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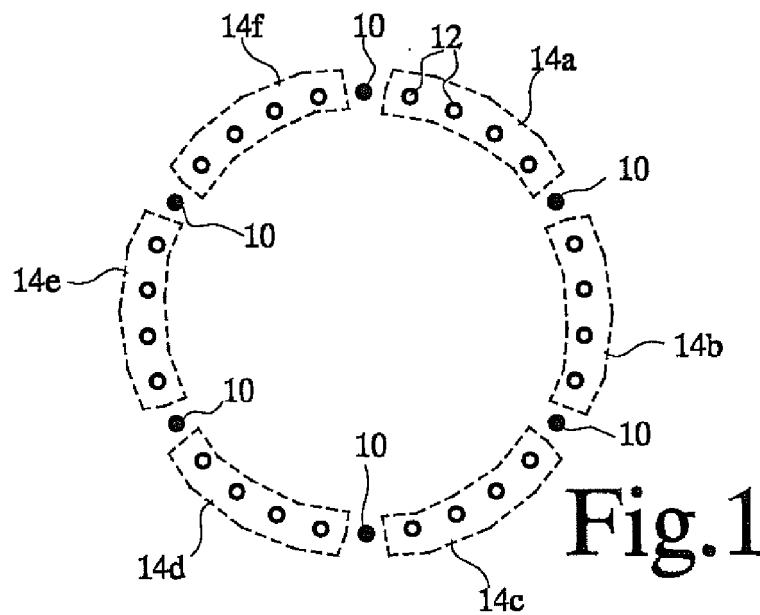
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(54) **Antenna system, radar device and radar method with 360 degree coverage**

(57) An antenna system has a number of transmission antennas (10) arranged at respective positions at corners of a polygon. A plurality of groups (14a-f) of reception antennas (12) are provided, each at positions between the positions of transmission antennas at neighbouring corners of the polygon. A target reflects the sig-

nals from the transmission antennas (10). Reflections of the signals of each of the are received in the reception antennas (12). An antenna output signal is computed from a complex weighted sum of reflections corresponding to different combinations of transmission antennas and reception antennas.



Description

Field of the invention

[0001] The invention relates to an antenna system, radar device and radar method.

Background art

[0002] WO2007/082335 discloses a radar device with 360 degree coverage that comprises a plurality of transmission antennas in a linear array and a circular array of reception antennas in a plane that is orthogonal to the linear array direction. Typically, the transmission antennas are arranged along the central axis of the circular array.

[0003] WO2007/082335 explains that this arrangement can be used to simulate a much larger array with one transmission antenna and a plurality of reception antennas. With a synthetic aperture radar, wherein reflections are measured by transmission-reception measurements at a series of positions an antenna pattern can be realized with a main lobe in a selectable direction. Conventionally, a synthetic aperture radar is realized by moving a single antenna successively to different positions to obtain the measurements, or by using respective antennas at different positions for both transmission and reception. When a single transmission antenna is used in combination with an array of reception antennas at different positions, reflection values can be obtained that each correspond to a virtual measurement of transmission and reception with an antenna positioned midway between the positions of a transmission and reception antenna. These reflection values can be used according to synthetic aperture radar techniques.

[0004] WO2007/082335 proposes the use of transmission antennas along a linear array in a direction orthogonal to the plane of the reception antennas. In this way a virtual phased array can be realized with arrays of antenna locations in a plurality of planes successively along the linear array. For this purpose, the transmission antennas are used in a multiplexed way, for example by means of time, frequency or code division multiplexing. This makes it possible to distinguish the received signals from different transmission antennas at each reception antenna, so that distinct virtual antenna locations can be realized for each combination of a transmission antenna and a reception antenna.

[0005] Because the virtual antennas locations lie midway a transmission antenna and the reception antennas in the circular array, the diameter of the virtual phased array is about half that of the actual array of reception antennas. This has the effect that the angular resolution of the antenna pattern is coarser than that of a phased array with antennas at the locations of the reception antennas in the actual array.

Summary

[0006] Among others, it is an object to provide for an antenna system that can realize an antenna pattern with a higher resolution.

[0007] An antenna system is provided that comprises at least three transmission antennas arranged at respective positions at corners of a polygon and a plurality of groups of reception antennas, each group comprising reception antennas at positions between the positions of transmission antennas at neighbouring corners of the polygon. The polygon may be a two-dimensional polygon, such as a hexagon for example preferably a regular polygon (a polygon with equal length sides and equal angle corners), the groups of transmission antennas lying between successive pairs of adjacent corners of the polygon. In this context the positions of the reception antennas are said to be between those of the transmission antennas in the sense that they lie at least substantially on a circle or ellipse through the corners of the polygon, or in that they lie at least substantially on edges of the polygon, that is, on straight lines between successive corners. Alternatively a three dimensional polygon with transmission antennas at its corners may be used, with reception antennas on the ribs of the polygon, or on its faces, or on the surface of a sphere through the corners, for example on great circles of that sphere through adjacent pairs of corners, or on sphere surface segments between such great circles.

