NBSIR 75-813

ELECTRONIC EAVESDROPPING TECHNIQUES AND EQUIPMENT

R. N. Jones

Electromagnetics Division
Institute for Basic Standards
National Bureau of Standards
Boulder, Colorado 80302

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Prepared for:
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NATIONAL BUREAU OF STANDARDS, Richard W. Roberts, Director

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ELECTRONIC EAVESDROPPING TECHNIQUES AND EQUIPMENT

FOREWORD

The National Bureau of Standards (NBS) has established a Law Enforcement Standards Laboratory (LESL) for the National Institute of Law Enforcement and Criminal Justice (NILECJ) of the Law Enforcement Assistance Administration, Department of Justice. 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.

The Electromagnetics Division of NBS prepared this report under the direction of Marshall J. Treado, Program Manager for Communication Systems and Jacob J. Diamond, Chief of LESL.

This document, Electronic Eavesdropping Techniques and Equipment, describes various techniques and types of equipment used for electronic voice surveillance. It is intended to serve as a background reference and information guide for users and prospective users of equipment.

ELECTRONIC EAVESDROPPING TECHNIQUES AND EQUIPMENT

1. INTRODUCTION

Voice surveillance using electronic techniques has become an essential activity of law enforcement organizations at almost all levels of government. Often the lives and safety of law enforcement officers, and others as well, depend upon the reliability of miniaturized and concealed communications devices. Furthermore, the apprehension of criminals and the successful prosecution of criminal cases can depend upon evidence obtained by these techniques. These considerations clearly indicate the importance of this type of equipment.

The advertising, manufacture, and distribution of equipment intended for use in surreptitious information-gathering is controlled by title III of the "Omnibus Crime Control and Safe Streets Act of 1968" (Public Law 90-351) as amended. One of the objectives of this law is the prohibition of surreptitious information-gathering by all except law enforcement agencies. In addition to protecting the public against the undesirable use of such devices, the law has made it more difficult for law enforcement agencies to procure and use them legitimately. Nevertheless, this type of equipment is being manufactured, purchased, and used. One discouraging aspect of the situation is that some of the devices being manufactured and sold are of very poor quality and are immensely overpriced.

IMPORTANT NOTICE

All transmitting equipment must comply with the licensing and operating requirements of Part 89 of the Federal Communications Commission (FCC) Rules and Regulations, including Section 89.117(b) which requires type acceptance. Such equipment may not be marketed prior to a grant of type acceptance by the FCC. Proscriptions concerning the marketing of radiofrequency devices are contained in Volume II, Part 2, Subpart I of the FCC Rules and Regulations. (See Title 47, Code of Federal Regulations, Part 89, Subpart A and Part 2, Subpart I.) Court-ordered eavesdropping requiring radiofrequency devices may be accomplished either by the use of type accepted transmitters operating on specific frequencies authorized to the licensee, or by use of low power transmitters which conform to the requirements of Part 15, Subpart E of the FCC Rules and Regulations.

This report has a two-fold purpose: first, to help inform law enforcement personnel concerning the application and functioning of undercover communications equipment and, second, to be the forerunner of a voluntary standard to be used in the selection, evaluation, and procurement of such equipment.

The information contained in this report has been derived from a number of sources including law enforcement personnel, manufacturers, publications, and laboratory measurements. This report is concerned with the types of devices available and their application, capabilities, advantages, and disadvantages. An attempt has been made to bring together a body of information which will assist the police officer in performing his duties safely and effectively. Although the variety of circumstances under which such equipment may be used is seemingly unlimited, there are some basic technical rules, facts, and techniques which are generally applicable in most situations. Understanding and utilizing scientific techniques can go a long way toward the realization of success in an undercover surveillance situation.

While the topic of immediate interest is surveillance or offensive activity, countersurveillance or defensive activity cannot be ignored completely because of the strong influence these activities have on each other. Being involved with either of these activities requires a sound knowledge of the other. While a detailed treatment of countersurveillance is not within the scope of this report, it will be mentioned where it is of importance in the understanding of surveillance equipment and its use.

The equipment and techniques discussed herein are concerned only with the interception of voice or audio communication, and, therefore, no information is included on video or optical techniques. An annotated bibliography is provided as a guide to further reading.

2. RADIATING DEVICES AND RECEIVERS

2.1 General

In this category is the miniaturized transmitter which may be worn on the body, concealed in some stationary location, or concealed in a vehicle or portable container of almost any type. Because of this versatility, the miniature transmitter is used in a wide variety of situations. These transmitters are particularly useful in circumstances where unrestricted mobility is required. In contrast to hard-wire devices (see section 4.0), the miniature transmitter is most often used when operation is required for only a relatively short period of time, such as a few minutes or hours rather than days or weeks. This time limitation is imposed primarily by the lifetime of the power supply.

The use of miniature transmitters brings into play a great many factors which can cause performance to vary widely in seemingly similar circumstances. In this context, it is useful to look at a complete communications system involving the transmitter, the propagation medium and the receiver. Figure 1 is highly oversimplified; relaying information successfully from one location to another is an involved procedure. It has been estimated by users of typical equipment that the causes of failure are approximately as follows:

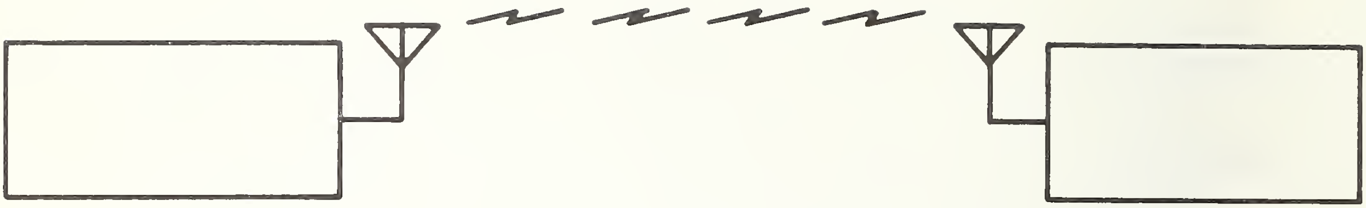
Power supply failure (batteries)	50%
Operator error	45%
Equipment failure (circuitry)	5%

Because surveillance needs often arise on short notice and adverse conditions are frequently encountered, it is imperative that persons using surveillance equipment become familiar with all aspects of its use. The importance of well-trained personnel can hardly be overemphasized.

2.2 Operating Frequencies

With few exceptions, miniature transmitters used in police work operate in the following four frequency ranges:

25- 50 MHz
88-120 MHz
150-174 MHz
400-512 MHz



Transmitter

1. Power supply (usually batteries)
2. Electronic circuitry such as the oscillator, modulator, amplifiers, and filters
3. Antenna

Propagation Medium

1. Atmosphere including all physical obstructions and other radio signals

Receiver

1. Power supply
2. Electronic circuitry such as the local oscillator, speaker, amplifiers and filters
3. Antenna

Figure 1. Model communication system.

Some experimental work has been conducted over the past few decades to determine which frequencies are best from a propagation standpoint, but the investigators have not produced conclusive evidence indicating that one frequency is better than another in a majority of circumstances. One such investigation was conducted by Rice [17], who compared propagation into buildings at 35 MHz with that at 150 MHz. In this study, 150 MHz was found to be slightly better on a statistical basis, but the difference was so small that the issue must still remain in doubt as far as any specific situation is concerned. Other work was reported by Huber [7] regarding the propagation behavior of frequencies from 0.1 to 1.0 GHz as related to communication from the inside of automobiles. This study clearly showed some frequencies to be superior to others, but factors other than frequency influenced the measurements so that definite conclusions concerning frequency selection could not be drawn.

For a number of reasons, the trend has been toward the higher frequencies. The use of higher frequencies is advantageous because shorter antennas are easier to conceal. Figure 2 shows the length of quarter-wavelength antennas in air for frequencies in the range from 25 to 600 MHz, with the specific frequency bands mentioned above shown as the solid portions of the curve. Note that at 25 MHz a quarter-wavelength antenna would be 300 centimeters (approximately 10 feet) long, while at 500 MHz it is only 15 centimeters (approximately 1/2 foot) long. The use of antennas shorter than a quarter-wavelength reduces radiation efficiency, thus reducing the effective communication range.

Interference must also be taken into consideration in frequency selection. Both man-made and natural interference decrease significantly with increasing frequency, which further strengthens the tendency toward the use of higher frequencies. As more use has been made of radios for communication purposes, the lower frequency bands have become more crowded, constantly increasing the chances for interference or interception. As a precaution, an FM receiver can be used to monitor the frequency spectrum in the location where the undercover operation is to take place, and an unused frequency can be selected.

The use of higher frequencies improves the signal-to-noise ratio. As solid state technology improves and better devices and techniques are developed, the use of frequencies above the UHF region will almost certainly become common practice for surveillance work.

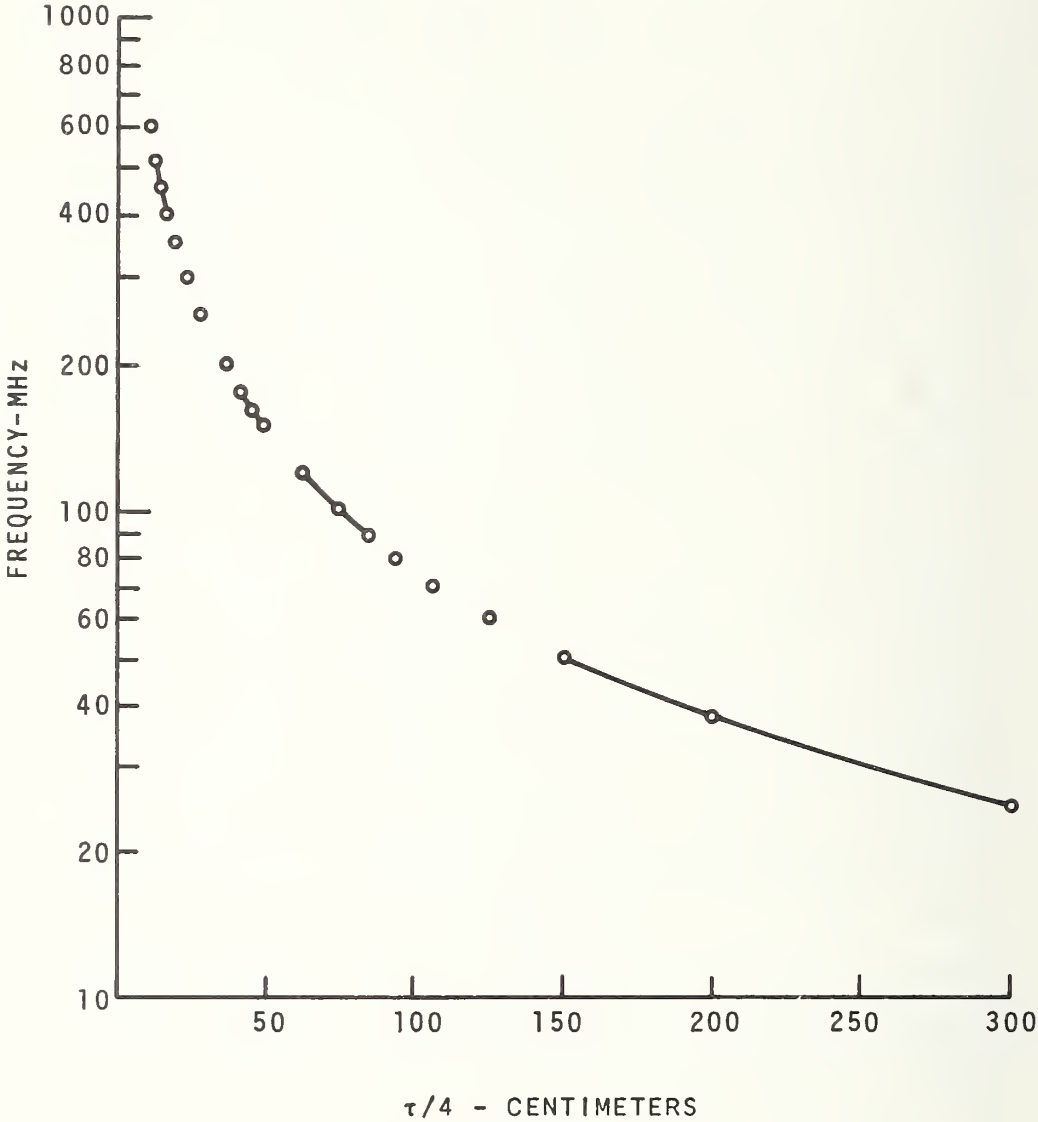


Figure 2. Length (in air) of quarter-wavelength antennas for the frequency range from 25 to 600 MHz.

2.2.1 25-50 MHz Band

The use of frequencies in this band for surveillance purposes is decreasing. There are several reasons for this. Principally, this band offers poor security compared to higher frequency bands. The 25 to 50 MHz band is very heavily used, and this has greatly increased the possibility of either undesired detection or interference from other signal sources. In addition, these frequencies are reflected by the night-time ionosphere, further increasing the problems of interference and security. These disadvantages, coupled with the requirement for fairly long antennas which are difficult to conceal, have caused surveillance personnel to abandon these frequencies for higher ones.

Harmonic radiation is an additional disadvantage of operation in the 25-50 MHz band. Transistor oscillators are characteristically rich in odd-number harmonics, and unless the output is filtered, their use can lead to difficulties for other users. The third harmonics of frequencies between 29.3 and 40 MHz fall within the 88 to 120 MHz band. Unfiltered transmissions can thus result in detection by receivers operating in the 88 to 108 MHz commercial FM band or interference with aircraft communication.

2.2.2 88-120 MHz Band

This frequency range includes the commercial broadcast FM band extending from 88 to 108 MHz. Receivers of good quality are mass produced and may be purchased at prices far below those of receivers of comparable quality on other frequency bands. Also, some of these receivers can be tuned to operate above the commercial FM band, at frequencies as high as 120 MHz. For these reasons, the 88 to 120 MHz frequency range is attractive, and has been widely used for surveillance purposes.

There are, several reasons however, why such use is undesirable. With millions of receivers in this band in constant use, it is evident that this frequency range affords less security than almost any frequency band that could be chosen. Also of importance is the fact that the commonly available commercial receiver is not crystal controlled and, therefore, more subject to drift with the attendant loss of signal strength. A second reason for avoiding this frequency band is that the portion from 108 to 120 MHz is used for aircraft landing systems, and any interference, especially in the vicinity of airports, can be very dangerous. Some electronic eavesdropping equipment manufacturers produce and sell equipment which operates at these frequencies, and articles have been written which openly advocate use of the aircraft band [3]. While there may be no intention to create a hazard, it is evident that once a device is sold, the manufacturer loses all control over its use. The best policy is not to use equipment operating in this range. It is not only a potential hazard, but is also in violation of FCC and FAA regulations.

2.2.3 150-174 MHz Band

Surveillance equipment utilizing these frequencies is usually more sophisticated in design than that designed to operate at lower frequencies. Most of the higher quality body-mounted transmitters and receivers manufactured during the past few years operate within this band. When comparing this frequency range with the lower ones already discussed, several advantages appear. First, better security exists because there are fewer receivers in existence. Next, interference is lower because of lighter communication traffic, lower incidence of ionospheric reflection, and lower levels of natural and man-made noise. Finally, higher radiation efficiencies can be achieved using shorter antennas.

2.2.4 400-512 MHz Band

Even lower interference is likely in this band and detectors which might lead to discovery are relatively rare. However, some reception difficulties can be expected in areas where physical obstructions are numerous. The shorter antennas required may be an overriding consideration because, at these frequencies, a quarter-wavelength antenna can be easily concealed.

2.2.5 Summary

Following is a summary of the significant points regarding the four frequency ranges:

25 to 50 MHz

Advantages	Disadvantages
a. For same power, possibly better coverage in crowded areas.	a. Requires longer antennas. b. A much-used frequency band, with consequently poor security. c. Skywave propagation at night may result in undesired signal transmission or reception. d. Third harmonic radiation.

88 to 120 MHz

Advantages	Disadvantages
a. Low cost receivers available.	a. Violates FCC regulation. b. Minimum security; easily monitored because of availability of receivers. c. 108 to 120 MHz may interfere with aircraft navigation and communication.

150 to 174 MHz

Advantages	Disadvantages
a. Quarter-wavelength antennas short enough for concealment on body. b. Good equipment available. c. Good security compared to lower frequencies.	a. Equipment is expensive. b. Band heavily used in many areas of the country.

400 to 512 MHz

Advantages	Disadvantages
a. Rarely monitored; best from security standpoint. b. Requires very short antennas. c. Low level of interference.	a. Equipment is expensive. b. Few sources of equipment.

2.3 Power Output, Operating Time and Operating Distance

The maximum practical distance between transmitter and receiver for satisfactory communication can be very important in surveillance applications. This distance is dependent upon a number of things including transmitter power output, gains of transmitting and receiving antennas, and receiver sensitivity. Still other factors are the local conditions such as the terrain, the conductivity and dielectric constant of the earth, the building density, and the heights of the antennas. The fact that any or all of these factors may vary with time and location makes accurate prediction of operating distance nearly impossible. General statements are often made about the operating distance or coverage area of a transmitter, but it is unwise to rely heavily upon information of this type. Such statements are likely to be based on a few specific experiences in a given locality, and performance may be found to differ widely in different situations. Claims about operating distance are not dependable criteria for determining the effectiveness of a transmitter under a given set of conditions and should not be used to determine the superiority of one transmitter over another.

There are two approaches to objective measurement of transmitter output. One is to make comparative field strength measurements under carefully standardized conditions, and the other is to measure the transmitter power into a 50 ohm termination. Either approach may present difficulties. The field strength approach requires a measurement site free of obstruction and a receiver or field strength meter. The intensity of the field radiated by each transmitter must be measured and plotted over a period of time. This method presents several problems, including the determination of the proper type antenna to use to achieve accurate data, the necessity for receiver calibration in the case where the transmitters to be compared operate on different frequencies, and the possibility of other radio signals on the same frequency leading to erroneous field strength measurements. Clearly, this is not an ideal approach unless field test facilities and highly skilled personnel are available.

