Feb. 17, 1970 D. A. ALSBERG ET AL 3,496,569

PHASED ARRAY MULTIBEAM FORMATION ANTENNA SYSTEM

Filed Feb. 16, 1967 2 Sheets-Sheet 1

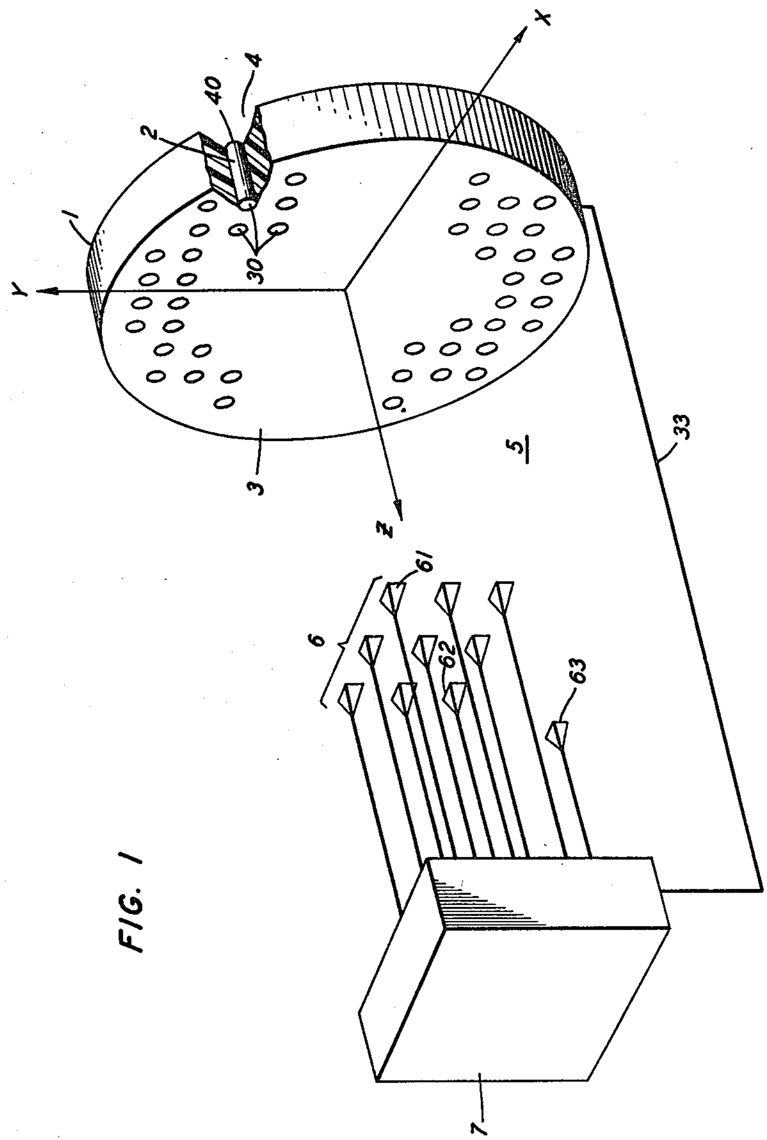

FIG. 1

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FIG. 2

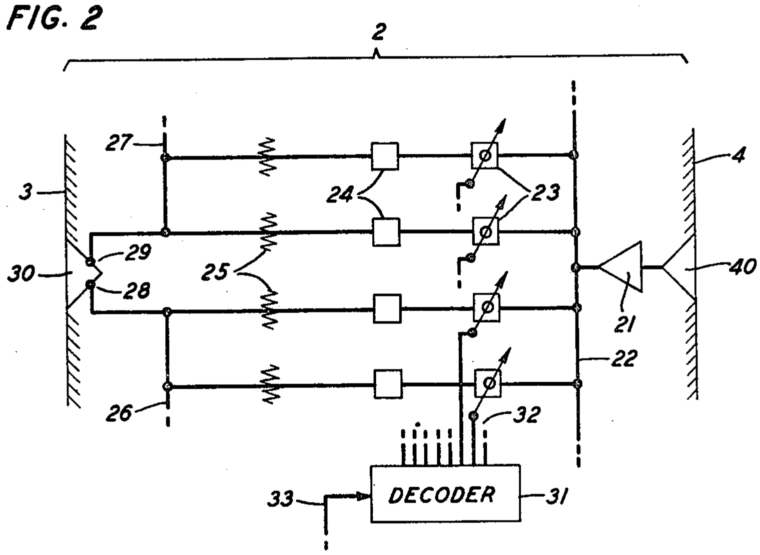


FIG. 3

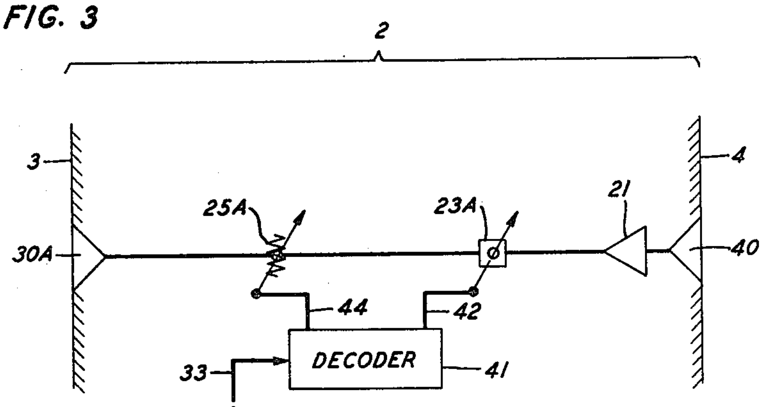
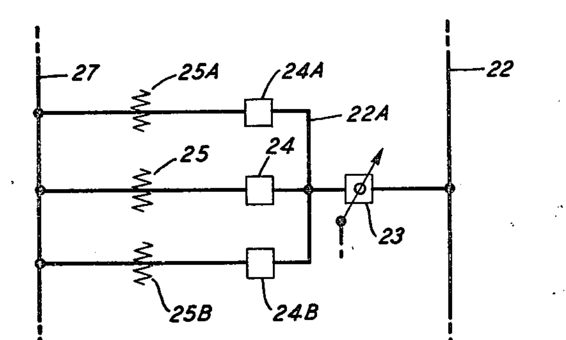


FIG. 4



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PHASED ARRAY MULTIBEAM FORMATION ANTENNA SYSTEM

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U.S. Cl. 343—754 **8 Claims**

ABSTRACT OF THE DISCLOSURE

A beam forming means for a multibeam phased array radar receiver in which all high frequency couplings between the antenna and the rest of the radar system are accomplished by space feed techniques using space multiplexing.

Background of the invention

This invention relates to the art of radio communications and more particularly to a multiplex phased array antenna system capable of simultaneously forming a separate beam for each of a plurality of signal sources in space.

Phased array antenna systems have been known for some time and the basic principles, particularly for linear arrays, are quite old as disclosed in U.S. Patent 2,286,-839, granted June 16, 1942 to S. A. Schelkunoff. This patent describes a directive linear array antenna system and cites other art related to the same subject. Two-dimensional planar arrays for radar applications have been developed from these principles and, because of the number of antenna elements involved, the circuitry leading to them has become quite complicated and costly. This complication and cost have become immensely aggravated by planar arrays required to simultaneously form a plurality of beams. Multibeam phased array radars generally accomplish the beam forming function remote from the antenna proper in what is currently a rather massive structure located in the main building housing the radar. The elements of the antenna are connected to the beam forming networks by a circuit structure known as a corporate feed which comprises lengthy coaxial cables constructed closely as to length and phase stability. Also, in the beam forming network, additional waveguides and coaxial lines are used in achieving the summation of the signals from the antenna elements. These elaborate cables and formation networks contribute significantly to the high cost of multifunction array radars. Applicants are aware that single function array radar systems exist which use a space feed to good adavntage and accomplish the phase control required for each antenna element through a phase shifter incorporated immediately behind the antenna element. However, applicants are not aware that the advantages of space feed have either been appreciated or successfully realized in a practical structure by anyone in multifunction array radar systems.