[0008] As a result of placement of reception antennas between the transmission antennas on the polygon, the midpoints between reception antennas and transmission antennas also lie substantially on the polygon. Thus a larger spatial extent of positions of virtual antennas can be realized than when the transmission antennas lie in the centre of a circle of reception antennas, which leads to a better angular resolution of the antenna.

[0009] In an embodiment the antenna system comprises a plurality of further transmission antennas, each located adjacent a respective one of the at least three transmission antennas, at a distance from the respective one of the transmission antennas that is substantially half of a distance between adjacent reception antennas in the group. Thus it is possible to realize a greater density of positions of virtual antennas, using only a small number of real antennas, which makes it possible to realize better side lobe suppression. The direction between each transmission antenna and its adjacent further transmission antenna may be substantially the same as a direction to their closest reception antenna.

[0010] In an embodiment, orthogonal projections of the positions of the reception antennas of at least one of the groups onto a line connecting the positions of the corresponding group of reception antennas at neighboring corners of the polygon lie equidistantly from one another. In this embodiment the reception antennas in the group do not all lie on a straight line. They may lie on a curved line, such as a circle for example. In this embodiment the real

mutual distances between the positions of adjacent reception antennas of the group will not all be equal. Rather, the distances between their projections will be equal. This makes it possible to provide for better side lobe suppression.

[0011] In an embodiment the antenna system comprises a plurality of receivers, a multiplexer coupled between the reception elements and the first and second receiver, and a controller coupled to a control input of the multiplexer, the multiplexer being configured to connect a plurality of reception antennas of a same selectable one of the groups to the plurality of receivers in parallel, for concurrent reception. In this way a simple circuit structure can be realized that makes it possible to perform the antenna measurements in shorter time.

[0012] In an embodiment the transmission antennas and the reception antennas comprise an array of conductor structures on a curved surface of a common substrate. Thus a compact panoramic antenna structure can be realized that can be easily manufactured.

Brief description of the drawing

[0013] These and other objects and advantageous aspects will become apparent from a description of exemplary embodiments, using the following figures.

Figure 1 shows positions of transmission and reception antennas

Figure 2 shows a radar signal processing system.

Figure 3 shows a perspective view of an antenna structure

Figure 4 shows positions of additional transmission antennas

Figure 5 shows reception antennas at variable distances

Figure 6 shows multiple rings of antennas

Detailed description of exemplary embodiments

[0014] Figure 1 shows a spatial arrangement of transmission antennas 10 and reception antennas 12. Transmission antennas 10 and reception antennas are placed at positions along the same circle. The reception antennas 12 can be divided into groups of reception antennas located between respective pairs of transmission antennas 10 along the circle. The groups have been schematically indicated by dashed lines 14a-f. Although six transmission antennas 10 and six groups of four reception antennas 12 have been shown by way of example, it should be appreciated that a different number of reception antennas 12 (for example at least four eight or more) may be used in each group 14a-f and that a different number of transmission antennas 10 and a correspondingly different number of groups 14a-f may be used. Preferably successive transmission antennas 10 are located at equal angles from each other, that is, on a regular polygon, so that when N transmission antennas 10 are

used, each pair of successive transmission antennas 10 is located at $1/N$ th of the full circle from each other.

[0015] Figure 2 shows a radar signal processing system. The system comprises a signal generator 20, a demultiplexer 22, transmission antennas 10, reception antennas 12, a plurality of first multiplexers 24a-f, a second and third multiplexer 26a,b, a first and second receiver 28a,b and a control and signal processing circuit 29. Signal generator 20 is coupled to transmission antennas 10 via demultiplexer 22. The reception antennas 12 of each group 14a-f are coupled to a respective pair of the first multiplexers 24a-f (only part of the connections shown, for the sake of clarity), half being connected to one first multiplexer of the pair and the other half to the other first multiplexer. The outputs of the first multiplexers 24a-f for part of respective positions in the groups are coupled to signal inputs of second multiplexers 26a,b and the outputs of part of the first multiplexers 24a-f for the other positions in the groups are coupled to signal inputs of third multiplexers 26a,b. So that different first multiplexers 24a-f that are connected to reception antennas 12 from the same group are coupled to different second multiplexers. The outputs of the second and third multiplexers 26a,b are coupled to first inputs of first and second receiver 28a,b respectively. First and second receiver 28a,b have second inputs coupled to the output of signal generator 20. Control and signal processing circuit 29 has inputs coupled to outputs of first and second receiver 28a, b and control outputs coupled to signal generator 20, demultiplexer 22, first multiplexers 24a-f, second multiplexer 26a and third multiplexer 26b.

