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A MODERN TWO-WAY RADIO SYSTEM*

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Summary—*The general problems and limitations encountered in two-way police communication are discussed. A receiver circuit especially adapted to the adverse conditions imposed upon this class of equipment is described in detail and performance curves are shown. Several transmitters are described and their salient features pointed out. A new type of ultra-high frequency antenna system is described and its general theory of operation explained.*

INTRODUCTION

THE acceptance of radio communication as an essential part of a municipal police system has opened up a new field for the radio engineer. It has presented to him a set of conditions and requirements not heretofore encountered in radio communication. Give a radio engineer an efficient antenna, a skilled operator, and power on the proper frequency, and his communication range far exceeds that required for municipal police service. The conditions presented to him by municipal police radio are quite different; low antennas on a moving vehicle, in many cases unskilled operators, and limited power supply. Modern municipal police radio systems are being put on the higher frequencies with their more or less line-of-sight transmission. The frequencies now assigned by the Federal Communications Commission for experimental use by stations of this class lie between thirty and forty-two megacycles. The choice of this frequency range to localize the communications has made possible two-way communication. Today, two-way duplex radio communications from a moving automobile in a properly equipped city with an efficient maintenance organization approaches the simplicity and reliability of a telephone call from the corner drug store. In fact, a call put through from a car to a wire extension of a police telephone system can often not be distinguished from a call from a regular telephone station.

GENERAL CONSIDERATIONS

Police radio systems in common use today are classified as either "one-way" or "two-way." In a one-way system, headquarters can talk to the cars, but the cars are not equipped with transmitters for reply-

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ing to headquarters. In a two-way system, the cars are equipped with transmitters and can reply to headquarters. Two-way systems are divided into two types, duplex and simplex. When using the duplex system, transmission and reception may be carried on simultaneously as is the case during an ordinary telephone conversation. The simplex system does not permit this feature; i.e., it is not possible to receive when the transmitter is being used, nor is it possible to transmit while receiving a signal.

In the development of police radio communication apparatus, it was necessary to solicit the co-operation of police departments and to consider carefully the merits of these systems with the view of determining which appeared to be the more suitable. After numerous comparative tests, it became obvious that the duplex method offered several major performance features over those which it was possible to obtain with other systems. A number of these outstanding points are listed below.

1. It is the normal method of direct verbal or telephone conversation.

2. It allows messages to be transmitted, acknowledged, and discussed more quickly.

3. It is simpler to operate.

4. It allows the use of telephone extensions on the radio circuit.

5. It allows headquarters to supervise all car-to-car communications.

6. It increases the car-to-car communication range since headquarters acts as a relay station.

Of course, two frequencies are required for a duplex system and only time will tell whether the operational advantages listed above outweigh the additional channel and equipment required.

A block diagram of a complete duplex system is shown in Fig. 1. The car equipment is all controlled from a remote control unit which is mounted on the dashboard of the car. A handset is mounted on top of this unit and it is only necessary to remove this handset to put the car transmitter on the air. The removal of this handset automatically connects the earphone in the handset across the loud speaker. In the event that the operator wishes to listen to this earphone alone, a switch is provided on the loud speaker for turning it off and substituting a resistance load. The remote control unit also contains a calling tone button, a receiver volume control knob, a receiver vernier tuning knob, and two pilot lights, one for the transmitter and one for the receiver. As far as the operator is concerned, this unit is the only one which requires his attention. This remote control unit also has mounted on it a switch for changing the equipment from duplex operation for talking with headquarters to simplex operation for talking between cars. A push button is mounted on the handset for controlling the transmitter plate voltage and shorting the receiver output when simplex operation is used.

Although a good antenna can usually be constructed on police headquarters, the antennas on the car must of necessity be low and, therefore, relatively inefficient. The transmitting antenna usually takes the form of a vertical rod or flexible "fish pole" as long as practical. There has also been developed a bumper antenna for use on the

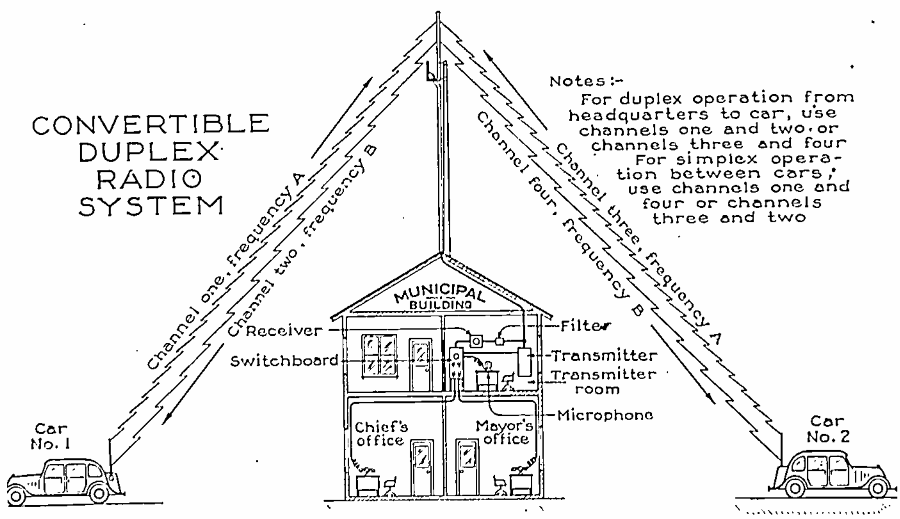

Fig. 1—Municipal police radio installation with duplex operation from headquarters to each car and simplex operation from car to car through the headquarters transmitter.

transmitter when the radio installation must be inconspicuous. This antenna looks exactly like the normal rear bumper and is insulated and fed at one end. Its efficiency as a radiator, is of course, not as great as that of a vertical radiator. The receiving antenna may be the usual roof antenna although, for greatest signal pickup, the transmitting antenna, when this is of the vertical type, should be used. This antenna, when properly connected to the car receiver, usually gives from two to five times the pickup that the roof antenna gives. It is a bit more complicated to use the same antenna for both transmitting and receiving, however. In a two-frequency duplex system, a very sharp filter must be used in the antenna lead to the receiver and in a single frequency simplex system, the antenna must be switched back and forth between transmitter and receiver. The filter used in the two-frequency duplex system must be very selective since the signal on the antenna from the car transmitter may be several million times stronger than the signal from headquarters to which the receiver is tuned. A filter has been developed for this purpose making use of a section of transmission line. The attenuation characteristic of this filter is such that it is possible to obtain satisfactory receiver operation on the same antenna which is being used to radiate the signals from a fifteen-watt transmitter only four per cent removed in frequency.

