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C. M. SIMPSON

2,576,150

DIRECTIVE ANTENNA SYSTEM

Filed Oct. 8, 1946

3 Sheets-Sheet 1

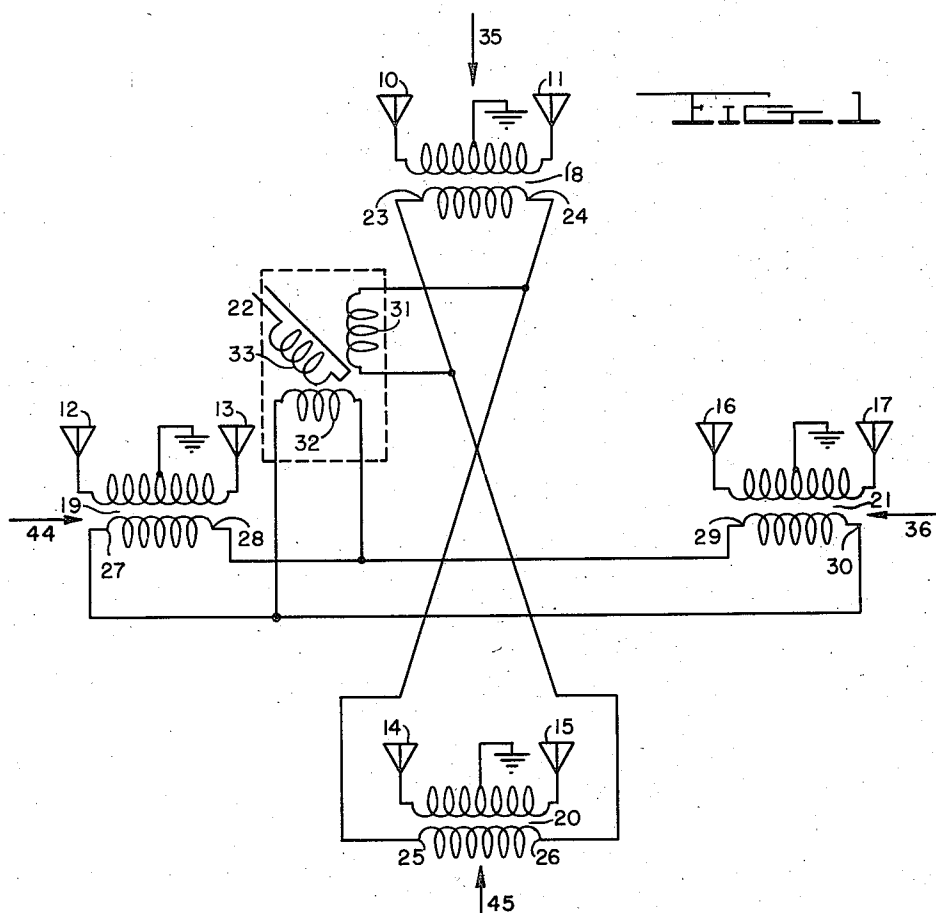


FIG. 1

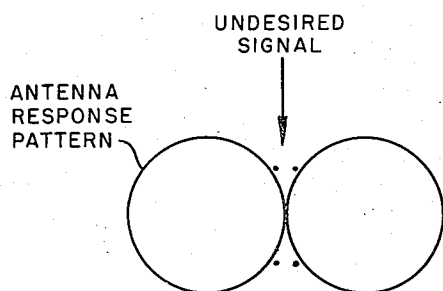


Fig 1^A

Inventor

CLIFFORD M. SIMPSON

McHayer

Attorney

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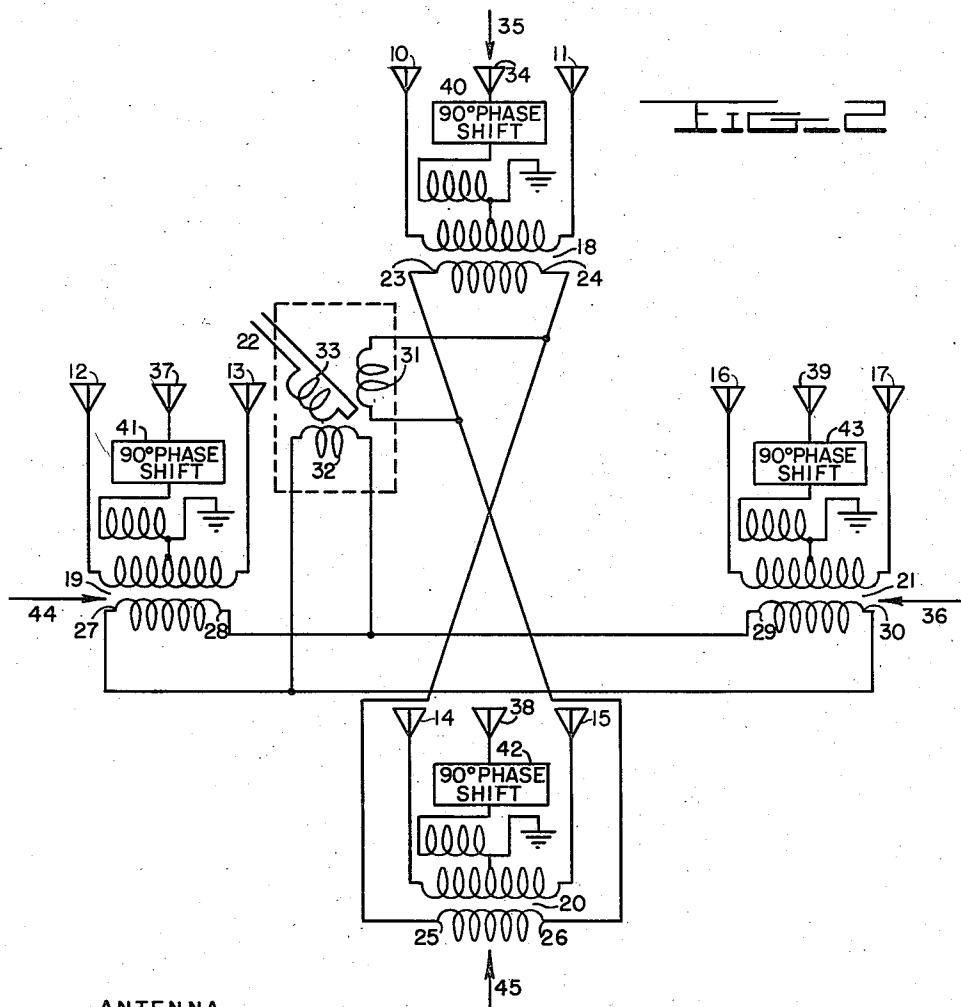