[0016] Figure 3 shows a perspective view of an example of an antenna structure. The antenna structure comprises a cylindrical dielectric substrate 30. Antenna elements 32, 34 of the transmission and reception antennas are provided as conductor structures on an outward facing surface of cylindrical dielectric substrate 30. A ground plane 36 is provided on an inward facing surface of cylindrical dielectric substrate 30.

[0017] In an example of operation, control and signal processing circuit 29 controls demultiplexer 22 to feed a transmission signal from signal generator 20 successively to different ones of the transmission antennas 10, to activate the transmission antennas 10 individually. While the transmission signal is fed to an active transmission antenna 10, control and signal processing circuit 29 controls first multiplexers 24a-f in successive time intervals to feed received signals from respective ones of the reception antennas 12 of a same group 14a-f of reception antennas 12 adjacent the active transmission antenna 10 to second and third multiplexers 26a,b. Control and signal processing circuit 29 controls second and third multiplexers 26a,b to feed the received signals from different reception antennas 12 in the selected group to first and second receiver 28a,b respectively. First and second receiver 28a,b determine target response coefficients $S(m,n)$, relating the transmitted signal from a transmission antenna 10 (the value of the label "m" distinguishing

transmission antennas at different positions) to the received signal from a reception antenna (the value of the label "n" distinguishing reception antennas at different positions), the target response coefficients being represented for example in terms in phase and quadrature phase component values. In an embodiment the target response coefficients may be corrected for attenuation due to target distance (determined for example from response delay) and/or amplifier gain etc.

[0018] Control and signal processing circuit 29 causes measurements of coefficients $S(m,n)$ to be performed for each of the reception antennas 12 in the groups adjacent the active transmission antenna 10. This is repeated for all of the transmission antennas 10. In a far field approximation the coefficients $S(m,n)$ measured for each pair of a transmission antenna 10 (m) and a reception antenna 12 (n) are equal to coefficients obtained by transmission from, and reception at, a virtual antenna at a position $p(m,n) = (r(m) + r(n))/2$ midway between the positions $r(m)$, $r(n)$ of the actual transmission antenna 10 and reception antenna 12 of the pair. Thus coefficients for virtual antennas at a plurality of positions $p(m,n)$ are notionally obtained.

[0019] Although an embodiment has been shown wherein two receivers 28a,b are used, it should be appreciated that in alternative embodiments only one receiver or more receivers may be used. At one extreme, a respective receiver may be provided for each antenna element and at the other extreme a set of multiplexers may be provided that selectively connects any one of the antenna elements to a single receiver. Use of a plurality of receivers has the advantage that less measurement time is needed, so that target motion can have less effect on measurement. Use of multiplexers and less receivers than antenna elements reduces circuit size. Using different multiplexers in parallel for receiver antennas between respective pairs of transmission antennas 10, using the multiplexer structure described for figure 2, has the advantage that shorter measurement time can be combined with reduced circuit complexity.

[0020] Control and signal processing circuit 29 applies a synthetic aperture computation technique to the measured coefficients $S(m,n)$ for the positions $p(m,n)$, to obtain a direction sensitive coefficient $S(d)$. Herein d is a direction vector. Direction sensitive coefficients $S(d)$ for a plurality of different directions d are computed, preferable along 360 degrees from the antenna.

[0021] The direction sensitive coefficients $S(d)$ for different directions may be computed as a sum of measured coefficients $S(m,n)$, multiplied by different complex weight factors $w(d,m,n)$: $S(d) = \sum w(d,m,n) * S(m,n)$ summed over the antennas labelled by m, n . If there is only one reflecting object, the resulting direction sensitive coefficient $S(d)$ is proportional to the intrinsic reflection coefficient of the object, to the intrinsic direction sensitivity of individual antenna elements and to a direction dependent antenna pattern factor $F(k,d)$ that is due to the complex weight factors. If one neglects position de-

pendent variations of the direction sensitivity of individual antenna elements, the antenna pattern factor $F(k,d)$ corresponds to a discrete Fourier transform of the weight factors: $\sum w(d,m,n) * \exp(2\pi i k \cdot p(m,n))$, the sum being taken over the antennas labelled by m, n . Herein k is a wave vector in the direction of the object, with a size that is inversely proportional to the wavelength λ of the radar radiation.

[0022] The complex weight factors $w(d,m,n)$ may be selected according to techniques for designing synthetic aperture radars, which are known per se. The design aims to realize an antenna pattern factor $F(k,d)$ that has a main antenna lobe with a maximum amplitude when the wave vector and the direction vector are aligned, with a decay of the amplitude as a function of the angle between the wave vector and the direction vector when these vectors are not aligned. The width of main antenna lobe represents the resolution, i.e. the ability to distinguish objects at different angles.

