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LAW ENFORCEMENT STANDARDS PROGRAM

REPEATERS FOR LAW ENFORCEMENT COMMUNICATION SYSTEMS

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REPEATERS FOR LAW ENFORCEMENT COMMUNICATION SYSTEMS

prepared for the
National Institute of Law Enforcement and Criminal Justice
Law Enforcement Assistance Administration
U.S. Department of Justice

by

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OCTOBER 1974

U.S. DEPARTMENT OF JUSTICE
Law Enforcement Assistance Administration
National Institute of Law Enforcement and Criminal Justice

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FOREWORD

Following a Congressional mandate* to develop new and improved techniques, systems, and equipment to strengthen law enforcement and criminal justice, the National Institute of Law Enforcement and Criminal Justice (NILECJ) has established the Law Enforcement Standards Laboratory (LESL) at the National Bureau of Standards. LESL's function is to conduct research that will assist law enforcement and criminal justice agencies in the selection and procurement of quality equipment.

In response to priorities established by NILECJ, LESL is (1) subjecting existing equipment to laboratory testing and evaluation and (2) conducting research leading to the development of several series of documents, including national voluntary equipment standards, user guidelines, state-of-the-art surveys and other reports.

This document, LESP–RPT–0206.00, Repeaters for Law Enforcement Communication Systems, is a law enforcement equipment report prepared by LESL and issued by NILECJ. Additional reports as well as other documents will be issued under the LESL program in the areas of protective equipment, communications equipment, security systems, weapons, emergency equipment, investigative aids, vehicles and clothing.

Technical comments and suggestions concerning the subject matter of this report are invited from all interested parties. Comments should be addressed to the Program Manager for Standards, National Institute of Law Enforcement and Criminal Justice, Law Enforcement Assistance Administration, U.S. Department of Justice, Washington, D.C. 20531.

Lester D. Shubin
Manager Standards Program
National Institute of Law
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*Section 402(b) of the Omnibus Crime Control and Safe Streets Act of 1968, as amended.

REPEATERS FOR LAW ENFORCEMENT COMMUNICATION SYSTEMS

ABSTRACT

This report is concerned with FM repeaters used in land mobile communications sytems. Repeater systems are described with emphasis on appropriate antenna site selection, signal-rejection techniques, and specialized transmission-line components for the transmission and reception of signals. Repeaters using the vehicle transceiver are mentioned. Repeaters at microwave frequencies are described to the extent that their use for control and as audio links is pertinent. Measurement techniques that are unique to land-mobile repeaters are discussed.

1. INTRODUCTION

A repeater is a device which receives, amplifies, and retransmits a signal to provide improved communication range and coverage [6]. Even with a good base station antenna site, it is possible that a hill, a building, or other obstruction can cause a shadow region where received signals are extremely weak. In such cases, rather than attempting to improve signal strength by increasing the power radiated by the base station, an unmanned repeater station can be located outside the shadow region to retransmit received signals into the region and vice versa [4]. Mountain tops, tall building roofs, and existing commercial broadcast towers provide excellent sites for a repeater. Otherwise, a special tower installation is necessary.

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

2. REPEATER SYSTEMS

Repeater systems provide a dependable technique for increasing the signal strength in shadowed areas within the service region. Use of repeaters will enhance mobile-to-mobile coverage in terrain that would otherwise result in unsatisfactory communications. Personal transceivers, with their low power and reduced antenna efficiency, will also benefit from the increased signal strength provided by the repeater. The equipment configurations described herein can provide reliable communications coverage over the required service area.

The transmitting and receiving capabilities of a repeater should be in proper balance; that is, the service area for transmitting and the one for receiving should be as nearly identical as possible to provide transmission and reception to the same geographical area and to minimize interference with other communication systems. Thus, a repeater working with vehicular transceivers normally requires less transmitter power than one designed for personal transceivers because of the latter's lower power and reduced antenna efficiency. Systems that frequently utilize personal transceivers usually require additional hardware to improve the balance. This hardware may include directional antennas, remote receivers, and voting receivers for improving the receiving capability of the repeater receiver. Some factors determining the degree of balance are the insertion loss of the duplexer at the receiver, the receiver desensitization at the repeater site, and the frequency separation.

2.1 Repeaters Under Local Control

There are shadow regions caused by large buildings in most metropolitan areas where both personal-to-personal transceiver and personal-to-base transceiver coverage is required. Figure 1 illustrates the communication paths between personal transceivers, A and B, by means of a local repeater (under local control) using separate transmit and receive antennas. Vertical separation between the antennas usually provides the isolation necessary to reduce receiver desensitization for vertically polarized signals. The smaller the frequency separation between receiver frequency F_1 and transmitter frequency F_2, the greater will be the required vertical antenna separation. While this two-antenna installation normally is less expensive than other systems, it lacks the signal rejection capabilities of a single antenna with duplexer.