In the earlier application, Ser. No. 598,781, filed Dec. 2, 1966 by D. A. Alsberg, now Patent 3,406,399 one of the coinventors of the present invention, and assigned to the same assignee as the present application, a phased array system is disclosed which greatly simplifies the feed structure. That invention embodied a frequency multiplex principle in which local oscillators, one for each beam to be formed, transmitted beating frequencies through space to the antenna array. Modulators and other circuitry providing frequency separation functions were included in each of the antenna elements to cooperate with the local oscillators to form the required

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beams. This resulted in the complete elimination of all the conventional corporate feed structures with consequent simplification and economy.

Summary of the invention

The present invention embodies a quite different principle and results in still greater simplification and economy than that achieved by the above-cited copending application in that the local oscillators, modulators and other associated circuitry have all been eliminated. Whereas the copending application embodied the principle of frequency multiplexing, the present invention embodies a space multiplex principle involving an array of receiving elements which simultaneously receive microwave energy from a plurality of sources located in space. Each element has a feed horn and a phase control means so the energy received by the element may be radiated with controlled phase to a plurality of receiving horns located behind the array. In this way, the energy received by the array from all the sources in space can be simultaneously brought to a focus at different selected ones of the receiving horns at the rear of the array. In one embodiment, a separate phase control means is provided in each receiving element for each beam to be formed. In another embodiment, a single phase control means and variable attenuator is included in each element to control the phase and magnitude of the radiated energy to represent the vector sum of all the beams to be formed.

Brief description of the drawings

The invention may be better understood by reference to the accompanying drawings, in which:

FIG. 1 illustrates an antenna system embodying the principles of this invention;

FIGS. 2 and 3 disclose two different embodiments of the phase control means in the receiving elements of FIG. 1 for steering the several beams to be formed; and

FIG. 4 illustrates a variant of one of the phase control channels of FIG. 2 to utilize a "two out of three" voting scheme.

Detailed description

In FIG. 1 an antenna array **1**, shown in planar configuration, comprises a plurality of receiving elements **2** extending through a suitable supporting medium so that their front faces are coplanar to form the front plane surface **4**. The back ends of each of the receiving elements **2** form the back face **3** of the array. A receiving antenna **40** is positioned at the front end of each of the receiving elements while an internal space feed horn **30** is positioned at the rear end of each of these elements. The general arrangement of this array will be recognized as quite conventional and it will be understood that energy being received from any point in space in front of the array will be received by all of the receiving antennas **40** of all the receiving elements **2**. It is well known that if the energy in each element is properly adjusted in phase it can be focused at any point in the internal space region **5** behind the antenna. The manner by which this is attained in the practice of the present invention will be more particularly described later with reference to FIGS. 2 and 3.

A receiver chassis **7**, which contains conventional beam receivers and data processors of the same kind customarily used with all phased array receiver systems, is positioned back of the antenna array. A plurality of receiving horns **6** are positioned at different locations in the internal space region **5** to receive the energy transmitted by the internal space feed horns **30** of the antenna array. The internal space region **5** is generally surrounded by a microwave anechoic wall, not shown, which will completely absorb all stray microwave energy to reduce crosstalk between the several beams. The space feed horns **6** are connected to the receiver chassis **7** so that the energy they receive may be transmitted to the beam receivers in this chassis. Although nine separate receiving horns are illustrated as being positioned in the same plane, a coplanar arrangement is not essential. As previously mentioned, energy received from any one source in space, constituting one beam, may be focused by the receiving elements **2** so that the energy transmitted from all of the internal space feed horns **30** may be caused to arrive coherent at one of the receiving horns **6**. For example, assume that one of the beams is caused to focus on receiving horn **61** while another beam arriving from a different point in space may be simultaneously focused on another one of the receiving horns **62**. There are, therefore, as many receiving horns as there are beams to be formed. The phase control elements in each of the receiving elements **2** are under control of beam steering information transmitted over channel **33** from the data processors in receiver chassis **7**. As the principles of beam steering in phased array systems are now well known, further details relating to the formulation and the transmission of such information is unnecessary to a complete understanding of this invention. This information may be in either digital or analog form although, preferably, it will arrive in digital form as it is usually desired that the phase control devices be adapted to operate with that form of information. By reason of the fact that a plurality of differently located receiving horns **6** are employed in this system, it may be quite aptly called a space multiplex system, thereby distinguishing from the frequency multiplex system of the above-mentioned copending application. It has been said that it is not essential that the receiving horns **6** be coplanar. To illustrate this, one receiving horn **63** is shown in FIG. 1 at a different distance from all the others. If all of the receiving horns are arranged so that no two are at the same distance or at the same angular position with reference to the back face **3** of the antenna array, a greater degree of isolation between beams may be effected.