[0023] In an embodiment the weight factors $w(d,m,n)$ may be selected as phase vectors $\exp(-2\pi i k' \cdot p(m,n))$, where k' is a wavevector in the direction d , but there is considerable freedom in the selection of the weight factors $w(d,m,n)$. In an embodiment weight factors for certain combinations of transmission and reception antennas may be made zero. For example only weight factors for pairs in a sector of the circle that faces the direction d are non zero. In an embodiment the amplitude of the weight factors may be different for different pairs. An optimization algorithm may be used to select the values of the weight factors. Such optimization algorithms are known from the field of synthetic aperture radar.

[0024] As a result of the known properties of discrete Fourier transforms, the width of the main lobe of the antenna pattern factor $F(k,d)$ depends inversely on the size of the spatial range of the positions $p(m,n)$. As will be appreciated the positions $p(m,n)$ of the virtual antennas are located approximately on the circle on which the transmission antennas 10 and the reception antennas 12 are located. As a result, resolution, that is, the width of main lobe in the plane of the circle, is inversely proportional to the radius of the circle. By placing both transmission antennas 10 and reception antennas 12 substantially on the circle, resolution is increased compared to a configuration in which the transmission antenna is at the mid point of the circle.

[0025] As shown for example in figure 3, the carrier structure of antenna elements 32, 34 may have the effect that individual antenna elements 32, 34 are useful only for a limited range of directions. Accordingly, the complex weight factors $w(d,m,n)$ for directions d outside this range involving to these antennas may be set to zero. In an embodiment each group 14a-f of reception antennas may be used only (have non zero weight factors $w(d,m,n)$) for a sector of directions " d " between angles around a broadside direction through the centre of the group. In a further embodiment the sector may be limited by virtual lines from the centre of the circle through the positions of the

transmission antennas 10 on either side of the group. In this embodiment the reception antennas are used as linear arrays for respective angle ranges. In other embodiment adjacent pairs of such linear arrays, or triplets, may be used for respective angle ranges. Each group 14a-f of reception antennas may be used only for a sector of directions "d" between angles defined by lines from the centre of the circle through the middle of neighboring groups for example.

[0026] As will be appreciated, the multiplexer structure makes it possible to measure received reflections of a signal from a transmission antenna 10 at reception antennas in a same group in parallel. Measurements from all reception antennas 12 in the group may be performed before switching transmission from another transmission antenna 10. Or measurements from all reception antennas 12 may be performed while only switches between the adjacent transmission antennas on either side of the group are made. In this way, the effect of target motion on measurements with reception antennas within a group can be minimized. Instead of two receivers, a greater number receivers may be used, for example as many receivers as reception antennas in a group. In the latter case, the second and third multiplexer are not needed. When motion is not an issue, a single receiver may suffice, with a multiplexer structure to couple any reception antenna to that receiver.

[0027] Preferably measurements from reception antennas in adjacent groups are made contiguously, i.e. without intervening measurements from other groups. In this way the effects of motion may be kept low. In an embodiment, first level multiplexers are provided associated with respective groups, the reception antennas of the group being coupled to inputs of the associated multiplexer of the group. In this embodiment a pair of second level multiplexers is provided, coupled to a first and second receiver, and with inputs coupled to outputs of the first level multiplexers so that first level multiplexers associated with successive sides of the polygon are alternately coupled to a first and second one of the second level multiplexers. In operation the multiplexers may be controlled to connect reception antennas from adjacent groups to the receivers in parallel, while a transmission antenna between the groups is active. This may reduce effects of target motion on the measurements.

[0028] Figure 4 shows a further spatial arrangement of transmission antennas 10, 40 and reception antennas 12. Neighboring reception antennas 12 in the groups 14a-f are placed substantially equidistantly along the circle. Compared to figure 1 additional transmission antennas 40 have been added, each located on the circle adjacent a respective one of transmission antennas 10 and between neighboring groups 14a-f of reception antennas 12 of that respective one of transmission antennas 10. The distance between the reception antennas 10 and the additional transmission antenna 40 between neighboring groups 14a-f is half that of the distance between neighboring reception antennas 12 in the groups 14a-f.

[0029] In operation, coefficients are measured of signals for transmission antennas 10 each paired with reception antennas 12 from the neighboring groups 14a-f, as well as for additional transmission antenna 40, each paired with reception antennas 12 from the neighboring groups 14a-f. Thus antenna to antenna coefficient are obtained for a denser set of positions $p(m,n)$ of virtual antennas. The antenna to antenna coefficient for this denser set are used for the synthetic aperture computation. According to the known properties of the discrete Fourier transform, the density of the positions $p(m,n)$ determines the amount of aliasing in the antenna pattern factor $F(k,d)$, which corresponds to side lobe amplitude. The use of pairs of transmission antennas between groups increases density and therefore reduces the side lobe pattern compared to the use of single transmission antennas 10 between groups.