FIG. 2

ANTENNA
RESPONSE
PATTERN

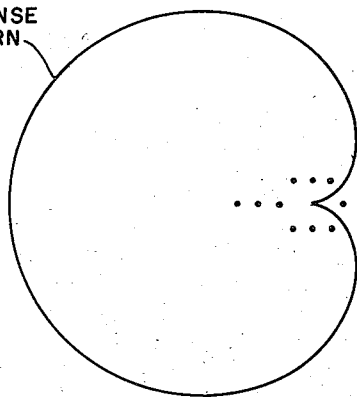


FIG. 2A

Inventor
CLIFFORD M. SIMPSON

M. Hayes

Attorney

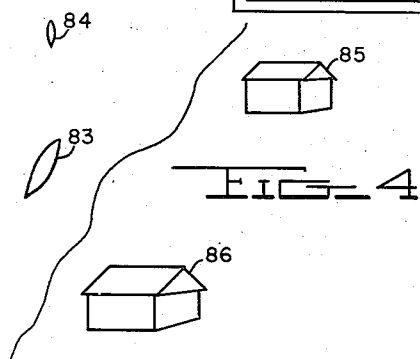
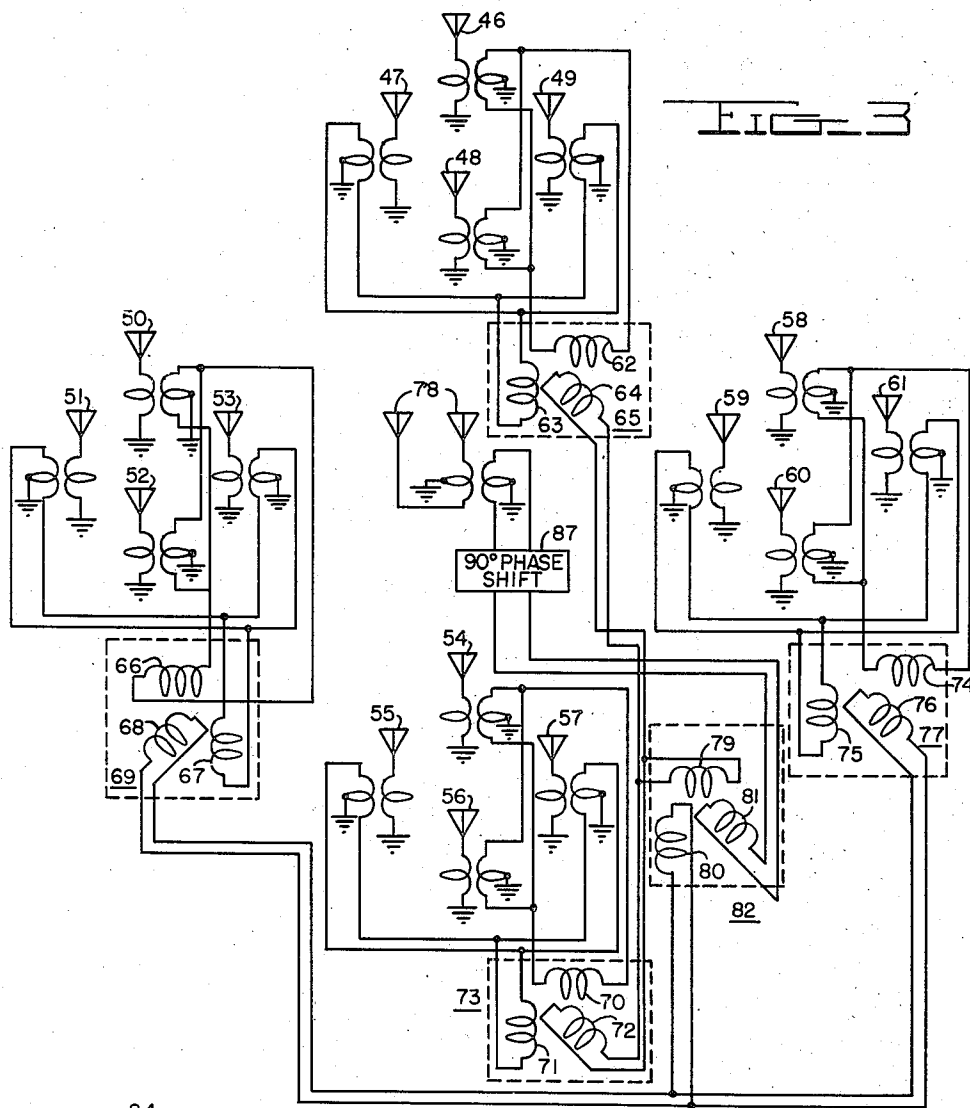
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Inventor
CLIFFORD M. SIMPSON

M. O. Hayes
Attorney

UNITED STATES PATENT OFFICE

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DIRECTIVE ANTENNA SYSTEM

Clifford M. Simpson, Manhattan, Kans.

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8 Claims. (Cl. 343—100)

(Granted under the act of March 3, 1883, as amended April 30, 1928; 370 O. G. 757)

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This invention relates to an antenna system and more particularly to a directive antenna system.

One of the objects of this invention is to provide a directive antenna system whose properties of indicating the direction of incoming signals cannot be destroyed by undesirable signals.

Another object of this invention is to provide a direction-finding system which will exclude signals from an unwanted direction but which will possess the direction finding properties of a conventional direction-finding system with respect to signals from any other direction.

A further object of this invention is to provide a direction-finding system which will facilitate the transmission of messages to a desired position without permitting other positions to intercept such messages.

Other objects and advantages of the invention will be apparent from the following detailed description when taken in conjunction with the accompanying drawings which illustrate preferred embodiments of the invention and in which:

Fig. 1 is a schematic diagram of one embodiment of this invention

Fig. 1A shows in general the response pattern of the embodiment of Fig. 1,

Figs. 2 and 3 are schematic diagrams of alternate embodiments of this invention

Fig. 2A shows the response pattern of the embodiments illustrated in Figs. 2 and 3, and

Fig. 4 is a schematic diagram illustrating how this invention may be used as an aid to maintaining a measure of secrecy in radio communication.

In accordance with the present invention the discrimination against signals from an unwanted direction is effected by replacing the single non-directional antenna located at each corner of a rhomboid in an ordinary Adcock system with a highly directional antenna or a combination of antennas electrically similar to each other. When no sense antennas are used, the combination at each of such corners, or collector set as it will be hereafter called, consists in one embodiment of the invention of an even number of antennas symmetrically arranged about a geometric center, with the outputs of pairs of antennas in the collector set so combined that no resultant output will be obtained from the collector set for a signal coming from a specific direction. For all other directions, however, a resultant output will be obtained from each set. If, then, the outputs from diagonal sets are so

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combined that the properties of an Adcock array are preserved, the subject antenna arrays will indicate the direction of incoming signals while excluding interfering signals from a particular direction.