FIG. 2 schematically illustrates the circuit structure embodied in each of the receiving elements **2** of the antenna array **1**, shown in FIG. 1. At the front face **4** of the array each element contains a receiving antenna **40** which may be of conventional construction. The energy received by this antenna is amplified by a low noise high gain amplifier **31**, the output of which is distributed to a plurality of phase control channels by means of a power divider **22**. Each of the phase control channels contains a variable phase control means **23** and a fixed phase control means **24** as well as an attenuator **25**. The addition of the attenuator **25** is optional and its purpose will be explained more fully later. The signals emerging from the several phase control channels are evenly divided between power combiners **26** and **27** to be applied to the vertically and horizontally polarized ports **28** and **29** of a dual polarized internal space feed horn **30**. Feed horns **30** transmit the signals to all of the receiving horns **6** shown in FIG. 1. There are as many phase control channels included between the power divider **22** and the power combiners **26** and **27** as there are beams to be formed. The amplification required of amplifier **21** depends on the number of beams to be formed.

Assuming that energy has been received from a particular source in space, it will arrive at all of the receiving antennas **40** on the front face **4** of the array at generally different instants of time. This beam will be controlled by one of the phase control channels in each of the receiving elements **2** so that the energy from this source emerging from the internal space feed horns **30** of all the receiving elements will arrive coherently at only one of the receiving horns **6** shown in FIG. 1. The manner by which this is done can be more easily understood by considering first that all of the fixed phase shifters **24** of all the receiving elements are caused to provide identical phase shifts. Now if the variable phase shifter **23** in one of the channels of each of the receiving elements **2** is adjusted so that the energy received from a single source in space is caused to have coherence at all of the internal space feed horns **30**, this energy will emerge from the rear face **3** of the array as a plane wave normal to the axis of the array. This is equivalent to saying that any given wave front received by the receiving antennas **40** of the array can be converted into a quantized plane wave front as it emerges from the rear face **3** by proper adjustment of one of the variable phase controls **23** in each of the receiving elements **2**. Of course this plane wave front will not converge on any particular receiving horn **6** but can be made to do so by properly adjusting the associated fixed phase shifter **24** in the same phase control channel of each of the receiving elements **2** so that the quantized plane wave front will be converted into a converging spherical wave front coming to a focus at one of the receiving horns **6** shown in FIG. 1. Thus it will be clear that the function of the fixed phase shifters **24** is to provide focusing for the array on the several receiving horns **6** in the internal space region **5** back of the antenna array while the variable phase control means **23** in the several channels provide the steering function. Once the fixed phase shifters **24** are adjusted, steering is thereafter accomplished for each beam by adjusting one of the variable phase control means **23** in each of the receiving elements **2**. While both a variable and a fixed phase control means is shown in each of the channels, it is quite possible to combine their functions into a single variable phase shifter under computer control so that it accomplishes both the focusing and the steering functions. As previously stated, the attenuators **25** are optional but, if used, they may serve a two-fold purpose. First, they can provide additional control over the space tapering of the beams to achieve low sidelobes for all feed locations even when widely separated. Second, they can be used to eliminate amplitude distribution asymmetries due to the off-axis locations of the receiving horns **6**. Moreover, if desired, attenuators **25** can also be made variable and under control of the data processors to provide variable beam tapering.

