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SOME FACTORS TO BE CONSIDERED IN THE SELECTION OF A LARGE AREA POLICE RADIO SYSTEM

Frank Bramley

(Mr. Bramley's article on "Some Factors to be considered in the Selection and Operation of a large area Police Radio System," is a timely one. It is an expression of some years of experience in organizing and maintaining the Connecticut State Police Radio system—one of the pioneers in the field of state police radio. The article has been written as an aid to the police officer and the radio technician in planning and maintaining a radio installation. Mr. Bramley is Supervisor of Radio Maintenance, the Connecticut State Police, and has been associated with that system since its establishment in 1940.—EDITOR.)

Six years ago, when the State of Connecticut was considering the establishment of a State Police Radio System, the use of a two-way communications system on a state-wide basis was comparatively new and the use of Frequency Modulation completely untried. Today, no one would question the need for two-way communication for police vehicles, and today the use of FM to provide such a service needs no justification. Connecticut was the first to use FM for a state-wide system and remains first, we believe, in methods of use and maintenance. This paper will set forth the ideas behind the Connecticut system, the reasons why it is successful in fulfilling the needs of modern police communication, and the methods to use in planning a similar system.

Primary Considerations

When communications facilities are to be established that will cover a number of cities, towns or other political subdivisions, a variety of factors must be considered. Unfortunately in the past, often the only consideration was political, and the system suffered accordingly. Factors that should be considered in the first instance are the area to be covered and the type of terrain within this area. From these two factors can be decided the type and the power of the stations that will be required. These factors will also effectively determine the minimum number of stations that will be required, but other factors may affect the optimum number. One of the other factors is the administrative organization of the political

or police subdivisions within the area involved. Whereas a certain number of stations might satisfactorily cover an area, it may be more practical to increase the number of stations so that each subdivision will have its own station. If the area policed by one troop should require the use of more than one station, both can be controlled from a single point. This and countless other technical problems are at this stage of the art easily solved.

The system can and must be adapted to the administrative policies of the particular police department in question. No set policy can be suggested that will meet the needs of all large area systems. The prospective user must make his own decisions based upon the known facts and the experience of others.

The Basic Systems of Radio Broadcasting

At the present time there are two basic systems of radio broadcasting available to police. The original system, known as Amplitude Modulation or AM, has been in use for many years and its disadvantages are well known. The great amount of static, interference, noise and fading usually encountered is not easily eliminated.

The new and superior system known as Frequency Modulation or FM, sometimes called PM (Phase Modulation), has come to be the standard system for police. It is inherently free of noise, and station interference is greatly reduced. It is well to point out that the higher quality so much advertised for FM broadcasting is not observed on police FM equipment because such equipment is designed for communication only, not for the reproduction of music.

There are two general frequencies or wave lengths currently available for police use, with the probability of others being made available soon. The low frequencies just below the present broadcast band have been used by police for many years and are presently occupied by many high-powered municipal and state police stations. At night one may hear such stations from all over the country; the interference is terrific. The high frequency band, known as the 30-40 megacycle band, has also been used for some years. It is the only band presently available to police that is adaptable to two-way communication. Interference is much less here because the properties of high frequency waves allow them to travel only short distances. Thus, many stations may operate on the same frequency even though separated by 100 miles or less. Only occasionally do distant stations cause interference. Static from storms is also reduced to a minimum; but ignition noise in mobile receivers

may be a problem. The use of FM type equipment reduces static and interfering noises to the vanishing point and decreases the effects of fading and station interference so greatly that the range of communication is increased from three to six times over that obtained with AM equipment.

Technical Requirements of FM.

Technical requirements of FM make it necessary to use high frequencies. The properties of these high frequencies are such that they may be propagated best over level ground and to the greatest distance when the transmitting equipment is at a high elevation. Because these very short, high frequency waves act somewhat like light waves, there are likely to be shadows behind high hills and in deep valleys. Unless the transmitter is placed upon the highest available point, these shadows tend to become deeper and larger. FM on these frequencies, however, gives results far superior to AM stations on similar frequencies. FM, therefore, gives excellent results even in moderately hilly and occasionally mountainous country such as exists in Connecticut, Massachusetts, and many other states. FM on these same frequencies may not give satisfactory results in truly mountainous areas found, for example, in Vermont, New Hampshire, and many western states. In such areas, systems combining AM and FM, high frequencies and low frequencies, are usually the best answer.

