The equipment cost of this last method is very high, but it is economically feasible on long communication circuits with a severe shortage of channels. Use of voice and data combinations by nuclear security forces will probably be in the form of voice plus data to control remote devices or to transmit data from remotely located sensors to a central location. Rixon, Inc.; Data Signal, Inc.; Atlantic Research, Inc.; and Dantel, Inc. offer equipment that can be attached to existing communication links to transmit narrow-band data and voice information.

4.3 Radio System Types

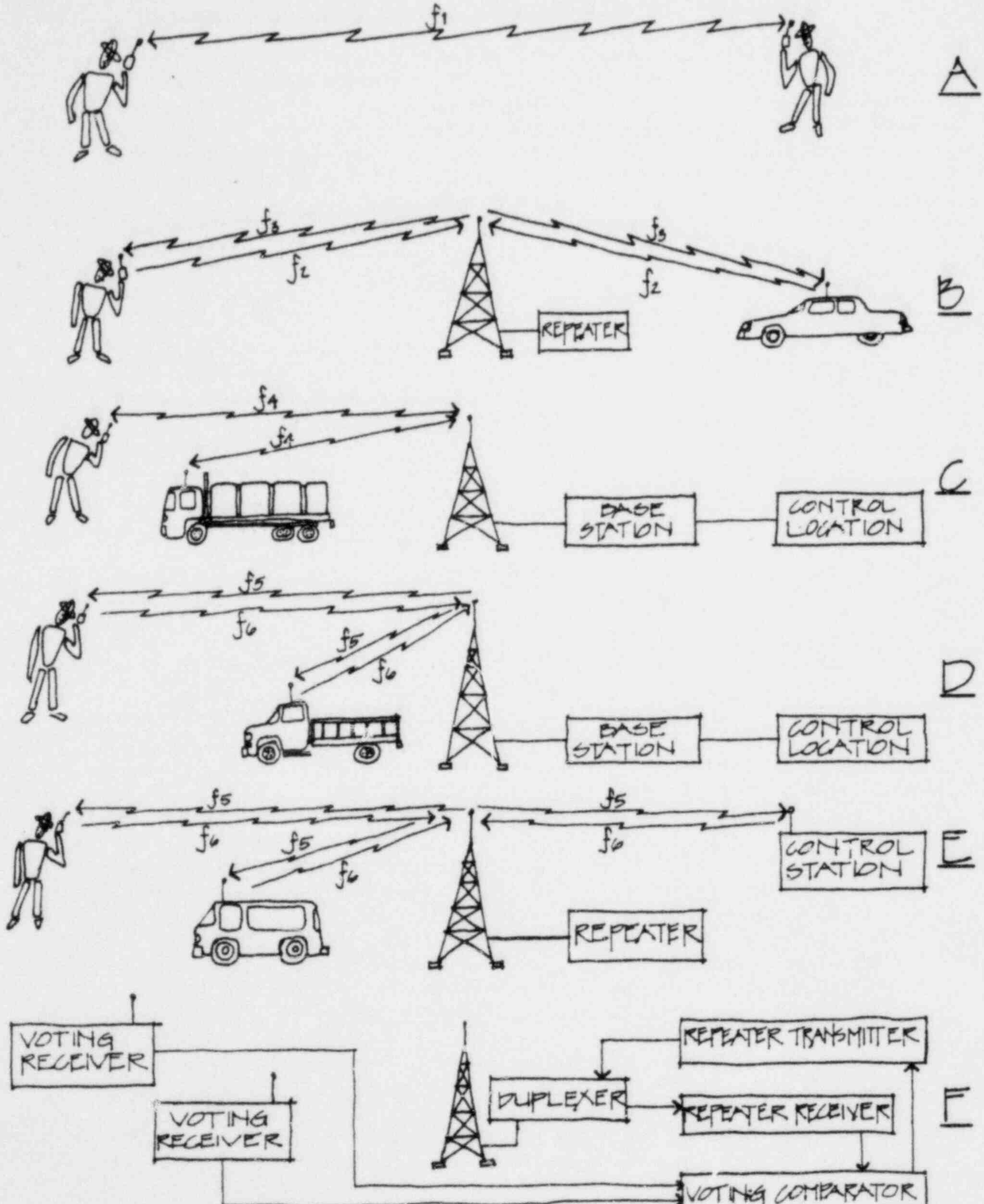
The design of a radio communication system entails first determining the basic type of system required. This determination must account for the locations to be served by the system and the input to and output from the system at each. Some designers conceive of a communication system initially as an amorphous block and place detail in the block as the requirements are developed. Another technique conceives of a generalized radio at the first locations encountered that must have radio communications. A second radio is added at the second location and details are added as necessary for the required interface(s) with the first radio. A third radio is then added for the third location and the process of adding interface details is repeated. Either process requires knowledge of what radio techniques can and cannot accomplish.

The basic decisions that must be made in designing a mobile radio system are the following:

1. communicators, places, and times of communications,
2. locations where data must be originated and received and data bandwidth,
3. the geographic area requiring radio coverage,
4. the use of portable and mobile radios,
5. the number of channels required,
6. the fixed locations where access to the system is required,
7. comparison of simplex vs repeater operation,
8. decision for purchasing own services or leasing from RCC company.

The simplest system is two portable radios operating on the same frequency, as illustrated in Fig. 20*a*. If the frequency chosen or assigned for this operation is prone to interference, say from radio stations and industrial noise, the use of CTCSS tones or other controlled squelch techniques discussed in paragraph 4.1.1 may be used to reduce the effect of the interference. If mobile instead of portable operation is required, mobile units may be substituted for the portable units in Fig. 20*a*. If the portable or mobile units need to communicate with each other when too far apart for direct contact, they can operate through a repeater (called a mobile relay station in the FCC Rules and Regulations), as illustrated in Fig. 20*b*. When using a repeater, the mobile and portable units transmit on one frequency and receive on a second ($f2$ and $f3$ in the figure). If the location of the repeater is too remote to obtain immediate service, if closely spaced mobile and portable units require a higher reliability of communications, or if a second channel not requiring a repeater is needed, a second channel using frequency $f1$ can be provided to permit mobile and portable units to operate either as shown in Fig. 20*a* or Fig. 20*b*.

Some communication systems do not allow the mobile and portable units to communicate with each other, but only with a central dispatcher. If this is the case, a system of the type shown in Fig. 20*c* can be employed. In this case the base station can communicate with the mobile and portable units operating on frequency $f4$. The dispatcher for the system, or whoever requires communication with the mobiles and portables, will occupy the control location shown which can be co-located with the base station or at a remote location connected to the base station with a wireline. The mobile and portable units shown in Fig. 20*c* can communicate directly with eac



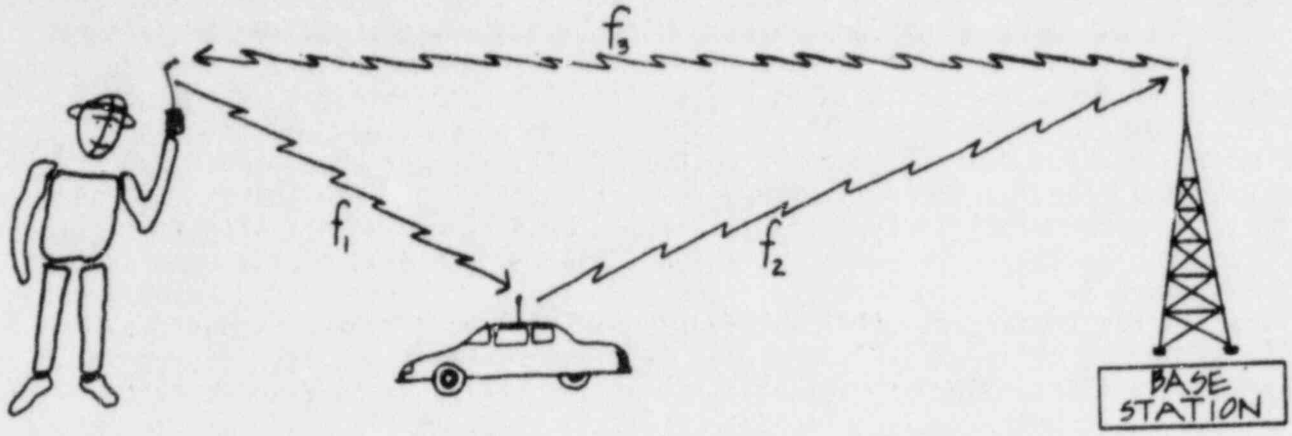
EXEMPLARY RADIO SYSTEM TYPES

FIGURE 20

other, if the distance between them is not too great - which may be a disadvantage. Another possible disadvantage is the fact that the reception of the portable and mobile unit transmissions at the base station might be obscured by transmissions of another base station operating on the same frequency. If either of these two disadvantages are potential problems, the system configuration shown in Fig. 20*d* should be considered which provides one frequency, *f*5, for the base station to transmit to the mobiles and portables and a second frequency, *f*6, for the replies. Note that the base station in Fig. 20*d* could be a repeater with local control, in which case it would be a slight modification of Fig. 20*b*. A repeater with local control would have a switch on it to enable and disable the repeating function; therefore, Figs. 20*b* and 20*d* are practically identical. Incidentally, the different services authorized by Parts 89 and 91 of the FCC Rules and Regulations have some frequencies set aside for mobile-only operation. If mobile-only frequencies are used for *f*2 and *f*6 it would enhance the probability that the mobile and portable unit transmissions would not be obliterated by another base station operating.

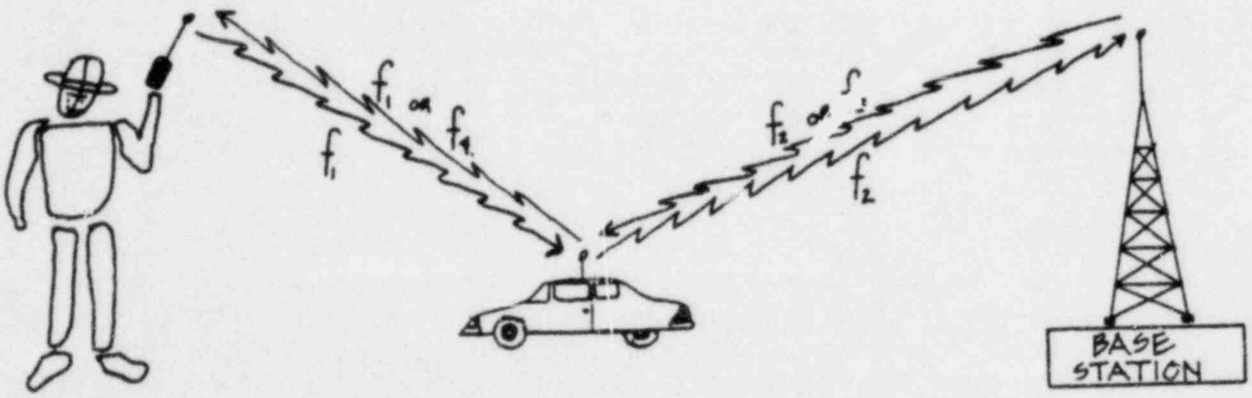
With or without a wireline control location, a radio system utilizing a repeater can be controlled by another radio called a control station, as shown in Fig. 20*e*. The control station and the repeater can be equipped to employ special commands from the control station. Transmitted as CTCSS tones or digital commands, these commands can, for example, enable and disable the repeat function for all but the control station, turn the repeater off and on, warn of illegal entry at the repeater station site, and control an emergency power unit at the repeater site. One of the problems often realized with a configuration such as shown in Fig. 20*e* is that the greater power and range of the mobile units, as compared with the portable units, often cause mobile unit transmissions to obliterate portable unit transmissions, especially on a busy channel. Another problem is that the low-power unit is often insufficient to cover the intended area, while the mobile unit can cover it with ease. Voting receivers, as shown in Fig. 20*f*, can ameliorate these problems. The voting receivers and the repeater receiver are connected to a voting comparator, which selects the receiver with the best signal, to be retransmitted by the repeater transmitter and sent to the local control location, if any. The voting receivers and the portable units can use tone control like CTCSS to differentiate them from the mobile units, and the system can be made to preferentially receive signals from portable units over mobile units, if desired.

For a fixed-base transmitter, the desired area of coverage and the use of portables will establish the required transmitter antenna height(s), effective radiated power (ERP), number of transmitter sites, and configuration of voting system. The propagation path calculation techniques presented in Appendix I can be used to determine whether one or several transmitter sites are required and the best locations for such sites. These same calculations can be useful in selecting voting site locations. It may be that the geographical area is too large and the cost of implementing voting receivers is not considered economically feasible. In this case the use of vehicular repeaters should be considered. A low-power vehicular repeater, as shown in Fig. 21, will enable an individual to leave his car and still maintain radio contact with a location that is too far away to communicate directly with a portable unit. Two basic versions of the use of vehicular repeaters to extend portable-to-base station range are shown in the figure. The version shown in Fig. 21*b* will cost 20 to 50% more than that shown in Fig. 21*a* but will provide greater base-to-portable range because of the 10 to 15 dB greater antenna gain of the mobile unit.



A

ONE-WAY REPEATER
DIRECT RECEPTION BY PORTABLE



B

TWO-WAY REPEATER

VEHICULAR REPEATER TECHNIQUES

FIGURE 21

The points of access to the system and the choice of repeater or simplex operation will determine the number of wireline control points and control station control points required. The availability, services offered, and cost of local RCC companies will be the major factors in the decision whether to employ their services or to build a private system.

Figure 22 illustrates a typical mobile radio communication system employing half-duplex operation with one central transmission site, voting receivers for extended portable-unit operation, a secondary control point implemented with a control station, and one with a remote control unit.

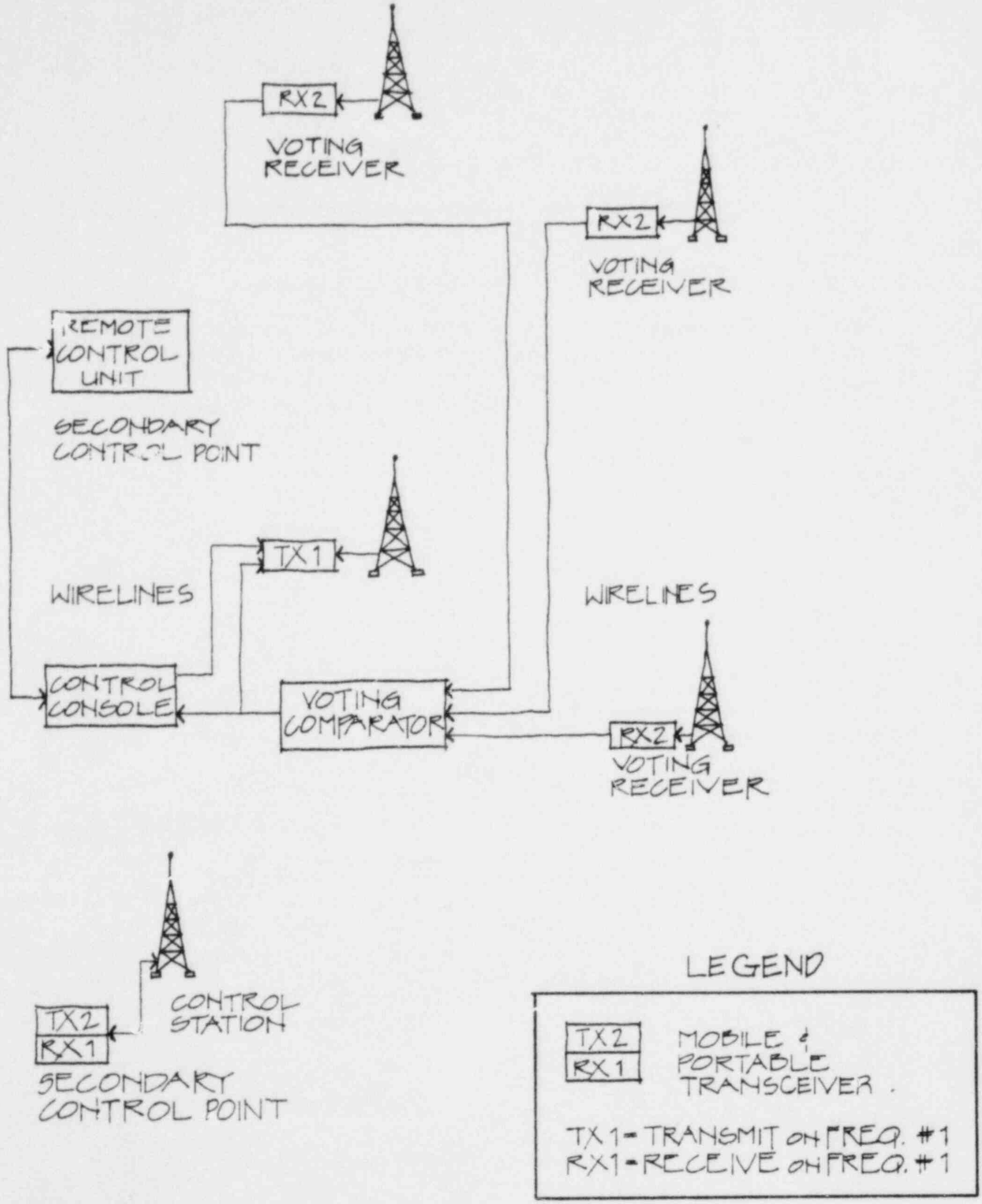
The use of preprogrammed (preselected) messages should be considered in the design of a radio system. Preprogrammed messages can be originated in a mobile unit by depressing the appropriate switch and presented to the dispatcher as a lighted display. Typical ones include "acknowledgement of last transmission," "on duty," "going off duty," "arrived at location to which directed," and "emergency assistance required." Hardware for techniques of this type is just beginning to appear on the market. Appendix V discusses uses of these techniques in future systems.

4.4 Radio System Components

Bidding documents for a mobile radio communication system contain specifications for each major component of the system, such as repeaters, base stations, control stations, mobile transceivers, portable transceivers, paging receivers, and antenna towers. The statements used in these specifications should define the results desired rather than the means for attaining them.[40] Ambiguous statements and statements defining performance characteristics that cannot be measured easily, such as "voice intelligibility," "coverage area," "received signal probability," and "communication probability," should be avoided. Instead, such terms as "transmitter power delivered to the antenna input connector shall not be less than ___W" and "line level shall be more than ___ V and less than ___ V throughout the passband from ___ Hz to ___ Hz" should be used. The procurement package for a communication system should include a specification that macroscopically defines the system, the interfaces between the components of the system, and the minimum performance standards for the system. The general system specification should take precedence over the detailed equipment specifications. System performance standards and the method of testing should include the following items, as detailed in EIA Standard RS-237.*

1. System rf loss: the system rf loss expressed in dB is the ratio of the power delivered by the transmitter to its transmission line, to the power required at the receiver input terminals to produce a SINAD ratio of 12 dB, under standard test conditions.

*Electronic Industries Association Standard RS-237 and some of the other EIA standards do not yet include requirements for the 850-MHz frequencies made available by FCC Docket 18262; however, revisions of these standards are expected to correct this deficiency in the near future, and in spite of this deficiency, they still can be used as standards with little modification for 850-MHz equipment.



TYPICAL MOBILE RADIO COMMUNICATION SYSTEM

FIGURE 22

2. System stability: the variation in system rf loss due to the effects of environmental conditions.

3. Audio input: the power applied to the audio input terminals of the system.

4. Audio output: the power delivered by the system to a standard load under standard test conditions, as defined by EIA Standards.

5. Audio-frequency response: the response denoting the closeness of the system output amplitude audio frequency characteristic under standard test conditions to that of the system input.

6. Accumulated audio harmonic distortion: the change in harmonic content of the modulating signal as a result of passing through the system.

7. Audio intermodulation distortion: the distortion resulting from sum-and-difference frequencies in the output when more than one frequency is applied simultaneously to the input of the system.

8. Signal-to-internal noise ratio: the ratio of signal under the standard test modulation to the noise in the absence of modulation, both measured at the output of the receiver.

9. System operation delay and recovery time: the time required for the transmitter to provide rated rf output after activation of the local control push to talk (ptt) plus the time required for the system receiver to provide useful output.

10. Spurious emissions from licensed devices: generally, emissions on frequencies other than the assigned one, but EIA defines them as emissions on a frequency or frequencies outside an occupied band sufficient to ensure transmission of information of required quality for the class of communication desired; reduction in the level of spurious emissions will not affect the quality of the information being transmitted.

11. In[illegible]al and restricted radiation: radio-frequency radiation from devices e[illegible]ng licensed devices.

12. System interference rejection: a measure of the ability of a system to prevent greater than a 6-dB reduction in the 12-dB SINAD ratio under standard test conditions when a single undesired signal is introduced into the system.

13. System intermodulation interference rejection: a measure of the ability of a system to prevent greater than a 6-dB reduction in the 12-dB SINAD ratio under standard test conditions when two or more undesired signals are introduced into the system.

14. System undesired signal rejection: the ability of a system to prevent audible or functional outputs due to external signals in the absence of the desired signal.

The description and performance of each major component of the system should be stated succinctly. Generally, a separate specification is written for each major component, such as a repeater, a base station, a mobile transceiver, and a portable transceiver. Typical performance and physical characteristics that should be considered in the specifications for these components are discussed generally below and presented in the exemplary specifications that follow.

Applicable FCC Rules and Regulations should be invoked by the specifications to cover such equipment characteristics as frequency stability, off-frequency radiation, use of type-accepted equipment, emission limitations, modulation requirements, delay timers, and limitations on use of secondary signaling, as discussed in paragraph 2.2. In addition, the unique requirements for repeaters, control stations, portable radio transceivers, and mobile transceivers should be noted, as the following exemplary specifications illustrate.

All type-accepted radio equipment used on frequencies authorized by the FCC must be listed on "Radio Equipment List, Equipment Acceptable for Licensing," otherwise known as the "Type-Accepted List," which can be obtained at any FCC office. Use of this equipment assures the licensee that the equipment will meet basic FCC requirements such as modulation type, spurious emission, and bandwidth of operation.

Reliability per se is difficult to specify; however, specifying mechanical and performance characteristics that appear only in top-of-the-line equipment manufactured by reputable companies will greatly enhance reliability. The reliability considerations should include the specification of environmental conditions for the intended use of the equipment. Unless dictated otherwise by the intended user, the specifications should invoke the applicable paragraphs of the EIA and National Institute for Law Enforcement and Criminal Justice standards, as indicated below. A list of the EIA Specifications and NILECJ Standards for communication systems is provided in Appendices VI and VII, respectively.

The mechanical characteristic specifications for radio equipment items should include such parameters as size, weight, type of enclosure, arrangement of displays, arrangement of controls, type of construction, and any other physical features required by the overall system design.

Automatic identification of radio transmitters and emergency alarm provisions are stated in Parts 89.153 (for public safety licensees) and 91.153 (for industrial licensees) of the FCC Rules and Regulations. These requirements stipulate that the base station can identify for the mobile and portable units if simplex operation is used; however, the facility may require that each mobile and portable unit identify itself for security reasons. Transmitter identification can be performed automatically and can be combined with provisions to indicate an emergency alarm when the operator pushes a special button or pulls on a special lanyard. Parts 89.107 (for public safety licensees) and 91.103 (for industrial licensees) stipulate that automatic, nonvoice emissions for identification and alarm be limited to 2 sec, including automatic repeats. A useful adjunct to a radio system that employs radio units with automatic identification and emergency alarm is automatic location of mobile and portable units because this permits rapid location of an individual who has signaled an emergency. Parts 89.120 (for public safety licensees) and 91.120 (for industrial licensees), which are almost identical, state the recently passed interim provisions for the operation of Automatic Vehicle Monitoring (AVM) systems. These systems can provide for automatic location of mobile and portable units, as stipulated in Part 89.120 (also Part 91.120) of the FCC Rules and Regulations.

The frequency stability for all fixed-station transmitters must be ± 0.002% for vhf low-band, ± 0.0005% for vhf high-band, ± 0.00025% for uhf, and ± 0.00015% for 800-MHz stations. There is no FCC requirement for receiver (receiver local oscillator) stability, and equipment suppliers usually provide units in which the local oscillator stability is less than that of the transmitter stability unless the specifications state otherwise. A frequency drift of 0.00025% at 450 MHz equals 1125 Hz. If a base station drifts to this extreme in one direction and an associated receiver does so in the opposite direction, apparent receiver sensitivity may decrease noticeably. For this reason, in systems in which the mobile and/or portable units may be operating near the maximum talk-back range of the system, the repeater or base receiver frequency stability should equal that of the transmitter. The charge for this extra stability will vary from zero to approximately $150 per frequency. Sometimes more than one transmitter must be used to cover an area occupied by associated mobile and portable stations. When this is the case, several techniques may be used to prevent interference among transmitters: only one transmitter may be permitted on the air at a time, or the transmitters may operate simultaneously with their frequency stability increased so the beat frequency between them falls in the audio spectrum where it will not interfere with the reception at a mobile or a portable unit. This requires a frequency stability of about ± 0.00005% for uhf stations and ± 0.0001% for vhf high-band stations. The associated mobile and portable receivers in such a system need not have this extreme stability but only that which the FCC requires for transmitters in the system.

Before receiver squelch circuits were developed, radio operators either had to listen to a constant rushing noise from their receivers when there was no communication on the channel or had to turn the volume controls down until they wished to communicate; this resulted in many missed calls. Early squelch circuits disabled the receiver speaker until a signal above a preestablished level was detected by the receiver; these circuits were known as carrier-operated squelch circuits. Later developments in carrier-operated squelch circuits enabled operators to detect a signal above a preestablished signal-to-noise level to open the squelch, that is, to connect the receiver to the speaker at lower signal levels without having the squelch open on noise bursts. Operation and testing standards for carrier-operated squelch circuits are detailed in Sects. 6, 7, and 9 of EIA Standard RS-204-A. Still later developments enabled the squelch circuit to operate by a coded signal from a transmitter in the same system as the receiver; the squelch circuit remained closed when transmitters associated with other radio systems came on the same channel.

The coded signal can be a subaudible signal in the 67- to 250.3-Hz range which is impressed on the carrier along with the voice communications. This type of squelch circuit is called a Continuous Tone-Controlled Squelch System (CTCSS), and standards for the operation and testing of such circuits are detailed in EIA Standard RS-220. Other types of coded squelch systems fall into two general categories, pulse coding and frequency coding. The operation and testing of these squelch systems are presented in EIA Standard RS-374.

The specifications should state the squelch system requirements and should invoke the appropriate EIA standards. Coded squelch systems may be employed for selecting individual receivers (individual-call), groups of receivers in a system (group-call), and all the receivers in a system (all-call). If this option is used, the specifications must state how many receivers are in each group and the type of coded squelch system to be used to open the squelch on the selected receivers. Some systems use pulse coding for individual call and CTCSS for group call and all call.

The frequencies for a CTCSS squelch system should be selected with care. Standard CTCSS frequencies consist of the two groups listed in paragraph 3.1 of EIA Standard RS-220. In general, any frequency selected should differ from any other one used in the same geographical area but should be selected from the same group as the others used in that area. These precautions are necessary because intermodulation-product frequencies contain all the CTCSS frequencies of those causing the products. The CTCSS frequencies, in turn, produce intermodulation products. The frequencies in the two groups listed in RS-220 have been selected so that the product of any combination of CTCSS frequencies in one group will not result in another frequency within the same group. If these precautions are not observed, the reasons for using the CTCSS technique may be defeated because false opening of the receiver squelch circuits by intermodulation-frequency products could occur frequently.

Radio transmitter specifications should require a time-out timer to turn off the transmitter automatically if the push-to-talk circuitry is actuated for longer than a predetermined time, usually between 30 and 180 sec. Turning the transmitter off prevents the inadvertent keying of it from interfering with other users of the communication channel. The timer should be reset each time the push-to-talk switch is released and reactuated.

Specifications for radio transmitters should include at least the following items. The values given are the best performance figures that can be obtained from production equipment at the present time. Note that some of these values are attained by only one or two manufacturers today, and no manufacturers attain all these characteristics in production equipment.

1. Modulation. Transmitter modulation should be in accordance with Parts 89.105, 89.107, 89.109, 89.120, 89.124, and/or 89.126 of the FCC Rules and Regulations for public safety licensees and in accordance with Parts 91.103, 91.104, 91.112, and/or 91.120 of the FCC Rules and Regulations for industrial licensees, as applicable. Generally, normal voice communications will be by 16F3 modulation with a maximum audio frequency of 3000 Hz.

2. Output power. Transmitter output power should be specified to cover the service area based upon calculations such as presented in Appendix I. Use of excessive power increases the probability of interference, with resultant FCC action.

3. Operating frequencies. The operating frequencies should be those stated on the station license. Up to 12 channel combinations (receive and transmit) can be obtained on mobile and portable production units today. Base stations usually have one to four channels of operation, and repeaters usually have one. Frequencies must be selected for one of the vehicular repeater techniques illustrated in Fig. 21, if required.

4. Frequency adjustment. The specifications should require that a variable reactance be included for each transmitter channel to permit setting the transmitter oscillator to the exact frequency of operation.

5. Audio-frequency levels and response. The audio-frequency response stated in EIA Standard RS-316-A, paragraph 4.5, should be invoked. It states, basically, that the audio-frequency response shall not vary more than +1 or -3 dB from a true 6-dB-per-octave preemphasis characteristic from 300 to 3000 Hz referred to the 1000-Hz level. This paragraph also furnishes exceptions and test conditions that should be specified. The acoustic sensitivity and method of measurement provided in EIA Standard RS-316-A, paragraph 4.3, should be specified.

6. Audio distortion. The audio-frequency allowable distortion and method of testing should be as specified in paragraph 4.6 of the National Institute of Law Enforcement and Criminal Justice (NILECJ) Standard 0203.00. The NILECJ standards occasionally are more stringent and more detailed than the EIA standards and are noted in this document when they will produce a superior system; however, as with the EIA standards, they often omit requirements for equipment for operation in the 850-MHz region of the spectrum.

Specifications for the receiver section of the radio units should include at least the items listed below. The values given are the best performance figures that can be obtained from standard production equipment at the present time. Some of the values are attained by only one or two manufacturers today, and no manufacturer can attain all of these characteristics.

1. Operating frequencies. The specifications should state that the receiver operating frequencies be selected with the same control and the same control action used to select transmitter operating frequencies for any particular channel. A receiver may have one or more frequency channels for monitoring only, with no corresponding transmitting frequency for which the radio unit is authorized to operate. In this case, the transmitter must be disabled when this frequency is selected on the receiver. The receiver may be required to have a scanning function, with two or more frequencies scanned. One of the scanned frequencies may be assigned a priority that will cause the receiver to tune to that frequency whenever a signal appears on it.

2. Modulation acceptance. The modulation acceptance bandwidth must be keyed to the rated deviation of the system for which the radio unit is intended, as stated in EIA Standard RS-204-A, paragraph 10. This paragraph describes the accepted method of measuring receiver modulation acceptance. Rated deviation of radio communication systems being installed at the present time is usually ± 7.5 KHz.

3. Selectivity characteristics. Receiver adjacent-channel selectivity and desensitization measure the receiver's ability to receive the desired signal in the presence of modulated signals that differ in frequency by the spacing of one channel from that desired in the input signal. A standard method of measuring this parameter with two signal generators is provided in EIA Standard RS-204-A, paragraph 11.3.

4. Sensitivity. There are five receiver sensitivity parameters that can be specified: usable sensitivity, quieting sensitivity, alerting sensitivity, carrier squelch sensitivity, and coded squelch sensitivity. Usually, only one or two of these are used in any one specification. Usable sensitivity is the minimum signal from a standard input source with a standard modulation that will produce at least 50% of the receiver's rated audio-power output with a 12-dB SINAD. Usable sensitivity should be tested as described in EIA Standard RS-204-A, paragraph 4.3. Modern top-of-the-line receivers have a usable sensitivity of 0.18 μV in the vhf band and 0.35 μV in the uhf and 850-MHz bands. Quieting sensitivity is the minimum signal from an unmodulated standard input-signal source required to produce 20 dB of noise quieting measured at the receiver output. Quieting sensitivity can be tested by the method described in EIA Standard RS-204-A, paragraph 5.3, and should be at least 0.25 μV in the vhf band and 0.5 μV in the uhf and 850-MHz bands. Alerting sensitivity is the minimum signal level of a standard rf input signal that will activate alerting or selective-address circuitry in the receiver and should not exceed the usable sensitivity of the receiver. The EIA Standard RS-316-A, paragraph 3.8, presents a standard method of measuring alerting sensitivity. Carrier squelch sensitivity is the minimum signal from a standard input-signal source modulated with a standard test modulation that will open the receiver squelch circuit and provide more than a specified signal-to-noise ratio. The EIA Standard RS-204-A, paragraph 6, provides a standard method of measuring carrier squelch sensitivity, which should be at least 0.2 μV. Coded squelch operation should conform to the standard requirements contained in EIA Standard RS-220 if the CTCSS is employed and should conform to the requirements contained in EIA Standard RS-374 if other types of coding are employed.