The fact that a plurality of beams are being simultaneously formed gives rise to a tendency toward a substantial amount of crosstalk which can be easily reduced to practical levels by several means. One of these means is illustrated in FIG. 2 where half of the phase control channels are combined in power combiner **26** while the other half are combined in power combiner **27**. Now by feeding the combined energies from these two power combiners to the vertically and horizontally polarized ports **28** and **29**, respectively, the polarization provides a considerable degree of crosstalk reduction. Another means of reducing crosstalk is in the proper spatial separation of the receiving horns **6**. If these receiving horns are randomly placed, both as to focal distance from the rear face of the antenna array as well as to their angular relationship with reference to the principal axis of the array, crosstalk is further reduced. As previously mentioned, receiving horn **63** in FIG. 1 illustrates this arrangement. A third method of reducing crosstalk is to employ the well known "two out of three" voting scheme. This is readily implemented by dividing the output from the variable phase shifter **23** in each phase control channel into three equal parts as illustrated in FIG. 4. As shown in FIG. 4, this is accomplished by introducing an additional power divider **22A** between the variable phase shifter **23** and the fixed phase shifter. Thus each channel beginning at power divider **22** emerges as three channels at power combiner **27**. Each of these three channels may contain its own fixed phase shifter **24, 24A** and **24B** as well as its own attenuator **25, 25A** and **25B**. Alternatively, the focusing functions of the fixed phase shifters may be imposed on the variable phase shifter **23** and controlled electronically. Moreover, the attenuators are also optional, depending upon whether they are needed for sidelobe reduction or amplitude equalization in a particular application. Where this voting scheme is used, the number of receiving horns **6** may be tripled so that each beam is focused on three horns instead of only one. In order to be recognized, the beam receivers and data processors are programmed to require simultaneous arrival of beam energy on at least two of the three horns. There is an almost one hundred percent probability that when energy arrives simultaneously at two of the three horns it is not due to crosstalk. By way of example, assume in FIG. 4 that signal energy passing through fixed phase shifter **24** of each receiving element **2** is focused on receiving horn **61** of FIG. 1 and that the energies passing through phase shifters **24A** and **24B** are similarly focused on receiving horns **62** and **63**, respectively. Now if simultaneous beams are reecived from space to momentarily produce a sidelobe interference at horn **62** and practically cancel the signal it receives, there is a negligible probability that this will also occur at the same instant at horns **61** and **63**.

The beam steering information is supplied from the receiving chassis **7** by way of the beam control signal channel **33** as shown in FIG. 1. In FIG. 2 channel **33** is shown connected to a decoder **31** from which a plurality of phase control channels **32** emerge and terminate in the several phase control means **23**. It is customary in present day practice to supply this information in digital form and decoder **31** simply receives the digital data in a conventional manner, separates it according to the address to which the data is to go and transmits this data to the several phase control means **23** which also are of the digital type. From the description thus far it will be quite evident that all of the component elements are of a conventional nature well known in phase array radar technology.

FIG. 3 shows an alternative circuit embodiment for the receiving elements **2**. In this case only a single channel connects the receiving antenna **40** to the internal space feed horn **30A**. Space feed horn **30A** performs the same function as does feed horn **30** shown in FIG. 2 except that it is not of the dual polarized type. At this point it may be mentioned that the embodiment shown in FIG. 2 may also operate with the non-polarized space feed horn **30A** in which case only a single power combiner is used. The arrangement shown in FIG. 3 is an extreme simplification of the invention which greatly reduces the number of components that must be used to provide the multibeam formation function. A single phase control means **23A** and a single variable attenuator **25A** are serially connected in the single channel existing between the output circuit of preamplifier **21** and the internal space feed horn **30A**. The phase control means **23A** is controlled by information obtained from decoder **41** by way of the phase control channel **42**. The manner by which this is done is the same as described for the phase control means **23** of FIG. 2. Since the number of phase control means have been considerably reduced, it is economically feasible to increase the quality of the single phase control means **23A**. Whereas the phase control means **23** in FIG. 2 may be operated by four or five digital bits, an additional bit can be economically included in the phase control means **23A** of FIG. 3 if desired. The fact that the network in FIG. 2 existing between the power divider **22** and the power combiners **26** and **27** can be readily represented by an equivalent network of controlled amplitude and phase demonstrates the essential equivalence of these two embodiments of the invention. The equivalence can be realized when both the phase and amplitude are controlled so that the energy radiated by each space feed horn **30A** corresponds to the vector sum of all the signals received from space by its receiving antenna **40**. The amplitude, of course, is controlled in the embodiment of FIG. 3 by control of the variable attenuator **25A** from data received from decoder **41** by way of the amplitude control channel **44**. It will be evident that the simplification thus effected, insofar as the receiving elements **2** are concerned, throws little extra burden on the data processing equipment which is now required to give both phase and amplitude information over the beam control signal channel **33**. However, it is obvious that this is only a straightforward routine programming problem for the digital computer equipment in the reeciver chassis.