[0030] Although an example has been shown with each time two transmission antennas 10, 40 between adjacent groups, at half the distance between successive reception antennas 12 in the groups 14a-f, it should be appreciated that more (N) transmission antennas 10, 40 may be used between adjacent groups at a smaller distance ($1/N$) to obtain an even denser set of positions $p(m,n)$.

[0031] Although the antenna positions have been described as positions on a circle, it should be appreciated that because of the discrete nature of the antennas, the antennas are equivalently located at the corners of a two dimensional polygon. The transmission antennas may be located at the corners of a hexangle for example.

[0032] Although a single ring of antennas on a circular ring has been shown, it should be appreciated that instead of a circle another closed curve may be used, such as an ellipse.

[0033] In the embodiment the weight factors $w(d,m,n)$ are selected as phase vectors $\exp(-2\pi i k' p(m,n))$, the output signal of the antenna system for a direction is a discrete Fourier transform of the coefficients as a function of virtual antenna position, computed for a spatial frequency k' that corresponds to the direction. In an embodiment the antenna output may be computed using weight factors $w(d,m,n)$ in the form of phase vectors $\exp(-2\pi i k' q(m,n)h)$, wherein q assumes integer values and " h " is a distance. As will be appreciated this would correspond to the previous embodiment in the case that the virtual positions are equidistant, with a distance " h ", but these weight factors can be used also if this is not the case, using nearest integer values $q(m,n)$ to $p(m,n)e/h$, where e is the unit vector along the side of a polygon between successive transmission antennas 10, for example. It should be emphasized that the antenna output may be computed using this type of phase vector no matter whether the virtual positions are in fact equidistant.

[0034] The use of this type of phase vector has the advantage that a fast Fourier transform algorithm may be used to compute the weighted sum of coefficients for virtual positions along the side of the polygon. A fast Fou-

rier transform algorithm produces the weighted sums for a plurality of main lobe directions together. This takes less time than a sum of the times that would be needed for computing Fourier transforms along the side for each main lobe direction individually. To facilitate the use of the fast Fourier transform, the number of antennas in each group 14a-f is preferably a power of two.

[0035] Next, if reception from a plurality of sides of the polygon is used to realize a main lobe in a spatial direction, the results of Fourier transforms for different sides may be added, using different combinations of spatial frequency values for the respective sides, which each substantially corresponds to the component in the direction of the respective sides of the same direction dependent two dimensional spatial frequency vector k' that is determined by the main lobe direction. Optionally the results of the Fourier transforms for different sides may be added after multiplying with complex weight vectors that account for the relative positions of the sides.

[0036] When the transmission antennas 10 at successive corners of a polygon is an integer multiple of the distance between successive reception antennas 12 in a group of reception antennas 12 along the side of the polygon between these successive corners, the fast Fourier transform may be computed for virtual positions obtained from combinations of positions of both these transmission antennas 10 and the reception antennas 12 in the group. Otherwise it may be preferred to compute each fast Fourier transform for an individual transmission antenna 10 at one corner at a time combined with the reception antennas 12 and to add the results of the fast Fourier transforms after multiplying with complex weight vectors.

[0037] In each of the embodiments of figures 1 and 4, the reception antennas 10 within groups 14a-f may lie equidistantly along the circle.

[0038] Figure 5 shows a detail of another embodiment wherein the distances between reception antennas in a group varies, so that the normal projections 50 of their positions on a chord 52 of the circle between the positions of the transmission antennas 10 on either side of the group 14a-f lie equidistantly. During signal processing by control and signal processing circuit 29 phase corrections may be applied to the antenna signals corresponding to the travel time back and forth between the reception antenna position and its projection in a direction perpendicular to the chord, before applying the Fast Fourier transform. The equidistant projections make it possible to reduce the side lobes in the antenna pattern factor $F(k,d)$, at least for main lobe directions perpendicular to chord 52.

[0039] As shown in figure 6, a plurality of rings 60 of antennas (reception antennas not shown) may be used, with the rings 60 at a distance from each other along a direction perpendicular to the rings. Thus increased resolution as a function of the elevation angle from the ring may be realized. In this embodiment each ring may comprise transmission antennas 10 and reception antennas

as described for the single ring. Alternatively transmission antennas 10 may be provided only in a subset of the rings, for example only in the uppermost and lowermost ring. Thus a limited number of transmission antennas may be combined with a larger spatial range of virtual antenna positions $p(m,n)$. A plurality of transmission antennas may be used in the uppermost and lowermost ring, at half the distance between the rings of reception antennas.

