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NRL REPORT 3627

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DIRECTIVE COMMUNICATION SYSTEM WITH MUTUALLY ALIGNING ANTENNAS

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DIRECTIVE COMMUNICATION SYSTEM WITH MUTUALLY ALIGNING ANTENNAS

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ABSTRACT

A basic directive communication system with mutually aligning antennas has been developed for shipboard use. This system promises to provide more reliable communication and greater security from enemy interception and jamming. The system has been operated in the Laboratory, and on river trials with one terminal mobile. It has been found that the direction indicator and antenna control circuitry, which are essential in a system of this type, perform reasonably well. It is planned to attempt to develop this basic system into an improved automatic directive communication system for Naval use.

PROBLEM STATUS

This is an interim report on this problem; work is continuing.

AUTHORIZATION

NRL Problem No. R01-13R
BuShips Problem No. S1427
NR 501-130

DIRECTIVE COMMUNICATION SYSTEM WITH MUTUALLY ALIGNING ANTENNAS

INTRODUCTION

At present it is general practice for Naval shipboard communication systems to employ antennas having as nearly as possible an omnidirectional pattern in the horizontal plane. This practice permits communication to stations in any direction. Even after the very-high and ultra-high frequencies were utilized increasingly for shipboard communication, omnidirectional antennas still continued to be used. However, at these frequencies the antenna size required is so reduced that it is practicable to use directive antennas as a means of improving communications. The increased gain obtained through the use of directive antennas will provide more reliable communication at frequencies now used by omnidirectional systems, and may permit satisfactory communication at higher frequency ranges which will not provide reliable omnidirectional communication. In addition, in military applications the directive system will offer greater security from enemy interception, direction finding and jamming.

Although directive communication offers these particular advantages, in mobile applications the advantages can not be realized unless the directive antennas at the terminal stations can be mutually aligned, and held in alignment regardless of the movements of the individual mobile stations. An experimental directive communication system embodying the control circuits required for directive antenna alignment is under development. This directive communication system is described in this report.

GENERAL DESCRIPTION OF THE SYSTEM UNDER DEVELOPMENT

In the basic system a directive sense is obtained from a continually rotating directive search antenna which intercepts a signal from a calling station having any bearing relative to the ship being called. To insure contact, the calling signal must possess an omnidirectional characteristic. In order to obtain the maximum range possible for the system, a call is transmitted by a directive antenna while it is rotated through one complete revolution; or if the bearing of the desired station is known, the antenna may be directed toward the desired station before the call is transmitted in order to avoid possible enemy direction finding from other bearings. This calling antenna is also used for communication.

The procedure necessary to establish communication is indicated in Figure 1. When Station 1 transmits a call in the manner described above, a directional sense is determined by Station 2, and its antenna control circuits align the communication antenna upon the calling ship. When the antenna is aligned, Station 2 then transmits a guidance signal to Station 1 using its aligned communication antenna. Station 1 then uses this guidance signal through its continually rotating search antenna to establish direction, and then aligns its communication antenna. When the positioning of Station 1 antenna is completed, directional communication may be carried on between the two stations. As shown, each station requires a rotating search antenna to establish direction, and a communication antenna for transmitting both the guidance and communication signals.

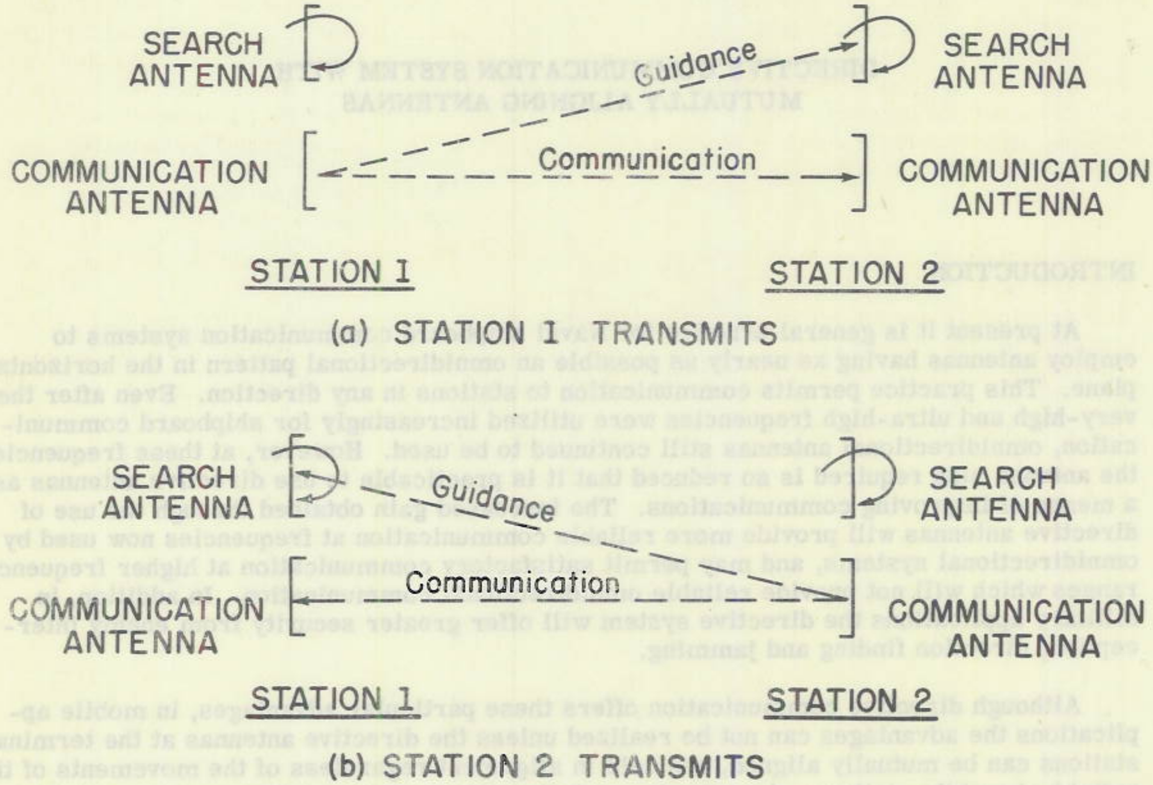
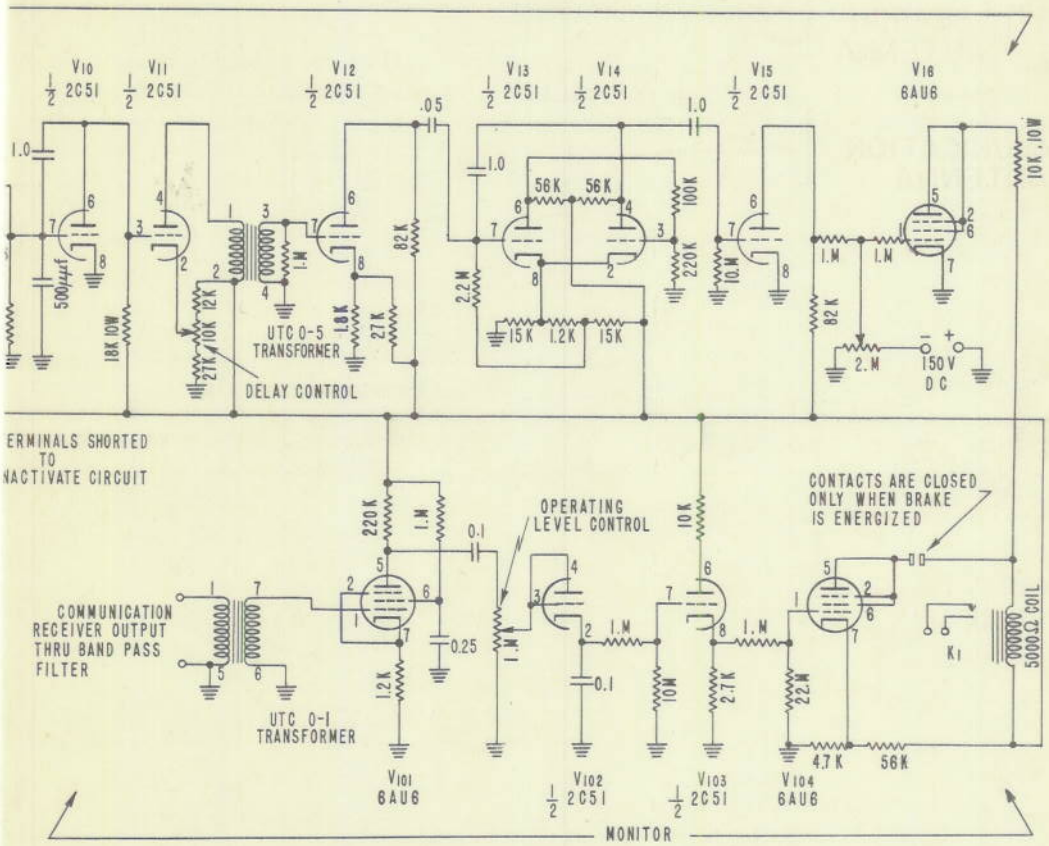