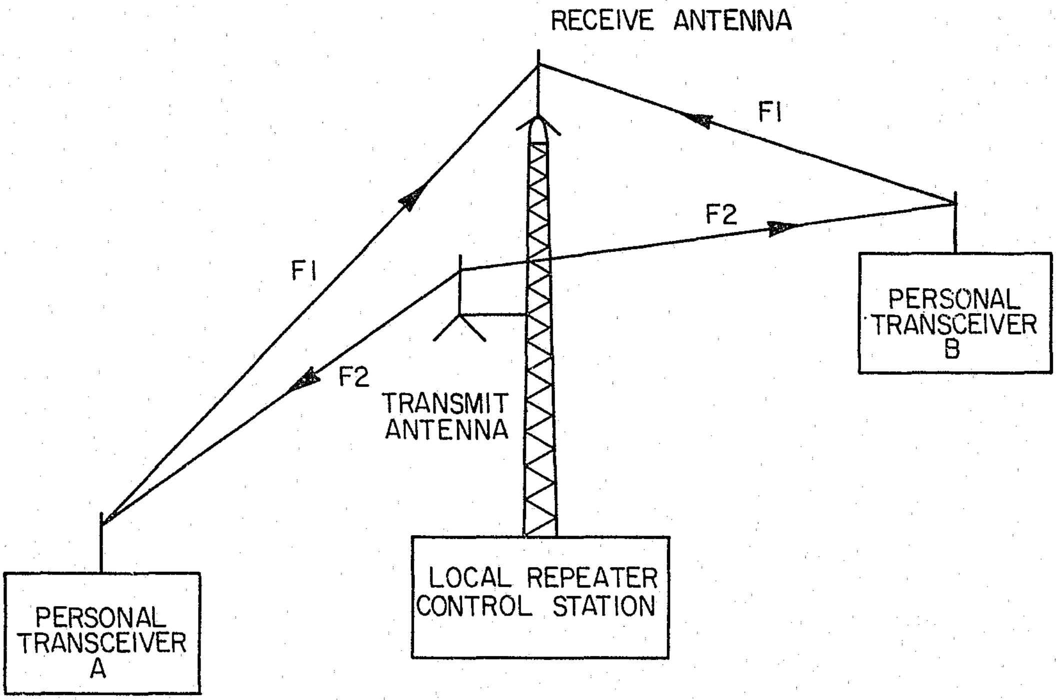

Figure 1—Block Diagram of a Repeater Under Local Control

2.2 Repeaters Under Remote Control

The remote repeater, figure 2, is equipped with a telephone line or radio link for control which can be used to turn the repeater on and off. This line or link can also be used to provide audio to the transmitter, thus giving control to the dispatch center in the event of priority dispatch information. Reception at the dispatch center of a signal from a remote receiver is often used to activate a transmitter in the vicinity of that receiver [5].

The remote repeater takes advantage of line-of-sight coverage of the required service area. A remote site will likely be located well away from sources of impulsive noise (mainly from automobile ignitions) which tend to limit receiver sensitivity. However, a remote site which serves many users requires careful scrutiny of all frequencies in use, including the local oscillators and other frequency mixing products. When interference problems arise, these data