The invention has been illustrated as having a planar antenna array. While this simplifies the description, a planar array is not essential and a non-planar array may be used with equal facility. As previously stated, conventional and well known circuit elements are used in the fabrication and practice of this invention. Assuming, for example, that sixteen beams are to be simultaneously formed, the output of the preamplifier **21** of each of the receiving elements **2** would be divided into sixteen equal parts by means of a binary network of printed circuit hybrids. Such a network is readily realized by existing printed circuit technology. The beam steering phase shifters **23** are also achievable in stripline configuration using varactor diodes to switch the several bits directly from the digital information obtained from the decoder. The fixed phase shifters and attenuators may also be fabricated in stripline by a line length perturbation and by the deposition of resistive material on a ceramic substrate. The power combiners may also be achieved using stripline technology. From these examples it will be obvious to those skilled in this art that various substitutions of equivalent devices may be made without departing from the scope of the invention. It is also quite evident that an antenna system has been disclosed which performs the entire beam forming and steering functions within the receiving element of the phased array antenna. By using a unique combination of space feed and space multiplexing principles, all the hard wire radio frequency connections between the antenna elements and the phase steering apparatus of conventional phased array systems are completely eliminated.

What is claimed is:

1. A multibeam phased array receiving antenna system comprising an array of receiving elements for receiving microwave energy from a plurality of sources located in space in front of said elements, each element having a receiving antenna at its front face to receive said energy, an internal space feed horn at the back face of each element for radiating the energy received by its element into an internal space region behind said array of elements, a separate phase control channel for each beam to be formed included in each of said receiving elements, a power divider coupling each of said channels to said receiving antenna, a power combiner coupling said channels to said internal space feed horn, an individual phase controller in each phase control channel for controlling the phase of the energy radiated by said internal space feed horn, and a plurality of receiving horns equalling the number of simultaneous beams to be formed, said horns being located at different points behind said array of elements.

2. The combination of claim **1** and means coupling each of said phase controllers to a source of phase control signals.

3. The combination of claim **1** wherein each of said phase control channels includes a variable phase control means, a fixed phase control means, and an attenuator serially connected between said power divider and said power combiner.

4. The combination of claim **1** wherein each of said phase control channels includes a variable phase control means, three fixed phase control means and three attenuators, an additional power divider coupling said variable phase control means to each of said fixed phase control means, and means including one of said three attenuators coupling each of said fixed phase control means to said power combiner.

5. The combination of claim 1 wherein said receiving horns are positioned in a coplanar array.

6. The combination of claim 1 wherein said receiving horns are located at arbitrarily different focal distances from and angular directions with reference to said planar array of receiving elements.

7. A multibeam phased array receiving antenna system comprising an array of receiving elements for receiving microwave energy from a plurality of sources located in space in front of said elements, each element having a receiving antenna at its front face to receive said energy, an internal space feed horn at the back face of each element for radiating the energy received by its element into an internal space region behind said array of elements, a single channel coupling each receiving antenna to its internal space feed horn, said channel including a variable phase control means, a variable attenuator and a decoder means for simultaneously controlling the energy radiated by said space feed horn in both phase and magnitude in accordance with the vector sum of all signals received from space by said receiving antenna and a plurality of receiving horns equalling the number of simultaneous beams to be formed, said horns being located at different points behind said array of elements.

8. The combination of claim 7 and means coupling said decoder means to a source of beam control signals.

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ELI LIEBERMAN, Primary Examiner

U.S. Cl. X.R.

343—778, 854