POLARIMETRIC PHASE ARRAY RADAR SYSTEM AND METHOD FOR OPERATING THEREOF

TECHNOLOGICAL FIELD

The present invention relates generally to radar systems, and in particular, to polarimetric phase array radar systems for determination of a target range, an elevation angle and an azimuth angle of a target.

BACKGROUND

An array antenna used in radar systems includes a plurality of individually radiating antenna elements. In some array antennas, the individual antenna elements are coupled to a transmitter through phase shifters and attenuators configured for controlling the phase and amplitude of the transmitted signal. Similarly, the individual antenna elements are coupled to a receiver through phase shifters and attenuators configured for controlling the phase and amplitude of the received signal. A device comprising both a transmitter and a receiver which are combined and share common circuitry is here referred to as a transceiver. The relative phase and amplitude of the radio frequency signal passing between the plurality of antenna elements and a corresponding plurality of individual transceiver elements are controlled to obtain a desired radiation pattern. The pattern obtained is a result of the combined action of all the individual transceiver and antenna elements.

In the past, radars were used to transmit and receive radio waves having only a single polarization. As a consequence, a target which can reflect only a singly polarized beam perpendicular to the incident polarized beam has the potential of being invisible, even if a target has a strong reflection coefficient.

Polarimetric systems (also referred to as "dual polarization systems ") have been used primarily because of their properties regarding signal to clutter enhancement or improved target classification and identification. Polarimetric radars transmit and receive both horizontal *and* vertical polarizations. Beams having horizontal polarization provide

essential information about horizontal "properties" of the target, whereas vertically polarized beams provide essential information about vertical "properties" of the target. Since the power returned from the radar is a complicated function of the target size, shape, orientation, density, reflectivity, etc, the additional information received from the second type of polarization can provide improved target detection.

A monopulse radar technique and/or a radar interferometric technique can be used to gather angle information about a target, for example, when used in a tracking radar.

The basic monopulse radar system uses four antennas, or four quadrants of a single antenna that are controlled together. The target is illuminated by all four quadrants, and a comparator network is used to produce four return signals. These return signals include a “sum” signal (Σ) that is a combination of the received signal from all four quadrants, an elevation angle difference signal (Δ_E) that is formed by subtracting the signal from the two upper quadrants from the signal from the two lower quadrants and an azimuth angle difference signal (Δ_A) formed by subtracting the signals from the left quadrants from the signals from right quadrants. In a tracking radar, the sum signal is used to track the target's distance from the monopulse radar system and the azimuth difference signal is used to determine the target's position to the left or right of the radar system. The elevation difference signal may be used to determine the target's position relative to the horizon.

A radar interferometer is a receiving system that determines the angle of arrival of a wave by a phase comparison of the signals received at separate antennas or separate points on the same antenna.

Monopulse phased array systems are known in the art. These systems include a number of antenna elements arranged in an array. Each of the antenna elements is connected to a T/R (transmitter/receiver) module through a corresponding transmitting/receiving channel, which is under the control of a beam steering system. The beam steering system is fed by a transmitting signal from the T/R module for forming a transmitting beam. Upon reception of reflected signals, a sum signal, an elevation difference signal, and an azimuth difference signal are taken from the beam steering system. The phased array system includes a combination unit that combines the signals received from all the antenna elements and derives a total sum signal (Σ), a total elevation angle difference signal (Δ_E) and a total azimuth angle difference signal (Δ_A) from which

regulation signals (Δ_E /Σ) and (Δ_A /Σ) for re-steering the transmitting beam generated under the control of the beam steering system can be obtained.

GENERAL DESCRIPTION

Disclosed herein is a polarimetric phase array radar system for determination of at least one target parameter selected from a target elevation angle and a target azimuth angle, comprising:

an array comprising a plurality of transceiver elements, each transceiver element being configured to transmit radar transmitting signal components of a dual-polarization radar signal having either a single type polarization or simultaneously two types of polarization and to receive a radar receiving signal component having a single type of polarization;

wherein

in transmitting mode, each of said plurality of transceiver elements is operative to transmit a radar signal component having at least one type of polarization; and

in receiving mode, for processing radar signal components, said plurality of transceiver elements of the array are divided into two sub-arrays, said two sub-arrays being arranged in two half parts of the array in two ways selected from:

(i) a right half part and a left half part for determination of the target azimuth angle, and

(ii) an upper half part and a lower half part for determination of the target elevation angle;

each sub-array comprises a first portion of the transceiver elements and a corresponding second portion of the transceiver elements operating with a first type polarization and a second type of polarization, correspondingly;

for each sub-array, the first portion of the transceiver elements and the second portion of the transceiver elements have phase centers located in the corresponding half part, and

each sub-array is operative to receive a radar signal component having the first type polarization by the first portion of the transceiver elements having a first predetermined dynamic distribution adapted for optimization and depending at least on one characteristic selected from a total number of the transceiver elements, an operating frequency and said at least one target parameter; and simultaneously to receive a radar signal component having the second type polarization by the second portion of the transceiver elements having a second predetermined dynamic distribution adapted for optimization and depending at least on one characteristic selected from the total number of the transceiver elements, the operating frequency and said at least one target parameter; and

a signal processing system coupled to the transceiver elements, and configured for processing radar receiving signal components having a single type of polarization by using a radar interferometric technique, and generating said at least one target parameter.

Also disclosed is a polarimetric phase array radar system for determination of at least one target parameter selected from a target range, a target elevation angle and a target azimuth angle, comprising:

an array comprising a plurality of transceiver elements, each transceiver element being configured to transmit radar transmitting signal components of a dual-polarization radar signal having either a single type polarization or simultaneously two types of polarization and to receive a radar receiving signal component having a single type of polarization;

wherein

in transmitting mode, said plurality of transceiver elements are operative to transmit a radar signal component having at least one type of polarization; and

in receiving mode, for processing radar signal components, said plurality of transceiver elements of the array are divided into four sub-arrays arranged in four quadrant parts of the array selected from: an upper left quadrant part, an upper right quadrant part, a lower left quadrant part and a lower right quadrant part of the array;

each sub-array comprises a first portion of the transceiver elements and a corresponding second portion of the transceiver elements operating with a first type of polarization and a second type of polarization, correspondingly;

for each sub-array, the first portion of the transceiver elements and second portion of the transceiver elements have phase centers located in the corresponding quadrant part, and

each sub-array is operative

to receive a radar signal component having the first type polarization by the first portion of the transceiver elements having a first predetermined dynamic distribution adapted for optimization and depending at least on one characteristic selected from a total number of the transceiver elements, an operating frequency and said at least one target parameter, and simultaneously

to receive a radar signal component having the second type polarization by the second portion of the transceiver elements having a second predetermined dynamic distribution adapted for optimization and depending at least on one characteristic selected from the total number of the transceiver elements, the operating frequency and said at least one target parameter; and

a signal processing system coupled to the transceiver elements, and configured for processing radar receiving signal components having a single type of polarization by using a monopulse radar technique, and generating said at least one target parameter.

Also disclosed is a method of operating a polarimetric phase array radar system for determination of at least one target parameter selected from a target elevation angle and a target azimuth angle, comprising:

providing an array comprising a plurality of transceiver elements, each transceiver element is configured to transmit radar signal components of a dual-polarization radar signal having either a single type polarization or simultaneously two types of polarization and to receive a radar signal component having a single type of polarization;

wherein in the transmitting mode, operating said plurality of transceiver elements to transmit a radar signal component having at least one type of polarization; and

wherein in the receiving mode, selecting two sub-arrays from said array of the plurality of transceiver elements, said two sub-arrays being arranged in two half parts of the array in two ways selected from:

(i) a right half part and a left half part for determination of the target azimuth angle, and

(ii) an upper half part and a lower half part for determination of the target elevation angle;

each sub-array comprising a first portion of the transceiver elements operating with a first type of polarization and a corresponding second portion of the transceiver elements operating with a second type of polarization;

for each sub-array,

providing a first predetermined dynamic distribution adapted for optimization to the first portion of the transceiver elements and a second predetermined dynamic distribution adapted for optimization to the second portion of the transceiver elements; the first and second predetermined dynamic distributions depending at least on one characteristic selected from a total number transceiver elements, an operating frequency and said at least one parameter of the target;

receiving a radar signal component having one type of polarization by a first portion of the transceiver elements and simultaneously receiving a radar signal component having the second type of polarization by a second portion of the transceiver elements; and

calculating said at least one parameter of the target by using a radar interferometric technique.

Also disclosed is a method of operating a polarimetric phase array radar system for determination of at least one target parameter, comprising:

providing an array comprising a plurality of transceiver elements, each transceiver element is configured to transmit radar signal components of a dual-polarization radar signal having either a single type polarization or simultaneously two types of polarization and to receive a radar signal component having a single type of polarization;

wherein in the transmitting mode, operating said plurality of transceiver elements to transmit a radar signal component having at least one type of polarization; and

wherein in the receiving mode, dividing the array of said plurality of transceiver elements into four sub-arrays arranged in four quadrant parts of the array selected from: an upper left quadrant part, an upper right quadrant part, a lower left quadrant part and a lower right quadrant part of the array;

each sub-array comprises a first portion of the transceiver elements and a corresponding second portion of the transceiver elements operating with a first type of polarization and a second type of polarization, correspondingly;

for each sub-array,

providing a first predetermined dynamic distribution adapted for optimization to the first portion of the transceiver elements and a second predetermined dynamic distribution adapted for optimization to the second portion of the transceiver elements; the first and second predetermined dynamic distributions depending at least on one characteristic selected from a total number transceiver elements, an operating frequency and said at least one parameter of the target;

receiving a radar signal component having one type of polarization by a first portion of the transceiver elements and simultaneously receiving a radar signal component having the second type of polarization by a second portion of the transceiver elements; and

calculating said at least one parameter of the target by using a monopulse tracking technique.

