

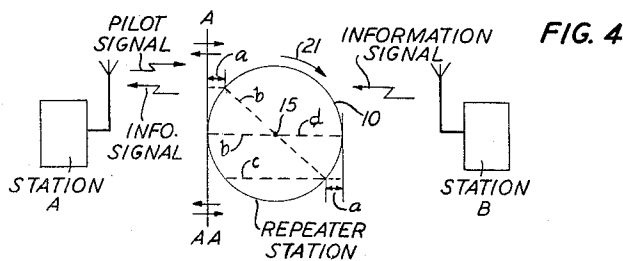
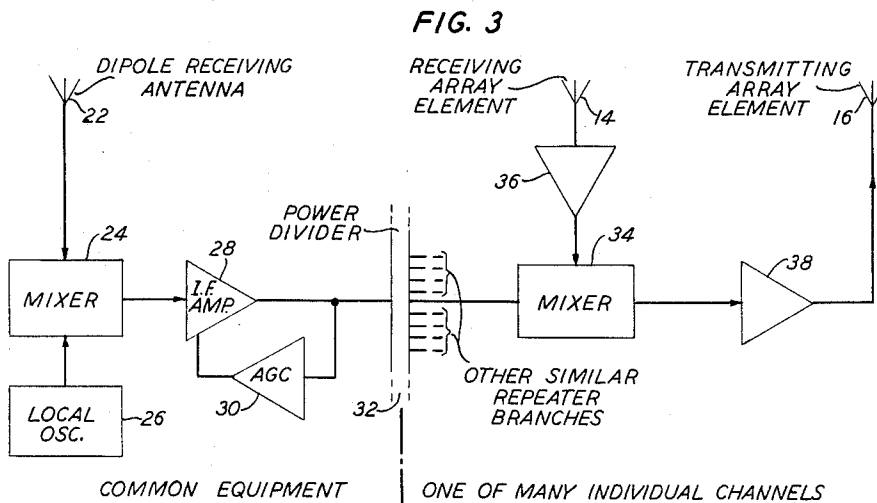
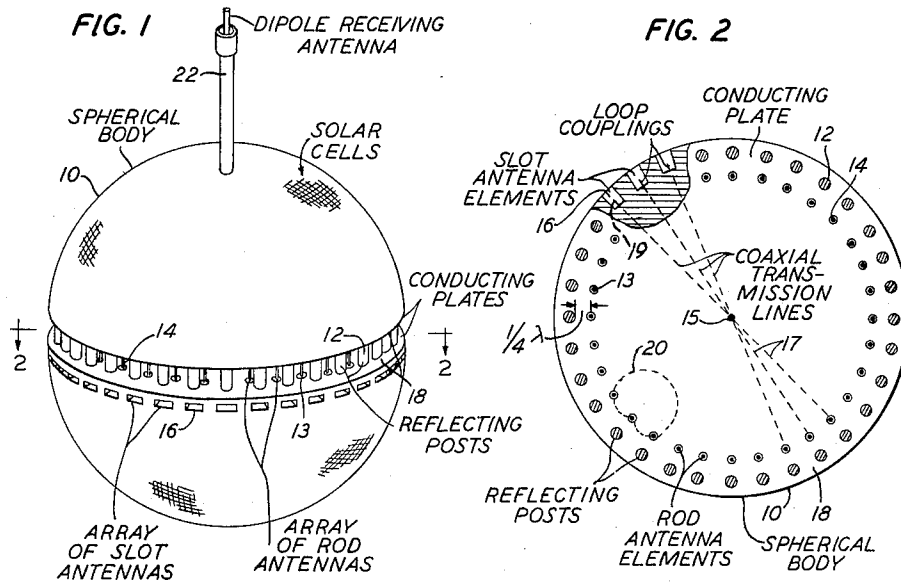
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ANTENNA SYSTEM

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ANTENNA SYSTEM

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This invention relates to antenna arrays and, more particularly, to a so-called Van Atta array modified to provide partially or completely isotropic antenna coverage.