FM on 30-40 megacycles can, under the most favorable circumstances, cover an area as large as 200 miles in diameter, but it is best to consider it as being thoroughly reliable in an area 50 miles in diameter. This allows a sufficient margin of safety to cover extraordinary conditions and to provide strong signals at every point within the area.

Uses of High Frequency and FM.

The use of high frequencies and FM make it possible for each troop of a large state police force to have its own station and to operate all of these stations on the same frequency. In this way each troop knows what the others are doing, and the work of the troops can be co-ordinated by headquarters for any particular area. In Connecticut, each troop conducts its own business through its own station, yet if an emergency arises requiring the co-ordination of several troops, headquarters for the whole state, in Hartford, assumes control. Since in a state of this size each barracks can hear and communicate with every other barracks, such a plan works out very successfully. In larger areas, co-ordination of parts of the whole area would seem sufficient, because if direct communication between stations is not possible because of the distance involved,

relay operations are always practical. Direct intercommunication of main stations in areas up to at least 10,000 square miles should be possible. This would amount to distances of 100 to 150 miles assuming reasonable antenna heights. The range of the cars, of course, is not as great because of their lower power. Their communication range is usually confined to their own or adjacent troop areas. It should be pointed out that conservation of channels (frequencies) available to police is of utmost importance at this time. Use of radio by police and other services has expanded to the point where interference between stations is an extremely serious matter. The contemplated post-war expansion is beyond imagination. Each and every method of channel conservation must be utilized to the utmost.

The use of FM makes it possible for all the main stations to operate on the same frequency because one of the most useful properties of FM is the reduction of station interference. Each car in the field communicates with its nearest station and when this station answers it dominates any other that might be on the air at the same time and no serious interference is caused. All car transmitters are placed on a frequency separate from the main stations so that the car calls to the station will not be drowned out by the more powerful main stations.

Placing cars on a separate frequency might not seem to be conservation of channels but the reverse is true because large area systems could not successfully operate all their main stations on the same frequency unless the cars were on a separate frequency. Even small systems involving only a few cars should use the same principle. This is true because certain channels have been set aside for main stations, and other channels for exclusive car use. Most main stations use higher power and thus carry farther and cause interference at greater distances than cars. As the number of main stations increases, the weaker signals from the cars have less and less chance of being heard. If the cars are on an exclusive car frequency, it is unlikely that interference from adjacent areas will ever seriously interfere, particularly if FM is being used.

Desirability of Car-to-Car Communication

In the usual two-way police radio systems, the car, the main stations, and all associated receiving equipment are tuned to the same frequency. This makes it possible not only for the cars to talk to the main station but also to talk to each other. The very desirable feature of car-to-car communication finds much use whenever two or more cars are working on the same case. It is especially valuable in any serious crime involving

an auto chase or where blockade plans are involved. It is obviously essential that cars be able to communicate directly with each other with no necessity that their signals be relayed through the main station. Yet, in the operation of a large system containing several main stations and perhaps hundreds of mobile units, it is essential that the mobile units be on a separate frequency. An ingenious expedient, called three-way operation, makes it possible for the cars to talk to each other by merely throwing a switch; yet for normal operations, use of two-way avoids interference when talking to their barracks. Since the usual three-way frequency is of necessity the same frequency used by the main stations, the cars can readily substitute for a main station. In Connecticut, this expedient has been used whenever emergency communication was necessary and the main station was temporarily out of service. It is essential that any large area system use this principle.

Remote Point Operation

One of the most outstanding new ideas used in Connecticut was the placing of all the receiving and transmitting equipment at a remote point and operating it electronically over a telephone line. The advantages of such a system are immediately apparent. Police radio equipment has usually been placed at the police station where the man-made electrical noise is terrific. While FM tends to reduce all interfering noises, the limiting factor in any receiving system is still noise. You can't communicate with a station you can't hear. If we place our receiving equipment at some high point far away from probable sources of noise, we shall be able to hear very weak and distant stations more clearly. Likewise, the transmitter will be more efficient because at a high point the waves will carry farther and fill in the deep valleys and behind the lower hills. The efficiency gained makes less power necessary, lowering the cost and the upkeep of the equipment.