An antenna system is also contemplated in which a sense antenna may be added at the geometric center of each antenna collector set, thus requiring that an odd number of antennas comprise each set. By causing the phase of the output from this sense antenna to be shifted approximately 90° and then combining this output with the resultant output from the other antennas in the set, a signal may be excluded whose direction is at right angles to the direction of the signals excluded when an even number of antennas comprise the set. Further contemplated ramifications of this system permit the same result to be obtained by replacing the sense antenna in each collector set by one sense antenna at the geometric center of the antenna array and introducing the output from this sense antenna to the resultant output from all of the collector sets.

In Fig. 1, to which reference is now had, a schematic diagram is shown of an antenna array consisting of a pair of antennas at each corner of a rhomboid. This embodiment comprises antennas 10 thru 17 inclusive, transformers 18 thru 21 inclusive, and windings 31, 32 and 33 of a goniometer 22. The antennas 10 thru 17 inclusive may be ordinary vertical antennas having non-directional properties and are so arranged that the plane containing each collector set is parallel to the plane containing the antennas of the other collector sets. Additionally, the distances between the two antennas of each collector set are normally equal and are small as compared to the distances between diagonal collector sets 10—11 and 14—15 and between the mid-points of collector sets 12—13 and 16—17, both of which distances are normally equal. As a typical example, the distance between diagonal collector sets may be taken as $\lambda/5$ or 20% of the wave length of the signal being received, while the difference between the two antennas of a collector set may be taken as $\lambda/20$. Although the spacings between the antennas in a collector set and the spacings between diagonal collector sets are normally equal, other spacings may be used to produce special results in accordance with recognized direction-finding practices. For example, in order to obtain an expanded scale in certain quadrants, the spacing between diagonal collector sets 10—11 and 14—15

might be made much different than the spacing between the mid-points of collector sets 12—13 and 16—17.

In this diagram, the primary winding of transformer 18 is connected between the antennas 10 and 11 and its center-tap is grounded; the center tap of the primary winding of transformer 20, which connects the antennas 14 and 15, is also grounded. The secondaries of the transformers 18 and 20 are cross-connected so that terminal 23 of transformer 18 is joined to terminal 26 of transformer 20 and terminal 24 of transformer 18 is joined to terminal 25 of transformer 20. Voltage is derived across the winding 31 of the goniometer 22 by linking the cross-connections to the terminals of the winding 31. In the same manner, the centers of the primary windings of transformers 19 and 21 are grounded, said windings connecting antenna sets 12—13 and 16—17, respectively. Additionally, the secondaries of the transformers are cross-connected so that terminals 27 and 28 of transformer 19 are linked to terminals 30 and 29 of transformer 21, respectively. From these cross-connections, connections are made to the terminals of the winding 32, which is the other fixed winding of the goniometer 22. The winding 33 of the goniometer is rotatable and combines vectorially the voltages of windings 31 and 32 when rotated.

Consider now the signal 35 which is coming from such a direction that its wavefront is parallel to the planes containing the collector sets. Since the wavefront will reach the antennas 10 and 11 at the same time, voltages of equal amplitude and the same phase will be induced in these antennas and these voltages will appear at the ends of the primary winding of transformer 18. Thus, because of the fact that no voltage difference exists across the primary winding, no voltage will be induced in the secondary winding of the transformer 18. Likewise, no voltage will be induced in the secondary winding of the transformer 20 because of equal voltages on the antennas 14—15. Thus the winding 31 of the goniometer 22 will not receive excitation from the signal 35. In like manner, antennas 12, 13, 16, and 17 will receive equal voltages and thus the secondary windings of the transformers 19 and 21 will receive no electromotive force to be transmitted to the winding 32 of the goniometer 22. Since neither winding 31 nor winding 32 has voltage applied to it as a result of the signal 35 being intercepted by the collector sets, the winding 33 of the goniometer 22 will receive no excitation when it is rotated.

Consider, however, the signal 36 whose wavefront is perpendicular to the planes containing the collector sets. Now, the voltage intercepted by the antenna 11 will be different in phase than the signal intercepted by the antenna 10. Thus a resultant voltage will exist between the antennas 10 and 11 and this voltage will be induced from the primary winding to the secondary winding of transformer 18. Also since the antennas 14 and 15 are in the same position as the antennas 10 and 11, respectively, with respect to the wavefront of the signal 36, the same voltage difference will appear between the antennas 14 and 15, and therefore across the secondary of the transformer 20, as will appear across the secondary of the transformer 18. By cross connecting the two secondary windings, therefore, the current from one secondary winding will be equal in amplitude and opposite in phase to the current from the other winding, leaving no resultant cur-

rent through the winding 31. Consequently, the total reaction of the antenna collector sets 10—11 and 14—15 to the signal 36 is the same as if the collector sets were replaced by the single antennas of the ordinary Adcock system.

