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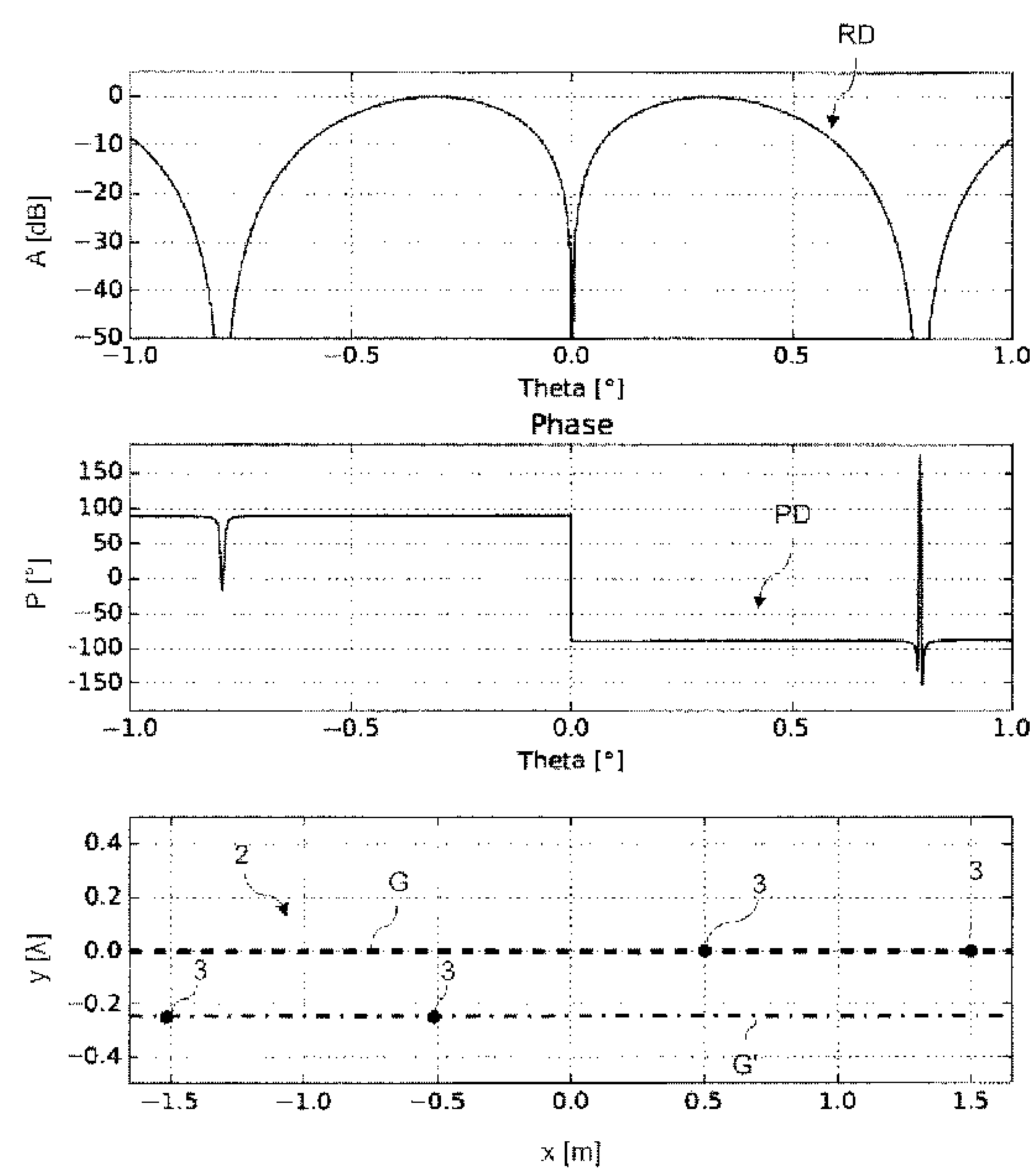

Fig. 3

(57) Abrégé/Abstract:
The invention relates to a synthetic-aperture radar method for remote sensing of the earth's surface by means of a radar device (1), which is moved across the earth's surface in an azimuth direction (x), wherein the radar device (1) comprises a transmitting device for emitting radar pulses and a receiving device for receiving radar echoes. In a defined operating mode of the radar device (1), radar pulses are emitted by the transmitting device and radar echos are received by the receiving device, wherein, for the defined operating mode, resolution cells are defined, which are area segments on the earth's surface having identical dimensions and which represent the spatial resolution of the defined operating mode. Furthermore, in the defined operating mode, raw SAR data are captured by the receipt of radar echos that originate from one or more backscattering arrangements (2) installed on the earth's surface, each composed of a plurality of backscattering elements (3), wherein the backscattering elements (3) of each backscattering arrangement (2) are position relative to each other in such a way that all backscattering elements (3) of the backscattering arrangement (2) lie within one resolution cell, and wherein each backscattering arrangement (2) has one or more backscattering parameters known in advance. The raw SAR data are subjected to signal processing, which comprises the production of SAR radar images of the earth's surface from the raw SAR data and which is dependent on the one or more backscattering parameters known in advance.

Abstract

The invention relates to a synthetic aperture radar method for remote sensing of the surface of the Earth by means of a radar device moving in an azimuth direction (x) above the surface of the Earth, wherein the radar device comprises a transmitting device for emitting radar pulses and a receiving device for receiving radar echoes. In a predetermined operating mode of the radar device, radar pulses are emitted by the transmitting device and radar echoes are received by the receiving device, wherein resolution cells are defined for the predetermined operating mode, which form surface segments on the surface of the Earth having identical dimensions and represent the spatial resolution of the predetermined operating mode. Furthermore, in the predetermined operating mode, SAR raw data are acquired by receiving radar echoes originating from one or more backscattering arrangements, which are installed on the surface of the Earth and each comprise a plurality of backscattering elements, wherein the backscattering elements of each backscattering arrangement are positioned relative to each other such that all backscattering elements of the respective backscattering arrangement are located within one resolution cell, and wherein each backscattering arrangement has one or more pre-known backscatter parameters. The SAR raw data are subjected to a signal processing which comprises the generation of SAR radar images of the surface of the Earth from the SAR raw data and is dependent on the one or more pre-known backscatter parameters.