The importance of placing radio equipment at remote, high altitude points cannot be over-estimated. We believe there is no single item that contributes more to the success of a wide-area communication system than this method of installation. Such placement however, is not without attendant difficulties. Since the equipment must be controlled from a barracks or police station of some sort, a remote control circuit is necessary. The usual method has been to use a telephone line. Over this line are carried the signals picked up by the receivers, and over this line are sent the voice signals to the cars. The transmitting equipment, and sometimes the receiving equipment, may be turned off and on over this line, too. Such a line must be

maintained in better condition than is usual for rural phone lines because of the multiple and rather delicate control circuits operating over it. If lead-covered cable were available, the troubles would be few; but the usual variety of open wire, rural line is likely to be a great source of trouble, especially if any great length of it is necessary. Many of the troubles likely to be encountered with this sort of control circuit are of a minor nature, but such lines invariably fail completely in any emergency involving ice storms, hurricanes, and heavy snows—just the time when police communications are needed most. Despite these difficulties, remote control by land line is thoroughly practical and in many parts of the country would be reliable.

Under present proposed rulings of the Federal Communications Commission, a special group of radio channels has been set aside for police that could be used to control remote equipment by radio. This method is already being used in some parts of the country, notably New Hampshire and California. It is believed that after the war, this method will entirely supersede wire control. The Connecticut State Police and others already have made plans to use it. In such a system the control point operates a small, low-powered radio transmitter which sends out a narrow beam of radio waves directed at the remote transmitter. These waves are picked up at the remote transmitter, and in turn they control the operation of the regular station. For reception, the signals are picked up as usual at the remote point but are retransmitted by another small transmitter and directed toward the control point, where they are finally received and utilized. While such a system sounds complicated and expensive, actually it is not. The cost of additional equipment will be completely offset in a few years by the rental of the telephone lines usually required. The increase in reliability has been found very great.

Power Supply for Remote Control

Remote equipment must also be supplied with power. In most cases, commercial lines are the most practical source in spite of the fact that their failure is occasionally to be expected. In practice they do not fail nearly so often as the telephone lines because of their more rugged construction; but again, in any really serious storm they do fail and it may be several days before they are repaired. For this reason, it is imperative that an emergency source of power be provided at the remote point. Such a supply is much less costly than one that could provide power on a continuous basis, and the problem of fuel supply is much simpler. The emergency supply must be so arranged

that it will take over automatically, immediately upon failure of the commercial source, and relinquish when the commercial supply returns. In addition, experience has shown that some means must be provided to notify the technicians that the equipment is operating on the emergency power source; otherwise the fuel and battery supply will become exhausted before any remedial steps are taken. Modern electronic knowledge readily solves such a problem.

Even though all radio equipment is located in an urban area, it is still essential, in the light of Connecticut experience, to have an emergency source of power if uninterrupted service is to be provided.

Selection of the Station Site

One of the most important acts in planning a large area communications system is the selection of the station site. The most obvious location will be the troop headquarters building. While this location might be desirable from a standpoint of economy, *it will seldom be satisfactory from any other standpoint.* First, the use of high frequency waves makes a high elevation mandatory; and second, the ignition noise at troop headquarters is invariably high. Troop headquarters will seldom be located on a mountain peak, and the operation of automobile motors near the receiving point raises the noise level to an unsatisfactory degree. We would go so far as to say that if there is any one factor that makes the Connecticut system definitely superior, it is the location of both receiving and transmitting equipment at high altitude, noise-free points. Several installations using similar equipment, but installed in low, noise-saturated locations near the troop headquarters, could be cited. They are failing to give satisfactory results. We make these statements even despite the aforementioned difficulties encountered in remote installations.

There are, altogether, six factors to be considered in the selection of a site. First, the station must be at a high elevation, preferably the highest elevation in the area to be served. Second, such a point should be near the center of the area concerned. If the highest available point is at one edge of the served area it would be better to use a lower point nearer to the center. Third, the selected point should be distant from cities or other probable sources of electrical interference such as high tension power lines, electric substations, or factories. Fourth, a reasonably reliable source of electric power must be available; likewise, telephone lines, if they are to be used for control purposes. The amount of power necessary is unlikely to exceed ten kilowatts, not much more than that supplied to

a small modern home; in fact, the maximum power consumption of a 250 watt FM station and all associated equipment is about three kilowatts. Fifth, the site should be accessible by automobile the year round, since the equipment should be inspected and serviced at least once a month. Sixth, the desired site must be available for purchase or lease. This fact alone can cause considerable difficulty. Often several possible sites must be selected with the hope that one can be purchased for a reasonable sum. A plot 100 feet square is usually sufficient for the building with its tower and associated guy wires. A study of contour maps by the U. S. Geological Survey and consultations with local power and telephone engineers will save much time with respect to the preliminary selection of a site.