But a response will be obtained by the winding 32 from the reaction of collector sets 12—13 and 16—17. Considering first the collector set 16—17, the voltage induced in antenna 17 will be different in phase than the signal intercepted by the antenna 16. This voltage difference will appear across the terminals 29 and 30 of the transformer 21. Although the difference in phase between the antennas 12 and 13 will be same as the difference between antennas 16 and 17, the resultant output voltage from the collector set containing antennas 12 and 13 will be different in phase from the resultant output voltage of the collector set containing antennas 16 and 17. This phenomenon occurs when the distance between the midpoints of the two collector sets is different than λ , the wave length of the signal or integral multiple thereof. Consequently, the difference vector voltage between antennas 12 and 13 is equal in amplitude to but different in phase than the difference vector voltage between antennas 16 and 17. Thus a resultant voltage will appear across the connections between transformers 19 and 21 and this voltage will be introduced to the winding 32 of the goniometer 22. The feature of phase differences between antennas of a collector set and also between collector sets is maintained for signals from any direction except signals 35 and signal 45, which is travelling in a plane 180° different in azimuth from signal 35. Since no response is obtained from signals having the direction of signals 35 and 45 and since maximum response is obtained from a signal having the direction of signal 36 and a signal 180° different in azimuth from signal 36, it may be seen that the response pattern of the antenna array of Fig. 1 will be a "figure-eight" pattern, as shown in Fig. 1A. Thus, by rotating winding 33 a position may be found where no voltage is induced therein, permitting the indication of the bearing of the received signal.

The antenna system shown in Fig. 2 is physically similar to that shown in Fig. 1 except for the addition of the antennas 34, 37, 38 and 39 and associated phase shifters 40, 41, 42 and 43. In addition to being non-directional and vertical, the antenna 34 is located in the same plane as that containing antennas 10 and 11 and is mid way between those antennas. Antenna 37 is situated in like manner with respect to antennas 12 and 13, antenna 38 with respect to antennas 14 and 15, and antenna 39 with respect to antennas 16 and 17. The phase shifters 40, 41, 42 and 43 shift by approximately 90° the phases of the signals received by antennas 34, 37, 38 and 39, respectively, the reason for this shift being that the vector difference of the voltages between the two outer antennas of a collector set is approximately 90° out of phase with the voltage vector of the middle antenna. Thus, it can be seen that the direction of the signal excluded by the antenna system will no longer be in the direction of signal 35 or signal 45. The reason for this lies in the fact that although the resultant output, for a signal having the direction of signals 35 or 45, of the two outer antennas of each collector set is zero, the middle antenna will have an output and this output, therefore, will be the resultant output of the

complete collector set. If the 90° phase shift is produced in such a direction, however, that the voltage from the middle antenna, for example antenna 34, directly opposes the difference voltages between the two outer antennas, such as antennas 10 and 11, a signal having the direction of the signal 36 may now be excluded from the antenna system as an undesirable signal. This can be more easily seen by discussing the action on the signal 36 of the collector set containing antennas 16, 17 and 39, as shown in Fig. 2. Thus it can be seen that the voltage intercepted by the antenna 17 will be different in phase than the signal intercepted by the antenna 16. By connecting the transformer 21 between these antennas, the vector difference of the voltage between the antennas will be obtained. But, since the antenna 39 is midway between the antennas 16 and 17, the signal received by the antenna 39 has a phase which is different from that of the two antennas by the same amount and therefore the vector of the signal intercepted by this antenna will be half way between the voltage vectors of antennas 16 and 17. Therefore the vector difference of the voltages between antennas 16 and 17 will form the base of an isosceles triangle with the voltage vectors of antennas 16 and 17 and the vector of the voltage of antenna 39 will lie on the altitude of this triangle. It is a basic principle of plane geometry that the base and altitude of an isosceles triangle are perpendicular to each other. If the altitude of the triangle, as represented by the signal on the antenna 39, is shifted 90° in phase it will be parallel to the base, as represented by the vector difference of the voltages on the two outer antennas. If this shift is made in such a direction as to oppose the vector of the voltage difference the collector set containing antennas 16, 17 and 39, and each of the other collector sets, will have a resultant response of zero to the signal 36. Thus it will be seen that if a signal having the direction of signal 36 is excluded the maximum sensitivity will occur from a signal 44, which is displaced 180° in azimuth with respect to signal 36, since the voltage of the middle antenna and the difference voltage between the two outer antennas now add directly in each collector set to produce a signal of reinforced strength in the set. Consequently a cardioid pattern of sensitivity, as illustrated by Fig. 2A will be produced, with the zero sensitivity of the pattern occurring, for example, for a signal having the direction of signal 36 and the maximum sensitivity being realized for a signal of such direction as signal 44, which is displaced 180° in azimuth with respect to the signal 36. As for the signals 35 and 45, the antenna system of Fig. 2 will respond to them with outputs of equal amplitude.