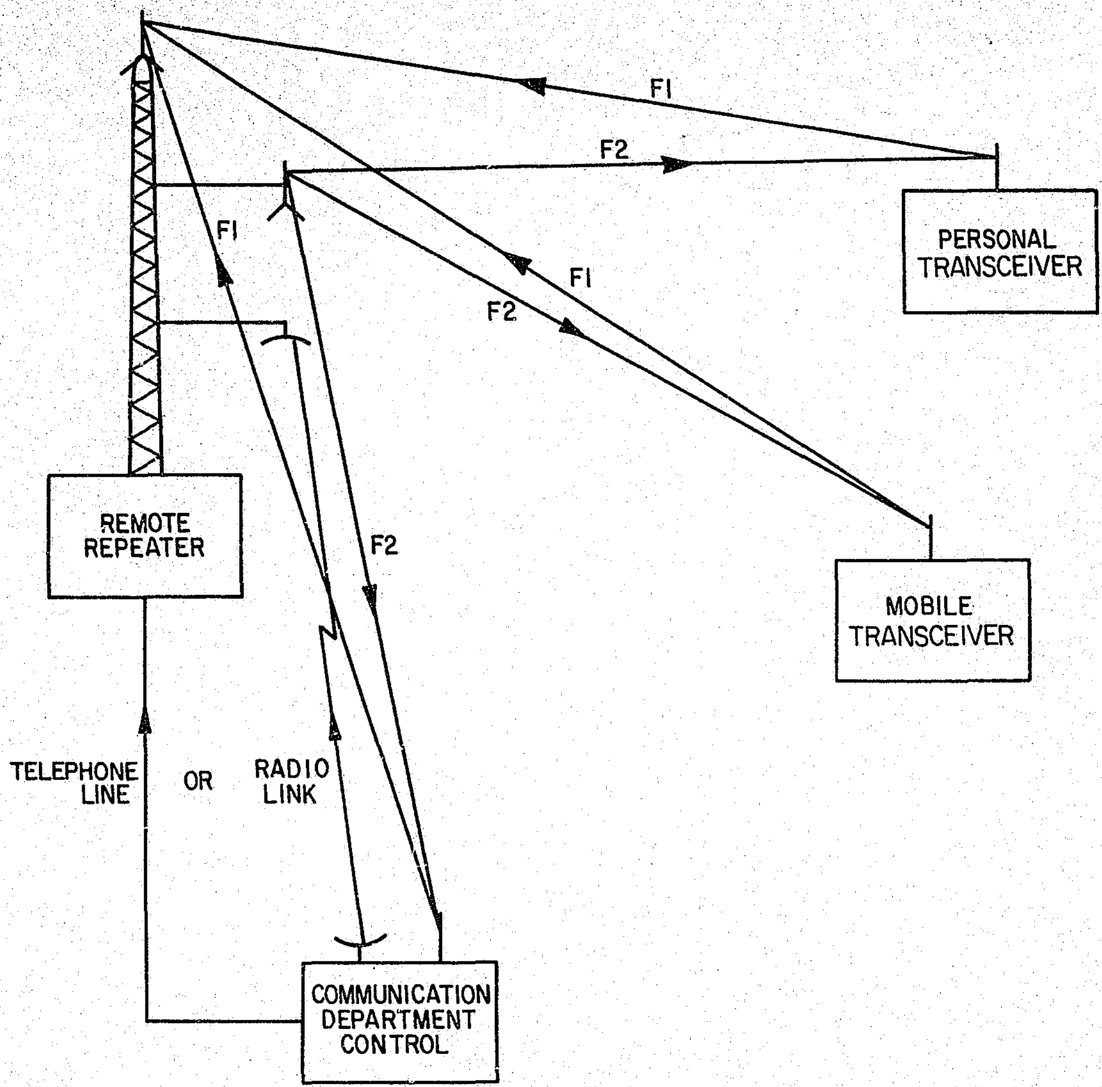

Figure 2—Block Diagram of a Repeater Under Remote Control

are essential for locating sources of intermodulation of the transmitter or receiver, excessive local oscillator leakage, and undesirable mixing products. The availability of commercial power, telephone lines, year-around access, emergency generator systems, and delivery of fuel to the site are additional factors in site selection.

2.3 Repeaters Using a Single Antenna and Duplexer

Limited antenna space on existing towers may preclude the use of two antennas. Moreover, use of a common antenna on either a local or remote repeater has the advantage of identical transmitter and receiver coverage provided the repeater is also balanced [1, 7]. However, frequency pairs in the 150-MHz band are rarely ideally separated for repeater use, whereas the frequency separation in the 450-MHz band is always an entirely adequate 5-MHz. When the assigned pair differs by only a few hundred kilohertz, additional system hardware such as cavities, crystal filters, and other rejection components are usually required to reduce the effects of interference. Figure 3 illustrates the use of a single antenna interconnected to the repeater by a duplexer.