Synthetic aperture radar method and synthetic aperture radar system

The invention relates to a synthetic aperture radar method for remote sensing of the surface of the Earth and a synthetic aperture radar system.

Synthetic aperture radar methods, also denoted by SAR methods, enable remote sensing of the surface of the Earth by detecting radar pulses reflected at the surface and emitted by a radar device which usually moves at a constant speed above the surface of the earth in a so-called azimuth direction. In doing so, strips of the surface having a width in the so-called range direction, which extends perpendicularly to the azimuth direction, are acquired.

With SAR methods, it is taken advantage of the finding that, due to the moving radar system, the same areas of the Earth are detected from different sensor positions, so that amplitude and phase information and finally a radar image of the surface of the earth can be obtained. Thus, a synthetic aperture in the azimuth direction is generated.

In SAR methods, signal processing is used to obtain corresponding SAR radar images from the raw SAR data initially acquired. For the generation of meaningful SAR images various calibration methods are known. In one class of these methods, individual backscattering elements with a pre-known position on the surface of the Earth and with pre-known backscatter parameters are detected. Calibration is carried out by matching the pre-known backscatter parameters with the SAR radar images. A distinction is made between different calibration methods. With the so-called geometric calibration, the individual pixels of the SAR radar images are linked with geographical locations of the backscattering elements on the surface of the Earth. During a radiometric calibration, the pixels of the SAR radar images are matched with the known radar cross-sections of the backscattering elements. Calibration methods for SAR systems per se are known from the state of the art and are described, for example, in documents [1] and [2].

Usually, individually installed passive corner reflectors are used to calibrate SAR radar images. The corresponding backscatter parameters of these corner reflectors can be controlled only to a limited extent. In addition, there is the problem that such corner reflectors often must have very large dimensions in case of longer-wave radar radiation, so that they are difficult to manufacture and to install.

From the state of the art, also backscattering elements in the form of active transponders are known, which actively emit a radar echo in response to the received radar radiation. Such active transponders are described in document [3], for example. Also the backscatter parameters of such transponders can be controlled only within certain limits.

It is the object of the invention to provide a synthetic aperture radar method and a corresponding synthetic aperture radar system, which allow to generate the SAR raw data such that they are adapted very specifically to the purpose of the signal postprocessing.

This object is solved by the synthetic aperture radar method according to claim 1 and by the synthetic aperture radar system according to claim 11, respectively. Further embodiments of the invention are defined in the dependent claims.

The SAR method according to the invention is used for remote sensing of the surface of the Earth by means of a radar device which moves in an azimuth direction above the surface of the Earth, wherein the radar device comprises a transmitting device for emitting radar pulses and a receiving device for receiving radar echoes. The transmitting device and the receiving device may be arranged on a common platform, but it is also possible that these two devices are positioned on different platforms, such as two synchronously moving satellites.

With the method according to the invention, in a predetermined operating mode of the radar device, radar pulses are emitted by the transmitting device and radar echoes are received by the receiving device, wherein resolution cells are defined for the predetermined operating mode, which form surface segments on the surface of the Earth having identical dimensions and represent the spatial resolution of the predetermined operating mode. In other words, the resolution cells describe the smallest possible surface segment that can just be spatially resolved in the predetermined operating mode. Preferably, the resolution cells are rectangles with one edge in the azimuth direction and one edge perpendicular to the azimuth direction (i.e. in the range direction).

In the predetermined operating mode, raw SAR data are acquired by receiving radar echoes. These radar echoes originate from one or more backscattering arrangements installed on the surface of the Earth, each comprising a plurality of backscattering elements. In other words, the backscattering arrangements with their backscattering elements have been dedicatedly installed by persons in a predetermined pattern. The term backscattering elements shall be understood broadly. They can be passive backscattering elements which generate the radar echoes solely by reflection. The backscattering elements can also be active backscattering elements in the form of so-called transponders which actively emit a corresponding radar echo in response to a received radar signal. The backscattering elements of each backscattering arrangement are positioned relative to each other such that all backscattering elements of the respective backscattering arrangement are located within one resolution cell. In addition, each backscattering arrangement has one or more pre-known backscatter parameters resulting from the deterministic arrangement of the backscattering elements.

During the method according to the invention, the SAR raw data are subjected to signal processing which comprises the generation of SAR radar images of the surface of the Earth from the SAR raw data. This signal processing is dependent on the one or more backscatter parameters mentioned above. These backscatter parameters result inter alia from the geometric arrangement of the backscattering elements.

The invention is based on the finding that, by positioning backscattering elements within one resolution cell, novel point targets having defined backscatter properties can be provided, wherein these backscatter properties are incorporated into the signal processing in a suitable manner. In other words, the raw SAR data can be generated such that they are adapted to the type of the signal processing.

The above term of backscatter parameters is to be understood broadly and relates to those features which characterize the backscattering behavior of the backscattering arrangement. Preferably, the one or more pre-known backscatter parameters of each backscattering arrangement comprise the radar cross-section of the respective backscattering arrangement for the emitted radar pulses. The definition of the radar cross-section is known per se and this cross-section depends inter alia on the wavelength and the angle of the incident radiation. The radar cross-section can be derived from a known positioning and from known properties of the backscattering elements. Alternatively or additionally, the one or more pre-known backscatter parameters comprise the backscatter diagram or the phase diagram, respectively, of the respective backscattering arrangement for the emitted radar pulses, i.e. the angle-dependent (absolute) amplitude or the angle-dependent phase, respectively, of the backscattered radar radiation. Alternatively or additionally, the one or more pre-known backscatter parameters comprise the position of the backscattering centers of the backscattering elements of the respective backscattering arrangement on the surface of the Earth. If applicable, from this, a mean position of the backscattering center for the entire backscattering arrangement can be determined. Depending on the type of signal processing, different ones of the mentioned backscatter parameters are further processed.