An antenna array that retransmits an incoming electromagnetic wave in the direction from which the incoming wave impinges upon the array is disclosed in L. C. Van Atta Patent 2,908,002, issued October 6, 1959. In this so-called Van Atta array, an even number of antenna elements are distributed equal distances apart on either side of a center of symmetry in a planar array. Corresponding elements on either side of the center of symmetry are connected together in pairs by way of transmission lines, all having equal electrical lengths. As a result of the placement of antenna elements and the interconnections between designated pairs of antenna elements by transmission lines having equal electrical lengths, an electromagnetic wave, impinging within the radiation pattern of the individual array elements and regardless of the angle of incidence, traverses the same distance from the wavefront at an arbitrarily chosen point to each element of the array, through the transmission line to the corresponding element, and back in the direction of the incoming wave to the initial wavefront. Accordingly, transmission from the array occurs in the direction to the source of the impinging wave.

It has been recognized that the Van Atta array might be employed to great advantage in directional transmission from a communication station which is subject to variations in orientation with respect to the desired direction of transmission, as for example, space communication satellites and mobile radio stations. To fully utilize the advantageous characteristics of the Van Atta array in a communication station which is subject to unlimited orientation changes with respect to the desired direction of transmission, it is necessary to distribute the array elements over the station in such a way that isotropic antenna coverage is obtained. Then, regardless of the orientation of the station, some antenna elements will be in a position to carry out transmission in a particular direction. There are certain applications in which what might be termed a partially isotropic antenna coverage might suffice, i.e., the antenna array elements are distributed in a circle to provide isotropic antenna coverage only in the plane of the circle.

R. C. Hansen in an article in the Proceedings of the IRE, June 1961 at page 1066, entitled "Communications Satellites Using Arrays," considers the application of the Van Atta array to unstabilized space satellite communication repeaters. He suggests using the Van Atta array on a satellite to function much like a corner reflector. Information signals radiated from a ground station are reflected from the satellite, after being amplified in the transmission lines if desired, toward the same ground station. Owing to diffraction the returned beam spreads, however, so that its field of illumination covers other ground stations remote from the first ground station, thus permitting communication therewith.

The difficulty of adapting the Van Atta array to circular or spherical configurations is apparent from Hansen's article. Specifically, Hansen suggests that the conventional planar Van Atta array be modified to a circular array by readjusting the electrical lengths of the interconnections between paired antenna elements to account for

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the deviation of the placement of elements from a plane. The electrical lengths required of the interconnections between paired elements to produce transmission in the direction to the source of incident signals, however, change as a function of the angle of incidence of the signal impinging upon the array. Deviations of the direction of transmission from the direction to the source of received signals consequently occur. To minimize this effect, Hansen says that several individual arrays of a few elements each should be used to cover the field of operation of the station. Such a scheme might also be considered to be unsatisfactory because the individual arrays do not cooperate with one another informing the resultant returned beam. At any rate, the very fact that the Van Atta array produces deviations in the direction of transmission from the direction to the source of received signals when adapted to a circular or spherical configuration requires that the antenna array be designed so that the returned signal forms a wider beam than would be the case without this effect to insure that the direction of transmission will include the station with which it is desired to communicate. This, in turn, tends to offset the principal advantage of use of the Van Atta array in communication stations, that of permitting high gain transmission of the returned signal.

It is, therefore, the object of the present invention to improve the Van Atta array having elements arranged in a circular or spherical configuration and to more fully exploit the directional characteristics of the Van Atta array used in communication stations.

In accordance with the above object, plural antenna elements are arranged in a circular or spherical configuration and diametrically opposite elements are connected together with transmission lines having equal electrical lengths. This arrangement provides equal path lengths from an arbitrarily chosen wavefront of an electromagnetic wave impinging upon the array in any direction to each antenna element, through the transmission line to the corresponding, opposite antenna element and back in the direction to the source of the impinging wave to the initial wavefront.