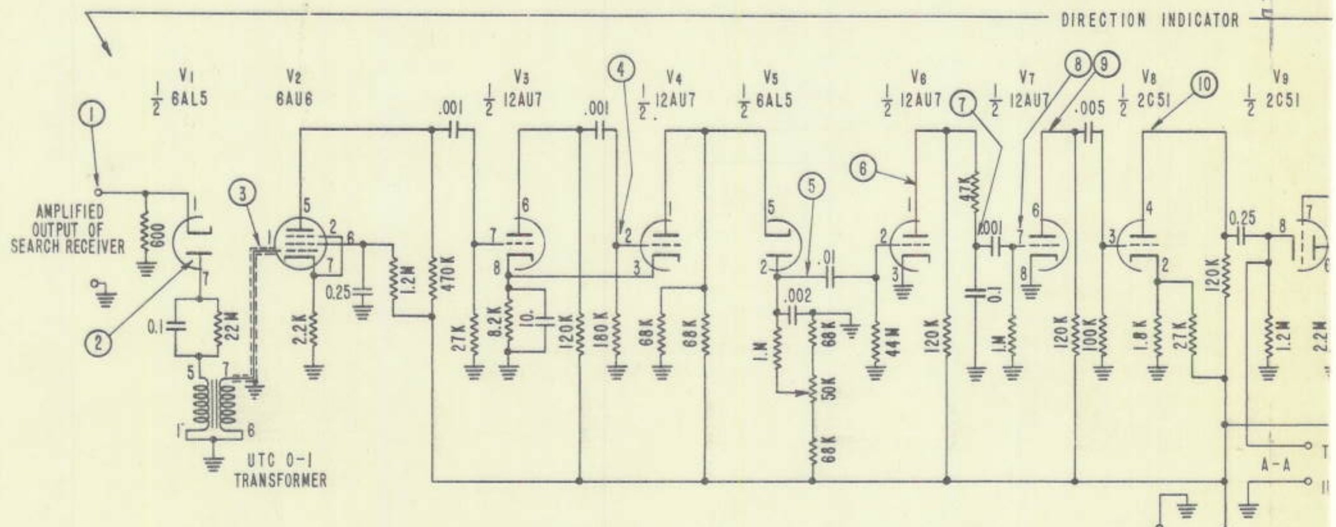
Figure 1 - Communication and guidance linkage in the system

For the present, effort has been concentrated on the development of a simplified system with the essential direction indicating and control circuits for the alignment of the communication antennas. This simplified system will maintain approximate communication antenna alignment provided that the communication periods are relatively short, and that the change in relative bearing between the ships is not rapid. Linkage of the antenna control with the ship's gyro-compass may be desirable as an aid in directing the communication antenna. This has not as yet been incorporated into the simplified system; however, this does not appear to be too difficult.[1]

[1] Where service conditions require maintenance of antenna alignment for extended periods, some form of continuous tracking must be provided. One way this may be accomplished is by the use of a pulsed system having a "look-through" feature, and with a repetition rate above the speech frequencies. Thus speech may be transmitted by standard pulse modulation techniques with simultaneous two-way continuous guidance being provided by the pulsed signals. Some means of identifying the individual signals would also be required so that a particular station could be selected from a group, and so that established communication between two stations would not be disrupted by a routine call of a third station from a different bearing.



ction indicator and monitor



OPERATION OF INDIVIDUAL STAGES

V_1 Rectifies incoming audio envelope. The long time constant circuit (R=22.M, C=0.1 μfd) acts to hold the crest voltage so that there will be no response to subsequent minor antenna lobes. Due to the filter action of the R-C circuit, only the serrations of the audio voltage rising to the crest are present at the interstage transformer. Since the end of the serrations corresponds to the crest of the major lobe, the serrations are amplified and shaped in subsequent stages to provide a pulse coincident with the crest of the wave.

V_2-V_8 Amplifying and shaping stages to provide a marker pulse coincident with the wave crest.

V_9-V_{11} Response delay circuit to prevent possible action on an initial minor antenna lobe.

V_{12} Amplifier developing sharp negative pulse to trigger multivibrator.

V_{13} - V_{14} One-shot multivibrator holding approximately four seconds to permit the communication antenna to position and monitor circuit to take control.

V_{15} Amplifier.

V_{16} Control tube operating sensitive relay K_1.

V_{101} - V_{104} Monitor circuit amplifier, rectifier, and relay control stages. This circuit holds relay K_1 closed as long as the communication signal is at a suitable operating level.

Note: All capacitor values in μfd unless otherwise indicated. Resistance in ohms: K = 1,000 and M = 1,000,000.

Note: Circled numbers refer to waveforms shown in Figure 3.

Figure 2 - Schematic diagram of dire

DETAILED DESCRIPTION

The first problem encountered in development of the system was the determination of the direction of a signal and the presentation of the directional information in a form suitable for automatically controlling the position of the communication antenna. A directional sense is established through the reception of a tone-modulated r-f signal by a continually rotating directive search antenna. The search receiver output rises to a maximum at the instant the rotating antenna is directed toward the signal. This output is an audio frequency voltage which forms a characteristic envelope determined by the directive antenna pattern, with the crest of the envelope indicating the bearing of the received signal. Two individual methods of utilizing this output crest to establish direction were considered, and the more satisfactory method was selected.

The Direction Indicator

In the first direction indicating circuit[2] considered, an attempt was made to obtain a direction index by balancing the varying voltage of the peaked signal against a reference voltage. The reference voltage was obtained by using the peaked signal to charge a capacitor having a slow discharge characteristic. This reference level and the rectified envelope of the peaked signal were then applied to a two-tube thyratron circuit arranged with one tube normally conducting, and the second tube only conducting while the envelope exceeded the established reference level. By means of a lagged relay, momentary continuity was obtained at the instant the signal envelope voltage fell below the reference voltage level. Since the reference level remained proportional to the peak signal voltage regardless of signal amplitude, the direction index was reasonably accurate even with wide variations in signal amplitude. However, the circuit was not ideal because relatively small changes in search antenna rotational speed affected the accuracy of the index point, and because the thyratron circuit showed a tendency to self oscillate if an input signal was applied continuously to the rectifier circuit. For these reasons this particular circuit was abandoned.

Later a more satisfactory direction indicator was developed. Figure 2 shows a schematic diagram of the indicator and explains the function of the individual stages.

In order to illustrate the circuit operation necessary to provide a direction index pulse, a group of waveform photographs obtained with a dual beam oscillograph is presented in Figure 3. View A shows the amplified audio output envelope of the search receiver when the station is within range of a calling signal. Provided that the propagation path is direct, the major crest of this envelope occurs at the instant the rotating search antenna is directed toward the alternate station. In the remaining oscillograms, the various circuit events required for the generation of the index pulse are compared in time with the amplified audio envelope developed at the receiver by the rotating search antenna.

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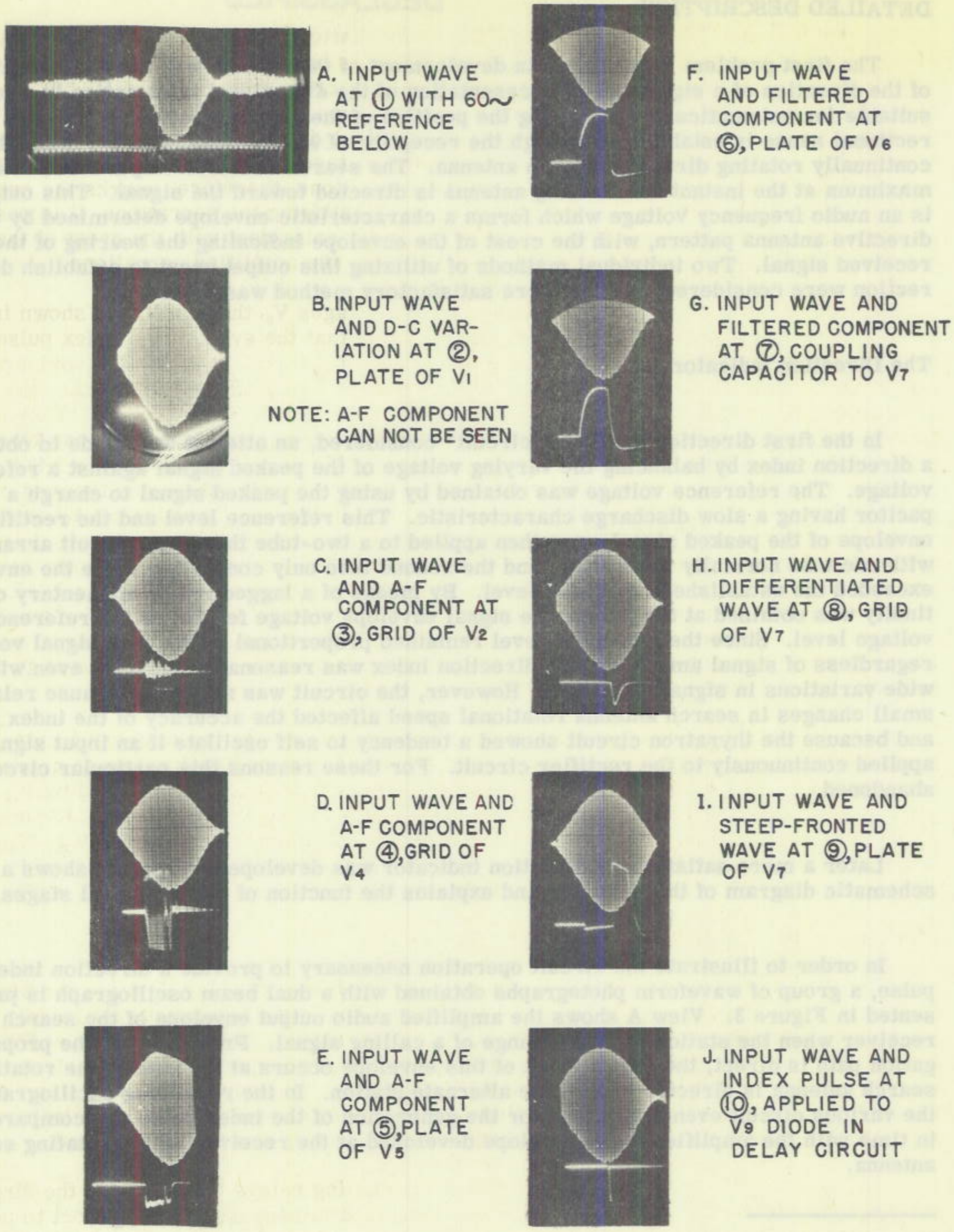
[2] *This circuit is described more fully in NRL Conf. ltr. C-3910-98/48 of 27 October 1948 to BuShips.*