A car receiver used in this class of service is of the fixed tuned variety and is required to stand by on a given frequency waiting for calls. The time of receiving signals runs from approximately fifty per cent of the time on a busy day in a large city to approximately five per cent of the time in a small municipality giving half-hour routine calls. The receiver, then, must be on frequency when the call comes and for most efficient operation should be silent between calls. These two points are considered in more detail later in this paper.

The car transmitter for this class of service must be ready for instant operation and yet not draw any power from the car storage battery in the stand-by condition. Therefore, filament type tubes are more suitable than the indirect heater type with their longer warming-up period.

The Receivers

A police radio receiver must necessarily meet service demands that are unusually severe. The receiver must not only be of sturdy mechanical construction to withstand the vibration and shocks encountered in mobile service, but, also, should have an electrical design which incorporates features for meeting the adverse reception conditions that are frequently encountered.

Let us consider, for example, a patrol car that is operated in one of the larger cities. In such cases, the car may be operating in the midst of heavy traffic, surrounded by high buildings containing much steel work and, of course, in close proximity to various types of electrical systems, each of which acts as a potential source of interference to radio reception. To function satisfactorily in an area of this nature, the radio receiver should possess electrical characteristics which provide for (1) maximum rejection of electrical interference; (2) exceedingly rapid and effective automatic volume control, and (3) excellent sensitivity. Even in the small municipalities where reception conditions are, in general, better than those encountered in the larger metropolitan areas, it will contribute substantially to the over-all performance of the system if the car receivers possess the above electrical features.

For quite some time, radio engineers have known that both the superheterodyne and superregenerative principles of reception possess very desirable electrical characteristics. However, neither principle in itself appeared to afford all that was desirable in a receiver. In the development of a receiver for police service, a circuit was needed which would provide for the electrical performance mentioned above, and at the same time give stable and reliable operation. With these points as an objective, a receiver was developed which, in effect, incorporates the most desirable features of both the superheterodyne and superregenerative performance. In brief, the combination of a superre-

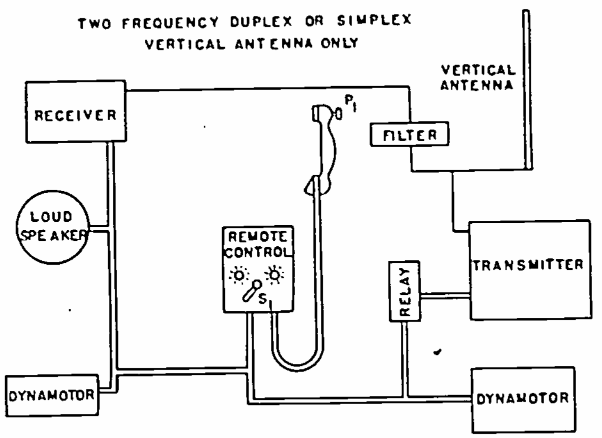

Fig. 2—Block diagram of patrol car installation with duplex operation from car to headquarters and simplex operation from car to car through the headquarters transmitter.

generative second detector with the standard principle of superheterodyne action has made possible the production of a police radio receiver unit which possesses great sensitivity, almost entirely excludes interference from automobile ignition systems and other similar electrical devices and with an automatic volume control that is remarkably fast.

The advantages to be gained through the use of a receiver of this type will, it is believed, become more apparent through the points brought out in the following sections:

Noise Suppression

The interference to police radio reception which is occasioned by the operation of electrical machinery, appliances, electric trolley systems, and automobiles is a matter of great importance and, therefore, merits very careful consideration. It has been found that receivers which are quite satisfactory for reception in rural localities are practically unusable in metropolitan areas where many electrical devices are in use. Of the various forms of electrical interference that may be encountered from time to time perhaps that originating from automobile ignition systems is the most troublesome. Fig. 3 shows two oscillograms in which the effect on reception due to near-by automobile ignition is pictured. The lower oscillogram shows the audio output of an ordinary superheterodyne police receiver, while the upper oscillogram shows the audio output of a similar receiver using a combination of superheterodyne and superregenerative circuits. The vertical

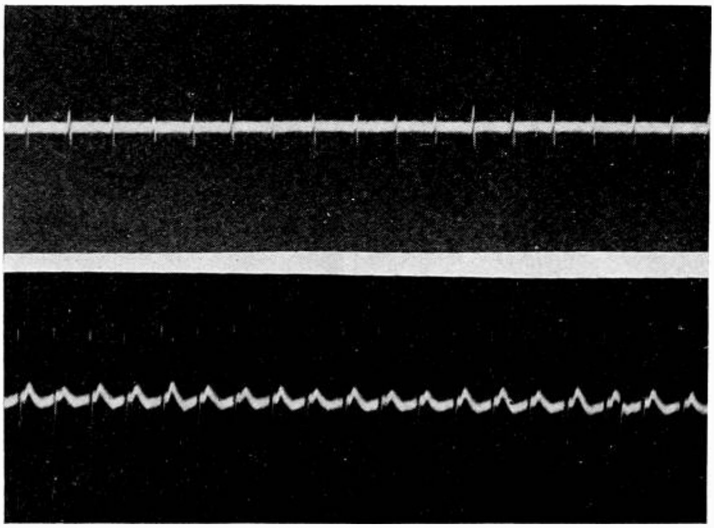

Fig. 3—Oscillograms showing the quenching effect on noise of the combined superheterodyne-superregenerative receiver.

lines which appear at regular intervals indicate the magnitude of interference originating from an automobile ignition system. A comparison of these two oscillograms very strikingly shows the quenching effect on this interference that is produced by the use of a superregenerative second detector.

Automatic Volume Control

At frequencies available for use by municipal police organizations, the signal strength of the transmitter will vary in intensity as the distance between the transmitter and receiver is increased and, also, further variations may be produced due to the presence of structures which absorb or reflect the signal. It follows, therefore, that a mobile receiver is called upon to meet field strength variations which quite frequently are found to undergo a 100:1 ratio within a linear distance of two or three feet. It is at once obvious that an extremely rapid automatic volume control is necessary in order to maintain the signal at the proper level whenever such a condition is encountered. Due to the inherent nature of a superregenerative circuit to produce automatic volume control, such a receiver as is here described will deliver a loud speaker output that is substantially constant under extreme conditions of antenna input variation.

Sensitivity

It is a well-established fact that a superregenerative circuit is capable of producing unusually high sensitivity. By combining the

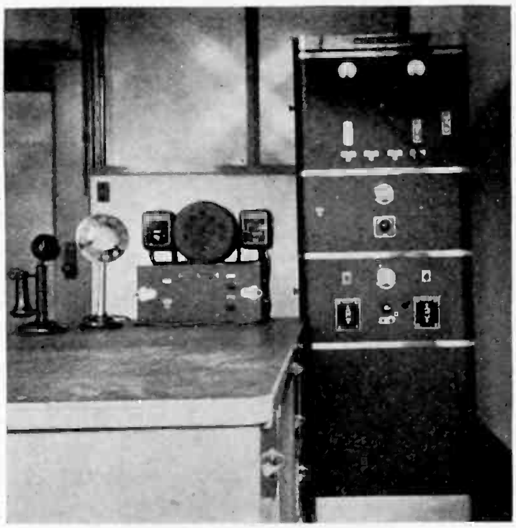

Fig. 4—75/150-watt 30- to 42-megacycle transmitter and superheterodyne-superregenerative receiver using two antennas installed in Hamilton, Ohio.

superregenerative feature with a superheterodyne, which in itself has good sensitivity, the resultant sensitivity of the arrangement is ample for meeting unusually strenuous service demands.