In a conventional polarimetric phased array radar system (PPARS) every antenna element receives, simultaneously, signals having two types of polarization, e.g., horizontal polarization and vertical polarization. Accordingly, two separate receiving channels are required for each antenna element coupled through multi-mode antenna feeds of the element.

Problems exist with phased array systems having two channels for each antenna element. A double number of parts is required when compared to a singly polarized phased array radar system that results in complexity of development and in increased cost

of production. Moreover, it increases size and weight of the system, requires increased power, and produces increased heat that in turn limits the maximum operating time of the antenna and/or imposes restrictions on the environmental conditions in which the system can operate.

Thus, there is still a need in the art for, and it would be useful to have, a novel polarimetric phase array radar system with a reduced number of parts and, thus, reduced sizes and costs, and increased reliability in use.

The present invention partially eliminates the deficiencies of the prior art polarimetric phase array radar systems without deterioration of the performance of the antenna, and provides a polarimetric phase array radar system for determination of at least one parameter of a target. The parameter of the target is selected from a target range, a target elevation angle and a target azimuth angle.

The polarimetric phase array radar system includes an array having a plurality of transceiver elements configured to transmit radar transmitting signal components of a dual-polarization radar signal having either a single type polarization or simultaneously two types of polarization. The array of transceiver elements also configured to receive a radar receiving signal component having a single type of polarization.

In transmitting mode, the plurality of transceiver elements is operative to transmit a radar signal component having one or two types of polarization.

In receiving mode, the plurality of transceiver elements is divided into at least two sub-arrays. Each sub-array includes a first portion of the transceiver elements and a second portion of the transceiver elements, and is operative to receive a radar signal component having a first type polarization by the first portion of the transceiver elements and to receive a radar signal component having a second type polarization by the second portion of the transceiver elements.

According to one example, the first and second types of polarization are horizontal polarization and vertical polarization.

According to one example, the first and second types of polarization are left-handed circular polarization and right handed circular polarization.

The first portion of the transceiver elements has a first predetermined dynamic distribution, and the second portion of the transceiver elements has a second predetermined dynamic distribution. The first and second predetermined dynamic

distributions depend at least on a total number of the transceiver elements, on operating frequency and on at least one parameter of the target.

The polarimetric phase array radar system also includes a signal processing unit coupled to the transceiver elements, and is configured for processing radar receiving signal components having different polarization and generating the target parameters.

According to an embodiment of the present invention, the plurality of transceiver elements is divided into four sub-arrays. The four sub-arrays are arranged in four quadrant parts of the array selected from an upper left part, an upper right part, a lower left part and a lower right part of the array, correspondingly.

According to an embodiment of the present invention, for each sub-array of the four sub-arrays, the first and second portions of the transceiver elements have phase centers located in the corresponding quadrant part.

According to one embodiment of the present invention, for each sub-array, all the transceiver elements of the first and second portions are located in a corresponding quadrant part of the array.

According to another embodiment of the present invention, for each sub-array, a majority of the transceiver elements of the first and/or second portions is located in one quadrant part of the array, while a minority of the transceiver elements of the first and/or second portions is located in neighboring quadrant parts of the array.

According to an embodiment of the present invention, for each sub-array, of the four sub-arrays, the transceiver elements of the first portion are interleaved with the transceiver elements of the second portion.

According to an embodiment of the present invention, the first and second predetermined dynamic distributions of the transceiver elements of the first and second portions are stored in the form of look-up tables.

According to an embodiment of the present invention, each transceiver element of the polarimetric phase array radar system includes an antenna element having first and second multi-mode antenna feeds configured for transmitting and receiving a dual-polarization radar signal that includes first and second signal components having first and second types of polarization, correspondingly.

The transceiver element also includes a radio frequency source configured for generating a radar transmitting signal and a power distributing element electrically coupled to the radio frequency source. The power distributing element is configured to

distribute the radar signal generated by the radio frequency source between a first line coupled to the first multi-mode antenna feed for transmitting the first signal component having the first type of polarization and a second line coupled to the second multi-mode antenna feed for transmitting the second signal component having the second type of polarization.

The transceiver element also includes first and second transmitter phase shifters arranged in the first and second lines downstream of the power distributing element. The first and second transmitter phase shifters are configured to provide required phase shifts to first and second transmitting signal components transferred in the first and second lines, correspondingly.

According to an embodiment of the present invention, the power distributing element includes a radio frequency (RF) power one-to-two divider. The RF power one-to-two divider is configured for splitting the transmitting signal generated by the radio frequency source simultaneously into a first transmitting signal component relayed to the first line and a second transmitting signal component relayed to the second line.

According to another embodiment of the present invention, the power distributing element includes a radio frequency power switch configured to selectively couple the radar transmitting signal generated by the radio frequency source to the first line when the switch is in a switch first position and to the second line when the switch is in a switch second position.

The transceiver element also includes a first duplexer and a second duplexer arranged downstream of the first and a second phase shifters, correspondingly. The first duplexer and second duplexer are configured in transmitting mode, to provide shifted transmitting signal components in the first and second transmitting lines to the first and second multi-mode antenna feeds for transmitting the first and second transmitting signal components having the first and second types of polarization, correspondingly. The first duplexer and second duplexer are configured in receiving mode, to receive first and second receiving signal components having the first and second types of polarization provided by the first and second multi-mode antenna feeds and to provide the first and second receiving signal components to a receiving line.

The transceiver element also includes a selecting switch arranged in the receiving line and coupled to the first and second duplexers. The selecting switch is configured for switching between receiving the first receiving signal component provided by the antenna

element and having the first type of polarization and the second receiving signal component provided by the antenna element and having the second type of polarization.

The transceiver element also includes a receiver phase shifter coupled to the selecting switch and configured to receive (i) the first receiving signal component having the first type of polarization from the selecting switch when the selecting switch is in a first position, and (ii) the second receiving signal component having the second type of polarization when the selecting switch is in a second position. The receiver phase shifter provides a required phase shift to the receiving signal component transferred through the receiver phase shifter, and generates a shifted receiving signal component of a single type of polarization.

The transceiver element also includes a transceiver element comprising an amplifier/attenuator unit arranged downstream of the selecting switch and configured for a desired tapering of power of the receiving signal components of the dual-polarization radar signal received on an aperture of the antenna element.

The present invention further provides a method of operating the polarimetric phase array radar system described above for determination of the target parameter. The method includes in the transmitting mode, operating said plurality of transceiver elements to transmit a radar signal component having at least one type of polarization.

In the receiving mode, the method includes selecting at least two sub-arrays from the array of the plurality of transceiver elements. Each sub-array includes a first portion of the transceiver elements and a second portion of the transceiver elements. For each sub-array, a first predetermined dynamic distribution is provided to the first portion of the transceiver elements, and a second predetermined dynamic distribution is provided to the second portion of the transceiver elements. The first and second predetermined dynamic distributions depend at least on one characteristic selected from a total number transceiver elements, an operating frequency and said at least one target parameter.

The method also includes receiving a radar signal component having one type of polarization by a first portion of the transceiver elements and receiving a radar signal component having another type of polarization by a second portion of the transceiver elements, and calculating at least one parameter of the target.

According to an embodiment of the present invention, the selecting of at least two sub-arrays includes selecting four sub-arrays of the transceiver elements, and calculating one or more parameters of the target by applying a monopulse tracking technique.

According to this embodiment, the calculating of one or more parameters of the target includes: summing signal components having at least one type of polarization received from the four sub-arrays to calculate a four sub-array sum signal (Σ), and summing signal components having at least one type of polarization received from any two sub-arrays to calculate a first two sub-array sum signal and from two other sub-arrays to calculate a second two sub-array sum signal. Then, a difference signal (Δ) between the first two sub-array sum signal and the second two sub-array sum signal is generated. The method further includes processing the four sub-array sum signal (Σ) and the difference signal (Δ) for generating the target parameters.

According to another embodiment of the present invention, the selecting of at least two sub-arrays includes selecting two sub-arrays of the transceiver elements, and calculating one or more parameters of the target by applying an interferometric technique. According to this embodiment, the calculating of one or more parameters of the target includes generating a phase difference signal between the signal components having at least one type of polarization received from said at least two sub-arrays, and calculating a distance between phase centers of the transceiver elements of said at least two sub-arrays for at least one portion of the transceiver elements selected from the first portion and second portion and corresponding to said at least one type of polarization. The phase difference signal and the distance between phase centers are processed for generating the target parameters.

According to an embodiment of the present invention, the method includes tapering of a power of the signal components of the radar signal received on an aperture of antenna elements for reducing side lobs level to a desired magnitude.

The polarimetric phase array radar system of the present invention has many of the advantages of the prior art techniques, while simultaneously overcoming some of the disadvantages normally associated therewith.

The polarimetric phase array radar system according to the present invention may be adapted for certain applications, in which size and cost are critical, such as airborne and/or space radar systems.