In a particularly preferred embodiment, the signal processing comprises a calibration of the SAR radar images, in which the SAR radar images are matched with the one or more pre-known backscatter parameters. Calibration may comprise in particular a radiometric calibration and/or a geometric calibration and/or a polarimetric calibration. All these calibration methods are known per se from the state of the art and are therefore not described in detail. It is essential to the invention that now backscatter parameters of novel point targets in the form of the above defined backscattering arrangements are processed during the calibration. With the geometric calibration, locations on the surface of the Earth which, according to the invention, correspond to the positions of backscattering arrangements are linked with corresponding pixels of the SAR radar images. With the radiometric calibration, the SAR radar images are compared with targets with known radar cross-sections, which, according to the invention, represent the backscattering arrangements. With the polarimetric calibration, the backscattering is distinguished on the basis of the polarization of the radar beams.

In addition to the application of calibration, the method according to the invention may also be used for other purposes, e.g. for determining the orbit of satellites on which the radar equipment is located, or for target identification in which, by means of a signal processing adapted to the previously known backscatter parameters, targets on which the corresponding backscattering arrangement is located can be identified. For orbit determination and target identification, the strongly angle-dependent backscatter diagrams of a plurality of installed backscattering arrays are used.

As already mentioned above, all or at least a part of the backscattering elements can be passive reflectors. In other words, in a preferred embodiment, the backscattering elements of a respective backscattering arrangement of at least a part of the backscattering arrangements comprise one or more passive reflectors. Preferably, these passive reflectors are corner reflectors, i.e. objects with at least two reflection surfaces perpendicular to each other, which usually consist of metal (e.g. aluminum).

As corner reflectors, dihedral corner reflectors with two planar reflection surfaces or trihedral corner reflectors with three planar reflection surfaces and possibly also bruderhedral corner reflectors can be used, for example. Bruderhedral corner reflectors comprise a reflecting surface in the form of a cylinder at one end of which an annular reflecting surface perpendicular to the axis of the cylinder extends outwardly. A bruderhedral reflector may also be a segment of a cylinder with an attached ring-shaped reflecting surface. When corner reflectors are used, the longest edge of each corner reflector preferably has a length of at least five times, preferably ten times, the wavelength of the radar radiation.

As also already mentioned above, all or at least a part of the backscattering elements can also be active transponders that actively emit a radar echo depending on the received radar beams.

In a preferred variant, the backscattering elements of a respective backscattering arrangement of at least a part of the backscattering arrangements are arranged at a uniform distance in the azimuth direction and/or perpendicular to the azimuth direction.

In another preferred embodiment, all backscattering elements of a respective backscattering arrangement of at least a part of the backscattering arrangements are located on a straight line extending in the azimuth direction. It is also possible that a respective backscattering arrangement of at least a part of the backscattering arrangements comprises a plurality of subgroups each having at least two backscattering elements, wherein a respective subgroup is characterised by a straight line on which all backscattering elements of the respective subgroup are located and which extends in the azimuth direction. The straight lines of at least two subgroups, and in particular of all subgroups, are offset to each other in the direction perpendicular to the azimuth direction.

In a preferred variant of the above embodiment, the backscattering arrangement comprises a pair of subgroups which cover different sections in the azimuth direction and/or which are arranged on straight lines which are offset from each other by 1/4 of the wavelength of the radar radiation of the radar device in the direction perpendicular to the azimuth direction. With the offset of 1/4 of the wavelength, special backscatter diagrams with a notch (so called notch patterns) can be generated. If applicable, the backscattering arrangement may consist of only one pair of the subgroups described above.

In a preferred variant, the above subgroups cover adjacent sections in the azimuth direction, wherein the backscattering element at one end of the associated section has the same azimuth position as the backscattering element at the beginning of the adjacent section. In another variant, the respective subgroups comprise the same number of backscattering elements. Furthermore, a backscattering arrangement may consist of two subgroups of backscattering elements which cover adjacent sections in the azimuth direction, wherein the backscattering elements of the different subgroups are arranged on straight lines which are positioned offset from each other perpendicularly to the azimuth direction. Preferably, all backscattering elements of the backscattering arrangement are positioned in azimuth direction at a uniform distance, and preferably, each subgroup comprises the same number of backscattering elements. Thus, the formation of a notch in the backscatter diagram in the main beam direction is achieved, provided that the offset of the two straight lines is 1/4 of the wavelength of the radar radiation.

The method according to the invention can be used for any operating modes having resolution cells of different size. In a preferred variant, the extension of a respective resolution cell in the azimuth direction is between 0.24 m and 500 m, whereas the extension of the resolution cell perpendicular to the azimuth direction is preferably between 0.6 m and 500 m. Preferably, the resolution cell is a rectangle with edges parallel and perpendicular to the azimuth direction. With the above-mentioned extensions, typical known spatial resolutions of SAR missions in operation or planned are covered. The extensions of rectangular resolution cells for different missions are stated below:

- TerraSAR-X:
  Azimuth: 0.24 m to 40 m
  Range: 0.6 m to 3.3 m
- Sentinel-1:
  Azimuth: 5 m to 40 m
  Range: 5 m to 20 m
- BIOMASS:
  The resolution cells should have a dimension of 50 m or less in the azimuth direction and 50 m or less in the range direction.
- Tandem-L:
  The resolution should be between 5 m and 500 m in both the azimuth direction and the range direction.

In addition to the method described above, the invention relates to a synthetic aperture radar system for remote sensing of the surface of the Earth, comprising a radar device which, during operation, moves in an azimuth direction above the surface of the Earth, wherein the radar device comprises a transmitting device for emitting radar pulses and a receiving device for receiving radar echoes. The synthetic aperture radar system is configured such that the method according to the invention or one or more preferred variants of the method according to the invention can be carried out with this system. The backscattering arrangement defined in the method according to the invention is thus part of the synthetic aperture radar system. The signal processing according to the invention is carried out in the radar system by means of a computing means. Depending on the configuration, the computing means may be located on the platform on which the radar device is located, or it may be integrated in a ground station to which the raw SAR data of the radar equipment are transmitted. It is also possible that part of the signal processing may be carried out by a computing means on the platform of the radar device and another part of the signal processing may be carried out by a computing means at a ground station.