The combined principles that are utilized in the circuit of this receiver are such as to eliminate effectively the difficulties that have sometimes been encountered in the past in connection with superregenerative equipment. It has been possible to provide the salient electrical features outlined herein and, at the same time, maintain good audio quality that is substantially free from hiss, features that are not found in ordinary receivers employing the usual method of superregeneration.

The ability of the superregenerative detector to discriminate against ignition interference depends upon the relative duration of the oscillatory condition, and for best performance, the ratio of carrier frequency to quench frequency should be kept at 300 or greater.

In consideration of this fact, there are two paths open to the receiver development engineer; either to make a straight superregenerative receiver with its two disadvantages of poor selectivity and reradiation or to combine the superregenerative principle with the superheterodyne principle to get the advantages of both.

There are two methods of combining these two principles in a receiver. One way is first to convert to an intermediate frequency in

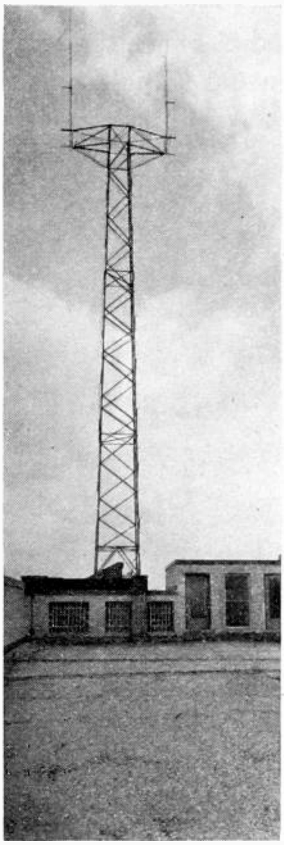

Fig. 5—The transmitting and receiving antennas installed on one tower in Hamilton, Ohio.

the neighborhood of 3000 kilocycles and, after getting selectivity at this frequency, convert again to a relatively high frequency, say 25,000 kilocycles, and then design the superregenerative detector to operate at this frequency. In this way the superregenerative detector operates at a frequency where good noise discrimination can be obtained and yet the selective circuits in the intermediate-frequency amplifier are tuned to a low enough frequency so that excellent selectivity can be obtained. Another method of combining the two principles into a single receiver is to convert to an intermediate frequency which is approximately 300 times the quench frequency. For example, if a quench frequency of thirty kilocycles is used, design the superheterodyne converter to give an intermediate frequency of 9000 kilocycles and then design the superregenerative detector to work directly at the output of the intermediate-frequency amplifier. This method makes a much simpler receiver for police use and at the same time gives ample selectivity and noise discrimination.

Although it is possible to adjust the superregenerative detector in the laboratory so that the hiss is not objectionable, it is impossible to hold this adjustment over long periods of time in police service under conditions of varying supply voltage, temperature, and humidity. Also, the best adjustment for sensitivity and noise elimination does give some hiss. Of course, this hiss disappears when a carrier is present at the receiver but, in police service, the receiver is standing by at maximum sensitivity a great deal of the time waiting for a signal to appear. It is, then, very desirable to incorporate in this receiver, as in any police receiver, a carrier-off noise elimination circuit. In this receiver, the superregenerative detector is adjusted well into the hiss area and then a carrier-off noise suppressor circuit is used to cut off this hiss when the headquarters transmitter is off the air. Of course, the presence of the headquarters carrier which opens this noise suppressor circuit also causes the superregenerative detector to stop hissing and so, in a properly operating system, the hiss is seldom audible within the reliable service area.

The adjustment of this noise suppressor circuit can be varied in the service shop and is set for the conditions to be encountered. A receiver which is to work in areas of high signal strength and extreme noise would be adjusted to a less sensitive condition than one to operate in rural areas of weak signal strength and low noise.

The phenomenon used to obtain a carrier-off noise suppressor is that the plate current of the superregenerative detector decreases with the presence of a signal on its grid.

A schematic diagram of the superregenerative circuit and the noise suppressor is shown in Fig. 6. It can be seen from this schematic that the direct voltage between point A and ground will increase with the presence of a signal on the grid of the superregenerative tube since its plate current will decrease. N_1 is a neon glow tube which will have a constant voltage drop across it when it is glowing regardless of the current through the tube. All of the voltage change at point A is then transferred to resistor R_{91}. This voltage change is used in such a way and is of sufficient amplitude to cause the high-mu audio amplifier tube V_5 to be cut off in the no-signal condition and to work at normal bias when a signal of two microvolts or more is present at the input of the receiver. The small copper oxide rectifier, RTX_1, is connected as shown to prevent the bias on V_5 from becoming more positive than

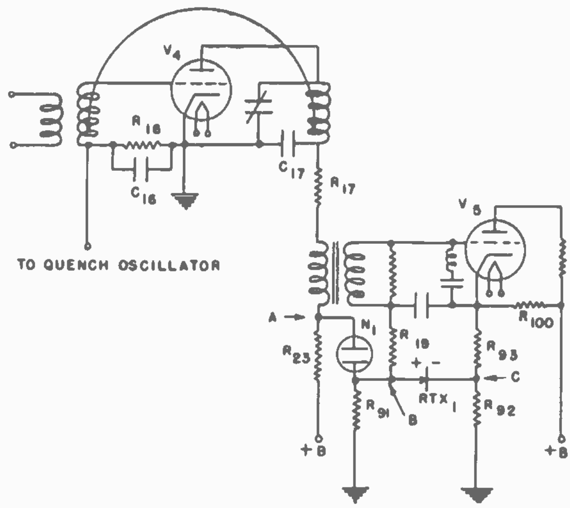

Fig. 6—Schematic diagram of superregenerative circuit and carrier-off noise suppression circuit used in model 4SH2A1 receivers.

its normal operating bias when high signal levels are present at the receiver input terminals.