The polarimetric phase array radar system according to the present invention may be easily and efficiently manufactured.

The polarimetric phase array radar system according to the present invention is of durable and reliable construction.

The polarimetric phase array radar system according to the present invention may have lower overall operation and maintenance costs.

The polarimetric phase array radar system according to the present invention may have a relatively low manufacturing cost.

There has thus been outlined, rather broadly, the more important features of the invention in order that the detailed description thereof that follows hereinafter may be better understood. Additional details and advantages of the invention will be set forth in the detailed description, and in part will be appreciated from the description, or may be learned by practice of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to better understand the subject matter that is disclosed herein and to exemplify how it may be carried out in practice, embodiments will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

Fig. 1 shows a polarimetric phase array radar system for determination of at least one parameter of a target, according to an embodiment of the present invention;

Fig. 2 shows a schematic block diagram of the transceiver element for the phase array radar system shown in **Fig. 1**, according to an embodiment of the present invention;

Figs. 3A and 3B schematically illustrate examples of arrangement of the antenna elements of the transceiver elements in the array of the polarimetric phase array radar system shown in **Fig. 1** that utilizes the monopulse method for calculation of target parameters;

Figs. 4A and 4B illustrate an example of simulations of the sum signal pattern and azimuth difference signal pattern in azimuth plane versus azimuth angle of a target when the boresight angle is 0 degrees and the distribution of the transceiver elements corresponds to the distribution shown in **Fig. 3A**;

Figs. 5A and 5B illustrate an example of simulations of the sum signal pattern and azimuth difference signal pattern in azimuth plane versus azimuth angle of a target when the boresight angle is 0 degrees and the distribution of the transceiver elements corresponds to the distribution shown in **Fig. 3B**;

Fig. 6 illustrates dependencies of the monopulse ratio versus azimuth angle obtained for the transceiver elements of the first and second portions of the array that receive signals having vertical and horizontal polarizations, when the boresight angle is 0 degrees and for the distribution of the transceiver elements corresponds to the distribution shown in **Figs. 3A and 3B**;

Figs. 7A and 7B illustrate an example of simulations of the sum signal pattern and elevation difference signal pattern in elevation plane versus elevation angle of a target when the boresight angle is 0 degrees and the distribution of the transceiver elements corresponds to the distribution shown in **Fig. 3A**;

Fig. 8 illustrates dependencies of the monopulse ratio versus elevation angle obtained for the transceiver elements of the array that receive the signals having vertical polarization and horizontal polarization when the boresight angle is 0 degrees and the distribution of the transceiver elements corresponds to the distribution shown in **Fig. 3A**;

Figs. 9A and 9B illustrate an example of simulations of the sum signal pattern and azimuth difference signal pattern in azimuth plane versus azimuth angle of a target when the boresight angle is 30 degrees and the distribution of the transceiver elements corresponds to the distribution shown in **Fig. 3A**;

Figs. 10A and 10B illustrate an example of simulations of the sum signal pattern and azimuth difference signal pattern in azimuth plane versus azimuth angle of a target when the boresight angle is 30 degrees and the distribution of the transceiver elements corresponds to the distribution shown in **Fig. 3B**;

Fig. 11 illustrates dependencies of the monopulse ratio versus azimuth angle obtained for the transceiver elements of the array that receive the signals having vertical and horizontal polarizations, when the boresight angle is 30 degrees and distribution of the transceiver elements corresponds to the distribution shown in **Figs. 3A and 3B**;

Figs. 12A and 12B illustrate an example of simulations of the sum signal pattern and azimuth difference signal pattern in azimuth plane versus azimuth angle of a target when the boresight angle is 50 degrees and the distribution of the transceiver elements corresponds to the distribution shown in **Fig. 3A**;

Figs. 13A and 13B illustrate dependencies of the monopulse ratio versus azimuth angle obtained for the transceiver elements of the array that receive signals having vertical and horizontal polarizations, when the boresight angle is 50 degrees and distribution of the transceiver elements corresponds to the distribution shown in **Fig. 3B**;

Fig. 14 illustrates dependencies of the monopulse ratio versus azimuth angle obtained for the transceiver elements of the array that receive signals having vertical polarization and horizontal polarization when the boresight angle is 50 degrees and distribution of the transceiver elements corresponds to the distribution shown in **Figs. 3A and 3B**;

Figs. 15A and 15B schematically illustrate examples of an arrangement of the antenna elements of the transceiver elements in the array of the polarimetric phase array radar system shown in **Fig. 1** that utilizes the interferometric method for determination of the azimuth angle of a target;

Figs. 16A and 16B schematically illustrate examples of an arrangement of the antenna elements of the transceiver elements in the array of the polarimetric phase array radar system shown in **Fig. 1** that utilizes the interferometric method for determination of the elevation angle of a target; and

Figs. 17 - 19 illustrate examples of dependencies between the phase difference signals of vertical and horizontal polarization versus the azimuth angle of the target for the case when the boresight angle equals 0 degrees, 30 degrees and 50 degrees, correspondingly.

DETAILED DESCRIPTION OF EMBODIMENTS

The principles of the polarimetric phase array radar system (PPARS) according to the present invention may be better understood with reference to the drawings and the accompanying description, wherein like reference numerals have been used throughout to designate identical elements. It is to be understood that these drawings, which are not necessarily to scale, are given for illustrative purposes only and are not intended to limit the scope of the invention. For example, the dimensions of some of the elements in the figures may be exaggerated relative to other elements to help improve understanding of various embodiments. In addition, the description and drawings do not necessarily require the order illustrated. It will be further appreciated that certain actions and/or steps may be described or depicted in a particular order of occurrence while those skilled in the art will understand that such specificity with respect to sequence is not actually required.

It should be noted that the blocks as well as other elements in these figures are intended as functional entities only, such that the functional relationships between the

entities are shown, rather than any physical connections and/or physical relationships. Those versed in the art should appreciate that many of the examples provided have suitable alternatives which may be utilized.

Referring to **Fig. 1**, a polarimetric phase array radar system **10** for determination of at least one parameter of a target is illustrated, according to an embodiment of the present invention. Examples of the target parameters include, but are not limited to, a target range, a target elevation angle and a target azimuth angle.

The polarimetric phase array radar system **10** includes an array **11** comprising a plurality of transceiver elements **12**. The transceiver elements **12** are configured to transmit radar signal components of a dual-polarization radar signal that have either a single type polarization or simultaneously two types of polarization. Moreover, the transceiver elements **12** are configured to receive a radar signal component having only a single type of polarization. According to one example, the two types of polarization can be horizontal polarization and vertical polarization. According to another example, the two types of polarization can be left-handed circular polarization and right handed circular polarization.

Thus, in the system of the present invention, there is a need only in one receiving channel for one type of polarization for each antenna element coupled through the multi-mode antenna feeds of the element. Accordingly, the number of parts that is required for implementation of the transmitter of the present invention is reduced when compared to a conventional polarimetric phased array system in which every antenna element is coupled to two separate receiving channels transferring simultaneously signals having two types of polarization. Thus, the complexity of development of the system of the present invention, having only one receiving channel, may be reduced and the cost of production may be decreased. Moreover, the system size and weight of the system of the present invention may be decreased when compared to a conventional polarimetric phased array system. Likewise, the system of the present invention may require decreased electric power and produce decreased heat during operation.

Each transceiver element **12** includes an antenna element **21** having multi-mode antenna feeds (not shown) configured for transmitting and receiving a dual-polarization radar signal through corresponding receiving/transmitting channels.

According to one embodiment of the present invention, the antenna elements **21** of the transceiver elements **12** are mounted on a flat plate (not shown) and have a plain arrangement.

According to another embodiment of the present invention, the antenna elements **21** of the transceiver elements **12** are spatially positioned.

Referring to **Fig. 2**, the transceiver element **12** for a phase array radar system shown in **Fig. 1** is illustrated, according to an embodiment of the present invention. The transceiver element includes the antenna elements **21** having multi-mode antenna feeds (not shown) configured for transmitting and receiving a dual-polarization radar signal.

It should be noted that the subject of this invention is not limited to any particular implementation of the antenna elements **21**. Hence, the antenna elements **21** may be implemented in various alternatives. Examples of the radiating elements **21** include, but are not limited to, patch antenna elements; stacked patch antenna elements, microstrip antenna elements, dipole antenna elements, horn antenna elements, tapered-Slot Antenna (TSA) elements (also known as Vivaldi) and other antenna elements or a combination thereof. Consequently, the type, shape and configuration of the antenna elements **21** may be selected to be suitable for the technology adopted for the antenna array.

The transceiver element **12** includes a transmitting portion **22** and a receiving portion **23**. The transmitting portion **22** of the transceiver element **12** includes a radio frequency (RF) source **221** having an input waveform generator (not shown) configured for generating an RF radar signal. The transmitting portion **22** further includes a power distributing element **222** electrically coupled to the RF source **221** and configured to distribute the signal generated by the input waveform generator into a first line **223** for transmitting a radar signal component having a first type of polarization and into a second line **224** for transmitting a radar signal component having a second type of polarization. The first line **223** is coupled to the first multi-mode antenna feed (not shown) of the antenna element **21** for transmitting the first signal component having the first type of polarization. Likewise, the second line **224** is coupled to the second multi-mode antenna feed (not shown) for transmitting the second signal component having the second type of polarization.