[0040] In another embodiment the antennas may be arranged on a three dimensional sphere, with the transmission antennas 10 at the corners of a three dimensional polygon. Regular polygons (a tetraeder, cube, pentaheder, octaheder, dodecaheder or regular twenty plane) may be used for example, or polygons derived from these regular polygons by cutting off corners. When three dimensional polygons are used, the case the reception antennas 12 may be located on the ribs between corners, or planes between corners.

[0041] In the received signals at reception antennas 12, signals from different transmission antennas 10 may be distinguished on the bases of time division multiplexing of transmission from transmission antennas 10. Alternatively, frequency division multiplexing (FDM) or code division mutiplexing (CDM) may be used, which are known per se. The transmission and computation of output signals may be combined with other techniques, such distance resolution and/or target speed resolution on the basis of pulse delay measurement, Doppler shift, or FM-CW techniques (Frequency Modulated Continuous Wave techniques). Reflections from targets at different distances and/or at different target speeds may be resolved before or after combining the coefficients for different combinations of transmission antennas 10 and reception antennas 12.

Claims

1. An antenna system comprising

- at least three transmission antennas arranged at respective positions at corners of a polygon;
- a plurality of groups of reception antennas, each group comprising reception antennas at positions between the positions of transmission antennas at neighbouring corners of the polygon.

2. An antenna system according to claim 1, wherein the polygon is a regular two dimensional polygon, the groups of reception antennas lying at positions between respective different pairs of adjacent corners of the polygon.

3. An antenna system according to claim 2, wherein the positions of the reception antennas substantially lie on a circle through the corners of the polygon.

4. An antenna system according to any one of the preceding claims, comprising a plurality of further transmission antennas, each located adjacent a respective one of the at least three transmission antennas, at a distance from the respective one of the transmission antennas that is substantially half of a distance between adjacent reception antennas in the group. 5

5. An antenna system according to any one of the preceding claims, wherein orthogonal projections of the positions of the reception antennas of at least one of the groups onto a line connecting the positions of the corresponding group of reception antennas at neighboring corners of the polygon lie equidistantly from one another. 10 15

6. An antenna system according to any one of the preceding claims, comprising a plurality of receivers, a multiplexer structure coupled between the reception elements and the first and second receiver, and a controller coupled to a control input of the multiplexer, the multiplexer structure being configured to connect a plurality of reception antennas of a same selectable one of the groups to the plurality of receivers in parallel, for concurrent reception. 20 25

7. An antenna system according to any one of the preceding claims, wherein the transmission antennas and the reception antennas comprise an array of conductor structures on a curved surface of a common substrate. 30

8. A method of processing reflections received by an antenna system, 35
 - transmitting signals from at least three transmission antennas arranged at respective positions at corners of a polygon;
 - receiving reflections of each of the signals at reception antennas in at least part of a plurality of groups of reception antennas, each group comprising reception antennas at positions between the positions of transmission antennas at neighbouring corners of the polygon; 40 45
 - computing a complex weighted sum of reflections received by the reception antennas in at least a selected first and second one of the groups, from signals transmitted by a first, second and third one of the transmission antennas, the first and second group lying between the first one of the transmission antennas and the second and third one of the transmission antennas respectively. 50 55