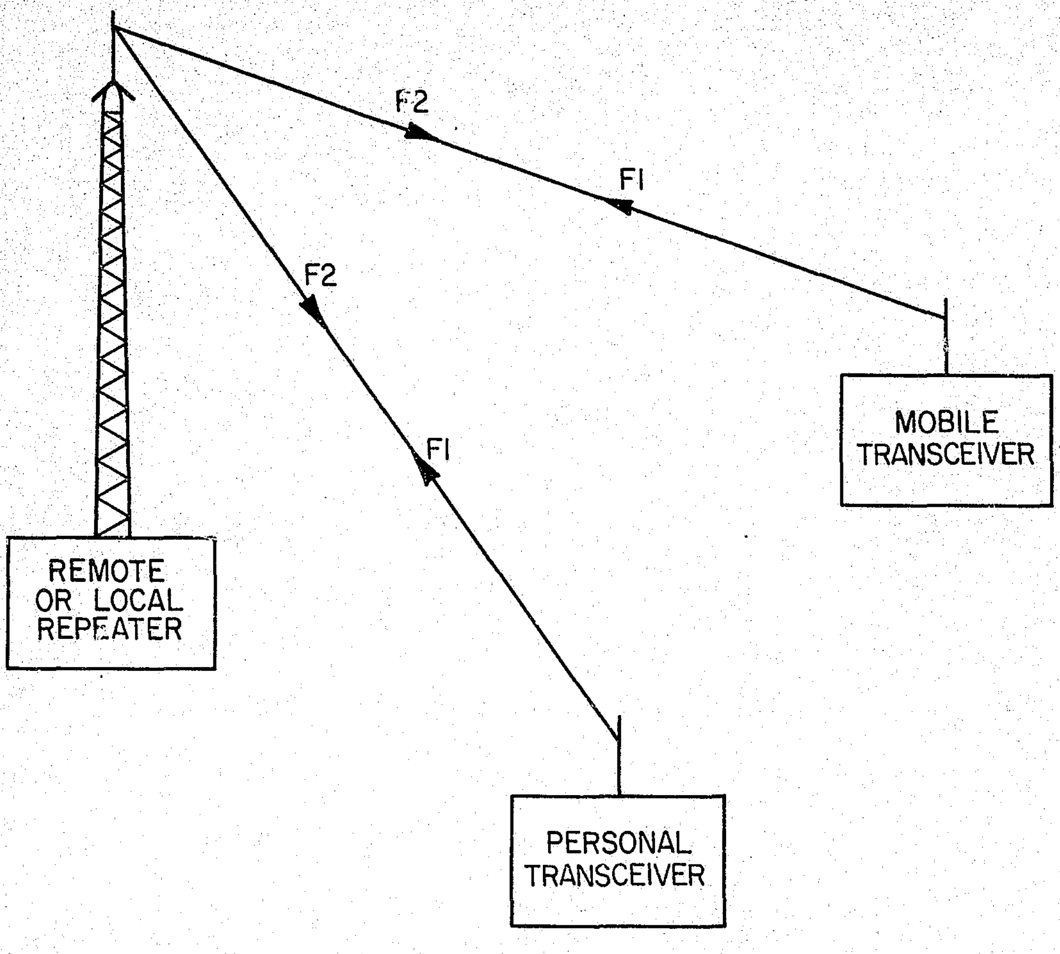

Figure 3—Block Diagram of a Repeater Using Single Antenna and Duplexer

2.4 Repeaters Using Two Antenna Sites

A repeater can be arranged so that the horizontal separation of antennas yields sufficient isolation between the transmitted and received signals for satisfactory repeater performance. If each antenna is in line-of-sight view of the desired service area with a hill or other obstruction between the two antennas, ideal isolation between transmitter and receiver can be achieved. Wire lines or a radio link between sites interconnect the receiver to the transmitter. This approach to repeater siting is particularly advantageous when the intermodulation products of other systems at the transmitter site degrade the receiver performance. Figure 4 illustrates a two-antenna-site repeater system.

2.5 Repeaters Using Voting Receivers

An extension of the two-antenna-site repeater using voting receivers is shown in figure 5. Multiple receivers are positioned such that one or more will receive signals from a transmitter at any location within the service area. These signals are relayed to a comparator which votes or selects the signal with the highest quality.

There are three selection techniques which are suitable for law enforcement communications systems. The three techniques are audio quality selection, rf signal level selection, and quieting level selection [4].