In the following, exemplary embodiments of the invention are described in detail on the basis of the attached figures, in which:

Fig. 1 is a schematic view used to explain the SAR principle which is used for the invention;

Fig. 2 is a view of a first embodiment of a backscattering arrangement which can be used in the method according to the invention, and of the backscatter parameters belonging to this arrangement;

Fig. 3 is a view of a second embodiment of a backscattering arrangement which can be used in the method according to the invention, and of the backscatter parameters belonging to this arrangement; and

Fig. 4 is a schematic plan view in direction of the radar beam, which shows a possible configuration of the backscattering elements of the embodiment of Fig. 3.

For a better understanding, at first the principle of SAR measurement using the radar radiation emitted by a satellite is explained on the basis of Fig. 1. The satellite shown in Fig. 1 is indicated by reference sign SA and moves in the direction of depicted arrow M which corresponds to the x-direction of the Cartesian coordinate system shown in Fig. 1. This x-direction is usually also denoted by azimuth. Satellite SA, whose altitude above the surface of the Earth is represented by the z coordinate of the coordinate system, comprises a radar device 1, which is schematically indicated as an antenna and includes a transmitting device and a receiving device (not shown separately). If applicable, a transmitting device and a receiving device located on different satellites moving synchronously to each other may also be used.

During the movement of satellite SA, its transmission device continuously transmits radar pulses towards the surface of the Earth with a predetermined pulse repetition frequency, wherein the contour of a just emitted radar pulse on the surface of the Earth is denoted by RP. The radar echo of each emitted radar pulse is detected by sampling the radar radiation, which is reflected at the surface of the Earth, in the direction y of the Cartesian coordinate system. The direction y is usually also denoted by range. In the embodiment shown, only information of the radar radiation between the two lines L and L', which have a distance of several kilometers (e.g. 30 km), is considered when evaluating of the radar echoes. This is also indicated by the hatched area within the radar pulse RP. As raw data of the SAR measurement, for a plurality of radar pulses, and thus for a plurality of azimuth positions, a plurality of analog data samples (also referred to as data samples) are obtained, each of which corresponds to a range position.

The principle of SAR measurement is henceforth based on the fact that due to the movement of satellite SA, points on the surface of the Earth are detected several times from different perspectives. This is illustrated in Fig. 1 for point P. In the depicted scenario, this point P has the smallest possible distance to satellite SA. By moving the satellite in direction M, this distance becomes larger and larger. Before reaching the position shown in Fig. 1, this distance became smaller and smaller. Due to the Doppler effect, a frequency shift occurs during the detection of the radar echo, which can be suitably evaluated, so that finally an amplitude and phase information, and thus, a pixel of the surface of the Earth can be obtained for the points on the surface of the Earth where the radar pulses are reflected. The pixels obtained represent an SAR radar image of the acquired surface area of the surface of the Earth. The corresponding calculation of pixels of the surface of the Earth from SAR raw data is well known for a skilled person and will therefore not be explained in detail. With the SAR measuring method, a larger synthetic aperture corresponding to the extent of the radar pulse on the surface of the Earth is simulated by a plurality of radar pulses from a small aperture radar transmitter.

The essence of the invention is based on the fact that an SAR radar device, as shown for example in Fig. 1, detects one and possibly several backscattering arrangements which were installed on the surface of the Earth by persons and comprise several backscattering elements with predetermined distances and dimensions. The distances between the individual backscattering elements are chosen such that they fit into one resolution cell of the currently used operating mode of the SAR radar device. The resolution cells cover the captured area of the surface of the Earth in the form of contiguous (non-overlapping) surface segments of identical size. Preferably, the surface segments are rectangles and the size of a surface segment corresponds to the spatial extent which can just be resolved by the radar device. In other words, a backscattering arrangement for the SAR radar represents a point target, since the individual backscatterers cannot be resolved due to their distance, which is smaller than the size of one resolution cell.

The individual backscattering elements of the backscattering arrangement are arranged in a predetermined pattern, and also the reflection properties of the individual backscattering elements are known, so that there are pre-known backscatter parameters for the corresponding backscattering arrangement. In the embodiment described here, these backscatter parameters comprise the radar cross-section and the backscatter diagram of the entire backscattering arrangement, as well as the position of the backscattering centers of the individual backscattering elements. These values can be determined from the arrangement pattern of the backscattering elements and the information about the structure of the individual elements.

Conceptually, the backscattering arrangements used in the method according to the invention can each be interpreted as a backscattering target located between a point target and a distributed point target, wherein it is essential to the invention that the individual backscattering elements are not randomly distributed but are arranged in a predetermined pattern, so that backscatter parameters of that arrangement are previously known. The response of a backscattering arrangement to a radar pulse is therefore deterministic and is used in the embodiments of the invention described here to calibrate SAR radar images.

Fig. 2 shows a first variant of a backscattering arrangement that can be used in the method according to the invention. In the lowermost diagram of Fig. 2, a top view of the backscattering arrangement is shown, wherein the abscissa of this diagram is the azimuth direction x and the ordinate is the range direction y. The azimuth direction is denoted in meters, whereas the range direction is depicted as a portion of the wavelength λ of the radar radiation. The backscattering arrangement is denoted by reference sign 2 and comprises 54 uniformly spaced trihedral corner reflectors, which are only schematically indicated and, for the sake of clarity, are only partially marked with reference sign 3. In the embodiment shown, all corner reflectors are arranged along a straight line G which extends in azimuth direction.