Using the power output measurement approach is much simpler, but not without possible complications. The procedure is to connect a good quality power meter to the antenna output terminal of the transmitter and record the power over a specified time interval. However, power meters do not yield accurate results unless the output impedance of the transmitter matches the input impedance of the power meter. The input impedance of most power meters is 50 ohms. Providing the output impedance of the transmitter is also 50 ohms, an adapter from the transmitter output connector to the power meter input connector is usually all that is needed to make the measurement. If the output impedance of the transmitter is not 50 ohms, some sort of a matching or tuning network is necessary. The tuning network is inserted between the transmitter and power meter and is varied until the power meter reading is maximized, after which the measurement can proceed.

It is common to encounter miniature surveillance transmitters which are neither 50 ohms at the antenna output connector nor equipped with a coaxial connector. Some do not have a ground connection but instead have only a screw terminal for the attachment of an antenna wire. With such a combination of output connectors and terminal conditions, the task of making meaningful measurements becomes extremely difficult.

There is a need for standardization if there is to be meaningful and objective comparison of equipment performance. Ideally, there should be a convenient and straightforward means of measuring transmitter power output without ambiguity, and specifications should spell out not only maximum transmitter power output but also some indication of how this power decreases with transmission time.

One final, important point regarding the measurement of transmitter power output using a power meter is the manner in which the power is distributed over the frequency spectrum. Because most power meters utilize a broadband resistive element, such as a bolometer, as the sensing device, the power measurement alone will not provide sufficient information. If a particular transmitter has an output spectrum rich in harmonics, it will not be distinguishable from a second transmitter which shows the same power output but has had the harmonic frequencies drastically suppressed. It is possible to have a situation where as much as one-half of the power radiated is at the harmonic and other spurious frequencies. Such spurious radiation is detrimental in that it substantially increases the risk of detection.

Figure 3 [9] is a plot of operating range versus signal loss in decibels (dB), with the point 1.0 on the x-axis of the graph representing a maximum range, whatever this may be in actual distance. It can be seen that a decrease of 6 dB in the received signal strength corresponds to an effective reduction of this range by one-half. A loss of 20 dB reduces the range by a factor of 10. This illustrates how drastically the operating range can vary from one situation to another, especially when it is realized that many things such as building density, antenna types and orientations, and antenna position with respect to the body of the wearer can all contribute losses of several dB. Thus, claims about operating range do not offer a reliable basis on which to compare equipment. The best procedure is to make comparative measurements under identical conditions. Only then can superior performance be recognized.

2.3.1 Batteries

Most body-worn transmitters and receivers can be equipped with a number of different types of batteries. Even though there are wide differences in their chemical composition, these batteries are near enough to the same physical shape and size that they may be interchanged or adapted to fit. This permits the user to select the best type for a particular application. Manufacturers of the equipment usually recommend the most advisable type to use. The importance of battery quality is paramount, and the user should insure that the use of poor batteries is avoided. Detailed information on batteries is available [8]. Even recently purchased batteries may have already suffered sufficient shelf-life deterioration to cause significant degradation in the performance of a transmitter or receiver.

With undercover surveillance equipment, such as body-worn transmitters and receivers, the two most frequently used types of batteries are the alkaline and the mercury primary batteries. Nickel-cadmium batteries, which are rechargeable, have not as yet found wide acceptance in undercover work. The carbon-zinc or common flashlight battery is generally not suitable because of its low capability for meeting high-current drain requirements. Alkaline and mercury batteries are desirable mainly because they are able to supply relatively large amounts of energy for their size. Alkaline batteries are less expensive and more readily available than mercury batteries. However, body transmitters using mercury batteries usually have a less rapid decay in power output (see figures 11 and 15).

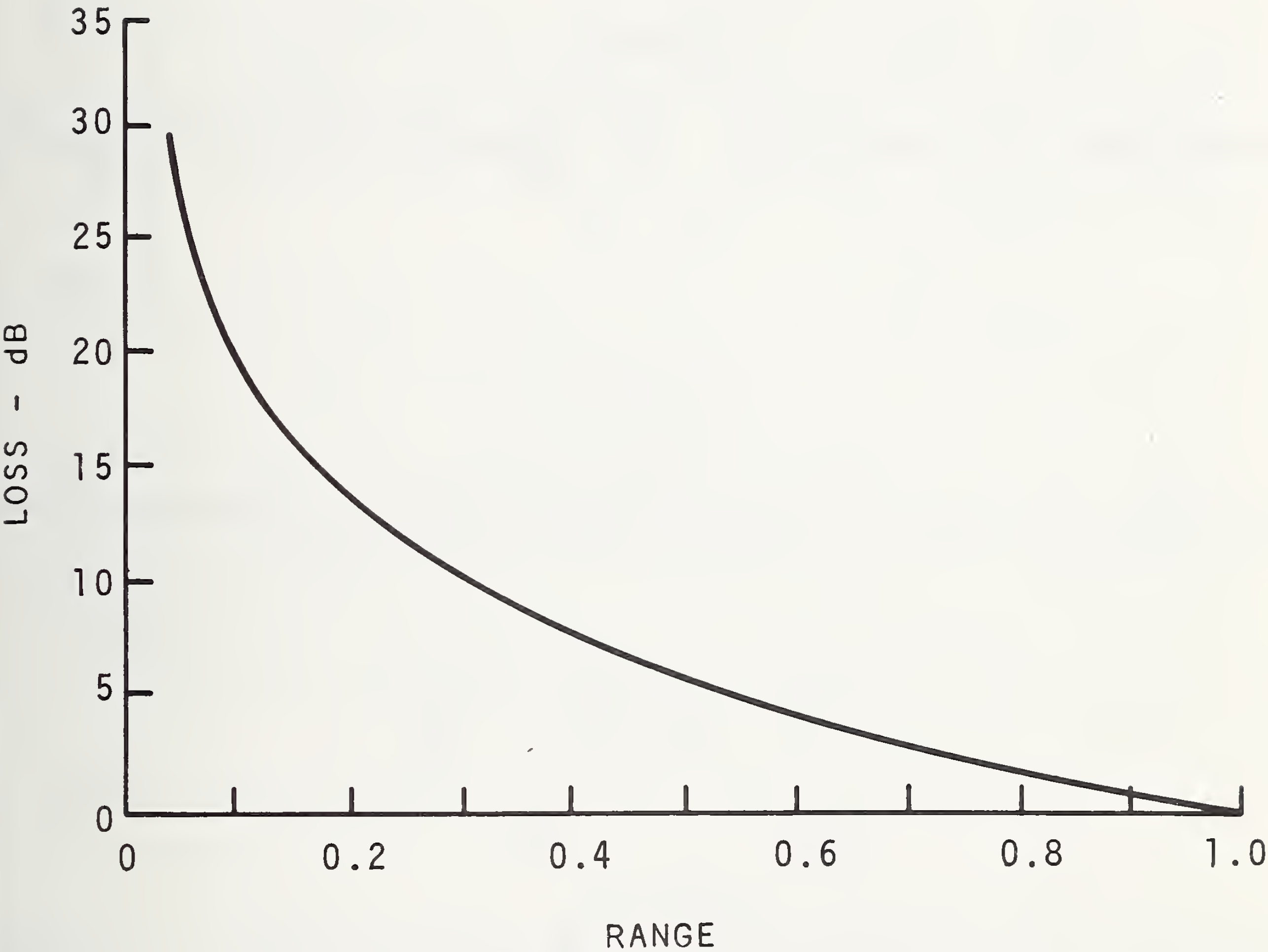


Figure 3. Normalized range as a function of signal loss in decibels.

A good measure of the condition of a battery is its ability to sustain a moderate current drain. One test that may be used on a <u>9-volt alkaline</u> battery is to determine whether it will supply 75-80 milliamperes of current for a period of 45 seconds. This can easily be done using the circuit shown in figure 4. If the battery is at an acceptable state of charge, the voltmeter indication should not drop below 9 volts for a period of 45 seconds.

It is not appropriate to test mercury batteries in the same manner because mercury batteries sustain a nearly constant voltage under load until they are almost completely discharged. Therefore, even though a mercury battery has undergone considerable use and is near the end of its lifetime, the current drain test might not indicate it. At present there appears to be no simple and reliable method for determining the state-of-charge of a mercury battery. Mercury batteries, fortunately, have a shelf-life of approximately two and one-half years. The best way to be confident of the freshness of a mercury battery is to make sure that its open terminal voltage is what it should be and to use batteries with fairly recent dates of manufacture. To avoid the possibility of battery failure during an operation requires vigilance. Points to remember about batteries include the following:

a. Know the milliampere hours the battery can supply and the transmitter current drain.

b. Make sure the batteries are fresh. If possible, use a fresh battery for each mission.

c. Keep a log of battery life expended.

d. For improved shelf-life, batteries should be stored at temperatures well below normal room temperature.

Neither the alkaline nor the mercury batteries are rechargeable and, once discharged, must be discarded. Care must be taken with mercury batteries to assure that they are not burned because toxic vapors are emitted which can endanger life. One further point regarding batteries is that their contents are corrosive and they should not be stored in an instrument for longer periods of time than necessary. Corrosion can cause serious damage to an expensive item of equipment.

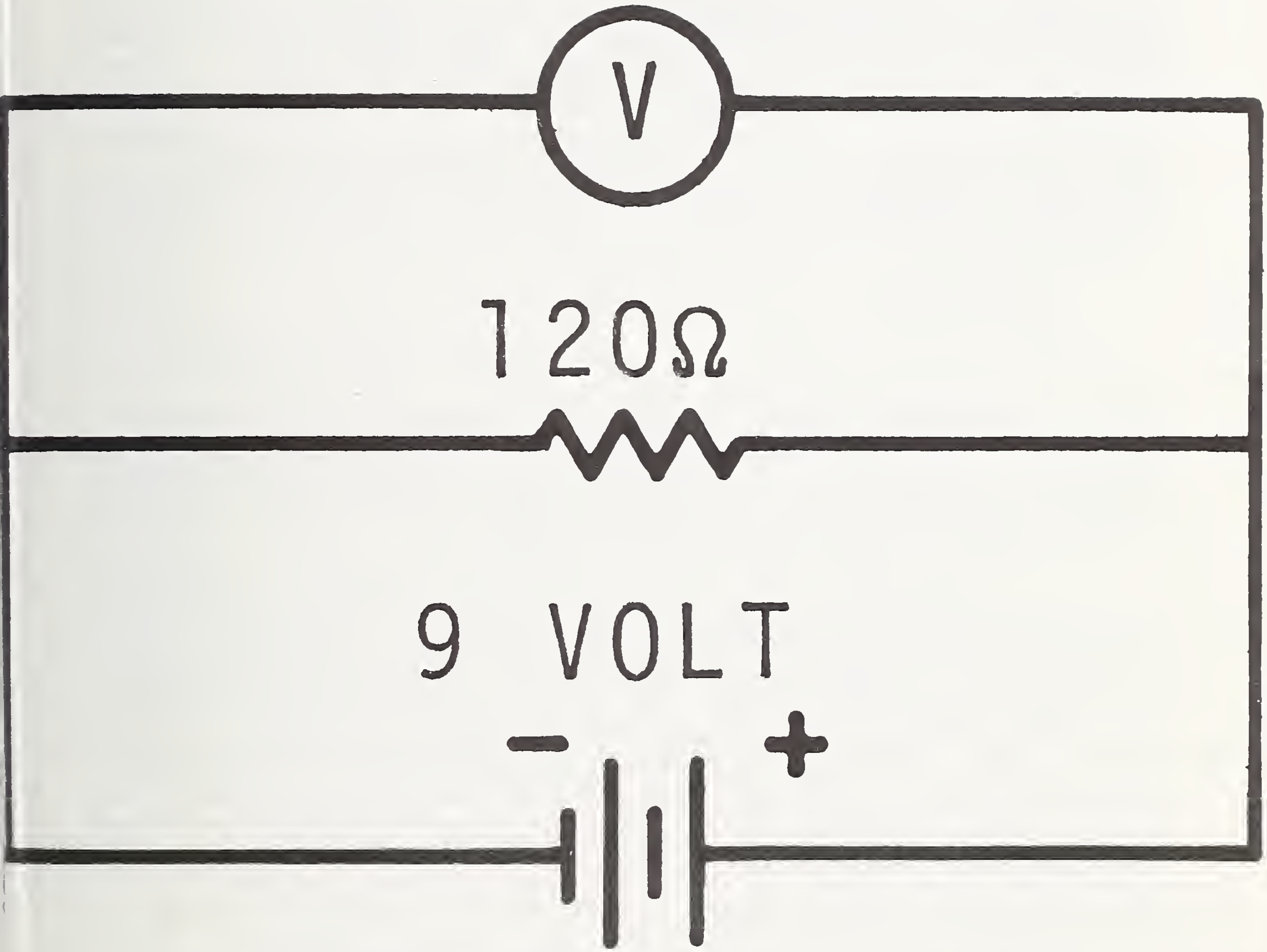


Figure 4. Battery test circuit.

Another important consideration is the effect of ambient temperature on battery operation and life. Some types of batteries suffer severe reductions in performance when subjected to either extreme heat or extreme cold. One example is the carbon-zinc (flashlight) battery, which suffers in its ability to perform when temperatures are below 0°C (32°F) or above 50°C (122°F). Also, the mercury battery is a poor performer at temperatures below 5°C (41°F), but is an excellent performer at high temperatures. See reference [8].

2.4 Crystal Control vs. Free-Running Oscillators

Undercover transmitters and receivers should be crystal-controlled because free running oscillators drift in frequency and can be changed by modulation, making it difficult to sustain optimum performance over long periods of time without retuning. Crystal-controlled equipment should operate with a frequency tolerance of a few parts per million. This tolerance varies with frequency; however, tolerances of ten parts per million are typical in the 150 MHz range.

In some instances, the requirement for miniaturization may be so critical that the extra size incurred by the addition of crystal-control circuitry cannot be tolerated. In these situations, extremely small and very low-powered transmitters of a size comparable to a one-inch section of a common lead pencil can be used. In equipment this small, hearing aid batteries are used, and transmitter output power is typically in the vicinity of 10 mW. Frequency drift in devices not having crystal control will typically be of the order of 10 kHz per hour under normal operating conditions.

2.5 Automatic Volume Control

It is evident that voice modulations reaching the transmitter will be at different intensities, depending on the proximity of each speaker to the microphone. The wearer of the transmitter will of course be much closer than the other speakers. Consequently, it is probable that the wearer's voice will be too loud while others may barely be heard. This brings about the critical need for automatic volume control circuitry in the transmitter so that all those talking may be heard distinctly.

2.6 Modulation and Audiofrequency Response

Because of circuit simplicity, good fidelity and the relatively low power drain, frequency modulation is used almost exclusively in undercover transmitters, although there appears to be no reason why other types of modulation could not be used in order to provide better security.

Most of the frequency components of the human voice are in the range from 300 Hz to 3000 Hz. This is the audiofrequency response for which the equipment should be designed. Broader responses are not only unnecessary but may even be detrimental, because sounds could be transmitted which may interfere with the intelligibility of the conversation being monitored.

2.7 Frequency Deviation

Federal Communications Commission (FCC) regulations pertaining to public safety communications equipment authorize a maximum frequency deviation of ±5 kHz for FM systems. It is important that surveillance transmitters be designed to satisfy this requirement, not solely because of the FCC regulations, but because the transmitters must be compatible with the receiving equipment commonly used in law enforcement communications. Clarity of reproduction is another reason for using equipment with the proper frequency deviation and modulation bandwidth. Using bandwidths narrower than those specified may create difficulty in identifying the speakers, while the use of broader bandwidths does not improve voice reproduction and may introduce unwanted sounds. It is particularly important that surveillance recordings be clear and intelligible because of their possible use as court evidence. In general, ±5 kHz frequency deviation and 3 kHz audiofrequency response provide adequate voice reproduction. In surveillance work problems can arise related to the loudness of the modulating voices and the action of the automatic volume control (AVC) circuits, which may, in some cases, produce recordings unsuitable as court evidence.

2.8 Packaging

Miniature transmitters have been packaged or concealed in almost every way imaginable, as dictated by specialized needs. Lamps, plugs, chair legs and flower pots have all been used to conceal a transmitter. Some have achieved fame and attracted international attention, such as the one concealed in the shoe of a diplomat and the one in the seal above an embassy desk. These are all custom-made devices, which for the most part would be unavailable to a police department unless it had direct contact with a facility which could produce them. Some of these devices are available, but information regarding specific suppliers is not easily obtained.

Good quality transmitters and receivers can be packaged in small ruggedized containers with dimensions on the order of 3" x 2" x 3/4", and can be either body worn or concealed in some unlikely location. The particular situation dictates the necessary concealment precautions and in this the agent must use his own judgment. If he cannot wear heavy clothing or outer garments, concealment may be a severe problem.

Electronic packaging has to be considered, especially in the sense that the devices used should be repairable and the circuitry should be accessible for trouble-shooting purposes. Devices which are potted in an epoxy envelope, although weatherproof, are not repairable in the event of circuit failure. It is characteristically the very low-priced and lower quality devices that are manufactured in this way. Epoxy-potted transmitters usually operate in the 100 to 120 MHz range.

2.9 Ease of Detection

Detection may occur by visual observation, physical search (frisking), or by the use of electronic defensive (countermeasures) equipment. Little can be said of the likelihood of detection by visual or physical means except that the smaller the device is, the less apt it is to be discovered. Obviously, discovery is dependent upon how cleverly it is concealed.

Detection by electronic methods deserves more thorough attention. Consider the following three factors for the bearing they have on detection:

Operating Frequency: As has already been mentioned, transmitters operating in the 88 to 108 MHz band are more apt to be detected due to the fact that receivers covering this band are extremely common. It does not require a very vivid imagination to picture an undercover agent in a situation where someone is tuning through this frequency band and picks up the broadcast of voices and sounds from within the room, or hears the oscillatory squeal of energy fed back to the receiver by a concealed transmitter. These frequencies should be avoided.

Power Output: High power output increases operating range. But the greater the power radiated, the wider the area of coverage, with the consequence that detection is more probable. Therefore, it is advisable to avoid using a one-watt transmitter, for example, where a one-quarter watt unit would do. Where there is a reasonable choice, it is much wiser to improve receiver sensitivity or antenna efficiency than to increase transmitter power.

Harmonics: Good equipment radiates energy primarily at the fundamental frequency, and filters out and suppresses the harmonics. This makes it less likely that the energy being radiated will affect other equipment, such as television receivers, which may draw suspicion and lead to discovery. It is not unreasonable to expect the level of radiated harmonic and other spurious energy to be at least 35 dB below that of the fundamental output of the transmitter. Devices may be discovered by detection of the energy radiated at their harmonic frequencies because antenna efficiency may be better at the harmonic frequencies than it is at the fundamental frequency. Searching by electronic methods is often done by starting at the high-frequency region and working downward.