NOTE: CIRCLED NUMBERS CORRESPOND TO THOSE OF THE SCHEMATIC DIAGRAM, FIG. 2. THE DU MONT TYPE 279 DUAL BEAM OSCILLOGRAPH SHOWS THE INPUT WAVE AND AN ASSOCIATED TRACE WITHIN THE DIRECTION INDICATOR SIMULTANEOUSLY.

Figure 3 - Direction indicator waveforms

In the direction indicator, the audio voltage variation is applied to a filter in the plate circuit of V_1 (Figure 2). As shown in Figure 3B, this long time-constant circuit is charged through the diode which then acts to retain the major crest voltage in the circuit so that there is no response to subsequent minor antenna lobes. Recurrent serrations due to the audio-frequency component of the signal appear on the d-c wave up to the crest point.[3] Due to the action of the filter in holding the maximum voltage applied, these serrations do not appear beyond the crest. The cessation of the serrations, therefore, marks the crest of the major antenna lobe. By amplifying, filtering, and rectifying the serrations, it is possible to obtain from the resulting square wave an index pulse coincident with the crest of the major antenna lobe. Oscillograms C and D (Figure 3) show the amplified serrations.

The action of the subsequent shaping circuits, stages V_5 through V_8, is shown in the remaining photographs of Figure 3. It may be noted that the event of the index pulse shown in view J corresponds closely with the crest of the input wave. In order to avoid a possible false index due to circuit response to a minor antenna lobe received before the major lobe is rotated past the incoming signal bearing, it is necessary to delay passage of the index pulse to the antenna control circuit until the voltage crest of the major lobe can be sampled. The necessary delay action is obtained in stages V_9, V_{10} and V_{11}. In this circuit V_{10} normally conducts, and the voltage drop across the plate resistor of this tube holds the grid of V_{11} negative with respect to its cathode, so that the tube V_{11} is in cut-off condition. When a signal is first received, negative pulses accumulate through diode V_9, and tube V_{10} is driven to cut-off on the second or third pulse. Since there is no longer a voltage drop across the plate resistor of V_{10}, the grid of V_{11} is now positive with respect to its cathode. The 1-μfd capacitor in the circuit serves as a coupling capacitor to the grid of V_{11} which acts as an amplifier, and the direction indicating pulses pass through the delay circuit. The circuit is so adjusted that response does not occur with one major lobe, or with two successive pulses produced by adjacent minor lobes.

Stage V_{12} is a conventional amplifier which develops a negative triggering pulse to operate a one-shot multivibrator, V_{13}-V_{14}, which increases the pulse duration to approximately four seconds. This pulse, initiated by response to a signal peak, is amplified by V_{15}, and applied to the relay control tube V_{16}, which closes and holds relay K_1 to permit the communication antenna to rotate into position. The operation of the monitor circuit, V_{101}-V_{104}, shown in Figure 2, is described later.

The Communication Antenna Positioning Control

The operation of the direction indicator and the closing of relay K_1 mark the bearing of the other station in terms of the momentary position of the comparatively rapidly rotating search antenna. To utilize this indication, it is necessary to instantaneously record the position, and to retain it long enough to permit rotation of the communication antenna to the indicated bearing. During the development of the directive communication system, several schemes for memorizing the indicated direction and directing the communication antenna to the required bearing were considered before a satisfactory control was evolved.

Originally, a 13-sector control circuit using holding relays for retaining the directional information was investigated. This system was not ideal because it was subject to positional error approaching the width of a sector, and was dependent, for continued reliability, upon the satisfactory performance of the many sector relays, and of a special commutator and brush arrangement.

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[3] *These serrations are of small magnitude and are not visible in oscillogram B (Fig. 3). The visible variations are due to other causes.*

A second experimental circuit[4] which was considered used a potentiometer and capacitor combination as the direction indicating element, with a sawtooth "sweep voltage" being obtained from the potentiometer for each revolution of the search antenna. At the instant the direction indicating circuit acted, the rising voltage was sampled, and stored in the capacitor as a position reference. This circuit did not prove entirely satisfactory since it would provide false directional information when the search antenna crossed its maximum-to-zero resistance point, and because of the continuous mechanical wear on the potentiometer elements.

The most satisfactory antenna positioning control developed employs a synchro-unit to retain the directional reference. This control, shown in Figure 4, employs a synchro-generator mechanically coupled to the shaft of the continually rotating search antenna, and electrically connected to a synchro-motor. This synchro-motor rotates, following the rotation of the search antenna until the direction indicator acts, and is then instantaneously braked and held as the directional index. At the instant of braking, the synchro-motor stator leads are switched from the search antenna synchro-generator to a control transformer coupled to the communication antenna shaft.

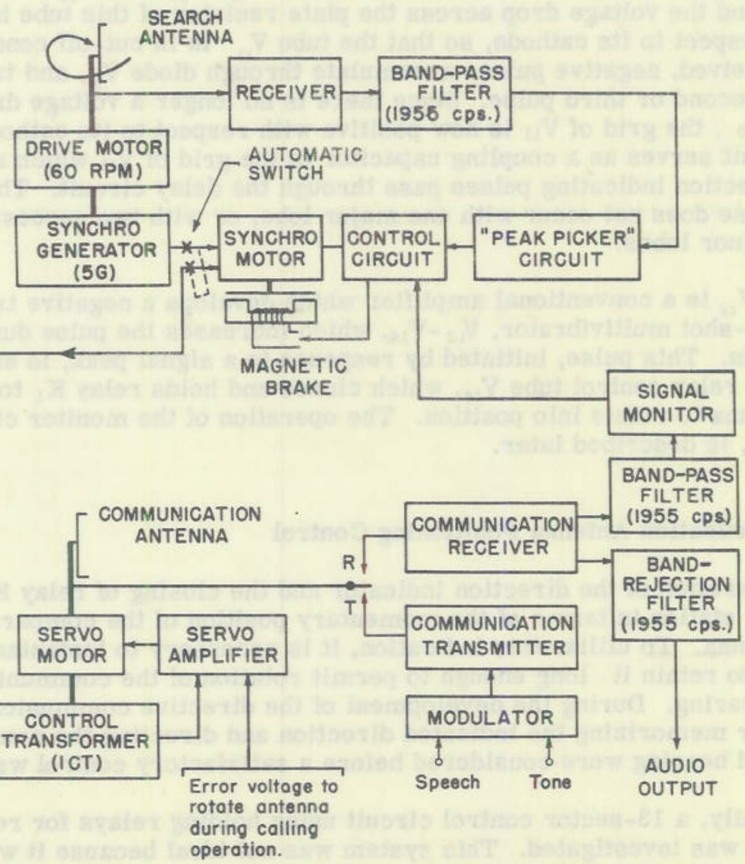

Figure 4 - Block diagram of system using braked synchro motor

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[4] *These circuits are described more fully in NRL Conf. ltr. C-3910-98/48 of 27 October 1948 to BuShips.*

The control transformer provides an error voltage determined by the difference between the braked synchro-motor and the control transformer shaft positions. This error voltage is applied through a servo-amplifier to a servo-motor which rotates the communication antenna to the position indicated by the braked synchro motor. Another "error voltage source" obtained from the a-c supply is provided so that a fixed voltage may be applied to the servo-amplifier to rotate the communication antenna slowly through 360 degrees, when it is desired to initiate a call to another station.