In accordance with a feature of the invention, in a communication system in which information is to be transmitted from a first station to a second station via a repeater subject to changes in orientation with respect to the first and second stations, the repeater is provided with a Van Atta array of any configuration. A pilot signal is radiated from the second station toward the repeater, the information is radiated from the first station toward the repeater, and the information received at the repeater by a single element antenna is modulated upon the pilot signal intercepted by each antenna element of the Van Atta array while the latter is traversing the transmission line. As a result, a signal bearing the information from the first station is returned directly toward the second station and it is not necessary to design the returned beam to be wide enough to reach both the first and second stations simultaneously, as required by Hansen's proposal in the above-mentioned publication. Higher gain transmission to the second station is therefore possible.

The above and other features of the invention will be considered in detail in the following specification taken in conjunction with the drawing in which:

FIG. 1 is a perspective view of a circular Van Atta array mounted on the surface of a spherical body;

FIG. 2 is a section view of the spherical body of FIG. 1;

FIG. 3 is a schematic diagram in block form of communication circuitry for impressing information on signals intercepted by Van Atta array elements; and

FIG. 4 is a diagram depicting a repeater station provided with a circular Van Atta array linking two terminal

stations and illustrating geometrical relationships helpful in understanding the mode of operation of the spherical or circular Van Atta array.

In FIG. 1 a circular Van Atta array is shown mounted on a conducting spherical body 10, which, by way of example, could serve as a space satellite communication repeater. Body 10 is divided into hemispheres maintained in predetermined relationship to one another by a ring of reflecting posts 12, made of conducting material, distributed around the periphery of a slot separating the hemispheres. An array of rod antenna elements 14 is arranged in a ring circumscribed by the ring of posts 12. Each rod element 14, as shown in FIG. 2, is aligned with the center point 15 of body 10 and the adjacent one of reflecting posts 12 at a distance from the adjacent post 12 of a quarter wavelength of the wave to be accommodated. One end of each rod element 14 is fastened to body 10 at one of a pair of conducting plates 18 comprising the adjacent plane surfaces of the hemispheres of body 10. The other end of each rod element 14 passes through an opening 13 in the other one of conducting plates 18 to a connecting circuit to be described below. Rod elements 14 each exhibit somewhat of a directional, cardioid radiation pattern, as represented for a single rod element 14 by a dashed outline 20 in FIG. 2, because of the placement of the adjacent reflecting post 12 a quarter wavelength away therefrom. Thus, posts 12 serve two functions, that of physically connecting the hemispheres comprising body 10 and that of making the radiation pattern of rod elements 14 directional toward center point 15.

An array of slot antenna elements 16, one for each rod element 14, is also distributed around the periphery of body 10 forming a ring around the surface of one of the hemispheres. Each slot element 16 is placed diametrically opposite a rod element 14 on body 10 and electrically connected thereto with a transmission line 17 (some of which are shown in FIG. 2) having an electrical length equal to that of all the remainder of transmission lines 17 connecting other diametrically opposite pairs of slot elements 16 and rod elements 14. Couplings between transmission lines 17 and rod elements 14 and slot elements 16 are provided. If, by way of example transmission lines 17 are coaxial cables, the center conductor of the coaxial cable could be coupled to slot elements 16 by means of loop couplings 19 and to rod elements 14 directly and the outer conductor could be grounded to body 10. Transmission lines 17 need not pass through center point 15. This is shown in FIG. 2 merely to simplify the drawing. Instead, to avoid congestion in the vicinity of center point 15, transmission lines 17 can be laid out along any paths between element pairs so long as the electrical lengths of all transmission lines 17 are equal. Conducting plates 18 define a radial transmission line to provide access for impinging electromagnetic waves through satellite body 10 to and from rod elements 14.