2.10 Antennas

Overall system performance can be greatly affected by the type of antenna used, the type of installation, and the conditions of operation. Monopole antennas are used exclusively with body-worn transmitters, because they are omnidirectional and of very simple construction. For many reasons, other antenna configurations are impractical.

One important fact to consider is that best communication usually occurs between two monopole antennas when they are oriented parallel to one another; i.e., polarization should be the same in both antennas. Either they both should be vertical or both horizontal. Although this is generally true, local distortions in field configuration caused by conducting objects such as steel in a building can cause significant variations.

Normally, the optimum length for an omnidirectional monopole antenna is approximately one-quarter wavelength at the operating frequency. However, this is modified somewhat in the case of antennas placed next to the body. Because of the added capacitance between the antenna and the body of the wearer, resonance occurs when the length of the antenna is 4 or 5 percent shorter than one-quarter wavelength.

The requirements that the antenna be both small and located next to the body constitute very severe handicaps to efficient communication. Antennas which are short compared to a quarter wavelength are not efficient. In addition, the human body is a good absorber of radio energy. These constraints combine to place very severe limitations on the distances over which satisfactory communication can be achieved. Given ideal antenna conditions, it is entirely possible to maintain good communication with transmitters of one watt or less at distances of several miles. However, when antennas are shortened and placed next to the body, the range may drop to a few hundred feet or less, depending upon local propagation conditions.

The subject of body-worn antennas is a complex one. One study of this topic has been prepared for the Law Enforcement Assistance Administration by the Aerospace Corporation of El Segundo, California [9].

2.11 Propagation Conditions

The propagation medium is an important component of the communications system. This is the part of the system over which the operator has almost no control. An accurate prediction of how well a system will work in a given situation is not possible to any high degree of accuracy without actually making field strength measurements. This is usually impractical, so the next best thing is to examine some of the variables and do those things which will enhance the probability of success.

Two factors which affect the performance of an antenna are the conductivity and the dielectric constant of the ground. These vary widely around the country, and can make a difference in field strength of as much as several dB. The moisture content of the soil is also a factor, as higher amounts of moisture enhance propagation. While these factors are not controllable, they are mentioned for general interest.

Some factors are controllable by the operators. One way to improve the received signal from a vertical monopole is to elevate the receiving antenna. Improvements of several decibels in received signal strength can be realized by choosing listening post locations so that the angle between transmitter and receiver is 30 to 45 degrees from the horizontal.

A transmitter or receiver does not perform well when placed inside an automobile. The metal enclosure acts as a shield which attenuates high-frequency electromagnetic energy. If there were no windows in the car, or an outside antenna, there would be essentially no transmission or reception at all. The metal used as building reinforcement also reduces the strength of a transmitted signal. Even the average home may seriously hamper inside-to-outside communication because of the use of foil-backed insulation in the walls. A transmitter enclosed in a metal container is completely ineffective. This fact was once used in an extortion case involving a money drop. The criminal, suspecting that a transmitter was concealed in the package, placed it in a metal suitcase and thereby escaped because the transmitter was useless. The wearer of a transmitter may position himself near openings such as non-metallic doors or windows, thereby avoiding the shielding effects of unseen metal barriers. The use of such tactics comes with experience and a general understanding of the behavior of radio energy.

2.12 Body-Mounted Transmitters

There are a number of other features which may be important in the field use of body-mounted transmitters and these are discussed below.

2.12.1 Polarity Protection

When installing batteries in a body-mounted transmitter, it is very important that the batteries be oriented for correct polarity. Most units employ alkaline batteries equipped with snap-on connectors. These batteries can not be installed with the incorrect polarity because the connectors at the positive and negative terminals are different from each other and the battery will not fit the receptacle unless it is correctly oriented.

Occasionally a body-worn transmitter may be encountered which utilizes mercury batteries. A group of four of five individual cells are usually held in place by a cardboard or plastic sleeve, and two such groups are required to power the transmitter. Because the mercury cells are usually not equipped with snap-on connectors like the alkaline batteries, it is possible to install them with reversed polarity.

There are at least two possible consequences of imposing the incorrect voltage polarity. First, the transmitter will not operate and the operator may not know why. Next, the transmitter may be permanently damaged. This can happen with either mercury or alkaline batteries because even a very brief, momentary exposure to reversed polarity can result in irreversible damage. Whether or not such damage will result depends upon the circuit, and better quality units have built-in polarity protection.

2.12.2 Antenna Connector

A common trouble spot in body-worn transmitters is the connector between the antenna lead and the transmitter. A wide variety of connectors are used by various manufacturers and most have both advantages and disadvantages. There are the simple plug-in microphone jack types, the screw-on types, and the twist-lock types. Two considerations are important. First is the possibility that the lead will be pulled out of the socket during use, will work loose, or will otherwise break the connection. Second is the ease of making repairs if the antenna lead is broken. Some units combine the microphone wire and the antenna wire into one lead.

2.12.3 Microphone

Although microphones will be discussed in detail in a later section, it is worthy to note here that two different mounting schemes are used. Some miniature transmitters have the microphone built into the case of the transmitter, while others use a microphone connected by a cable. If the microphone is mounted in the case, there should be a dirt seal to protect it against clogging and subsequent damage or loss of sensitivity. A piece of foam-like material is a satisfactory protector for this purpose.

Most of the better transmitters use the electrodynamic type of microphone, which has excellent sensitivity and adequate frequency response for voice communication. Electret microphones of adequate quality are a relatively recent development. They provide better frequency response and may be expected to find increased use in undercover equipment. Both types are rugged, but electret microphones have a limited lifetime of about three years of operation at maximum sensitivity. Should this be overcome and costs made competitive with the electrodynamic types, electret microphones could come into common use.

2.12.4 Location of On-Off Switch

Because miniature transmitters are often located where they are subject to being jolted, or where other materials may rub against them, it is important that the on-off switch be of a positive type requiring a fairly strong force to operate and that it be in a location where it is not apt to be moved accidentally. In some situations it may be desirable to make it either difficult or impossible for the wearer to turn the switch off while the surveillance operation is under way. Some manufacturers make special provisions for this but may not indicate it in their specifications.

2.12.5 Ruggedness

Body-worn equipment should be constructed to withstand severe physical shocks. Construction should be such that dropping from chest height to a concrete floor will not permanently affect operation. This requires either an all-metal case of heavy gauge or very high performance plastic. If plastic materials are used, they should not soften when warm or shatter in severe cold.

2.12.6 Size

The primary factor limiting the smallness of a transmitter is the size of the batteries required to supply the power. In general, a crystal-controlled transmitter with batteries, having an output in the 0.2 to 1 watt range, can be contained in a volume slightly smaller than a cigarette package. In such a transmitter, the batteries occupy approximately 75 percent of the total volume, and the crystal control feature adds additional bulk. Transmitters no larger than the eraser portion of a common lead pencil are available, but these devices are not crystal controlled, have a power output of only a milliwatt or so, and their greater frequency instability restricts their application and dependability. Such low-power transmitters are not suitable for applications where they must be placed next to a large power absorber such as the human body. They may be used as room bugs where long distances to a listening post are not involved.

2.13 Telephone Tapping Transmitters [15]

There are several types of telephone tapping transmitters usable for monitoring both sides of a telephone conversation. In general, they are not crystal controlled and have a power output ranging from a few milliwatts to perhaps one quarter watt; many of them utilize the telephone line as an antenna. All types may be located either by their radiated signal or by visual inspection. The poorer ones may be found by the current they draw from the telephone lines. If the current drain is sufficient, it can give an indication of trouble on the line and draw the attention of the telephone company repair facilities. Some difficult problems are encountered in evaluating the output power of telephone tapping transmitters. Because of the antenna arrangements they utilize, it is not feasible to make output power measurements into a 50 ohm load, and it becomes necessary to rely on field strength measurements to determine the radiated power.

2.13.1 The Drop-In Telephone Transmitter

This device looks very much like the mouthpiece unit of a telephone. The carbon microphone mouthpiece drops out easily if the retaining ring over the mouthpiece is unscrewed. The drop-in transmitter may be substituted in its place very quickly and the telephone returned to apparently normal operation. The telephone transmitter draws its power from the telephone line and operates only when the receiver is lifted from the cradle. Both sides of the telephone conversation modulate the rf carrier frequency of the telephone transmitter which may be received and recorded at a remote location. One of the main advantages of the device is that it takes only a few seconds to install, and the better ones are so cleverly constructed that they may be difficult to recognize by anyone who is not extremely familiar with the telephone equipment. The drop-in transmitter does not require a separate antenna but instead utilizes the telephone line for this purpose. However, it is possible to detect the use of this type of transmitter by means of impedance measurements or by measuring the current drain while the telephone is in use.

2.13.2 The Series-Connected Telephone Transmitter

Any accessible location on the telephone line to be tapped, such as a terminal block, may be used as an installation point for a series-connected transmitter. Therefore, direct access to the telephone instrument is not required. The circuit in figure 5 illustrates the method of connection. The polarity is not important, so the transmitter may be installed in either side of the line. Because series-connected transmitters draw current from the telephone line, they can be detected in the same manner as drop-in transmitters.

2.13.3 The Parallel-Connected Telephone Transmitter

Figure 6 illustrates the method used to connect a parallel transmitter to a telephone line. Again, the polarity is usually not important, but there are several differences between this installation and the series transmitter. Because the parallel transmitter is powered by a separate battery, it draws no current from the phone line and is essentially undetectable by impedance or current measurement techniques. As with any battery-powered device, it has a limited operating time. The transmitter is activated when the receiver is lifted.

2.14 Receivers

Receivers used in undercover work are not always packaged in miniaturized form because in many instances concealment is not required. The sensitivity of a receiver has almost nothing to do with its physical size. Receiver components and measurable characteristics which distinguish good quality equipment from poor quality equipment are discussed below.

2.14.1 Sensitivity

Sensitivity is probably the most important characteristic of receiver quality. It is a measure of how weak a signal can be detected, and therefore is of first-order importance in determining the operating range of an undercover receiver. There are two common methods of specifying this information. The first is in terms of microvolts for 20 dB quieting [13]. The second is in terms of microvolts for 12 dB SINAD [8]. Either is an acceptable method, although the 12 dB SINAD provides a better measure of true receiver performance because it is made under modulated conditions. As a general rule of thumb, one may add 0.1 microvolt to the 12 dB SINAD sensitivity figure to obtain a comparable sensitivity for a receiver rated on the basis of 20 dB quieting. Although this is not exact, it does provide a quick means of comparing two receivers which are specified in these different ways. For example, a good receiver should be capable of at least 0.4 microvolt sensitivity at 12 dB SINAD or 0.5 microvolt for 20 dB quieting.

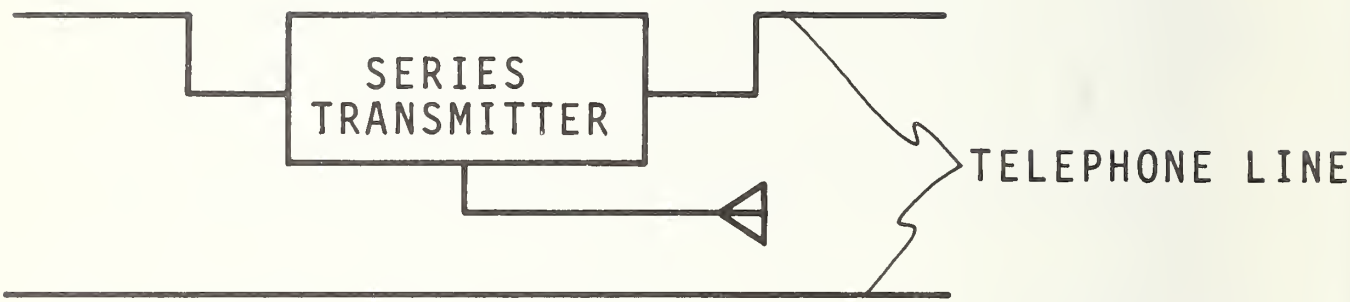


Figure 5. Series-connected telephone transmitter.

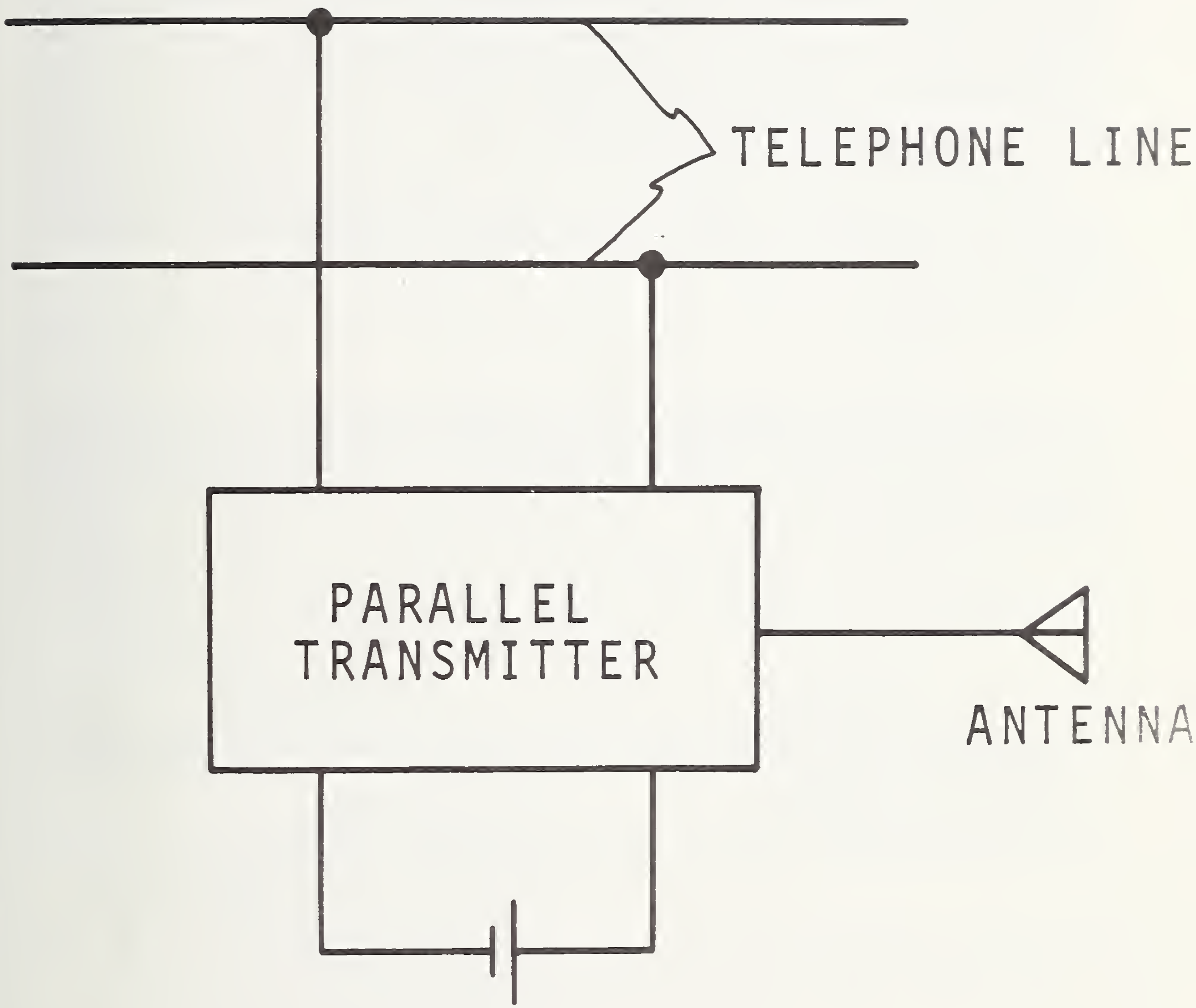


Figure 6. Parallel-connected telephone transmitter.

2.14.2 Frequency Control

The receiver should be equipped with a crystal-controlled local oscillator for automatic frequency control. Otherwise, it will tend to drift or detune, causing fading of the received signal. This is especially important if the receiver is to be unattended for extended periods of time.

2.14.3 Adjacent Channel Rejection

Adjacent channel rejection, also termed selectivity, is achieved through the use of good filter networks which reject signals at nearby frequencies, preventing unwanted interference.

2.14.4 Antenna

Much the same considerations apply to receiving antennas as to transmitting antennas, particularly if they are worn on the body (section 2.10). Where the receiver is not body-worn, one would normally use antennas which have higher gains and/or directivities.

2.15 Advantages and Disadvantages of Body-Worn Transmitters and Receivers

Advantages	Disadvantages
1. Completely portable (small and lightweight).	1. Limited period of operation.
2. Quickly installed.	2. Limited and uncertain range of operation.
3. Highly versatile.	3. Can be located by electromagnetic sensors.
	4. Will not relay information when surrounded by a conducting shield such as a car body, airplane, or metal suitcase.
	5. Quality (intelligibility) of transmitted information may vary.
	6. Subject to locally generated interference and atmospheric noise.
	7. Personal contact with subject often necessary.

3. TESTS OF RADIATING DEVICES

3.1 Laboratory Tests of Body-Worn Transmitters

A limited number of measurements were performed to evaluate some of the equipment which is now commercially available to law enforcement agencies for electronic surveillance work. Five transmitters were tested to determine some of their operating characteristics. All units were of the FM crystal-controlled type, operating on either mercury or alkaline batteries and capable of output powers of one watt or less.

The units were tested for frequency stability, output power as a function of time, spurious emissions, AM hum and noise, and dc current drain and efficiency.

The testing was performed under laboratory conditions of approximately 23°C (73°F), 40 percent relative humidity, and atmospheric pressure of 630 mm Hg, with each transmitter radiating into a 50 ohm load. Table 1 shows some of the test results. Others are described below. The following units were tested.

#1--Nominal rf output 1 watt, carrier frequency 165.188 MHz, frequency modulated, powered by three 4.2 volt mercury batteries.

#2--Nominal rf output 250 milliwatts, carrier frequency 165.188 MHz, frequency modulated, powered by three 4.2 volt mercury batteries.

#3--Nominal rf output 250 milliwatts, carrier frequency 151.625 MHz, frequency modulated, powered by two 7 volt mercury batteries.