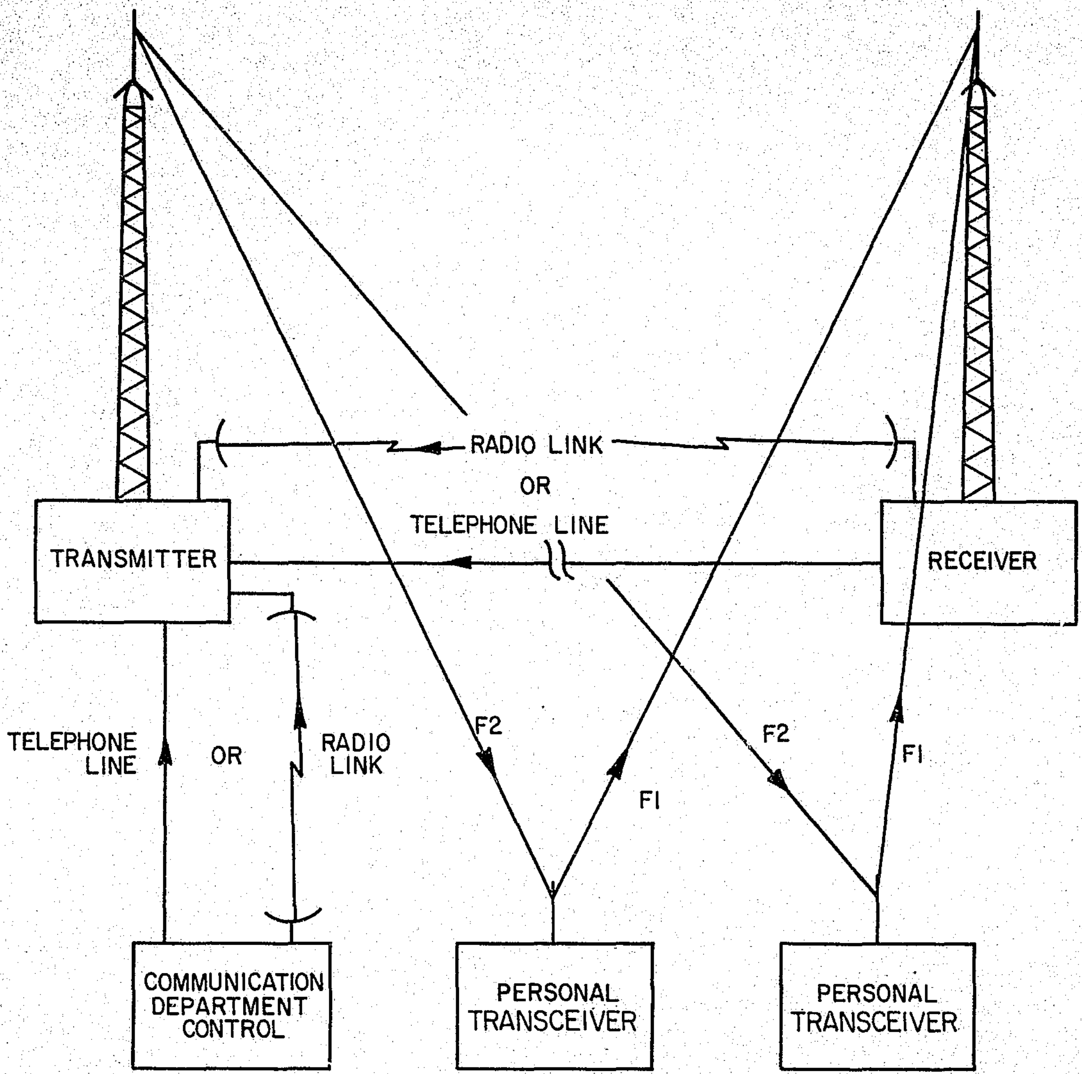

Figure 4—Block Diagram of a Repeater Using Two Antenna Sites

In the first system, the audio signals from the satellite receivers are analyzed by the comparator for certain signal quality characteristics. The characteristics considered are rf signal level, frequency distribution, syllabic rate, and noise level during pauses in speech. In this system, the satellite receiver requires no additional special circuitry and all of the selection equipment may be located at a central position.

In the rf signal level selection system, the selector compares the received rf signal level from each receiver and chooses the receiver with the highest level. Measurements of received rf signal level can only be performed at the receiver, however, and the measurement information must be conveyed to the selector. Consequently, each satellite receiver is equipped with encoder circuitry which generates coded tone combinations which correspond to various rf signal levels. The coded tones are sent along with the receiver audio output to the voting selector, where the tones provide the information required to choose the best audio signal.

The third method is quieting level selection. In this method, the selector compares the quieting levels on the lines from the unsquelched receivers and chooses the receiver line with the least amount of noise. It is necessary in this system that the squelch status of the receiver be known at the voting selector. This information is conveyed to the selector by means of a