The Communications Building

The building should be vandalproof and burglarproof. Connecticut uses a welded steel plate construction although from the standpoint of insulation against extremes of temperature, materials having better insulation qualities are to be preferred. Temperatures in our steel buildings vary between —30° and +150°F. While the equipment is capable of withstanding such variations, it unquestionably would be subjected to less strain if these variations were restricted. Thermostatically-controlled air circulation is provided when inside temperatures exceed —70°F., but no provision is made to heat the building in cold weather. Some degradation of receiver sensitivity is experienced with below-zero temperatures, but loss of sensitivity at low temperatures can be minimized by making readjustments at low temperatures. Technicians readjust the equipment with this in mind and with the change in seasons. Although by no means essential, provision for keeping the temperature in the radio equipment building reasonably constant would be a desirable refinement. A double-walled masonry building with an insulating barrier between the inner and outer walls is probably the most practical means of providing such a feature. That, together with automatic ventilation at high temperatures, would be a worth while improvement. Extremely rugged roof construction must be provided if heavy ice formation on the mast is possible.

Main Station Power Requirements

The power of the main station should be no more than necessary to cover the required area and provide a safety factor. The trend is to increase the ability of receiving equipment to respond to weak signals and to reduce the power of transmitting equipment. This trend is in line with the necessary practice of channel conservation; interference is reduced thereby.

A basic fact, frequently overlooked, is that no improvement in reception will be noted by small changes in transmitter power. The power must be doubled before improvement will be apparent. For this reason, the manufacturers' practice of uprating their equipment is to be decried. There is absolutely no discernible difference between a transmitter rated at 25 watts and one rated at 35 watts except that the power consumption of the 35-watt equipment is likely to be larger. If the 25-watt station is increased to 50 watts, there is a just barely discernible improvement, and, in a police car, the battery use will be about doubled. Fifty-watt transmitters in cars are of doubtful value since oversized batteries and generators must be installed. Twenty-five-watt car installations do not necessarily require such special equipment. They do, however, require a good battery and careful use by the operator. A battery which will start the car is not necessarily one that will properly operate the radio. With the usual extra police equipment, a 40-ampere generator is highly desirable, and a battery capable of withstanding high charging rates, with low internal voltage drop, is essential.

The Police Aerial

Connecticut pioneered the use of the so-called "top aerial." Its efficiency has been demonstrated to be superior to all previous types of police aerials. If maximum coverage with a minimum number of transmitting stations is required for mobile units, this type of aerial is the answer. Not only is it more efficient than any type of "side aerial" but it is also completely non-directional. All types of side or cowl aerials have highly directional properties and it is often found that police cars so equipped can reach their station when proceeding in one direction but cannot do so when moving in the opposite direction. Side-mounted aerials are much used in Connecticut now because we have increased the efficiency of the receiving equipment to the point where top aerials are not absolutely necessary. Cowl-mounted, telescopic aerials are satisfactory in cars used by detectives when the sacrifice in range can be tolerated and the probability of recognition must be minimized. The control unit is mounted inside of the glove compartment in such installations.

Car radio control units are designed so that the operator may turn the loudspeaker off and yet be able to receive instructions through an earpiece. This enables Headquarters to instruct the officer without the knowledge of his passengers. Under difficult reception conditions an earpiece always provides greater intelligibility than does a loudspeaker, and all

cars are so equipped. The microphone in cars must for simplicity be of carbon type, but it has been found that with main stations a definite increase of intelligibility can be obtained by using a higher quality microphone.

Reducing the "Noise Level"

Tests made in moving police vehicles indicate that the noise level due to motor and road surface sounds, air rush, etc., is in the vicinity of 90 decibels and often rises to 110 decibels.[1] Such a volume of noise indicates that every possible precaution must be taken to insure adequate understandability in police vehicles. The angle at which the loudspeaker is mounted and the design of the grill through which the sound is projected is of major importance. Special efforts must be made to mount the speaker so that sound is directed exactly at the eardrum of the officer. This means that the plane of the speaker should be exactly at right angles to a line extending from the speaker to the listener's ear. Probably greater improvement can be obtained by this expedient than by any other method.