#4--Nominal rf output 10 milliwatts, carrier frequency 159.300 MHz, frequency modulated, powered by one 9 volt alkaline battery.

#5--Nominal rf output 50 milliwatts, carrier frequency 154.890 MHz, phase modulated, powered by one 9 volt alkaline battery.

#6--Nominal rf output 100 milliwatts, carrier frequency 154.890 MHz, frequency modulated, powered by one 9 volt alkaline battery.

Table 1

Laboratory Test Results

Parameter	TRANSMITTER #1	#2	#3	#4	#5
Frequency Stability parts per million	3 ppm over period of 4 hr. 45 min.	5 ppm over period of 2 hr. 45 min.	5 ppm over period of 3 hr. 45 min.	6 ppm over period of 3 hr. 45 min.	1 ppm over period of 45 min.
Harmonic Suppression	33 dB	33 dB	31 dB	6 dB	30 dB
AM Hum & Noise	57.7 dB	52.8 dB	50.1 dB	24.9 dB	25.1 dB
D.C. Current	230 ma at 10.0 volts	97.8 ma @ 9.3 volts	56 ma @ 11.0 volts	34 ma @ 9.3 volts	74 ma @ 9.3 volts
Efficiency into 50 Ω Load	65.9%	32.4%	34.1%	2.6%	6.2%

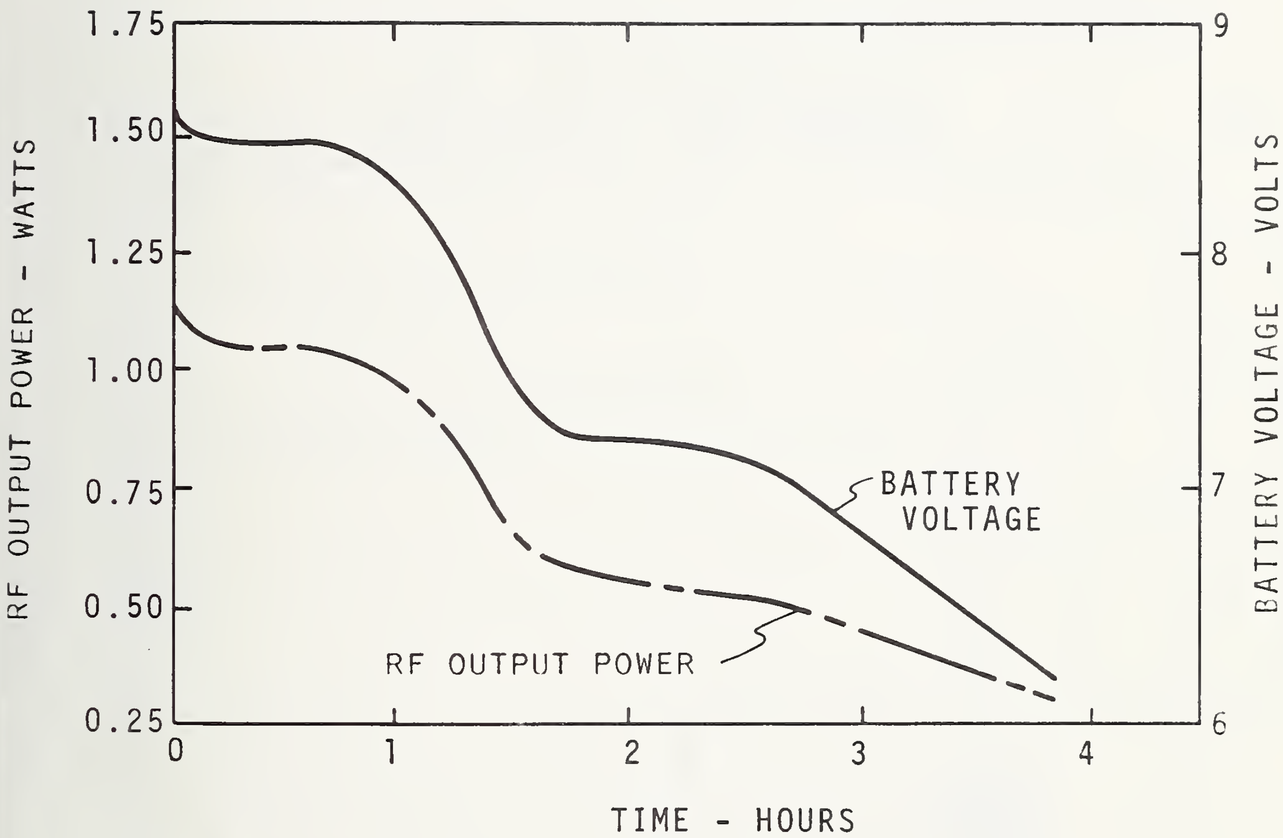


Figure 7. Decay of output power and battery voltage for transmitter #1.

TRANSMITTER #1:

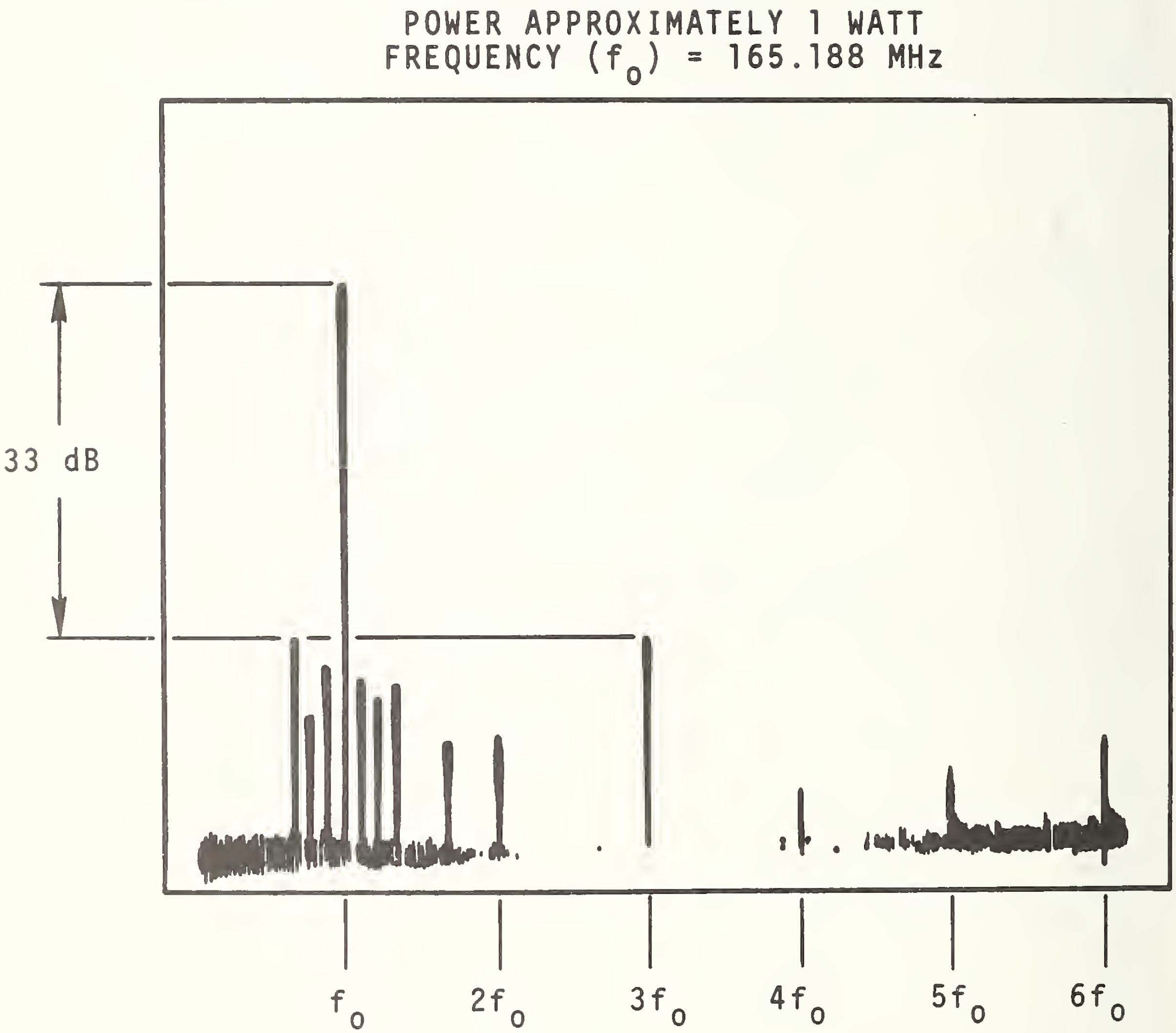


Figure 8. Output spectrum of transmitter #1.

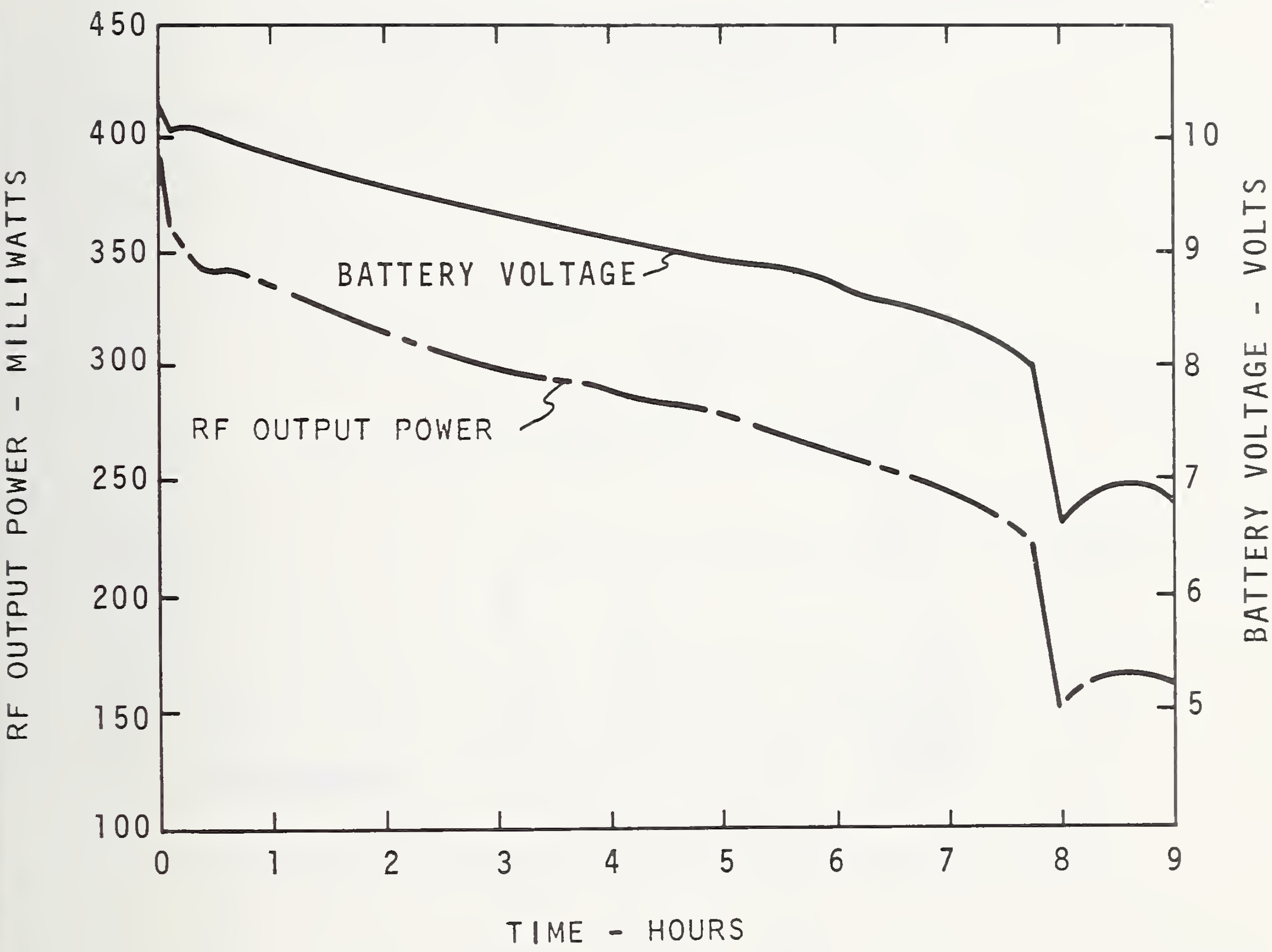


Figure 9. Decay of output power and battery voltage for transmitter #2.

TRANSMITTER #2:

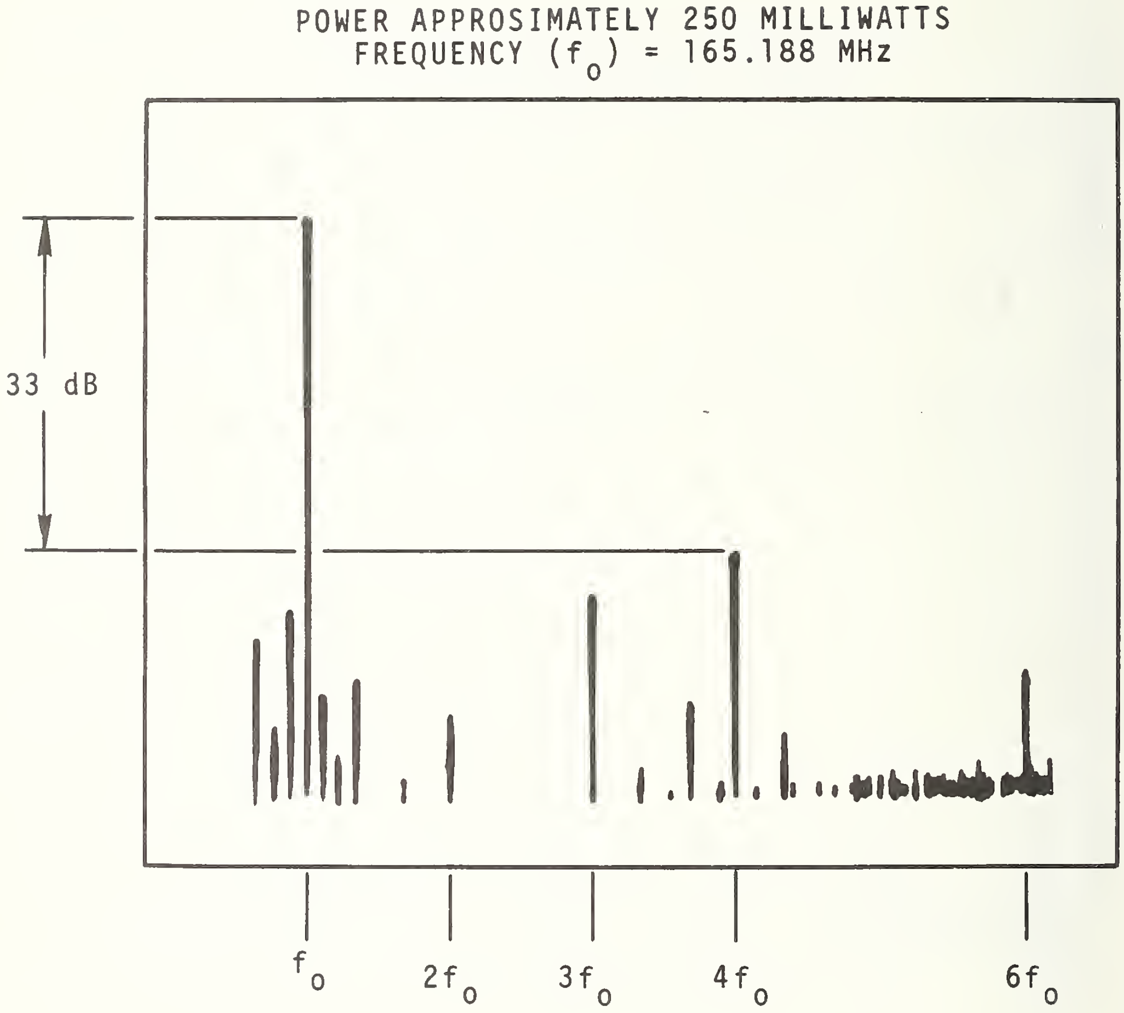


Figure 10. Output spectrum of transmitter #2.

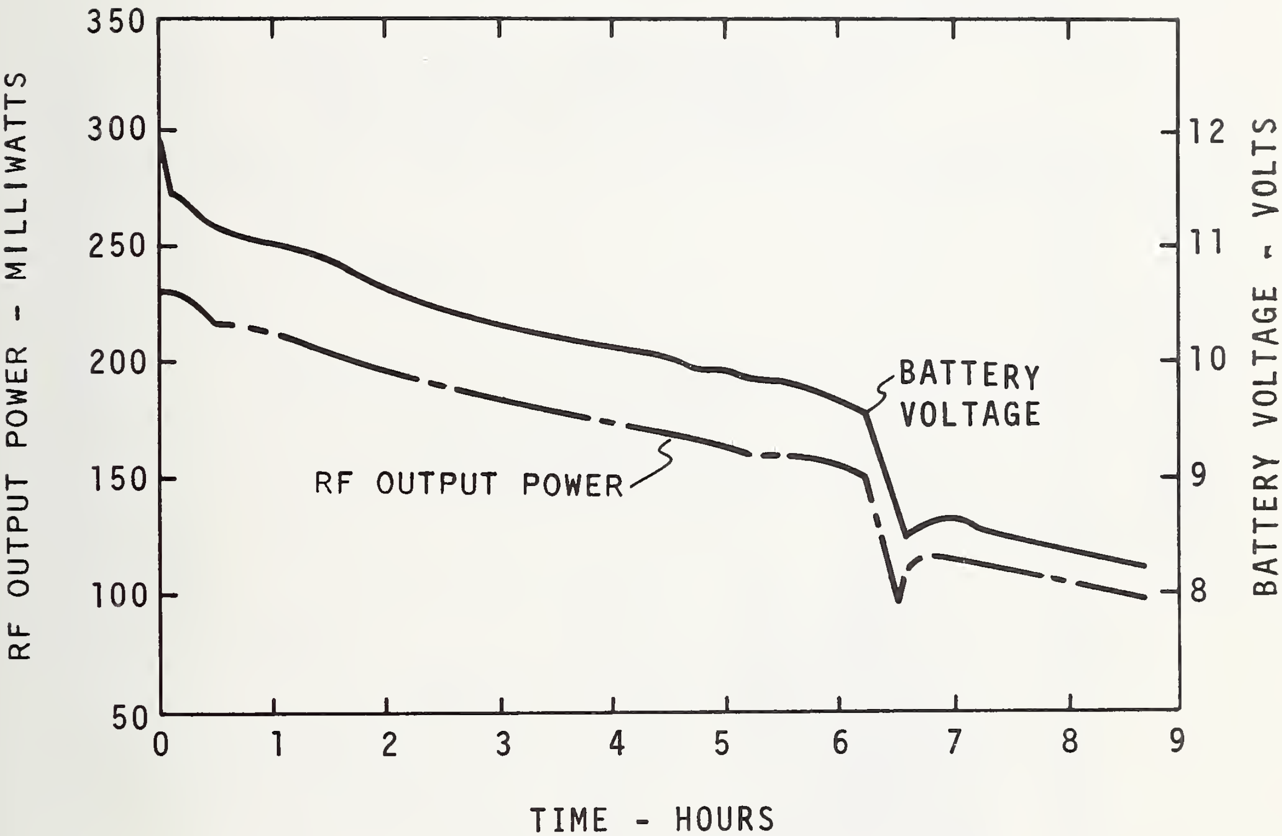


Figure 11. Decay of output power and battery voltage for transmitter #3.