When incoming electromagnetic waves impinge upon the surface of body 10, they can take either of two alternative paths through the array. First, they can be intercepted by the radial transmission line comprising conducting plates 18, in which case they pass rod antenna elements 14 on the side of body 10 nearest to the impinging wave without being intercepted because they are shielded from these rod elements 14 by their adjacent posts 12. The incoming waves then traverse the radial transmission line comprising plates 18 to rod elements 14 on the far side of body 10. Each of rod elements 14 on the far side of body 10 intercepts a portion of the incoming wave conveyed on the radial transmission line comprising conducting plates 18. Such portion is coupled by transmission line 17 to the diametrically opposite slot element 16 and then retransmitted from slot element 16. Alternatively, the incoming wave may be intercepted by slot elements 16 on the side of body 10 nearest the impinging wave and retransmitted by means of the reciprocal paths

through transmission lines 17, rod elements 14, and the radial transmission line comprising conducting plates 18. The interconnection of diametrically opposite pairs of antenna elements by transmission lines 17 of equal electrical lengths and the intrinsic geometry of a circle result in equal path lengths for waves impinging upon body 10 from any arbitrarily chosen wavefront measured through each pair of antenna elements and back to the initial wavefront in the direction to the source of the incoming wave, regardless of the direction of incidence of the wave. Therefore, the condition for return of an electromagnetic wave in the direction to the source of an impinging wave is met by the described structure.

The arrangement of FIGS. 1 and 2 provides antenna coverage which is isotropic in the diametrical plane of body 10 parallel to the planes of slot elements 16 or of rod elements 14. If completely isotropic coverage is desired the array elements would be distributed over the entire surface of body 10, again diametrically opposite elements being connected together with transmission lines 17, all of equal electrical length. In this case, all of body 10 would probably have to be transparent to electromagnetic waves to permit access to and from rod elements 14.

FIG. 4 illustrates the relationship which exists between the path lengths of the portions of an incident electromagnetic wave intercepted and radiated by the various antenna elements. Line A to AA represents the wavefront of the incoming electromagnetic wave at a point where it impinges upon body 10. The path length of the portion of the wave intercepted by an antenna element located where line A to AA is tangent to body 10 and conveyed on a transmission line 17 to the diametrically opposite antenna element is b , where b is the electrical length of transmission line 17. Moreover, the path length from the diametrically opposite element through the radial transmission line composed of plates 18 back to line A to AA is d , where d is the diameter of body 10. For this case the total path length is the sum of b and d . The path length of the portion of the wave intercepted by some element to one side of the element of the first situation between line A to AA and body 10 is designated by a . As in the previous case, the path length to the diametrically opposite element through a transmission line 17 is b . In traversing the radial transmission line composed of plates 18 back to line A to AA the path length is indicated by c . It is evident from the symmetry of a circle that the distance c is shorter than d by the distance $2a$ and, therefore, the total path length in this case is also the sum of b and d . Likewise, regardless of the tangent point of line A to AA on body 10 (i.e., the direction of incidence of electromagnetic waves upon body 10), the path lengths from line A to AA, through body 10, and back to line A to AA are equal, and a true Van Atta array of circularly, or for that matter spherically, arranged components is attained.

A Van Atta array may be employed with great advantage to transmit information in a directional beam to a remote station A from body 10, both of which are depicted in FIG. 4. Body 10 may constitute a terminal station containing an original source of signals, as might be the case in a weather or other exploratory satellite, or may serve as a repeater station to relay information from a remote station B, also shown in FIG. 4, to station A. The information signal at body 10 to be transmitted to station A is modulated in each transmission line 17 of the Van Atta array upon a pilot signal radiated from station A. As described above, the pilot signal, in this case containing the desired information, is returned in a directional beam oriented toward remote station A despite changes in orientation of body 10 relative to station A represented by curved line 21. It should be noted that this feature is not limited to the circular or spherical Van Atta array configuration.