5. Squelch blocking. The receiver squelch tends to close in the presence of modulation on the rf signal because the modulation causes the transmitter power to appear in the sidebands of the transmitted signal and to be absent from the carrier signal sampled by the squelch circuitry. The EIA Standard RS-316-A provided the standard method of measurement and the allowable performance limits for squelch blocking a receiver.

6. Receiver attack time. Time required to produce audio power output after application of a modulated rf signal, should be measured as described in EIA Standard RS-204-A, paragraph 8.3, and should be less than 150 msec.

7. Receiver squelch closing time. The time between removal of the radio-frequency input signal to the receiver and the closing of the squelch, should be measured as described in EIA Standard RS-204-A, paragraph 9.3, and should be less than 250 msec.

8. Spurious and image response. Radio receivers are receptive to signals at many frequencies other than the one to which they are tuned. The most sensitive of these is the image frequency, which is the same distance away from the desired channel frequency as the intermediate frequency but in the opposite direction. The receiver's sensitivity to any other frequency is called a spurious frequency response. If a strong signal falls on the image frequency or on one of the more sensitive of the spurious frequencies, it could interfere with the desired signal if the receiver has insufficient rejection capabilities.

9. Intermodulation rejection characteristics. When two signals on different frequencies mix in a nonlinear device, all their intermodulation products are generated (Appendix II). The intermodulation rejection capability of a receiver is a measure of its ability to resist this phenomenon.

10. Audio output. The audio output of a receiver may be used to drive a local loudspeaker and/or a wireline serving other points. The receiver must be able to provide sufficient audio output power for all these points without objectionable distortion.

11. Hum and noise. All electrical and electronic devices produce electronic noise in all their circuits. A radio receiver must produce a signal level sufficient to mask completely the internally generated noise.

Specifications for the major components of a mobile radio communication system are discussed below, and typical methods of specifying the performance and physical characteristics are presented. Remember that the specifications for any system are unique, and the parameters of all the components comprising the system must be specified as a function of cost, required reliability, system performance, and the state of the art at the time the system is to be installed.

4.4.1 Repeaters

4.4.1.1 Applicable FCC Rules and Regulations. Specifications for any radio equipment should invoke the requirements of the FCC Rules and Regulations in general to cover such characteristics as frequency stability, off-frequency radiation, use of type-accepted equipment, emission limitations, modulation requirements, and timers. Some of the requirements for these characteristics may be invoked by stating that the equipment must meet the applicable requirements of the FCC Rules and Regulations. The Rules and Regulations that especially apply to repeaters are listed below for reference.

1. General. The FCC requires that applications for authorizations for repeater frequencies below 450 MHz state that the applicant requires prompt mobile-to-mobile communication over ranges greater than allowed by direct communication. The FCC also requires that each repeater with an output power greater than 1 W and an input frequency below 50 MHz use a coded squelch system. The FCC further requires that repeaters with an input frequency above 50 MHz add a coded squelch system if activated consistently by undesired signals and thereby cause interference to others.

2. Frequency selection. The output frequency of a repeater must be authorized for use by the same group of individuals authorized to use the repeater input (receive) frequency. For example, a licensee may be eligible for frequency authorizations in the business and the power radio service and can license a repeater with a power radio service input frequency and a business radio service output frequency. Any other station that could be authorized for the input power radio frequency could be authorized for the business radio frequency, but not vice versa.

3. Timers. Each repeater must have a time-out timer that will deactivate the repeater within 5 sec. after the input signal has ceased and must have a timer that will deactivate the repeater if the input signal continues for more than 3 min. This requirement is reflected in Sect. 4.4.1.7, item 3. A dropout-delay timer prevents the repeater from cycling whenever a mobile unit passes through a temporary null while transmitting. This cycling is very annoying to anyone listening, and a specification for a dropout-delay timer is presented in Sect. 4.4.1.7, item 2.

Sometimes closer tolerances than required by the FCC are desirable or necessary. Furthermore, many factors that affect the design and operation of a radio communication system should be reflected in the repeater specification but are not contained in the FCC Rules and Regulations. These items are discussed in the following paragraphs, but a word of caution is needed: each system must be engineered for the purpose it must fulfill. The statements given here represent only the factors that must be considered, are not exhaustive, and do not provide the limits that should be contained in any one specification.

4.4.1.2 Reliability. Reliability per se is difficult to specify; however, particular attention is paid to specifying mechanical and performance characteristics that appear only in top-of-the-line equipment manufactured by reputable companies. This will greatly enhance reliability. The reliability considerations should specify environmental conditions applicable to the intended use of the repeaters. Unless the intended use dictates otherwise, the specifications should state that the repeaters should meet the temperature range and humidity requirements stated in Sect. 4 of NILECJ-STD-0213.00 (Law Enforcement Standards Program, FM Repeater Systems) and the minimum standards established in EIA Standards RS-152-B (Minimum Standards for Land Mobile Communication FM or PM Transmitters) and RS-204-A (Minimum Standards for Land Mobile Communication FM or PM Receivers).

4.4.1.3 Installation. The options available for repeater installation are limited by the coverage which the repeater must afford. Sometimes the repeater must be installed using an existing communications building and tower, or perhaps the repeater must be provided with a new building and tower which is to be installed at a convenient location in a vacant field or the repeater could be installed on a mountain (or building) top with no latitude for site location and only minimal space available for locating a short tower. Each of these locations are unique and the installation contractor must be provided with complete instructions concerning what he must install and how it is to be installed. These instructions must include where in the enclosure each piece of equipment is to be located, how the transmission lines, power lines, input control lines and local control and signal lines are to be run, dressed and protected from mechanical damage, lightning and weather. Lightning protection consideration must include the type of ground or counterpoise that must be used which, in turn, is a function of local soil conductivity; and it must include precautions against incurring any inductance or unnecessary resistance between any exposed metallic components of the installation and the single-point ground connection.

4.4.1.4 Mechanical characteristics. Mechanical characteristics of the repeater should be specified to the extent that reliability and maintainability of the system is assured. These specifications should include provisions typified by the following example:

1. Cabinet. The cabinet that houses the station shall be suitable for exposed indoor installation on a bench or floor and shall be constructed of steel finished with baked enamel or an approved equal in quality and durability. All components of the unit shall be assembled for easy removal from the unit for servicing. Each cabinet shall have a door lock.

2. Accessibility. All parts that require periodic service or maintenance and all tuneable circuit adjustments shall be easily accessible.

3. Humidity. The station shall meet or exceed all specified EIA standards when subjected to high-humidity tests, in accordance with EIA Standards RS-152-B, Sect. 13 (for transmitters), and RS-204-A, Sect. 21 (for receivers).

4. Environment. The station shall meet the specified performance requirements when subjected to any combination of the following environmental conditions: (a) temperature, -30 to +60°C; (b) relative humidity, 0 to 90%; (c) power-input voltage, 117 V ± 10%; and (d) power input frequency, 60 Hz ± 5%.

5. Solid-state circuitry. All active circuit components except the exciter stage, final radio-frequency amplifier, and associated control circuitry shall be solid state. Failure of the final frequency amplifier shall cause the exciter output power to be applied directly to the antenna output terminals when the transmitter is actuated.

4.4.1.5 Circuitry. Generally, today's technology will permit specifying solid-state circuitry throughout the repeater except in high-power radio-frequency amplifiers, as reflected in the preceding paragraph. However, for enhanced reliability, the repeater specifications should contain provisions for mounting the radio receiver and transmitter on separate printed-circuit boards. The reasoning behind this is twofold: larger boards tend to break more easily than smaller ones, and a transceiver with a separate receiver and transmitter is easier to service. Plated-through eyelets should be specified for all printed-circuit boards to guard against bad solder joints on the boards. Systems that use multiple repeater sites with interlocking control circuitry between them should be specified to ensure that failure of the control circuitry will permit use of the most essential repeater sites or an alternate means of control. Overall system reliability can be enhanced with backup or secondary transmission sites that can be switched on if the primary facilities fail. Often, such schemes fail because control circuitry fails. The effects of such failures can be minimized by requiring manual control capability or fail-safe provisions that ensure at least one means of communication even after the control circuitry fails.

4.4.1.6 Operational features. The operational features of the repeater should include the requirements for local and wireline control, if required. Generally, local control is always required for maintenance, but this is included as part of the control chassis. Other local control may be required for dispatching from a position with a separate local-control unit or from a control panel contained in a dispatch console. Other local-control features include selection of a backup repeater or transmitter, indication of whether the main or the backup facilities are in use, and status of the emergency power facilities. Wirelines may be controlled by dc or tone techniques. Direct-current control is slightly less expensive and simpler but less versatile and requires continuous metallic circuits (no hybrids, transformers, loading, or amplifiers).

4.4.1.7 Electrical characteristics. The following should be considered for electrical-characteristic requirements for a repeater:

1. Control. The repeater shall be provided with an extended local-control unit if it is to be controlled from a point near the equipment location.

2. Dropout delay timer. A dropout delay timer shall be provided in the station to keep the transmitter push-to-talk circuitry activated for 0, 1, 2, 4, or 5 sec after the received signal is removed. A manual adjustment shall be provided to select the delay period.

3. Time-out timer. An automatic timer shall be provided to turn off the transmitter after preset intervals, in accordance with FCC Rules and Regulations. The timer shall be automatically reset when the push-to-talk circuit is actuated. A manual adjustment shall be provided to select the setting of this timer.

4. Metering. Meters and circuits shall be provided to enable troubleshooting, alignment, and adjustment of all essential circuits in the station. All metering points shall be decoupled to prevent observable interaction between circuits and to minimize the effect of the metering action upon the circuit being measured.

5. Automatic identification. The transmitter shall periodically transmit automatically its identity in a manner that meets the requirements of the FCC Rules and Regulations.

4.4.1.8 Transmitter. The following transmitter characteristics should be included in the repeater specification:

1. Modulation. The deviation limiter circuit required by the FCC Rules and Regulations shall have a continuously variable control. This control shall be set for ± 5 KHz after the transmitter has been installed.

2. Power output. The primary transmitter shall deliver at least 180 W into the duplexer, and the backup transmitter shall deliver at least 15 W. Both transmitters shall be capable of maintaining this power output continuously. Exciter output shall be at least 15 W.*

3. Frequency adjustment. A device shall be included to permit setting the transmitter oscillator to the exact frequency of operation.

4. Audio-frequency response. The audio-frequency response shall not vary more than +1 and -3 dB from a 6-dB-per-octave preemphasis characteristic from 300 to 3000 Hz, as referenced to the 1000-Hz level in accordance with EIA Standard RS-152-B, Sect. 7.

5. Audio distortion. Total audio harmonic distortion shall not exceed 5% with a 1000-Hz test tone at a level sufficient to produce two-thirds maximum deviation, in accordance with EIA Standard RS-152-B, Sect. 6.

6. Frequency modulation noise and residual hum. Frequency modulation noise and residual hum shall be at least 55 dB below two-thirds maximum deviation at a 1000-Hz test tone, as measured through a standard 6-dB-per-octave deemphasis network.

7. Amplitude modulation noise and residual hum. Amplitude modulation noise and residual hum shall be at least -35 dB when measured in accordance with EIA Standard RS-152-B, Sect. 16.

8. Audio sensitivity. The microphone, audio circuitry, and modulator shall be designed and adjusted to produce maximum deviation by an operator using normal conversational tones with the microphone 6 in. from the lips and to produce two-thirds maximum deviation at 1000 Hz with an input of -20 dBm at the control line terminals.

9. Tuning procedure. Provide built-in meter(s), switches, and circuitry to enable tuning adjustments without use of additional patch cords, intercabling, or meters.

10. Spurious emissions. Transmitter spurious and harmonic emissions shall be -70 dB.

4.4.1.9 Receiver. The following characteristics are typical of those that should be included in the specification for the repeater receiver:

1. Selectivity. Selectivity characteristics shall be at least -85 dB at ± 25 KHz when measured in accordance with EIA Standard RS-204-A, Sect. 11.

2. Sensitivity. Receiver sensitivity shall be 0.35 μV, 12-dB SINAD.

*Power output specifications should be chosen carefully since the FCC requires that no more power than actually necessary be used.

3. Modulation acceptance. The receiver modulation acceptance shall be determined by the mobile unit transmitter characteristics in accordance with EIA Standard RS-204-A, Sect. 10.

4. Audio output characteristics. Line output level available shall be at least +11 dBm at 600 Ω; response shall not vary more than +1 to -3 dB, as defined in EIA Standard RS-204-A, paragraph 15.2.2; total harmonic distortion shall not exceed 5% at 1000 Hz; hum and noise shall be less than 50 dB below line output level; available speaker output power shall be at least 0.5 W; and speaker input impedance shall match the receiver output impedance.

5. Carrier squelch circuit. The carrier-actuated squelch circuit shall be of the noise-compensated, adjustable-sensitivity type. At the threshold setting, a signal of 0.25 μV shall provide positive squelch opening. The squelch circuit shall not respond to noise bursts.

6. Coded squelch circuit. The receiver shall be muted until the incoming signal is modulated with the CTCSS frequency assigned to the users of the radio equipment, as specified in EIA Standard RS-220, paragraph 4. The secondary repeater shall be muted until the incoming signal contains the unique group-call assigned to the secondary group. A switch shall be provided on the control chassis or on the front of the station to transfer the receiver from coded squelch operation to carrier-operated squelch operation.

7. Intermodulation rejection. Intermodulation rejection shall be at least -80 dB.

8. Spurious and image rejection. Spurious and image rejection shall be at least -90 dB.

4.4.1.10 Antenna coupling system. There are several methods of specifying the antenna coupling system: it may be detailed completely with elaborate installation drawings for one repeater site, or it may be defined more generally for several.

The antenna, transmission line, and isolation system shall be designed and installed by the contractor on the basis of the characteristics of the transmitter and receiver provided, the characteristics of the site for the station, and the requirements of the contract documents.

The following should also be considered:

1. The maximum power rating of all components in the transmitter transmission line shall exceed the maximum transmitter power output by 25%.

2. The total transmitter-to-antenna and the total antenna-to-receiver insertion loss of devices installed to permit duplex operation shall be less than 1.5 dB.

3. Transmitter noise isolation at the repeater receiver frequency shall be sufficient to preclude more than 1 dB of desensitization.

4. Transmitter-to-receiver isolation at the transmitter frequency shall prevent receiver desensitization to a level above 0.35 µV, 12-dB SINAD.

5. All cavities and other isolation devices shall be mounted adjacent to the station they serve.

6. The voltage standing-wave ratio in the transmission line shall not exceed 1.5 to 1.0 at any point in the line.

7. Circulators, cavity isolators, and/or similar devices shall be provided as necessary to prevent interference from radiating sources that exist at the time of bid opening. The insertion loss of devices installed in a transmission line to meet the requirements of this paragraph shall not exceed 2.5 dB without approval.

4.4.1.11 Controller. If the repeater has provisions for interconnecting a mobile or portable unit with the public-switched telephone system upon command from a mobile or portable unit (otherwise known as an "autopatch"), it must be under the control of an operator who can override the autopatch. This requirement is now in a state of flux and FCC Docket 29846 should be consulted when designing a radio-telephone interconnect system. Inputs to the controller can be made by telephone wireline or radio control link.

Typical requirements of a controller are the following:

1. The controller shall enable multiple-tone (tone pad) access to and control of repeater "off-on" functions via the local public-switched telephone system and by repeater receiver input. Each function shall be controlled by a one- to five-digit selection.

2. Dedicated control functions shall include repeater enable/disable, coded squelch off/on, autopatch enable/disable, output rf power high/low, autopatch digit count function enable/disable, and six undefined functions for future use.

3. The controller shall lock out access after any control function is exercised. A four-sequential-digit unlock code shall unlock the controller for the next control function.

4. Wire-wrap connections shall be used to alter control characteristics.

5. A tone pad shall be provided on the unit to enable local testing of control functions.

6. Control-function tones shall not be transmitted on the rf carrier, but telephone dialing tones shall. This retransmission enable and disable shall be controlled by the autopatch access command.

4.4.1.12 Autopatch assembly. The autopatch assembly shall enable interfacing the repeater audio circuitry with the local public-switched telephone system. The autopatch assembly shall have the following features:

1. digit count that shall, when enabled, drop (disconnect) the patch if an eighth digit is received;

2. three- or four-digit coded access command;

3. circuitry and configuration that permit direct connection to the public switched telephone system by dialup line; and

4. automatic disconnection (hangup) of the dialup line if no carrier is received by the repeater for an adjustable interval of 15 sec to 2 min (internal screwdriver adjustment).

4.4.1.13 Power supply. An ac power supply shall be provided to switch to an external, owner-supplied battery if the prime ac input power fails. The repeater shall operate satisfactorily on low power with 14 to 18 V dc input from the battery. Upon resumption of prime ac input power, the ac power supply shall switch back to ac, fully recharge the battery, and maintain a trickle charge rate.

4.4.2 Base stations

A base station has almost the same components as a repeater, except that it lacks both the duplexer and the interconnections between the receiver and transmitter that enable the station to receive and transmit simultaneously. Also, the base station can have more than one channel of operation, while the isolation needed between the repeater receiver and repeater transmitter limits its frequency span of operation. If the base station has several channels, it can be programmed to scan these separate frequencies automatically and lock onto any channel that has a signal on it, or it can be switched manually from channel to channel. It can be wired so that it is switched manually or if it automatically scans, it will still revert to a channel designated the "priority channel" whenever a signal appears on the priority channel. Alternatively, it can be programmed to switch to the priority channel only when a signal with a particular squelch control code appears on that channel.

The following is identical to the material presented in paragraph 4.4.1 above except for the changes that make it apply to base stations:

4.4.2.1 Applicable FCC Rules and Regulations. Specifications for any radio equipment should invoke the requirements of the FCC Rules and Regulations to cover such characteristics as frequency stability, off-frequency radiation, use of type-accepted equipment, emission limitations, modulation requirements, and timers. Generally, the requirements for these characteristics may be invoked by simply stating that the equipment must meet the applicable requirements of the FCC Rules and Regulations.

Sometimes, closer tolerances than required by the FCC are desirable or mandatory. Many factors that affect the design and operation of a radio communication system should be reflected in the base station specification but yet are not contained in the FCC Rules and Regulations. These items are discussed in the following paragraphs, but as a word of caution, each system must be engineered for the purpose it must fulfill. The statements given here represent only the factors that must be considered, are not exhaustive, and do not provide specification limits that should be contained in any one specification.

4.4.2.2 Reliability. Although reliability per se is difficult to specify, particular attention is given to specifying mechanical characteristics. Also, specifying performance characteristics that appear in only top-of-the-line equipment manufactured by reputable companies will greatly enhance reliability. The reliability specifications should include environmental conditions that affect the use of the repeaters. Unless the intended user dictates otherwise, the specifications should require that the base stations meet the minimum standards established in EIA Standards RS-152-B (Minimum Standards for Land Mobile Communication FM or PM Transmitters) and RS-204-A (Minimum Standards for Land Mobile Communication FM or PM Receivers).

4.4.2.3 Installation. The options for base station installation are limited by the coverage the station must afford. Sometimes it must be installed on an existing communications building and tower, on a new building and tower located in a vacant field, or on top of a mountain (or building) with no latitude for site location and only minimal space for a short tower. Since each location is unique, the installation contractor must be provided with complete instructions concerning what must be installed and how it is to be installed. Such instructions must include where each piece of equipment is to be located and how the transmission lines, power lines, input control lines, and local control and signal lines are to be run, dressed, and protected from mechanical damage, lightning, and weather. Protection against lightning must include the type of ground or counterpoise that must be used, which, in turn, is a function of local soil conductivity. Protection must also include precautions against inductance or unnecessary resistance between exposed metallic components of the installation and the single-point ground connection.

4.4.2.4 Mechanical characteristics. Mechanical characteristics of the base station should be specified to the extent that reliability and maintainability of the system is ensured. These specifications should include provisions typified by the following:

1. Cabinet. The cabinet that houses the station shall be suitable for exposed indoor installation on a bench or floor and shall be constructed of steel finished with baked enamel or an approved equal in quality and durability. All components of the unit shall be assembled for easy removal from the unit for servicing. Each cabinet shall have a door lock.

2. Accessibility. All parts that require periodic service or maintenance and all tuneable circuit adjustments shall be easily accessible.

3. Humidity. The station shall meet or exceed all specified EIA standards when subjected to high-humidity tests in accordance with EIA Standards RS-152-B, Sect. 13 (for transmitters), and RS-204-A, Sect. 21 (for receivers).

4. Environment. The station shall meet the specified performance requirements when subjected to any combination of the following environmental conditions: temperature, -30 to +60°C; relative humidity, 0 to 90%; power input voltage, 117 V ± 10%; and power input frequency, 60 Hz ± 5%.

5. Solid-state circuitry. All active circuit components except the exciter stage, final radio-frequency amplifier, and associated control circuitry, shall be solid state. Failure of the final frequency amplifier shall cause the exciter output power to be applied directly to the antenna output terminals when the transmitter is actuated.

4.4.2.5 Circuitry. Generally, present technology will permit specifying solid-state circuitry throughout the base station except in high-power radio-frequency amplifiers, as reflected in the preceding paragraph. However, to enhance reliability, the base station specifications should contain provisions for mounting the radio receiver and transmitter on separate printed-circuit boards. The reasoning behind this is twofold: larger boards tend to break more easily than smaller ones and a transceiver with receiver and transmitter separated is easier to service. Plated-through eyelets should be specified for all printed-circuit boards to help prevent bad solder joints on the boards. Systems that use multiple base station sites with interlocking control circuitry between them should be specified to ensure that should the control circuitry fail, the most essential of the base station sites or an alternate means of control will be used. Overall system reliability can be enhanced through use of backup or secondary transmission sites that can be switched on if the primary facilities fail. Often, such schemes fail because the control circuitry fails. The effects of such a failure can be reduced with alternate modes of manual control or with provisions that ensure at least one means of communication after the control circuitry fails.

4.4.2.6 Operational features. The operational features of the base station should include the requirements for local and wireline control, if required. Generally, local control is always required for maintenance, but this will be included as part of the control chassis. Other local control may be required for dispatching from a dispatch position with a separate local control unit or from a control panel contained in a dispatch console. Other local control features may include a backup base station, indication of whether the main or the backup facilities are in use, and the status of the emergency power facilities.

4.4.2.7 Electrical characteristics. The following should be considered for inclusion as electrical characteristic requirements for a base station:

1. Control. The base station shall be provided with an extended local control unit.

2. Time-out timer. An automatic timer shall be provided to turn off the transmitter after it has been actuated by the push-to-talk circuit for a preset period.

3. Metering. Meters and circuits shall be provided to enable troubleshooting, alignment, and adjustment of all essential circuits in the station. All metering points shall be decoupled to minimize both the interaction between circuits and the effect of the metering action on the circuit being measured.

4. Automatic identification. The transmitter shall periodically transmit its identity automatically in a manner that meets the requirements of the FCC Rules and Regulations.

4.4.2.8 Transmitter. The following transmitter characteristics should be included in the base station specification:

1. Modulation. The deviation limiter circuit required by the FCC Rules and Regulations shall have a continuously variable control. This control shall be set for ± 5 KHz after the transmitter has been installed.

2. Power output. The primary transmitter shall deliver at least 200 W into the duplexer, and the backup transmitter shall deliver at least 15 W. Both transmitters shall be capable of maintaining this power output continuously. Exciter output power shall be at least 15 W.

3. Frequency adjustment. A device shall be included to permit setting the transmitter oscillator to the exact frequency of operation.

4. Audio-frequency response. The audio-frequency response shall not vary more than +1 or -3 dB from a 6-dB-per-octave preemphasis characteristic from 300 to 3000 Hz as referenced to the 1000-Hz level, in accordance with EIA Standard RS-152-B, Sect. 7.

5. Audio distortion. Total audio harmonic distortion shall not exceed 5% with a 1000-Hz test tone at a level sufficient to produce two-thirds maximum deviation, in accordance with EIA Standard RS-152-B, Sect. 6.

6. Frequency-modulation noise and residual hum. Frequency-modulation noise and residual hum shall be at least 55 dB below two-thirds maximum deviation at 1000-Hz test tone, as measured through a standard 6-dB-per-octave deemphasis network.

7. Amplitude-modulation noise and residual hum. Amplitude-modulation noise and residual hum shall be at least -35 dB, in accordance with EIA Standard RS-152-B, Sect. 16.

8. Audio sensitivity. The microphone, audio circuitry, and modulator shall be designed and adjusted to produce maximum deviation by an operator using normal conversational tones with the microphone 6 in. from the lips and to produce two-thirds maximum deviation at 1000 Hz with an input of -20 dBm at the control line terminals.

9. Tuning procedure. Built-in meter(s), switches, and circuitry shall be provided to enable tuning adjustments without use of additional patch cords, intercabling, or meters.

10. Spurious emissions. Transmitter spurious and harmonic emissions shall be -70 dB.

4.4.2.9 Receiver. The following items are typical of those that should be included in the base station receiver specification:

1. Selectivity. Selectivity characteristics shall be at least -85 dB at ± 25 KHz, in accordance with EIA Standard RS-204-A, Sect. 11.

2. Sensitivity. Receiver sensitivity shall be 0.35 μV, 12-dB SINAD.

3. Modulation acceptance. The receiver modulation acceptance shall be determined by the mobile unit transmitter characteristics in accordance with EIA Standard RS-204-A, Sect. 10.

4. Audio output characteristics. The line output level shall be at least +11 dBm at 600 Ω. Response shall not vary more than +1 to -3 dB, as defined in EIA Standard RS-204-A, paragraph 15.2.2. Total harmonic distortion shall not exceed 5% at 1000 Hz. Hum and noise shall be less than 50 dB below line output level. Available speaker output power shall be at least 0.5 W, and the speaker input impedance shall match the receiver output impedance.

5. Carrier squelch circuit. The carrier-actuated squelch circuit shall be of the noise-compensated, adjustable-sensitivity type. At the threshold setting, a signal of 0.25 μV shall provide positive squelch opening. The squelch circuit shall not respond to noise bursts.

6. Coded squelch circuit. The receiver shall be muted until the incoming signal is modulated with the CTCSS frequency assigned to the users of the radio equipment, as specified in EIA Standard RS-220, paragraph 4. The secondary base station shall be muted until the incoming signal contains the unique group call assigned to the secondary group. A switch shall be provided on the control chassis or on the front of the station to transfer the receiver from coded squelch operation to carrier-operated squelch operation.

7. Intermodulation rejection. Intermodulation rejection shall be at least -80 dB.

8. Spurious and image rejection. Spurious and image rejection shall be at least -90 dB.

4.4.2.10 Antenna coupling system. There are two methods of specifying the antenna coupling system: detail it completely with elaborate installation drawings or specify several base sites. If only one base station site is to be constructed, drawings and detailed specifications could be used.

The antenna, transmission line, and isolation system shall be designed and installed by the contractor on the basis of the characteristics of the transmitter and receiver provided; the characteristics of the station site; and the requirements of the contract documents. These requirements include the following:

1. The maximum power rating of all components in the transmitter transmission line shall exceed the maximum transmitter power output by 25%.

2. All cavities and other isolation devices shall be mounted adjacent to the station they serve.

3. The VSWR in the transmission line shall not exceed 1.5 to 1.0 at any point in the line.

4. Circulators, cavity isolators, or similar devices shall be provided, as necessary, to prevent interference from radiating sources that exist at time of bid opening. The insertion loss of devices installed in a transmission line shall not exceed 2.5 dB without approval.

4.4.2.11 Controller. If the base station is equipped to interconnect a mobile or portable unit with the public-switched telephone system upon command from a mobile or portable unit (otherwise known as an "autopatch"), it must be controlled by an operator who can override the autopatch. This requirement is now in a state of flux, and the results of FCC Docket 20846 should be consulted when one designs radio-telephone interconnect systems. Inputs to the controller can be made by telephone wireline or radio control link.

Typical requirements of a controller are the following:

1. General specification. The controller shall enable multiple-tone (tone pad) access to and control of base station "off/on" functions by the local public-switched telephone system and by base station receiver input. Each function shall be controlled by a one- to five-digit selection.

2. Dedicated control functions. These shall include transmitter "off/on," coded squelch "off/on," autopatch enable-disable, output radio-frequency power high-low, autopatch digit-count function enable-disable, and six undefined functions for future use.

3. Access lockout. The controller shall lockout access after any control function is exercised. A four-sequential-digit unlock code shall unlock the controller for the next control function.

4. Wire-wrap connections. These shall be used to alter control characteristics.

5. Tone pad. One shall be provided on the unit to enable local testing of control functions.

4.4.2.12 Autopatch assembly. The autopatch assembly shall permit the base station audio circuitry to be interfaced with the local public-switched telephone system. The autopatch assembly shall have the following features:

1. Digit count. When enabled, this will drop (disconnect) the patch if an eighth digit is received.

2. Three- or four-digit-coded access command for autopatch.

3. Direct connection to the public-switched telephone system. The circuitry and configuration of the autopatch shall permit such connection by dialup line.

4. Automatic disconnection (hang up) of the dialup line. This will occur if no carrier is received by the base station for an adjustable interval of 15 sec to 2 min. This adjustment shall be an internal manual adjustment.

4.4.2.13 Power supply. An ac power supply shall be provided. In the event of prime ac input power failure, it will switch to an external, owner-supplied battery. The base station shall operate satisfactorily in a low-power mode with 14 to 18 V dc input from the battery. Upon resumption of prime ac input power, the ac power supply shall switch back to ac, recharge the battery, and upon full charge of the battery, maintain a trickle charge rate.

4.4.3 Control stations

A control station is a base station that transmits on the input or receive frequency of a repeater and receives on the output or transmit frequency of a repeater. A multiple-channel base station can have one of its channels configured as a control channel in this manner, in which case the station may have two licenses, one as a base station and another as a control station. Since a control station operates on the same frequencies as do mobile units that use the repeater, the FCC has placed limitations on many control station installations to prevent them from obliterating transmissions from mobile units. These limitations are presented as notes to the list of frequencies available for licensing for each service. The limitations pertain to control station transmitter power output and antenna directivity. Typical requirements for control stations are reflected in the following exemplary specifications.

4.4.3.1 General considerations.

1. Each control station shall be capable of being used with local, extended local, and remote control.

2. Each control station shall be provided with the power level adjusted and antenna installed to produce a signal of at least 10 dB above that required for 20-dB quieting of the associated repeater. This power level or a higher one shall be employed when the control station is used as a simplex base station. The maximum power output of the control station and the antenna selection and installation shall conform to the requirements of paragraph 91.304(b)(33) of the FCC Rules and Regulations.

3. Each control station shall be provided with transmitter, receiver, control chassis, speaker with volume control, wireline interface circuitry, power supply, antenna, and transmission line.

4. Multiple-frequency control stations shall have multiple receivers and shall monitor continuously each designated frequency. They shall transmit on the frequency selected by operator at the local- or remote-control point with the group-call assigned to the area of the control point.

4.4.3.2 Mechanical characteristics.

1. Cabinet. The cabinet that houses the station shall be constructed for exposed indoor installation on a desk or table if no larger than 4000 $in.^3$ If larger than 4000 $in.^3$, it shall be installed on the floor beside a desk or table with extended-local control on the desk or table. The cabinet shall be constructed of steel and finished with baked enamel or an approved equal in quality and durability.

2. Accessibility. All parts that require periodic service or maintenance and all tuneable circuit adjustments shall be easily accessible.

3. Humidity. The equipment shall meet or exceed all applicable EIA standards when subjected to high-humidity tests, in accordance with EIA Standards RS-152-B, Sect. 13 (for transmitters), and RS-204-A, Sect. 21 (for receivers).

4. Environment. The station shall meet the specified performance requirements when subjected to any combination of the following environmental conditions: temperature, -30 to +60°C; relative humidity, 0 to 90%; power-input voltage, 117 V ac ± 10%; and power-input frequency, 60 Hz ± 5%.

5. Circuitry. All active circuit components shall be solid state.

4.4.3.3 Electrical characteristics.

1. Time-out timer. An automatic timer shall prevent keying the transmitter for extended periods.

2. Metering. Centralized test jacks will permit tuning adjustments with an external test set. Meter points shall be decoupled to prevent observable interaction between circuits and to minimize the effect of the metering action upon the circuit being measured.

3. Controls and displays. All controls shall be configured on the basis of sound engineering principles to minimize the time required to operate the station. Each control station shall be operable with local control and shall be able to accommodate twice the number of remote-control units specified. Each control station shall have all controls necessary for initiating an individual selective-call, a group-call, or an all-call transmission. The group-call transmitted by a control station shall be unique to the entity employing the control point that actuated the control station. A group-call shall be initiated by each control point when the operator actuates the push-to-talk switch without first actuating a control to initiate an all-call or an individual selective-call. Specific control and display components and their functions are described below.

a. Channel-control switches shall be provided for each channel to disconnect the local speaker from the channel, to select the channel for local monitor only, or to select the channel for monitoring and transmitting. Only one channel shall be selectable for transmitting at a time.

b. An individual volume control shall be provided to adjust the local audio-level output for each channel.

c. Two light-emitting diode (LED) indicators shall be mounted with the channel-control switches to indicate channel use. A green LED shall indicate that the channel is receiving a signal, and a red LED shall indicate that the channel is being used to transmit from the control station.