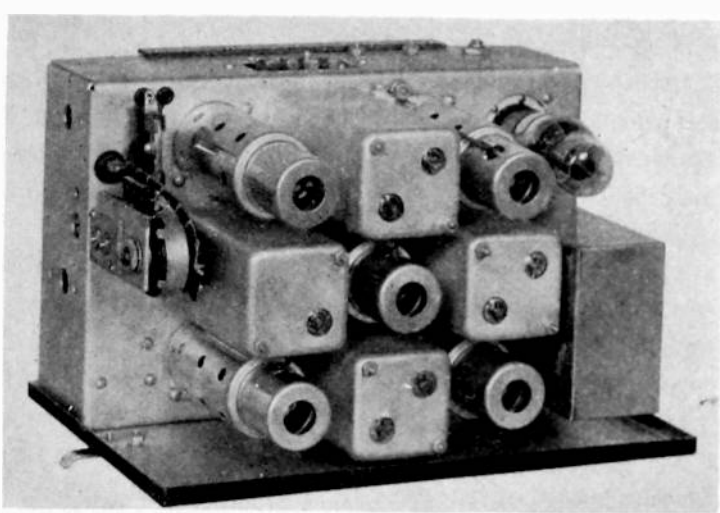

Fig. 7—Superheterodyne-superregenerative car and station house receiver chassis model 4SH2A1.

In order to take care of variations in signal strength in excess of that which the superregenerative detector can take care of alone, the conventional type of automatic volume control is used also. This makes the output response substantially flat over wide variations of signal strength. Fig. 8 shows the automatic volume control curve of the 4SH2A1 receiver.

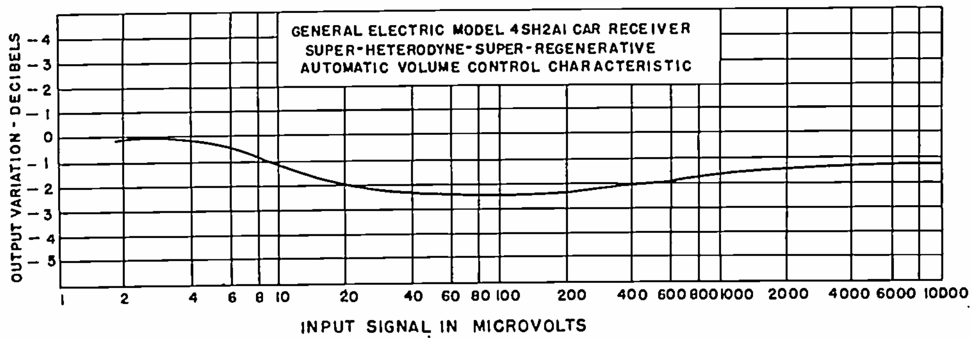

Fig. 8

The police car receivers here described employ a dynamic type loud speaker capable of giving excellent reproduction of the voice frequencies. The over-all fidelity of the receiver is shown in Fig. 9.

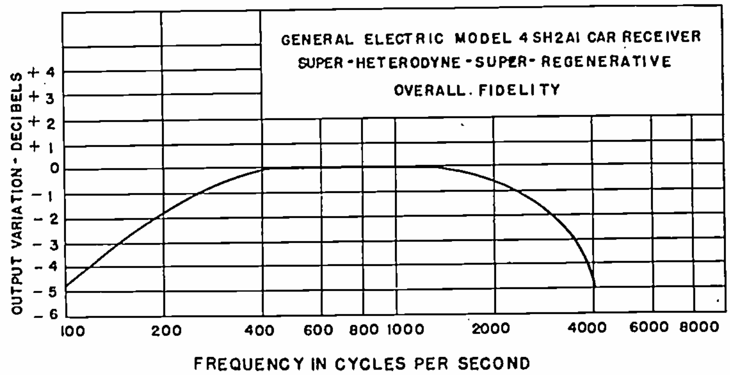

Fig. 9

Another important feature in police radio equipment is that of making the equipment so that it can be quickly repaired or replaced. These receivers are held in their cases by snap catches and the same receiver chassis will fit into either a car or headquarters installation. This simplifies the stocking of spares and makes it unnecessary for the serviceman to become familiar with more than one chassis.

The Car Transmitter

The car transmitter for municipal police service also has imposed upon it a unique set of adverse conditions. It may be required to operate at a temperature of minus forty degrees centigrade or of plus fifty degrees centigrade. It is required to do this under conditions of extreme shock and vibration day after day without attention. It must usually be placed at the rear of the car in the trunk or under the rear deck to be near the antenna. This is the point of greatest throw when

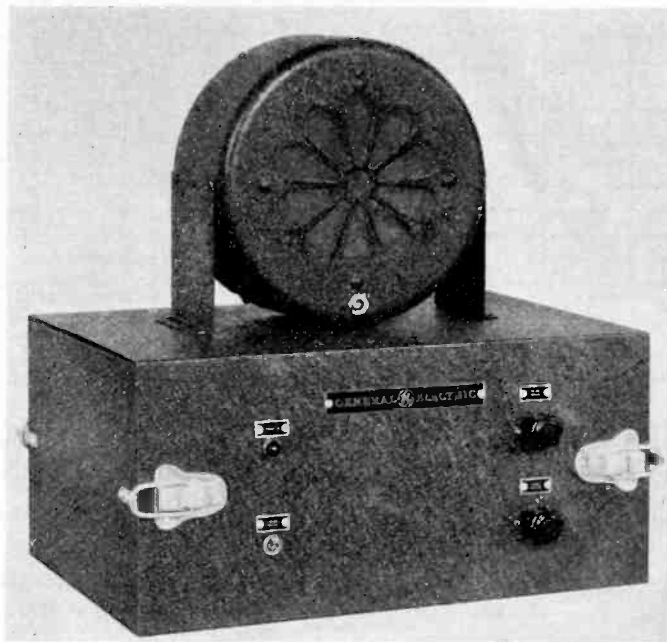

Fig. 10—Superheterodyne-superregenerative station house receiver model 4SH3A1 for municipal police use, 30 to 42 megacycles.

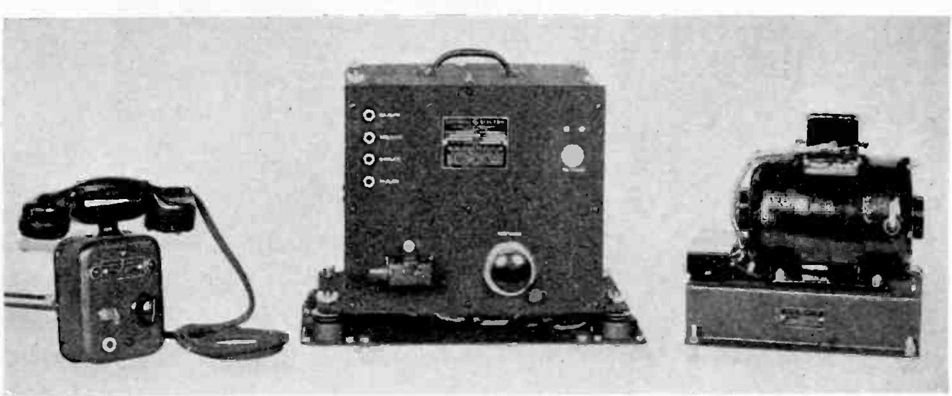

Fig. 11—Control unit, 15-watt 30- to 42-megacycle car transmitter model 4G1A1 and six-volt dynamotor unit used in municipal police patrol car installation.

riding over rough roads. The transmitter should take no continuous drain from the storage battery and yet be ready for service in a time not exceeding two or three seconds after turning it on. The transmitter is thus not given any warming-up period and must be on frequency every time it is turned on. Its frequency stability is of prime importance since the operator at headquarters does not have time to tune his receiver for every call nor does he know when a call is about to come in. In order not to require a special storage battery, the car transmitter must be as efficient as possible in order to insure maximum power output with minimum power input. Frequency stability, ruggedness, and efficiency cannot be overstressed in this class of equipment.