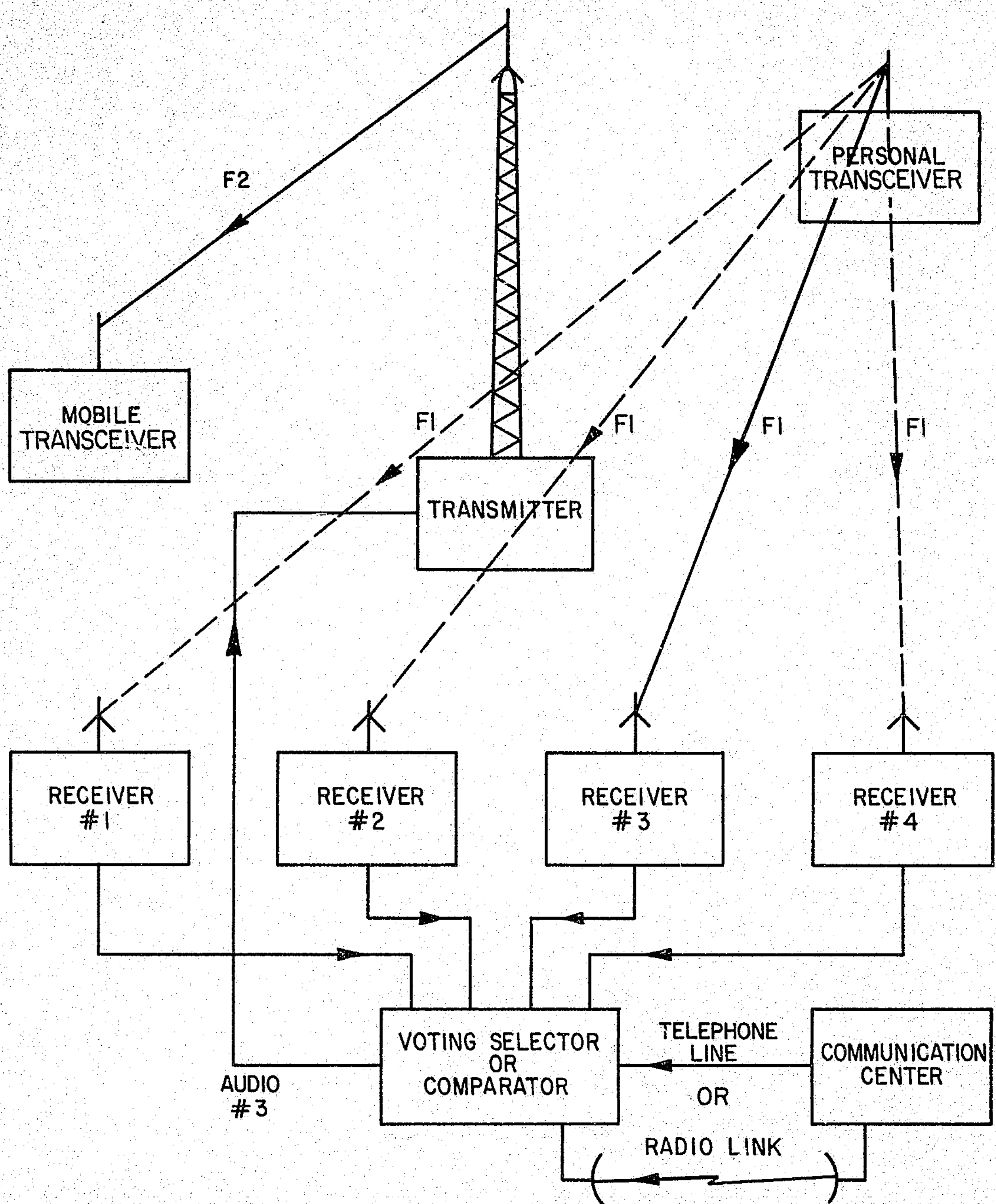

Figure 5—Block Diagram of a Repeater Using Voting Receivers

tone or dc signal generated at the satellite receiver when the receiver is squelched. The audio portion of the selected rf signal is routed to the repeater transmitter, usually via telephone lines.

2.6 Vehicular Transceiver as a Repeater

The transceiver installed in a vehicle can be interconnected to perform the repeat function for personal transceivers as illustrated in figure 6. When the user leaves the vehicle, the personal transceiver he carries may not transmit to the base station satisfactorily because of

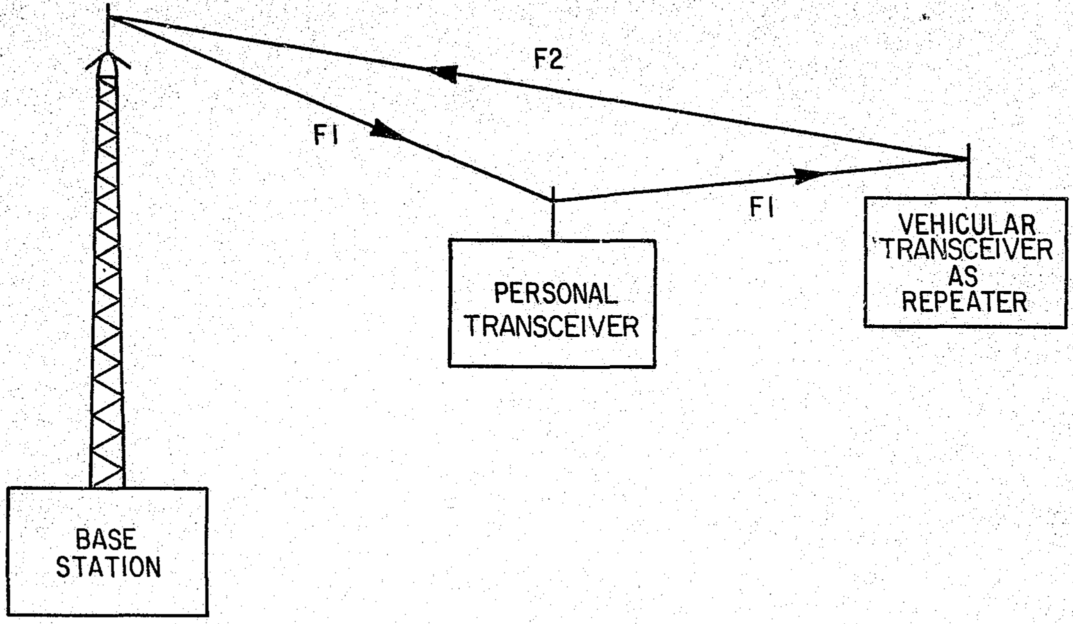

Figure 6—Block Diagram of a System Using the Vehicular Transceiver as a Repeater

poor transmitting position or low transmitter power. By arranging the vehicular transceiver to function as a repeater, the personal transceiver has the equivalent power of the vehicular transceiver.