4.4.3.4 Transmitter.

1. Modulation. The deviation-limiter circuit required by the FCC Rules and Regulations shall have a continuously variable control. This control shall be set for ± 5 KHz after the transmitter has been installed.

2. Frequency adjustment. A device shall be included to permit setting the transmitter oscillator to the exact frequency of operation.

3. Audio-frequency response. The audio-frequency response shall not vary more than +1 or -3 dB from a 6-dB-per-octave preemphasis characteristic from 300 to 3000 Hz as referenced to the 1000-Hz level, in accordance with EIA Standard RS-152-B, Sect. 7.

4. Audio distortion. Total audio harmonic distortion shall not exceed 3% with a 1000-Hz test tone at a level sufficient to produce two-thirds maximum deviation, in accordance with EIA Standard RS-152-B, Sect. 6.

5. Frequency-modulated noise and residual hum. Frequency-modulated noise and residual hum shall be at least 55 dB below two-thirds maximum deviation at 1000-Hz test tone, as measured through a standard 6-dB-per-octave deemphasis network.

6. Amplitude-modulated noise and residual hum. Amplitude-modulated noise and residual hum shall be at least -35 dB, in accordance with EIA Standard RS-152-B, Sect. 16.

7. Audio sensitivity. The microphone, audio circuitry, and modulator shall be designed and adjusted to produce maximum deviation by an operator using normal conversational tones with the microphone 6 in. from the lips and to produce two-thirds maximum deviation at 1000 Hz with an input of -20 dBm at the control line terminals.

4.4.3.5 Receiver.

1. Selectivity: at least -85 dB at ± 25 kHz, in accordance with EIA Standard RS-204-A, Sect. 11

2. Sensitivity: 0.35 μV, 12-dB SINAD

3. Modulation acceptance: determined by the repeater characteristics, in accordance with EIA standards

4. Audio output characteristics:

   a. Line-output level at least +11 dBm at 600 Ω

   b. Response not to vary more than +1 to -3 dB, as defined in EIA Standard RS-204-A, paragraph 15.2.2

   c. Total harmonic distortion no greater than 5% at 1000 Hz

   d. Hum and noise more than 50 dB below line-output level

e. Available speaker-output power of at least 3 W and speaker-input impedance that matches receiver-output impedance

5. Squelch circuit: two types, carrier squelch circuit and coded squelch circuit

   a. Carrier squelch circuit:

      i. Of the noise-compensated, adjustable-sensitivity type

      ii. Positive squelch opening provided by a signal of 0.25 μV at the threshold setting

      iii. No response to noise bursts by the squelch circuit

   b. Coded squelch operation:

      i. With receivers of vhf high-band control stations muted until the incoming signal is modulated with the CTCSS frequency assigned to the users of the radio equipment, as specified in EIA Standard RS-220, paragraph 4

      ii. With receivers of uhf control stations muted until the incoming signal has the all call, group call, or individual selective call assigned to the control station

   c. Switch: on the control chassis or the front of the station to transfer the receiver from coded squelch operation to carrier-operated squelch operation

6. Intermodulation rejection: at least -80 dB

7. Spurious and image rejection: at least -100 dB

8. Frequency stability: above ± 0.0002%

4.4.3.6 Antenna coupling system. The antenna, transmission line, and isolation system shall be designed and installed by the contractor on the basis of the requirements of the applicable FCC Rules and Regulations, the characteristics of the transmitter and receiver supplied, the characteristics of the station site, and the requirements of the contract documents.

Typical requirements include the following:

1. that the maximum power rating of all components in the transmitter transmission line exceed the maximum power output of the transmitter by at least 25%;

2. that the VSWR in the transmission line not exceed 1.5 to 1.0 at any point in the line; and

3. that circulators, cavity isolators, and similar devices be provided to prevent interference from radiating sources existing at time of bid opening.

The design of each control station installation shall be submitted for approval at least four months before scheduled installation of the control station. Schedule 45 days for response to the submittal.

4.4.4 Mobile transceivers

Mobile transceivers have a wide latitude of configuration. Units producing 20 W of power can be mounted under the instrument panel of the vehicle, while the units with higher power outputs must be mounted in the trunk, as illustrated in Fig. 23. The maximum power output available in mobile units is approximately 150 W. The channel configuration of mobile units can vary from one simplex channel to 12-channel units with a combination of simplex and half-duplex channels. Mobile units may have the ancillary function of vehicular relay, as shown in Fig. 21. When the mobile unit transmitter transmits to the portable unit, its power output must be limited to 2.5 W. Typical mobile unit specifications that address the requirements for a mobile transceiver are presented below.

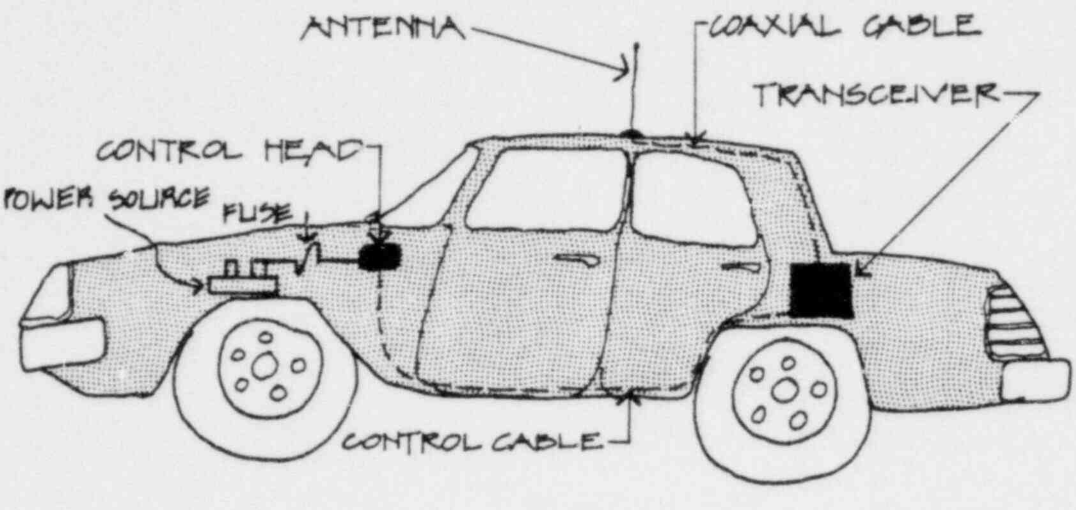
4.4.4.1 General considerations. Mobile units shall be provided with six-channel transceiver, control head, call-light, antenna, cabling, and other items necessary for public safety radio services.

1. Standards. Mobile units shall meet the applicable shock, temperature, vibration, and humidity requirements described in EIA Standards RS-152-B and RS-204-A.

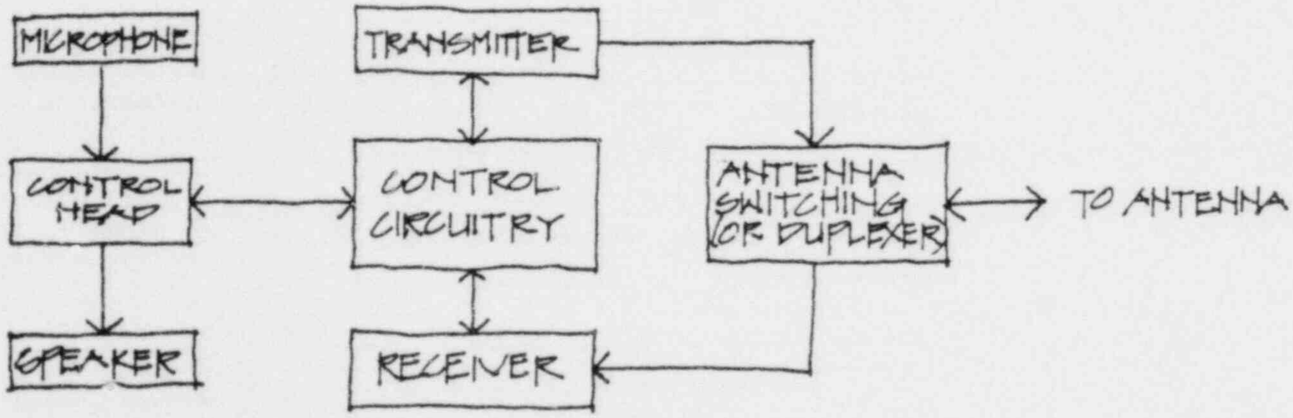
2. Installation. The mobile units shall be installed in vehicles in the trunk, under the dash, or in another location approved by the owner. A lock on each unit shall lock the drawer into the mount to prevent unauthorized access to the unit. All cables and leads shall be routed, dressed, and secured to prevent both damage from vibration and contact with other objects. (Each unit shall be clearly marked to indicate the frequency, group-call assignment, and unit identification of each channel, and the device for recording this information shall be permanently attached to the unit ((not the housing)) and shall be readable when the unit is locked into the housing. The system shall provide for changing the individual unit identification and group-call assignments but in a manner that will prevent unauthorized personnel from making these changes. All mobile unit installations shall be identical except for differences in plug-in frequency determining elements, group-call assignments, and unit identification.) Note: the portion of this paragraph within the parentheses "( )" would not be required by mobile units using CTCSS squelch control.

3. Housing. The mobile unit housing shall completely enclose the transceiver and power supply and shall protect it from dirt, dust, moisture, splashing water, and physical damage from tools and other equipment in the vicinity of the housing. Maintenance access shall enable troubleshooting and servicing the unit while it is installed in the vehicle.

4. Cooling. External heat radiators shall be incorporated to keep the radio-frequency power amplifiers within conservative operating temperatures without allowing airborne contaminants to enter the unit.



MOBILE RADIO UNIT INSTALLATION



BLOCK DIAGRAM OF MOBILE TRANSCEIVER

FIGURE 23

5. Cabling.

a. All cabling required to interconnect the radio unit, control unit, vehicle battery, and fusing facilities shall be insulated, weatherproof material and shall have plugs of quality matching that of the radio set.

b. All connectors shall have screw fasteners or other means of securing the plug to the drawer unit to prevent loosening by vibration or shock.

6. Control unit.

a. A matching control unit including all control functions to operate the radio set except the coded squelch disable switch shall be part of the mobile unit. The coded squelch disable switch shall be part of the microphone hanger bracket.

b. The control unit shall be mounted in a location convenient to the driver of the vehicle and shall be connected to the radio set with a suitable cabling kit. The control unit shall be mounted so as to minimize injury to the driver and passengers in case of an accident. The call-light shall be mounted in a position to enable it to be observed through the windows from the front or the side of the vehicle. The call light shall be illuminated upon receipt of a selective call and shall remain illuminated until the mobile unit transmitter is next actuated. A power "on/off" indicator shall be provided.

c. The control unit shall be of minimum physical size to perform the specified functions and shall be consistent with current human factors engineering principles.

d. A palm-type microphone, designed to reduce stray noise pickup, shall be part of the control unit. Features of the microphone shall be as follows:

i. The microphone shall have a sturdy, high-impact-resistant plastic housing and shall be ruggedly constructed.

ii. The microphone cable shall be a self-retracting coiled cord and shall be terminated with a convenient plug-and-socket connection.

iii. A push-to-talk switch shall be intergral to the microphone.

iv. The microphone hanger shall be mounted for convenient access to the vehicle operator. The design of the hanger shall facilitate easy insertion and removal of the microphone and shall prevent it from becoming dislodged from the hanger.

v. The mobile unit receiver coded squelch shall be disabled when the microphone is removed from the hanger. There shall be no other switch on the hanger for disabling the coded squelch.

e. A tone pad shall be incorporated with the control unit of designated mobile units to enable the mobile unit operator to initiate local telephone interconnect calls without operator assistance.

7. Construction. The receiver and the transmitter in the transceiver shall be of modular construction with a rugged diecast chassis. The chassis shall be secured to sheet metal support members and the front panel by rivets and/or bolts to form a mechanically solid unit.

4.4.4.3 Electrical characteristics.

1. Metering. The mobile unit installed in the vehicle shall be equipped for metering of all essential circuit functions. All metering points shall be properly decoupled and connected to the designated metering jacks.

2. Power source. The mobile unit shall operate from a nominal 12 V dc, negative-ground power source, as defined in the applicable EIA standards and shall have positive-action, reverse-polarity protection. The input power shall be adequately fused to ensure fast and positive interruption of the power in case of an internal short circuit. Provisions shall accommodate positive-ground power sources when necessary.

3. Channel assignment. The rf and group-call assignments of each channel of the mobile unit shall be specified in the contract documents.

4. Automatic identification. The transmitter shall identify the vehicle in which it is mounted each time the microphone switch is actuated. Identification coding shall ensure at least a 99% probability of receiving the identification number of the vehicle at the dispatch console monitoring the channel on which the mobile unit is operating when the signal level at the uhf receiver used is above 12-dB quieting. (See Note following Sect. 4.4.4.9.)

5. Vehicular repeater. The provisions for interfacing with portable units, shown in Figs. 21 and 24, should be specified.

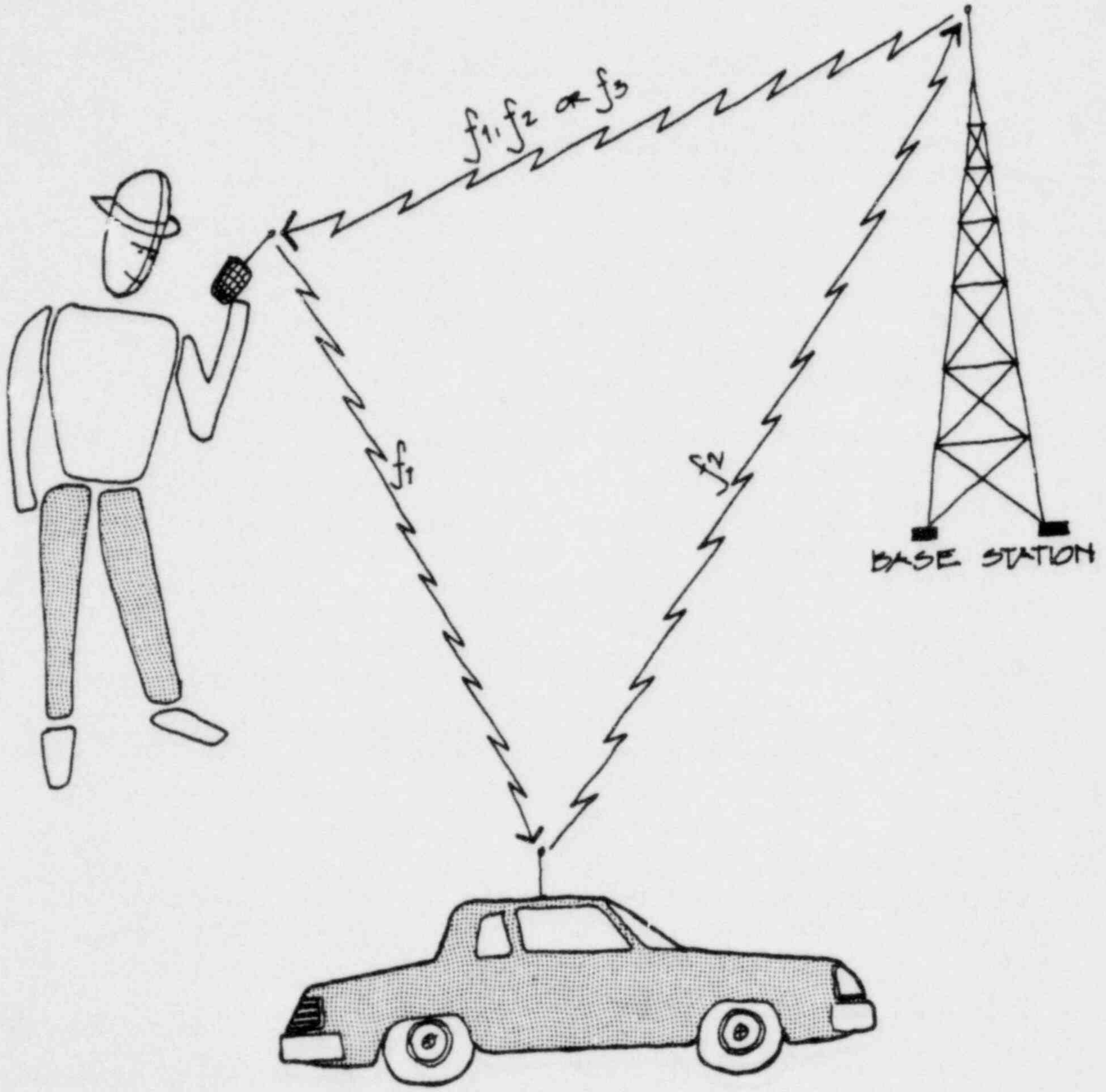
4.4.4.4 Transmitter.

1. Modulation. The deviation limiter circuit required by the FCC Rules and Regulations shall have a continuously variable control. This control shall be set for ± 5 KHz after the transmitter has been installed.

2. Power output. The transmitter shall deliver at least 58 W into the antenna and shall be rated as intermittent, as defined in EIA Standard RS-152-B.

3. Frequency stability. Transmitter frequency stability shall be ±0.0002% over the temperature range -30°C to +60°C and with a power source variation of ± 10%. A variable reactance shall be included for each channel to permit setting the transmitter oscillator to the exact frequency of operation.

4. Audio-frequency response. The audio-frequency response shall not vary more than +1 or -3 dB from a 6-dB-per-octave preemphasis characteristic 300 to 3000 Hz as referenced to the 1000-Hz level, in accordance with EIA Standard RS-152-B.



VEHICULAR REPEATER

FIGURE 24

5. Audio distortion. Total audio harmonic distortion shall not exceed 3% with a 1000-Hz tone at a level sufficient to produce two-thirds maximum deviation, in accordance with EIA Standard RS-152-B.

6. Frequency-modulation noise and residual hum. Frequency-modulation noise and residual hum shall be at least 60 dB below two-thirds maximum deviation at a 1000-Hz test tone, as measured through a standard 6-dB-per-octave deemphasis network.

7. Amplitude-modulation noise and residual hum. Amplitude-modulation noise and residual hum shall be at least -35 dB, in accordance with EIA Standard RS-152-B.

8. Audio sensitivity. The microphone, audio circuitry, and modulator shall be designed and adjusted to produce maximum deviation by an operator using normal conversational tones with the microphone 6 in. from the lips.

9. Spurious emissions. Transmitter spurious and harmonic emissions shall be -80 dB.

10. Time-out timer. An automatic timer in the transceiver shall prevent keying the transmitter for extended periods. The timer shall turn off the transmitter after it has been keyed on for 60 sec. The time-out timer shall be reset automatically by the push-to-talk circuitry.

11. Tone generator. (Note: This paragraph is required only if CTCSS squelch control is used.) A tone generator shall modulate the transmitter with the CTCSS frequency 123.0 Hz, in accordance with EIA Standard RS-220.

4.4.4.5 Receiver

1. Selectivity: at least -90 dB at ± 25 KHz, in accordance with EIA Standard RS-204-A
2. Sensitivity: at least 0.35 μV, 12-dB SINAD
3. Modulation acceptance: determined by the repeater or base station transmitter characteristics, in accordance with EIA Standard RS-204-A
4. Audio-output characteristics:
   a. Variation in response no greater than +1 dB to -8 dB, as defined in EIA Standard RS-204-A
   b. Total harmonic distortion no greater than 5% at 1000 Hz
   c. Hum and noise more than 50 dB below line output level
   d. Speaker-output power at least 10 W
5. Carrier-actuated squelch circuits:
   a. Of the noise-compensated, adjustable-sensitivity type

b. Positive squelch opening provided by a signal of 0.25 μV at the threshold setting

c. Unresponsive to noise bursts

d. Receiver muted when the microphone is in the microphone-hanger bracket until the incoming signal contains the individual-selective-call, group-call, or all-call assigned to the unit; provisions for changing the selective-call, group-call, and all-call assigned to each unit

e. (Note: This paragraph required only if CTCSS squelch control is used.) Receiver muted when the microphone is in the microphone-hanger bracket until the incoming signal is modulated with CTCSS frequency, 123.0 Hz, as specified in EIA Standard RS-220, paragraph 4

6. Intermodulation rejection: at least 80 dB

7. Spurious and image rejection: at least -100 dB

8. Receiver frequency stability: at least ± 0.0002%

4.4.4.6 Loudspeaker.

1. The loudspeaker shall be designed for good sound reproduction in the voice-frequency range, 300 to 3000 Hz.

2. The loudspeaker shall be mounted on the vehicle firewall, dash, or other suitable location approved by the owner.

3. The loudspeaker impedance and power-handling capabilities shall match the characteristics of the mobile unit receiver output.

4.4.4.7 Antenna switching.

1. The antenna-switching device shall be designed to prevent intermodulation and spurious emissions.

2. The antenna-switching device shall be enclosed to eliminate contamination from dust, dirt, water, and atmospheric corrosion.

4.4.4.8 Antenna.

1. Mobile units shall be provided with antennas, antenna cables, and all mounting hardware for a complete installation.

2. Mobile antennas mounted in buses shall be Sinclair Radio Laboratories model ASP772L or Communications Products Company model 1073 or an approved equal. All other mobile antennas shall be Decibel Products, Inc., type DB-7360Z or an approved equal.*

*If preferred, mobile antennas can be specified by the required antenna type, mounting arrangement, cable and connector types, horizontal gain, and mechanical characteristics.

3. Each antenna shall be trimmed after installation to produce minimum VSWR in the transmission line at a frequency of 491.500 MHz.

4. Antennas for passenger automobiles and pickups shall be mounted near the center of the roof of the vehicle. On buses, they shall be mounted on the roof in a position approved by the owner. On other types of vehicles, their location shall be designated by the owner.

5. All mobile antennas shall be connected to the mobile transceivers with 1/4-in. Decibel Products, Inc., Superflex Heliax cable or an approved equal.

4.4.4.9 Installation. Location and mounting position of mobile units shall be coordinated with the owner. Cables and wires shall be protected from physical damage by bushings, grommets, tape, and other approved methods of padding when installed through partitions or around hard objects. A metallic raceway shall be provided where necessary to protect cables and wires from abrasion or other damage under normal circumstances. All equipment and cables shall be firmly attached to the vehicle. Antenna coaxial cables shall be concealed between the headliner and the roof of the vehicle.

Note: If any form of automatic status signaling such as "duress only," "duress," "in service," "out of service," "out of vehicle," or "arrived at designated location" is desired, the requirements for this option should be included in a paragraph immediately following Sect. 4.4.4.3, item 4 above. Corresponding requirements must be included in the dispatch console and portable units used in the same system (Sect. 4.5.2).

4.4.5 Portable Transceivers

Portable transceivers, popularly known as "portables," "handy-talkies," and "walky-talkies" and referred to in the FCC Rules and Regulations as "hand-carried units" and "hand-carried transmitters," are extremely convenient devices but have some definite disadvantages. These units have very sensitive receivers and low-power transmitters (up to 4 or 5 W in the smaller type that can be carried in the palm of the hand or on a belt loop and up to 20 or 30 W in the larger "lunch-pail"-type units). A competitive effort to minimize the size of portable units has produced the balance among size, battery life, and performance characteristics for top-of-the-line units reflected in the following exemplary specification.

4.4.5.1 General specification. Portable transceivers shall be provided for use in the system as specified in the general specification. Each portable radio unit shall be complete with nickel-cadmium battery, antenna, carrying case, and desk or vehicular charger, as specified.

4.4.5.2 Mechanical characteristrics. The size, weight, and construction of the portable radio unit shall permit one-hand operation and operation of the unit as a fixed radio station when it is installed in a desk charger. All operating controls except the push-to-talk switch shall be on top of the unit. The battery shall be capable of being quickly and easily removed from the unit by "twist-off" action without opening the unit case. The radio unit housing shall be constructed of highly impact-resistant material and shall be sealed to protect internally mounted circuitry against dust, moisture, and splashing water. The portable radio shall be supplied with a leather carrying case, cover, metal swivel mount, and belt loop attachment.

4.4.5.3 Desk battery charger. Desk battery chargers shall accept one portable unit complete with a battery or a portable unit battery. The charger shall operate from 117 V ac ± 10%. Each charger shall be capable of completely charging within 16 hr., a battery that has been discharged to the end of its usable capacity. There shall be no damage to the battery if the unit is left in the charger for an extended period. The portable unit shall operate as specified (receive and transmit) while inserted in the charger. (Some manufacturers offer rapid-charge battery chargers, which could be specified here. These chargers cost approximately twice as much as a standard charger and may shorten battery life slightly. They will charge the battery in one-tenth to one-twentieth of the time a standard charger takes to do so.)

4.4.5.4 Vehicular charger. The vehicular charger shall accept one portable unit with a battery and will automatically charge the battery of the portable unit to enable the vehicle operator to use the portable unit as a mobile radio unit. Each vehicular charger shall have a microphone, hanger bracket, and antenna, as specified in the associated mobile radio specifications; a speaker, an audio amplifier that provides at least 5 W of audio power, and an automatically operating radio-frequency amplifier that provides at least 25 W of radio-frequency power to the antenna.

4.4.5.5 Channel assignment. The radio-frequency carrier and group-call assignment of each channel shall be those specified in the contract documents.

4.4.5.6 Transmitter. Characteristics of the transmitter and criteria for them are as follows:

1. Frequency stability. The radio-frequency stability shall be better than ± 0.0005% over the temperature range -30°C to +60°C (25°C, reference).

2. Spurious and harmonic emissions. These shall be at least 50 dB below the output carrier and shall be tested in accordance with paragraph 5.3 of EIA Standard RS-152-B.

3. Audio distortion. Audio distortion at 1000 Hz with 3000-Hz deviation shall be no greater than 8%, as specified in NILECJ-STD 0203.00.

4. Power output. The radio-frequency power output to the antenna on all channels except the vehicular repeater channel shall be no less than 3.5 W, and the power output on the vehicular repeater channel shall be more than 2 W and less than 2.5 W.

5. Deviation limiter. The deviation limiter circuit shall act instantaneously. It shall have a variable control to establish the point of 100% modulation of the transmitter under normal speech conditions and shall prevent deviation in excess of 100% under extremely loud talking conditions. The limiter circuit shall have a continuously variable control to permit transmitter deviation adjustments to any value (factory set at ± 5 KHz before shipment) between zero and the maximum permissible system deviation.

6. Audio filter. A low-pass audio filter shall be incorporated into the circuit following the deviation-limiter circuit. (Note: this requirement will not be necessary if CTCSS techniques are not employed.)

7. Audio response. Audio response shall be within +1 to -3 dB of the 6-db-per-octave preemphasis characteristic between 300 to 3000 Hz, as defined in EIA Standard RS-316-A.

8. Frequency-modulation noise. The FM noise level, measured at two-thirds rated deviation with a 1000-Hz modulating signal, shall be at least 50 dB below the output carrier.

9. Emission. Transmitter emission shall be 16F3, as defined by the FCC Rules and Regulations.

10. Amplitude-modulation hum. The AM hum shall not exceed -60 dB, as defined in EIA Standard RS-316-A.

11. Automatic identification. The transmitter shall identify itself with a unique identification number each time the press-to-talk switch is actuated. Identification coding shall ensure at least a 99% probability of receiving the ID number at the supervisory console when the signal level at the uhf receiver receiving the signal from the portable is above 12-dB quieting (see Note following Sect. 4.4.4.9).

12. Time-out timer. An automatic timer in the transceiver shall prevent keying the transmitter for extended periods. The timer shall turn off the transmitter after it has been keyed on for 60 sec. The time-out timer shall be automatically reset by the push-to-talk circuitry.

13. Tone generator. The transmitter shall include a tone generator that modulates the transmitter, in accordance with EIA Standard RS-220 requirements with the CTCSS frequency specified in the contract documents.

4.4.5.7 Receiver. Characteristics of the receiver and criteria for them are as follows:

1. Input impedance. The rf input impedance at the external antenna terminal shall be designed for an optimum match to the antenna.

2. Frequency stability. The frequency stability shall be better than ± 0.0005% over the temperature range -30°C to +60°C (25°C reference).

3. Carrier squelch. The 12-dB-SINAD carrier squelch sensitivity, as defined by EIA Standard RS-204-A, shall be at least 0.35 μV. The carrier squelch shall be of the noise-compensated, adjustable-sensitivity type and shall not respond to noise bursts.

4. CTCSS squelch. When the CTCSS circuit is actuated, the receiver shall be muted until the incoming signal is modulated with the CTCSS frequency identified in the contract documents, as specified in EIA Standard RS-220. (Note: EIA Standard RS-374 should be cited here if a coded squelch technique other than CTCSS is employed.)

5. Selectivity. The 12-dB-SINAD selectivity, as defined by EIA Standard RS-204-A, shall be at least -70 dB.

6. Intermodulation interference rejection. The intermodulation interference rejection shall be at least -65 dB.

7. Spurious rejection. The spurious rejection shall be at least -55 dB.

8. Audio-output power. The receiver audio output power shall be at least 500 mW to the speaker at less than 5% distortion, with the received carrier modulated at 70% deviation with a 1000-Hz tone.

9. Audio response. The audio response shall not vary more than +2 to -10 dB, as defined in EIA Standard RS-316-A.

10. Modulation acceptance. The receiver modulation acceptance shall be determined by the repeater/base station transmitter characteristics, in accordance with EIA Standard RS-204-A.

11. Squelch blocking. The receiver shall not exceed the minimum requirements for squelch blocking, as specified in EIA Standard RS-316-A.

12. Receiver attack time. The receiver attack time shall be less than 150 msec, in accordance with EIA Standard RS-204-A.

13. Receiver closing time. The receiver closing time shall be less than 250 msec, in accordance with EIA Standard RS-204-A.

4.4.5.8 Antenna. Portable units shall be provided with Antenna Specialists Co. flexible helical antennas, models PG4, PG6, PG8, PG12, or an approved equal. (Note: A telescoping one-fourth-wavelength antenna could be specified here to provide greater operating range with a consequent sacrifice in convenience due to the antenna's unwieldy telescoping.)

4.4.5.9 Battery. Each portable unit shall be provided with a nickel-cadmium battery. Battery capacity shall provide 8 hr. operation with a 5-5-90% duty cycle.

Note that the most unreliable component of a communication system using portable units is the portable unit battery. Proper charging-discharging cyclic use of these batteries in accordance with the battery manufacturer's recommendations will prolong their life significantly and prevent loss of communications during emergencies because of battery memory.[41] Percent-duty cycle (5-5-90) specifies transmit 5% of the time, receive message 5% of the time, and be quiescent 90% of the time.

4.4.6 Paging Receivers

Requirements for paging receivers must be developed with extreme care since a wide spectrum of paging receivers is available on the market. The first decision that must be made is whether tone, tone-and-message, or tone-and-voice units are required. The relative advantages and disadvantages of these three types are presented in Sect. 4.1.2. The second consideration is quality versus price. The tone-and-voice pagers that meet the exemplary specifications below have list prices approaching $400. Inexpensive foreign, tone-only pagers are available in the United States for under $140. The cheaper units have less sensitivity, less interference rejection, more falsing, are more easily damaged by shock (dropping), and usually contain less-expensive batteries. If pagers are to be used as part of a communication system to safeguard a nuclear facility, they should be the most reliable available; hence, they should be top-of-the-line units, as reflected in the exemplary specifications below.

4.4.6.1 General considerations. Each pager shall be provided with a battery and a battery charger. The pager shall be capable of operation while in the battery charger.

4.4.6.2 Mechanical characteristics. The size, weight, and configuration of the paging receiver shall permit carrying the unit in a shirt or coat pocket and manipulating the controls of the pager without having to remove it from the pocket. The battery shall be capable of being quickly and easily removed from the unit without disturbing the radio-frequency or audio circuitry of the receiver. The housing shall be constructed of highly impact-resistant material and shall be sealed to protect internally mounted circuitry against dust, moisture, and water. Circuitry shall be all solid state. The decoder shall not contain reed switches. The pager shall have a spring-loaded pocket clip.

4.4.6.3 Battery charger. The battery charger shall be a desk-type charger that shall accept one pager unit complete with battery or a pager unit battery. Each charger shall operate from 117 V ac ± 10%. Each charger shall be capable of completely charging within 16 hours a battery that has been discharged to the end of its useful capacity. There shall be no damage to the battery if the unit is left in the charger for an extended time. The pager shall operate as specified while inserted in the charger.

4.4.6.4 Coding. The paging system shall be a two-tone sequential system (Note 1) with individual-call and group-call.

4.4.6.5 Sensitivity. Receiver sensitivity shall be 10 μVm, 12-dB SINAD and 18 μVm, 20-dB quieting for voice messages and 4 μV for tone paging (Note 2).

4.4.6.6 Controls. The receiver shall have an external volume control (Note 3), an "on/off" switch, and a test switch. The volume for the alert tone shall be an internal preset adjustment.