Station tracking can be accomplished in the control arrangement just described by repeating the direction finding operation at frequent intervals on the signal being received. This operation requires that the guidance signal be present along with the communication signal. Where simultaneous transmission and reception is not possible, the tracking operation can only be performed at a particular station while that station is receiving. Continuous tracking would require co-channel or adjacent-channel operation to permit simultaneous transmission and reception at each station.

The Monitor

Tracking by repeated signal sampling would cause the synchro-motor in the circuit to be repeatedly braked and released. In order to avoid unnecessary braking of the synchro-motor, and to obtain limited tracking in the experimental system, a monitor circuit was developed. This monitor (V_{101} through V_{104}, Figure 2) operates from the guidance tone present on the signal received through the communication receiver, and separated from the voice frequencies by a band-pass filter (Figure 4). The monitor consists of an amplifier stage, a diode rectifier, and stages to operate the control relay so that as long as the communication signal remains above a selected threshold level, the communication antenna is held in position.

If the signal falls below the selected threshold level through loss of antenna alignment due to movement of the individual stations, the direction indicator operates, and redirects the communication antenna as required. If, on the other hand, the signal is lost due to fading, the direction indicator is activated, but the communication antenna does not rotate from its original bearing until a signal is received to provide a direction index, and then moves only if a new direction is indicated. To insure that the monitor does not operate before the direction indicator responds to a signal, interlocking between the two is provided by opening the plate circuit of tube V_{104} whenever the synchro-motor brake is deenergized.

The Modified Relay Control Circuit

In order to compare the performance and reliability of the vacuum tube relay control circuit (V_{16} and V_{104}) shown in Figure 2 with that of a thyratron circuit, appropriate thyratrons were substituted for vacuum tubes for relay control. Figure 5 shows the modified thyratron control circuit insofar as it differs from the original circuit. The plates of the thyratrons were operated from an a-c power source, so that conduction could be controlled by the thyratron grid after initial firing. The use of a-c on the plates was found to introduce a slight positioning error, for if the positioning index occurred during a negative half cycle of a-c voltage on the thyratron plate, the thyratron controlled relay K_1 could not operate until the plate became positive. Since no marked improvement in the reliability of relay operation with the thyratrons was noted, and because slight positioning error was introduced by the modification, the vacuum tube control circuit shown in Figure 2 is considered to be preferable.

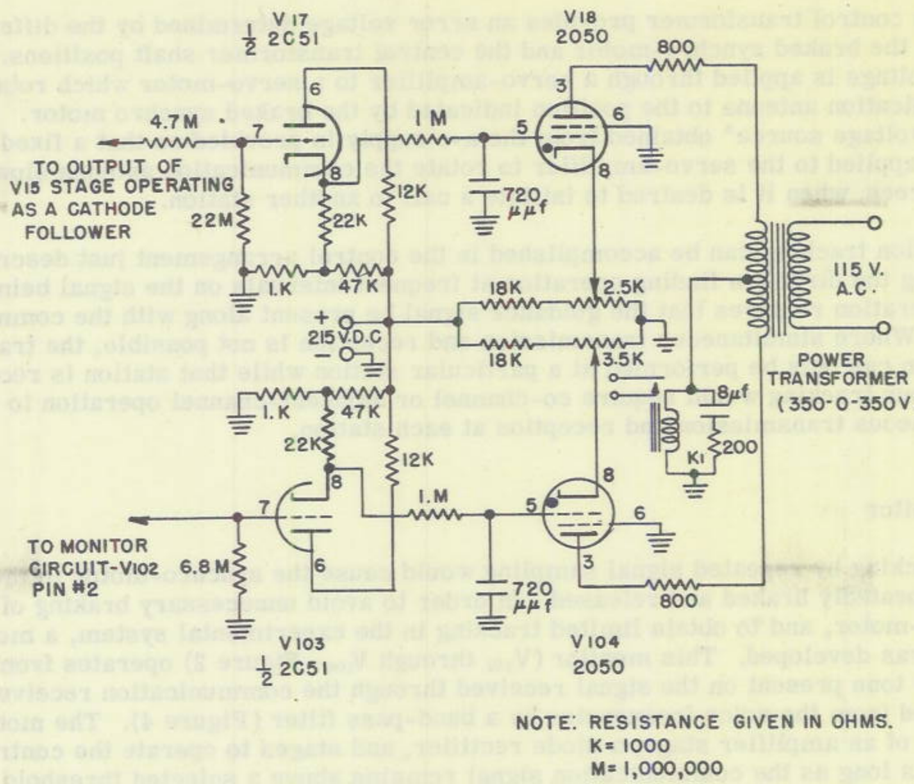


Figure 5 - Schematic diagram of modified relay control circuit using thyratrons

THE ASSEMBLY OF A COMPLETE SYSTEM

After laboratory investigation indicated that the direction indicator and antenna control circuit were practical, consideration was given to the use of these developments in a complete system. To do this, necessary equipment for two stations was assembled, and both stations were set up for operation. A block diagram of the complete installation for one station using the vacuum tube operated control relay (K_1) is shown in Figure 6. The second station was identical, except that thyratron tubes were used for relay control (Figure 5). In Figure 6, the interconnecting circuits have been identified according to function. Terminal numbers, where shown, refer to existing terminal strip markings on standard Navy equipments. The Model TDZ transmitter and the Models RDZ and AN/APR-1 receivers were used for the experimental system, since they were the highest frequency communication equipments readily available.

Carrier frequencies of 385 and 388.2 megacycles were selected for use at the respective stations in order to place operation of the communication system in the upper frequency range of the transmitter and communication receivers. Identical three-element directive antennas with reflecting screens were used for search and communication. These antennas provided a major lobe of 35-degree width between half-power points, with minor side and back lobes, the largest minor lobe being 13 db below the major lobe. Use was made of this antenna which was based on an already proven design since it provided sufficient directivity for the purposes of the trials. The system under development can be adapted readily to any form of directive antenna giving a single main lobe with a sufficient degree of attenuation of minor lobes.