2.7 Repeaters for Microwave Frequencies

To conserve VHF and UHF spectra, information from communication centers to remote base stations is usually transmitted by microwave links. Microwave repeaters are sometimes necessary to amplify and redirect signals when obstructions are in the link path. Because directional antennas are readily available at these frequencies, the energy is contained within a narrow beam between transmitter and receiver antennas, thereby minimizing interference from other radio services. However, multipath propagation, where the terrain reflects part of the beam so that signals from more than one direction and path length are received, can result in destructive interference. Space diversity is one technique for reducing the effects of multipath propagation. Two receiving antennas can be mounted on the tower approximately 10 to 25 meters (33 to 82 feet) apart, and a diversity switch will automatically select the larger signal for the input to the receiver. Figure 7 illustrates a typical repeater in a microwave system. Multiple input signals can be transmitted simultaneously using a frequency division multiplexer connected to the FM transmitter. Highly directional antennas, usually reflectors 1 to 5 meters (3 to 16 feet) in diameter, direct the signal to and from the repeater. Multiple repeaters, at distances ranging from 15 to 60 kilometers (9 to 36 miles), are used if required by the terrain. For engineering economy of the communication system, careful and well-planned site selection is important.

3. REPEATER SYSTEM ANCILLARY EQUIPMENT

Specialized transmission-line components are required in most repeater systems because of the close frequency spacing between the transmitted and received signals. Undesired intermodulation products, generated in the non-linear elements of both receiver and transmitter by the strong fields from other nearby systems, will degrade the performance of a repeater [2].

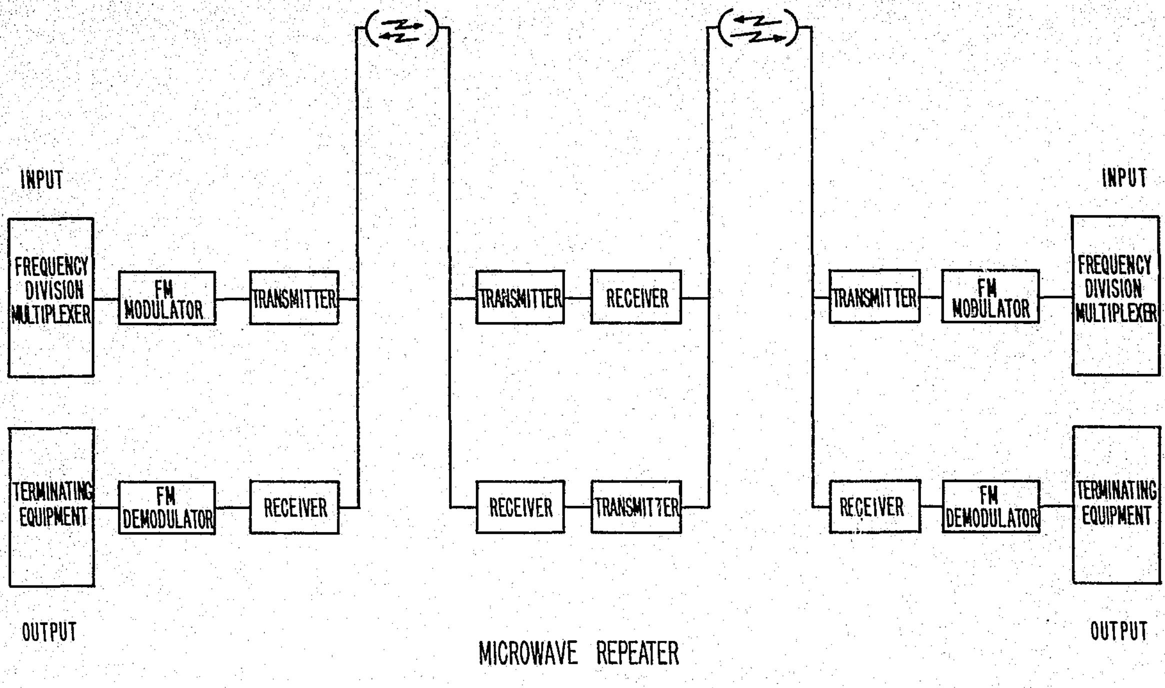

Figure 7—Block Diagram of a Microwave Repeater

The use of selective signaling, such as continuous sub-audible tone equipment, will reduce co-channel and adjacent channel interference and reduce the voice traffic that must be monitored by the transceiver user. Automatic equipment is available to provide call letter identification of the repeater. Identification is required by the FCC at 30-minute intervals or at the end of a message group.

3.1 Transmission Line Components

Three critical factors to consider in the selection of appropriate components for the transmission line system in land-mobile repeaters are transmitter noise interference, receiver desensitization, and intermodulation [8]. Their effects can be minimized by the appropriate choice of transmission line components. When frequencies are closely spaced, a duplexer can be used to reduce the transmitter noise delivered to the antenna. Many multiple antenna installations require the use of an isolator or a ferrite circulator to reduce transmitter noise. However, one should be aware that the addition of a circulator or isolator may produce harmonics, thus requiring a low-pass filter inserted after the isolator or circulator to reduce harmonically related spurious emission.

When tower space is limited, a single antenna with a diplexer can serve more than one repeater. A good quality, low-loss transmission line will help compensate for the additional losses introduced by the diplexer [10].