4.4.6.7 Receiver selectivity. Receiver selectivity shall be 70 dB at 30 KHz.

4.4.6.8 Receiver spurious rejection. Receiver spurious rejection shall be at least -60 dB.

4.4.6.9 Audio output. Maximum audio output shall be at least 75-dB-sound-pressure level at 12 in. for both voice and tone.

4.4.6.10 Frequency stability. Receiver frequency stability shall be at least ± 0.0015%.

4.4.6.11 Falsing. The contractor shall demonstrate that ten paging receivers, located at sites approved by the owner, will have less than five false pages in a five-day test.

4.4.6.12 Shock stability. The pager shall meet or exceed the shock stability requirements of EIA Standard RS-316-A.

4.4.6.13 Battery. The battery capacity shall enable receiving fifteen 45-sec messages per day for five days before the battery needs recharging.

Notes:

1. Refer to paragraph 4.1.2 for the maximum number of pagers that can be used in a system with two-tone sequential coding and the methods available for coding with a greater number of pagers. The problem is that with more elaborate coding schemes, the coding begins to occupy a significant amount of transmitter time, leaving an insufficient amount of time for messages.

2. The values shown are for vhf high-band pagers. Sensitivity of uhf pagers should be 25 µV/m, 12-dB SINAD and 45 µV/m, 20-dB quieting for voice messages and 15 µV/m for tone paging. If tone-only or tone-and-message paging is to be used in lieu of tone-and-voice paging, only the tone-paging sensitivity need be given. Pager sensitivity is given in field strength instead of receiver input voltage because the antenna of the pager is an integral part of the unit (either a part of the case or a part of the pocket clip), and the design of the antenna is contained in the specification, since sensitivity requirements are stated in terms of field strength. The sensitivities of less-expensive pagers will be from 3 to 10 dB less than the values given here.

3. The requirement for the external volume control should not be contained in a specification for tone-only or tone-and-message pagers. The user tends to leave the alert-tone volume control turned down if it is available.

4.4.7 Antenna towers

The early concept for vhf mobile radio communication systems was to get the base station antenna as high as possible and use the maximum allowable base station power output. Interference among base stations resulted so that the mobile unit personnel frequently could hear the base station but those at the base station could not hear the mobile unit, even without interference. A well-balanced system is designed to provide good radio reception by the base station and by the mobile units throughout the area of operation and to minimize signals outside the area of operation. The usual process is to calculate the height of the base station (or repeater) tower required to receive the mobile unit transmissions (Appendix I) based upon the mobile unit transmitter power and antenna gains that will be used. This assumes that a location for the tower has been selected. If it has not, another variable must be put into the equation for the tower locations possible. Two disadvantages result from a base station antenna being too high: greater interference to other stations operating on the same and adjacent channels and greater interference from radio noise sources (industrial, scientific, and medical) and from other stations operating on the same and adjacent channels.

The FCC Rules and Regulations Part 1, paragraphs 1.1301 through 1.1319, states the conditions and situations under which an environmental impact statement must be submitted to the Environmental Protection Agency and the information that must be contained in the environmental impact statement. Generally, for mobile radio systems, the construction of an antenna tower taller than 300 ft. will require an environmental impact statement.

Part 17 of the FCC Rules and Regulations states the conditions and situations under which approval must be obtained from the Federal Aviation Administration (FAA) before an antenna tower can be constructed and states the process for requesting such approval. Generally, FAA approval must be obtained for any antenna tower over 200 ft. high except in the vicinity of airports, where approval of shorter antenna towers must be obtained, the height depending on location in relation to the airport.

In addition to the above considerations, the design of an antenna tower is an electrical and structural engineering project, as illustrated by the following specifications for a particular system. Even though these specifications cannot be used for any other system than the one for which they were created, they contain all the elements that should be contained in an antenna tower specification.

4.4.7.1 General specification. Each antenna tower shall be provided with all antennas, coaxial cables, fittings, lightning protection, tower lighting, torque arms, and special antenna-mounting brackets required for a complete and satisfactorily operating system. Where the paint is chipped or removed from the surface of existing towers or their associated hardware, the metal surfaces shall be thoroughly cleaned, primed, and painted, as specified in paragraph 4.4.7.6. No welding or modifications shall be performed on any towers.

4.4.7.2 Antenna tower. A 300-ft., self-supporting Allied tower SS-SR, a Pi-rod SS-B-380 tower or an approved equal shall be provided. The tower shall be designed and constructed to accommodate the following equipment in a 60-psf (122.5-mph) wind load, in accordance with EIA Standard RS-222C. The tower foundation shall be reinforced concrete, designed and constructed in strict accordance with the manufacturer's recommendations, and it shall adequately support the tower under the loading conditions specified.

1. A uhf and vhf high-band antenna shall be top mounted at the 300-ft. level of tower legs 2 and 3, respectively, at a distance of 54 in. from the outside of the vertical tower member (Note 1) and directly opposite the center of the tower. Two uhf antennas shall be mounted at the 275 ft. level with side-arm brackets supporting each antenna on tower legs 2 and 3 at a distance of 54 in. from the outside vertical tower member and directly opposite the center of the tower (Note 2). Six air-dielectric cables shall be provided, one from each antenna to the associated equipment. The transmission cables shall be attached to a cable ladder. The cable ladder shall consist of 3-ft. intervals, extending from the 275-ft. level to the 20-ft. level. The cable ladder and transmission cables shall be on the inside of the tower and midway between tower legs 2 and 3. A lightning protection system shall be provided. A 4-ft., 12-GHz antenna shall be mounted on tower leg 1 at the 100-ft. level. The tower

shall include a climbing ladder which shall conform to OSHA requirements. The cable ladder shall be in close proximity to the climbing ladder, enabling the transmission cables to be serviced from the climbing ladder. The tower shall be designed to support all appurtenances in the specified wind load specified in the FAA Advisory Circular #70/7460-1. The lighting equipment shall employ Crouse-Hinds Company Flasher Control Unit switched by arc-quenched, metal enclosed mercury tubes, Type TSS-23 #51603, or approved equal, and Photoelectric Control Unit, Crouse-Hinds Type PEC-4 #51711, or approved equal. A cable tray shall be installed between tower and building at a level that provides direct entrance to the wall entry plate and shall be in line with the equipment room cable tray above equipment racks. The cable tray shall be a ladder, flat rung type, with minimum dimensions of 12 in. wide and 4 in. deep. The tray shall be attached to the tower and to the building or other support as may be required.

2. The tower shall be a tapered, self-supporting structure with a minimum center-to-center leg spacing of 54 in. from the 300- to 240-ft. level. This leg spacing shall taper to a center-to-center leg spacing at the base of 25 to 31 ft. The tower shall be triangular in cross section and shall use solid leg members (Note 3) sized appropriately for reactions encountered. All tower members shall be hot dipped galvanized after fabrication in accordance with ASTM Standards A123 (structure members) and A153 (hardware).

3. A soil test report may be obtained from the owner for use in designing the tower foundation (Note 4).

4. The tower shall be installed at the southwest corner of the Maintenance Shop with tower legs 2 and 3 parallel to the south wall of the building. The reference leg, leg 1, of the tower shall be the south leg of the tower. Tower legs 2 and 3 shall be spaced approximately 10 ft. from the south wall and the center of the tower approximately 5 ft. east of the west wall.

Notes:

1. The spacing of the antenna from the tower can be chosen, depending on the design of the antenna and the tower, to produce the antenna radiation pattern necessary to cover the desired service area.

2. Placing the antennas directly above each other on the tower maximizes the isolation between them because the type of antennas used in this application have a null directly above and below them.

3. Hollow, tubular towers are less expensive than solid-rod towers, but in areas with a high concentration of corrosive chemicals (industrial and salt spray) in the air, the solid-rod type is recommended.

4. Providing soil test data to bidders will reduce their bid costs because the bidder does not have to put as much contingency in the bid if the soil conditions are known.

4.4.7.3 Antennas.

1. The uhf antennas shall be Decibel Products, Inc. model DB-410 or an approved equal.*

2. The vhf high-band antennas shall be Decibel Products, Inc. model DB-304, or an approved equal.*

3. The 12-GHz microwave antenna shall be Andrew Corporation type LD4-122A with radome, Andrew Corporation type LR-4, or an approved equal.*

4. All antenna installations shall be designed to withstand a 100-mph wind loading.

4.4.7.4 Transmission cables.

1. Air-dielectric cables, unless otherwise noted, shall be of the 1-5/8-in. Andrew type HJ7-50A or an approved equal. All new and existing air-dielectric cables opened to the atmosphere shall be purged with dry air before being pressurized.
(Note: air-dielectric cable has less transmission loss but is more expensive than a foam-dielectric cable of the same diameter.)

2. All foam-dielectric cables shall be of the 1/2-in. Andrew type LDF4-50 or an approved equal.

3. The 12-GHz antenna shall be connected to the terminal equipment with the Andrew Corporation type EW 122 elliptical waveguide or an approved equal.

4. Air-dielectric cables shall be provided for the installation of all new antennas on the maintenance shop tower and shall be installed from the antenna to within 10 ft. of the equipment cabinet. A foam-dielectric jumper, not to exceed 10 ft. in length, may be used at the equipment end of each transmission cable. No jumpers shall be used at the antenna end of a transmission cable.

4.4.7.5 Transmission cable pressurization equipment. Pressurization equipment shall be provided for the maintenance shop and shall be an Andrew Corporation type 1930B automatic dehydrator or an approved equal. The pressurization equipment necessary includes gauges, tubing, check valves, and distribution manifolds to maintain a 5-psi pressure in all air-dielectric coaxial cables. Anywhere in the system, a leak exceeding 0.5 lb./in.^{2} per day shall be located and repaired. The combined leaks of all transmission lines and associated pressurization equipment shall not cause the dehydrator to run more than 5% of the time. The pressurization equipment shall be located in the transmitter room of the maintenance shop.

*If preferred, these antennas can be specified by stating the required horizontal and vertical directivity (or gain), mounting type, wire harness type, connector type, lightning protection provisions, wind survival rating, antenna type, antenna construction, and phasing of elements.

4.4.7.6 Paint specifications

1. Surface preparation

   a. Cleaning of all surfaces with Napko 216 thinner, Xylol or an approved equal to remove any oil, grease, or other foreign matter.

   b. Application of a 10% solution of phosphoric acid and water to phosphatize and dull all surfaces.

   c. Rinsing with fresh water to remove residual salts and allowing to dry before painting.

2. Coating methods

   a. Prime coat

      i. Airless spray application of one coat of Napko 5616 epoxy primer or an approved equal to a dry film thickness of 2.0 to 3.0 mils and thinning with Napko 218 thinner, or an approved equal, as may be required for proper application.

      ii. Finish colors having the chromaticity and luminence to satisfy Federal Standard FED-STD 595: Orange 12197 and White 17875, painted in alternate bands, in compliance with FAA Obstruction Marking Advisory Circular AC 70/7460-1E.

4.4.8 Lightning protection

The subject of lightning is still open to much speculation, and excellent basic research is now being conducted on the subject.[42,43] A good lightning protection system will dissipate static charge buildup to minimize the probability of a lightning strike, and it will conduct the current in a lightning strike to earth ground with minimum electrical and structural damage. The following is an exemplary specification that illustrates the essential features of a lightning protection system.

4.4.8.1 General specification. Lightning protection shall be provided to protect operating personnel and ensure the probability of uninterrupted communications in a hostile electrical environment.

4.4.8.2 Grounding system. The grounding system shall provide the bonding necessary to ensure electrical continuity at each station and tower site. Lightning protection shall include lightning rods, heavy-gauge down conductors, bonding straps, peripheral ground rings, and ground rods (Fig. 25). The peripheral ground rings and the interconnecting bonding conductors between ground rods, buildings, equipment housing, and fences shall have a minimum bend radius of 8 in. and shall be buried a minimum of 18 in. below grade level. All bonding connectors shall be noncorrosive bolt clamps or cadweld splices. All fences and other equipment within 10 ft. of the grounding rings and radial extensions shall be bonded to the grounding system. Connections to coaxial cables and plated towers shall be made with the manufacturer's recommended grounding

LIGHTNING PROTECTION SYSTEM

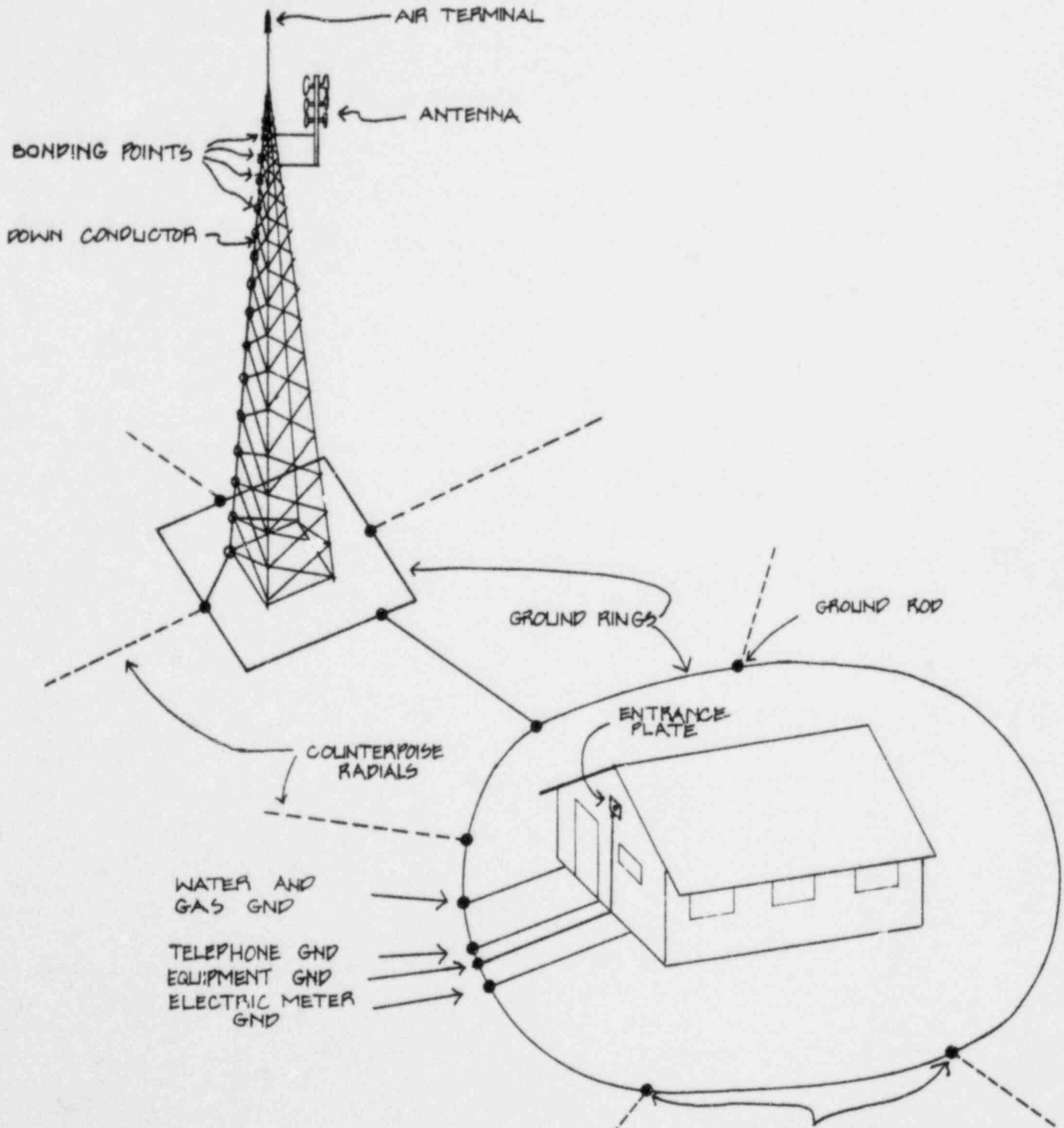


FIGURE 25

kits and clamps. Dissimilar metals shall be bonded only with approved connectors. Existing equipment such as towers, antenna mast, and coaxial transmission cables shall be modified to meet specified lightning protection requirements.*

4.4.8.3 Equipment and installation requirements.

1. Equipment needed includes the following:

a. Air terminal. The air terminal shall be a 5/8-in. diam. by 24-in.-long highly polished tubular copper point with nickel tip and necessary hardware for mounting on the tower beacon base plate and connecting to the down conductors.

b. Down conductors. These shall be uninsulated ropelay 28-strand, 14-gauge, heavy-duty lightning conductors 1/2 in. in diameter and 99.97% pure copper and shall be installed with a minimum bend radius of 8 in.

c. Buried conductors. The buried conductors shall be uninsulated, tinned, copper conductors of the same minimum bend radius and gauge as the down conductors.

d. Ground rods. These shall all be 3/4-in.-diam. by 10-ft.-long copper-clad ground rods.

e. Ground rod clamps. All ground rod clamps shall be of the superior heavy-duty, two-bolt type. The clamps at the tower ground rods shall be capable of connecting the 1/2-in. down conductor in parallel with the ground rod and of connecting the 1/2-in.-diam. horizontal and perpendicular conductors.

f. Tower-grounding clamps. All tower-grounding clamps shall be of the heavy-duty, two-bolt type capable of connecting the vertical tower members in parallel with the 1/2-in.-diam. down conductors.

2. Installation

a. Air terminal. The air terminal, or lightning rod, shall be mounted above the tower cap and the beacon plate and be as close as possible to the vertical tower member that supports the down conductor.

b. Down conductor. The down conductor shall be connected to and in line with the air terminal. The conductor shall be clamped onto the outside of the tower and in line with the same vertical tower member to the base of the tower and ground rod. The clamp spacing shall not exceed 3 ft.

*If a ground grid is installed in the facility, it should, of course, be used as the grounding element.

c. Buried conductors. The conductors shall be buried a minimum of 18 in. below grade level. A conductor shall encircle the tower and interconnect all ground rods and equipment grounding rings. All conductors shall be continuous in length and spliced only at the connectors. All metal objects such as fences, poles, and buildings within 10 ft. of the buried conductors shall be bonded to the buried conductor. The bonding conductors between each tower leg and tower ground rods shall be as direct and as short as possible. The tower leg bonding clamps shall be located near the base of the tower but sufficiently high above the tower base plate to allow the conductors to be installed with a minimum bend radius of 8 in.

d. Ground rods. These shall ground the vertical members of each tower and the building entrance plate. The tower ground rods shall be spaced 1 ft. from the tower foundation on the outside of the tower and directly in line with the tower leg and the center of the tower structure. The building entrance plate ground rod shall be located directly below the plate but spaced 2 ft. from the building.

e. Antennas. All antenna masts installed on buildings shall be connected to the lightning protection system, if such exists, or to the metal frame of the building. When installed on nonmetal buildings or poles, the antenna shall be connected to a down conductor and ground rod. All antenna masts installed on the tower shall be connected to the air terminal down conductor. An approved antenna manufacturer's grounding kit consisting of a clamp and a flat, heavy-gauge, braided copper strap shall be used. The clamp connection on the antenna mast shall be wrapped with aluminum tape and sealed. The grounding strap shall be clamped in place and connected to the down conductor.

f. Transmission cables. Those installed on the antenna tower shall be on the inside of the tower and shall remain on the same side of the tower from the antenna level to the base of the tower. The transmission lines shall not be bundled and shall be spaced adequately for clamping and bonding to the down conductor. When there are too many transmission cables to be properly installed close to the down conductor, a cable ladder shall be used. The face of the tower used to support the cable ladder shall include one of the vertical tower members that supports the down conductor. The cable ladder shall consist of cross pieces designed to clamp to the tower near the vertical tower member supporting the down conductor. The cross pieces shall be spaced at 3-ft. intervals, and each shall include a cable clamp for each cable. The cable clamps shall be Microflect B233 or an approved equal. All ladder parts shall be galvanized. All transmission cables shall be installed in parallel and bonded to the down conductor at 100-ft. intervals with approved grounding kits from transmission cable manufacturers. Each transmission cable ground connection shall be taped and sealed as recommended by the transmission cable manufacturer. Each transmission line and antenna mast shall be bonded to the down conductor just below the antenna mast and at a point just before the transmission cable starts to curve away from the ladder to enter the cable tray. The curved portion of the transmission cable shall be within the tower structure. The cable tray shall be in line with the ladder and shall be bonded to the down conductor.

g. Cable tray. A cable tray shall be provided to support many transmission cables between the tower and the equipment building. The cable tray shall be bonded to the down conductor of the tower and to the building entrance plate.

h. Transmission cable building entrance plate. A copper plate shall be provided for bonding each transmission cable at the building entrance. The plate shall be equipped with approved grounding clamps and ground lug for transmission cables. The plate shall be connected to the down conductor and ground rod. The down conductor shall be installed directly below the plate, secured to the building, and protected by a full-length ground conductor guard.

i. Equipment grounding. All equipment, including transmitters, receivers, consoles, brackets, and frames, shall be electrically bonded and connected to the common grounding system. The lightning protection common ground system contained within buildings shall be a 1/2-in.-diam. conductor (same gauge and type as the down conductor) to facilitate grounding individual pieces of equipment. All equipment racks, consoles, etc., shall be interconnected, and the common ground shall be extended at floor level to the building ground and/or external ground system.

4.4.8.4 Land lines and power lines.

1. Land lines. All equipment shall be protected from inductive lightning surges and switching transients associated with telephone lines, data lines, and control lines by TII Industries, Inc. arrester model TII-16A, or an approved equal, and shall be in compliance with the local telephone company and OEM recommendations.

2. Power lines. All branch circuits supplying power to any radio equipment, including base stations, control stations, consoles, etc., shall be protected from inductive surges, switching transients, and induced lightning by Transtector Systems protector model ACP-1000-120T or an approved equal.

4.5 Radio System Accessories

The use of radio has developed considerably since the days when it was used simply to provide voice communications between two individuals. Radio systems today enable remote control of lights and mechanical and electronic devices; transmission of printed messages simultaneously with voice messages; automatic indication of vehicle (and portable unit) status at the control location; interfacing with computers; interconnection with the public-switched telephone system; and interfacing with an automatic vehicle location system. These functions are typical of those that can be achieved by adding accessories to standard base, mobile, and portable radio units. Other accessories permit unattended operation of remote base and repeater stations, operation on standby power when prime power sources fail, and automatic activation of standby facilities in case of component failure of the radio equipment in use. Accessory equipment for these functions is discussed in the following paragraphs as it pertains to the design of a communications system for nuclear facility security.

4.5.1 Emergency power

An emergency power source should be considered vital to any mobile radio communication system and is required for nuclear facilities.[3] The mobile units operate independently of prime power and, if the fixed-facility portion of the radio communication system (the base station or repeater and associated control stations and control circuitry) has independent emergency power sources, the system can continue to provide communication service regardless of the status of the prime power source. Usually, control stations are equipped with batteries that float across the line and power the control station for 8, 12, or 24 hr. (depending upon transmitting time and battery size) in the event of power failure. Repeaters and base stations with rf output power levels up to about 50 or 60 W can be equipped with batteries that float on line in the same manner as the control stations discussed above. These can be used to power the stations for a short time upon failure of prime power, but if the duty cycle of these stations requires that the transmitter be activated much of the time, the life of the battery will be short. Higher power repeaters and base stations (those with vacuum tubes in the final rf output stage that cannot be switched off in the event of prime power failure) and base stations that require a high-duty cycle will usually require that an engine-driven emergency electric power generator[44] be used to supply power in case of prime power failure. Other equipment in the control center, such as consoles, recorders, lights, air conditioners, and public-switched telephone terminal equipment, must be supplied with emergency power, usually in the form of an engine-driven electric power generator to enable use of the communication system when the prime power source fails.

Occasionally, especially for facilities in mountainous areas, repeaters are located in isolated areas that cannot be serviced readily in inclement weather. These same locations tend to suffer power failures more often than the more heavily populated areas and need to have emergency power sources that can operate for extended periods. The emergency power source used in such instances is usually a battery bank recharged with an automatically started engine-driven generator, a wind-driven generator, a solar-powered generator, or a thermoelectric generator.[44]

4.5.2 Status signaling

Several manufacturers, including Reach, Speedcall, Synthetics, Coded Communications, Motorola, G.E., and Bramco, offer built-in and add-on devices that enable predetermined messages to be displayed in the control center upon selection by the operator of a vehicle, an individual carrying a portable unit, or by some mechanical device in the vehicle.

Typical messages include: "I need help" (usually initiated by a hidden button or lanyard), "engine started" (initiated automatically by engine sensor), "low oil pressure" (initiated by engine sensor), "arrived at scene" (initiated by operator depressing switch), "arrived at duty station" (initiated by operator), "leaving duty station" (initiated by operator), "message acknowledged" (initiated by operator), "low tire pressure" (initiated by air pressure sensor on wheel), and "responding to directive" (initiated by operator).

The messages that are entered manually by the operator can be initiated by the operator pushing one of a series of buttons (switches) mounted in line under or above the control head of the mobile unit, and the messages entered automatically can be initiated by sensors mounted in the vehicle.

4.5.3 Digital messages

More elaborate signaling of status by the mobile can be combined with printed message transmission by incorporating digital terminals in the mobile units. These terminals have typewriter keyboards, paper printers (or other types of visual readout such as cathode-ray tubes and liquid-crystal displays) and function keys. The function keys are mounted in a row above the standard keyboard and sometimes also on either side of the keyboard to enable sending predetermined messages of the type listed in the preceding paragraph plus terminal commands such as "transmit message," "print next page," and "print stored message."

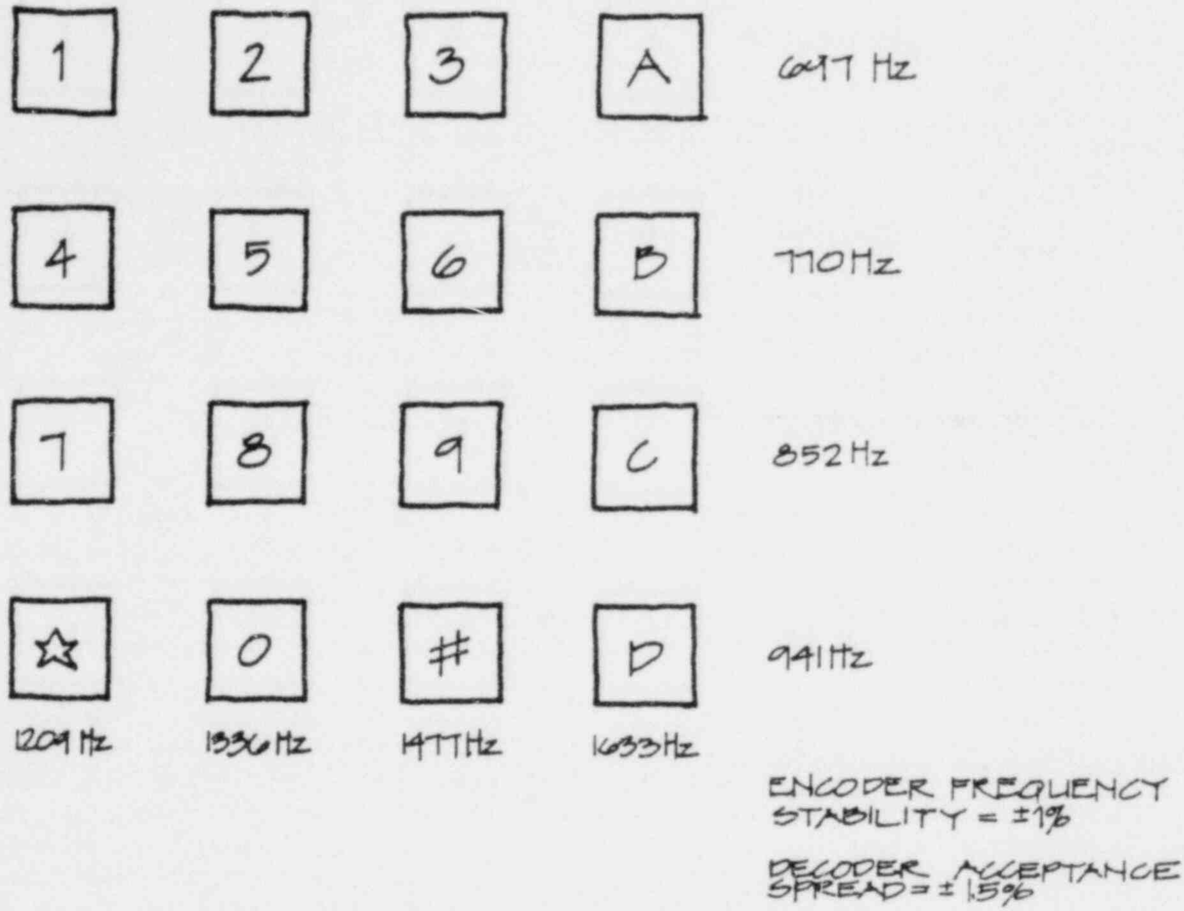
4.5.4 Remote control

A mobile or portable radio can be equipped with a tone pad similar to the one illustrated in Fig. 26, and any receiver on one of the channels used by the mobile unit can be equipped with a decoder that will be activated by any desired number of code sequences entered on the tone pad. Any particular code entered in the mobile unit on the tone pad can be used to control any predetermined action at a remote receiver site. The receiver site can be the associated base station (or repeater), a separate monitor receiver, or another mobile or portable unit. Typical remote actions so controlled are listed below. This list, by no means exhaustive, is limited only by the imagination and ingenuity of the designer. However, the list does reflect the remote responses[45] that could be used in the protection of a nuclear facility: connect receiver to loudspeaker to enable a public address from the mobile or portable unit; connect base station (or repeater) to a telephone line to enable the mobile unit to receive or originate a telephone call; turn on flood lights; actuate a siren; actuate a receiver (or intercommunication circuit) that can be monitored by someone who must be alerted in an emergency; lock a door or a gate.

It should be obvious that this concept can be reversed, and a tone pad can be used at the base station control location or at a control station to cause a remote response at another receiver, which could be fixed, mobile, or portable.

4.5.5 Microphones, speakers, and other items

Ancillary items such as switches, lights, microphones, and speakers are necessary for humans to use radio equipment. These items have become so familiar to the public that they need not be detailed he , but types of microphones like carbon and peizoelectric are defined in the Glossary.



TONE PAD BUTTON CONFIGURATION
FOR
16-BUTTON PAD
SHOWING
TONES FOR EACH ROW & COLUMN

FIGURE 26

5. HYBRID AND COMBINATION SYSTEMS

5.1 Hybrid Systems

A hybrid system is a combination radio and telephone system or a radio system used in lieu of a telephone system.

5.1.1 Point-to-point communications by means of control stations

Two control stations in a mobile radio system can communicate with each other through a repeater, as shown in Fig. 12, in the same way that two mobiles communicate with each other. Interaction of two control stations constitutes point-to-point communication and it must not exceed the authorization granted by station licenses and the FCC Rules and Regulations. The FCC sanctions this use of control stations only during emergencies to save lives or property, especially when telephone facilities are not available.

5.1.2 Interconnection

Point-to-point microwave systems, mobile radio systems, and wireline telephone systems are all voice communication systems and can be interconnected. The interconnection can be permanent, in which case it is said to be a "dedicated" interconnection. It can be temporarily connected with switches or patch cords and disconnected when desired, or it can be automatically connected and disconnected by the appropriate codes on a telephone or radio instrument. The individuals using a hybrid wireline and microwave system seldom realize that the circuit is hybrid. Most long-distance calls today employ microwave circuits for part of their paths. Usually, when a mobile radio system is interconnected with a telephone system, the operation is simplex, and both parties must realize that only one of them can talk at a time. This is necessitated by the "voice-operated transmit" (VOX) switch used in the base transmitter to key it automatically when the person on the wireline telephone end is talking. Tone-signaling devices patterned after the telephone industry's 12- and 16-button tone-pad units have become standard in the U.S. for automatically interconnecting systems and for remote keying and control.

5.2 Combination Systems

Combination systems are usually large communication networks that in some manner combine mobile radio, telephone, satellite, or microwave facilities. They usually are used to link diversified centers that have large geographic separation and need mobile radio communication coverage along corridors linking the separated facilities. They have some form of point-to-point communication linking the separated facilities - usually microwave, but can be common carrier facilities. Point-to-point communication is usually interfaced with the public-switched telephone network at major switching centers. Mobile radio base stations are located along the corridors between the facilities and are interconnected with the point-to-point network. If the point-to-point network is formed by a microwave system, it will usually follow these same corridors. If mobile-to-mobile communications are needed in the corridor, mobile radio repeaters will be used in lieu of the mobile radio base stations mentioned above. Such systems are found along major pipelines like the Trans-Alaska Pipeline from Prudhoe Bay to Valdez, and the Texas Eastern Pipeline from Texas to New Jersey; along major toll roads like the New Jersey Turnpike, and the New York State Throughway; and along major inland waterways like the St. Lawrence Waterway and the Panama Canal.

6. COMMAND AND CONTROL CENTERS

6.1 Command and Control Center Designs

The nerve center of any communication system is its command and control center with consoles and status displays. The status displays may be part of the consoles or mounted separately.