When using a radar radiation in the C band (f = 5.405 GHz), the phase characteristic PD shown in the middle diagram of Fig. 2 is obtained, which indicates the phase P of the backscattered radar echo as a function of the azimuth angle Theta in the event that the radar device is located at position x = 0 in the lowermost diagram. The azimuth angle represents the inclination with respect to the azimuth direction, measured from the straight line between the radar device and the mean position of the backscattering arrangement (i.e. x = 0). As can be seen, phase shifts occur due to destructive superposition of the reflected radar waves at approximately -0.5° and +0.5°.

The top diagram of Fig. 2 shows for the above radar radiation in the C-band the backscatter diagram RD of the backscattering arrangement in the form of the (absolute) amplitude A of the received radar echo as a function of the azimuth angle Theta. As can be seen, the amplitude of the radar echo in the main backscattering direction (Theta = 0°) is at the maximum and decreases to zero at 0.5° and -0.5° due to destructive superposition of the reflected radar waves. In addition to the phase diagram PD and the backscatter diagram RD, from the backscattering arrangement also the backscattering centers of backscattering elements 3 and the radar cross-section of the entire backscattering arrangement for the received radar radiation are known. This information originates from the knowledge about the structure of the backscattering elements and their positioning on the surface of the Earth.

In the embodiment described here, a calibration of the SAR radar images is carried out with the known backscatter parameters of the arrangement. In doing so, both a geometric calibration and a radiometric calibration can be carried out. During the geometric calibration, the individual pixels of the SAR images are assigned to geographic locations on the surface of the Earth. For this, the information about the position of the backscattering centers of backscattering elements 3 is used, from which an averaged backscattering center for the entire backscattering arrangement 2 and thus a position for this entire backscattering arrangement on the surface of the Earth can be determined. During the radiometric calibration, the pixel intensities of the SAR radar images are matched with the radar cross-section of backscattering arrangement 2. Thus, a processing of the SAR images is performed in consideration of pre-known backscatter parameters of the arrangement of Fig. 2.

In addition to geometric and radiometric calibration, further processing operations of SAR radar images can also be carried out with the known backscatter parameters, such as antenna pointing determination, which is also a type of calibration. The calibration methods mentioned are known per se from the state of the art and described, for example, in the publications [1] and [2] mentioned above.

Another example of a signal processing of SAR radar images using the pre-known backscatter parameters of the deterministic arrangement of backscattering elements is the target identification of objects on which a corresponding backscattering arrangement is arranged. The objects can only be suitably identified if the signal processing of the SAR radar images uses the knowledge about the backscatter parameters of the backscattering arrangement. The target identification of objects can, for example, be used in the military field, and corresponding methods for target identification are known per se.

By using suitable backscattering elements, which have a radar cross-section depending on the polarization of the radar radiation, a polarimetric calibration known per se can also be carried out depending on the polarizations of the radar radiation. For polarimetric calibration, backscattering elements in the form of dihedral corner reflectors are particularly suitable, since these change the polarization of the radar radiation after reflection. In particular, in a backscattering arrangement, a point target can be achieved by twisting individual dihedral corner reflectors relative to each other, the polarimetric response of which changes significantly versus the incidence angle.

Fig. 3 shows a second embodiment of a backscattering arrangement which can be used in the method according to the invention. The diagrams shown in Fig. 3 correspond to the diagrams in Fig. 2, so that their legend is not explained again. In contrast to the backscattering arrangement of Fig. 2, the arrangement 2 of Fig. 3 now comprises only four backscattering elements 3, which in turn are designed as trihedral corner reflectors. In the embodiment of Fig. 3, the backscattering elements are arranged on two mutually offset straight lines G and G', which extend in the azimuth direction x. The two left backscattering elements are offset with respect to the two right backscattering elements by the distance $\lambda/4$ in the range direction y. As can be derived from the middle diagram of Fig. 3, this results in a phase shift of 180° at the azimuth angle Theta of 0° due to the destructive superposition of the radar radiation. This in turn implicates that the backscatter diagram RD is a so-called notch pattern which has a notch at the azimuth angle of 0°. With such a notch pattern, signal processing of the SAR radar images for calibration or other purposes can be carried out analogously to the embodiment of Fig. 2. In particular, a notch pattern is also suitable for antenna pointing determination. Such a notch pattern is already used in publication [1], wherein, however, the notch pattern is not generated by the backscatter diagram, but by the antenna diagram.

In another preferred embodiment, a backscattering arrangement is used within the invention, which simulates a single backscatterer for radar radiation in the long-wave P band (frequencies from 230 MHz to 1 GHz). The longer the wavelength of the radar radiation, the larger a single reflector must be designed for use for calibration purposes. Preferably, the edge length of a trihedral corner reflector should be at least 10λ, so that a single reflector should have edge lengths in the range of several meters. To avoid this, a backscattering arrangement can be used which generates, by positioning several reflectors with smaller edge lengths, a backscatter diagram which can be used similar to the backscatter diagram of a large reflector.

Fig. 4 shows the specific structure of the four reflectors of Fig. 3 in a schematic plan view in the direction of the received radar radiation. As can be seen, the four reflectors 3 are trihedral corner reflectors with three metallic sides 301, 302 and 303, which are formed as triangles and which all stand on each other at an angle of 90°. The triangles extend into the sheet plane of Fig. 4 and end at a common tip 304 which represents the backscattering center of the respective corner reflector. The backscattering centers of the two left corner reflectors are arranged on the straight line G' which extends in the azimuth direction. In contrast, the backscattering centers of the two right corner reflectors are arranged on straight line G which extends offset and parallel to straight line G'. The offset of the straight lines is $\lambda/4$, as already explained with respect to Fig. 3. The range direction extending perpendicular to the azimuth direction is shown by the line R in Fig. 4 for clarification. The arrangement of the individual trihedral corner reflectors was chosen to be very compact in Fig. 4, as adjacent corner reflectors are each rotated by an angle of 180° about the corresponding backscattering centers 304.

The above embodiments of backscattering arrangements are merely exemplary and other arrangements are also possible, wherein it is essential to the invention that the individual backscattering elements within one resolution cell are arranged deterministically according to a predetermined pattern, so that certain backscatter properties of the backscattering arrangement are known and can be used during a processing of the SAR radar images and in particular for calibration.