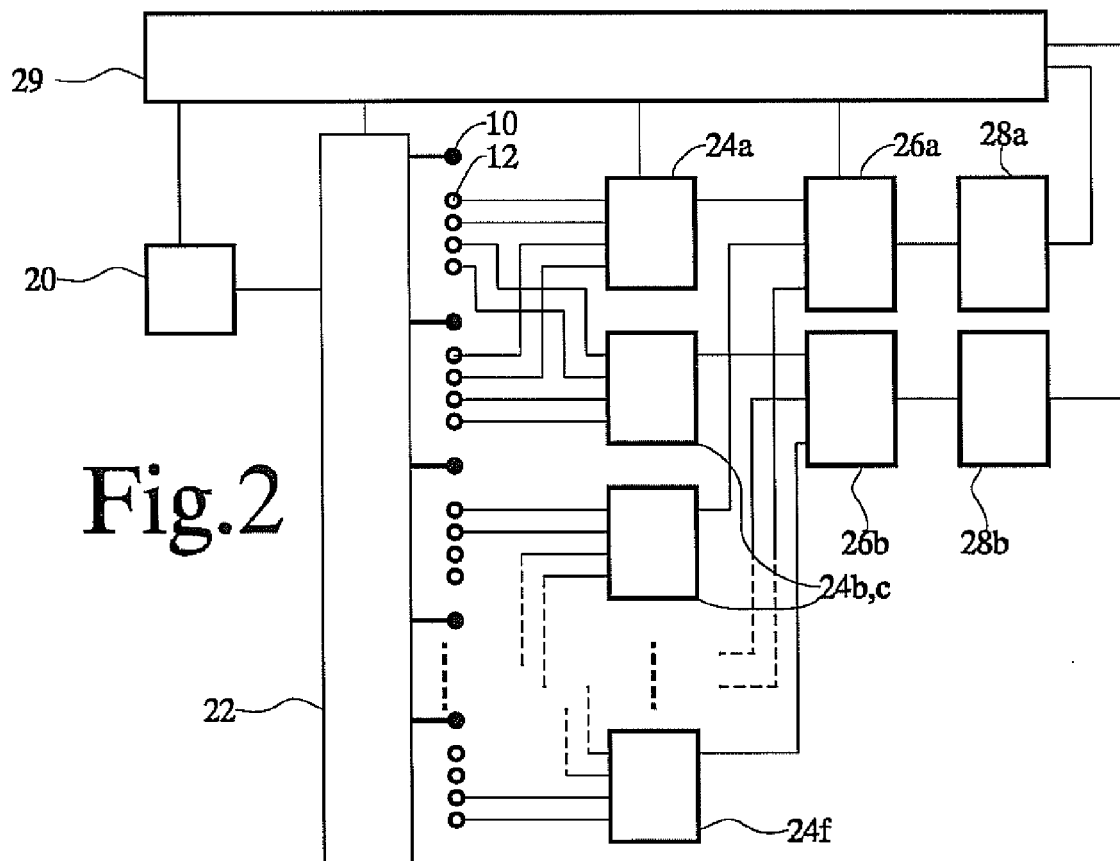
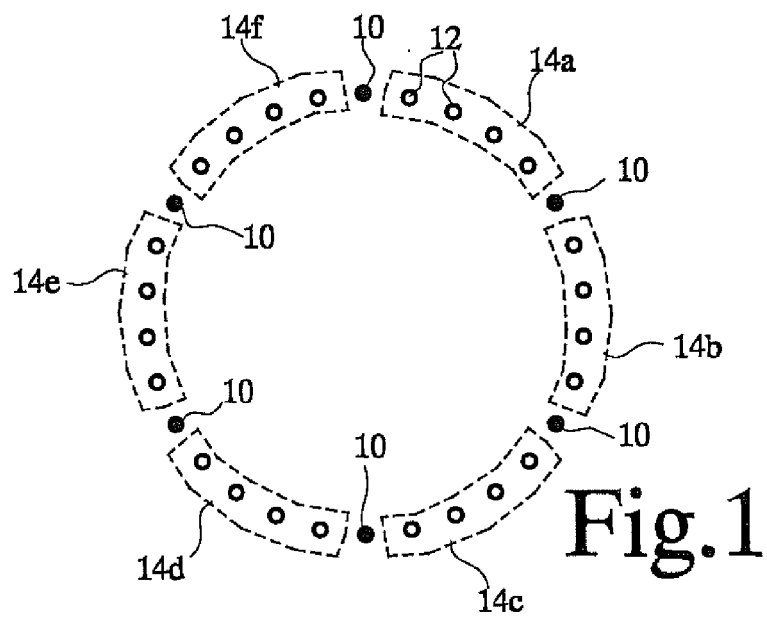


Fig.3

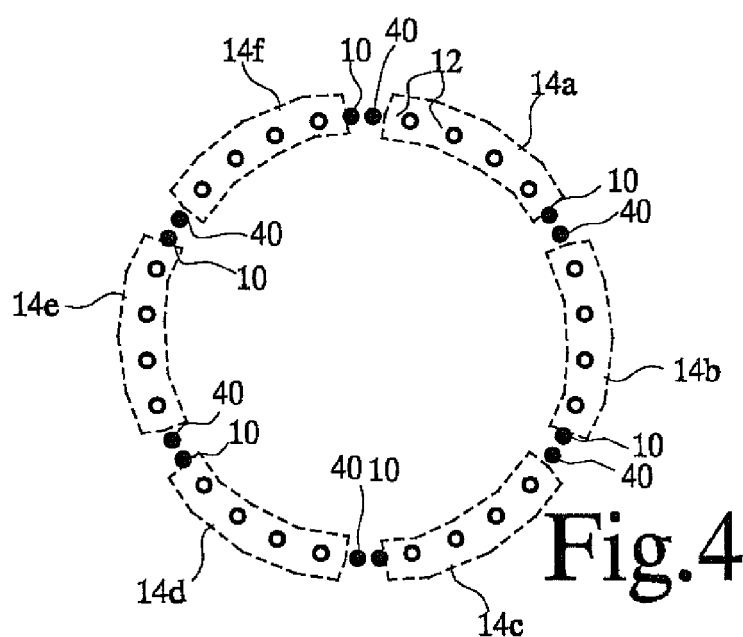
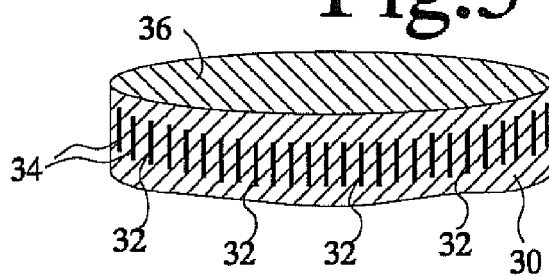