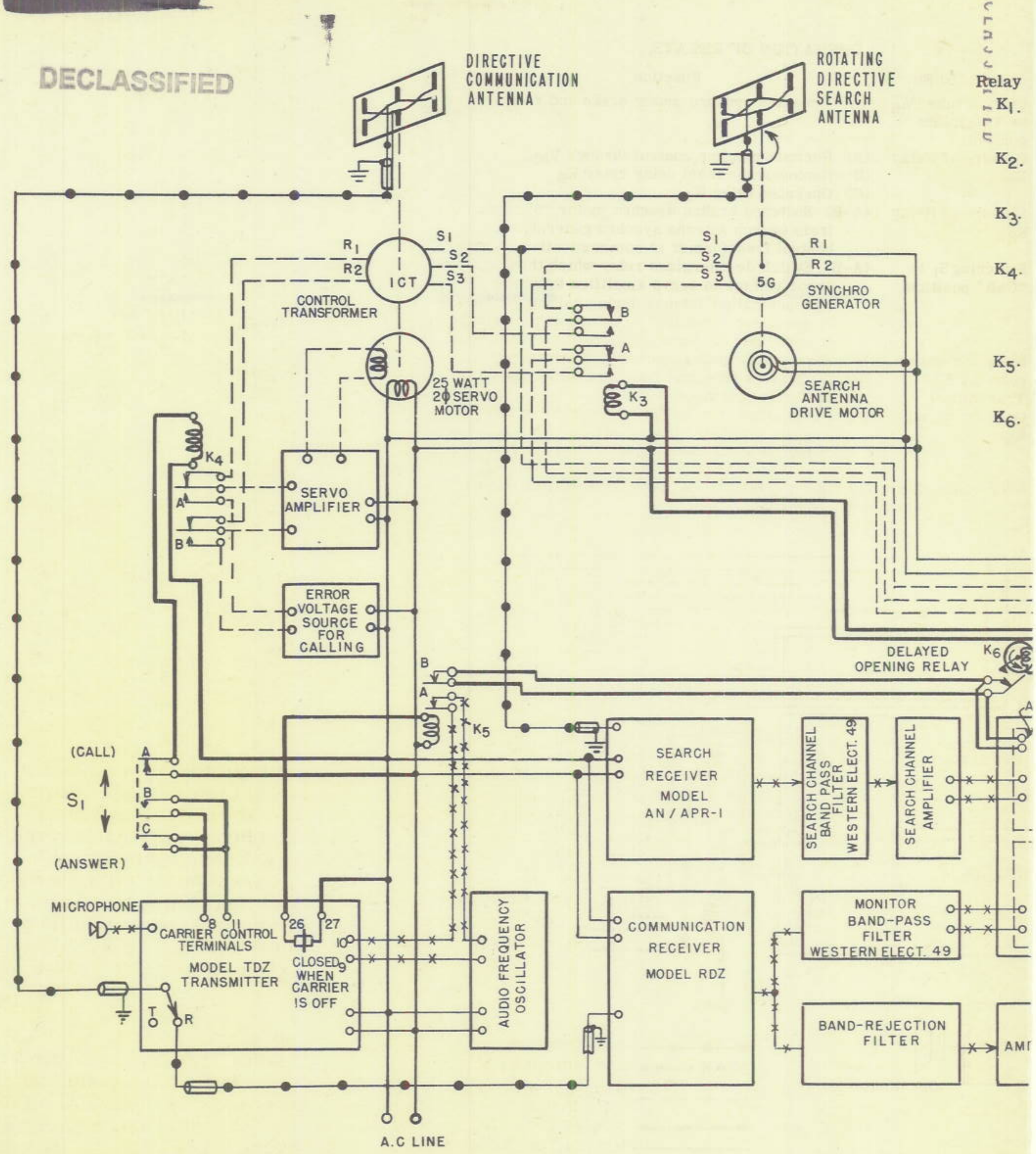
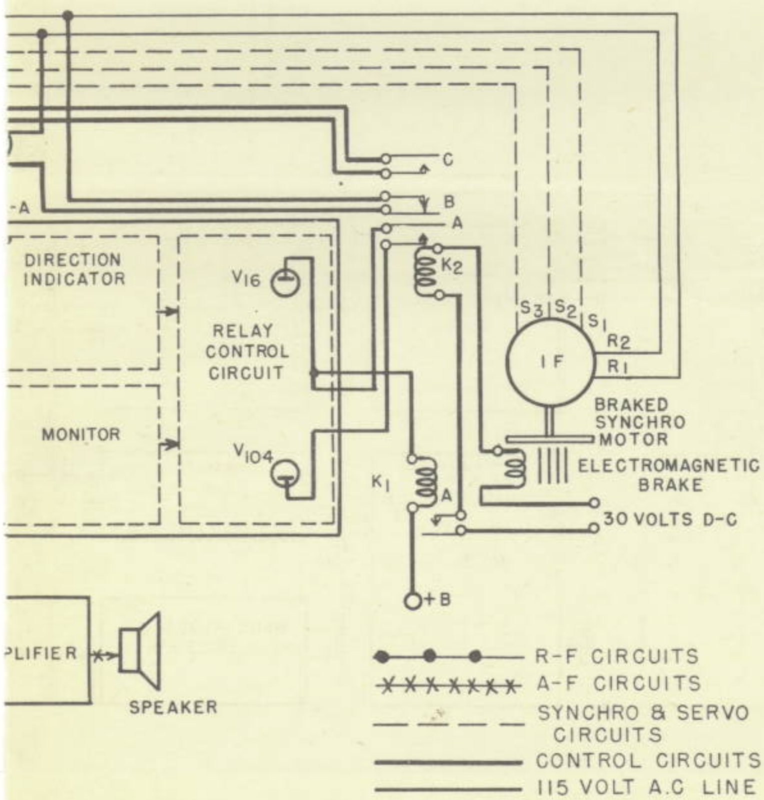


Figure 6 - Mutually aligning

OPERATION OF RELAYS

Operated By	Function
Control tube (V_{16} or V_{104}) plate current.	(A) Operates synchro motor brake and relay K_2.
Closure of Relay K_1.	(A) Permits monitor control through V_{104} (B) Removes a-c from delay relay K_6. (C) Operates relay K_3.
Closure of Relay K_2.	(A-B) Switches braked synchro motor "S" leads from search antenna synchro generator to control transformer at communication antenna.
Switching S_1 to "Call" position.	(A-B) Switch de-energizes relay which then applies error voltage to servo amplifier to rotate communication antenna during calling period. In energized condition, relay connects control transformer to servo amplifier.
Normally closed relay in TDZ Transmitter.	(A) Places tone modulation on TDZ carrier. (B) Inactivates direction indicator while transmitter is energized.
Opening of relay K_2	(A) Permits synchro motor to resynchronize with synchro generator before braking again in response to an index pulse.

Note: Direction indicator terminals (A-A) inactivate the circuit when short-circuited.



'*communication system*

An audio tone of 1955 cps was used at each station for guidance tone modulation of the transmitter. This particular frequency was selected since a band-pass filter of this frequency was available for use at the search receiver output to improve the signal-to-noise ratio of the guidance tone, as well as to remove voice modulation. More satisfactory operation may be obtained using filters at other audio frequencies, or even outside the speech frequency band, to avoid the necessity of removing the guidance tone from the speech. Both the direction indicator and monitor input circuits were provided with the band-pass filters. A band-rejection filter between the communication receiver and the speaker amplifier served to remove tone from the voice channel.

The synchro-motor brake was constructed from a relay coil assembly mounted on a flexible metal leaf with the pole faces nearly touching a low-inertia steel disc geared to the shaft of the synchro-motor. When energized by control circuit relay K_1, the electromagnet is drawn against the disc, and acts as an effective brake. A four to one speed reduction between the synchro-motor and the disc was employed as a means of reducing the rapid oscillation of the disc which occurred when the brake was released. The equipment operates from a 115-volt, 60-cycle power source. The power requirement for the various terminal units at one station of the system, excluding the receivers and the transmitter, is 940 watts.

Operation of the system is initiated by throwing switch S_1 (Figure 6) at either station to the "call" position. This action causes the communication antenna to rotate at the calling speed (3.3 rpm was chosen to permit an adequate number of interceptions by the 60 rpm search antenna). This causes the transmitter to emit a modulated carrier, and deactivates the direction indicator through relay K_5. Switch S_1 must be held in the "call" position until the communication antenna completes one revolution (18 seconds), and is then released. When the signal is received via the rotating search antenna at the remote station, its communication antenna is automatically directed toward the station originating the call. After the alignment process is completed at the remote station, 18 seconds are allowed to lapse to insure that the calling station has completed its 18-second call. Then switch S_1 is placed in the "answer" position for a period of 4 to 5 seconds, causing the transmission of a tone-modulated signal from the aligned communication antenna in the direction of the calling station, and the deactivation of the remote station direction indicator. Upon reception of the answer signal by the rotating search antenna, the communication antenna at the original calling station is automatically directed toward the remote station. Both communication antennas are now aligned, and the station originating the call may begin communication in the usual manner, that is, with the microphone or key. The remote station may then respond with microphone or key. Should the relative bearing between stations change due to ship movements during the course of two-way communication, automatic tracking arrangements[5] reposition both antennas as necessary.

PERFORMANCE OF THE SYSTEM

Initial operation of the system was obtained with the two stations set up on adjacent buildings, separated approximately 400 feet. After adjustments had been made so that the direction indicator and antenna control units functioned satisfactorily over this short range, lengths of attenuating cable were introduced into the transmission circuit so that the effective separation was gradually increased to the equivalent of several nautical miles, and operational studies were made under this condition. During these studies satisfactory antenna alignment was obtained on comparatively weak signals.

[5] *The simplified tracking arrangement used in the present system operates only on the receiving end, and would not be adequate to maintain antenna alignment during long transmissions during which the relative bearing between ships changed considerably.*

While the equipment was still set up, a further study was made to correlate the useful transmission range of the mutually aligning portion of the system with that of a standard communication circuit as represented by the Model TDZ-RDZ combination. For this investigation the same receiver was used for the search and the communication functions in order to insure equal receiver sensitivity for each condition. The receiver output was applied to the direction indicator through a band-pass filter to improve the signal-to-noise ratio. From oscillographic observations it was possible to determine at what value of signal-plus-noise-to-noise ratio the performance of the direction indicator became unreliable. Improper operation was caused by deterioration of the index pulse into a number of thinner pulses which caused erratic response of the relay control tube (V_{16}) operating relay K_1. Satisfactory direction indicator operation was obtained with signal-plus-noise-to-noise ratios at the receiver output of 5 db or more. Using the Western Electric Type 49K Filter,[6] the 5-db ratio was transformed into a 22-db ratio at the input to the direction indicator. It is, therefore, evident that with the present system satisfactory antenna alignment will be obtained with received signals providing a receiver output signal-plus-noise-to-noise ratio of 5 db or above.[7]

Since the studies conducted under the fixed station conditions with little actual separation between stations indicated that a workable system had been devised, operational studies between two stations separated by several miles were planned. These plans called for locating one station on shipboard so that the performance of the system could be determined under mobile operating conditions.

The shipboard trials of the directive communication system with mutually aligning antennas were carried on between a fixed terminal station at this Laboratory and a mobile station located aboard a Naval Patrol Craft, the E-PCS-1426, on the Potomac River. The arrangement of equipment on shipboard, and the placement of the directive antennas on the foredeck is shown in Figures 7 and 8. The antennas were mounted so that obstruction by the ship's superstructure was minimum when the ship was approaching the fixed station. Information with regard to the equipments used and the operating conditions established for the system trials is indicated in Table 1.