The invention described above has a number of advantages. In particular, with the arrangement of several backscattering elements within one resolution cell of a SAR system, point targets with adjustable angle-dependent backscattering patterns can be provided. The backscattering patterns can be suitably adjusted to carry out an efficient calibration of SAR radar images, for example. In particular, the backscattering patterns may also have a sharp notch in the main beam direction, as shown in the embodiment of Fig. 3, if applicable. This characteristic can be used for the above mentioned antenna pointing determination or for orbit determination. In a preferred variant, the backscattering arrangements are also adjustable, i.e. the position of the backscattering elements contained therein and their orientation can be changed. In this way, different types of backscattering targets can be generated as required.

In the foregoing, the invention was described on the basis of passive backscattering elements which reflect the incident radar radiation. Nevertheless, the invention can also be applied analogously to active backscattering elements in the form of transponders. Such transponders actively generate from the received radar radiation a response signal which corresponds to the reflected radar echo of passive backscattering elements. The dependence between the incident radar radiation and the resulting response is known for the individual transponders. The use of active transponders is well known from the state of the art and described in document [3], for example.

References:

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Claims

1.A synthetic aperture radar method for remote sensing of the surface of the Earth by means of a radar device moving in an azimuth direction (x) above the surface of the Earth, the radar device comprising transmitting device for emitting radar pulses and a receiving device for receiving radar echoes, wherein

- in a predetermined operating mode of the radar device, radar pulses are emitted by the transmitting device and radar echoes are received by the receiving device, wherein resolution cells are defined for the predetermined operating mode, which form surface segments on the surface of the Earth having identical dimensions and represent the spatial resolution of the predetermined operating mode;
- in the predetermined operating mode, SAR raw data are acquired by receiving radar echoes originating from one or more backscattering arrangements, which are installed on the surface of the Earth and each comprise a plurality of backscattering elements, wherein the backscattering elements of each backscattering arrangement are positioned relative to each other such that all backscattering elements of the respective backscattering arrangement are located within one resolution cell, and wherein each backscattering arrangement has one or more pre-known backscatter parameters;
- the SAR raw data are subjected to a signal processing which comprises the generation of SAR radar images of the surface of the Earth from the SAR raw data and is dependent on the one or more pre-known backscatter parameters.

2. The method according to claim 1, characterized in that the pre-known one or more backscatter parameters of each backscattering arrangement comprise the radar cross-section of the respective backscattering arrangement for the emitted radar pulses and/or the backscatter diagram (RD) of the respective backscattering arrangement for the emitted radar pulses and/or the phase

diagram (PD) of the respective backscattering arrangement for the emitted radar pulses and/or the positions of the backscattering centers of the backscattering elements of the respective backscattering arrangement on the surface of the Earth.

3. The method according to any of claim 1 and claim 2, characterized in that the signal processing comprises a calibration of the SAR radar images, in which the SAR radar images are matched with the one or more pre-known backscatter parameters, wherein the calibration comprises in particular a radiometric calibration and/or a geometric calibration and/or a polarimetric calibration.

4. The method according to any of claim 1, claim 2 and claim 3, characterized in that the backscattering elements of a respective backscattering arrangement of at least a part of the backscattering arrangements comprise one or more passive reflectors.

5. The method according to claim 4, characterized in that the one or more passive reflectors comprise one or more corner reflectors, in particular one or more dihedral corner reflectors and/or one or more trihedral corner reflectors and/or one or more bruderhedral corner reflectors.

6. The method according to claim 4 wherein the backscattering elements of a respective backscattering arrangement of at least a part of the backscattering arrangements comprise one or more active transponders.

7. The method according to claim 6 wherein the backscattering elements of a respective backscattering arrangement of at least a part of the backscattering arrangements are located on a straight line (G) extending in azimuth direction (x).

8. The method according to claim 7 wherein a respective backscattering arrangement of at least a part of said backscattering arrangements comprises a plurality of subgroups each having at least two backscattering elements, wherein a respective subgroup is characterized by a straight line (G, G') on which all backscattering elements of the respective subgroup are located and which extends in the azimuth direction (x), wherein the straight lines (G, G') of at least two subgroups are offset to one another in a direction perpendicular to the azimuth direction (x).

9. The method according to claim 8 wherein the respective backscattering arrangement comprises a pair of subgroups covering different sections in the azimuth direction (x) and/or being arranged on straight lines which are offset to one another by ¼ of the wavelength of the radar radiation of the radar device in the direction perpendicular to the azimuth direction (x).

10. The method according to claim 9 wherein the extension of a respective resolution cell in the azimuth direction is between 0.24 m and 500 m and/or the extension of a resolution cell perpendicular to the azimuth direction is between 0.6 m and 500 m.

11. A synthetic aperture radar system for remote sensing of the surface of the Earth, comprising a radar device which, during operation, moves in an azimuth direction (x) above the surface of the Earth, wherein the radar device comprises a transmitting device for emitting radar pulses and a receiving device for receiving radar echoes, wherein the synthetic aperture radar system is configured such that

- in a predetermined operating mode of the radar device, radar pulses are emitted by the transmitting device and radar echoes are received by the receiving device, wherein resolution cells are defined for the predetermined operating mode, which form surface segments on the surface of the Earth having identical dimensions and represent the spatial resolution of the predetermined operating mode;

- in the predetermined operating mode, SAR raw data are acquired by receiving radar echoes originating from one or more backscattering arrangements, which are installed on the surface of the Earth and each comprise a plurality of backscattering elements, wherein the backscattering elements of each backscattering arrangement are positioned relative to each other such that all backscattering elements of the respective backscattering arrangement are located within one resolution cell, and wherein each backscattering arrangement has one or more pre-known backscatter parameters;
- the SAR raw are subjected to a signal processing which comprises the generation of SAR radar images of the surface of the Earth from the SAR raw data and is dependent on the one or more pre-known backscatter parameters.