FIG. 3 discloses circuitry for modulating information

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transmitted to the repeater station from remote station B upon a pilot signal transmitted to the repeater station from remote station A. The information signal is intercepted in the repeater by a single dipole antenna 22, also shown in FIG. 1. The intercepted signal is beat in a mixer 24 with the output of a local oscillator 26. The resulting intermediate-frequency signal is applied to an intermediate-frequency amplifier 28 provided with an automatic gain control loop 30, and then to a power divider 32 for distribution to individual transmission lines 17 interconnecting the paired antenna elements. The circuitry comprising one of these transmission lines 17 is illustrated in FIG. 3 to the right of power divider 32. In each transmission line 17 the intermediate-frequency signal from power divider 32 is beat in a mixer 34 with the portion of the pilot signal intercepted by antenna array element 14 after amplification and separation in a narrow band amplifier 36. One of the modulation sidebands is separated and amplified for transmission by a narrow band power amplifier 38 and then applied to an antenna array element 16 for radiation back to remote station A together with the signals contributed by the other array elements.

In the arrangement shown in FIG. 3, the returned pilot signal is of a frequency different from that impinging upon the station due to the beating operation in mixer 34. In order for an impinging signal to be returned in the direction to the source of incident signals under these circumstances, the distance between the transmitting array elements and center point 15 must differ from the distance between the receiving array elements and center point 15 in the ratio of wavelength of the transmitted pilot signal to wavelength of the received pilot signal. The displacement between elements to satisfy the requirement may be adjusted within limits either by changing the position of the array of slot elements 16 on the surface of body 10 to form a chain further away or closer to plates 18 or by changing the diameter of the chain of rod elements 14 with the slot formed of plates 18.

It will be noted that in the repeater application of FIG. 3 the paired antenna elements are used unilaterally, i.e., rod elements 14 are employed to receive and slot elements 16 to transmit the pilot wave. If the frequency of both the received and returned pilot signals are the same the paired antenna elements could be used bilaterally, as was explained in conjunction with FIGS. 1 and 2.

What is claimed is:

1. In an antenna system, a first group of antennas that are distributed equal distances from a center point, a second group of antennas that are distributed equal distances from said center point, each of the antennas of said second group being located diametrically opposite a different antenna of said first group, and means of equal electrical lengths for interconnecting diametrically opposite antennas of said first group and said second group to form antenna pairs, both antennas of each of said pairs being oriented for operation in the same direction.

2. An antenna system for retransmitting incoming electromagnetic waves comprising a spherical body, a first set of antenna elements distributed over the surface of said body, a second set of antenna elements distributed over the surface of said body such that each element lies diametrically opposite a different element of said first set, means for connecting diametrically opposite elements of said first and said second set with electromagnetic signal paths having equal transmission delays, both elements of each connected pair being directional in the same direction, and electromagnetically transparent passage means through said body to the elements of said second set.

3. In an antenna system, a first set of antenna elements distributed in a circle, a second set of antenna elements distributed in a circle, each element of said second set lying on a line defined by a center point and

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the point of location of a different element of said first set, diametrically opposite elements of said first and second sets having at least partially coincident radiation patterns, and electrical connections having equal transmission delays interconnecting diametrically opposite elements of said first and second sets.

4. An antenna system comprising a spherical body, a first array distributed in a circle over the surface of said body, each element of said first array being directional radially from said sphere, a second array distributed in a circle over the surface of said body, each element of said second array being located diametrically opposite a different element of said first array and being directional toward its diametrically opposite first array element, means for interconnecting each element of said first array with its diametrically opposite second array element, and an electromagnetically transparent passage through said body to said second array elements to permit signals impinging upon the surface of said body to traverse said body to the elements of said second array.

5. An antenna system for retransmitting an incident electromagnetic wave in the direction of incidence comprising a spherical body having an array of individual slot antennas disposed in a ring around said body, said body being divided into two parts maintained at a predetermined separation by reflecting posts distributed between the plane adjacent surfaces of said parts, each of said parts being diametrically opposite a different one of said slots, said plane surfaces of said parts defining a transmission path through said body, an array of rod antennas, each lying parallel to and a quarter wavelength of the electromagnetic wave being accommodated away from a different one of said posts between the corresponding post and the center of said body, and means having equal transmission delays coupling each of said slot antennas with the diametrically opposite rod antenna.