According to one embodiment of the present invention, the power distributing element **222** includes a radio frequency power one-to-two divider (not shown) configured for splitting the signal generated by the radio frequency source simultaneously into a first

signal component relayed to the first line **223** and a second signal component relayed to the second line **224**. In this case, the transceiver elements **12** are operative to transmit a dual-polarization radar signal having simultaneously transmitting signal components with two types of polarization.

According to another embodiment of the present invention, the power distributing element **222** includes a radio frequency power switch (not shown) configured to selectively couple the radar signal generated by the radio frequency source to the first line **223** in a switch first position and to the second line **224** in a switch second position. In this case, the transceiver elements **12** are operative to transmit a radar signal component having a single type of polarization.

The transmitting portion **22** further includes a first transmitter (TR) phase shifter **225a** and a second transmitter phase shifter **225b** arranged, correspondingly, in the first and second lines **223** and **224** downstream of the power distributing element **222**. The first and second transmitter phase shifters **225a** and **225b** are adapted to provide required phase shifts to the first and second transmitting signal components of the first and second polarizations, correspondingly.

According to an embodiment, the transmitting portion **22** further includes a first transmitter amplifier/attenuator **226a** and a second transmitter amplifier/attenuator **226b** coupled to the first and second transmitter phase shifters **225a** and **225b**, correspondingly. The first and second transmitter amplifier/attenuators **226a** and **226b** are configured to provide desired tapering (i.e., amplification/attenuation) to the first and second transmitting signal components of the first and second polarizations, correspondingly. Although in the embodiment shown in **Fig. 2**, the first transmitter amplifier/attenuator **226a** and the second transmitter amplifier/attenuator **226b** are arranged downstream of the first and second transmitter phase shifters **225a** and **225b**, when desired the first and second transmitter amplifier/attenuators can be arranged upstream of the first and second transmitter phase shifters **225a** and **225b**.

According to one embodiment of the present invention, the transceiver element **12** includes a first duplexer **227a** and second duplexer **227b** arranged downstream of the first and second phase shifters **225a** and **225b**, correspondingly. The first duplexer **227a** and second duplexer **227b** isolate the transmitting portion **22** from the receiving portion **23**, while permitting them to share a common antenna element **21**. For example, the first

duplexer **227a** and second duplexer **227b** can be implemented as switches. Alternatively, the first duplexer **227a** and second duplexer **227b** can be implemented as circulators.

The first and second duplexers **227a** and **227b** are configured in transmitting mode, to provide shifted transmitting signal components transferred in the first and second transmitting lines **223** and **224** to the first and second multi-mode antenna feeds for transmitting the first and second transmitting signal components having first and second types of polarization, correspondingly.

In receiving mode, the first and second duplexers **227a** and **227b** are configured to receive the first and second receiving signal components of a received dual-polarization radar signal and provide these receiving signal components to a receiving line **231** of the receiving portion **23**

The receiving portion **23** of the transceiver element **12** includes a selecting switch **232** arranged in the receiving line **231** and is coupled to the first and a second duplexers **227a** and **227b**. The selecting switch **232** is configured for switching between receiving the first receiving signal component provided by the antenna element **21** and having the first type of polarization and the second receiving signal component provided by the antenna element **21** and having the second type of polarization.

The receiving portion **23** of the transceiver element **12** further includes a receiver (RX) phase shifter **233** coupled to the selecting switch **232**. The receiver phase shifter **233** is configured to receive the first receiving signal component having the first type of polarization from the selecting switch when the selecting switch being in a first position and to receive the second receiving signal component having the second type of polarization when the selecting switch being in a second position. In operation, the receiver phase shifter provides a required phase shift to the receiving signal component transferred through the receiver phase shifter and generates a shifted receiving signal component of a single type of polarization.

The transceiver elements **12** form a plurality of the receiving channels. Each receiver channel may include a receiver amplifier/attenuator **243**, an analog-to-digital converter (ADC) **245** and other conventional elements arranged in the receiving line **231** and utilized in a receiving portion of radar systems. Although in the embodiment shown in **Fig. 2**, the receiver amplifier/attenuator **243** is arranged downstream of the receiver phase shifter **233**, when desired the RX amplifier/attenuator **243** can be arranged upstream of the RX phase shifter **233**.

The polarimetric phase array radar system (**10** in **Fig. 1)** includes a signal processor system (not shown) arranged downstream of the receiving channels and coupled to the ADC **245**. The signal processor system is configured for processing radar receiving signal components having different polarization and generating the target parameters.

According to one embodiment of the present invention, in the receiving mode of operation, to be able to track a target with the polarimetric phase array radar system (**10** in **Fig. 1**), use is made of the monopulse principle. **Fig. 3A** schematically illustrates one example of an arrangement of distribution of the transceiver elements **12** in the array **11** of the polarimetric phase array radar system shown in **Fig. 1** that utilizes the monopulse method for calculation of target parameters. To implement the monopulse principle, the array **11** of the transceiver elements **12** is divided into four sub-arrays **110**. The four sub-arrays **110** are arranged in four quadrant parts of the array **11** selected from an upper left quadrant part **A**, an upper right quadrant part **B**, a lower left quadrant part **C** and a lower right quadrant part **D** of the array, correspondingly.

Each sub-array **110** comprises a first portion of the transceiver elements and a second portion of the transceiver elements. As will be described hereinbelow, the transceiver elements of the first and second portions operate with the first type and second type of polarization, correspondingly. The transceiver elements of the first and second portions that belong to the sub-array **110** located at the lower right quadrant part **A** are indicated by reference symbols **A1** and **A2**, correspondingly. Likewise, the transceiver elements of the first and second portions that belong to the lower right quadrant part **B** are indicated by reference symbols **B1** and **B2**, the transceiver elements of the first and second portions that belong to the lower right quadrant part **C** are indicated by reference symbols **C1** and **C2**, and the transceiver elements of the first and second portions that belong to the lower right quadrant part **D** are indicated by reference symbols **D1** and **D2**, correspondingly.

According to the embodiment, for one or more quadrant parts **A, B, C** and/or **D**, the transceiver elements of the first portion and the transceiver elements of the second portion of each sub-array can be interleaved with each other.

According to an embodiment, for each sub-array **110**, the transceiver elements of the first and second portions should have phase centers located in the corresponding quadrant parts **A, B, C** and **D,** correspondingly. In particular, the transceiver elements **A1**

and **A2** should have phase centers located in the corresponding quadrant part **A**, the transceiver elements **B1** and **B2** should have phase centers located in the corresponding quadrant part **B**, the transceiver elements **C1** and **C2** should have phase centers located in the corresponding quadrant part **C**, and the transceiver elements **D1** and **D2** should have phase centers located in the corresponding quadrant part **D**, correspondingly.

As shown in **Fig. 3A**, for each sub-array **110,** all the transceiver elements in the first and second portions are located in the corresponding quadrant parts **A, B, C** and **D** of the array. However, when desired, for each sub-array only a majority of the transceiver elements of the first and/or second portions may be located in one quadrant part of the array, whilst a minority of the transceiver elements of the first and/or second portions may be located in neighboring quadrant parts of the array, provided that the phase centers of the transceiver elements of the first and second portions are nevertheless located in the corresponding quadrant parts. As shown in **Fig. 3B**, only a majority of the transceiver elements of the first and second portions is located in the corresponding quadrant part of the array, whilst a minority of the transceiver elements of the first and second portions is located in neighboring quadrant parts. In particular, a majority of the transceiver elements **A1** and **A2** of the first and second portions are located in the quadrant part **A**, while a few elements **A1** and **A2** are yet located in the quadrant parts **A** and **C** of the array.

Nevertheless, the phase centers of the transceiver elements **A1** and **A2** of the first and second portions should be located in the quadrant part **A**. Likewise, for the other quadrant parts **B**, **C** and **D** of the array the phase centers of the transceiver elements of the first and second portions should be located in the corresponding quadrant parts.

In receiving mode of operation, each sub-array **110** is configured to receive a radar signal component having a first type polarization by the first portion of the transceiver elements; and to receive a radar signal component having a second type polarization by the second portion of the transceiver elements. The first portion of the transceiver elements has a first predetermined spatial dynamic distribution, while the second portion of the transceiver elements has a second predetermined spatial dynamic distribution.

According to an embodiment of the present invention, in order to provide an optimal performance of the polarimetric phase array radar system (such as an accurate beam deflection angle, low side lobes, low active return loss, low cross polarization, etc.), an optimization of the first and second predetermined spatial dynamic distributions of the transceiver elements in the first and second portions depends on one or more system

parameters. For example, the first and second predetermined spatial dynamic distributions are different for different operating frequencies. The distributions are different for different numbers of the transceiver elements in the array, and also depend on the coupling between the antenna elements, etc. Moreover, the first and second predetermined spatial dynamic distributions can be different for different boresight (beam deflection) angles and for different target parameters, such as a target range, a target elevation angle, a target azimuth angle**.**

The optimal distributions of the transceiver elements in the first and second portions for operation at a particular frequency and for a certain target parameter can be determined by using standard optimization methods. Examples of the optimization methods include, but are not limited to, the Genetic Algorithm, Newton's method, Quasi-Newton method, Monte Carlo method, etc. These methods are known per se and therefore are not expounded here below.