A good console will be designed on the basis of sound human factors principles[39] to take advantage of the correlative, motor, and cognitive abilities of the users of the console and to compensate for human frailties such as boredom, fatigue, and inattentiveness. A console must be designed with space and other provisions (access, power supply capacity, ports, etc.,) for future expansion. The basic features that should be considered are listed as follows:

1. writing surface,
2. storage space,
3. access for maintenance and modification,
4. keyboard,
5. illuminated switches,
6. clock,
7. telephone instrument,
8. telephone-radio interconnect controls,
9. display of identification of calling unit,
10. display of activity on all channels controlled,
11. all-call, group-call, and individual-call selector control,
12. recorder control,
13. selected channel speaker and volume control,
14. unselected channel speaker and volume control,
15. selected-audio-to-speaker-or-headset control,
16. channel-select switch for each assigned channel,
17. monitor-select switch for each assigned channel,
18. all-mute switch with timed restore control,
19. type of receiver and transmitter control (dc or tone),
20. number of operating positions,
21. physical dimensions,
22. access ports for remote-control units,
23. control provisions extended to remote-control units,
24. recording provisions,
25. method of monitoring control actions taken at secondary control point,
26. override provisions for remote-control units,
27. method of interconnecting remote-control units (dc or tone),
28. channel cross-connect control,
29. call-light for each assigned channel,
30. transmit light for each assigned radio channel,
31. transmit switch for each assigned channel,
32. mode-select switch for each channel with more than one mode of control or operation,
33. mute switch for each assigned channel,
34. repeater disable switch for each radio channel employing a repeater,

35. foot-operated transmit switch,
36. volume control for each assigned channel,
37. volume unit (VU) meter,
38. microphone,
39. jacks for headsets,
40. alert tone annunciator,
41. intercommunication switch,
42. electric utility strip,
43. control location (for channels with more than one control point).

Status and situation displays must be designed and installed on the basis of sound human factor principles. These principles, related to status and situation displays, include the following:

1. displays located in a position not fatiguing to observe;
2. displays with adequate space for pertinent information;
3. information on displays organized logically with respect to time and space;
4. audible signals, color, or flashing to display information for immediate attention; and
5. special-purpose (tactical) presented separately from general-purpose (strategic) information (See notes following Sect. 4.4.4.9.)

The layout of the command and control center should be based on the requirements of the consoles; status and situation displays; and peripheral equipment such as recorders, data terminals, and printers. Supervision, operation, expansion, and maintenance provisions must be specified.

The following exemplary specifications illustrate how these factors may be incorporated into a control console specification and still encourage competitive bidding.

6.1.1 General specifications

Each control console shall control designated system channels during normal and emergency operations. Its displays and controls shall permit the following:

1. answering incoming calls from telephones, mobile radio units, or portable radio units;

2. identifying calling unit number and radio channel used if call comes from mobile or portable unit;

3. monitoring traffic on any combination of assigned radio channels;

4. exercising control over all assigned radio channels;

5. initiating all-call, group-call, and individual selective-call transmissions on any assigned radio channel;

6. recording and playing back telephone and radio messages selectable by channel number and start times (facilities on secondary and supervisory control consoles).

6.1.2 Mechanical characteristics

1. Each console shall be a desk with turret and writing surface, associated tape recorder and repro er, and two matching swivel chairs mounted on carpet rollers.

2. Console design and characteristics shall conform to current human engineering standards.

3. Writing surface shall be not less than 15 in. nor more than 19 in. deep.

4. Writing surface shall be 29.5 ± 1 in. above the floor.

5. Leg-leveling devices shall be provided at each point where the console contacts the floor.

6. Writing surface shall be a high-pressure bonded-plastic laminate with finished edges.

7. Finish of the metal surfaces shall be vinyl polyester baked enamel applied over primed surface or an approved equal in quality and durability. Color chips shall be provided to the owner for color selection.

8. A multidrawer pedestal shall be provided in each side of the console except in consoles containing cathode-ray tube displays, which shall have only one.

9. Electronic equipment mounted inside the console shall be mounted on equipment mounting racks that can be swung out 90° on plug-in modules or by another approved method for ease of access.

6.1.3 Electrical characteristics

6.1.3.1 Solid-state circuitry. This shall be used throughout the console. Plug-in sealed reed relays will be considered solid-state relays.

6.1.3.2 Radio interface controls. Multiple-position consoles shall be designed with one position designated as a supervisory position with positive control of all channels, including backup mode selection; the other positions shall be designed as dispatch positions. Multiple- and single-position consoles shall include all controls and displays for complete control of each assigned radio channel. These basic features shall include but shall not be limited to the following:

1. digital clock (24 hr.) with LED display,
2. selected channel speaker with volume control,
3. unselected channel speaker with volume control,
4. selected-audio-to-speaker-or-headset switch,
5. channel-select switch for each assigned channel,
6. monitor-select switch for each assigned channel,
7. all-channel select switch,
8. group-channel select switch,
9. all-channel mute with timed restore switch,
10. phone patch control for each assigned channel (not required on secondary console),

11. channel cross-connect (to interconnect any two radio channels - not required on secondary console),
12. call-light of approved color for each assigned receive channel,
13. transmit light (red) for each assigned transmitter,
14. transmit switch for each channel,
15. mode select for each channel with more than one mode of control,
16. mute switch (15 to 20 dB) for each assigned channel,
17. repeater disable switch for each channel,
18. foot-operated transmit switch,
19. volume control for selected channels,
20. volume control for unselected channels,
21. Vu meter,
22. remote control of channel selection in service vehicles,
23. microphone,
24. jacks for two headsets,
25. alert tone annunciator (momentary actuation),
26. alarm tone annunciator with manual reset switch,
27. intercommunication switch,
28. spring-loaded digital bypass switch,
29. ac utility strip (120 V),
30. annunciator activated by use of pound (#) button on tone pad of mobile unit to alert operator.

6.1.3.3 Forty-channel recorder. As specified below, this shall be provided near the supervisory control console in the maintenance shop and connected into the console to record radio and telephone traffic on circuits assigned to the console. The specifications include the following:

1. The recorder installation shall be standard Dictaphone Corporation, Stancil-Hoffman Corporation, or Magnasync/Moviola Corporation equipment. The recorder shall include automatic gain control on each channel, time-code annotation, automatic scanning, and failure alarm.

2. A forty-channel reproducer shall be provided with the recorder, shall be of the same manufacture as the recorder, and shall include automatic scanning, time code readout, two headsets, bulk tape eraser, tape splicer, head demagnetizer, and cleaning kit.

3. The reproducer shall be suitable for mounting on a table or on the floor for operation. The recorder shall have two identical transports and shall be contained in an upright locked cabinet suitable for free-standing floor mounting.

4. The following accessories shall be provided: 3 spare 10.5 in. tape reels; 1 head cleaning kit; 1 lubricating kit; 1 head demagnetizer; 1 bulk type degausser; 1 monitor headset; 2 sets of maintenance manuals; 2 sets of operator's instruction manuals; and 30 reels of magnetic audio recording tape, 1 in. wide, 1-mil. Mylar, 3600 ft. on 10.5 in. reels.

6.1.3.4 Twenty-channel recorder. As specified below, this shall be near the secondary console in the alternate facility and connected into the console to record radio and telephone traffic on circuits assigned to the console:

1. Twenty-channel audio tape recorder, Dictaphone Corporation Series 4000 or an approved equal with digital time generator, auto-search option, and fail-safe option and

2. Portable twenty-channel tape reproducer, including digital search, reproducing amplifiers, and loudspeaker; must be suitable for reproducing recordings made on recorder specified in 6.1.3.4 item 1.

3. The following accessories shall be provided: 3 spare 10.5-in. tape reels, 1 head cleaning kit, 1 lubricating kit, 1 head demagnetizer, 1 bulk tape degausser, 1 monitor headset, 2 sets of maintenance manuals, 2 sets of operator's instruction manuals, 30 reels of magnetic audio recording tape, 1 in. 1-mil. Mylar, 3600 ft. on 10.5-in. reels.

6.1.3.5 Western Electric equipment. This shall be incorporated into each console to interface with the public-switched telephone system.

6.1.3.6 Switches. All console switches shall be push-on, push-off type with LED, or long-life incandescent lighting of the switch labeling.

6.1.3.7 Bell Telephone System equipment locations. Dedicated lines and terminal equipment shall be provided in the system to implement ring-down circuits between the supervisory control console and each of the following locations: secondary console in the alternate facility, police department dispatch room, fire department dispatch room, airport control consoles (one circuit shall include both consoles at the airport), and Emergency Operations Center (EOC).

6.1.3.8 Installation. All system channels that have a transmitter specified for installation at the transmitting site shall be assigned to the supervisory control console to be provided in the maintenance shop. All system channels that have a transmitter specified for installation at the airport shall be assigned to both control consoles to be provided at the airport. The four service channels shall be assigned also to the secondary control console to be provided in the alternate facility.

6.1.3.9 Approval. The contractor's proposed console design shall be submitted to the owner for approval within four months after award of contract. Thirty days shall be scheduled for receipt of approval.

6.2 Methods of Improving Reliability

The major constraint upon increased reliability is cost, but pouring money into a system will not ensure a high degree of reliability. Reliability is a function of overall system engineering. A few of the factors that should be considered to increase the reliability of a communication system or link are listed below:

1. competent operations and maintenance personnel trained to perform effectively on their own initiative during an emergency;

2. quality equipment that has been installed correctly;

3. backup radio transmitters, receivers, power supplies, and modems that can be switched into a communication circuit either automatically or manually;

4. physical protection against unauthorized access and pilferage;

5. alternate wireline or radio-frequency channels;

6. consideration of such environmental factors as temperature, dirt, insects, lightning, and humidity; and

7. secondary command and control center with redundant equipment and emergency power.[44]

7. SYSTEM APPROACH

7.1 System Procurement and Implementation

A facility that requires a security communication system will probably have established procurement and implementation policies and procedures which encompass a variety of methods to obtain the needed system. Five typical methods are discussed below with basic advantages and disadvantages of each.

7.1.1 Sole source procurement

The most rapid method is for the facility personnel to establish basic communication requirements and then negotiate with an equipment vendor for the design and implementation of the system. In addition to its rapidity, this method has two other basic advantages:

1. The vendor will probably have an experienced engineering staff that is familiar with the most recent pertinent technology and is engaged in the design of communication systems on a regular basis.

2. The vendor may be made responsible for the design, implementation, and performance of the system installed. This single source of responsibility minimizes the coordination and staffing required of the facility to get the system operational.

Three basic disadvantages of negotiating with a vendor to design and implement the security communication system are the following:

1. This method involves no competition for the facility's business; consequently, the cost of obtaining a system through this method will probably be the highest of the various methods discussed.

2. The vendor's business is to produce and sell equipment, and the maintenance of an engineering staff is a means to that end. The system designs developed by an equipment vendor will most certainly be compatible with the characteristics of the vendor's standard line of merchandise. This situation may result in design compromises to accommodate equipment characteristics rather than in an objective design based upon system requirements.

3. Proper evaluation of the vendor's design for the system and of the cost of the installed equipment requires experienced communication system engineers who know the current prices of similar systems installed by other vendors and who represent the facility in the negotiations with the selected vendor.

7.1.2 Design and implementation contractor selected through bidding

A second method that is slightly slower than the first discussed is to solicit technical and price proposals from several vendors for the design and implementation of the system. This method has both the basic advantage of price competition and those mentioned for the first method. The staffing required to prepare the request for proposals is greater than that of the first because more detailed requirements must be defined to provide a basis for competitive proposals. The difficulty (mentioned for the first method) in obtaining an objective system design increases for the second because of price competition. The major difficulty in evaluating the proposals is that the competing vendors will seldom approach the system design in the same way, and comparing the proposals may be like comparing apples with oranges.

7.1.3 Owner design and build

A third method that can be very rapid is for the engineering staff of the facility to design the system, the facility to procure the equipment and materials and implement the system with the facility's personnel. The equipment may be simply purchased from the vendor or procured through a competitive bidding process. The advantages and disadvantages of the two processes are the economic difference between them. Competitively bid prices for communication equipment may be 20 to 40% below the vendor's published list prices. The staffing required for this method is obviously greater than that of the methods discussed above. The facility's engineering staff may or may not be familiar with the most recent pertinent technology and may or may not have the experience gained from the design and implementation of communication systems on a regular basis. The facility's design and implementation must be considered in the use of this method since it may be either an advantage or a disadvantage. The use of this method minimizes the involvement of the vendor and reduces the responsibility from overall system quality and performance to responsibility for the quality and performance of only the system components purchased from the vendor. The division of responsibility creates difficulties in the event that the installed system requires modification or adjustment of the components to satisfy the system requirements.

7.1.4 Owner design and contractor build

A fourth frequently used method is the same as the third, except that the system installation is contracted rather than implemented by facility personnel. This method requires more time than any of the others because additional time is required to negotiate or solicit, receive, and evaluate bids for the installation work. This method requires less staffing than that of the third and it further divides the responsibility for system performance by involving the installation contractor.

7.1.5 Consultant design and contractor implementation

A fifth method that requires more time than the others is to obtain the services of a consulting communication engineering firm to design the system, prepare bidding documents, assist with the solicitation and evaluation of bids, and safeguard the interests of the facility in its relations with the implementation contractor. As in the first and second methods, this method will have the advantages of minimal staffing required by the facility, the designer's knowledge of the most recent pertinent technology, and experience gained from regular involvement in communication system design. This method affords price competition and more objectivity in the development of the system design than any of the vendor design methods because the consultant can act as an impartial third party and has only his reputation to protect. The net result is that the consultant wants to get the best possible system for the money for the owner and desires to see the contractor treated fairly.[46] The evaluation of the bids for implementation of the system will be simplified by the use of this method since the bidders will all be bidding on the same system design. The principal disadvantage of this method, compared to those discussed above, is the additional time required to select and hire the consultant.

7.2 Legal

The FCC Rules and Regulations (especially Parts 89 and 91) contain the bulk of the legal restrictions that must be observed when designing and implementing a wireline or mobile radio communication system. These rules and regulations, in turn, identify FAA restrictions on tower heights, painting and lighting, and EPA Environmental Impact Statement requirements as previously discussed. In addition, many areas have local and state laws which may affect design requirements, especially those concerning radio-wireline interconnection, tower design, fencing, fuel storage, building design, wiring, lightning protection systems, etc. One good example is the use of an entrance plate where one or more coaxial cables enter a building. Some local codes require that this plate be metal with all the coaxial cable shields grounded to it and the plate then grounded to an earth ground. Other codes require that this plate be an insulator and that all the coaxial cable shields be grounded to a common point outside of the plate and that the common ground be directly connected to an earth ground. The accepted communication system codes and standards of the EIA and the National Bureau of Standards, presented in Appendices VI and VII, must be augmented by local codification and invocation of Underwriters Laboratories and National Fire Protection Association specifications.

7.3 Technological

The state of the art in the communication disciplines is advancing at an ever-increasing pace. Exploitation of 800-MHz frequencies for mobile radio communications, automatic mobile radio and public-switched telephone system interconnection, digital control techniques, digital squelch circuits, high-powered all-solid-state transmitters, receiver voting comparators using digital logic, and subminiature transceivers are a few of the recent innovations to affect the design of mobile radio communications systems. Current advertising through bulk mailings, trade journals, and buyer's guides furnishes ready access to names of companies that manufacture and sell communication equipment and stand ready to furnish information concerning the capabilities of the equipment they offer.

7.4 Economics

A careful trade-off analysis must be made of the relative cost vs. operational advantage of the available practical approaches during the system requirements analysis. This trade-off should be made on the basis of the total system life cost as discussed in Appendix IV. If the best operational system that meets the required objectives cannot be funded, a lesser system must be implemented or a useful part of the ultimate system must be funded and firm plans made to implement the remaining parts at a later date.

7.5 Natural

Natural restrictions to communication system design and implementation are the most inviolable of all constraints. The following trade-offs, which must be made during the design process, establish the basis for the economic trade-offs mentioned above: (1) propagation characteristics vs. frequency, (2) frequency vs. antenna gain, (3) antenna gain vs. antenna size, (4) antenna height vs. antenna gain vs. power output vs. system range, (5) antenna height vs. real estate required for tower, (6) antenna size vs. antenna height vs. tower wind survival rating, (7) mobile and portable power output vs. voting receiver locations, (8) channel bandwidth vs. channel gain vs. information flow rates, (9) system complexity vs. system reliability, and (10) manual system functions vs. automatic system functions vs. reliability.

7.6 System Implementation

A complete set of well-written procurement documents embodies the design of the system and the desired method of implementation as well as ancillary requirements such as personnel training, maintenance, spares, support, etc. The procurement documents are legal documents that can be used to select the implementation contractor and form a legal agreement between the contractor and the purchaser. The following items are typical of a complete set of procurement documents:

1. notice to bidders,
2. instructions to bidders,
3. proposal form,
4. list of abbreviations,
5. general conditions of agreement,
6. supplementary conditions of agreement,
7. special conditions of agreement,
8. unit price schedule,
9. general specification,
10. physical facility construction and modifications,
11. detailed equipment specifications, including control consoles, paging transmitters, base stations, repeaters, control stations, remote control units, voting receivers, voting comparators, portable radio units, mobile/portable convertible radio units, mobile radiotelephone units, pocket paging receivers, voice recorders, towers and antennas, microwave terminals, microwave repeaters, emergency power units, batteries, multiplex equipment, lightning protection, guarantee period service, training, and spares.

7.7 System Support

Lack of system support after implementation dooms a system to an early demise. Every system must be supported by an adequate supply of trained operating personnel, trained maintenance personnel, operating and expendable spares, maintenance spares, system documentation, system updating, and means for system retirement and replacement at end of useful life.

7.7.1 Personnel training

Operation and maintenance personnel can be trained by the owner, a separate agency, or the implementation contractor. The following exemplary specification illustrates the points that should be included in a personnel training program and the methods by which they can be specified.

7.7.1.1 General. General considerations include the following.

1. Two training sessions will be provided for the personnel of each operating entity who will use the system. Each person shall be provided not less than 3 hr./day training on two separate days, not less than one week and not more than two weeks apart for dispatch personnel, supervisory personnel, and maintenance personnel. The number of trainees in any single training session shall not exceed 15.

Mobile and portable radio operators shall each be provided two training sessions as described above, except the minimum training period for each session may be 1 hr., and the maximum number of trainees in any single session may not exceed 25.

2. Training sessions shall include system description, equipment description, system operation, and a question-and-answer period.

3. Schedule the training sessions with the owner and allow 2 weeks notice before each session. Begin the training sessions at each dispatch center within 15 days after the installation is complete and the system operable.

7.7.1.2 System description. The following points should be covered in the training session.

1. The description of the entire system should include system configuration, equipment, and operation; use charts, diagrams, photographs, and audio-visual aids to convey an understanding of the system; and discuss the capabilities and limitations of the system and the implemented provisions for system growth

2. A description of emergency communication facilities should show their relationship to the police, fire, and public works communication facilities and include descriptions of the configuration, equipment, and operation of the communication facilities of each department, using visual aids to convey the information.

7.7.1.3 System equipment. To familiarize personnel with the equipment, take the following measures.

1. Include detailed descriptions of the equipment comprising the system, using actual items of equipment.

2. Describe all the equipment, including mobile units, portable units, equipment located at the receiver sites, equipment in the maintenance shop, and equipment at remote sites. Discuss the capabilities and limitations of the various items of equipment.

7.7.1.4 System operation. Trainees should become thoroughly familiar with the equipment.

1. Include a detailed demonstration of the operation of the particular department's system with the maximum practical participation by the dispatch personnel. Demonstrate proper dispatching procedures and common errors made by dispatchers. Inform all dispatchers of the content of the FCC Rules and Regulations that govern dispatching operations.

2. Demonstrate the operation of the mobile and portable units, equipment at repeater sites, and equipment at the dispatch center. Demonstrate both normal and emergency capabilities of the system to provide communications for each department in the demonstrations.

7.7.1.5 Question-and-answer period. Include a period for questions by the participating personnel and answers to the questions presented. Make every reasonable effort to achieve complete understanding of the system and its operation by the personnel who will operate the system.

7.7.2 Operating and expendable spares

Operating and expendable spares consist of such items as printer paper, recorder tape, fuel for emergency power units, ribbons, pens, etc. Attempts to save money by skimping on quality or quantity of these items usually increases total system life costs (see Appendix IV).

7.7.3 Maintenance spares

If the implementation contractor provides comprehensive guarantee service for an initial operating period, usually 6 or 12 months after system acceptance, and the owner keeps good records during this period, the owner can determine the type and quantity of maintenance spares that should be maintained. A spare parts inventory guarantee by the implementation contractor, as reflected in paragraph 7.7.3.6 of the exemplary Guarantee Period Service Specification below, will ensure that spare parts are available when needed.

7.7.3.1 General. The contractor shall furnish the owner with a written guarantee on all workmanship, materials, and equipment provided by the contractor. The written guarantee shall be made out to the owner in a form satisfactory to him, guaranteeing all the work under the contract to be free from faulty materials in every particular, free from improper workmanship, and free from damage from usual wear; and agreeing to replace or to re-execute without cost any work that may be found to be improper or imperfect and to make good all damage caused to other work or materials due to such defective work or due to its required replacement or re-execution. This guarantee shall cover a period of one year from the date of final acceptance for all work under the contract. This guarantee must be approved by the owner prior to acceptance and final payment. The final acceptance, payment, or any provision in the contract documents shall not relieve the contractor of the responsibility for neglect, faulty materials, or workmanship during the period covered by the guarantee.

7.7.3.2 Scope. The system and its components shall be maintained during the period of the guarantee at levels of performance equal to or better than specified.

7.7.3.3 Repairs.

1. Base station and repeater equipment. Within a maximum period of 4 hr. notice to a designated service station, the contractor's technician shall arrive at the station location to perform the service required to restore the station equipment to specified performance levels. This service must be provided at any time of day or night and as often as required, except on Sundays and designated holidays. On Sundays and designated holidays, provide the same service as described above, except the maximum response time may be increased from 4 to 6 hr. after notice.

2. Mobile and portable equipment. Mobile and portable equipment brought to the designated service station should be repaired on a first-come, first-served basis. Equipment shall be received at designated service stations for repair at any time between the hours of 8:00 AM and 5:00 PM of any day othe than Saturdays, Sundays, and designated holidays.

3. Equipment definition. Equipment shall include all transmitters, receivers, recording equipment, control circuitry, interface circuitry, batteries, emergency power units, antennas, antenna towers, tower lights, transmission lines and ancillary items furnished and installed by the contractor as part of the system. The only items of equipment excluded from this requirement are portable radio batteries.

4. Temporary repair. In the event that a permanent repair cannot be completed within 4 hr. of arrival at the owner's premises or the arrival of the mobile or portable equipment at the designated service station, temporary repairs may be made to place the equipment in operation. Equipment that has been temporarily repaired shall be permanently repaired within five calendar days.

5. Inability to repair. In the event that the contractor's personnel cannot complete permanent or temporary repair within 8 hr. of arrival at the owner's premises or the arrival of mobile or portable equipment at the service station, the faulty equipment shall be replaced with equal or better equipment and the equipment shall be left installed until the owner's equipment has been permanently repaired and placed back in service. In the event that temporarily repaired equipment cannot be permanently repaired within five calendar days, it shall be replaced with equal or better equipment and the equipment shall remain installed until the owner's equipment has been permanently repaired and placed back in service. In no event shall any base, mobile, or portable radio station remain out of service for a period longer than 8 hr. due to contractor's failure to repair or to replace equipment with a satisfactory substitution.

7.7.3.4 Preventive maintenance and inspection. The contractor shall perform a complete inspection of the system beginning 90 days before the expiration of the one-year guarantee period and report the results of this inspection to the owner in writing no later than 30 calendar days prior to the expiration of the one-year period. This inspection shall include all equipment and systems and a determination that the equipment is operating in accordance with the FCC Rules and Regulations, the original manufacturer's specifications, these specifications, and the needs of the owner. Perform any repairs to the equipment to provide operation in accordance with such rules, regulations, specifications, and needs.

7.7.3.5 Extra services. Upon written request of the owner and at rates effective at the time of performance, the contractor shall do the following.

1. Reinstall any communication equipment in vehicles or at locations different from where originally installed.

2. Repair and restore to normal operating condition any communication equipment not forming a part of the system as defined in this document, but forming a part of the owner's system.

3. Make improvements in the owner's communication system which are possible as a result of technological improvements.

4. Repair or replace any of the owner's equipment damaged by malicious mischief.

5. Replace portable radio batteries.

6. Replace or repair equipment damaged by causes beyond control of contractor.

The owner shall agree to pay promptly upon receipt of invoice for all authorized extra services.

7.7.3.6 Spare parts inventory. An inventory and supply of all replacement parts for the system shall be guaranteed to be available from the manufacturer of the system for a 10-year period from the date of final acceptance of the system by the owner.

7.7.3.7 Telephone and office. The contractor shall maintain an office with a telephone and staff capable of dispatching contractor's service personnel at any time (24 hr/day, seven days/week).

7.7.3.8 Holidays. Nine holidays in the year may be designated by the contractor but must be approved by the owner.

7.7.3.9 Designated service station. Prior to the final acceptance of the system by the owner, the contractor shall designate the name, address, and telephone number of the service station or stations and the name, address, and telephone number of the individual to represent the contractor with regard to the contractor's obligations under the provisions of the guarantee.

7.7.4 System documentation

System documentation must contain operation, maintenance, and troubleshooting aids to system use and upkeep. The following exemplary specification paragraphs illustrate how such aids can be specified:

7.7.4.1 Handbook. Three copies of a handbook to include all equipment with complete theory of operation, construction details, intercable diagrams, layout drawings, assembly drawings, alignment procedures, wiring diagrams, schematic diagrams, replacement part numbers, and troubleshooting guide shall be prepared for each installation.

7.7.4.2 Manufacturer's manual. A copy of each manufacturer's manual pertaining to equipment located at each of the centers shall be appended to the handbook for the center.

7.7.4.3 Complete manual. One copy of a complete manual for maintenance and troubleshooting, complete with wiring diagrams and schematics, for each ten portable units, mobile units, and paging units that form a part of the system. The manual shall be placed within a locked cabinet provided at the control center. No fewer than 15 copies of any particular manual shall be provided.

7.7.5 System updating and replacement

The life expectancy of every system is a function of the original system design and developments in the field of technology. This life expectancy can be realized to its fullest extent if the system is expanded and new technology incorporated during its natural life; however, good system management dictates that plans for system expansion and modernization go hand in hand with plans for system retirement and replacement to provide continuous service. If good management practices of this type are not employed, communications will be found wanting when they are needed the most, usually during an emergency. Such instances place the greatest strain on communication systems.

7.7.6 System retirement and replacement

Plans should be made to retire and replace the system at the end of its useful life. These should be made on the basis of total system life cost, as discussed in Appendix IV.

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9. GLOSSARY

Adjacent channel - The next higher or lower frequency assignment. Very-high frequency high-band channels are 15 KHz, and ultra-high frequency channels are 25 KHz apart.

Adjacent channel interference - Interference caused by a signal in the next higher or the next lower frequency assignment or by a signal on an adjacent cable or pair of wire (usually called cross-talk).

Ampere - A measure of electric current, usually symbolized by the letter "I." Ohm's Law, which may be proven empirically, states that current, voltage (E or V), and resistance (R) are interrelated by $E = I \times R$. This may be expanded in circuits containing reactance (X), which is caused by inductors and capacitors by the conjugate expression $E = I \times Z$, where $Z = R+jX$, where j is the square root of (-1), and Z the impedance of the circuit.

Amplitude distortion - Differences between the amplitude vs. frequency characteristics of the received signal and the originally transmitted signal.

Amplitude modulation - Transmission of information by changing the amplitude vs. time characteristics of a carrier frequency.

Antenna - A component which converts radio-frequency electrical energy to electromagnetic energy and vice versa.

Aperture area - Often called "effective aperture area," ratio of power received by an antenna to the power density (Poynting vector) of the incident electromagnetic energy. The aperture area of a short (less than 1/2 wavelength) dipole is 0.119 times the square of the wavelength of the incident energy.

APBX - Automatic private branch exchange, an internally programmed (automatic) switching device used to switch telephone trunk lines with subscriber instruments.

APCO - Association of Public Safety Communication Officers.

Arrestor, lightning - The generic class of components used to conduct high-voltage surges to ground with minimum damage and the class of components used to neutralize static charges before they attract a lightning strike.

Atmospheric noise - Noise in a receiver contributed by static discharges in the atmosphere.

Attenuation - The diminution of a signal between two points in a communication channel or between two points in an electrical circuit, usually expressed in dB.

Audio frequencies - Frequencies to which the human ear is sensitive, usually considered to be 30 to 20,000 Hz.

Azimuth - Connotation of angular measurement in a plane tangent to the earth at the location specified or being described.

Band-pass filter - A filter that will permit signals in a selected frequency band to pass through and will prohibit the passing of signals of other frequencies.

Band splitting - The process whereby established bandwidths of frequency assignments are reduced to make room for additional frequency assignments.

Bandwidth - The effective frequency spectrum occupancy of a signal, also used to designate signal-handling capabilities of a communication circuit or a component in a communication circuit.

Base station - A radio station that remains in a fixed location and communicates with other base, mobile, or portable stations.

Biphase - Binary modulation scheme in which the change from one state to another is represented by a 180° shift in the phase of the carrier frequency.

Bit - Contraction of "binary digit" which is the smallest unit of information in a digital binary system. Represents the decision between a one and a zero condition.

Building loss - The propagation attenuation which an electromagnetic signal experiences when passing through portions of a building.

Burst tone - An audio signal of very short duration used for signaling (e.g., deactivate the squelch circuit of a receiver).

Call-light - Lamp or other indicator that can be remotely actuated in a mobile unit by a dispatcher to inform the operator of the mobile unit that he should call the dispatcher. Such a device obviates repeated calls to a mobile unit when the operator temporarily leaves the vehicle.

Capacitance microphone - A microphone in which one plate of a capacitor is moved in correspondence to the input audio waveform, causing a subsequent change in capacitance of the circuit in which it is connected.

Capture effect - The phenomena exhibited by a FM receiver in the presence of two on-frequency signals, one of which is 6 to 10 dB greater than the other; i.e., only the stronger of the two signals will appear at the output of the receiver.

Carbon microphone - A microphone in which the input audio waveform impinges upon a loosely packed volume of fine carbon granules, causing a corresponding change in the electrical resistance across the volume and a subsequent change in current flow in the circuit to which it is connected.

Carrier frequency - The sinusoidal frequency output of a transmitter in the absence of any information signal modulation.

Cavity - A device filled with air or low dielectric material used as a tuned circuit low-pass, high-pass, band-pass, or band-reject in a radio-frequency transmission system between an antenna and a receiver or transmitter.

Channel - A continuous link composed of input transducer, interconnecting electrical (or electronic) medium, and output transducer which may be used to convey information from one point to another. Also used to denote that portion of the radio-frequency spectrum assigned to a particular frequency setting of an intercommunicating group of radio stations.

Cellular system - A mobile radio system which covers a large area through use of a series of cells. Each cell has its own repeater, or repeaters, and a frequency assignment pattern which permits reuse of frequencies in cells that are not in juxtaposition. Simultaneous calling or paging in the cells permits locating a mobile or portable unit and computer control to switch transmitters and receivers to maintain contact with the unit after it has been located, until the communication with the unit is terminated.

Circulator - A device which will permit electrical energy to pass in one direction only.

Circuit - A channel in which the interconnecting medium may be considered to be composed of wireline. Also used to denote a group of electrical and/or electronic components (resistors, transistors, capacitors, etc.) interconnected by conductors and designed to produce a particular transfer function.

Co-channel interference - Interference caused by a signal on the same frequency assignment or caused by a signal on the same cable or pair of wires.

Coded squelch - See Continuous Tone Code Squelch System.

Community repeater - A repeater that provides service for several groups of users and separates the groups by coded squelch operation. No two groups of users can employ a community repeater simultaneously, but its use by members of one group is not a distraction to members of other groups at times when they do not wish to access the community repeater.

Compandors - Contraction of compressors and expanders. Electronic equipment which compresses the frequency, amplitude, or frequency and amplitude characteristics of a signal for radio transmission (to conserve spectrum usage) and expands a received signal to reconstitute the originally generated signal.

Continuous Tone Code Squelch System (CTCSS) - The use of subaudible tones to remotely control a device. The CTCSS is commonly used to activate the audio circuitry of a radio receiver only when a companion transmitter is transmitting and to maintain the receiver in a muted condition when any other transmitter is transmitting. Signals other than subaudible tones may be used, such as a burst of audible tone, two or more sequential tones of different frequencies, or a code sequence. The trade-off is the number of discrete addresses that can be given vs. the time to transmit the coded address. If sufficient codes are available, a different one can be assigned to each receiver in a net and only the station being called will hear the transmission; this is often called "selective-calling."

Control point - Location where transmitter can be activated and deactivated.

Control station - A base station that performs as a control point, transmits on the input frequency of a repeater, and receives on the output frequency.