6. In a communication system, a first station, a second station subject to changes in orientation with respect to said first station, said second station comprising a plurality of paired antenna elements, the elements of each pair being interconnected by a transmission path, said elements being placed to retransmit in the direction of impinging electromagnetic waves, and means individual to each of said signal paths for modulating information to be transmitted from said second station to said first station upon electromagnetic waves intercepted by said elements, and means for illuminating said second station with a pilot wave transmitted from said first station, whereby said pilot wave is retransmitted from said elements impressed with said information in a highly directional beam toward said first station.

7. In a communication system, a first communication station, a second communication station, and a repeater station for relaying information from said first station to said second station, means for transmitting an information-bearing signal from said first station to said repeater, means for transmitting a direction-indicating signal from said second station to said repeater, said repeater having means for intercepting said information-bearing signal, a plurality of paired antenna elements for intercepting said direction-indicating signal, the elements of each pair being interconnected by transmission paths having equal transmission delays, said paired elements being arranged to retransmit incoming signals in the direction of reception, and means individual to said signal paths for impressing said information received from said first station upon said direction-indicating signal received from said second station, and means at said second station for intercepting said retransmitted signal radiated from said paired antenna elements of said repeater.

8. A communication system comprising a first station and a second station subject to changes in orientation with respect to said first station, said second station comprising a plurality of antenna elements each located the same distance from a central point, transmission lines introduc-

ing equal time delays interconnecting diametrically opposite pairs of said elements, one element of each of said pairs having at least part of its radiation pattern coincident with the other element of said pair, and means individual to each of said transmission lines for modulating information to be transmitted from said second station to said first station upon electromagnetic waves intercepted by said elements, and means for illuminating said second station with a pilot wave transmitted from said first station, whereby said pilot wave is retransmitted from said elements impressed with said information in a highly directional beam toward said first station.

9. In a communication system, the combination comprising a first communication station, a second communication station, and a repeater station for relaying information from said first station to said second station, means for transmitting an information-bearing signal from said first station to said repeater, means for transmitting a direction-indicating signal from said second station to said repeater, said repeater having means for intercepting said information-bearing signal, a first set of antenna units for accommodating said direction-indicating signal distributed equal distances from a center point, a second set of antenna units for accommodating said direction-indicating signal distributed equal distances from said center point, each of said units of said second set being located diametrically opposite a different unit of said first set, and means of equal electrical lengths for interconnecting each of said units of said first set with the diametrically opposite unit of said second set, the units of each interconnected pair both being oriented for operation in the same direction, and means individual to each of said interconnecting means for modulating said information received from said first station upon said direction-indicating signal received by said units from said second station, and means at said second station for intercepting said retransmitted signal radiated from said antenna units of said repeater.

10. In a communication system, the combination comprising a first communication station, a second communication station, and a repeater station for relaying information from said first station to said second station, means for transmitting an information-bearing signal from said first station to said repeater, means for transmitting a direction-indicating signal from said second station to said repeater, said repeater having means for intercepting said information-bearing signal, a first set of antenna units for receiving said direction-indicating signal distributed equal distances from a center point, a second set of antenna units for transmitting said direction-indicating signals distributed equal distances from said center point, each of said units of said second set being located diametrically opposite a different unit of said first set, and means of equal electrical lengths for interconnecting each of said units of said first set with the diametrically opposite unit of said second set, the units of each interconnected pair both being oriented for operation in the same direction, and means individual to each of said interconnecting means for modulating said information received from said first station upon said direction-indicating signal received by said units from said second station, the distance between the units of said first set and said center point being proportional to the distance between the units of said second set and said center point in the ratio of frequency of said transmitted direction-indicating signal to frequency of said received direction-indicating signal, and means at said second station for intercepting said retransmitted signal radiated from said antenna units of said repeater.

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CHESTER L. JUSTUS, *Primary Examiner.*