The schematic diagram of Fig. 3 contemplates the use of either sixteen or seventeen antennas, with four collector sets arranged at the four corners of a rhomboid and each collector set comprising four antennas arranged in a conventional Adcock set up. The antennas 46, 47, 48 and 49 comprise one collector set; another set is composed of antennas 50, 51, 52 and 53; a third set consists of antennas 54, 55, 56 and 57; and the last set, of antennas 58, 59, 60 and 61. A sense collector set 78 is normally located at the geometric center of the four collector sets. The antennas of each set are cross-connected in the conventional manner and the cross-connections are linked to the fixed windings of a goniometer.

Thus the cross-connections of antennas 46 and 48 is connected through a conventional Adcock arrangement to the winding 62 of the goniometer 65. In like manner, antennas 50 and 52, 54 and 56, and 58 and 60 are connected to the fixed windings 66, 70 and 74 of the goniometers 69, 73 and 77, respectively. Likewise, antennas 47 and 49, 51 and 53, 55 and 57, and 59 and 61 are connected through a conventional Adcock arrangement to windings 63, 67, 71 and 75 of the goniometers 65, 69, 73 and 77, respectively. The rotatable windings 64, 68, 72 and 76 of the goniometers 65, 69, 73 and 77, respectively, are so arranged that the signal from the unwanted direction is excluded in each goniometer. Since the position of the rotating winding is the deciding factor, it may be seen that the corresponding antennas of each collector set do not have to be located in a definite pattern with respect to each other. If, then, the rotatable windings of the goniometers which are used in connection with the diagonal collector sets are connected together and connections are made from these diagonally-connected goniometers to the fixed windings of a fifth goniometer, the rotatable windings of this latter goniometer will be able to give the directions of incoming signals without any difficulty being presented by the signals from the undesirable direction. In this application, however, the rotatable windings must remain in a fixed position once they have been adjusted to exclude the undesirable signals. Thus the rotatable windings 64 and 72 of goniometers 65 and 73, respectively, are connected together and the fixed winding 79 of the goniometer 82 is placed in parallel with these windings. The rotatable windings 68 and 76 of the goniometers 69 and 77, respectively, are also connected in parallel with the fixed winding 80 of the goniometer 82. Since the signal from the undesirable direction has already been excluded from the goniometers 65, 69, 73 and 77, the rotatable winding 81 of the goniometer 82 will be free to give the direction of any other incoming signals. The response pattern which will result is similar to the "figure eight" pattern shown in Fig. 1A, except that the null point of the "figure eight" may be changed merely by varying the position of the rotatable windings 64, 68, 72 and 76.

The above situation is particularly advantageous when used in such a situation as is diagrammed in Fig. 4. Assume that the friendly ship 83 desires to transmit a message to the friendly station 85 but is afraid to transmit this message openly and directly because of the danger that an unfriendly ship such as the ship 84 will intercept the message and thus be able to determine the position of the ship 83. If, now, the friendly station 86 sends out a continuous and strong signal and the ship 83 sends out a weaker signal at the same frequency, the signal from the ship 83 being modulated, however, to transmit the desired message, the ship 84 will not be able to intercept the message from the ship 83 because of the interfering signal from the station 86. But if the station 85 has an antenna array similar to that shown in Fig. 3, the rotating windings 64, 68, 72 and 76 of the goniometers 65, 69, 73 and 77, respectively, could be adjusted to exclude the interfering signal from the station 86. The rotating winding 81 of the goniometer 82 could then indicate clearly the direction of the ship 83 and the message from the ship could be plainly received.