Cross-modulation - The inadvertent transfer of modulation information from one carrier to another. Usually caused by faulty equipment or system designs.

Cross-talk - The inadvertent transfer of information from one communication circuit to another. Usually caused by faulty wireline installation or poor tuning of a multiplexer.

CTCSS - See Continuous Tone Code Squelch System.

dB - Decibels, or one-tenth of a Bell, which is a measure of relative signal power. The dB difference between two power levels is equal to 10 times the logarithm of their quotient. The dB difference between two voltage or current levels is equal to 20 times the logarithm of their quotient.

Desensitization - Reduction in apparent sensitivity of a receiver caused by interfering signals.

Dielectric - A substance in which the outer electrons of the individual atoms are not easily detached, as opposed to a conductor in which the outer electrons migrate easily from atom to atom. The measure of dielectric effect is "permittivity," usually denoted by the Greek letter epsilon, but denoted in this report by "e" and expressed in farads per meter. The velocity of electromagnetic radiation in a dielectric medium, which is not magnetic, is given by the expression $v = 1/\sqrt{e}$.

Diffraction - The nonreflective perturbation from straight-line propagation of electromagnetic waves by an obstacle.

Digital modulation - The amplitude or frequency modulation of a signal by a binary input as opposed to an analog (e.g., voice, music, etc.) input.

Dipole antenna - Electromagnetic radiator consisting of two equal elements that are excited with a transmission line at the point where they are closest together.

Directional antenna - An antenna which provides more gain (i.e., "focuses" the energy) in one direction than in another.

Distortion - The undesired change in waveform that occurs between two points in a communication channel.

Duobinary - See Biphase.

Duplex - A communication path in which information can flow in both directions simultaneously.

Duplexer - A communication channel component which is used to create a duplex path by separating the energy used to convey information in the two directions. A duplexer used with a repeater, for example, directs the energy from the repeater transmitter to the antenna and the energy received by the antenna to the repeater receiver.

Dynamic microphone - A microphone in which the audio energy causes relative motion between a magnet and a coil of wire, causing current to flow in correspondence to the input audio waveform.

Earth curvature loss - The increase in propagation loss over free-space loss caused by the presence of a portion of the surface of the earth in or near the propagation path.

EIA - Electronic Industries Association; see Appendix VI.

Elevation - The angle between the tangent to the earth's surface and the direction of maximum radiation of the antenna.

EPA - Environmental Protection Agency.

ERP - Effective radiated power, the radiated power in a particular direction from an antenna which is the transmitter power out minus the transmission line and mismatch losses plus the antenna gain in the particular direction.

FAA - Federal Aviation Administration, part of the Department of Transportation.

Fade - The reduction (often to the point of disappearance) of a signal caused by perturbation in the transmission capabilities of the medium used between the sender and the receiver.

Fade margin - The safety margin of a communication channel which allows for fades of a specified amount.

FCC - Federal Communications Commission, a board of commissioners appointed by the President to regulate interstate electrical communication systems and foreign electrical communication systems originating in the United States.

Filter, band pass - A device used to pass frequencies within a particular portion of the frequency spectrum and reject all frequencies outside that portion.

Filter, band reject - A device used to reject frequencies within a particular portion of the frequency spectrum and pass all frequencies outside that portion.

Filter, high pass - A device used to pass all frequencies above a particular frequency and to reject all frequencies below that frequency.

First Fresnel zone - The first boundary between the region where reflecting objects near the path between a receiver and a transmitter will cause reflections to be out of phase with the direct signal and the region where reflecting objects near the path will cause reflections to be in-phase. Each Fresnel zone is an imaginary ellipsoidal surface with the two foci being the transmitting and receiving antennas.

Foliage loss - The propagation attenuation an electromagnetic signal experiences when passing through vegetation.

Free-space loss - The propagation attentuation an electromagnetic signal experiences when traveling through a vacuum.

Frequency inversion - A simple scrambling technique in which the audio-frequency values of a modulating signal are divided into a constant (approximately 900,000) at the transmitter and the original audio signal is obtained at the receiver by dividing the scrambled signal into the same constant.

Frequency modulation - Transmission of information by changing the frequency vs. time characteristics of a carrier.

Frequency-shift keying (FSK) - Transmission of digital data by suddenly shifting the frequency of the modulation impressed upon a carrier between two states, one representing zero bits and the other representing one bit.

Front-to-back ratio - Gain of the antenna oriented to produce maximum signal compared with the gain of the same antenna rotated 180°.

Full-duplex - The descriptor of a communication channel which has separate means for conveying information in two directions (separate pairs of wires, separate frequencies, etc.) and communication in both directions can proceed simultaneously. A good example is the common telephone.

Gain, antenna - Ratio of the power received by an antenna to the power that would be received by an isotropic antenna in the same location. Note that gain is a function of antenna orientation, and manufacturer's published figures usually refer to the gain with the antenna oriented to produce the maximum signal.

Gain-bandwidth product - The figure of merit of a communication channel which determines the maximum amount of information that can be transmitted per unit of time in the channel. The foundation work in this field is "Mathematical Theory of Communication," by Shannon and Weaver, published by the University of Illinois in 1949. A more recent monograph of this field is contained in Chapter 41 of Ref. 29.

GHz - Giga-Hertz, 1,000,000,000 Hz.

Half-duplex - The descriptor of a communication channel which has separate means for conveying information in two directions (separate pair of wires or separate frequencies), but only one direction can be used at a time. A good example is use of a radio channel which employs a repeater. See Full-duplex.

Heaviside layer - The area of ionized particles above the earth's atmosphere which reflects radio frequencies, below a variable maximum frequency, back to the earth. The maximum frequency shifts from day to night, from season to season, and in 11-year cycles, all caused by solar radiation.

Hertz - Measurement of frequency; 1 Hertz is an oscillation of one cycle per second.

Heterodyne - The nonlinear combining of voltages (or currents) of two different frequencies. When f1 and f2 are heterodyned, the resultant products are f1, f2, f1 +/- f2, 2f1 +/- f2, 2f2 +/- f1, 3f2 +/- f1, etc. See Appendix II.

High band - Contraction of VHF high band which is the informal designation of the portion of the frequency spectrum between 150 and 173.4 MHz.

Horizontal angle - Azimuth angle between an arbitrary direction, usually North, and direction of maximum radiation of the antenna.

Hop - Designation of portion of a microwave chain of stations between two adjacent stations.

Hop length - Distance between the two adjacent stations of a hop.

Hz - Abbreviation for Hertz, q.v.

i.f. - Intermediate frequency. See Image frequency.

IFF/SIF - Identification Friend from Friend and Selective Identification Feature, a system of transponders used in aircraft and ships to identify particular aircraft and ships, or groups of aircraft and ships, from each other and to signify limited status changes such as "emergency," "lost," "hijacker aboard," etc.

Image frequency - The undesired heterodyne product half of the product pair f1 +/- f2. The desired half is the i.f. frequency in a superheterodyne receiver, as illustrated in Fig. 34.

Impedance - Denoted by the letter "Z." See Ampere.

Insertion loss - The measure of decrease of a signal caused by the introduction of a particular component in a circuit. Insertion loss is usually measured in dB. See Attenuation.

IMTS - Improved mobile telephone service, commercial mobile radiotelephone service offered by franchised telephone companies and radio common carriers.

Intermodulation interference - Interference signal created by the nonlinear mixing of two or more signals of other frequencies. See Appendix II.

Intrinsically safe - Ability of electrical or electronic equipment to meet the National Electrical Code, NFPA 70, which is concerned with the probability of a particular item of equipment (radio transceiver, telephone, amplifier, etc.) creating an explosion in a specified explosive atmosphere.

Isotropic antenna - A theoretical electromagnetic radiator, used as a standard of comparison, which radiates energy uniformly in all directions.

Kennelly-Heaviside layer. See Heaviside layer.

KHz - Kilo-Hertz, 1000 Hertz.

Knife-edge gain - The decrease in propagation loss from earth curvature loss and obstruction loss caused by the presence of a sharp edge (mountain ridge, barn roof, etc.) in the path between a transmitter and a receiver and approximately at right angles between the transmitter and receiver.

LED - Light-emitting diode, a semiconductor device which emits visible light when excited with an input voltage above the device's threshold voltage.

LORAN - Acronym for Long Range Navigation, which is a hyperbolic navigation system developed by the U.S. for over-water navigation of ships and aircraft.

Low band - Contraction of VHF low band which is the informal designation of the portion of the frequency spectrum between 25 and 50 MHz.

Masking - A scrambling technique in which a pseudo-noise signal overlays an information signal at the transmitter and the original information signal is obtained at the receiver by apriori knowledge of and removal of the masking signal.

MHz - Mega-Hertz, 1,000,000 Hertz.

Microphone - A transducer that converts sound (acoustic) energy to electrical energy.

Mobile relay station - Term used by the FCC to denote a radio repeater, that is, a fixed base station that receives on one frequency and automatically re-transmits the received information on a second.

Mobile station - Radio transceiver mounted in a vehicle for use while the vehicle is in motion.

Modem - Equipment for modulation-demodulation that converts an input signal into a form that can be transmitted over a radio or wireline and converts a received signal into the same format as the original input signal at the companion modem. Types of modulations commonly used on the transmission media between modems are frequency-shift keying (FSK), duobinary, biphase, quadraphase, pulse-width modulation, pulse-position modulation, and non-return to zero (NRZ).

Monopole antenna - Electromagnetic radiator consisting of an element projecting above a ground plane that is excited with a transmission line at the point where it is closest to the ground plane.

Multiplex - Term denoting the process or equipment used to combine several different communication channels onto a single carrier for transmission and vice versa. The reverse is often referred to as "demultiplex."

Multiplexed channel - A radio or wireline communication path (channel) used to convey two or more separate communication signals simultaneously.

NABER - National Association of Business and Educational Radio.

Ninety percent (90%) coverage - The probability that over 90% of a given area will have the specified type of communication at least 90% of the time.

Noise - Interference energy that reduces the ease of receiving desired information.

Nonreturn to zero (NRZ) - A type of digital encoding in which the carrier is not permitted to return to a quiescent level between binary bits.

Obstruction loss - The reduction in propagated signal energy between a transmitter and a receiver caused by a physical obstruction (building, mountain, etc.) in the propagation path.

Octave - A measure of frequency, distance, or other continuity in which the divisions occur every doubling (2, 4, 8, 16, 32, etc.).

Omega system - A worldwide navigation system sponsored by the U.S. Navy which uses a series of fixed transmitters radiating a very stable signal in the 10-KHz frequency range.

Omnidirectional antenna - An antenna that radiates uniformly in all azimuth directions.

Onsite telephone facility - Telephone switching equipment located on the subscriber's premise.

Operational fixed facility - A fixed radio station licensed by the FCC used to communicate with a similar companion station.

OSHA - Occupational Safety and Health Administration.

PABX - See APBX.

Page - To issue a command or call for someone who does not have the means to make an immediate reply.

Passband - The frequency spectrum which signals may occupy and pass through the designated equipment or channel. The edges of the passband are usually denoted by the frequencies where the channel attenuation is 3 dB less than the frequency in the channel where the attenuation is a minimum.

PBX - Private Branch Exchange is a telephone system component that interfaces trunk lines with local subscriber lines.

Phase distortion - Distortion caused by the different propagation velocities in different parts of the passband of a channel.

Piezoelectric effect - The production of an electrical current (or voltage) when a substance is subjected to mechanical deformation and vice versa.

Piezoelectric microphone - A microphone in which the deformation is produced by the impinging acoustic energy and the output energy is used to actuate an amplifier or transmitter.

Portable station - A radio station that can be moved from location to location while being used.

Poynting vector - Density of power flow of electromagentic propagation, in accordance with the expression P = 1/2(EXH*), where P = Poynting vector, E = electric vector component of the electromagnetic propagation, and H = magnetic vector component of the electromagnetic propagation. The symbol "X" indicates vector cross product, and the asterisk means that the complex conjugate is to be used.

Propagation - Transmission of energy between two locations.

Pseudorandom code transposition code - A transposition code in which the code cycle length is of sufficient magnitude that it cannot be observed and the transposition appears to be random.

PTT - Push-to-talk, designation of the circuit that responds to an operator depressing a switch on the microphone of a transmitter and causes the transmitter to produce a carrier.

Pulse-position modulation - A modulation scheme in which the relative position of information pulses with reference to marker pulses are used to convey information.

Pulse-width modulation - A modulation scheme in which the relative widths of the pulses in a pulse train are used to convey information.

Quadraphase modulation - A digital modulation scheme in which the binary digits are taken two at a time producing the four couplets 00, 01, 10, and 11, which are used to shift the carrier 0, 90, 180, and 270^o respectively.

Quieting - The reduction in receiver noise output caused by the introduction of an input signal.

Radio horizon - The point where electromagnetic radiation from the observer's location would be tangent to the earth's surface.

Radio station - A fixed, mobile, or portable radio transmitter and receiver combination.

Random-code transposition coding - A transposition code in which the code cycle never repeats.

Reactance - See Ampere.

Receiver - A device for receiving electromagnetic energy on a particular frequency and presenting an analog representation of the modulation impressed upon the received energy.

Reciprocity, Law of - The law which states that energy sources and energy sinks in a linear system can be interchanged and the same amount of energy will flow from source to sink. The application to radio systems is that the attenuation from a base transmitter to a mobile receiver is identical to that from the same mobile transmitter to the same base receiver.

Refraction - The bending of electromagnetic waves by passing through a medium which has a gradation in dielectric constant orthogonal to the axis of the radiation.

Rejection - The ability of a receiver to be unaffected by a potentially interfering signal on a frequency other than the assigned received frequency of the receiver.

Remote control - The actuation of a device by other than direct mechanical transmission of energy.

Repeater - See Mobile relay station.

rf - Radio frequency.

Rolling code transposition - Transposition scheme in which the transposition code is changed in a cyclical manner known only to the sender and receiver.

Selective-calling - See Continuous Tone Code Squelch System.

Selectivity - The ability of a receiver to reject a signal slightly to either side of the assigned received frequency of the receiver.

Sensitivity - The measure of the minimum amount of input energy to a device which will elicit the desired response.

Signal-to-noise level - The ratio of desired to undesired energy in a channel.

Simplex - Use of the same medium (pair of wires, frequency, etc.) for each path of a two-way communication channel. See Full-duplex and Half-duplex.

Simulcast - The transmission of the same information by two or more transmitters simultaneously.

SINAD - Signal plus noise and distortion, a method of measuring receiver sensitivity developed by EIA. See Refs. 47 and 48.

Single-sideband modulation (SSB) - A method of amplitude modulating a carrier in which the carrier itself and one of the two sidebands are suppressed.

Speaker - A transducer which converts electrical energy to acoustic energy.

Special mobile radio (SMR) - A system of base and mobile radio stations (first described in FCC Docket 18262) which is much more elaborate than the common system of a base station interconnecting mobiles, portables, and control points. A SMR requires special licensing and is not applicable to nuclear facility communication systems.

Spurious radiation - Undesired radiation generated as a by-product in an electrical or electronic device.

Spurious response - Undesired reaction to an input signal (i.e., an undesired transfer function).

Spurious response frequency - A frequency other than the desired to which a radio receiver is sensitive.

Squelch - Receiver circuit that prevents the inherent noise of a sensitive receiver in the absence of input signal from being emanated by the speaker. A squelch circuit can be actuated by an input carrier or by a signal impressed upon the carrier. See Continuous Tone Code Squelch System.

Stored-program PBX - A PBX which employs a computer-type memory device for storing the functions that are to be provided to each subscriber instrument.

Substitution coding - A coding scheme in which a set of characters are substituted for the characters in the message in accordance with a prearranged table (or tables).

System engineering - The logical design, implementation, and operation of a system within an established set of limitations with an established objective.

TACAN - Tactical Air Navigation, a set of ground stations and airborne stations which enable pilots to determine their course and location.

Telemetry - Use of radio techniques to display and record parameters measured at a remote location.

Terrain roughness loss - Propagation loss due to the deviation of the earth's surface from a perfectly smooth surface.

Tone pad - Device used for encoding desired telephone numbers into a subscriber's telephone as opposed to telephone dialing.

Transceiver - A combination of a radio receiver and a radio transmitter interconnected to enable use of either device.

Transducer - A device which converts energy from one form to another (microphones, loudspeakers, thermostats, phonograph cartridges, etc.).

Transfer function - The mathematical expression which defines the relationship between the input and the output of a circuit, component, or device.

Transmitter - A device for generating radio-frequency energy on a desired frequency with a desired modulation.

Transposition coding - Coding scheme in which characters in a message are transposed in accordance with preestablished rules.

Trunking - A technique whereby two or more communication media (wireline circuits, radio channels, etc.) are shared by several users.

Type accepted - Radio equipment approved by the FCC for licensing, sale, and use.

UHF - Ultra-high frequency, denotes frequencies in the 400- to 1000-MHz spectrum.

VHF - Very-high frequency, denotes frequencies in the 30- to 400-MHz spectrum. See High band.

Video - Frequency spectrum bandwidths necessary for transmitting television picture information in real time, usually 4.5 MHz and wider.

Voice operated transmit (VOX) - A push-to-talk circuit operated by input voice energy from a microphone.

Voltage Standing Wave Ratio (VSWR) - The ratio of maximum voltage to minimum voltage in a transmission line conveying radio-frequency energy. VSWR is a measure of the mismatch in impedance between the source and the sink in a circuit; the greater this mismatch, the greater the amount of energy that is wasted by being reflected by the sink (load, antenna, etc.) to the source.

Voting receiver - Radio receivers used at multiple sites to ensure reception from mobile and portable transmitters.

VU meter - Volume unit meter, a measuring device, usually installed on a console, which informs a radio operator of the audio level being sent to the transmitter modulator.

Watt - Measurement of power; watts = volts X amperes. See Ampere.

Waveguides - Hollow conductors used for transporting microwave (above 1000 MHz) energy.

Wavelength - The distance electromagnetic energy travels in one oscillation; wavelength x frequency = velocity of propagation.

Wired-program PBX - A PBX in which the functions provided each subscriber's instrument is wired into the device. See Stored-program PBX.

10. BIBLIOGRAPHY

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of tables, formulas, and graphs used by microwave system designers. Some of this material, such as the tables for antenna wind loading calculations, path profile plotting information, and noise and power calculation nomographs are useful to mobile radio system designers.

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Appendix I

PROPAGATION PATH CONSIDERATIONS

General Considerations

Visible light, x-rays, microwaves, infrared radiation and radio waves are electromagnetic radiations which differ in wavelength and frequency. The relationship between wavelength and frequency is fixed by the relationship "frequency is equal to wavelength divided by the velocity of propagation", or $f = L/c$. If L is the wavelength in meters, c is 300 meters per second and f is in MHz. The characteristics that are exhibited by different wavelengths (or frequencies) e.g., light stopped by wood which x-rays and radio waves penetrate, standard broadcast radio waves follow the curvature of the earth while light and microwaves will not, etc., are a result of the relationship of the wavelength of the radiation to the size of the objects with which the radiation interacts.[50]

These differing characteristics make the various regions of the electromagnetic spectrum useful for different purposes. If a hypothetical radio receiver could be tuned continuously from the extreme low end of the electromagnetic spectrum to the x-ray region (such a receiver is within the realm of possibility), it would pick up an interesting assortment of signals as it was tuned from one end of its band to the other. Some of the signals that could be received are listed in Table I-1.

Table I-1. Frequencies of the electromagnetic spectrum and corresponding signals

Frequency		Typical Signals
Hz	**KHz**	
10		
		Radiation from 60-Hz power lines
100		
		Radiation from 400-Hz aircraft power systems
1,000	1	
		Radiation of voice frequencies from telephone lines
10,000	10	Global navigation signals from the Omega system
		Long-range Navy communication signals
	100	Long-range navigation signals from the LORAN system
KHz	**MHz**	
		Marine navigation and communication signals
1,000	1	Standard AM broadcast signals, short-wave broadcasts, amateur bands, military, Voice of America - very congested
10,000	10	Standard-frequency broadcast by WWV Citizens' Band, vhf low band, Aircraft International short-wave - very congested
	100	TV channels 2 through 6, vhf high band, and FM broadcast band - very congested
		TV channels 7 through 83, military communications, and long-range radar signals
	1,000	TACAN navigation, IFF/SIF, and radar signals; satellite tracking and communication signals and commercial microwave signals
		Radar signals and microwave signals
	10,000	Radar signals and microwave signals
		High-resolution short-range radar and commercial microwave signals
		Satellite communications
	100,000	Experimental radar and satellite communications
	1,000,000	Near infrared
MHz	**GHz**	
10,000,000	10,000	Infrared
	100,000	Far infrared
		Visual light
	1,000,000	Ultraviolet
	10,000,000	Ultraviolet
	100,000,000	X-rays
		Gamma radiation

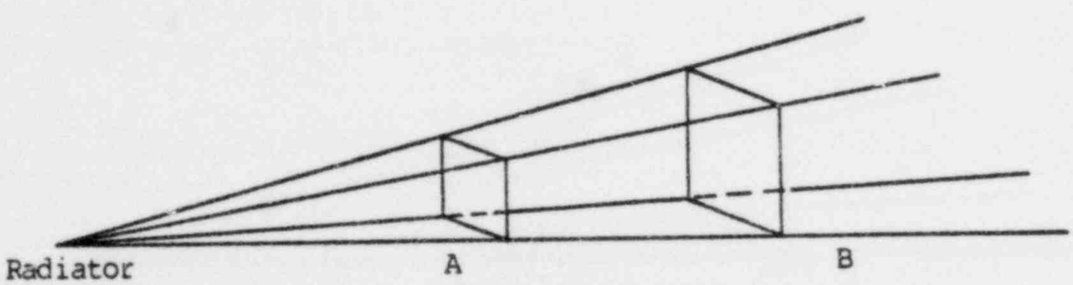
Only the more common signals are listed in Table I-1. Space precludes listing the uhf band, which is very popular for mobile radio communications in metropolitan areas and appears, along with many other signals, between TV channels 13 and 14. Reference 51 presents a comprehensive analysis of radio-frequency spectrum use. The radio frequencies to be used for nuclear facility security systems will be in the vhf low band (25 to 50 MHz), vhf high band (150 to 200 MHz) and in the uhf (450 to 512 MHz) and 800 MHz (806 to 821 and 851 to 866 MHz) regions of the electromagnetic spectrum. Each of these frequency spectrum regions has its own peculiarities, advantages, and disadvantages. Generally, as frequency increases, the cost of the equipment and frequency availability increases, while the propagation range and interference decrease.

Electromagnetic Energy Propagation

Radiation of electromagnetic energy from a source that radiates uniformly in all directions (a light bulb) is known as isotropic radiation. There is no perfect isotropic radiator (the light bulb radiates less energy toward the stem end than in the opposite direction), but a hypothetical isotropic radiator is the accepted standard of comparison for judging antenna performance.

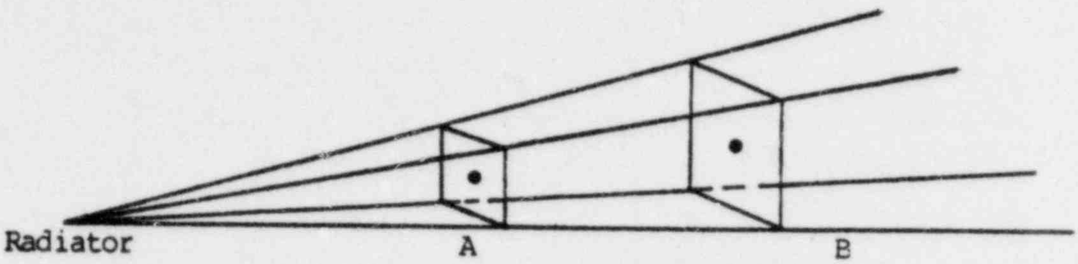
If a light bulb is placed against an extremely large, perfectly reflecting mirror, all the radiation will be in front of the mirror and none behind it. In fact, a person (receiver) in front of the mirror will receive twice as much light energy with the mirror in place as he would receive with the mirror absent. It may be said that the mirror and light bulb arrangement has a two-to-one gain (or 3-dB gain) over the light bulb alone. If the mirror were concave, as in an automobile headlamp reflector, a much higher gain would be realized.

From simple geometry, the rate can be determined at which radiation intensity (radiated power) decreases with distance from the radiator. If the rectangle at B is twice as far from the radiator as the rectangle at A, the rectangle at B has four times the area as the one at A (see Fig. 27). The energy from the radiator travels in approximately straight lines; therefore, the rectangle at B intercepts the same amount of energy as the one at A, assuming a lossless medium, and air is a lossless medium for all intents and purposes at the frequencies being discussed in this report.



RADIATION DIVERGENCE
FIGURE 27

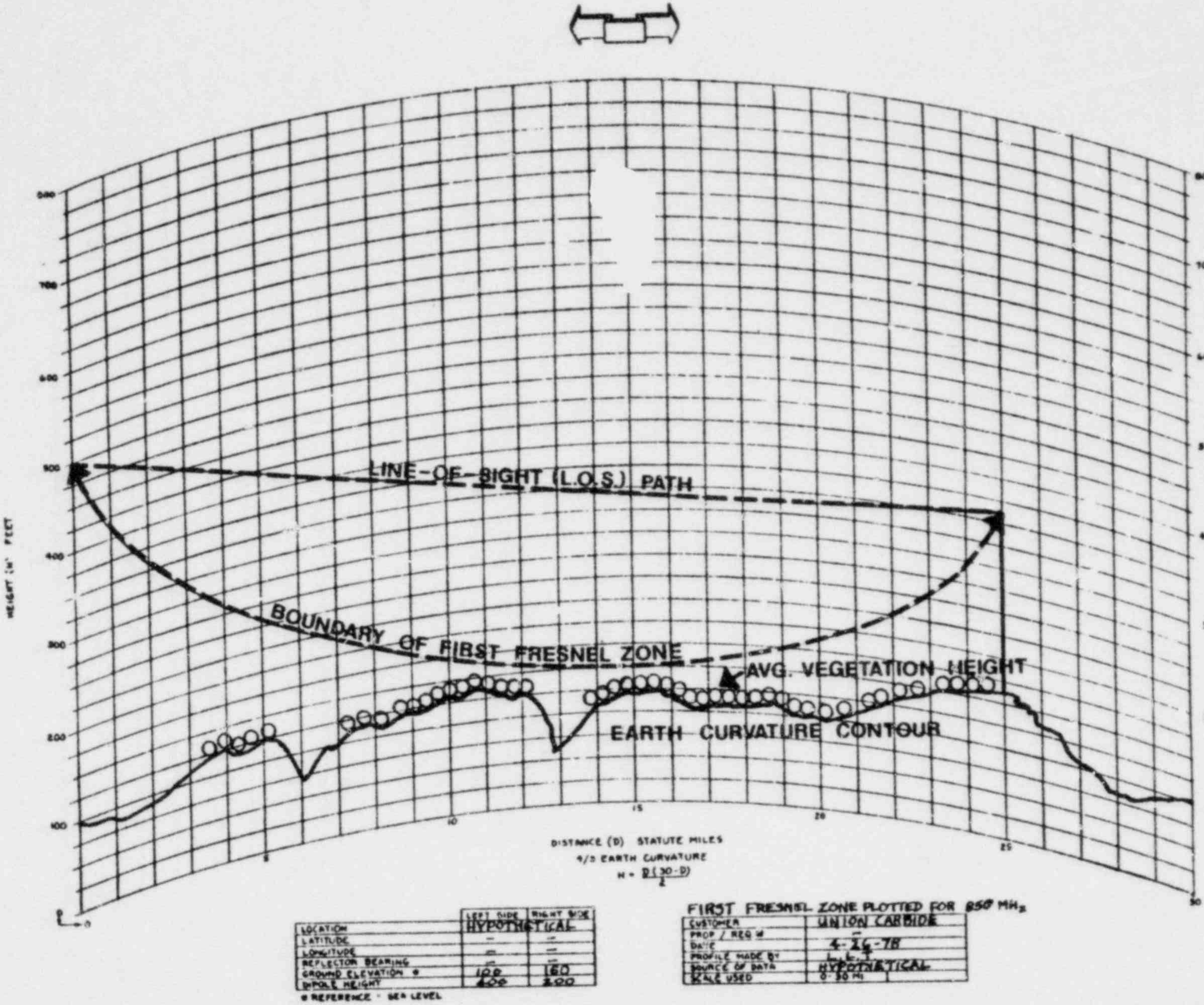
An antenna intercepts energy over an area known as its aperture area, which is constant for a given antenna and antenna orientation. Since the area at B is four times the area at A, yet the two intercept equal radiation, a constant-area antenna moved from A to B will intercept one-fourth the energy at B as it will at A. Energy decreases to one-fourth (6 dB less energy) of its original level as the distance doubles. This is commonly called the 6-dB-per-octave falloff and is experienced in free space (Fig. 28).



6dB PER OCTAVE FALL-OFF
FIGURE 28

Radiation loss from a base station to a mobile unit is greater than the loss in free space. The additional loss is the result of absorption and reflection. The absorption was first explained by James C. Maxwell in the mid-1800s[52] and is due to the fact that electromagnetic energy propagation near a conductor is partially absorbed by the conductor. The earth, trees, metal buildings, and similar topographic and demographic features are conductors at the frequencies being discussed. Trees, buildings, and other objects near the path between the mobile and base stations absorb, reflect, and propagate some of the electromagnetic energy. Some of the reflected energy goes on toward the receiving station. In fact, the only energy received by a mobile unit behind a hill is reflected energy because no direct path exists. If the mobile unit is in line of sight (LOS) to the base station, it will receive energy along the LOS path and inevitably receive reflected energy from the earth and other objects near the LOS path. Some of the reflected energy will be in-phase and add to the energy received along the LOS path, and some will be out-of-phase and will cancel some of the energy received along the LOS path. The distance of the reflecting object to the side of the LOS path and the length of the LOS path determine whether the reflections are in-phase or out-of-phase. As the mobile unit moves, these reflections will be alternately in-phase and out-of-phase, producing, especially near the maximum range from the base station, a noise known as the "picket fence effect."

The LOS path is not a direct path because the density of the atmosphere normally varies from a maximum at the surface of the earth to zero at extremely high altitudes. This variation in density causes the atmosphere to bend the path of the electromagnetic waves as a lens bends light waves. This bent or curved path follows a circle that has a radius of 4/3 the radius of the earth. For this reason, curved graph paper, called 4/3 earth-profile paper, is used in developing the design of vhf high-band, uhf and microwave systems, as shown in Fig. 29.



$^4/_3$ EARTH PROFILE PROPAGATION PLOT

FIGURE 29

Determining Mobile Radio Range

The Law of Reciprocity[53] holds for radio propagation, and the loss from the base station to the mobile is the same as the loss from the mobile to the base station. Therefore, base-to-mobile range (talk-out range) will be the same as mobile-to-base range (talk-back range) if the powers of the base station and mobile unit transmitter are identical, if the sensitivity of their receivers is the same, and if the noise environment experienced by the base station is the same as that experienced by the mobile unit.

The electromagnetic power received at a radio receiver from a radio transmitter on the same frequency is equal to the power out of the transmitter minus the line loss (line absorption and reflected energy loss) between the transmitter and the antenna, plus the gain of the transmitting antenna over an isotropic radiator, minus the propagation loss, plus the gain of the receiving antenna over an isotropic radiator, minus the line loss between the receiver and the antenna:

$$P(r) = P(t) - L(t),$$

where
$P(r)$ = received power (dB)
$P(t)$ = transmitted power (dB)
$L(t) = L(l) - L(g) + L(p)$

$L(p)$ = total propagation loss (dB)
$L(g)$ = sum of gains of both antennas (dB)
$L(l)$ = total line loss (dB).

Line loss

If the transmitter output impedance, transmission line characteristic impedance, and antenna input impedance are matched to produce a voltage standing wave ratio (VSWR) in the transmission line below about 1.5:1, the reflected energy loss can be ignored and the loss between the transmitter and the antenna will be the loss of the transmission line as published by the manufacturer of the line. The same ratio applies to the loss between the receiving antenna and the radio receiver.

Antenna gain

The gain of base station antennas over isotropic radiators is provided by the manufacturer as a function of azimuth and elevation from the antenna. The gain of mobile antennas is sometimes stated as gain over isotropic radiators and sometimes as gain over a 1/4-wavelength monopole. The gain of a 1/4-wavelength monopole over an isotropic radiator is 3 dB. Values of mobile radio antenna gain should be considered as the published gain of the antenna when mounted in the center of the roof of a sedan and they vary from 0 to approximately 5 dB. The gain will be less in some directions and more in others when mounted elsewhere on a vehicle. Values of effective portable radio antenna gains are a function of the design of the antenna and the manner in which the portable unit is held and varies from -5 to -20 dB.[28]

Propagation loss

The propagation loss between the transmitter and receiver is the sum of free space loss, earth curvature loss, foliage loss, terrain roughness loss, building loss, and obstruction loss less knife-edge gain (if any). The following procedures may be employed to determine the value of these factors.