Various approaches can be used when calculating the optimal distributions of the transceiver elements in the first and second portions. For example, the optimal distributions of the transceiver elements in the first and second portions can be calculated for each desired target elevation angle and target azimuth angle at a desired operation frequency. According to another example, the total range of the target elevation and target azimuth angles can be divided into several sub-ranges. Thus, for each sub-range of target elevation and target azimuth angles the optimal distributions of the transceiver elements in the first and second portions can be calculated at a desired frequency.

According to one embodiment of the present invention, calculation of the optimal distributions of the transceiver elements in the first and second portions is carried out in the signal processor system of the polarimetric phase array radar system of the present invention "on the fly", i.e., during operation of the system for tracking the target and determination of target parameters.

According to another embodiment of the present invention, calculation of the optimal distributions of the transceiver elements in the first and second portions is carried out in advance, for example, in the form of look-up tables. Thus, the look-up-tables can be stored in a memory of the signal processor system and used during operation of the system for tracking the target and determination of target parameters.

According to an embodiment of the present invention, calculated distributions of the transceiver elements in the first and second portions can be used for optimization of

other elements of the polarimetric phase array radar system of the present invention. For example, the optimal distributions of the transceiver elements in the first and second portions can be used for optimal operation of the amplifier/attenuator(s) (**243 in Fig. 2**) of the transceiver elements **12** to provide desired tapering of power of the receiving signal components of the dual-polarization radar signal received on apertures of the antenna elements **21**. The tapering of a power of the signal components of the radar signal can, for example, be required for reducing a level of the side lobs to a desired magnitude.

The tapering of a power of the signal components can be different for different distributions of the transceiver elements. According to an embodiment of the present invention, the optimal amplification or attenuation of magnitudes of the signal components can be determined "on the fly" during operation of the system for tracking the target. According to another embodiment, the optimal amplification or attenuation of magnitudes of the signal components are calculated in advance. These magnitudes can be stored in the form of look-up tables and utilized during operation of the system for tracking the target.

The described scheme of dividing the array **11** of the transceiver elements **12** into sub-arrays **110** employs the monopulse tracking technique for calculating the target parameters. The monopulse technique uses the four quadrants **A**, **B**, **C** and **D** of the array **11**. The elements are all steered together using the phase shifters (**233** in **Fig. 2**). The target is illuminated by all transceiver elements **12** of the four quadrants equally. The signal processor system of the polarimetric phase array radar system can be used to process return signal components of the first type polarization and the second type of polarization received by the four quadrants. For example, two types of polarization can be horizontal polarization and vertical polarization. Likewise, the two types of polarization can be left-handed circular polarization and right handed circular polarization.

The processing includes summing the signal components having one or two types of polarization received from the four sub-arrays to calculate four sub-array sum signals for one type or two types of polarization.

For the first type of polarization the sum signal Σ_1 is obtained by

$$\Sigma_1 = A_1 + B_1 + C_1 + D_1 ,$$

where A_1, B_1, C_1 and D_1 are the signal components having the first type of polarization received from the four sub-arrays **A**, **B**, **C** and **D**.

For the second type of polarization the sum signal Σ_2 is obtained by

$$\Sigma_2 = A_2 + B_2 + C_2 + D_2$$

where A_2, B_2, C_2 and D_2 are the signal components having the second type of polarization received from the four sub-arrays **A**, **B**, **C** and **D**.

In accordance with the monopulse method, the sum signals Σ_1 and Σ_2 can, for example, be used to track target distance.

The elevation difference signals for each type of polarization are formed by subtracting the signal components having one or two types of polarization that are received from the two upper quadrants from the signal components having two types of polarization that are received from the two lower quadrants.

For the first type of polarization the elevation difference signal Δel_1 is obtained by

$$\Delta el_1 = (A_1 + B_1) - (C_1 + D_1)$$

For the second type of polarization the elevation difference signal Δel_2 is obtained by

$$\Delta el_2 = (A_2 + B_2) - (C_2 + D_2)$$

The elevation difference signals for each type of polarization can be processed for calculation of the target's position relative to the horizon, since the target elevation angle is proportional to monopulse ratios $\Delta el_1/\Sigma_1$ and $\Delta el_2/\Sigma_2$. When desired, a weighted combination of Δel_1, Δel_2, Σ_1 and Σ_2 can be used for calculating the target's position relative to the horizon. An example of the combination includes, but is not limited to, the combination $(\alpha\,\Delta el_1 + \beta\,el_2)\big/(\gamma\Sigma_1 + \delta\,\Sigma_2)$, where α, β, γ and δ are the corresponding weights.

The azimuth difference signals for each type of polarization are formed by subtracting the signal components having one or two types of polarization that are received from the left quadrants from the signal components having two types of polarization that are received from the right quadrants.

For the first type of polarization the azimuth difference signal Δaz_1 is obtained by

$$\Delta az_1 = (A_1 + D_1) - (B_1 + C_1)$$

For the second type of polarization the elevation difference signal Δaz_2 is obtained by

$$\Delta az_2 = (A_2 + D_2) - (B_2 + C_2)$$

The azimuth difference signals for each type of polarization can be processed to calculate the target's position to the left or right, since the target azimuth angle is proportional to monopulse ratios $\Delta az_1/\Sigma_1$ and $\Delta az_2/\Sigma_2$. When desired, a weighted combination of Δaz_1, Δaz_2, and Σ_1, Σ_2 can be used for calculating the target's position to the left or right. An example of the combination includes, but is not limited to, the combination $(\alpha\,\Delta az_1 + \beta\,az_2)\big/(\gamma\Sigma_1 + \delta\,\Sigma_2)$, where α, β, γ and δ are the corresponding weights.

Examples of the results of simulations of the sum signal pattern (normalized to the maximum gain value) (curves **41a** and **41b**) and azimuth difference signal pattern (normalized to the maximum gain value) (curves **42a** and **42b**) in azimuth plane versus azimuth angle of a target are shown in **Figs. 4A and 4B** for the vertical polarization signal (curves **41a** and **42a**) and horizontal polarization signal (curves **41b** and **42b**). The simulations were carried out for the boresight angle of 0 degrees and for a circular array having a diameter of 8.3λ, where λ is the operating wavelength. **Figs. 4A and 4B** correspond to the case when the distribution of the transceiver elements corresponds to the distribution shown in **Fig. 3A**, i.e. when all the transceiver elements of the first and second portions are located in the corresponding quadrant parts **A, B, C** and **D** of the array.

Simulations were carried out also for the case when only a majority of the transceiver elements of the first and second portions is located in the corresponding quadrant part of the array, whilst a minority of the transceiver elements of the first and second portions is located in neighboring quadrant parts of the array. **Figs. 5A and 5B** illustrate an example of simulations of the sum signal pattern (normalized to the maximum gain value) (curves **51a** and **51b**) and azimuth difference signal pattern (normalized to the maximum gain value) (curves **52a** and **52b**) in azimuth plane versus azimuth angle of a target when the distribution of the transceiver elements corresponds to the distribution shown in **Fig. 3B**.

The values of the sum signals and azimuth difference signals can be used for calculation of the azimuth angle. **Fig. 6** illustrates dependencies of the monopulse ratio versus azimuth angle obtained for the transceiver elements of the first and second portions of the array that receive the signals having the vertical polarization (curves **61** and **63**) and the horizontal polarization (curves **62** and **64**). Curves **61** and **62** correspond to the

the distribution of the transceiver elements shown in **Fig. 3A**, while Curves **63** and **64** correspond to the the distribution of the transceiver elements shown in **Fig. 3B.**

Examples of the results of simulations of the sum signal pattern (normalized to the maximum gain value) (curves **71a** and **71b**) and elevation difference signal pattern (normalized to the maximum gain value) (curves **72a** and **72b**) in elevation plane versus elevation angle of a target are shown in **Figs. 7A and 7B** for the vertical polarization signal (curves **71a** and **72a**) and horizontal polarization signal (curves **71b** and **72b**). The simulations were carried out for the boresight angle of 0 degrees and for a circular array having a diameter of 8.3λ, where λ is the operating wavelength. **Figs. 7A and 7B** correspond to the case when the distribution of the transceiver elements corresponds to the distribution shown in **Fig. 3A**, i.e. when all the transceiver elements of the first and second portions are located in the corresponding quadrant parts **A, B, C** and **D** of the array.

The values of the sum signals and elevation difference signals can be used for calculation of the elevation angle. **Fig. 8** illustrates dependencies of the monopulse ratio versus elevation angle obtained for the transceiver elements of the first and second portions of the array that receive signals having vertical polarization (curve **81**) and horizontal polarization (curve **82**).

The technique of the present invention can be used for determination of the target parameters when scanning at various boresight angles.

Examples of the results of simulations of the sum signal pattern (normalized to the maximum gain value) (curves **91a** and **91b**) and azimuth difference signal pattern (normalized to the maximum gain value) (curves **92a** and **92b**) in azimuth plane versus azimuth angle of a target are shown in **Figs. 9A and 9B** for the vertical polarization signal (curves **91a** and **92a**) and horizontal polarization signal (curves **91b** and **92b**). The simulations were carried out for the boresight angle of 30 degrees and for a circular array having a diameter of 8.3λ, where λ is the operating wavelength. **Figs. 9A** and **9B** correspond to the case when the distribution of the transceiver elements corresponds to the distribution shown in **Fig. 3A**, i.e. when all the transceiver elements of the first and second portions are located in the corresponding quadrant parts **A, B, C** and **D** of the array.