TRANSMITTER #3:

POWER APPROXIMATELY 250 MILLIWATTS
FREQUENCY (f_o) = 151.625 MHz

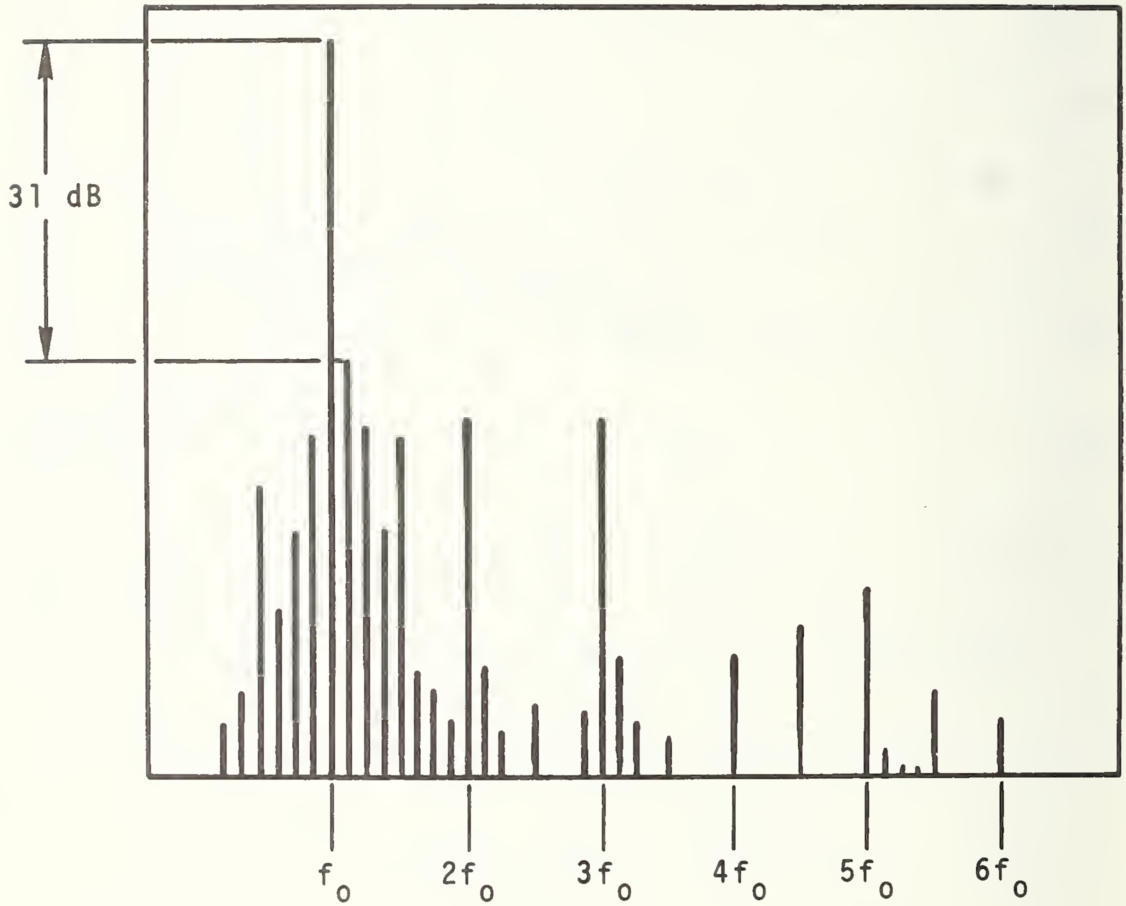


Figure 12. Output spectrum of transmitter #3.

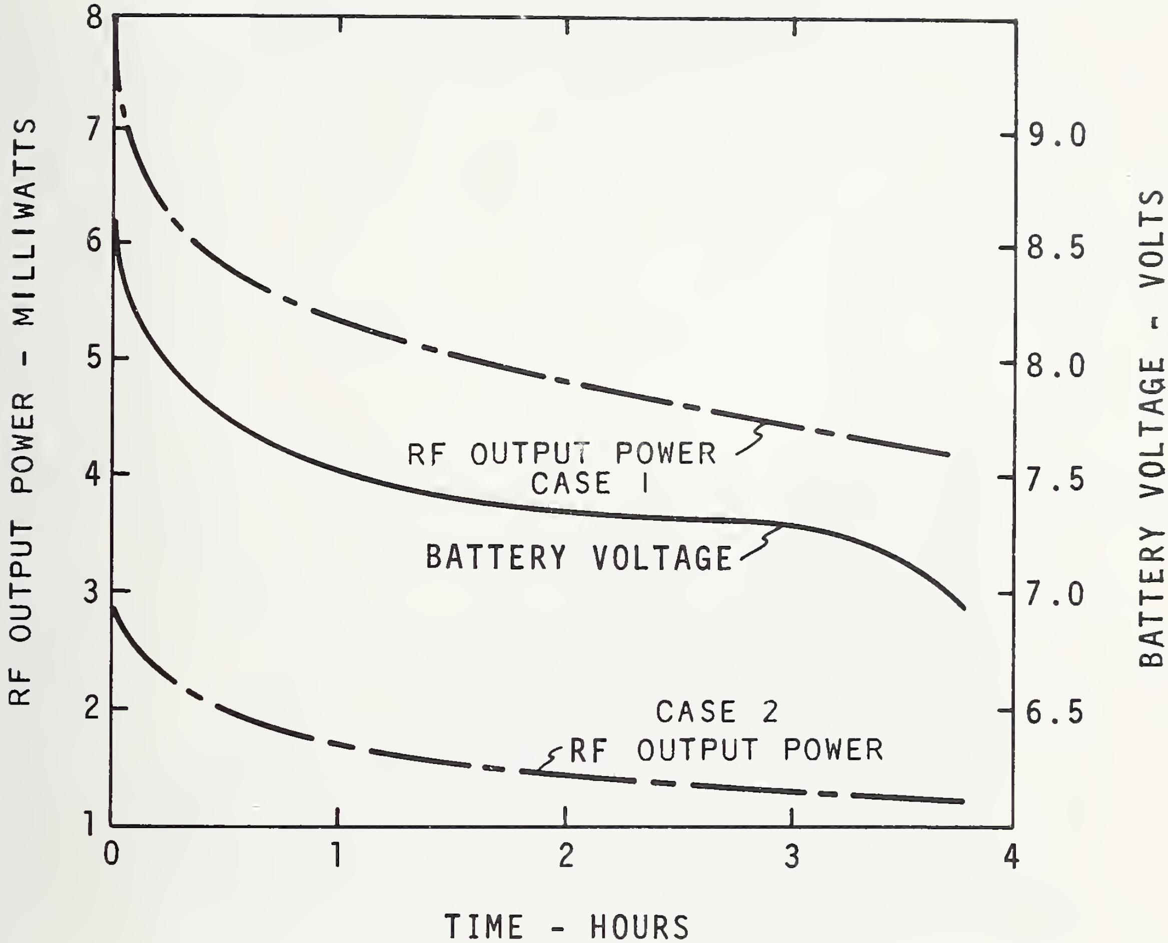


Figure 13. Decay of output power and battery voltage for transmitter #4.

TRANSMITTER #4:

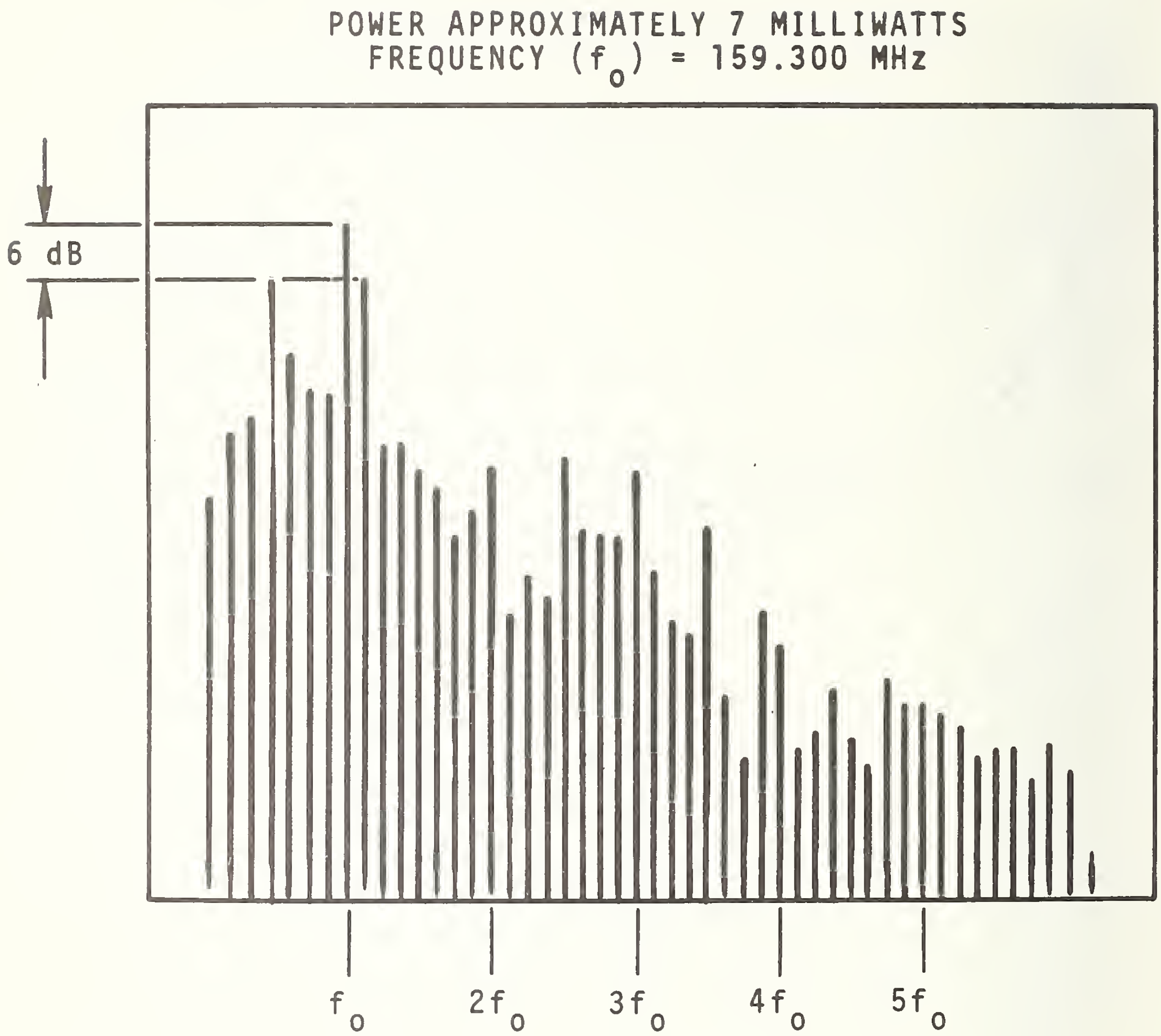


Figure 14. Output spectrum of transmitter #4.

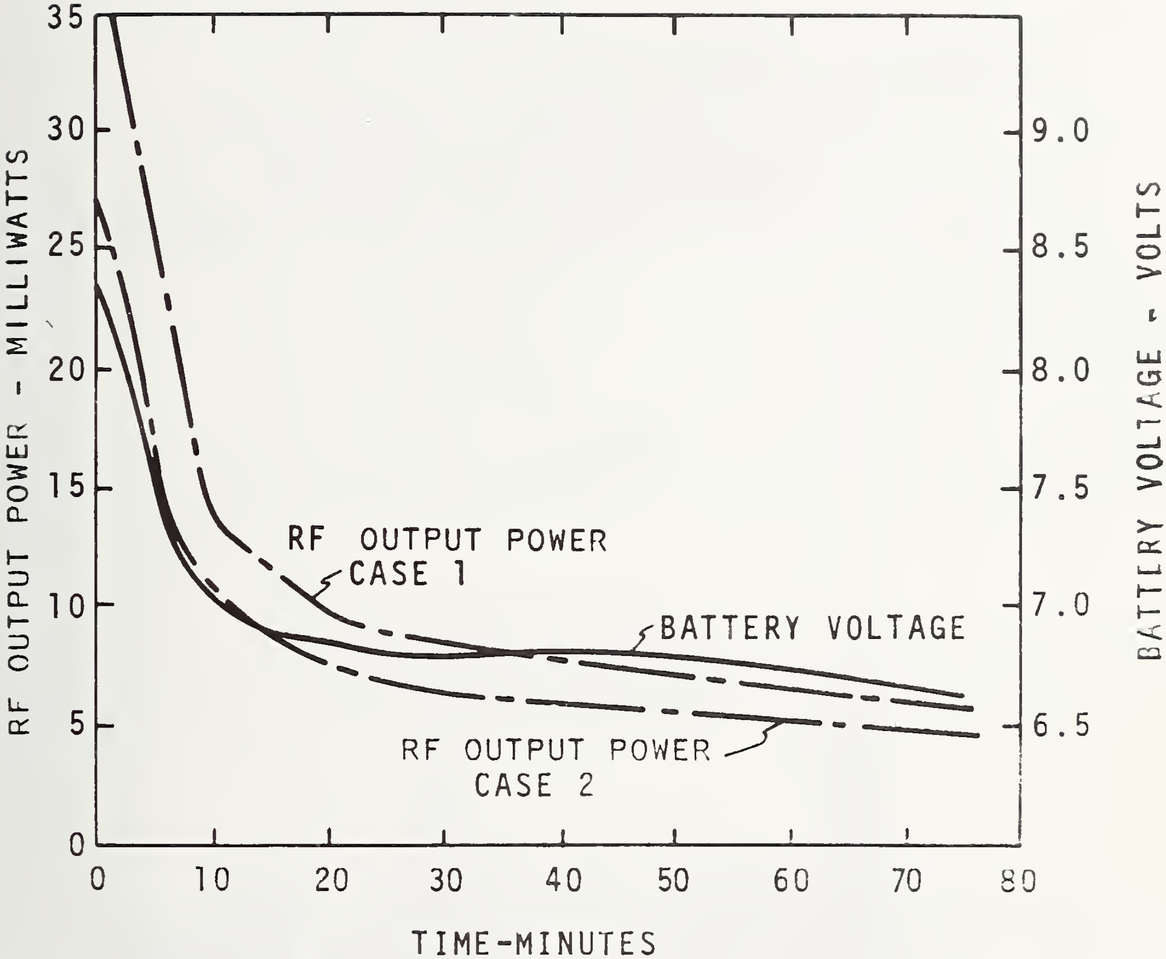


Figure 15. Decay of output power and battery voltage for transmitter #5.

TRANSMITTER #5:

POWER APPROXIMATELY 25 MILLIWATTS
FREQUENCY (f_o) = 154.890 MHz

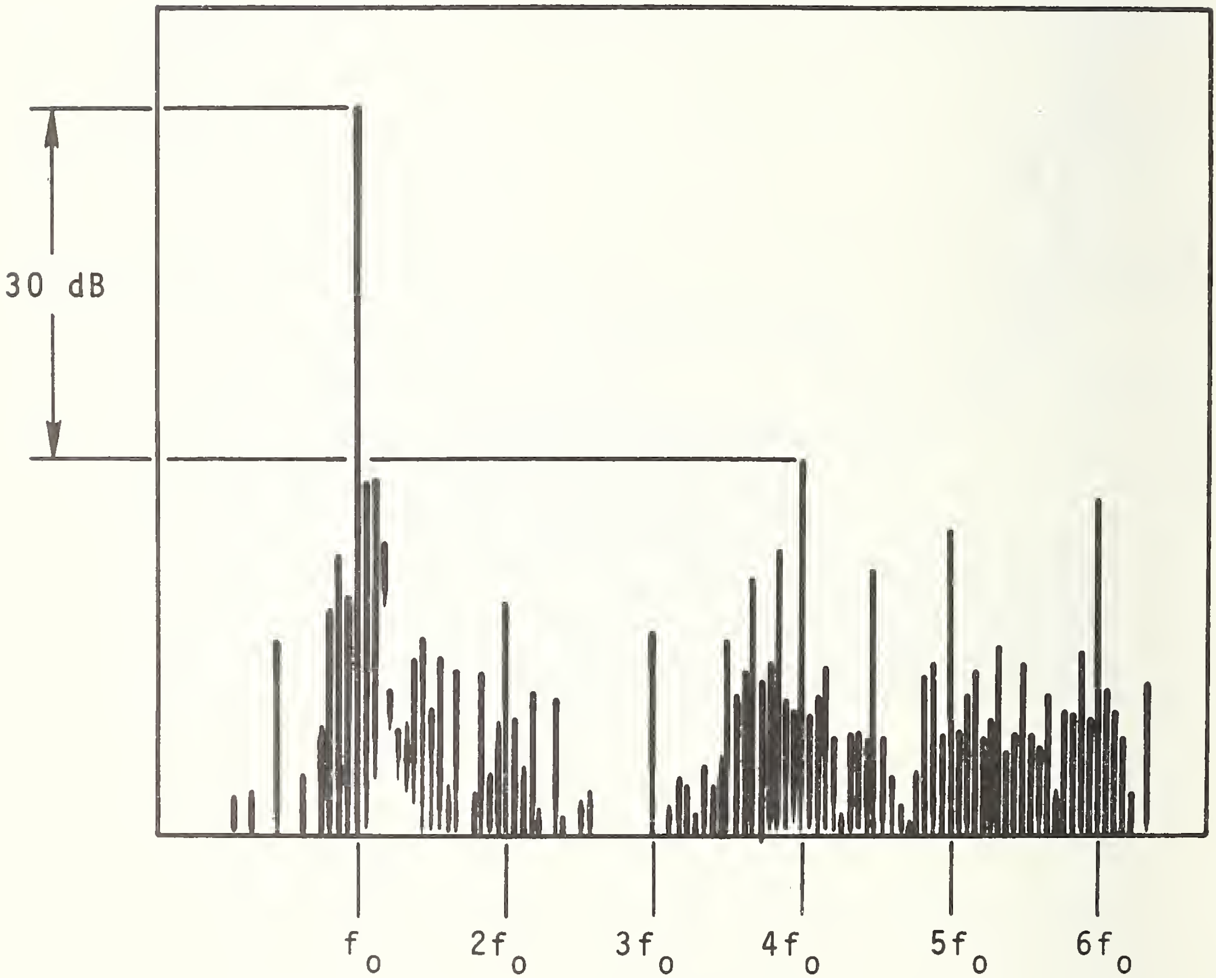


Figure 16. Output spectrum of transmitter #5.