Free space loss

Free space loss (dB) can be calculated by

$$L = 36.6 + 20 \times \log F + 20 \times \log D,$$

where F is the operating frequency (MHz),
D is the path length (miles), and
L is total free space loss (dB), as illustrated in Fig. 30.

(Only logarithms to base ten are used in this report.)

This will be the only propagation loss between the transmitter and receiver if the LOS between the two can clear all ground obstacles and atmospheric inversion layers[54] by more than 0.6 and less than 1.5 first Fresnel zone radius or more than approximately 10 Fresnel radii.

Fresnel zone

The radius of the first Fresnel zone as drawn in Fig. 29 and defined in the Glossary, can be found by the formula

$$R = 2280\ ((A \times B/(f \times A + f \times B))^{1/2},$$

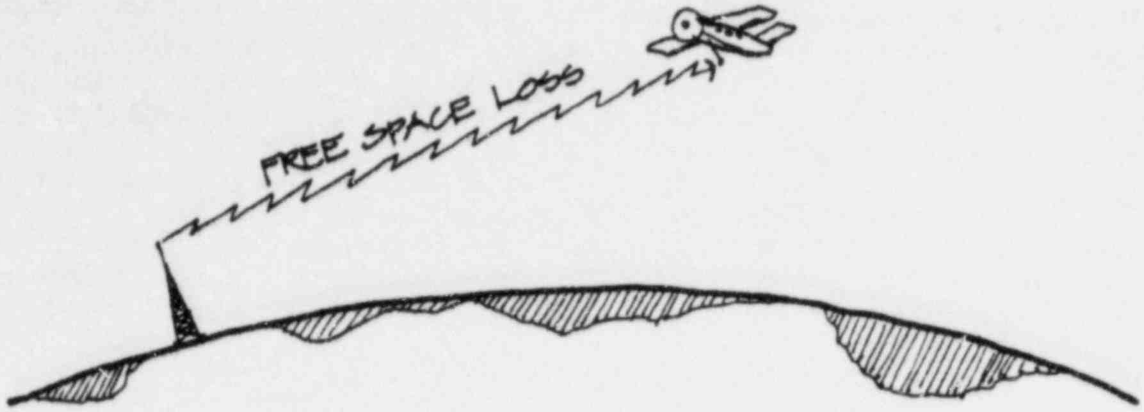
where A is the distance in miles from the transmitter to the obstruction in question,
B is the distance from the obstruction to the receiver, and
f is the frequency (MHz).
Using these dimensions, R is in feet. The radius of the tenth Fresnel zone is 3.16 times the radius of the first Fresnel zone. An excellent description of Fresnel zones is given in Ref. 55.

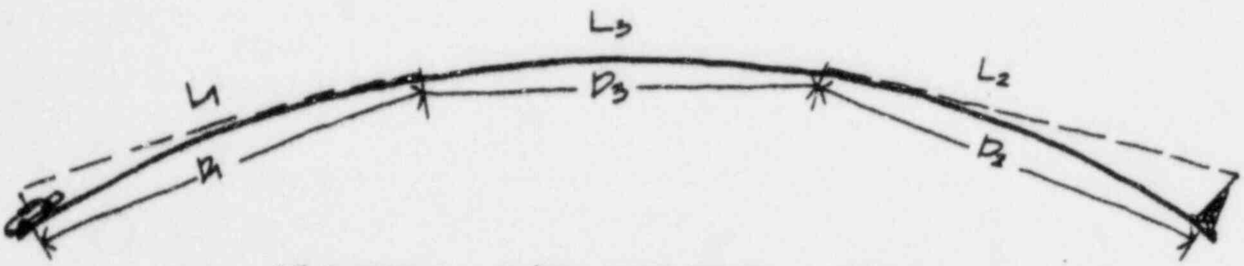
Earth curvature loss

Earth curvature loss is particularly difficult to predict in regions beyond the radio horizon. The transmitted power levels and receiver sensitivities of modern radio equipment make beyond-the-horizon ranges practical; therefore, much empirical research has been performed in this area.[56] The distance over smooth earth to the radio horizon from a transmitter or receiver can be obtained by plotting on 4/3 earth profile paper (see Fig. 29) or from the formula

$$D = 1.414 \quad h$$

where distance D is given in miles and antenna height h in feet.





EARTH CURVATURE LOSS
$L_1 + L_2 + L_3$

FIGURE 30

Bullington[57] laid the groundwork in determining earth curvature loss with empirical investigations. Nomographs based upon Bullington's work are presented in Refs. 55 and 56 and are available from equipment vendors and other sources. Reference 58 presents a method for performing these calculations on a pocket calculator, including the listing for recording this program on a Texas Instruments SR-52 calculator. The basis for the calculations is breaking the earth curvature loss into three components, $L1$, $L2$, and $L3$, as illustrated in Fig. 30. The component $L1$, the loss between the mobile unit and the horizon, is equal to 32 dB at vhf high-band frequencies, 27 dB at uhf frequencies, and 24.5 dB at 850 MHz if the antenna is mounted on the roof of a sedan, which produces a range to the radio horizon ($D1$) of 3.4 miles. The component $L2$, the loss between the base station and the horizon, can be obtained from one of the following formulas:

$L2 = (1 - 0.001216 \times D2)/(0.009118 \times D2)$ at vhf high band,
$L2 = (1 - 0.005368 \times D2)/(0.0239 \times D2)$ at uhf,
$L2 = (1 - 0.005 \times D2)/(0.015 \times D2)$ at 850 MHz,

where $L2$ is in decibels and
$D2$ is the distance from the antenna to the horizon.

These relationships hold only for antenna heights over approximately 50 ft. Component $L3$ is the loss between the radio horizons of the base station and the mobile unit. The distance $D3$ is that between these two horizons and is equal to the total path length minus $D1$ and $D2$ ($D3$ can, obviously, be a negative number and as such is just as useful in the following discussion as if it were a positive number). $L3$ can be calculated by one of the following:

$L3 = 0.62 \times D3 - 0.5$ at vhf high-band frequencies,
$L3 = 0.86 \times D3 - 0.3$ (valid only if $D3 < 20$ miles) at uhf,
$L3 = D3$ (valid only if $D3 < 15$ miles) at 850 MHz.

The propagation loss components of foliage, terrain roughness, and buildings are extremely difficult to calculate. Reference 59 presents the results of original work that developed a method to measure these losses through use of a test transmitter. It includes a discussion of a method of correlating foliage losses with infrared satellite photographs of the area in question. Generally, terrain roughness accounts for a loss of approximately 2 dB; foliage loss will vary as shown in Table I-2, and building loss will vary from 0 to almost infinity, depending on the construction of the building.

Table I-2. Foliage loss (dB)

	Vhf high band	Uhf	850 to 900 MHz
No trees	0	0	0
Some trees	0	2	4
More trees	3	6	9
Dense trees	5	10	15
Denser trees	8	25	40

Obstruction losses and knife-edge gains should be calculated by use of the examples and nomographs provided in Ref. 55, 56, or 57 or in the graphs presented in Fig. 31, all of which are based on Bullington's original work. This work is reproduced, along with additional pertinent data and information concerning radio propagation in Ref. 7.

An interesting adjunct to these formulas is the fact that the received power will increase by approximately 6 dB each time the base station antenna height is doubled and power received in a mobile unit will be reduced by 16 to 18 dB each time the range to the base transmitter is doubled.

Received power calculation

After all the losses, minus the gains, have been tallied, the power received can be determined by the formula

Power received = power transmitted x antilog (0.1 x dB).

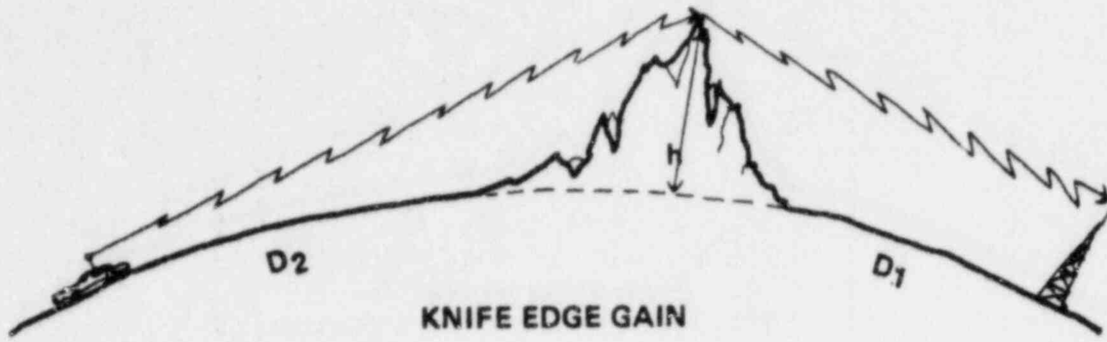
Received signal level

Receiver signal level is usually stated in terms of the input voltage in microvolts and their input impedance is normally 52 Ω. Receiver input voltage may be calculated using the formula

$$\text{Volts received} = (\text{power received} \times 52)^{1/2}.$$

The minimum useful signal level for most applications, usually considered a 90% coverage criterion, is 10 dB above 1 μV. In unusually noisy industrial conditions, this level will have to be increased by an amount equal to the local ambient radio-frequency noise level to provide a useful signal-to-noise level.

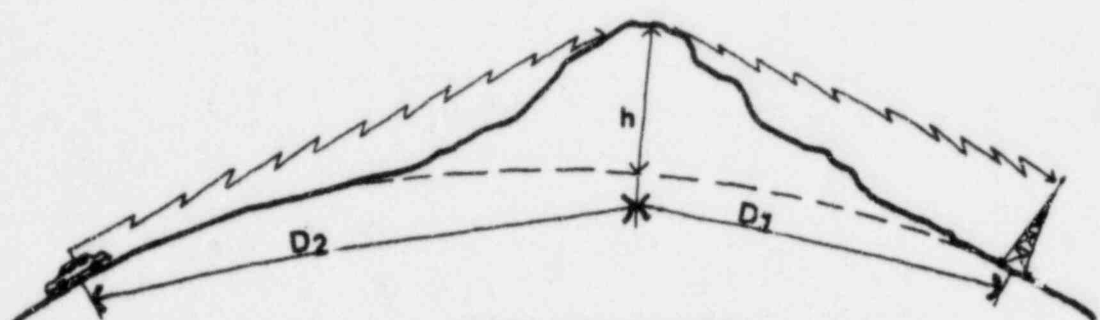
Figure 32 presents a comparison of measured signal level and calculated smooth earth signal level. The difference between the two curves is the propagation loss contribution of trees and terrain. The top LOS line is drawn for comparison of free space propagation, and the next lower line represents smooth earth propagation. The measured points, shown by the letter X, are the results of continuous field strength recordings made from a slowly moving vehicle. An example of such a recording is shown in Fig. 33. At long ranges, where $L3$ becomes significant, the averaged field strength measurements parallel the smooth earth calculated curve but are below the calculated curve. The difference between these two curves is the effect of trees, terrain, and local obstruction.



KNIFE EDGE GAIN

$D_1 \leq D_2$

h	D_0	GAIN
5	1000	25
10	1000	22.5
15	1000	22
20	1000	19
ANY	2000	5dB MORE THAN FOR SAME h AND D_0=1000
ANY	500	6dB LESS THAN FOR SAME h AND D_0=1000



OBSTRUCTION LOSS

$D_1 \leq D_2$

h	D_0	GAIN
5	1000	−19.
10	1000	−16
15	1000	−14.5
20	1 000	−13
ANY	2000	6dB LESS THAN FOR SAME h AND D_0=1000
ANY	500	6dB MORE THAN FOR SAME h AND D_0=1000

NOTES

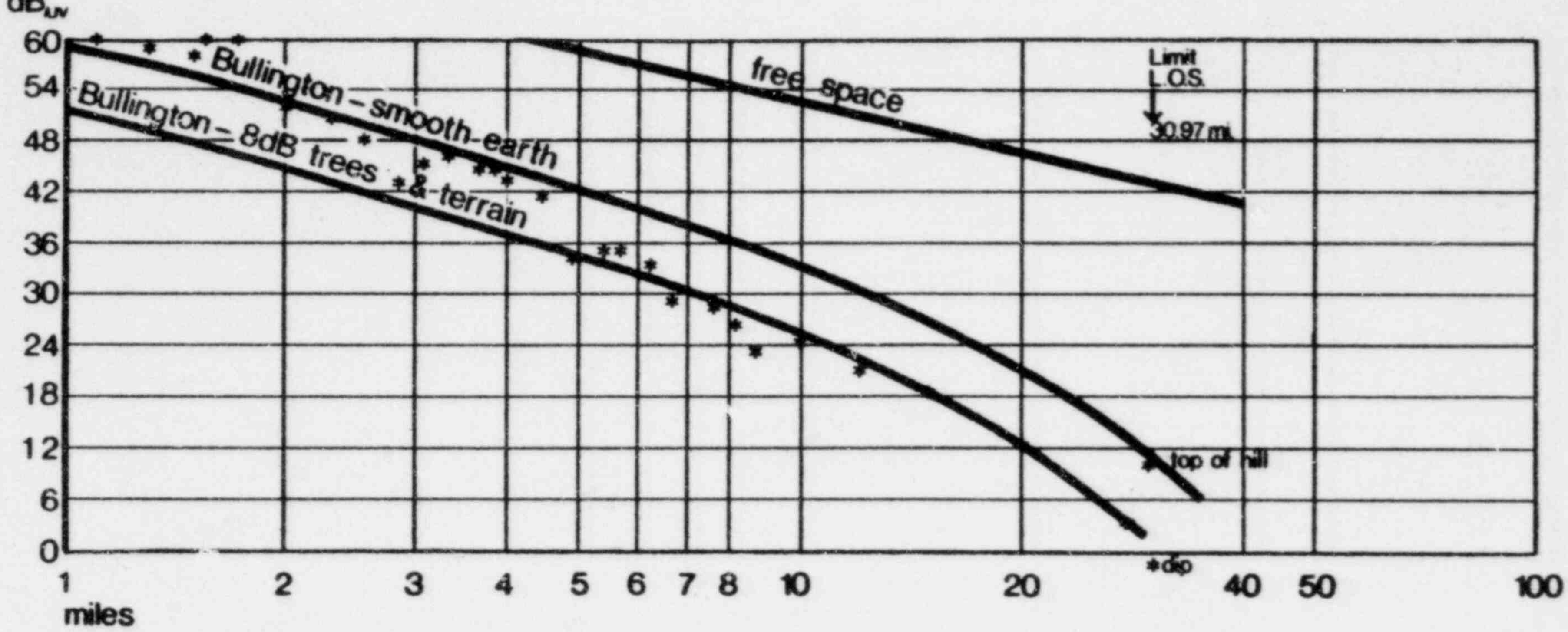
NOTE 1: VALUES SHOWN ARE FOR 150MHZ ADD 5dB FOR UHF

NOTE 2: VALUES SHOWN ARE FOR 150 MHZ ADD 4dB FOR UHF

NOTE 3: IN EITHER FIGURE, LET $D_0 = D_1$ BUT SLIGHTLY BETTER. GREATER ACCURACY MAY BE OBTAINED BY LETTING $D_0 = D_1 \times \frac{\sqrt{2}}{1+\frac{D_1}{D_2}}$

CALCULATING KNIFE EDGE GAIN AND OBSTRUCTION LOSS

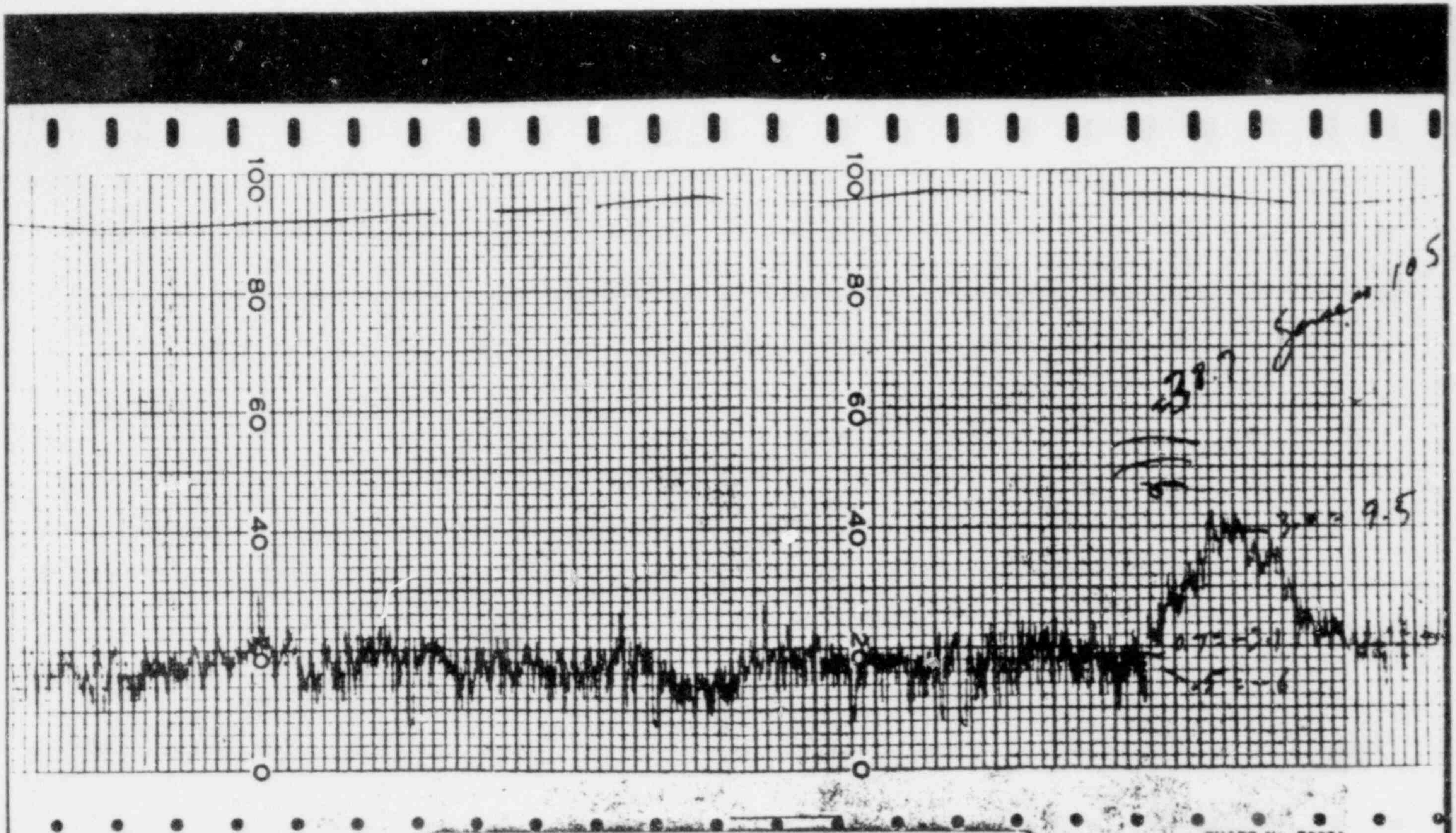
FIGURE 31



h · 480′
Tx Po · 9.5w
Ant. G · +6dB
Line · -4dB

MEASURED VS. CALCULATED PROPAGATION ATTENUATION

FIGURE 32



MEASURED FIELD STRENGTH RECORDING

FIGURE 33

Appendix II

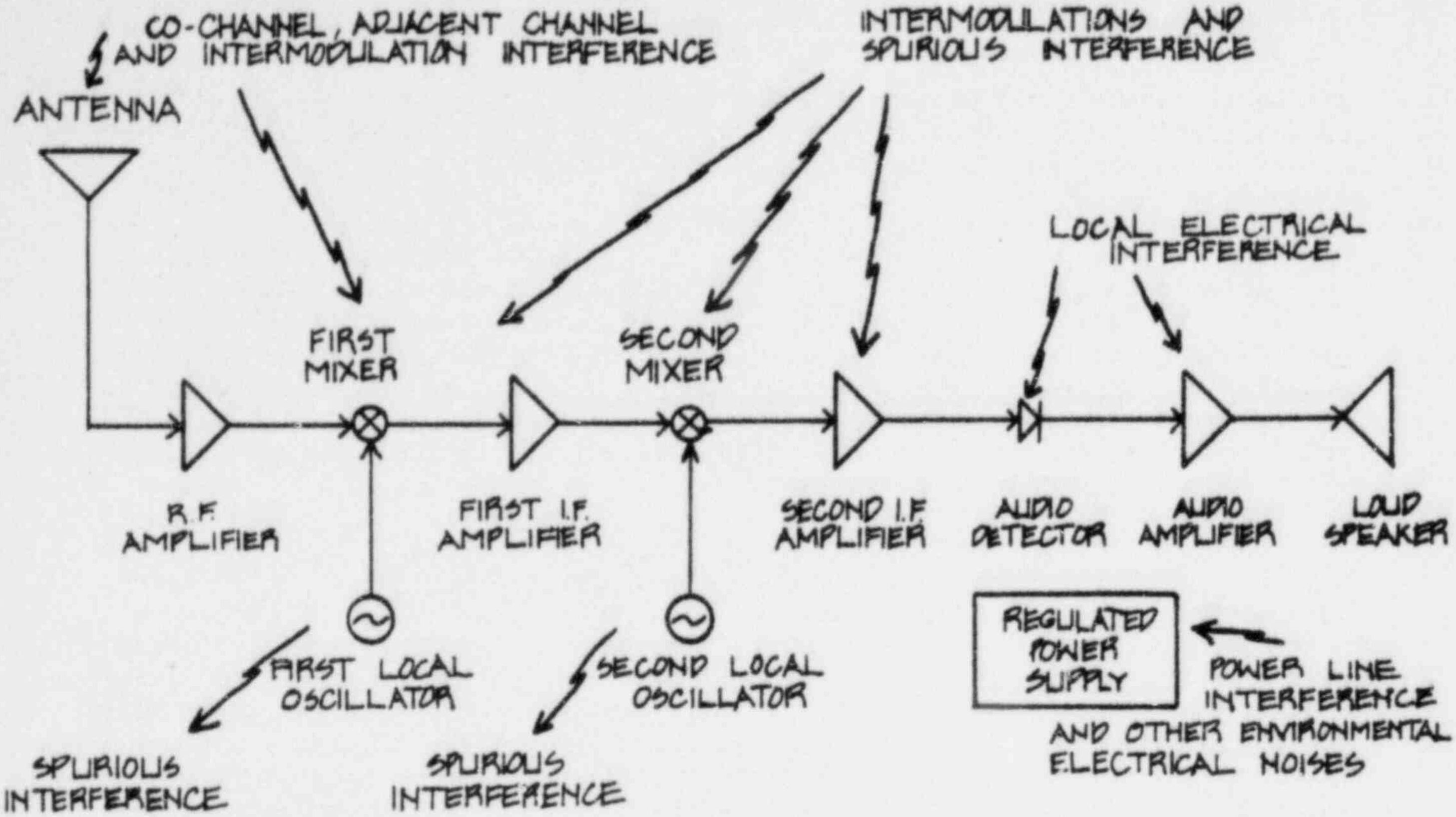
INTERFERENCE

Interference is any perturbing influence that lowers the signal-to-noise ratio at the output of a communication device. Some types of interference only constitute nuisances, others cause reception of erroneous messages, and still others cause entire messages to be missent or not received at the intended location. The types of interference that usually plague communication systems are illustrated in Fig. 34 and are discussed below with their outstanding manifestations and methods of correction.

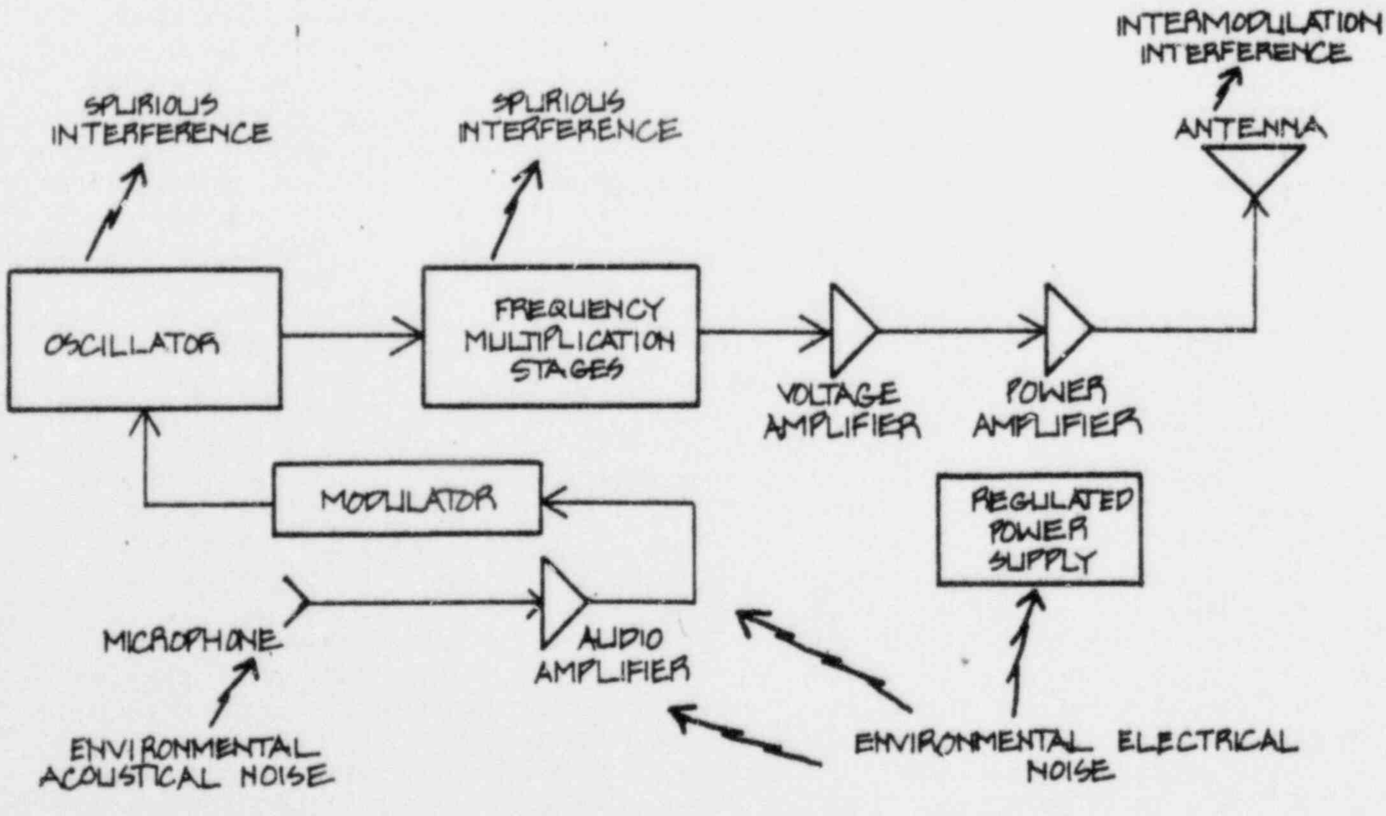
Co-channel interference exists when one or more users of the same communication channel interfere with the communications of other users. This seldom occurs on telephone systems and is caused by faulty switching, which can be corrected by the owner of the offending equipment. This type of interference is very common in radio communication systems and will become more prevalent as spectrum congestion increases. If the offending radio station is far away and the interference occurs spasmodically, it is probably the result of unusual propagation conditions.[60] If the station is close by and the interference is rather constant, the fault is that proper frequency coordination was not employed in selecting and assigning the frequencies used -- one or the other of the two stations.

Adjacent channel interference is very similar to co-channel interference. In telephone systems, adjacent channel interference is usually called crosstalk and is manifested by communication signals on one channel being imposed on those of a physically or electrically adjacent channel. As with co-channel interference, the correction is the responsibility of the owner of the equipment. Adjacent channel interference in radio communication systems is caused by users on the next higher or next lower adjacent frequency assignment having sufficient proximity and transmitted power to be heard.

Interference is much easier to avoid during system design stages than it is to correct after a system has been implemented. There are frequency coordinators for most radio services. The concerted motive of the frequency coordinators is to assist in selecting radio frequencies to provide maximum spectrum utilization and minimum co-channel and adjacent channel interference. The local FCC office, listed under "United States Government, Federal Communications Commission" in the telephone directory, will provide the name and address of the frequency coordinator of any service desired for any location in the United States. Use of CTCSS, burst tone, or other coded squelch techniques will reduce the effect of radio interference by silencing all radio receivers in a system until one of the transmitters in the same system is actuated. Design and orientation of base station antennas to maximize the gain in the direction of desired signal arrival and minimize gain in the direction of undesired signal arrival will reduce interference by enhancing "capture effect." Capture effect is the phenomenon displayed by an FM receiver when two signals on the same frequency are being received and one signal is 6 to 10 dB greater than the other. Under these conditions the stronger



TYPICAL RECEIVER BLOCK DIAGRAM



TYPICAL FM TRANSMITTER BLOCK DIAGRAM

FIGURE 34

of the two signals can be understood and the interference will be insignificant or unnoticeable. Cooperation between users of a common channel is another very effective way of reducing co-channel interference.

Intermodulation interference, a common nuisance in radio communication systems, is manifested by having two or more communication signals impressed upon the desired communication signal. It is caused by the nonlinear combination of two or more signals to create a new signal which is sufficiently close to the desired signal's frequency to appear with it.[61,62] The combinations of frequencies (designated by the letters A, B, and C) which are the usual culprits in producing intermodulation interference are listed below:

A-2B	A+2B-2C
2A-B	A-2B+2C
3A-2B	B+2A-2C
3B-2A	B-2A+2C
A+B-C	C+2A-2C
A-B+C	C-2A+2C

The solutions to intermodulation interference problems is to either eliminate one of the frequencies involved in the mixture or to eliminate the nonlinear device performing the mixing operation. Finding either can be most difficult! Generally, careful monitoring operations can enable a determination of which transmitters are producing the frequencies involved. Trial and error and sometimes direction finding techniques can reveal the nonlinear mixing device. Mixing devices are usually receiver input and transmitter output stages. Electronic equipment, such as audio systems, television receivers, computer peripheral devices, and such commonplace items as rusty fences, drain spouts, or rusty metal roofing, may become mixing devices. Use of circulators between transmitter antennas and any other device (duplexers, combiners, filters) in the transmitter output stage or radiating system, as illustrated in Fig. 35, is effective in reducing the sources of intermodulation mixing. Specifying receivers with good intermodulation rejection and using bandpass filters in all antenna feed lines, as illustrated in Fig. 35, are also other excellent methods of reducing the probability of intermodulating interference. All of these items are explained in the Glossary.

Spurious interference is when a spurious response frequency of a receiver coincides with a signal present in the environment of the receiver and is above the threshold response of the receiver at that particular spurious response frequency. Spurious interference will occur when the frequency of a spurious radiation of an electronic device coincides with the operating frequency of a receiver and is greater than 6 dB below the input signal to the receiver. The manifestation of spurious interference varies, but usually appears as noise on a communication signal. The solution is to identify the source and either eliminate the generation of the spurious signal or provide greater distance (or shielding) between the generation of the signal and the receiver which is experiencing the interference. Specifying electronic devices (including radio transmitters) with low spurious power generation characteristics and receivers with high spurious frequency rejection characteristics is effective in reducing the probability of spurious interference.