Simulations for the case of the boresight angle of 30 degrees were carried out also when only a majority of the transceiver elements of the first and second portions is located

in the corresponding quadrant part of the array, whilst a minority of the transceiver elements of the first and second portions is located in neighboring quadrant parts of the array. **Figs. 10A and 10B** illustrate an example of simulations of the sum signal pattern (normalized to the maximum gain value) (curves **101a** and **101b**) and azimuth difference signal pattern (normalized to the maximum gain value) (curves **102a** and **102b**) in azimuth plane versus azimuth angle of a target when the distribution of the transceiver elements corresponds to the distribution shown in **Fig. 3B**.

The values of the sum signals and azimuth difference signals for the case of the boresight angle of 30 degrees can be used for calculation of the azimuth angle. **Fig. 11** illustrates dependencies of the monopulse ratio versus azimuth angle obtained for the transceiver elements of the first and second portions of the array that receive signals having vertical polarization (curves **111** and **113**) and horizontal polarization (curves **112** and **114**). Curves **111** and **112** correspond to the the distribution of the transceiver elements shown in **Fig. 3A**, while curves **113** and **114** correspond to the the distribution of the transceiver elements shown in **Fig. 3B.**

Examples of the results of simulations of the sum signal pattern (normalized to the maximum gain value) (curves **121a** and **121b**) and azimuth difference signal pattern (normalized to the maximum gain value) (curves **122a** and **122b**) in azimuth plane versus azimuth angle of a target are shown in **Figs. 12A and 12B** for the vertical polarization signal (curves **121a** and **122a**) and horizontal polarization signal (curves **121b** and **122b**).

The simulations were carried out for the boresight angle of 50 degrees and for a circular array having a diameter of 8.3λ, where λ is the operating wavelength. **Figs. 12A** and **12B** correspond to the case when distribution of the transceiver elements corresponds to the distribution shown in **Fig. 3A**, i.e. when all the transceiver elements of the first and second portions are located in the corresponding quadrant parts **A, B, C** and **D** of the array.

Simulations for the case of the boresight angle of 50 degrees were carried out also when only a majority of the transceiver elements of the first and second portions is located in the corresponding quadrant part of the array, whilst a minority of the transceiver elements of the first and second portions is located in neighboring quadrant parts of the array. **Figs. 13A and 13B** illustrate an example of simulations of the sum signal pattern (normalized to the maximum gain value) (curves **131a** and **131b**) and azimuth difference signal pattern (normalized to the maximum gain value) (curves **132a** and **132b**) in

azimuth plane versus azimuth angle of a target when the distribution of the transceiver elements corresponds to the distribution shown in **Fig. 3B**.

The values of the sum signals and azimuth difference signals for the case of the boresight angle of 50 degrees can be used for calculation of the azimuth angle. **Fig. 14** illustrates dependencies of the monopulse ratio versus azimuth angle obtained for the transceiver elements of the first and second portions of the array that receive signals having vertical polarization (curves **141** and **143**) and horizontal polarization (curves **142** and **144**). Curves **141** and **142** correspond to the the distribution of the transceiver elements shown in **Fig. 3A**, while Curves **143** and **144** correspond to the the distribution of the transceiver elements shown in **Fig. 3B.** It should be noted that the curves **143** and **144** lie very close to each other.

According to a further embodiment of the present invention, in receiving mode of operation, to be able to track a target with the polarimetric phase array radar system (**10** in **Fig. 1**), use is made of the interferometric technique. **Figs. 15A and 15B** schematically illustrate examples of arrangement of the antenna elements **21** of the transceiver elements **12** in the array **11** of the polarimetric phase array radar system shown in **Fig. 1** that utilizes the interferometric method for calculation of target parameters. To implement the interferometric method, the array **11** of the transceiver elements **12** is divided into two sub-arrays **1100**. For determination of a target azimuth and elevation angles, the two sub-arrays **1100** can be arranged in two half parts of the array **11** in two ways, correspondingly.

Specifically, for determination of a target azimuth angle, the two sub-arrays **1100** are selected from a right half part **X** and a left half part **Y**. In its turn, for determination of a target elevation angle, the two sub-arrays **1100** are selected from an upper half part **I** and a lower half part **J** of the array.

Each sub-array **1100** comprises a first portion of the transceiver elements (indicated by reference numerals **X1** and **J1**) and a second portion of the transceiver elements (indicated by a reference numeral **Y2** and **I2**).

According to an embodiment, for distribution of the transceiver elements shown in **Fig. 15A**, in each sub-array **1100**, the transceiver elements **X1** are interleaved with the transceiver elements **X2** and the transceiver elements **Y1** are interleaved with the transceiver elements **Y2**. Likewise, for distribution of the transceiver elements shown in **Fig. 15B**, in each sub-array **1100**, the transceiver elements **J1** are interleaved with the

transceiver elements **J2** and the transceiver elements **I1** are interleaved with the transceiver elements **I2**.

According to an embodiment, for each sub-array **1100**, the first and second portions of the transceiver elements have phase centers located in the corresponding half part. In particular, for the distribution of the transceiver elements shown in **Fig. 15A**, the phase centers of the transceiver elements **X1** and **X2** are located in the half part **X**, whilst the phase centers of the transceiver elements **Y1** and **Y2** are located in the half part **Y**. Likewise, for the distribution of the transceiver elements shown in **Fig. 15B**, the phase centers of the transceiver elements **J1** and **J2** are located in the half part **J**, whilst the phase centers of the transceiver elements **I1** and **I2** are located in the half part **I**.

As shown in **Figs. 15A and 15B**, all the transceiver elements of the first and second portions are located in the corresponding half parts of the array. However, when desired, for each sub-array only a majority of the transceiver elements of the first and/or second portions may be located in one half part of the array, whilst a minority of the transceiver elements of the first and/or second portions may be located in the neighboring half part of the array, provided that the phase centers of the transceiver elements of the first and second portions are nevertheless located in the corresponding half parts.

For example, as shown in **Figs. 16A**, only a majority of the transceiver elements **X1** and **X2** are located in the right half part **X** of the array, whilst a minority of the transceiver elements of the first and second portions are located in the neighboring half part **Y** of the array. Nevertheless, the phase centers of the transceiver **X1** and **X2** should be located in the half part **X**.

In receiving mode of operation, each sub-array **1100** is configured to receive a radar signal component having a first type polarization by the first portion of the transceiver elements, and to receive a radar signal component having a second type of polarization by the second portion of the transceiver elements. The first portion of the transceiver elements has a first predetermined spatial dynamic distribution, while the second portion **2** of the transceiver elements has a second predetermined spatial dynamic distribution.

According to an embodiment of the present invention, in order to provide an optimal performance of the polarimetric phase array radar system (such as an accurate beam deflection angle, low side lobes, low active return loss, low cross polarization, etc.), an optimization of the first and second predetermined spatial dynamic distributions of the

transceiver elements in the first and second portions depends on one or more system parameters. For example, the first and second predetermined spatial dynamic distributions are different for different operating frequencies. The distributions are different for different numbers of the transceiver elements in the array, and also depend on the coupling between the antenna elements, etc. Moreover, the first and second predetermined spatial dynamic distributions are different for different target parameters, such as a target range, a target azimuth angle and a target elevation angle.

The optimal distributions of the transceiver elements in the first and second portions for operation at a particular frequency and for a certain target parameter can be determined by using standard optimization methods. Examples of the optimization methods include, but are not limited to, the Genetic Algorithm, Newton's method, Quasi-Newton method, Monte Carlo method, etc. These methods are known per se and therefore are not expounded herebelow.

Various approaches can be used when calculating the optimal distributions of the transceiver elements in the first and second portions. For example, the optimal distributions of the transceiver elements in the first and second portions can be calculated for each desired target elevation angle and target azimuth angle at a desired operation frequency. According to another example, the total range of the target elevation and target azimuth angles can be divided into several sub-ranges. Thus, for each sub-range of target elevation and target azimuth angles the optimal distributions of the transceiver elements in the first and second portions can be calculated at a desired frequency.

According to one embodiment of the present invention, calculation of the optimal distributions of the transceiver elements in the first and second portions is carried out in the signal processor system of the polarimetric phase array radar system of the present invention "on the fly", i.e., during operation of the system for tracking the target and determination of target parameters.

According to another embodiment of the present invention, calculation of the optimal distributions of the transceiver elements in the first and second portions is carried out in advance, for example, in the form of look-up tables. Thus, the look-up-tables can be stored in a memory of the signal processor system and used during operation of the system for tracking the target and determination of target parameters.

According to an embodiment of the present invention, calculated distributions of the transceiver elements in the first and second portions can be used for optimization of

other elements of the polarimetric phase array radar system of the present invention. For example, the optimal distributions of the transceiver elements in the first and second portions can be used for optimal operation of the amplifier/attenuator(s) (**243 in Fig. 2**) of the transceiver elements **12** to provide desired tapering of power of the receiving signal components of the dual-polarization radar signal received on apertures of the antenna elements **21**. The tapering of a power of the signal components of the radar signal can, for example, be required for reducing a level of the side lobs to a desired magnitude.