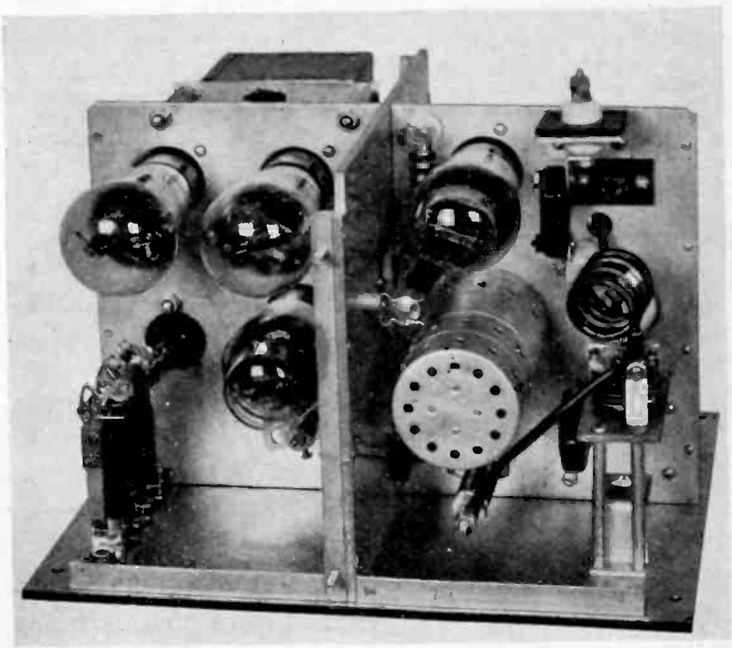

Fig. 12—The 15-watt car transmitter model 4G1A1 removed from its case.

The transmitter which has been developed to operate under these conditions makes use of five tubes. A type 47 tube is used to amplify the voltage from a double button carbon microphone. This 47 tube drives two 46's in class B push-pull. These 46's modulate a 2A3 power amplifier which is excited by a 2A3 master oscillator. This tube complement will give fifteen watts output 100 per cent modulated. It uses a specially designed master oscillator with very high frequency stability. This power output is made possible by the proper choice of high quality component parts and low loss connections throughout.

Only low loss insulation is used in the radio-frequency circuits of this transmitter and both the master oscillator and power amplifier coils are made of silver-plated copper tubing to insure low loss and good contact at the loading tap on the power amplifier coil. All tank connections in the master oscillator and power amplifier circuits are made with heavy cadmium-plated copper strips.

The transmitter is of extremely rugged construction as shown in Fig. 12. It is laid out in the form of a cross with the speech amplifier and modulator tubes in one section, the iron-core devices in the second section, the master oscillator parts in the third section, and the power amplifier parts in the fourth section where they are accessible for connection to the antenna.

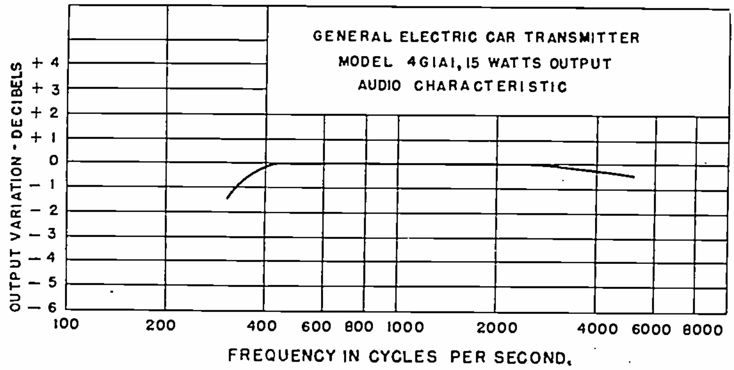

Fig. 13

The transmitter has four test jacks on its panel for checking its adjustment during operation. These jacks permit checking the plate current of the speech amplifier, the modulator, the master oscillator, and the power amplifier. Thus, it is possible to check rapidly the operation of the tubes in the transmitter and to adjust neutralization and loading without disturbing the installation of the equipment in any way. By talking into the microphone or pressing the tone button, the modulation can be checked. These jacks are indispensable in servicing or adjusting the transmitter.

The frequency characteristic of this transmitter is shown in Fig. 13. Full advantage is taken of this characteristic by the use of a double button carbon microphone which is mounted in a handset.

The model 4MA1A1 frequency monitor shown in Fig. 14 has been designed for checking and setting the frequency of the car transmitter.

This frequency monitor uses a low temperature coefficient crystal and the crystal oscillator coil is an integral part of the crystal plug-in unit, thus making it extremely easy to change frequency.

The Headquarters Transmitter

The power output of the transmitter at headquarters, of course, depends upon the service area to be covered. It is not the purpose of this discussion to set up coverage limits versus transmitter power output. This problem has been covered in The National Electrical Manufacturers Association Publication No. 35–27 dated August, 1935. This is largely a function of local conditions, both natural and man-made, of the antenna height and of receiver sensitivity.