Fig.4

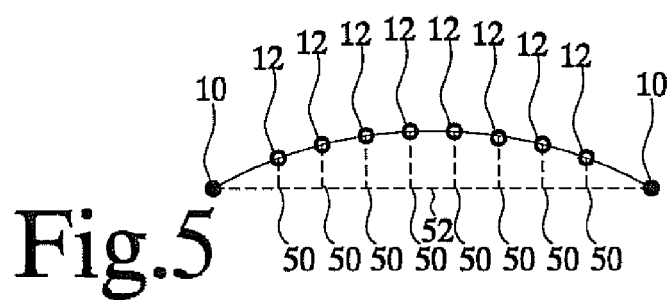


Fig.5

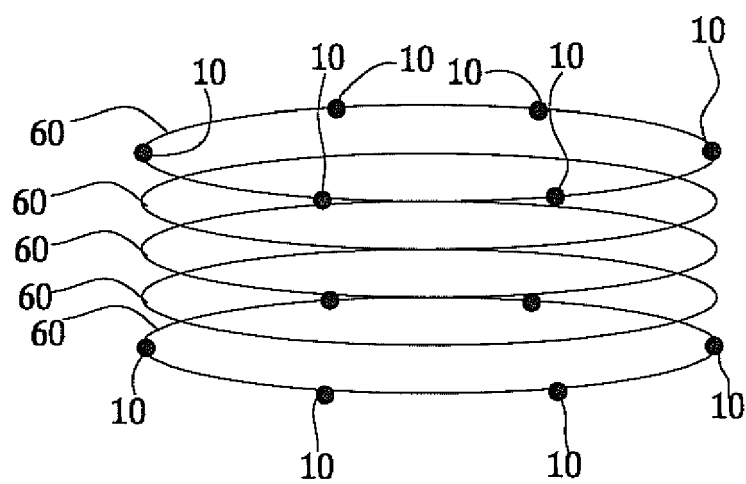


Fig.6



EUROPEAN SEARCH REPORT

Application Number
EP 10 15 5992

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	WO 2009/036507 A1 (TELEDYNE AUSTRALIA PTY LTD [AU]; LONGSTAFF DENNIS IAN [AU]) 26 March 2009 (2009-03-26)	1-6,8	INV. H01Q21/06 H01Q21/20
Y	* page 12, line 12 - page 18, line 27 * * figures 1-5 * * abstract *	7	
X	WO 2007/045026 A1 (GROUNDPROBE PTY LTD [AU]; STICKLEY GLEN [AU]; LONGSTAFF DENNIS [AU]) 26 April 2007 (2007-04-26)	1-6,8	
Y	* page 4, line 6 - page 13, line 7 * * figures 1-8 * * abstract *	7	
Y	WO 93/09577 A1 (CALLING COMMUNICATIONS CORP [US]) 13 May 1993 (1993-05-13) * page 5, line 28 - line 34 * * figure 6 * * abstract *	7	TECHNICAL FIELDS SEARCHED (IPC) H01Q
A	RALPH T HOCTOR ET AL: "The Unifying Role of the Coarray in Aperture Synthesis for Coherent and Incoherent Imaging" PROCEEDINGS OF THE IEEE, IEEE. NEW YORK, US LNKD- DOI:10.1109/5.54811, vol. 78, no. 4, 1 April 1990 (1990-04-01), pages 735-752, XP002567525 ISSN: 0018-9219 * page 746, paragraph V - page 750 *	1-8	
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 5 July 2010	Examiner von Walter, Sven-Uwe
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document			

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EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 10 15 5992

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05-07-2010

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
WO 2009036507 A1	26-03-2009	AU 2008301226 A1	26-03-2009
		EP 2191292 A1	02-06-2010

WO 2007045026 A1	26-04-2007	CA 2615821 A1	26-04-2007
		CN 101278441 A	01-10-2008
		EP 1938421 A1	02-07-2008
		RU 2374724 C1	27-11-2009
		US 2009033556 A1	05-02-2009
		ZA 200801562 A	28-01-2009

WO 9309577 A1	13-05-1993	AT 172060 T	15-10-1998
		AU 3123793 A	07-06-1993
		CA 2121675 A1	13-05-1993
		DE 69227254 D1	12-11-1998
		DE 69227254 T2	25-03-1999
		EP 0611490 A1	24-08-1994
		US 5650788 A	22-07-1997

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- WO 2007082335 A [0002] [0003] [0004]