Referring again to Fig. 3, the sense collector

set 78 and the phase shifter 87 may be added to the sixteen-antenna array discussed above. The sense collector set should have such electrical properties that it will indicate a null for signals arriving from the same direction as those signals which are excluded in each Adcock collector set. For example, two non-directional antennas arranged such that their plane is parallel to the wavefront of the signal to be excluded may be used. By shifting the voltage from the collector set 78 approximately 90° in phase by means of the phase shifter 87, and coupling this voltage to the rotating winding 81 of the goniometer 82, the directivity of a signal may now be indicated when the array comprising antennas 46 thru 61, inclusive, indicates maximum strength for the signal. This is accomplished by bucking out the maximum signal from the array with the phase-shifted signal of antenna 78. This action is somewhat different from that when the collector set 78 is not used, since in the array comprising antennas 46 thru 61, inclusive, the directivity of the signal is indicated when the goniometers are so positioned that the strength of the signal is at zero level.

Just as the addition of a third antenna to a collector set originally comprising two antennas will change the response pattern from a "figure eight" pattern to a cardioid pattern, so the addition of a fifth antenna to each four-antenna collector set will change the response from a "figure eight" to a cardioid response pattern. These antennas should be so arranged that one will be at the geometric center of each Adcock collector set. As in the arrangement shown in Fig. 2, the output of each center antenna is shifted approximately 90° in phase before being applied to the resultant output of the collector set. However, the five-antenna collector set is advantageous over the three-antenna collector set in that, in the former, the null direction of the cardioid pattern may be varied merely by changing the position of the rotatable goniometer winding of each collector set.

It should be noted that each pair of non-directional antennas in a collector set may be replaced by a single loop, since a pair of non-directional antennas is electrically similar to a loop antenna. Thus, the antennas 10 and 11, 12 and 13, 14 and 15, 16 and 17 in Fig. 1 may be replaced by loop antennas; likewise, pairs of antennas in the other arrangements shown may be replaced by loops.

It should be further noted that although the antenna arrangements described above have been discussed from the viewpoint of receiving incoming signals these same arrangements may also be used as arrangements for transmitting antennas. This may be accomplished by introducing the output of the transmitter to the same terminals which would normally connect to the receiving equipment.

While certain preferred embodiments of this invention have been described, it is realized that many modifications and variations of this invention may be made and no limitations upon this invention are intended other than may be imposed by the scope of the appended claims.

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

What is claimed is:

1. A directive antenna system, having sub-

stantially zero responsiveness to signals from a certain direction but finite responsiveness to signals from all other directions, said system comprising four identical antenna sets containing at least two non-directional antennas in each set arranged at the four corners of a rhomboid, each of said sets being adapted to provide an output signal characteristic of the direction of an incoming signal, means including a goniometer for vectorially combining the output signal from each of said sets with that from the set diagonally opposed thereto, said goniometer having two fixed windings and a rotatable winding, one of said fixed windings adapted to receive the combined output signal from one of said diagonal pairs, the other of said fixed windings adapted to receive the combined output signal from the other of said diagonal pairs, whereby there is induced in the rotatable winding of said goniometer a resultant voltage signal indicative of the direction of the incoming signal.

2. A directive antenna system, having substantially zero responsiveness to signals from a certain direction but finite responsiveness to signals from all other directions, said system comprising four identical antenna collector sets containing a plurality of non-directional antennas in each set, said sets arranged at the four corners of a rhomboid, a non-directional sense antenna located at the geometric center of each set, means for shifting by approximately 90° the phase of the sense antenna voltage, means for combining said phase shifted voltage with the output from the associated collector set to produce a first resultant voltage characteristic of the direction of the incoming signal, means for vectorially combining the voltages from each of said sets with that from the set diagonally opposed thereto, to thereby produce a second resultant voltage signal indicative of the direction of the incoming signal.

3. A directive antenna system, having substantially zero responsiveness to incoming signals from a certain direction but finite responsiveness to signals from all other directions, said system comprising four identical antenna sets containing two non-directional antennas in each set, said antenna sets arranged at the four corners of a rhomboid, said antennas further arranged such that the plane through each set is parallel to the planes through the other sets, means interconnecting the antennas of each set so as to provide an output signal therefrom which is characteristic of the direction of an incoming signal, means for vectorially combining the output signal from each set with that from the set diagonally opposed thereto to produce a pair of difference voltages, and goniometer means for combining the difference voltages to produce a resultant voltage signal indicative of the direction of the incoming signal.