The tapering of a power of the signal components can be different for different distributions of the transceiver elements. According to an embodiment of the present invention, the optimal amplification or attenuation of magnitudes of the signal components can be determined "on the fly" during operation of the system for tracking the target. According to another embodiment, the optimal amplification or attenuation of magnitudes of the signal components are calculated in advance. These magnitudes can be stored in the form of look-up tables and utilized during operation of the system for tracking the target.

The scheme of dividing the array **11** of the transceiver elements **12** into the sub-arrays **1100** employs the interferometric technique for calculating target parameters. The interferometric technique uses right and left half parts **(X** and **Y** in **Fig. 15A or Fig. 16A**) for determination of the azimuth target angle and upper and lower half parts (**I** and **J** in **Fig. 15B or Fig. 16A**) of the array **11** for determination of the elevation target angle. The elements are all steered together using the phase shifters (**233** in **Fig. 2**). The target is illuminated by all transceiver elements **12** of the two half parts equally. The signal processor system of the polarimetric phase array radar system can be used to process return signal components of the first type polarization and the second type of polarization received by the first and second portions of the transceiver elements, correspondingly, which are arranged in the right and left half parts of the array. For example, the two types of polarization can be horizontal polarization and a vertical polarization. Likewise, the two types of polarization can be left-handed circular polarization and right handed circular polarization.

For determination of the azimuth target angle, the processing includes generating phase difference signals $\Delta\varphi_1$ and $\Delta\varphi_2$ between the signal components received from the sub-arrays of the first and second portions of the left and right halves **X** and **Y**,

correspondingly, and calculating distances S_1 and S_2 between the phase centers of the antenna elements of the first and second portions of the left and right halves **X** and **Y**.

The azimuth target angle θaz_1 and θaz_2 for the first type and second type of polarization, correspondingly, can be obtained by

$$\theta az_1 = \sin^{-1}(\frac{\lambda\Delta\varphi_1}{2\pi S_1})$$

$$\theta az_2 = \sin^{-1}(\frac{\lambda\Delta\varphi_2}{2\pi S_2}) .$$

When desired, a weighted combination of phase difference signals $\Delta\varphi_1$ and $\Delta\varphi_2$ can be used for calculation of the azimuth target angle. Likewise, a weighted combination of the azimuth target angles θaz_1 and θaz_2 calculated for different polarization can be used.

For determination of the elevation target angle, the processing includes generating phase difference signals $\Delta\varphi_1$ and $\Delta\varphi_2$ between the signal components received from the sub-arrays of the first and second portions of the upper and lower halves **I** and **J**, correspondingly, and calculating distances S_1 and S_2 between the phase centers of the antenna elements of the first and second portions of the upper and lower halves **I** and **J**.

The azimuth target angle θel_1 and θel_2 for the first and second type of polarization, correspondingly, can be obtained by

$$\theta el_1 = \sin^{-1}(\frac{\lambda\Delta\varphi_1}{2\pi S_1})$$

$$\theta el_2 = \sin^{-1}(\frac{\lambda\Delta\varphi_2}{2\pi S_2}) .$$

When desired, a weighted combination of phase difference signals $\Delta\varphi_1$ and $\Delta\varphi_2$ can be used for calculation of the elevation target angle. Likewise, a weighted combination of the elevation target angles θel_1 and θel_2 calculated for different polarization can be used.

Simulations were carried out for the distributions of the transceiver elements shown in **Figs. 15A and 16A** for calculation of the dependencies between the phase difference signals $\Delta\varphi_1$ and $\Delta\varphi_2$ corresponding to the vertical and horizontal polarization versus the azimuth angle of the target. **Fig. 17** illustrates examples of such dependencies for the case when the boresight angle equals 0 degrees. The curves **171** and **172** correspond to the distributions of the transceiver elements shown in **Figs. 15A**, i.e., when

all the transceiver elements having the vertical and horizontal polarizations are located in the corresponding half parts **X** and **Y** of the array. In its turn, the curves **173** and **174** correspond to the distributions of the transceiver elements shown in **16A**, corresponding to the case when a minority of the transceiver elements **X1** and **X2** are also located in the neighboring half part **Y** of the array.

The technique of the present invention can also be used for determination of the azimuth and elevation angles when scanning at various boresight angles. **Figs. 18 and 19** illustrate examples of the dependencies between the phase difference signals of the vertical and horizontal polarization versus the azimuth angle of the target for the case when the boresight angle equals 30 and 50 degrees, correspondingly.

The curves **181**, **182**, **191** and **192** correspond to distributions of the transceiver elements shown in **Figs. 15A**, i.e., when all the transceiver elements having vertical and horizontal polarizations are located in the corresponding half parts **X** and **Y** of the array. In its turn, curves **183**, **184**, **193** and **194** correspond to distributions of the transceiver elements shown in **16A**.

As such, those skilled in the art to which the present invention pertains, can appreciate that while the present invention has been described in terms of preferred embodiments, the concept upon which this disclosure is based may readily be utilized as a basis for the designing of other structures and processes for carrying out the several purposes of the present invention.

Also, it is to be understood that the phraseology and terminology employed herein are for the purpose of description and should not be regarded as limiting.

It is important, therefore, that the scope of the invention is not construed as being limited by the illustrative embodiments set forth herein. Other variations are possible within the scope of the present invention as defined in the appended claims. Other combinations and sub-combinations of features, functions, elements and/or properties may be claimed through amendment of the present claims or presentation of new claims in this or a related application. Such amended or new claims, whether they are directed to different combinations or directed to the same combinations, whether different, broader, narrower or equal in scope to the original claims, are also regarded as included within the subject matter of the present description.

The reference to any prior art in this specification is not, and should not be taken as, an acknowledgment or any form of suggestion that the prior art forms part of the common general knowledge in Singapore.

CLAIMS:

1. A polarimetric phase array radar system for determination of at least one target parameter selected from a target elevation angle and a target azimuth angle, comprising:

an array comprising a plurality of transceiver elements, each transceiver element being configured to transmit radar transmitting signal components of a dual-polarization radar signal having either a single type polarization or simultaneously two types of polarization and to receive a radar receiving signal component having a single type of polarization;

wherein

in transmitting mode, each of said plurality of transceiver elements is operative to transmit a radar signal component having at least one type of polarization; and

in receiving mode, for processing radar signal components, said plurality of transceiver elements of the array are divided into two sub-arrays, said two sub-arrays being arranged in two half parts of the array in two ways selected from:

(i) a right half part and a left half part for determination of the target azimuth angle, and

(ii) an upper half part and a lower half part for determination of the target elevation angle;

each sub-array comprises a first portion of the transceiver elements and a corresponding second portion of the transceiver elements operating with a first type polarization and a second type of polarization, correspondingly;

for each sub-array, the first portion of the transceiver elements and the second portion of the transceiver elements have phase centers located in the corresponding half part, and

each sub-array is operative to receive a radar signal component having the first type polarization by the first portion of the transceiver elements having a first

predetermined dynamic distribution adapted for optimization and depending at least on one characteristic selected from a total number of the transceiver elements, an operating frequency and said at least one target parameter; and simultaneously to receive a radar signal component having the second type polarization by the second portion of the transceiver elements having a second predetermined dynamic distribution adapted for optimization and depending at least on one characteristic selected from the total number of the transceiver elements, the operating frequency and said at least one target parameter; and

a signal processing system coupled to the transceiver elements, and configured for processing radar receiving signal components having a single type of polarization by using a radar interferometric technique, and generating said at least one target parameter.

2. The system of claim 1, wherein for each sub-array of said two sub-arrays all the transceiver elements of the first and second portions are located in the corresponding half part of the array

3. The system of claim 1, wherein for each sub-array of said two sub-arrays, a majority of the transceiver elements of the first and/or second portions is located in one half part of the array, while a minority of the transceiver elements of the first and/or second portions is located in a neighboring half part of the array.

4. A polarimetric phase array radar system for determination of at least one target parameter selected from a target range, a target elevation angle and a target azimuth angle, comprising:

an array comprising a plurality of transceiver elements, each transceiver element being configured to transmit radar transmitting signal components of a dual-polarization radar signal having either a single type polarization or simultaneously two types of polarization and to receive a radar receiving signal component having a single type of polarization;

wherein

in transmitting mode, said plurality of transceiver elements are operative to transmit a radar signal component having at least one type of polarization; and

in receiving mode, for processing radar signal components, said plurality of transceiver elements of the array are divided into four sub-arrays arranged in four quadrant parts of the array selected from: an upper left quadrant part, an upper right quadrant part, a lower left quadrant part and a lower right quadrant part of the array;

each sub-array comprises a first portion of the transceiver elements and a corresponding second portion of the transceiver elements operating with a first type of polarization and a second type of polarization, correspondingly;

for each sub-array, the first portion of the transceiver elements and second portion of the transceiver elements have phase centers located in the corresponding quadrant part, and

each sub-array is operative

to receive a radar signal component having the first type polarization by the first portion of the transceiver elements having a first predetermined dynamic distribution adapted for optimization and depending at least on one characteristic selected from a total number of the transceiver elements, an operating frequency and said at least one target parameter, and simultaneously

to receive a radar signal component having the second type polarization by the second portion of the transceiver elements having a second predetermined dynamic distribution adapted for optimization and depending at least on one characteristic selected from the total number of the transceiver elements, the operating frequency and said at least one target parameter; and

a signal processing system coupled to the transceiver elements, and configured for processing radar receiving signal components having a single type of polarization by using a monopulse radar technique, and generating said at least one target parameter.