Separate carrier frequencies were set up with the possibility of simultaneous two-way operation in mind. However, it was found that the 3.2-megacycle separation was insufficient when using the Model AN/APR-1 receiver which had inherently poor selectivity. Extreme frequency separation was undesirable due to the relatively narrow resonance band of the particular directive antennas used. For this reason simultaneous two-way operation on separate channels with greater frequency separation was not attempted, and the frequency separation was left at 3.2 megacycles. Radio frequency power in the antenna was adjusted to 5 watts at each station, since the higher power available from the Model TDZ transmitter was not required for communication over the distances involved, and the possibility of interference to other stations was reduced. The propagation path between stations was considerably obstructed from the Laboratory to a point approximately two miles down the river. However, the path for several miles beyond this point was relatively clear, and much information was obtained with the mobile station moving in this region.

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[6] *The Western Electric Type 49K Filter resonance curve peaks at 1955 cps, and the 6 db down response points occur at 1890 cps and 2030 cps respectively.*

[7] *With equal search and communication receiver sensitivities, the guidance signal-plus-noise-to-noise ratio limit of 5 db is also the approximate lower limit for useful voice communication. Johannessen, H. R., and Howe, W. E. W., in NRL Report R-3233, February 18, 1949, discuss the matter of minimum useable signal-to-noise ratio for voice communication.*

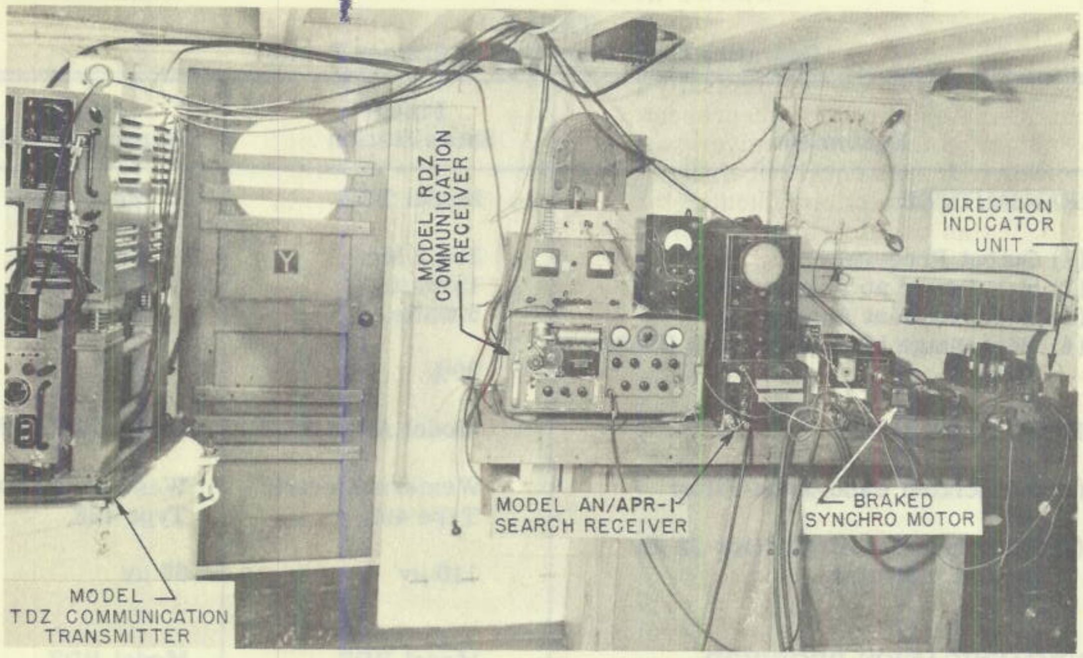

Figure 7 - Shipboard terminal of directive communication system

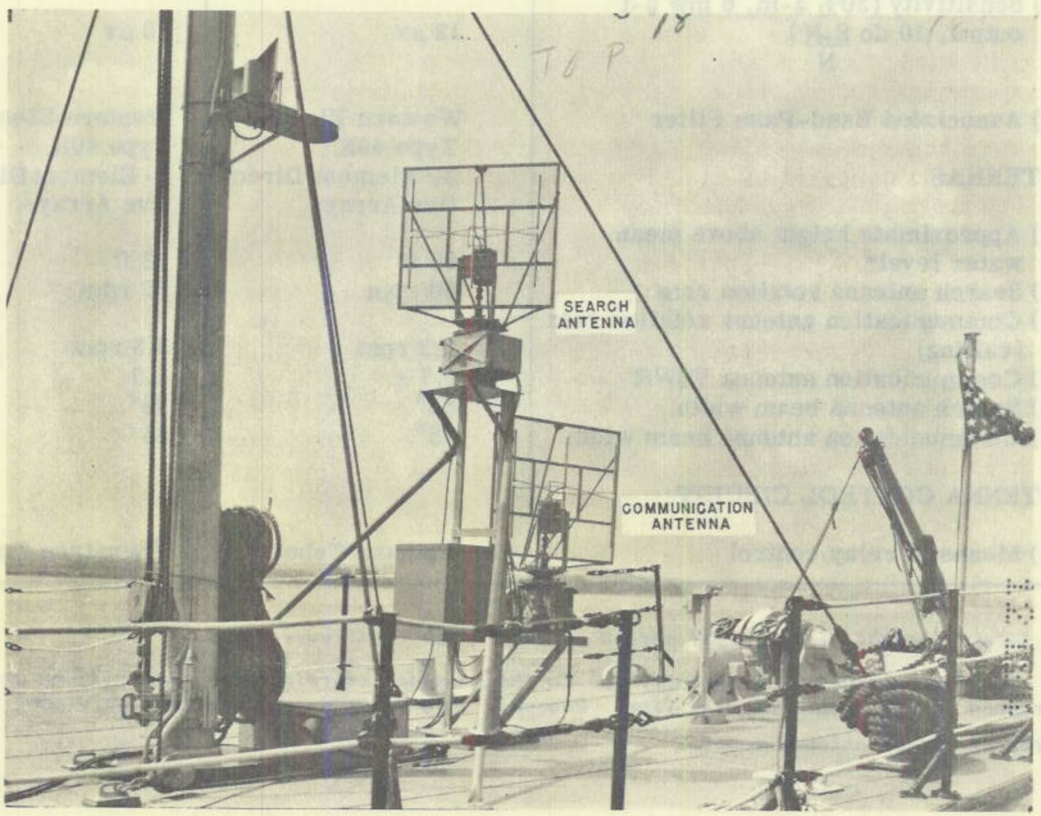

Figure 8 - Directive antennas mounted on ship's foredeck

TABLE 1
Operating Conditions During System Trials

Equipment	Fixed Shore Station	Mobile Shipboard Station
TRANSMITTER	Model TDZ	Model TDZ
(1) Output Frequency	388.2 Mc	385.0 Mc
(2) R-F Power at Transmitter	15 watts	10 watts
(3) R-F Power at Antenna	5 watts	5 watts
(4) Percentage Modulation with Guidance Tone	30%	30%
SEARCH RECEIVER	Model AN/APR-1	Model AN/APR-1
(1) Associated Band-Pass Filter	Western Electric Type 49K	Western Electric Type 49K
(2) Combined Sensitivity (for 22 db $\frac{S+N}{N}$ at indicator)	110 μv	60 μv
COMMUNICATION RECEIVER	Model RDZ	Model RDZ
(1) Sensitivity (30% a-m, 6 mw a-f output, 10 db $\frac{S+N}{N}$)	12 μv	10 μv
(2) Associated Band-Pass Filter	Western Electric Type 49K	Western Electric Type 49K
ANTENNAS	3- Element Directive Arrays	3- Element Directive Arrays
(1) Approximate height above mean water level*	65 ft	18 ft
(2) Search antenna rotation rate	60 rpm	60 rpm
(3) Communication antenna rotation rate (calling)	3.3 rpm	3.3 rpm
(4) Communication antenna VSWR	0.7 †	1.0
(5) Search antenna beam width	35°	35°
(6) Communication antenna beam width	35°	35°
ANTENNA CONTROL CIRCUIT		
(1) Means of relay control	Vacuum Tubes	Thyratron Tubes

* *Antenna height differential varied somewhat with tidal variation.*

† *The lower value was apparently due to the presence of rain water, later found entrapped in the copper coaxial line. However, this value was not sufficiently poor to greatly affect antenna power.*

It was known that the directive antennas in the system would provide considerable power gain over a system with nondirective antennas, and measurements were made to determine the actual gain obtained with the three-element directive arrays which were used. A sleeve dipole[8] was installed at each station to permit a direct comparison of antennas. The average power gain obtained by the use of the directive antennas as related to the dipoles was 26 db for the system. Theoretically, this increase in gain would approximately quadruple the communication range between stations, provided that the increased range is not limited at the radio horizon. From a theoretical viewpoint it would be necessary to increase the power output of a transmitter used in a nondirective system approximately 400 times to provide a signal equivalent to that provided by the directive system, all other conditions remaining the same.