4. A directive antenna system, having substantially zero responsiveness to incoming signals from a certain direction but finite responsiveness to signals from all other directions, said system comprising four identical antenna sets containing two non-directional antennas in each set, said antenna sets arranged at the four corners of a rhomboid, and located such that the plane through each set is parallel to the planes through the other sets, transformer means interconnecting the antennas of each of said sets to produce an output signal therefrom characteristic of the direction of the incoming signal, the output from the transformer means associated with

each of said sets cross connected with that associated with the set diagonally opposed thereto, a goniometer having a pair of fixed windings and a rotatable winding, one of said fixed windings adapted to receive the resultant output signal from one pair of said diagonally opposed antenna sets, the other of said fixed winding adapted to receive the resultant signal from the other of said diagonally opposed sets, whereby there is induced in said rotatable winding a resultant voltage signal indicative of the direction of the incoming signal.

5. A directive antenna system, having substantially zero responsiveness to incoming signals from a certain direction but finite responsiveness to signals from all other directions, said system comprising, four identical antenna sets containing three non-directional antennas in each set, said sets arranged at the four corners of a rhomboid, with the antennas of each set located in coplanar relationships, the antennas in each set being further arranged such that one antenna is mid way between the other two antennas, means for directly combining the outputs from the outer antennas of each set, means for shifting the phase of the output from the middle antenna in each set by approximately 90°, means for combining the phase-shifted output of said middle antenna with the combined output of said outer antennas, means for pairing the outputs of diagonal sets to produce difference voltages, and goniometer means for combining the difference voltages to produce a resultant voltage signal indicative of the direction of the incoming signal.

6. A directive antenna system having substantially zero responsiveness to signals from a certain direction but finite responsiveness to signals from all other directions, said system comprising, four identical antenna collector sets containing four non-directional antennas in each set, said sets arranged at the four corners of a rhomboid, the four antennas of each set arranged in a conventional Adcock arrangement at the four corners of a smaller rhomboid, a separate goniometer associated with each of said collector sets and having two fixed windings and a rotatable winding, means for connecting each pair of diagonal antennas in an Adcock set to a fixed winding of its respective goniometer, the rotatable winding of each of said goniometers being positioned to exclude an incoming signal arriving from a specific direction, means for combining the outputs from the goniometers of diagonal antenna sets to produce difference voltages, a goniometer common to all collector sets and having two fixed windings and a rotatable winding, one of said fixed winding adapted to receive the output signal from one pair of said diagonally opposed collector sets, the other of said fixed winding being adapted to receive the output signal from the other pair of diagonally opposed sets, whereby there is introduced in the rotatable winding of said last named goniometer a resultant voltage signal indicative of the direction of the incoming signal.

7. A directive antenna system having substantially zero responsiveness to signals from a certain direction but finite responsiveness to signals from unwanted directions, said system compris-

ing, four identical antenna collector sets containing four non-directional antennas in each set, said antenna sets arranged at the four corners of a rhomboid, a non-directional antenna located at the geometric center of said rhomboid, the four antennas comprising each set arranged in a conventional Adcock arrangement at the four corners of a smaller rhomboid, a separate goniometer associated with each of said collector sets and having two fixed windings and a rotatable winding, means for connecting each pair of diagonal antennas in an Adcock set to a fixed winding of its respective goniometer the rotatable winding of each of said goniometers being positioned to exclude an incoming signal arriving from a specific direction, means for combining the outputs from the goniometers of diagonal antenna sets to produce difference voltages, a goniometer common to all collector sets and having two fixed windings and a rotatable winding, one of said fixed windings adapted to receive the output signal from one pair of said diagonally opposed collector sets, the other of said fixed windings being adapted to receive the output signal from the other pair of diagonally opposed sets, means for shifting by 90° the phase of the output from the antenna located at the center of the four collector sets, and means for introducing said phase-shifted output to the rotatable winding of said last-named goniometer, whereby there is introduced in said rotatable winding a resultant voltage signal indicative of the direction of the incoming signal.

8. A direction finding antenna system for nullifying the effect of undesired signals from a given direction comprising a first and second pair of antenna elements located respectively along two lines at right angles to each other which cross at the geometrical center of said elements, a goniometer transformer having a first and second winding fixed at right angles to each other and a third winding inductively coupled thereto, said third winding being rotatable relative to said first and second winding, means for differentially coupling said first and second pair of antenna elements respectively to said first and second windings, said antenna elements having directional characteristics providing a minimum response in the same given direction, a non-directional antenna means located at the geometrical center of each of said antenna elements, phasing means for displacing the phase of the voltage in each of said non-directional antenna means by 90 degrees, means coupling the output of said phasing means to the said third winding of said goniometer transformer.

CLIFFORD M. SIMPSON.

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