Bandpass cavity filters can be installed in the transmission line to reduce interference from other systems. Since bandpass cavity filters are broader in frequency response than notch filters, they are ineffective when employed near the user's frequency. The notch filter is a bandstop filter with a rapid transition from pass to reject. This characteristic favors its use near the user's frequency. A crystal filter in the receiver transmission line will minimize interference that is within a few channel spacings of the user's frequency.

3.2 Failure-Mode Protection Components

Timing devices are used to limit the time that a transmitter can remain continuously in the transmit mode. The timer, while designed to protect the equipment in the event of a malfunction, also discourages excessively long communications. Many timers can be reset for another interval by releasing the press-to-talk switch momentarily. Most users prefer that timer reset be accomplished by the absence of the signal at the repeater receiver rather than the absence of the repeater carrier because the latter includes the carrier delay interval. Timer intervals are usually set at one to the maximum of 3 minutes allowed by the FCC, at the discretion of the communications officer.

Transmitter carrier delays are incorporated into a repeater system to minimize the on-off cycling that can occur with a marginal input signal. Delay intervals are typically one-half second to an maximum of 5 seconds.

3.3 Selective Tone-Coding Applications

To minimize the voice traffic that must be monitored by a mobile unit, a repeater system can be designed so that communications can be directed to specific groups within a department. Tone-controlled squelch systems may be utilized effectively for this purpose. These systems mimimize co-channel interference that can result from tropospheric enhancement (ducting) between geographical regions. Tone-coding equipment, while minimizing the annoyance of interference from weak undesired signals, does not assure satisfactory operation if a strong undesired signal captures the tone-controlled receiver. This capture can result in a lost message. In areas where capture problems exist, the use of voice grade telephone lines with tone-coding to the repeater site will insure that the repeater is always under the control of the communications center.

4. REPEATER SYSTEM MEASUREMENTS FOR VHF AND UHF

NILECJ standards for transmitters, receivers, and antennas describe the measurement methods applicable to most repeater components. While most repeater components are similar or identical to components used in base and mobile installations, the demands on repeater equipment are more stringent. Because of the simultaneous operation of the repeater transmitter and receiver, as well as the proximity of other transmitters and receivers, receiver desensitization caused by high level fields can be a problem. For example, careful shielding against high-level radiation is necessary to provide isolation for the repeater from all other transmitters and receivers at the site. Measurements of the receiver sensitivity, with and without the transmitter in operation, give a quantitative measure of the leakage [3, 9].

Proper adjustment of audio signal levels in a repeater is necessary to obtain reliable operation. One procedure that provides satisfactory results is to connect an on-frequency signal generator with 1000 Hz modulation and ±3 kHz deviation to the antenna input of the repeater receiver. The audio output of the receiver is connected to the audio input of the repeater transmitter, and the audio input level is adjusted to produce ±3 kHz of transmitter deviation. In addition, the modulation limiting control of the repeater transmitter is adjusted to limit the system to rated deviation as prescribed by the FCC.

5. GLOSSARY OF TERMS

5.1 Bandpass Filter

A filter which has a single transmission band, neither of the cutoff frequencies being zero or infinite.

5.2 Bandstop Filter

A filter which has a single band of attenuation between two cutoff frequencies, neither one being zero or infinite. The filter passes frequencies on either side of this band.

5.3 Continuous-Tone-Controlled Squelch

A form of selective signaling wherein the receiver is equipped with a tone-responsive device which allows audio signals to appear at the receiver audio output only when a carrier modulated with a specific tone is received. The tone must be continuously present for continuous audio output. The transmitter emitting the carrier is modulated with a continuous tone, whose frequency is the same as the tone required to operate the tone-responsive device in the receiver.

5.4 Desensitization

The reduction in receiver sensitivity which occurs when the level of any off-frequency signal is great enough to alter the sensitivity.

5.5 Diplexer

A device permitting an antenna system to be used simultaneously or separately by two transmitters or by two receivers.

5.6 Diplex Operation

Simultaneous transmission or reception of two signals using a specified common feature, such as a single antenna.

5.7 Duplexer

A device which permits a single antenna system to be used for both transmitting and receiving.

5.8 Duplex Operation

The operation utilizing two radio frequency channels, one for each direction of transmission, in such manner that intelligence can be transmitted concurrently in both directions.

5.9 Filter

A device for separating waves on the basis of their frequency by introducing relatively small insertion loss to waves in one or more frequency bands and relatively large insertion loss to waves of other frequencies.

5.10 High-pass Filter

A filter having a single transmission band extending from some critical or cutoff frequency, not zero, up to infinite frequency.

5.11 Low-pass Filter

A filter having a single transmission band extending from zero frequency up to some cutoff frequency, not infinite.

5.12 Notch Filter

A filter designed to attenuate or reject a specific frequency band with sharp cutoff at both ends.

5.13 Selective Signaling

A general method for signaling mobile, fixed, or repeater stations or groups of stations selectively (rather than all simultaneously) from a base or mobile station.

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