5. The system of claim 4, wherein for each sub-array of said four sub-arrays all the transceiver elements of the first and second portions are located in the corresponding quadrant part of the array.

6. The system of claim 4, wherein for each sub-array of said four sub-arrays, a majority of the transceiver elements of the first and/or second portions is located in one quadrant part of the array, while a minority of the transceiver elements of the first and/or second portions is located in neighboring quadrant parts of the array.

7. The system of claim 1, wherein for each sub-array, the transceiver elements of said first portion are interleaved with the transceiver elements of said second portion.

8. The system of claim 4, wherein for each sub-array, the transceiver elements of said first portion are interleaved with the transceiver elements of said second portion.

9. The system of claim 1, wherein said two types of polarization are selected from a horizontal polarization and a vertical polarization.

10. The system of claim 4, wherein said two types of polarization are selected from a horizontal polarization and a vertical polarization.

11. The system of claim 1, wherein said two types of polarization are selected from a left-handed circular polarization and a right handed circular polarization.

12. The system of claim 4, wherein said two types of polarization are selected from a left-handed circular polarization and a right handed circular polarization.

13. The system of claim 1, wherein each transceiver element of said plurality of transceiver elements comprises:

an antenna element comprising first and second multi-mode antenna feeds configured for transmitting and receiving a dual-polarization radar signal comprising first and second signal components having first and second types of polarization, correspondingly;

a radio frequency source configured for generating a radar transmitting signal;

a power distributing element electrically coupled to the radio frequency source, and configured to distribute the radar signal generated by the radio frequency source between a first line coupled to the first multi-mode antenna feed for transmitting the first signal component having the first type of polarization and a second line coupled to the second multi-mode antenna feed for transmitting the second signal component having the second type of polarization;

first and second transmitter phase shifters arranged in the first and second lines downstream of the power distributing element, and configured to provide required phase shifts to first and second transmitting signal components transferred in the first and second lines, correspondingly;

a first duplexer and a second duplexer arranged downstream of the first and second phase shifters, correspondingly, and configured

in transmitting mode, to provide shifted transmitting signal components in the first and second transmitting lines to the first and second multi-mode antenna feeds for transmitting the first and second transmitting signal components having the first and second types of polarization, correspondingly; and

in receiving mode, to receive first and second receiving signal components having the first and second types of polarization provided by the first and second multi-mode antenna feeds and to provide the first and second receiving signal components to a receiving line;

a selecting switch arranged in the receiving line and coupled to the first and a second duplexers and configured for switching between receiving the first receiving signal component provided by the antenna element and having the first type of polarization and the second receiving signal component provided by the antenna element and having the second type of polarization;

a receiver phase shifter coupled to the selecting switch and configured (i) to receive the first receiving signal component having the first type of polarization from the selecting switch when the selecting switch being in a first position, (ii) to receive the second receiving signal component having the second type of polarization when the selecting switch is in a second position, (iii) to provide a required phase shift to the receiving signal component transferred through the receiver phase shifter, and (iv) to generate a shifted receiving signal component of a single type of polarization.

14. The system of claim 4, wherein each transceiver element of said plurality of transceiver elements comprises:

an antenna element comprising first and second multi-mode antenna feeds configured for transmitting and receiving a dual-polarization radar signal comprising

first and second signal components having first and second types of polarization, correspondingly;

a radio frequency source configured for generating a radar transmitting signal;

a power distributing element electrically coupled to the radio frequency source, and configured to distribute the radar signal generated by the radio frequency source between a first line coupled to the first multi-mode antenna feed for transmitting the first signal component having the first type of polarization and a second line coupled to the second multi-mode antenna feed for transmitting the second signal component having the second type of polarization;

first and second transmitter phase shifters arranged in the first and second lines downstream of the power distributing element, and configured to provide required phase shifts to first and second transmitting signal components transferred in the first and second lines, correspondingly;

a first duplexer and a second duplexer arranged downstream of the first and second phase shifters, correspondingly, and configured

in transmitting mode, to provide shifted transmitting signal components in the first and second transmitting lines to the first and second multi-mode antenna feeds for transmitting the first and second transmitting signal components having the first and second types of polarization, correspondingly; and

in receiving mode, to receive first and second receiving signal components having the first and second types of polarization provided by the first and second multi-mode antenna feeds and to provide the first and second receiving signal components to a receiving line;

a selecting switch arranged in the receiving line and coupled to the first and a second duplexers and configured for switching between receiving the first receiving signal component provided by the antenna element and having the first type of polarization and the second receiving signal component provided by the antenna element and having the second type of polarization;

a receiver phase shifter coupled to the selecting switch and configured (i) to receive the first receiving signal component having the first type of polarization from the selecting switch when the selecting switch being in a first position, (ii) to receive the second receiving signal component having the second type of polarization when the selecting switch is in a second position, (iii) to provide a required phase shift to the receiving signal component transferred through the receiver phase shifter, and (iv) to generate a shifted receiving signal component of a single type of polarization.

15. A method of operating a polarimetric phase array radar system for determination of at least one target parameter selected from a target elevation angle and a target azimuth angle, comprising:

providing an array comprising a plurality of transceiver elements, each transceiver element is configured to transmit radar signal components of a dual-polarization radar signal having either a single type polarization or simultaneously two types of polarization and to receive a radar signal component having a single type of polarization;

wherein in the transmitting mode, operating said plurality of transceiver elements to transmit a radar signal component having at least one type of polarization; and

wherein in the receiving mode, selecting two sub-arrays from said array of the plurality of transceiver elements, said two sub-arrays being arranged in two half parts of the array in two ways selected from:

(i) a right half part and a left half part for determination of the target azimuth angle, and

(ii) an upper half part and a lower half part for determination of the target elevation angle;

each sub-array comprising a first portion of the transceiver elements operating with a first type of polarization and a corresponding second portion of the transceiver elements operating with a second type of polarization;

for each sub-array,

providing a first predetermined dynamic distribution adapted for optimization to the first portion of the transceiver elements and a second predetermined dynamic distribution adapted for optimization to the second portion of the transceiver elements; the first and second predetermined dynamic distributions depending at least on one characteristic selected from a total number transceiver elements, an operating frequency and said at least one parameter of the target;

receiving a radar signal component having one type of polarization by a first portion of the transceiver elements and simultaneously receiving a radar signal component having the second type of polarization by a second portion of the transceiver elements; and

calculating said at least one parameter of the target by using a radar interferometric technique.

16. A method of operating a polarimetric phase array radar system for determination of at least one target parameter, comprising:

providing an array comprising a plurality of transceiver elements, each transceiver element is configured to transmit radar signal components of a dual-polarization radar signal having either a single type polarization or simultaneously two types of polarization and to receive a radar signal component having a single type of polarization;

wherein in the transmitting mode, operating said plurality of transceiver elements to transmit a radar signal component having at least one type of polarization; and

wherein in the receiving mode, dividing the array of said plurality of transceiver elements into four sub-arrays arranged in four quadrant parts of the array selected from: an upper left quadrant part, an upper right quadrant part, a lower left quadrant part and a lower right quadrant part of the array;

each sub-array comprises a first portion of the transceiver elements and a corresponding second portion of the transceiver elements operating with a first type of polarization and a second type of polarization, correspondingly;

for each sub-array,

providing a first predetermined dynamic distribution adapted for optimization to the first portion of the transceiver elements and a second predetermined dynamic distribution adapted for optimization to the second portion of the transceiver elements; the first and second predetermined dynamic distributions depending at least on one characteristic selected from a total number transceiver elements, an operating frequency and said at least one parameter of the target;

receiving a radar signal component having one type of polarization by a first portion of the transceiver elements and simultaneously receiving a radar signal component having the second type of polarization by a second portion of the transceiver elements; and

calculating said at least one parameter of the target by using a monopulse tracking technique.

17. The method of claim 16, wherein said calculating of said at least one parameter of the target by applying the monopulse tracking technique comprises: summing signal components having at least one type of polarization received from the four sub-arrays to calculate a four sub-array sum signal (.SIGMA.); summing signal components having at least one type of polarization received from any two sub-arrays to calculate a first two sub-array sum signal and from two other sub-arrays to calculate a second two sub-array sum signal; generating a difference signal (.DELTA.) between said first two sub-array sum signal and said second two sub-array sum signal; and processing said four sub-array sum signal (.SIGMA.) and said difference signal (.DELTA.) for generating said at least one parameter of the target.

18. The method of claim 15, wherein calculating said at least one target parameter by using the radar interferometric technique comprises: generating a phase difference signal between the signal components having at least one type of polarization received from the two sub-arrays arranged in (i) a right half part and a left half part for determination of the target azimuth angle, and/or (ii) an upper half part and a lower half part for determination of the target elevation angle; calculating a distance between phase centers of the transceiver elements of said two sub-arrays for at least one portion

of the transceiver elements selected from the first portion and second portion and corresponding to said at least one type of polarization; and processing said phase difference signal and the distance between the phase centers for generating said at least one target parameter.

19. The method of claim 15, comprising tapering of a power of the signal components of the radar signal received on an aperture of antenna elements for reducing side lobs level to a desired magnitude.

20. The method of claim 16, comprising tapering of a power of the signal components of the radar signal received on an aperture of antenna elements for reducing side lobs level to a desired magnitude.