Units #1, #2 and #3 were designed for body-worn use, while units #4 and #5 were designed for stationary application in a building to provide security against holdups. Therefore, a direct comparison of the first three units with units #4 and #5 is not appropriate. All units were comparable in size to a cigarette package and therefore could be concealed on a person. With regard to table 1, the harmonic suppression is the difference in signal strength between the fundamental output frequency of the transmitter and the next most powerful component of the radiated spectrum. It is desirable that this difference be as large as possible; thus, the larger numbers indicate the better performance. Spectrum-pictures of the output of the five transmitters are shown in figures 8, 10, 12, 14, and 16. AM hum and noise is a measure of the undesired amplitude modulation produced within the transmitter, and again the larger numbers indicate the better performance. The efficiency values given in the last row were calculated from the relationship,

$$E = \frac{P_{rf}}{P_{dc}} \times 100,$$

where P_{rf} is the rf power of the transmitter and P_{dc} is the product of the dc current and dc voltage supplied by the transmitter batteries. The dc voltage and rf power data are shown graphically in figures 7, 9, 11, 13 and 15.

Transmitter #1

Figure 7 shows the decay in rf output power due to the expenditure of battery energy over the operating period. Also shown on the same graph is the battery voltage variation over the same time period. The output power was nearly constant for the first hour and did not fall below the half-power point until approximately two and one-half hours of operation. Three 4.2-volt mercury batteries were used to power the transmitter, and it appears that a cell failure may have occurred in one of the batteries near the end of the first hour. This would explain the rather significant drop in output power over the next 30 minutes of operation. This performance is apparently not typical, as is indicated by the data from the other transmitters. However, it does illustrate what can happen and shows how critical battery performance is to reliable operation. The output spectrum of this transmitter, shown in figure 8, remained essentially the same over a three-hour period.

Transmitter #2

As shown in figure 9, the decay in transmitter output was approximately linear after the first few minutes of operation, and the half-power output level was not reached until after 8 hours of operation. A cell failure appears to have occurred at approximately 7 hours and 45 minutes into the test. The batteries were three 4.2-volt mercury batteries of the same type and manufacturer as those used in the test of transmitter #1. This would appear to be typical of the expected performance. Figure 10 shows the output spectrum with the strongest spurious radiation being the fourth harmonic (660 MHz), which is approximately 33 dB lower than the fundamental carrier frequency output, f_0.

Transmitter #3

Referring to figure 11, it is apparent that the behavior of transmitter #3 was much the same as that of transmitter #2. Operation time to half-power output level was nearly the same. In this instance, the dc power supply was two 7-volt mercury batteries, and a cell failure occurred after approximately 6 hours and 15 minutes. The output spectrum (figure 12) shows the spurious radiation to be down approximately 31 dB below the fundamental. In contrast to transmitters #1 and #2, the most intense spurious radiation was evidently not a harmonic of the fundamental frequency.

Transmitter #4

One 9-volt carbon-zinc battery served as the dc supply for this transmitter, and its performance was noticeably different from those of transmitters #1, 2, and 3, which used mercury batteries. Transmitter #4 was received in a poorly adjusted condition, as can be seen from figures 13 and 14. For this reason, the spurious radiation level was only 6 dB below the fundamental carrier frequency output (figure 14). In this condition, this transmitter would be unacceptable for undercover work because of the ease with which it could be detected by its excessive spurious radiation. Elimination of unwanted spurious radiation wastes power; when a bandpass filter was inserted between the transmitter and power meter to eliminate the spurious energy, the output power showed a very significant drop. This is shown by the curves labeled case 1 and case 2 in figure 13. Compared to other transmitters using mercury batteries, it is apparent that a rather large initial drop in output power occurs soon after turn-on when using carbon-zinc batteries, although the decay rate after the first hour or so appears to be comparable. Also, the mercury batteries do not appear to suffer the radical voltage drops under load evidenced by the carbon-zinc batteries. It should be noted that the efficiencies of this transmitter and transmitter number 5 are quite low, which means that the radiated output energies are very low for the battery powers being expended.

Transmitter #5

As with transmitter #4, a 9-volt carbon-zinc battery was used as a dc power source for transmitter #5, and similar output characteristics were displayed, as shown in figure 15. However, the initial decay in output power was so severe that a half power level was reached after only a few minutes of operation. Such a transmitter might serve satisfactorily for short and intermittent use but would be unsatisfactory for most undercover missions. As with transmitter #4, a bandpass filter was inserted and the change in output power noted. Because the spurious radiation was an acceptable 30 dB below the carrier output (see fig. 16), there was a much less severe change in the output upon insertion of the filter, as is illustrated by the similarity between the curves of case 1 and case 2.

Carbon-zinc batteries are not recommended to power transmitters in undercover surveillance use because of their inability to provide adequate power. Both mercury batteries and alkaline batteries are much more satisfactory.

Transmitter #6

The sixth transmitter was tested to assess the difference in transmitter performance as a function of the type of battery used. It was operated until it reached its half-power output levels, first with a carbon-zinc battery and then with an alkaline battery. Figure 17 is a plot of the resulting data and shows a half-power lifetime of slightly more than one and one-half hours using the alkaline battery compared to only 15 minutes with the carbon-zinc battery. The performance of mercury batteries is similar to that of the alkaline.

3.2 Field Tests of Body-Worn Transmitters

When the antenna of a transmitter is mounted on a human body, the effective radiated power of the transmitter is considerably reduced. To study this phenomenon, an outdoor test range was established and measurements were made under simulated field conditions. The data thus gathered are very interesting, and illustrate the amount of variation and the complexity of the problem of maintaining dependable communication using body-worn equipment.

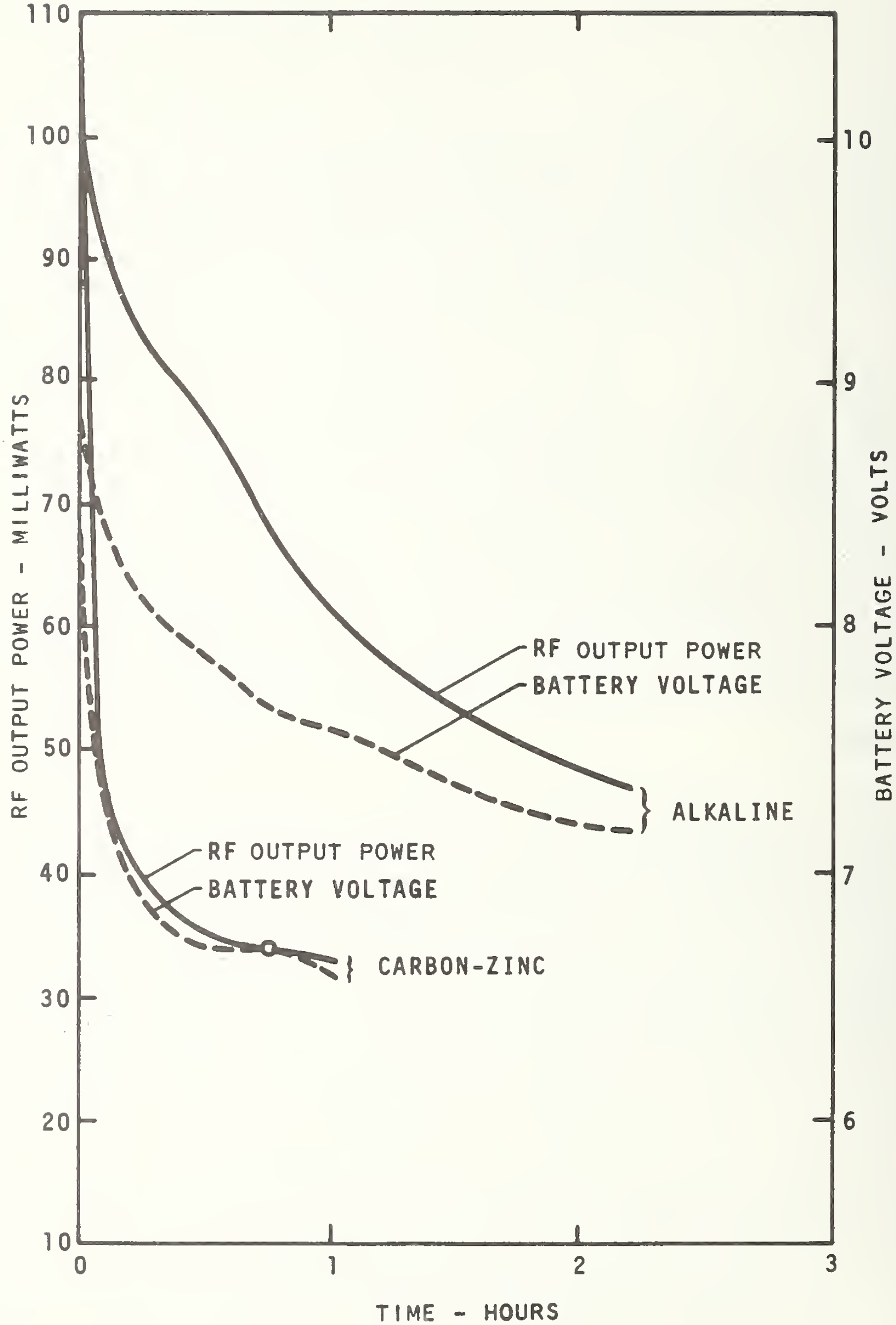


Figure 17. Decay of output power of transmitter #6 using alkaline and carbon-zinc batteries.

The measurement setup, using a field strength meter at the receiver location, is illustrated in figure 18. Transmitter #1, described in section 3.1, was used. Measurements were made in the daytime under warm, dry conditions, and there were no buildings or other obstructions in the area. Initial measurements were made with the transmitter and its antenna mounted on a wooden post, with the transmitter and receiver antennas oriented vertically. A series of measurements were then made with the transmitter and its antenna mounted in various locations on a person with the person oriented at different angles to the receiving antenna. In all cases, the first position was with the subject facing the receiver with arms extended downward at the sides. Succeeding observations were made with the subject rotated clockwise to the successive 90 degree positions. To observe the changes in field strength due to arm movement, the arms were moved through a variety of positions including extending them directly overhead, to the front, and to the sides. The arm movements followed a consistent pattern of continuous motion during which the field strength fluctuations were observed on the meter. These fluctuations are shown for measurements 2 through 6; the approximate variation of the field strength reading is indicated for each of the four facing positions. In some instances, arm movement appeared to increase signal strength perceptibly. The measurement conditions and data observed were as follows (observed field strengths at the receiver are given in dB above one microvolt per meter):

Measurement #1: Transmitter mounted on a vertical wooden post with transmitting and receiving antennas vertical. The observed field strength was 91.4 dB μV/m.

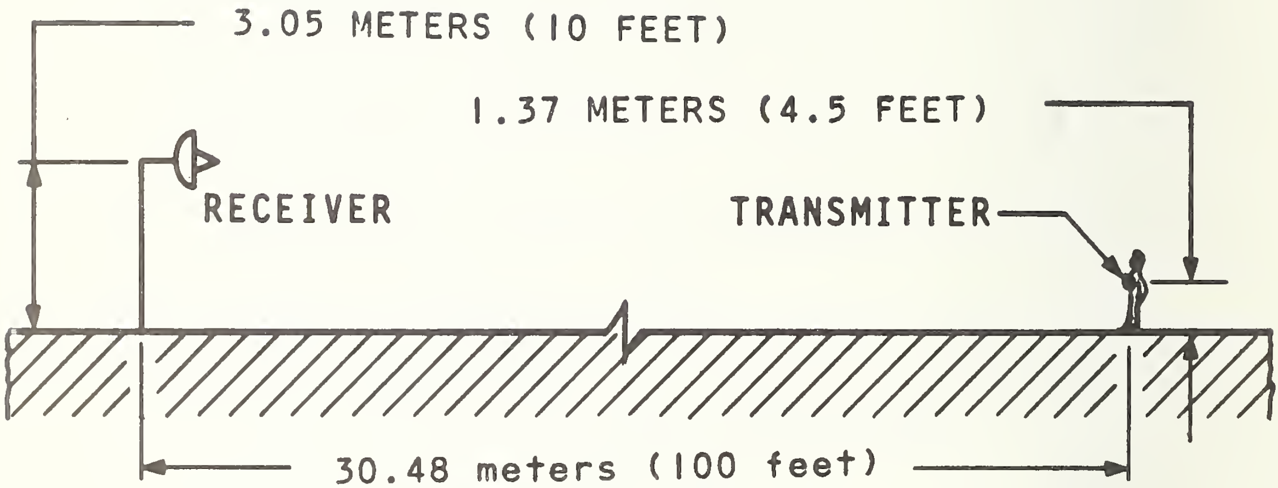
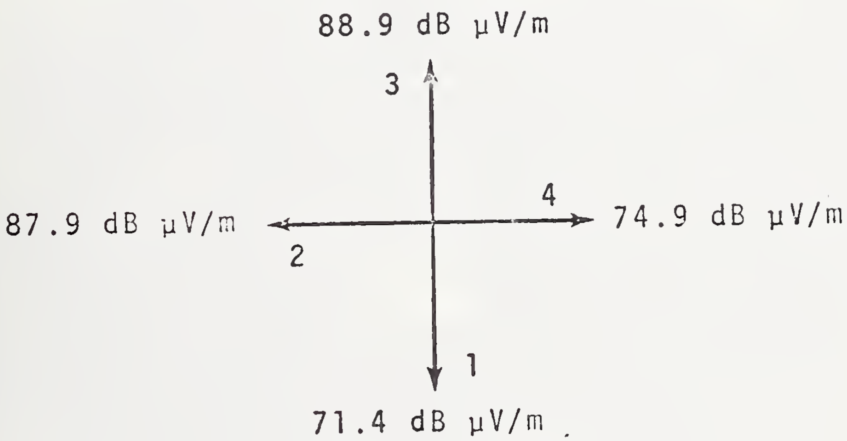


Figure 18. Test setup for field performance studies of body-worn transmitters.

Measurement #2: The transmitter was mounted on the left side of the person, at approximately waist level (see figure 19). The antenna extended up the left side of the chest to the shoulder. The subject was wearing a cotton "T-shirt." The subject was then oriented at the four quadrant angles to the transmitter, and the variations due to arm movements were noted at each position. The transmitting and receiving antennas were oriented vertically.



FACING RECEIVER
ARMS DOWN
IN ALL POSITIONS

Changes in Field Strength, E, with Arm Movement

Position	Variation (dB)
1	-12 to +3
2	-4 to +1
3	-4 to +1
4	-4 to +1

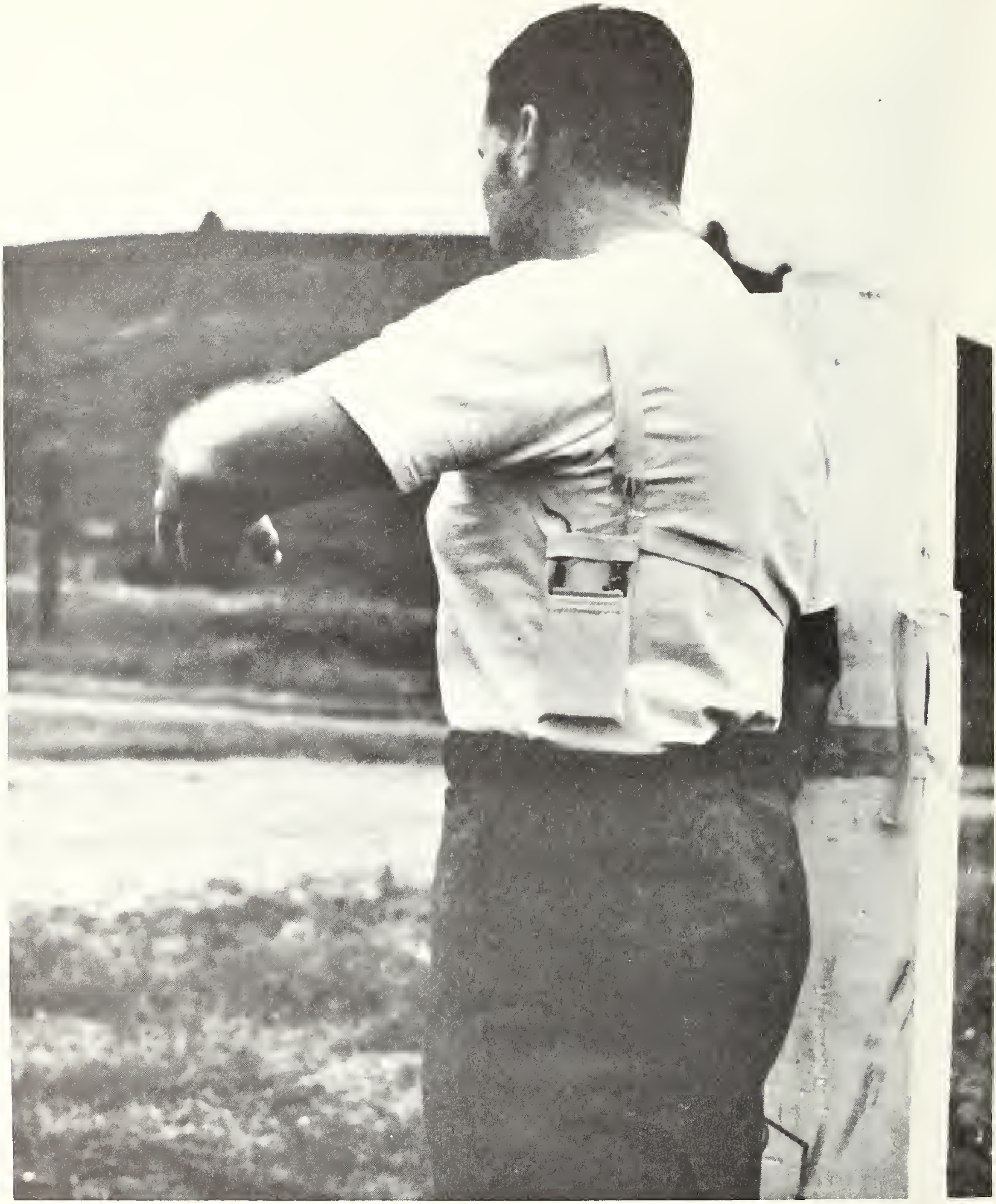
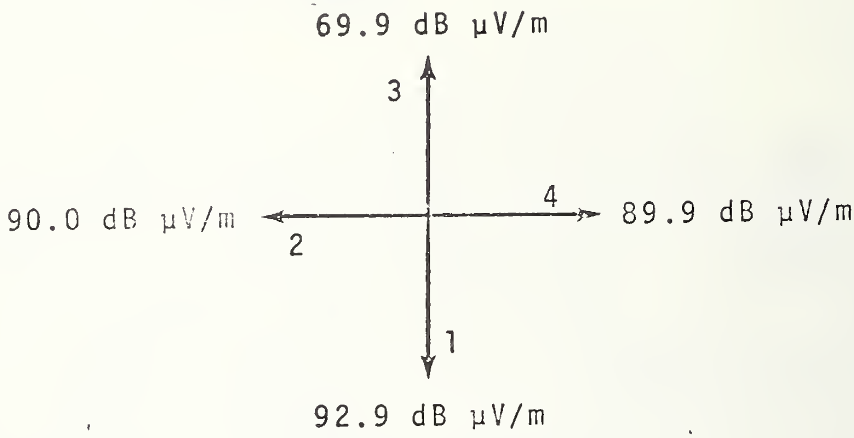


Figure 19. Transmitter position for measurement #2.