After the gain in the directive antenna system had been established, the attenuation over the propagation path of the system was determined from data obtained during several of the mobile system trials. It may be noted that, in general, the data for each individual run provide a smooth curve; and that day-to-day variation in propagation conditions would account for the deviation between individual runs. A curve has been provided indicating an average of the measurements, and a theoretical curve[9] originally established for dipole antennas at 18 and 65 foot heights, and raised by 26 db in order to represent the theoretical attenuation in the directive system, is also presented. As shown in Figure 9, the measured values of attenuation between antennas at 18 and 65 foot heights are in reasonable agreement with the theoretical curve.

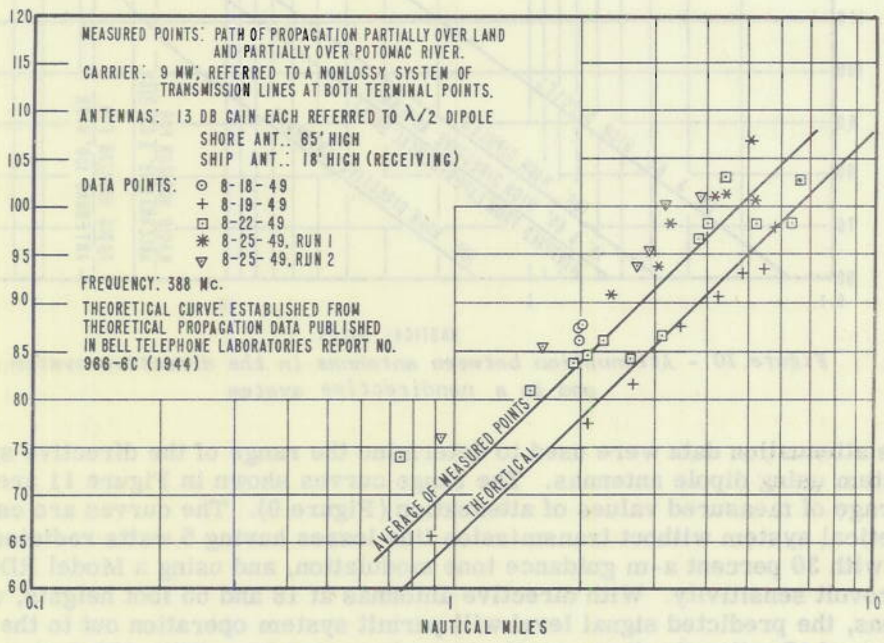

Figure 9 - Attenuation between antennas 18' and 65' high

[8] *A type AT-150/SRC antenna manufactured by the Bird Electronic Corporation at Cleveland, Ohio.*

[9] *This curve was established from theoretical propagation data published in Bell Telephone Laboratories Report No. 966-6C (1944).*

This fact substantiates the accuracy of the measurement of directive system gain, 26 db. It also confirms the assumption that the attenuation over the unobstructed portion of the propagation path established for the tests between the fixed and mobile stations is approximately the same as that encountered over sea water.

From the curve indicating the average of experimentally determined values of attenuation between the 18 and 65 foot directive antennas, theoretical curves have been set up for dipole antennas at the same heights, and for a directive and a nondirective system with antennas at a height of 100 feet, which is believed to be a representative antenna height for a typical Naval shipboard installation. These curves are presented in Figure 10.

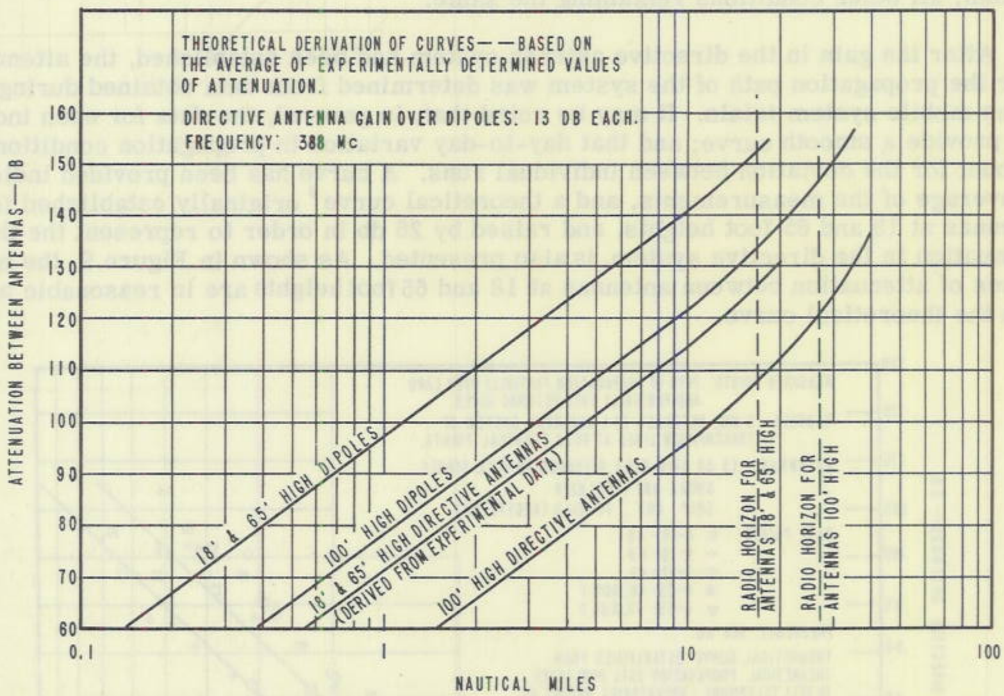

Figure 10 - Attenuation between antennas in the directive system and in a nondirective system

The attenuation data were used to determine the range of the directive system, and of a system using dipole antennas. The range curves shown in Figure 11 are derived from the average of measured values of attenuation (Figure 9). The curves are established for a theoretical system without transmission line losses having 5 watts radiated power[10] at 388 Mc with 30 percent a-m guidance tone modulation, and using a Model RDZ receiver of 10-microvolt sensitivity. With directive antennas at 18 and 65 foot heights, under these conditions, the predicted signal level will permit system operation out to the radio horizon, a distance of 17 miles for these particular antenna heights. With 100-foot antenna heights, a comparatively good receiver output signal will be provided at the radio horizon, 27 miles distant.

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10 *This value is a conservative estimate of the r-f power delivered by a Model TDZ transmitter if the losses from the receiving antenna to the receiver are referred to the transmitting end, and the losses over a relatively long transmission line between the transmitter and antenna are also included.*

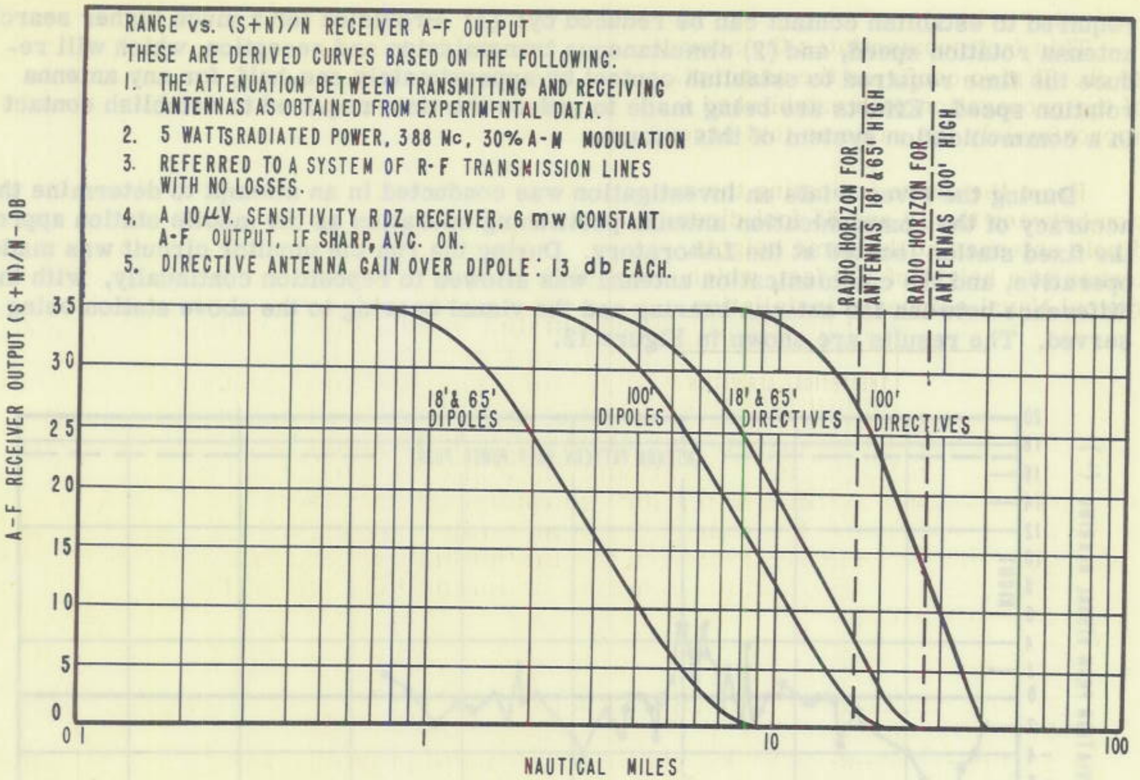

Figure 11 - System signal-plus-noise-to-noise ratio vs. distance

A subsequent investigation was made to determine the reliability of the antenna aligning portion of the system. At extreme ranges with comparatively low signal-to-noise ratios the direction indicator operated occasionally on noise peaks. With receiver output signal-plus-noise-to-noise ratios above 5 db, satisfactory antenna alignment occurred repeatedly. During the trials it was found that the terminal antennas could always be aligned and communication established in 40 to 50 seconds. The time required is determined by the necessary calling procedure and the inherent limitations of the present simplified system.