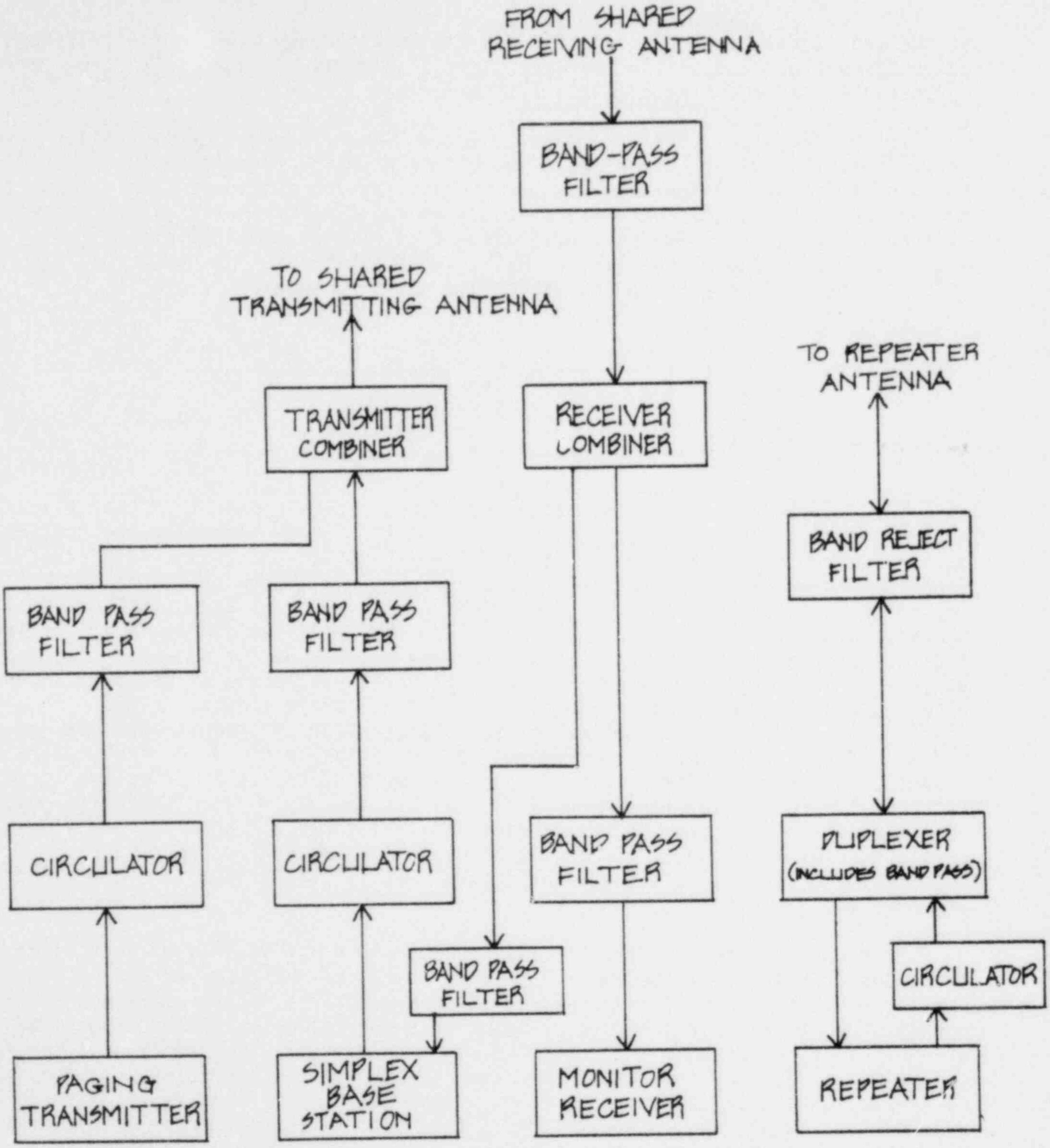


DIAGRAM OF ANTENNA SITE ILLUSTRATING USE OF INTERFERENCE REJECTION TECHNIQUES

FIGURE 35

Automotive interference is produced by the electrical power generation and ignition systems in vehicles. Experienced installers of mobile radio equipment are generally skilled at reducing the sources of this type of interference to tolerable levels, and the manufacturers of mobile radio equipment incorporate safeguards against this type of interference into their equipment. The presence of automotive interference can be determined easily since it will vary with the engine speed of the offending vehicle.

Atmospheric interference is caused by lightning and is of little concern to modern mobile radio systems if adequate precautions are taken to prevent lightning damage.[49]

Accustical noise interference can be very distracting and interfere with radio and telephone voice communications. Telephones such as available from Atkinson Dynamics, Inc., and radio control units, such as available from Motorola, General Electric, and others, are made for use in noisy locations, but it is better to locate the terminal units away from high ambient noise environments if possible.

Environmental interference is a generic appellation given to radiated electrical noise produced by electrical switching equipment, power line noise, electric motors, electric welders, diathermy equipment, etc. The FCC attaches the title "Industrial, Scientific and Medical" and "ISM" to these interfering sources and attempts to regulate them by the rules published in Part 15 of the FCC Rules and Regulations. Locating radio equipment at sites remote from these sources is the best way to avoid interference from them. It must be realized that interference is a two-way street and interference generated by mobile and portable radios can raise havoc with the electrical and electronic instrumentation and control equipment used in nuclear plants. References 63 and 64 present two excellent articles on this subject.

Appendix III

SYSTEM ENGINEERING

Any communication system should be developed through systems engineering to save time and money, to determine the actual requirements of the system, and to develop the minimum system that meets these requirements.[65] All too often a designer will develop a system by selecting components and building it much as a child will select blocks and other handy objects to build a structure that will later be identified with an imaginative name that matches the resultant structure as it is perceived.

System engineering is not esoteric; it is an orderly practical method of advancing from needs to satisfaction of needs. The basic steps that must be observed when employing the systems engineering process are listed below with a brief description of each.

Problem recognition - Identify the problem area. Determine who is supposed to design what communication system for the nuclear facility.

Problem definition - Define the problem completely but succinctly. Who needs to talk to whom via radio, telephone, page, etc. What data communication paths will be needed. Where should the control facilities be located.

Objectives - State the achievements necessary to solve the problem such as planners, schedulers, system designers, equipment experts, telephone experts, radio experts, etc.

System requirements - Establish the operational requirements necessary to meet the stated objectives. Completely define each communication subsystem component (radio, telephone, pager, control center, etc.) of the overall communication system.

Constraints - Establish and list the political, financial, chronological, and technological guidelines that may affect the system design and implementation.

System requirements analysis - Evaluate and validate the operational requirements and translate them into hardware requirements.

System synthesis - Develop several system design concepts that satisfy the requirements within the prescribed constraints.

System analysis - Evaluate the system design concepts and select the practical alternative.

Design optimization - Modify the selected alternative to attain maximum benefit in terms of time, economy, politics, and technological state of the art.

Equipment description - Select equipment that may be used to implement the system design.

Equipment analysis - Evaluate the selected equipment that may be used and determine the best configuration for implementing the system design.

Implementation planning and cost estimation - Plan, schedule, and estimate the cost of the system implementation.

System equipment specification - Specify the system performance and the equipment that is necessary to implement the solution.

Procurement documents - Combine the specifications with the necessary procurement documentation.

System procurement - Select the vendor best qualified for the implementation, based upon preestablished vendor selection criteria.

Implementation - Ascertain that the system implementation complies with the specifications and procurement documents.

Operator training - Train personnel to operate the system.

Maintenance training - Train personnel to maintain the system.

System support services - Provide spares, personnel, and expendables as necessary.

Operation, improvements, and maintenance - Create a plan to keep the operating system continuously maintained and technologically current.

Funding - Ensure that funds are available to provide the proper solution.

Documentation - Record the system evolution.

The above steps should not be followed in singular procession but in an iterative manner that ensures that each step will serve as a foundation for further progress on the project. The last two steps listed, funding and documentation, permeate the entire process.

Appendix IV

TOTAL SYSTEM LIFE COST

An ultimate criterion for a system is the economic expense incurred in attempting to satisfy a set of requirements. This is often called total system life cost (TSLC) and is the sum of original implementation costs (engineering, equipment, implementation, etc.) and all operational costs (e.g., personnel, operational spares, maintenance), minus the salvage gains when the system is retired.

It is practical and informative to examine the way in which isolated variables will affect TSLC.[66] For example, TSLC is a direct function of initial system cost as illustrated in Fig. 36.

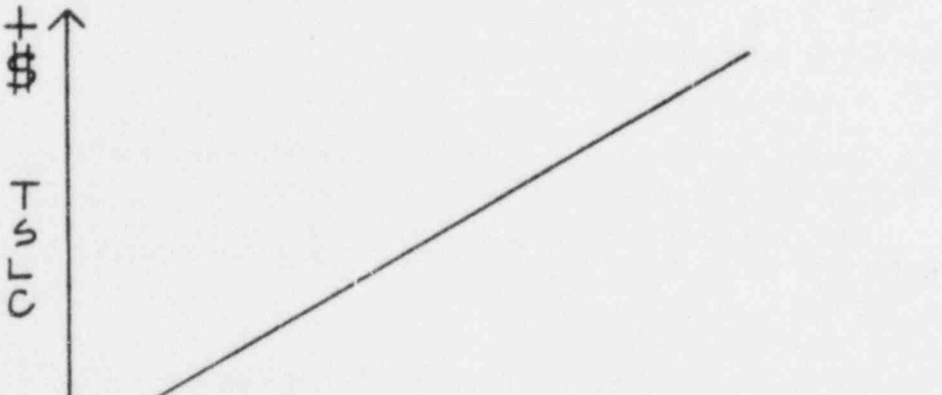


FIGURE 36

The reliability of the system influences TSLC to the extent that too much reliability will make the initial cost too high and too little will make the upkeep cost too high and will incur liability costs arising from the system not being available when needed (see Fig. 37). Note that the curve in the figure is asymptotic to the unattainable 100% reliability level and that there is a particular reliability point that will produce a minimum TSLC.

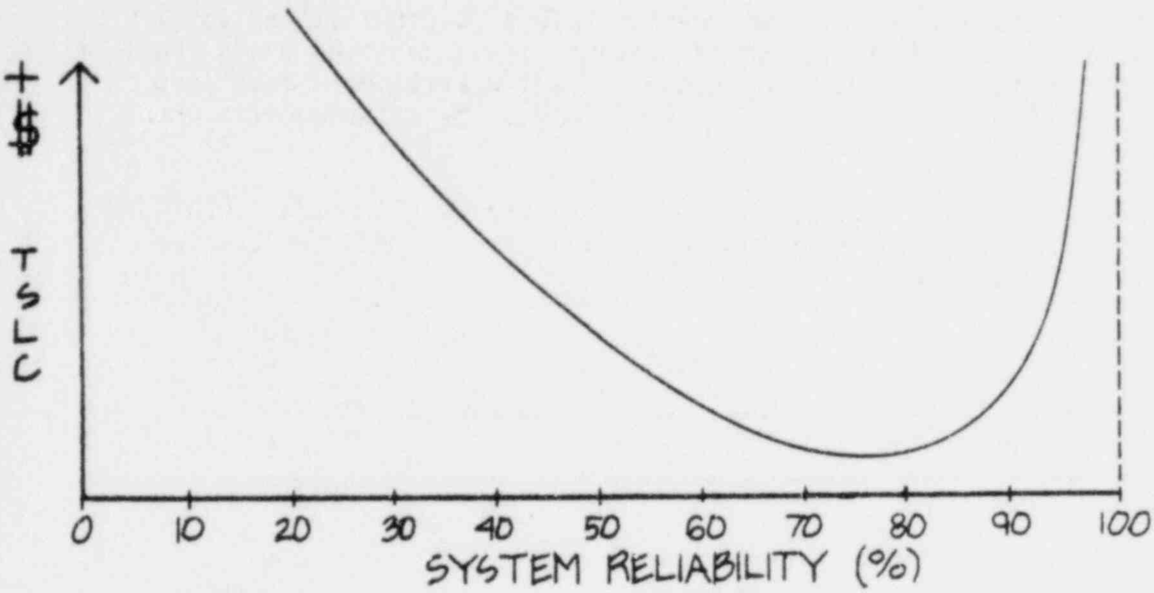


FIGURE 37

Excessive and expensive system failures will result from too little maintenance. On the other hand, excessive expenditures can be lavished on maintenance and TSLC will be a function of these costs as shown in Fig. 38.

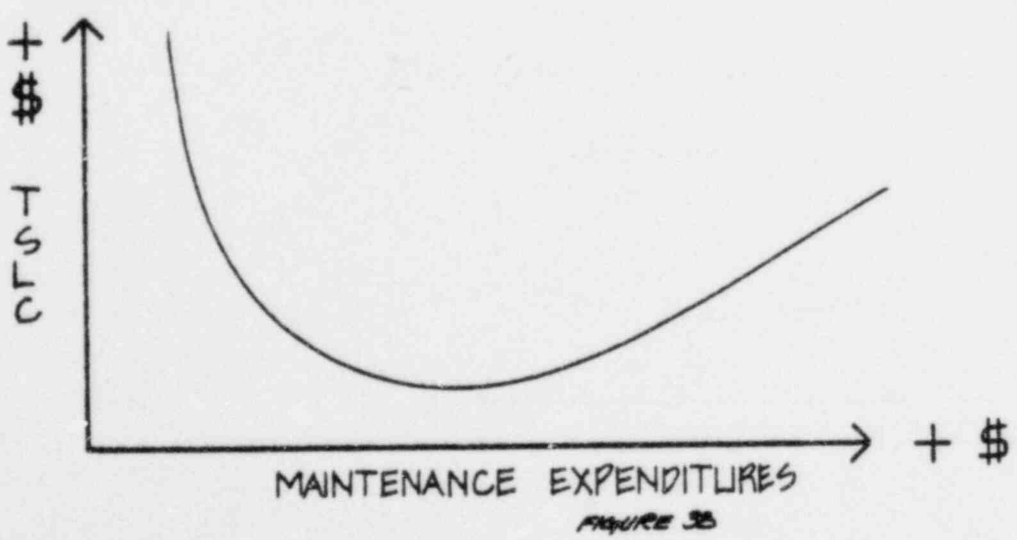


FIGURE 38

Maintenance can be further divided into preventive maintenance and repair costs. The curve for either one will have the same general shape as graphed above when plotted against TSLC; these two maintenance costs are interrelated, as shown in Fig. 39.

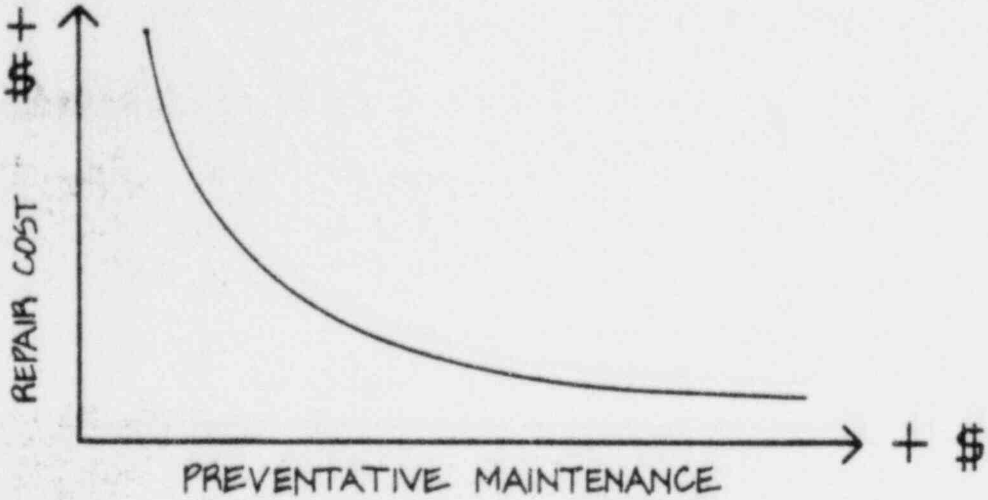


FIGURE 39

Personnel training costs vs TSLC will show a definite minimum as inadequate training produces system inefficiencies, but overindulgence in training will start to directly affect TSLC (see Fig. 40).

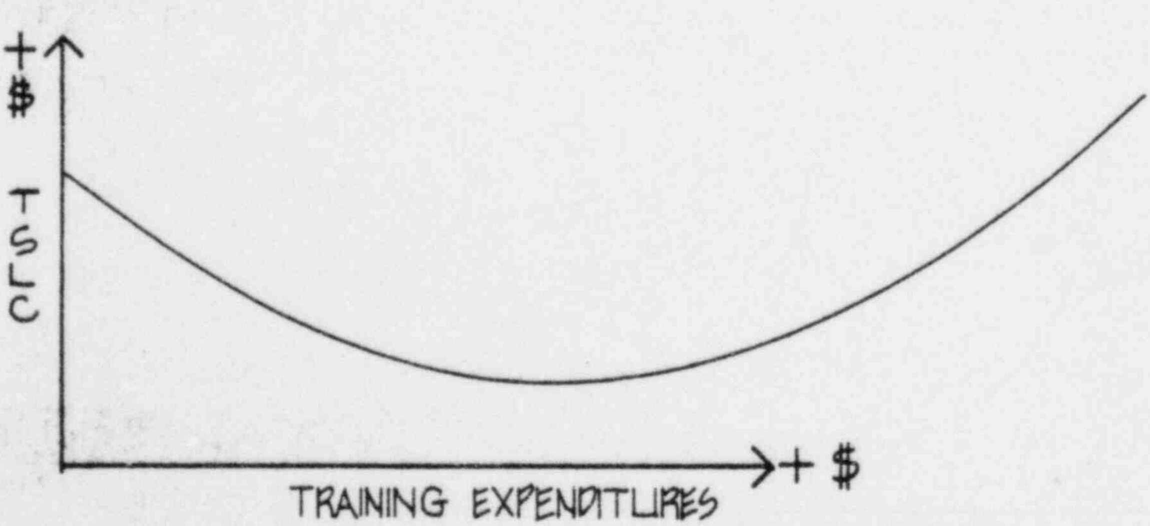


FIGURE 40

It should be obvious to anyone who seriously considers the interrelationships of these factors that they are not orthogonal to each other but are all interrelated. For example, the better the reliability of the system, the less that has to be spent on maintenance (see Fig. 41).

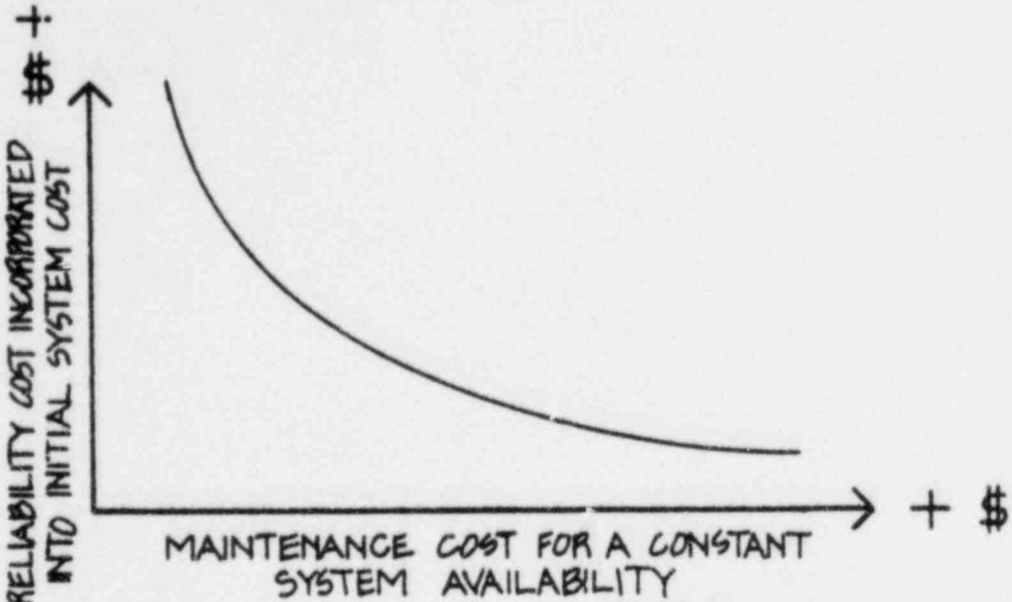


FIGURE 41

There is a useful relationship between initial system cost expenditures for automatic operation and human factors considerations that will reduce costs necessary for operator training but will increase the cost of maintaining the system because of the extra complexities required. These initial cost components will have an optimum value when plotted vs. TSLC (see Fig. 42.).

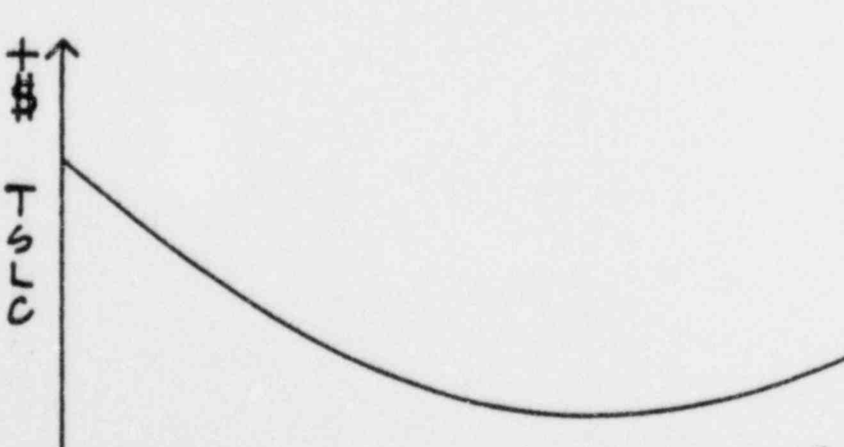


FIGURE 42

Similarily, expenditures for system backup modes of operation can enhance system reliability, decrease the need for constant maintenance, and increase the amount of equipment involved. There is an optimum level for backup provisions in a system, as shown by Fig. 43.

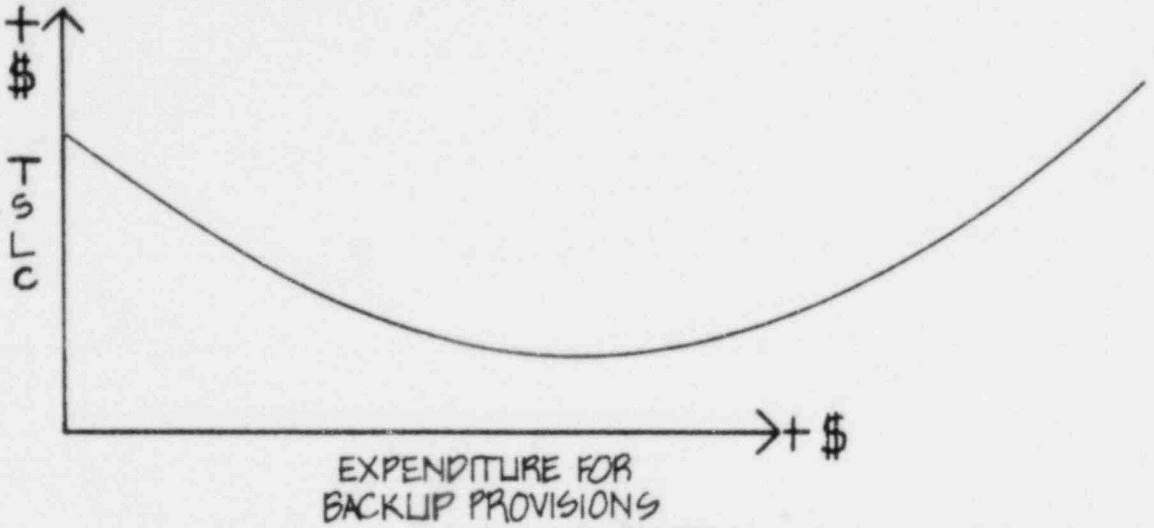


FIGURE 43

The point of this discussion is to create an awareness that good system engineering includes trade-offs for each system, throughout its useful life, to determine the amount of resources that should be applied to each facet of system implementation and operation to minimize the overall total system life cost.

Appendix V

FUTURE SYSTEMS

Communication system designers are expected to take advantage of emerging technological advances and create systems in the future with the following features:

1. narrower bandwidth operation and hence more channels in a given spectrum,
2. greater use of digital techniques with alphanumeric readout instead of the spoken word and hence more information transmitted per unit of time,
3. automatic location of mobile and portable units,
4. more versatile interconnect capabilities with wireline systems,
5. private telephone systems with built-in memories addressable from each instrument and a myriad of additional features.

The use of compandors, as discussed in Sect. 4.1.4, could be the next technique applied to reducing the spectrum bandwidth employed by each radio communication channel. On the other hand, digitization of speech permits breaking speech into basic components, eliminating the inherent redundancy of human speech, and transmitting only the information essential to reconstituting the speech at the receiver's location. Economics and speed of development will be the major determinants of which of these two techniques will be used to produce the next major reduction in radio channel bandwidth.

One of the major deterrents to the use of alphanumeric transmission of information by digital modulation is the production of inexpensive and reliable mobile printers. Xerox Corporation had an ill-fated sortie into this field several years ago to the dismay of many individuals needing mobile digital printers. It is expected that an inexpensive and reliable mobile digital printer will evolve from one of the many current efforts to produce such a device and will enable rapid and unattended reception of printed messages in a mobile unit. This feature, coupled either with status buttons or complete keyboards in the mobile unit, will permit use of digital transmission for transmitting messages in alphanumeric format and greatly reduce spectrum occupancy. Experimental keyboards have been built, tested, and used with portable radios by several police departments. No one has yet developed a printer for use with portable radios, but printer techniques developed and reduced to practice for pocket calculators will probably be applied to portable radios in the near future.

Automatic location of mobile and portable units has been a desired capability ever since the report of Ref. 67 appeared. References 68 to 70 are just a few of the publications written to either foster or report developments in this area.

Today, terrestrial triangulation and trilateration systems are competing with dead reckoning, sign post, and satellite navigation systems for emergence as an acceptable, usable, reliable, and economic location system. Each type system has advantages and disadvantages, and more than one example of each system is now in use on a trial basis. This subject should be studied in a detail far beyond the scope of this report before any location system is selected for use in a nuclear facility. The IEEE VTG, as discussed previously, is one of the best sources of information regarding developments in this area.

The FCC is, at the time of this writing, clarifying the Rules and Regulations pertaining to interconnection of radio and wireline systems. Manufacturers will respond quickly to the new and expanded rules with equipment that will perform the allowed interconnect functions. The result will be the ability to receive and originate telephone calls quickly and easily with a portable or mobile radio and to remotely control predetermined actions (lights, gates, delivery of precoded emergency messages, etc.) from a mobile or portable radio.

Telephone equipment manufacturers are adopting microcircuit technology and using it to produce APBX systems with a wide variety of functions that are quickly and easily invoked. These include all those identified in Sect. 3.1 plus automatic answering and message recording, digitized speech responses, automatic calling of predetermined numbers in an emergency and delivery of messages concerning the type of emergency in progress, single-button dialing of special numbers, automatic routing of calls on the basis of priority and economics, automatic tallying and auditing of toll calls, etc. The trade journals that cater to this market (Telephony, Telecommunications, Communications, etc.) continuously report developments in this area.

The net result of future technology is that it is becoming much easier to deliver a message to anyone anywhere, but easier still if the message is precoded and only the code designation of the message is delivered to the desired destination.

Appendix VI

APPLICABLE EIA SPECIFICATIONS

The EIA specifications below are provided to assist anyone interested in delving more deeply into current published standards applicable to radio equipment and radio systems. Copies of these specifications may be obtained from the Electronic Industries Association, Engineering Department, 2001 Eye Street, N.W., Washington, D.C. 20006.

EIA Standard RS-374, "Land Mobile Selective Signaling Standard," June 1970.

EIA Standard RS-232-C, "Interface Between Data Terminal Equipment and Data Communication Equipment Employing Serial Binary Data Interchange," August 1969.

EIA Standard RS-237, "Minimum Standard for Land-Mobile Communication Systems Using FM or PM in the 25-470 MC Frequency Spectrum," August 1960.

EIA Standard RS-220, "Continuous Tone-Controlled Squelch Systems (CTCSS)," April 1959.

EIA Standard RS-375-A, "Electrical Performance Standards for Direct View Monochrome Closed Circuit Television Monitors 525/60 Interlaced 2:1," October 1974.

EIA Standard RS-412-A, "Electrical Performance Standards for Direct View High Resolution Monochrome Closed Circuit Television Monitors," October 1974.

EIA Standard RS-250-B, "Electrical Performance Standards for Television Relay Facilities," September 1976.

EIA Standard RS-252-A, "Standard Microwave Transmission Systems," September 1972.

EIA Standard RS-247, "Analog-to-Digital Conversion Equipment," October 1961.

EIA Standard RS-310-B, "Racks, Panels, and Associated Equipment," December 1972.

EIA Standard RS-378, "Measurement of Spurious Radiation from FM and TV Broadcast Receivers in the Frequency Range of 100 to 1000 MHz - Using the EIA-Laurel Broad-Band Antenna," August 1970.

EIA Standard RS-388, "Minimum Standard for Test Conditions Common to FM or Land-Mobile Communications Equipment 25-470 MHz," January 1971.

EIA Standard RS-329-A, "Minimum Standards for Land-Mobile Communication Antennas Part I - Base or Fixed Station Antennas," December 1975.

EIA Standard RS-329-1, "Minimum Standards for Land-Mobile Communication Antennas Part II - Vehicular Antennas," August 1972.

EIA Standard RS-316-A, "Minimum Standards for Portable/Personal Land Mobile Communications FM or PM Equipment 25-1000 MHz," December 1974.

EIA Standard RS-215, "Basic Requirements for Broadcast Microphone Cables," November 1958.

EIA Standard RS-158, "Mechanical Considerations for Transmission Lines in Microwave Relay Applications," June 1956 (reaffirmed October 1962).

EIA Standard RS-200-A, "Circular Waveguides," March 1965.

EIA Standard RS-203, "Microwave Transmission Systems," January 1958.

EIA Standard RS-368, "Frequency Division Multiplex Equipment Standard for Nominal 4 KHz Channel Bandwidths (Non-Compandored) and Wideband Channels (Greater than 4 KHz)," September 1969.

EIA Standard RS-219, "Audio Facilities for Radio Broadcasting Systems," April 1959.

EIA Standard RS-224, "Magnetic Recording Tapes," August 1959.

EIA Standard RS-222-C, "Structural Standards for Steel Antenna Towers and Antenna Supporting Structures," March 1976.

EIA Standard RS-152-B, "Minimum Standards for Land Mobile Communication FM or PM Transmitters, 25-470 MHz," February 1970.

EIA Standard RS-204-A, "Minimum Standards for Land Mobile Communication FM or PM Receivers, 25-470 MHz," January 1972.

EIA Standard RS-195-B, "Electrical and Mechanical Characteristics for Terrestrial Microwave Relay System Antennas and Passive Reflectors," May 1978.

EIA Standard RS-366-A, "Interface Between Data Terminal Equipment and Automatic Calling Equipment for Data Communication," March 1979.

EIA Standard RS-499, "General Purpose 37-Position and 9-Position Interface for Data Terminal Equipment and Data Circuit-Terminating Equipment Employing Serial Binary Data Interchange," November 1977.

EIA Standard RS-422-A, "Electrical Characteristics of Balanced Voltage Digital Interface Circuits," December 1978.

EIA Standard RS-423-A, "Electrical Characteristics of Unbalanced Voltage Digital Interface Circuits," December 1978.

RETMA Standard TR-141, "Microwave Relay Systems for Communications," December 1955.

RETMA Standard RS-173, "Emergency Stand-by Power Generators and Accessories for Microwave Systems," December 1956.

Appendix VII

Applicable NILECJ Standards

The following standards, reports and user guides have been prepared by the Law Enforcement Standards Laboratory, National Bureau of Standards, under sponsorship of the Law Enforcement Assistance Administration. Additional publications of interest to communication system designers are currently being prepared to expand this series. They should be compared with the EIA standards when developing specifications for specific items of communication equipment. Copies of these standards may be obtained from the Law Enforcement Standards Laboratory, National Bureau of Standards; Washington, D.C. 20402.

NILECJ-STD-0212.00, "RF Coaxial Cable Assemblies for Mobile Transceivers," September 1975.

NILECJ-STD-0211.00, "Batteries for Personal/Portable Transceivers," June 1975.

NILECJ-STD-0603.00, "X-Ray Systems for Bomb Disarmament," June 1975.

LESP-RPT-0201.00, "Batteries Used with Law Enforcement Communications Equipment," May 1972.

LESP-RPT-0204.00, "Voice Privacy Equipment for Law Enforcement Communication Systems," May 1974.

LESP-RPT-0205, "Automatic Vehicle Location Techniques for Law Enforcement Use," January 1974.

NILECJ-STD-0203.00, "Personal/Portable FM Transmitter," October 1974.

LESP-RPT-0207.00, "Electronic Eavesdropping Techniques and Equipment," September 1975.

LESP-RPT-0206.00, "Repeaters for Law Enforcement Communication Systems," October 1974.

NILECJ-STD-0202.00, "Mobile FM Transmitters," October 1974.

NILECJ-STD-0207.00, "Mobile FM Receivers," June 1975.

NILECJ-STD-0213.00, "FM Repeater Systems," November 1977.

NILECJ-STD-0205.00, "Mobile Antennas," May 1974.

NILECJ-STD-0204.00, "Fixed and Base Station Antennas," November 1977.

NILECJ-STD-0214.00, "Body-Worn FM Transmitters," August 1978.

NBS Special Publication 480-19, "Digital Data Transmission Tests on Voice Channels," July 1977.

NILECJ-STD-0206.00, "Fixed and Base Station FM Receivers," September 1975.

NILECJ-STD-0201.00, "Fixed and Base Station FM Transmitters," September 1974.

NILECJ-STD-0209.00, "Personal FM Transceivers," April 1978.

NILECJ-STD-0208.00, "Personal Portable FM Receivers," October 1975.

LESP-RPT-0203.00, "Technical Terms and Definitions Used with Law Enforcement Communications Equipment (Radio Antennas, Transmitters and Receivers)," June 1973.

LESP-RPT-0202.00, "Batteries Used with Law Enforcement Communications Equipment: Chargers and Charging Techniques," June 1973.

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This report presents a basic discussion of communication techniques and factors relevant to designing communication systems for nuclear fixed site facility security systems.

The reader is provided communication fundamentals, design considerations, and specification techniques. Copious references and an annotated bibliography are provided for individuals who desire to delve deeper than the limits and areas of study of this report.

Ease of reading and use of this report are enhanced by relegating detailed communication design treatise to the Appendices. Sample procurement specifications are provided throughout the report for various communication system components and are distinguished from the regular text by using a smaller type.

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