Figure 20. Transmitter position for measurement #3.

Measurement #3: The transmitter was tucked into the belt with the antenna positioned vertically up the center of the chest over a "T-shirt" (see figure 20).

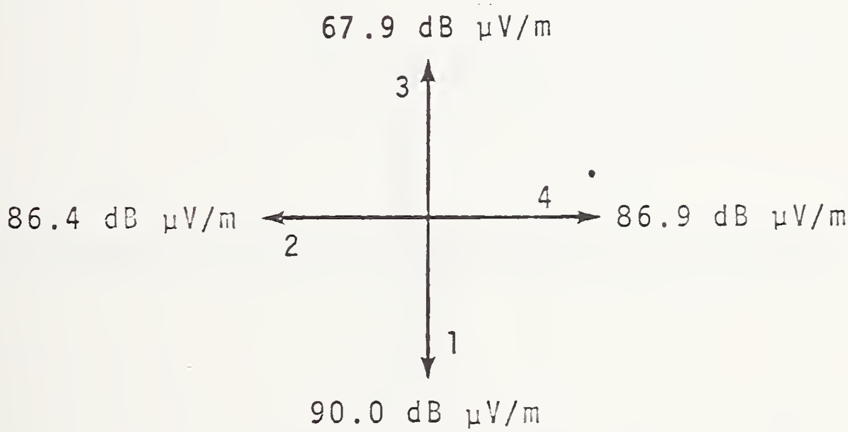


FACING RECEIVER
ARMS DOWN
IN ALL POSITIONS

Changes in Field Strength, E, with Arm Movement

Position	Variation (dB)
1	-6 to 0
2	-7 to +1
3	0 to +10
4	-7 to +1

Measurement #4: The transmitter was tucked into the belt with the antenna arranged vertically up the center of the chest next to the skin.

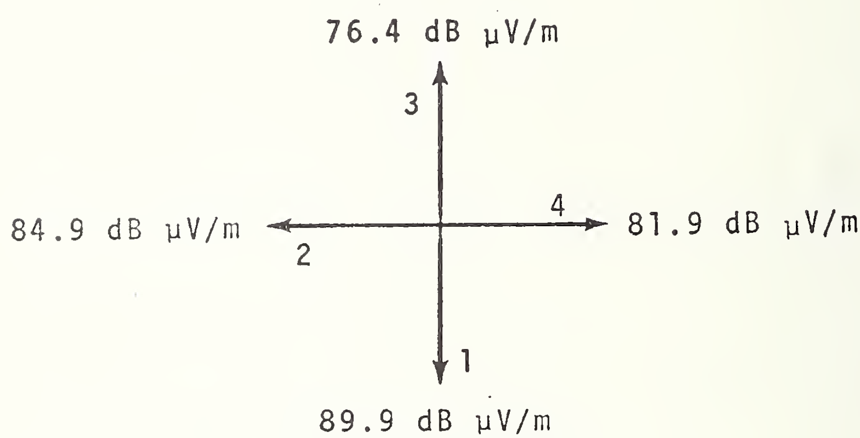


FACING RECEIVER
ARMS DOWN
IN ALL POSITIONS

Changes in Field Strength, E,
with Arm Movement

Position	Variation (dB)
1	-3 to +1
2	-10 to +2
3	-6 to +6
4	-10 to +2

Measurement #5: Both the transmitter and receiver antennas were oriented horizontally. The transmitter location was at the waist, with the antenna wrapped around the waist just above the belt.

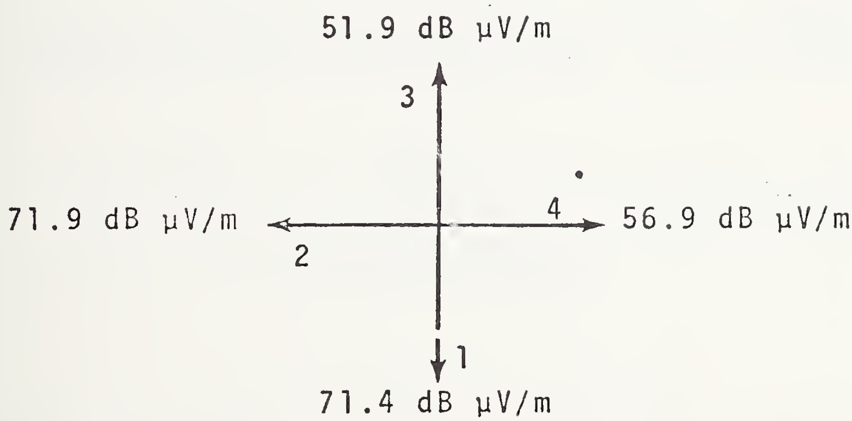


FACING RECEIVER
ARMS DOWN
IN ALL POSITIONS

Changes in Field Strength, E, with Arm Movement

Position	Variation (dB)
1	-0.5 to 0
2	0 to +5
3	-3 to +2
4	-7 to +1

Measurement #6. The transmitter antenna was oriented horizontally and the receiver antenna was oriented vertically. The transmitter and its antenna were mounted at the waist in the same manner as for measurement #5.

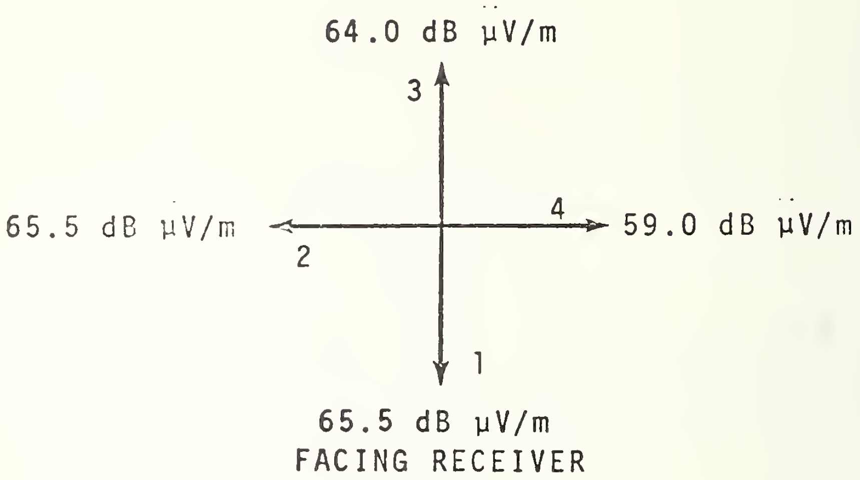


FACING RECEIVER
ARMS DOWN
IN ALL POSITIONS

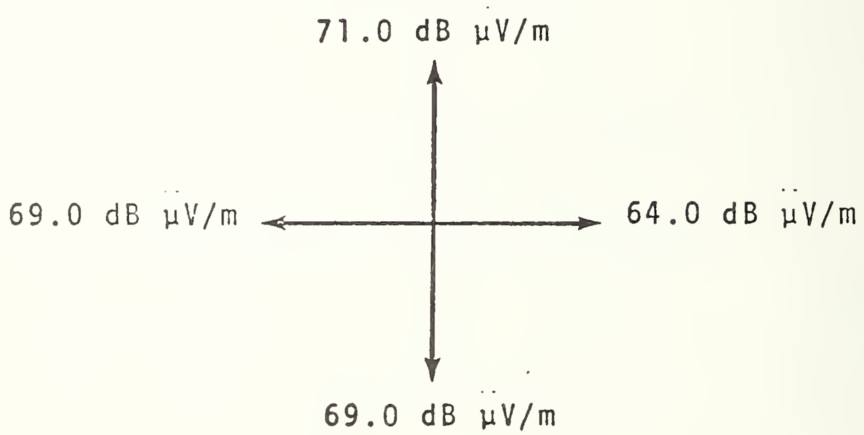
Changes in Field Strength, E,
with Arm Movement

Position	Variation (dB)
1	-9 to +1
2	-9 to +1
3	0 to +13
4	0 to +13

Measurement #7: Both the transmitter and receiver antennas were oriented vertically, with the transmitter mounted on the left hip of the subject and the antenna extended down the thigh toward the knee.



Measurement #8: The conditions were identical to those in #7 except that the transmitter was mounted at the knee of the subject and the antenna extended down the lower leg toward the ankle.



Note that measurements #1 through #6 were made on one day and measurements #7 and #8 were made on a second day. This allows the possibility that the radiated power from the transmitter might not have been equal on the two days. Therefore, it is not certain that upper-body mounting of the transmitter provides a larger signal, as the data would seem to indicate.

Although these data are by no means conclusive, several tentative conclusions can be drawn.

(1) When the body is between the transmitting and receiving antennas, there is a very significant reduction in the strength of the received signal. Therefore, the wearer should make every effort to keep himself oriented so that his transmitting antenna is on the same side of his body as the receiver.

(2) It is desirable to have the receiving antenna oriented parallel to the transmitting antenna. The data of measurement #6 show severe signal loss (approximately 25 dB) when the two antennas are perpendicular to each other.

(3) Arm movement is significant and can have a very important effect when communication is marginal. It is best to keep the arms as far away from the antenna as possible. Folding the arms across a chest-mounted antenna could attenuate a signal enough to make it unrecoverable.

4. NON-RADIATING DEVICES

4.1 General

The distinguishing feature of non-radiating surveillance devices is the medium used to convey information from one location to another. The information is transmitted over wires, usually telephone wires, instead of being broadcast.

Wired surveillance systems have several distinct advantages over radiating systems. Most notable is the security from detection by an electronic sweep made by a radio receiver. Because virtually no electromagnetic energy is radiated from the wired network, this means of discovery is eliminated. A second very important consideration is the virtually unlimited range that is possible. Although the range of radiating devices is usually measured in feet, the range of wired systems can be measured in miles. In addition, wired communication systems include a source of dc voltage. Many wired surveillance devices utilize this built-in voltage source to eliminate the troublesome and limiting battery requirement. A final advantage which cannot be overlooked is the reliability of the communication medium. Wires are not affected by atmospheric conditions, and signals of consistent and dependable quality are almost certain, with the additional benefit that natural and man-made radiation interference are eliminated.

While wired systems have many advantages, they also have limitations. Restricted mobility is most often the reason a wired surveillance system is not used. In cases where the person under surveillance is on the move or located away from a fixed listening post, the use of wired equipment is obviously not feasible. A second drawback is that prior access to the premises is required to install listening devices or telephone taps. Also, in most instances, more advance preparation time is needed to set up wired equipment, so it is difficult to respond quickly to emergencies. Where these restrictions pose insurmountable problems, there is no choice but to use radiating devices.

In some states there are laws which prohibit telephone tapping. Therefore, portable and body-worn transmitters and receivers are essentially the only undercover communications devices available to law enforcement officers for electronic surveillance.

4.2 Telephone Taps

Surveillance must often be carried out by using remotely located tape recording equipment to record telephone conversations. The fact that telephone companies install extra wiring in anticipation of future demands for service provides a unique and convenient situation for wiretapping. Almost invariably, there will be one or more pairs of conductors in a cable which are not in use and which can be appropriated for surveillance purposes. These pairs are easily located at various access points in a given building or neighborhood by someone who is familiar with the telephone system and its equipment. Thus, not only the telephone itself but the whole wire communication network offers a limitless range of possibilities to the skillful technician. Even if a thorough examination were to determine that the telephone itself was not being tapped, there would still be no guarantee that a hidden microphone was not present which was carrying the conversation within a room to a remote listening post via telephone wiring. In the following paragraphs, some of the more frequently used telephone tapping methods and equipment are discussed along with the methods used to detect them.

4.2.1 "Infinity Transmitter" or "Harmonica Bug" [1]

Although the infinity transmitter is installed in the telephone, it does not monitor telephone conversations. Instead, it enables someone to listen in on a room conversation by means of another telephone. Once the device is installed in a telephone, a listener dials the number of the altered telephone in the customary manner. However, just before the dialed telephone rings, an audible note or tone is transmitted over the phone line. This activates the bug, which opens the phone line without ringing, thereby enabling the caller to listen to any conversation taking place in the vicinity of the bugged telephone. The bug itself is an electronic switch which closes in response to the audio tone. It is wired in parallel with the hook switch on the telephone so that, upon being activated, it prevents the telephone from ringing and opens the phone line at the same time. When this bug is in operation, the telephone will be busy to all other callers even though the receiver is in the cradle in the usual position. Thus, one symptom of the presence of such a bug is the receipt of a busy signal when the phone is known not to be in use. This device must be installed in the telephone and can be located by physical search. Defensive equipment is manufactured which will place a tone sweep on the phone line and detect the voltage drop from 48 volts to approximately 8 volts when such a bug is activated. A tone sweep is necessary because these bugs can be made to respond to a wide range of audio frequencies. The name "harmonica bug" is derived from the use of a common harmonica to actuate the device.

4.2.2 Inductive Coupling or "Pick-Up Coils"

A current in a conductor gives rise to a magnetic field around the conductor; when the current varies either in magnitude or direction, the magnetic field also changes. Conversely, if a conductor is immersed in a changing magnetic field, a current will be produced. This is the principle of the transformer and is used as a means of tapping a telephone. Various types of coils and pick-up loops can be employed to couple to an active telephone line and hence to monitor the conversation in progress. Many such devices are used in conjunction with an audio amplifier to actuate a tape recorder or to modulate a radio transmitter. Such devices do not produce any measurable loading or draw any detectable extra current from the line and therefore can not be located by voltage or current measurements. Physical search is practically the only means of detecting such a device.

4.2.3 Three-Wire Systems

A telephone may be used for both tapping and bugging simultaneously by the use of a third conductor for bypassing the hookswitch and thereby activating the mouthpiece for use as a room bug. Telephone hookswitch bypass is the term sometimes used to refer to this method of eavesdropping and some highly sophisticated electronic devices are employed to accomplish it and to make detection difficult.

4.2.4 Dialed Number Recorder

Although not a device for intercepting oral communication, the dialed number recorder is used to monitor telephone calls by providing a record of all numbers dialed from a particular telephone. These devices usually provide a paper tape printout of numbers dialed, and in addition may provide the date and time a call was made. Such devices were once called "pen registers" because a pen riding on a moving chart was used. The pen records the groups of pulses emitted by the telephone dial mechanism as it returns to the rest position. The dialed number is ascertained by counting the number of pulses in each group. In telephone systems using touch-tone dialing, a touch-tone decoder with a printed readout is used. These instruments are manufactured mainly for use by the telephone companies. Application is very simple, requiring only the connection of a lead to each side of the telephone line. No legal implications are involved, and connection can be made anywhere along the line between the telephone and the exchange. Detection of the presence of a dialed number recorder is extremely difficult by any means other than visual inspection because these devices have a high input impedance and the line loading effect is negligible.

4.3 Concealed Microphones

Microphones cannot be found by electromagnetic sensing devices. The only means of discovery is through physical search. Installation requires access to the premises, but the degree of concealment is limited only by the imagination of the installer, the cleverness of his methods, and the time he has to work. The basic equipment required consists of a microphone as small as possible, the necessary length of shielded wire, and a tape recorder. Shielded wire is used where possible to avoid unwanted pickup such as power line hum or other noise coupled into the circuit. For short lead lengths, very fine wires can be run along baseboards, window sills, or under floor coverings. Conducting paint can be used to form a conducting path on a wall surface. This is done by simply painting thin conducting stripes on the surface as required, and making electrical connections at the ends of the painted stripes. These stripes can then be painted over with regular paint, making discovery difficult.

Excellent microphones as small as 9.5 mm x 6.35 mm x 4.76 mm (3/8" x 1/4" x 3/16") are available, with sensitivities such that they can pick up a whisper at 7.5 meter (25 feet). These can be combined with an amplifier of comparable size so that a listening post can be established several miles away, using a pair of unused telephone wires.

The small dynamic-type microphones commonly used for these purposes require a column of air (a leak) directly in front of the pick-up surface so that, in mounting them, a very small hole must be drilled in the object used for concealment. Sometimes, plastic tubing threaded through a crack serves this purpose and aids in concealment. Microphones equipped with a small section of metal tube directly over the microphone leak opening are available for attaching the tubing.