A survey has been conducted which indicates that the average age of police officers who use radio is 42.98 years.[2] These figures indicate that the average policeman who has to understand radio signals is probably a person whose hearing has decreased from the optimum by at least ten decibels; because of his age his ability to understand spoken orders by radio is considerably reduced.

Much equipment now being designed for police communication purposes has a very muffled sound; it is very difficult to understand. Care must be taken to select equipment that produces signals that are easy to understand or to insist upon the manufacturer's altering his equipment so that it will be easy to understand. Manufacturers have a tendency to be overzealous in their efforts to reduce noise, with the result that speech intelligibility may be considerably impaired. It is better to have a little noise than to be unable to understand spoken orders that may concern matters of life and death.

At the receiving point in troop headquarters, a volume adjustment readily accessible to the radio operator should be provided, but this adjustment must be of limited action; otherwise the volume is likely to be turned too low and calls missed. Provision for a fully modulated, yet never over-modulated, signal to the cars is most important. An automatic gain control in the control unit speech amplifier takes care of this.

[1] See "The Need for Low Noise Levels and High Intelligibility" by the author. The APCO Bulletin, December 1944.

[2] FCC Allocation Hearings, Washington, Volume II, 11-A (Tr. 2435-2443).

Experience has shown this to be necessary. If telephone lines are used for control purposes, provision must be made to compensate in the equipment for the variations in frequency response of the wire lines.

Reducing Maintenance Cost

Considerable reduction in maintenance requirements will be effected if the following practices are specified:

1. Provide all relays with dust covers.
2. Make all electrolytic capacitators plug-in type.
3. Design Main Station Control Units so that they may be grounded.
4. Make all units readily accessible and quickly removable.
5. Avoid the use of low voltage, electrolytic, cathode bypasses if possible.
6. Avoid the use of multiple paper condenser blocks.
7. Install car control cables in Greenfield conduit.
8. Mount equipment on car rear decks up off the floor.
9. Fasten all cables and wiring to the body at least every foot to prevent damage due to abrasion and vibration.
10. Use generator brush lead wire for flexible antenna pigtails.

The Vital Importance of Qualified Radio Personnel

A complete communications system with every technical refinement is of little use unless the men who control the system understand how to use it effectively. It may seen unnecessary to state something so obvious, but the facts are that a modern system can become so complicated that only highly trained technicians can successfully operate it. This should not be so. Every operation must be made simple and foolproof. Every control must be designed to perform only necessary minimum functions and be simply and completely labeled. The designers must assume that the operators have no technical training whatsoever and take care that every function approaches the automatic.

All radio operators, and this should mean every member of the department, should be trained in the use of their radio equipment not only by adequate instruction, previous to use, but also through frequent, supervised practice. This applies not only to use of radio in the main stations but also in the cars. It is surprising the amount of misinformation about the use of radio that is circulated among men who have not been trained.

Messaging

Messages must be short and businesslike. Nothing can contribute more to this end than the use of suitable codes. Preservation of secrecy is only one of the many reasons for using codes. The following reasons are equally important: Increased speed and accuracy, increased understandability, and reduced interference through reduction of time on the air.

Codes must be simple, easily memorized signals expressing only a minimum number of the most frequently issued orders and the probable replies. As experience indicates the need for more signals, the code system can be gradually extended. In this way the memorization process becomes very easy.

Efficiency in the use of a communications system comes with practice. Encouraging or even requiring frequent use, when the equipment is new, is one of the most desirable methods of familiarizing the officers with their equipment. Strict supervision must be maintained; and heavy penalties imposed for indiscretions or sloppy unbusinesslike use. If this is not done, the tendency is for rapid deterioration to an amateurish and inefficient system.

As an aid to attaining efficient use of a system under all conditions, codes should be set up for the various types of police emergencies that may occur in an area. Efficient operation will come only through frequent, well-supervised use.

Many police radio stations fail to appreciate the value of the two-way feature of the mobile units. Due to habits formed while one-way systems were in use, the car may be neglected. In a well-balanced system transmissions from mobile units should greatly exceed those from the main stations. In fact, the origination of complaints and the reporting of conditions requiring police activity by the mobile unit should nearly equal the number of such incidents originating at headquarters. A function of the mobile unit is to observe and report, and then, under the supervision and possibly with the assistance of headquarters, to act upon the situation. Only radio makes this possible. Station-to-station messages do have importance, but the necessity of radio to provide communication to and from the mobile units is the only valid argument for the continued existence of police radio.