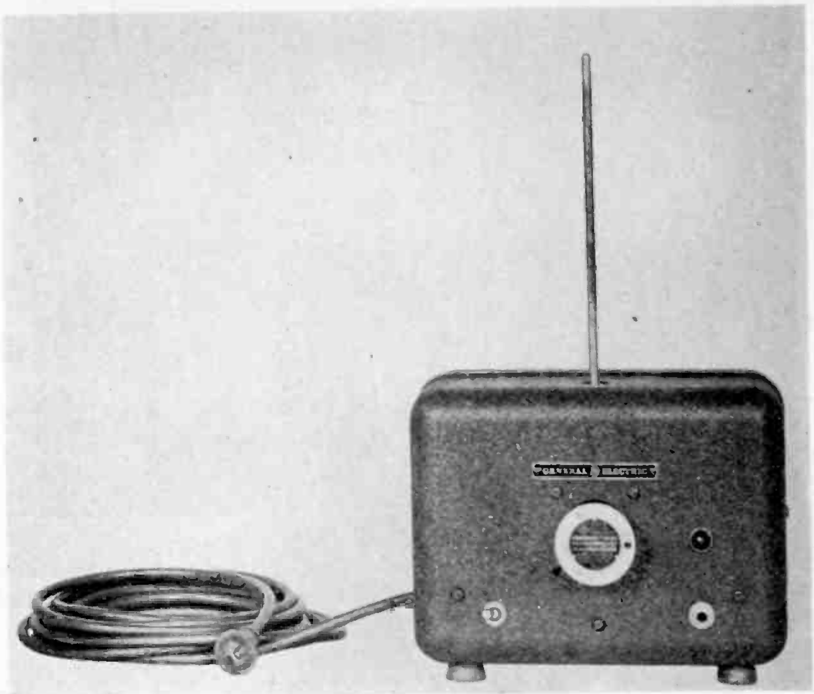

Fig. 14—Crystal controlled frequency monitor, 30 to 42 megacycles, for checking frequency settings.

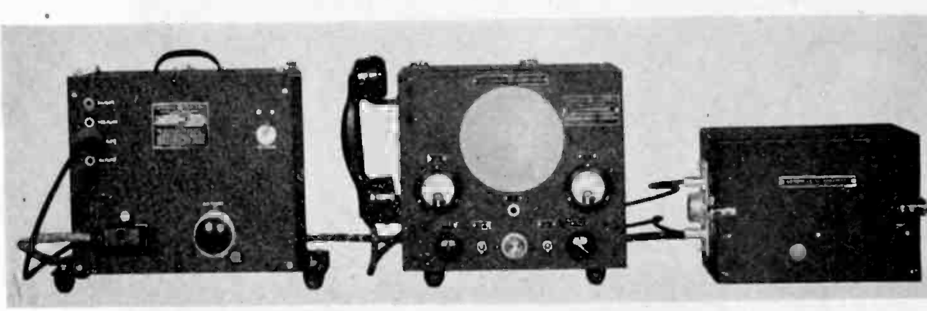

Fig. 15—General Electric 30- to 42-megacycle two-way radio communication equipment for police station house.

The present tendency is for the municipal police assignments to be in the thirty to forty-two megacycle band and, therefore, there has been developed a line of transmitters for use in this band, ranging in output power from fifteen watts to 1.5 kilowatts.

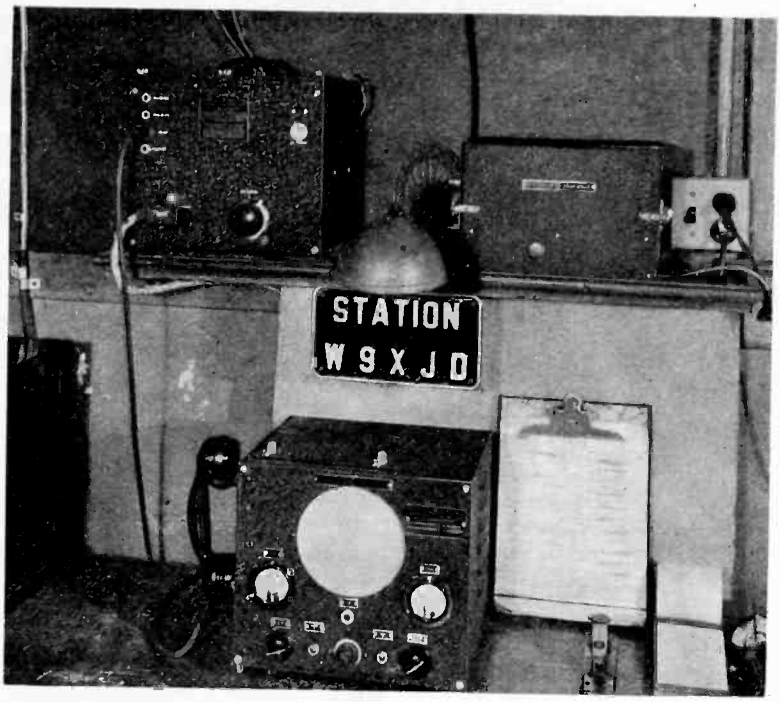

Fig. 16—Fifteen-watt 30- to 42-megacycle transmitter and superheterodyne-superregenerative receiver working from a common power supply and on a single antenna installed in Whiting, Indiana.

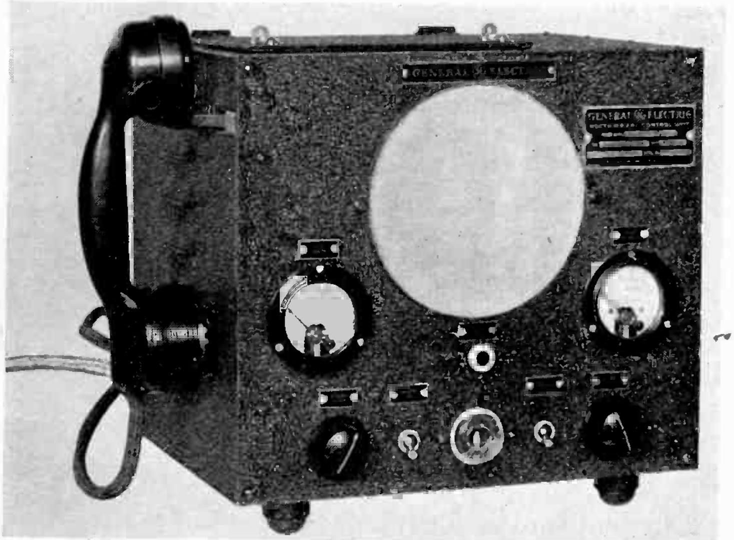

Fig. 17—Rectifier and control unit model 4MR1A1 for 15-watt 30- to 42-megacycle transmitter and receiver used in two-way police radiotelephone communication system.

The fifteen-watt headquarters transmitter is identical in every respect both mechanically and electrically with the fifteen-watt car transmitter. When operated as a headquarters transmitter, it is, of course, alternating-current operated using the same rectifier power supply for both transmitter and receiver. This single power supply and interchangeability of transmitter chassis and receiver chassis with those in the car installation greatly simplifies the problem of servicing

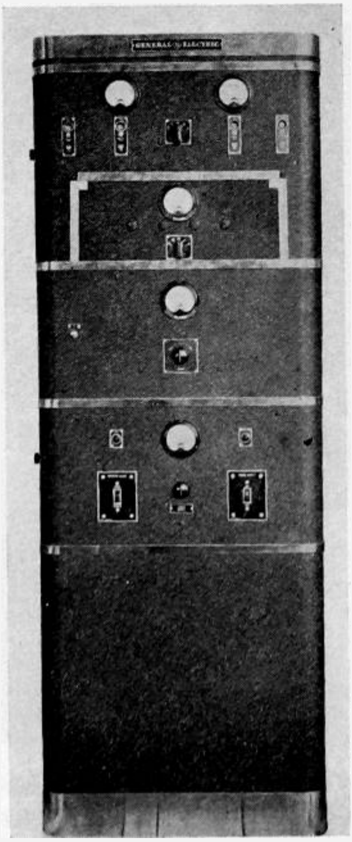

Fig. 18—75/150-watt 30- to 42-megacycle radiotelephone transmitter model 4G2C1 for municipal police use.

and stocking of spares. Such a headquarters equipment is shown in Fig. 15.