Because of the construction of the present antenna and the rotating mechanism, the search antenna rotation speed is limited to 1 rps, and the ratio of rotation speeds between the search and the calling (communication) antennas must be about 18 to 1, in order that the rapidly rotating search antenna may intercept the directional calling signal at least twice, in order to operate the direction indicator. Therefore, in calling, 18 seconds is required to rotate the communication antenna through one complete revolution while the call signal is transmitted. Where simultaneous transmission and reception is not possible, the station receiving the call must wait for 18 seconds before answering, to insure that the calling station has completed its transmission and is in readiness to receive a reply.

The answering signal must then be transmitted for a few seconds in order to permit alignment of the communication antenna at the station originating the call.[11] The time

[11] *Consideration is also being given to a special application of the directive system in which a command ship uses an omnidirectional antenna and picket ships use the directive system described. This would permit simultaneous contact with all vessels within range by the command ship, and directive reply from the outlying vessels. In such a modification of the directive system, the directive antennas could be aligned within three or four seconds.*

required to establish contact can be reduced by: (1) Provision for a much higher search antenna rotation speed, and (2) simultaneous transmission and reception, which will reduce the time required to establish contact by approximately one-half, for any antenna rotation speed. Efforts are being made to reduce the time required to establish contact in a communication system of this nature.

During the river trials an investigation was conducted in an attempt to determine the accuracy of the communication antenna positioning operation as the mobile station approached the fixed station located at the Laboratory. During the run the monitor circuit was made inoperative, and the communication antenna was allowed to reposition continually, with the difference between the antenna bearing and the visual bearing to the above station being observed. The results are shown in Figure 12.

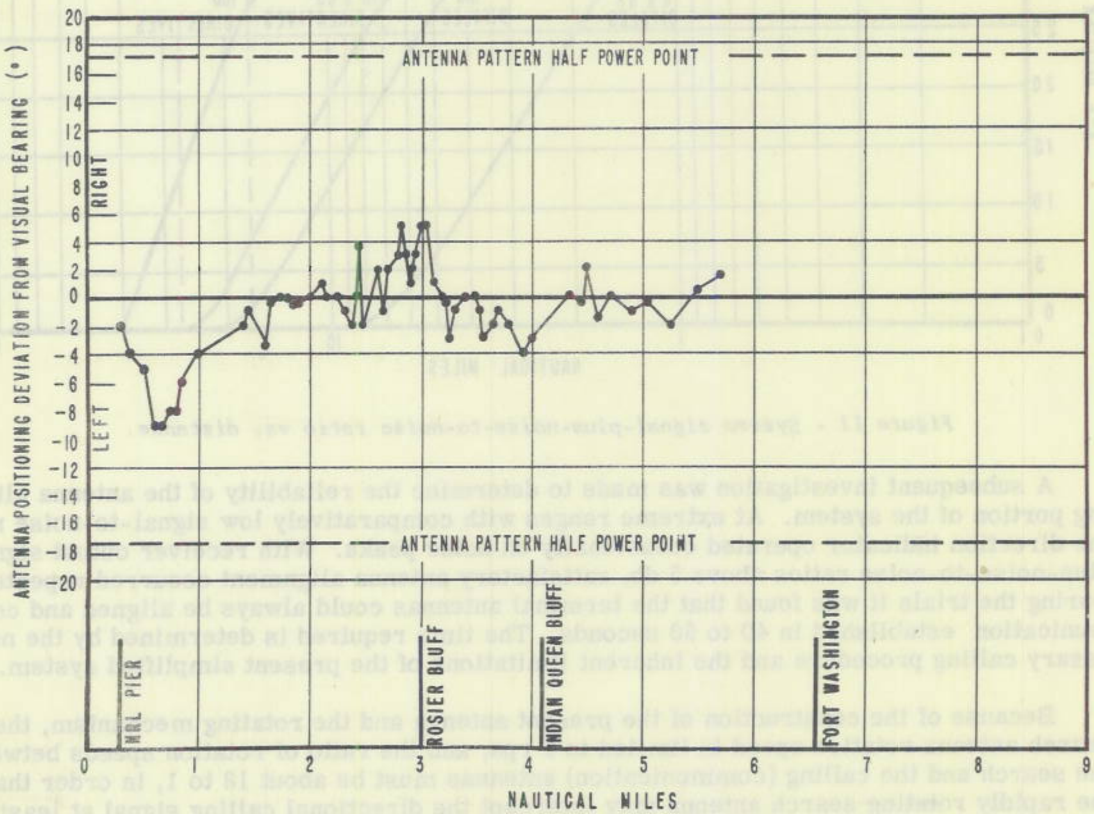

Figure 12 - Communication antenna positioning -- deviation from visual bearing

The greatest variations observed during sixty positioning operations at distances from 0.3 to 5.7 miles were 9^0 left, and 5^0 right, respectively. It is probable that the relatively large deviations which were observed at distances out to 1.5 miles were caused by reflection from a gas storage tank near the Laboratory. In fact, the effect of such reflections was noted during the trials when the communication antenna was found to deviate a few degrees from its regular bearing as large vessels passed near the mobile station. In these instances it is believed that the transmission path was not direct, and that the antenna orientation was in the direction of the maximum signal. However, if the comparatively large antenna deviations between 0 and 1.5 miles are neglected, the departures from the exact visual bearing are within plus 5 and minus 4 degrees. These deviations may have been caused by reflections of the signal from bluffs, or structures along the river bank. If these latter figures are considered to represent the actual antenna positioning error, the power loss with the 35° antennas is less than 0.5 db out of the 26.-db gain provided by the directive system.

FUTURE WORK AND PLANNING

Further study of the operation of the direction indicator is now in progress, and means of improving the sensitivity are being investigated. It is planned to attempt to reduce the time required for antenna alignment between stations, and to carry out any other necessary work to perfect the basic experimental system. The incorporation of continuous two-way antenna guidance will then be considered, and insofar as possible, the system will be made automatic. Later, consideration will be given to the problems involved in:

(1) Identifying the signals so that selected stations may be contacted.

(2) Coordinating the communication antenna control system with the ship's gyro-compass system.

(3) Providing the directional information obtained by the system in visual form for tactical or operational information.

(4) The simultaneous control from a single rotating search antenna of several communication antennas directed to separate stations, and

(5) The use of a suitable nondirective station as a terminal control unit for several directive stations.

CONCLUSIONS

The shipboard trials have indicated that the directive communication system described in this report is practicable, and is capable of providing improved communication, with a measured power gain of 26 db over that obtained with a nondirective system. Mutual antenna alignment between two stations is possible with a signal-plus-noise-to-noise ratio of 5 db at the output of the search receiver. Automatic alignment can be accomplished in 40 to 50 seconds; however, this time may be reduced considerably by using a system operating with simultaneous two-way transmission and reception, and, where practicable, by the use of higher antenna beam rotational speeds. It is believed that the means employed to provide direction indication and antenna positioning are as simple as can be evolved, considering the operational requirements of a system of this type.

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in maneuvering the ship in the narrow channel of the Potomac River during the shipboard trials made it possible to investigate thoroughly the performance of the preliminary directive communication system under mobile operating conditions.

Acknowledgment is also made of the efforts and contributions of our associates in the Communication Branch: to Mr. J. D. Wallace and Mr. H. R. Johannessen for the long range planning and consideration of the project, and for many valuable suggestions with regard to difficult phases of the work; to Dr. O. Norgorden for information with regard to the directive antennas and the propagation characteristics to be expected in directive transmission; and to Mr. Dean Howard and Mr. P. J. Quinn for the development and construction of individual units incorporated into the directive communication system, as well as aid in successfully carrying on the operational trials of the system. Credit is also due Mr. F. J. Shanahan, Mechanical Consultant, for advice and assistance with regard to the mechanical design of the directive antennas, the antenna rotating mounts, and other portions of the system.

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