In the use of a microphone for eavesdropping, it is important that precautions be taken to avoid rubbing against the microphone because this introduces noise. This becomes a problem especially when a microphone is used with a body-worn transmitter which is hidden in clothing. Friction from cloth rubbing against the microphone is called "clothes noise" and poses a problem in obtaining good quality sound reproduction.

Miniature surveillance microphones, with their amplifiers, have characteristics similar to those of the human ear. The fact that the ear and the microphone can detect the same sound at the same distance provides a guide to the limits of a physical search for a hidden microphone. There are devices such as the highly directional shotgun or parabolic microphones which have greater ranges, but they are much more difficult to conceal. These instruments can detect normal conversation at ranges of fifty to one hundred feet. Their increased range is derived from their directionality and, for some, their acoustic amplification. This directionality prevents interference from any direction other than that in which the device is pointed. One defense against such devices is to add background sounds, such as music. This, along with speaking in low voices, can render the recorded conversation unintelligible.

Microphone technology is an extensive field, and no attempt will be made to cover the subject in depth. However, several types of microphones which are of special interest in electronic surveillance, and which find fairly wide application, will be described briefly [2, 14, 16].

4.3.1 Carbon Microphones

The carbon microphone is the type used in the mouthpiece of the telephone transmitter. It operates on the principle that the resistance of a package of carbon granules varies as the external pressure on the package changes. When mounted behind a vibrating diaphragm and energized with a dc voltage, the carbon microphone will cause the current in the circuit to vary in accordance with the sound striking the diaphragm. This modulating effect enables the voice to be transmitted over the telephone circuit. Carbon microphones are very sensitive but have a rather high background noise of the hiss type. They do not lend themselves to miniaturization as well as other types of microphones.

4.3.2 Condenser Microphone

Also referred to as an electrostatic microphone, the condenser microphone utilizes a vibrating diaphram as one plate of a parallel-plate, air-dielectric capacitor. Sound striking the diaphram produces capacitance variations which, in turn, produce electrical impulses. Condenser microphones can be made very sensitive and reproduce sound with excellent fidelity, but they have the disadvantages of being fragile and sensitive to vibrations transmitted through solids. For these reasons, they are generally not suitable for eavesdropping applications.

4.3.3 Electrodynamic Microphone

Often called simply a dynamic microphone, this is the type most commonly used in electronic surveillance. These microphones have many desirable features. They can be very small, adequately sensitive, rugged, and require no external power source. The modulated current is generated by the motion of a coil of wire in the field of a permanent magnet.

4.3.4 Electret Microphone

Recent technology [5] has resulted in the development of miniature electret microphones which have many features useful in electronic surveillance work. An electret is the electrical analog to a permanent magnet. A permanently polarized dielectric material which is sensitive to pressure changes produced by acoustic energy is used as the sensing element. Operation is similar to that of the condenser microphone, but the electret microphone is much more resistant to shock and solid-borne vibration. Advantages of the electret are that no external bias is required, and it has a frequency response which is superior to those of other types. Superior frequency response, however, is not of first-order importance in electronic surveillance, where only voice frequencies are of interest. Electrets perform well under temperature extremes and may be slightly superior from the standpoint of ruggedness, but one precautionary note is worthy of mention. While it appears that better materials are being developed which will diminish the problem, periods of humidity in the range of 90 percent or more cause drastic loss of sensitivity. Should this problem be overcome and costs made competitive with those of the dynamic types, the electret may become the preferred type of microphone. At present, however, the electret appears to be little used, and it may be several years before this situation changes.

4.3.5 Induction Microphone

The induction microphone is very similar in principle of operation to the electrodynamic microphone in that both incorporate a moving conductor in the field of a permanent magnet. The induction microphone utilizes a fixed coil and a moving piece of magnetic material, whereas the electrodynamic type employs a moving coil and is often much smaller. A common example of the induction microphone is the ear piece of the telephone. These microphones are sometimes used as room bugs where concealment problems do not require a device as small as the electrodynamic type. Because they are used in telephones, they are inexpensive and readily available; this explains their common use.

4.4 Advantages and Disadvantages of Wired Surveillance Systems

Advantages

1. Unlimited range.
2. Operating time not limited by battery life.
3. Not subject to radiated electromagnetic interference.
4. Not detectable by electromagnetic sensors.
5. Personal contact with subject not required.

Disadvantages

1. Prior access to premises required.
2. Lack of mobility.
3. Outlawed in some states, court order required in others to use telephone system.
4. Installation requires highly skilled people.

5. TAPE RECORDERS

In gathering legal evidence through electronic surveillance, the tape recorder is an indispensable item. Whether the surveillance method is a radiating system involving transmitters and receivers or a wired system using a telephone tap or a concealed microphone, a tape recorder is invariably involved. Many very good tape recorders are available, but there are apparently none designed specifically for surveillance purposes. In general, most good tape recorders are adequate to perform the functions required by electronic surveillance, especially in regard to sensitivity and frequency response. Both open-reel and cassette-type recorders are used.

5.1 Open-Reel Tape Recorders

The main advantage of the open-reel recorder is its large tape capacity, which allows for very long periods of recording without the necessity of changing reels. It generally yields broader frequency response, but this is not required for good fidelity in voice reproduction since the voice frequency band is relatively narrow. Important options available on open-reel recorders include voice-actuation, and automatic shut-off at the end of a reel so that tape flap noise will not reveal the presence of a hidden recorder. Temperature extremes are to be avoided; the temperature inside the trunk of an automobile on a hot day, for example, can cause serious operational difficulties.

5.2 Cassette Tape Recorders

The cassette is being used increasingly in spite of its smaller recording capacity. This is due to the advantages of small size and ease of operation; it is much quicker and easier to change and handle the tape. Miniature versions of the cassette tape recorder are now making their appearance, and at least one model is available which is small enough for concealment within clothing, its dimensions being 5 mm x 7.5 mm x 2.5 mm (2" x 3" x 1"). This will have a significant bearing on the application of recorders and could conceivably displace radiating equipment in certain situations.

5.3 Telephone Recording Actuator

In order that a tape recorder not be required to run continuously, or be monitored continuously, a recorder actuator may be used. With the actuator, the tape recorder is turned on when the telephone receiver is lifted from the cradle and turned off when it is replaced. These actuator devices may be attached to a telephone line at any point between the telephone and the control switchboard. They are battery powered, so they create no detectable electrical effect on the telephone line. These devices utilize the fact that the voltage on the telephone line drops from 48 volts to approximately 8 volts when the receiver is lifted from the cradle.

6. CONCLUSIONS AND RECOMMENDATIONS

There are several standards available to gauge the quality and performance of personal/portable electronic equipment [3, 11, 12]. However, there is a degree of uniqueness about electronic surveillance equipment which would seem to require standards especially tailored for these devices. As an example, since battery life is so critically important in the case of body-worn transmitters, it follows that maximum use should be made of available power. This leads to the need for some standard for transmitter efficiency. This does not mean that a simple specification of efficiency based upon power delivered into a 50-ohm load would be appropriate, because few of these devices are designed to work into 50 ohms. It would be desirable to develop some criteria whereby a high level of efficiency could be assured, thereby providing the maximum signal strength and transmitting time consistent with the battery power available.

A second component of a standard should be a specification of operating frequencies. This would include a safeguard against the use of transmitters operating in the aircraft landing system bands, which could constitute a very serious hazard to air travel. A serious accident caused by an electronic surveillance system operating on instrument landing system frequencies is too high a price to pay for any evidence which might be thus obtained. The exclusion of these frequencies would eliminate the use of the detuned commercial FM receiver as a listening post, and require the purchase of receivers manufactured specifically for surveillance work. Although this is an economic penalty, it will likely pay off handsomely in terms of system performance because many commercial FM undercover receivers are of relatively poor quality.

Finally, the modulation bandwidths characteristic of high-fidelity equipment are not required for good quality voice communication. Therefore, the standard can afford to relax some of the requirements normally made of equipment used, for example, in the entertainment industry.

The need for high-quality training for those engaged in electronic surveillance work is most evident. This work encompasses a large body of knowledge, much of which is not found in textbooks and which can therefore be conveyed only by those with experience.

Much additional work is needed in the area of antenna design and evaluation, especially of body-mounted antennas where large variations in received signal strength are observable.

In the process of gathering information for the preparation of this report, one fact was outstandingly evident. This was that information regarding the manufacturers of electronic surveillance equipment and the places where such equipment could be purchased, was difficult to obtain. On the positive side, this would indicate that the present laws governing the advertising of such equipment are proving effective. From the side of law enforcement, however, this presents a serious problem. Where there is a legitimate need for electronic surveillance, law enforcement personnel need ready access to current information on the sources for the purchase of equipment and instruction in its use. Many law enforcement officials have expressed a desire for a users' guide that could be consulted for information on a particular type of equipment, who manufactures it, and how the products of the various manufacturers compare, for the money invested. The development of objective performance standards is a step in this direction.

APPENDIX A--ANNOTATED BIBLIOGRAPHY

1. Brown, R. M., "The Electronic Invasion," John F. Rider Publishing, Inc., New York, 1967.

This book deals with the many types and applications of devices usable for eavesdropping, as well as those used to detect the presence of such devices. For almost every device discussed, there is given the name of its manufacturer and often the prices as well. Because many manufacturers of such equipment are small firms, it may be found that many are no longer in business. The book is written in a popularized style and contains a great deal of general information along with some technical information, including circuit diagrams.

2. Dash, S., Schwartz, R. F., and Knowlton, R. E., "The Eavesdroppers," Rutgers University Press, New Brunswick, N.J., 1959.

This is a lengthy book written in three parts, namely the practice, the tools and the law as they pertain to eavesdropping. Probably because the book was written prior to the advent of miniaturized electronics, it does not deal with radiating equipment. However, it is quite comprehensive and informative on such subjects as video devices in use up to the date of publication. Also included is a good bibliography.

3. EIA Standard RS-316, "Minimum Standards for Portable/Personal Land Mobile Communications FM or PM Equipment 25-470 MHz," Electronics Industries Association, 11 West 42nd Street, New York, N.Y., July 1965.

4. Farmer, R. A., "SINAD System Design," IRE Transactions on Vehicular Communications, Volume VC-10, Number 1, April 1961, pp. 103-108.

This paper describes the SINAD system for evaluating performance of a mobile communications system as well as explaining its use and advantages in evaluating system components and parameters such as receiver sensitivity and selectivity. It also discusses the problems of site noise and propagation and terrain variations. Specific data are given for frequencies in the vicinity of 50, 150, and 450 MHz, which are the frequencies of major interest in undercover communications work.

5. Fraim, F., and Murphy, P., "Miniature Electret Microphones," Journal of the Audio Engineering Society, Vol. 18, No. 5, October 1970, pp. 511-517.

This technical paper discusses the development of miniaturized electret microphones, tells how they are constructed and the requirements of the preamplifiers used with them. The significant performance characteristics of the electret are discussed along with their strengths and weaknesses, and comparisons are made to other types of miniature microphones.

6. Greene, R. M., Jr., editor, "Business Intelligence and Espionage," Dow Jones-Irwin, Inc., Homewood, Illinois, Oct. 1966.

Chapter eleven of this book is entitled "Electronic Eavesdropping (Bugging): Its Use and Countermeasures." It is an essentially non-technical discussion of both radiating and wired devices used in undercover information-gathering activities. No attempt is made to delve into the engineering and technical characteristics of the devices described; instead, it gives an overview of the types of devices in use, a brief description of what they do and how they are applied.

7. Huber, J. L., "Signal Attenuation for Passenger Vehicles Between 0.1 and 1.0 GHz," Proceedings of the 1970 Carnahan Conference on Electronic Crime Countermeasures, Bulletin 92, April 1970.

Signal attenuation experienced when transmitted energy was radiated from the inside of various vehicles was observed to vary from 3 to 15 dB for a vertically polarized antenna and from 10 to 30 dB with a horizontally polarized antenna over the frequency range 0.1 to 1.0 GHz. Wide variations occurred in a cyclic pattern with the average attenuation over all frequencies being around 15 dB.

8. Jesch, R. L., and Berry, I. S., "Batteries Used with Law Enforcement Communications Equipment, Comparison and Performance Characteristics," LESP-RPT-0201.00, National Institute of Law Enforcement and Criminal Justice, U.S. Department of Justice, GPO Stock Number 2700-0156, May 1972.

This report is the result of an extensive literature search conducted in the field of primary and secondary batteries. It lists terms and definitions pertaining to batteries and their characteristics, reviews basic battery principles and types and assembles performance characteristics of battery systems into chart form for comparison purposes. Includes basic precautions and references to pertinent literature.

9. King, H. E., and Yowell, C. O., "Assessment of Technology Applicable to Body-Mounted Antennas," prepared for the Law Enforcement Assistance Administration, U.S. Department of Justice, Contract No. F04701072-C-0073, Controlled Access, March 1973.

This report was written in connection with a development effort on body-mounted antennas for police transceivers. Although these antennas are not necessarily designed for concealment such as those used with surveillance equipment, there are many common problems and interests in the two applications. The report contains a great deal of analytical and measurement information pertinent to the manufacture and use of surveillance equipment. Subject headings include electrically small antennas, antenna types, antenna and the body, and propagation information.

10. Mason, J. F., "Designers Compete for that Snug Automatic Bug in a Rug," Electronic Design, Vol. 21, No. 20, September 27, 1973, pp. 22-30.

This popularized article discusses many of the modern techniques of electronic audio surveillance and concentrates on devices utilizing the telephone. Both hard wire and transmitting devices are pictured and briefly explained. One page of this article shows the circuit diagram of a common telephone and tells twelve ways of tapping it. Some discussion of countermeasure devices is included near the end of the article, along with some predictions as to what the future will bring in the advancement and sophistication of electronic audio surveillance.

11. NILECJ-STD-0203.00, "NILECJ Standard for Personal/Portable FM Transmitters," National Institute of Law Enforcement and Criminal Justice, U.S. Department of Justice, (in press).

This document establishes performance requirements and methods of test for frequency modulated personal/portable transmitters used by law enforcement agencies. Equipment which meets these requirements is of superior quality and is suited to the needs of most law enforcement agencies. This standard may be referenced in procurement documents and used to determine whether or not purchased equipment meets stated requirements.

12. NILECJ-STD-0208.00, "NILECJ Standard for Personal/Portable FM Receivers," National Institute of Law Enforcement and Criminal Justice, U.S. Department of Justice, (in press).

This document establishes performance requirements and methods of test for frequency modulated personal/portable receivers used by law enforcement agencies. Equipment which meets these requirements is of superior quality and is suited to the needs of most law enforcement agencies. This standard may be referenced in procurement documents and used to determine whether or not purchased equipment meets stated requirements.

13. Oliver, B. M., and Cage, J. M., editors, "Electronic Measurements and Instrumentation," Inter-University Electronics Series, Vol. 12, McGraw-Hill Book Company, New York, N.Y., 1971.

This is a comprehensive book on the theory and techniques of a very wide variety of electrical and electronic measurements. Of particular importance to the subject of this report is chapter fourteen, which deals with measurements on transmitters and receivers. This chapter also includes a comprehensive listing of specifications concerned with radio receiving or transmitting equipment used for communication or navigation purposes. Specifications listed include those of the Electronic Industries Association (EIA), Aeronautical Radio Incorporated (ARINC), Federal Communications Commission (FCC), Military Specifications (MIL) and the Defense Communications Agency (DCA).

14. Olson, H. F., "Acoustical Engineering," D. Van Nostrand Company, Inc., Princeton, New Jersey, 1957, Chapter 8.

This book contains a very detailed chapter covering microphones. Theoretical relationships, equivalent mechanical and electrical circuits, and frequency response curves for the various types are given, along with cross-section drawings to illustrate operating principles. The book also has an excellent chapter on recording.

15. Pollock, D. A., "Methods of Electronic Audio Surveillance," Charles C. Thomas Publishing Co., 301-327 East Lawrence Avenue, Springfield, Illinois, 1973.

This book is presented as an electronics manual for detectives. Following an introductory chapter on basic electricity and electronics, the principles of audio, telephone and radio frequency communication systems are explained. A practical applications section on operational techniques is included, followed by some material on countermeasures. In the concluding section of the book are chapters on legal aspects, administrative control and ethics. An appendix comprising several sections includes a glossary of terms and a partial listing of distributors of audio surveillance devices and essential electronic components. The section on operational techniques is quite explicit in the explanations it gives for installing room bugs and telephone taps of various kinds.

16. Randall, R. H., "An Introduction to Acoustics," Addison-Wesley Press, Inc., Cambridge, Mass., 1951, pp. 240-246.

This is a college text which provides a discussion of various types of microphones, including carbon, capacitor, electrodynamic, and crystal types, and gives a comparison of their relative sensitivities.

17. Rice, L. P., "Radio Transmission and Buildings at 35 to 150 mc," The Bell System Technical Journal, January 1959, pp. 197-210.

Work done in an attempt to determine the relative merits of two frequencies for propagation into buildings is reported and analyzed statistically. Although not greatly different, the 150 mc coverage was found to be better than that at 35 mc in most instances. At both frequencies, reception was better on upper floors of the building than on lower floors, although this latter phenomenom may have been due to the elevation of the transmitting antenna used in the experiments.

18. Shrader, R. L., "Electronic Communication," Second Edition, McGraw-Hill Book Company, Inc., New York.

This book incorporates an electronics and radio communications theory course intended to prepare the reader for examinations required to obtain amateur and commercial Federal Communications Commission radio licenses. A great deal of the material is relevant to electronic surveillance. The book contains an excellent chapter on antennas, including a good discussion of the propagation of radio energy.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This report describes some of the methods and equipment used for electronic audio surveillance. The subject of countersurveillance (defensive) equipment and techniques, while not completely excluded, is confined to the minimum necessary to the understanding of offensive surveillance activity. Both radiating and hard wire methods are discussed along with the advantages, disadvantages and limitations of each. Particular attention is given to the subject of body-worn transmitters and the operational problems associated with their use including batteries and body-mounted antennas. Experimental data is included to illustrate some of the principles and problems surrounding their use. The conclusion includes recommendations of various items for inclusion in a standard for body-worn transmitters. A fairly extensive annotated bibliography is also provided.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Body-worn antenna; bugging; eavesdropping; electronic surveillance; microphones; receiver; tape recorder; telephone; transmitter; wire-tapping.

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