The 75/150-watt transmitter for 110- or 220-volt sixty-cycle operation has many unique features. It is designed for either local or remote control and for operation with either an open-wire or a concentric tube type of transmission line. The unit is of sectional design with rounded corners, black crackle finish, and stainless steel trim. The meters and controls are logically and conveniently arranged. This transmitter is shown in Figs. 18 and 19.

The rectifier unit contains two complete rectifiers; one to furnish voltage to all of the high voltage vacuum tubes and the other to provide for the low voltage tubes. Both of these rectifiers are of the mercury-vapor type. The high voltage rectifier tubes are protected by a time delay relay which prevents voltage from being applied to them before the filaments have reached their correct operating temperature.

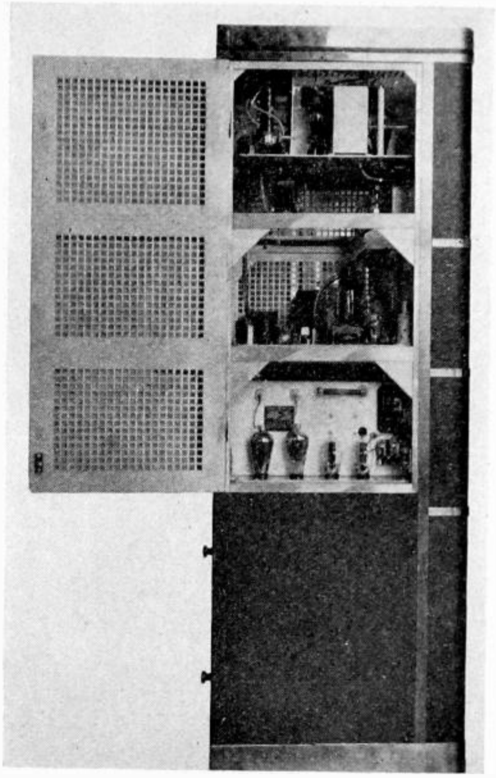

Fig. 19—75/150-watt 30- to 42-megacycle radiotelephone transmitter model 4G2C1 with side shields removed.

The transmitter is crystal controlled using a special low temperature-frequency coefficient quartz crystal which is practically unaffected by ordinary room temperature changes. This crystal operates in the band five to seven megacycles and the output of the transmitter in the band thirty to forty-two megacycles is within plus or minus 0.02 per cent of the assigned frequency for all normal temperatures encountered in a police headquarters installation.

The crystal oscillator is a type 802 pentode driving an 802 frequency tripler which in turn drives an 802 frequency doubler. Another 802 is used as the first intermediate power amplifier which drives the second intermediate power amplifier consisting of two 800's in push-pull.

This second intermediate power amplifier drives the power amplifier which consists of two 800's in push-pull in the seventy-five watt equipment and four 800's in push-pull parallel in the 150-watt equipment. A meter is located on the panel of the power amplifier compartment which can be used for monitoring the power amplifier plate and grid currents and the intermediate power amplifier plate current by means of a rotary selector switch. Operating personnel is positively protected from high voltage by means of door interlocks. A large storage compartment free from live wires is provided for the storage of spare tubes, etc.

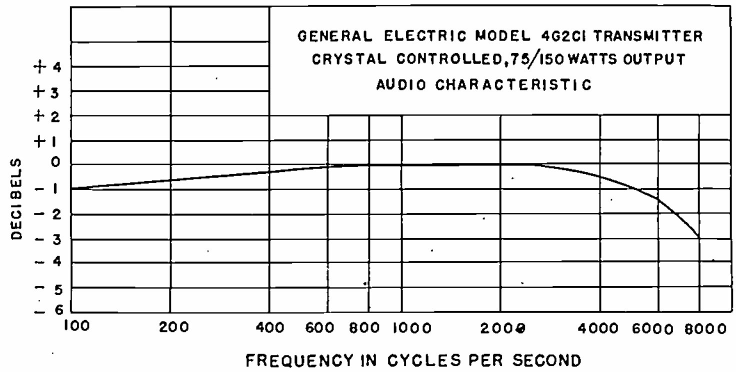

Fig. 20

This transmitter is capable of 100 per cent modulation either by voice or by a 1000-cycle calling tone. When modulating by voice, the output of the double button carbon microphone is amplified by a type 57 tube, the output of which drives a type 56. When modulating by tone, this type 56 tube is driven by another type 56 tube in an audio oscillator circuit. The output of the 56 drives two 2A3's operating push-pull class AB. These in turn drive two FP-146's working class B which fully modulate the radio-frequency power amplifier with a total harmonic distortion not exceeding nine per cent. The frequency characteristic of this transmitter is shown in Fig. 20.

Ultra-High-Frequency Antenna System

An end-fed vertical half-wave radiator has several advantages over other types of antennas for municipal police use. Among them may be mentioned the symmetrical horizontal field pattern and the amenability to installation on top of a tower, building, water tower, or other structure. In order to utilize a concentric transmission line, which inherently has a low surge impedance, to excite the half-wave radiator from the end, a quarter-wave impedance matching section is resorted to. To obtain the utmost efficiency of energy transfer, a method of connection has been developed which reduces the standing waves on the transmission line to a negligible value.

Fig. 21 shows the arrangements of the antenna system. The quarter-wave impedance matching section is short-circuited at the bottom and the grounded outer transmission line conductor connects to the short-circuiting bar. In as much as this point is at practically zero radio-frequency potential, the antenna system may be here connected to a

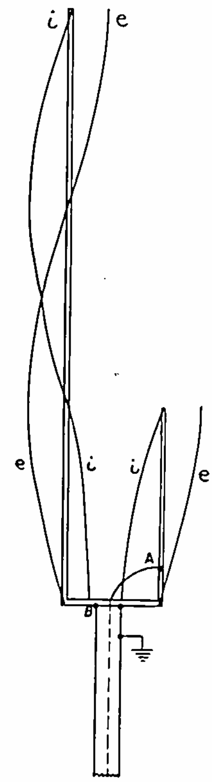

Fig. 21

grounded supporting structure, thus affording an easy method of mounting, and at the same time obtaining lightning protection.

It will be noted that the half-wave radiator is an extension of one of the quarter-wave conductors so that the antenna load is not reflected symmetrically to the quarter-wave transformer. By connecting the transmission line inner conductor to a correctly chosen point, *A*, and the outer conductor to point *B*, and by *properly dimensioning* the entire system, the quarter-wave section can be balanced, and the transmission line terminated in its surge impedance.

The concentric transmission lines are of usual construction utilizing isolantite beads to maintain the inner conductor coaxial. It is interesting to note that the three-eighth-inch line, which would have a surge impedance of seventy-two ohms if no beads were present (optimum ratio of diameters for minimum losses), actually has a surge impedance of forty-nine ohms due to the increased capacity per unit length. Thus, when transmitting an unmodulated carrier of fifteen watts, the radio-frequency voltage existing on the line is only 27.2 volts. The advantages of this antenna system may be briefly summarized as follows:

1. Properly matched throughout, thus obtaining maximum energy transfer to the antenna.

2. No feeder wires, guy wires, or other structures directly in the field of the antenna to alter its radiation pattern.

3. Entire antenna system at direct-current ground potential thus affording lightning protection.

4. Unaffected by the elements as are two-wire line antenna systems.

5. Adaptability of installation.

Concentric Band Elimination Filter

To obtain two-frequency duplex operation for mobile units, a vertical rod attached to the rear of the car has usually been used for transmitting while the horizontal antenna in the roof of the car has been used for receiving. It was soon recognized that this arrangement was not ideal because of the vertical polarization of the transmitted wave from the fixed station. This together with the advent of the steel-topped car, spurred on the development of a band elimination filter which would permit duplex operation with a single rod antenna.

Those familiar with high-frequency filter design are cognizant of the difficulties encountered and the practical impossibility of using lumped constants to obtain a transducer with sharply defined filter characteristics at ultra-high frequencies. This, of course, is due in part to the high resistance of an inductance and the low inductive reactance obtainable because of stray capacities, and results in a low circuit Q. This, in turn, results in poor filter characteristics, lack of selectivity, and attenuation in the pass bands comparable to that in the attenuated bands.

The concentric band elimination filter exhibits a high Q, a sharply defined impedance versus frequency characteristic with a high maximum impedance at the elimination frequency, and a pass characteristic at frequencies closely adjacent to that to be attenuated. Figs. 22 and 23 show the two fundamental arrangements. Observe that in Fig.

22, the free end is open-circuited, while in Fig. 23 the free end is short-circuited.

The concentric transmission line shown in Fig. 22 has an electrical length equal to one wave length at the frequency to be attenuated. The input is at the left end and the output is tapped off either at a point one-quarter wave length from the free end or at a point three-quarters wave length from the free end. In general, the open-ended type may be any number of half wave lengths long at the frequency to be attenuated and the output tap may be made at any point which is an odd number of quarter-wave lengths from the free end.

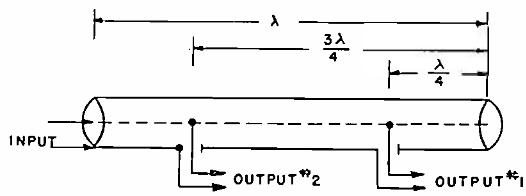

Fig. 22

The line shown in Fig. 23 is of the closed-end type; that is, at the free end the inner conductor is short-circuited to the outer conductor. In this type, the electrical length may be any number of odd quarter-wave lengths, three or greater, and the output tap may be made at any point which is any number of half-wave lengths from the short-circuited end.

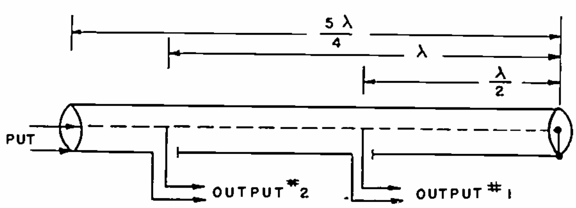

Fig. 23

When the outer transmission line conductor is grounded and the filter excited by applying a voltage whose frequency is f_t, a standing wave will exist on the inner conductor. For purposes of discussion and explanation of the band elimination characteristic, we need consider only the inner conductor and the standing waves of voltage thereon.

Fig. 24 shows three standing voltage waves in an open-ended line whose electrical length is one wave length at frequency f_t. Frequency f_h is higher than f_t and f_L is lower than f_t. It is apparent, from Fig. 24 and the general theory of standing waves on wires, that at the quarter-wave and at the three-quarter wave points practically no voltage exists at frequency f_t. However, at frequency f_h or f_L, a voltage does exist at the output points. At the quarter-wave point, the ratio of output to input voltage at frequency f_h is e_7/e_3, at frequency f_L is e_5/e_2.

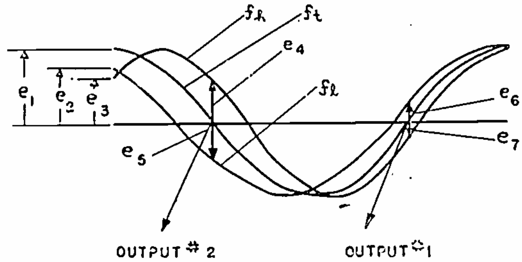

Fig. 24

The analysis of the closed-end type is similar to that of the open-end type, the difference being that at the free end of the closed type, the voltage is always zero instead of a maximum as in the open-end types. Fig. 25 shows the standing wave voltage plot for the closed-end type five-fourths wave length long.

It will be noted that a multiplicity of possible output points exists in each type of filter dependent upon the electrical length of the filter. At each of these output points, the voltage to be attenuated, at frequency f_t, is the same practically zero value. However, at frequencies other than f_t, the ratio of output to input voltage will, in general, be different at each output point.

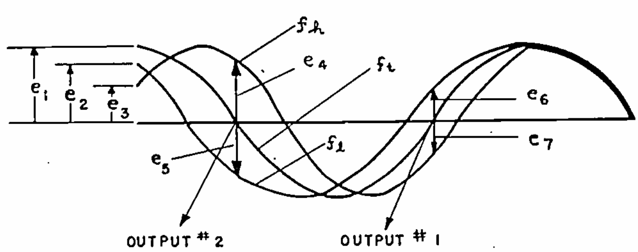

Fig. 25

Incidentally, the use of the filter is not limited to mobile units. A number of headquarters installations have been made wherein a filter and single antenna system have performed very satisfactorily in two-frequency duplex operation.

The operational details of the filter may be summarized as follows:

1. The filter is connected between the transmitting antenna and the receiver and operates in the thirty- to forty-two-megacycle band.

2. It is designed to attenuate the transmitted frequency.

3. Satisfactory operation of the receiver in conjunction with a fifteen-watt transmitter at frequencies to within four per cent of the transmitted frequency can be achieved.