12. The synthetic aperture radar system according to claim 11, wherein the synthetic aperture radar system is configured to carry out a method according to one of claim 2, claim 3, claim 4, claim 5, claim 6, claim 7, claim 8, claim 9 and claim 10.

PAT2221CA00

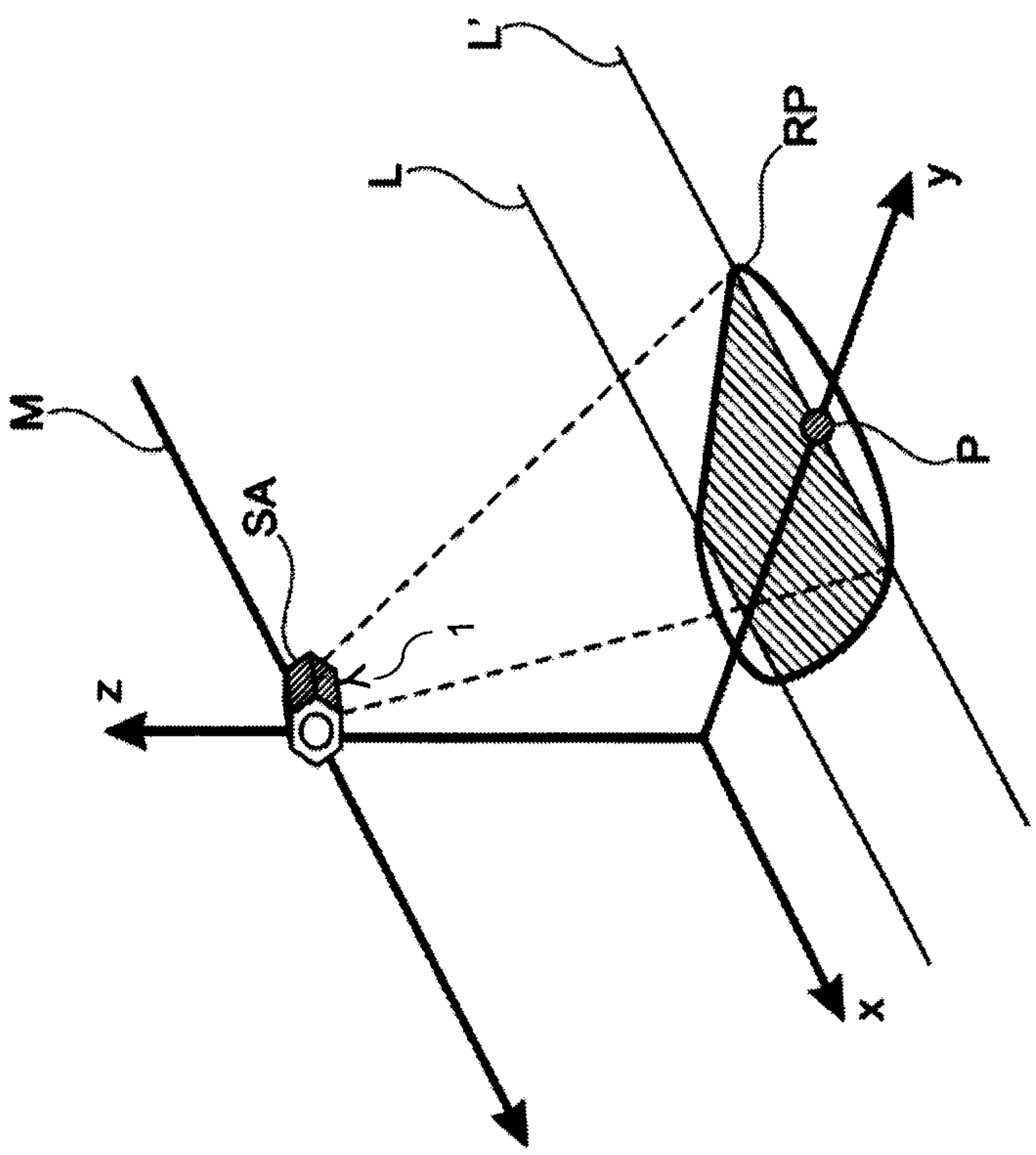


Fig. 1

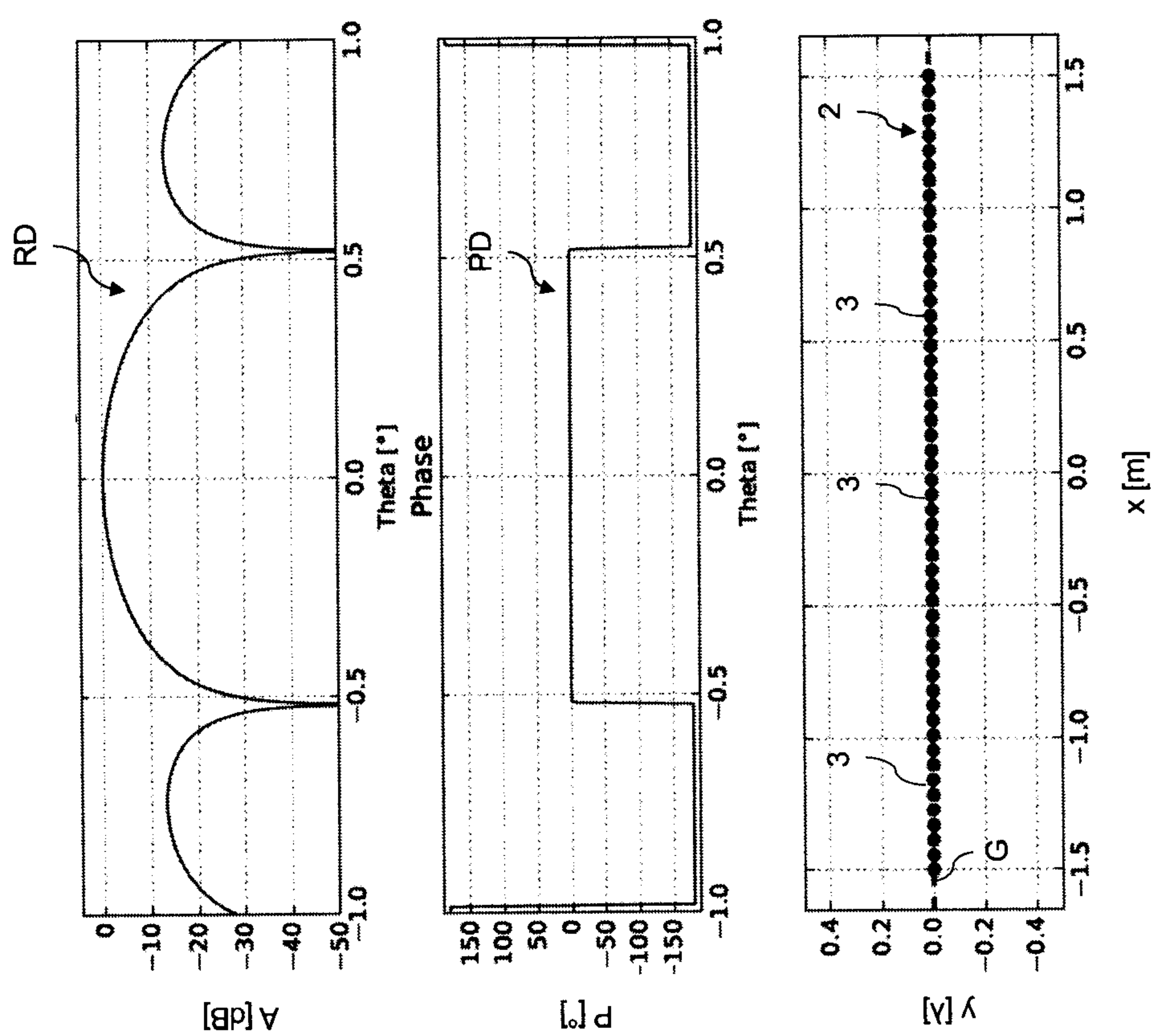


Fig. 2

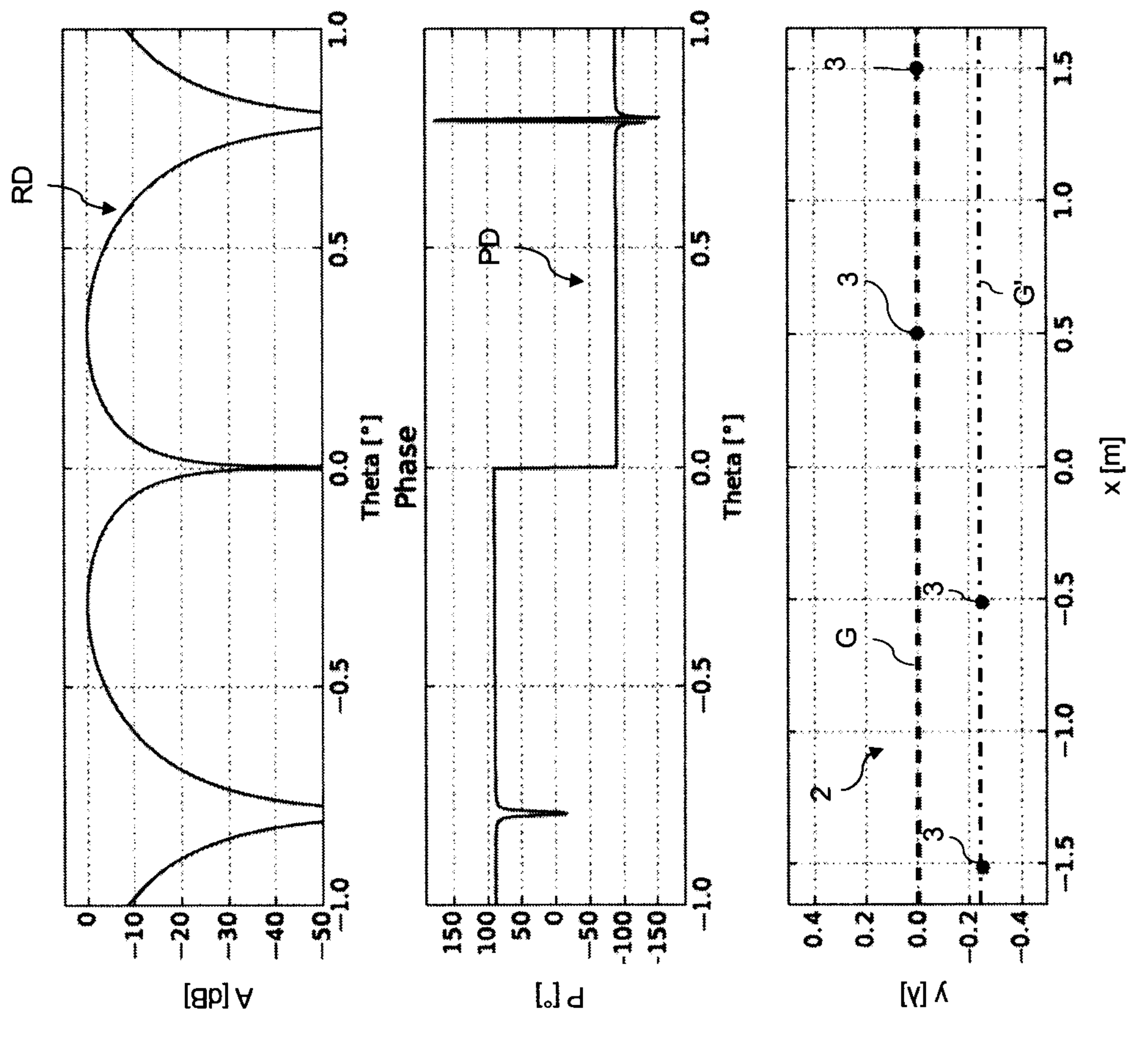
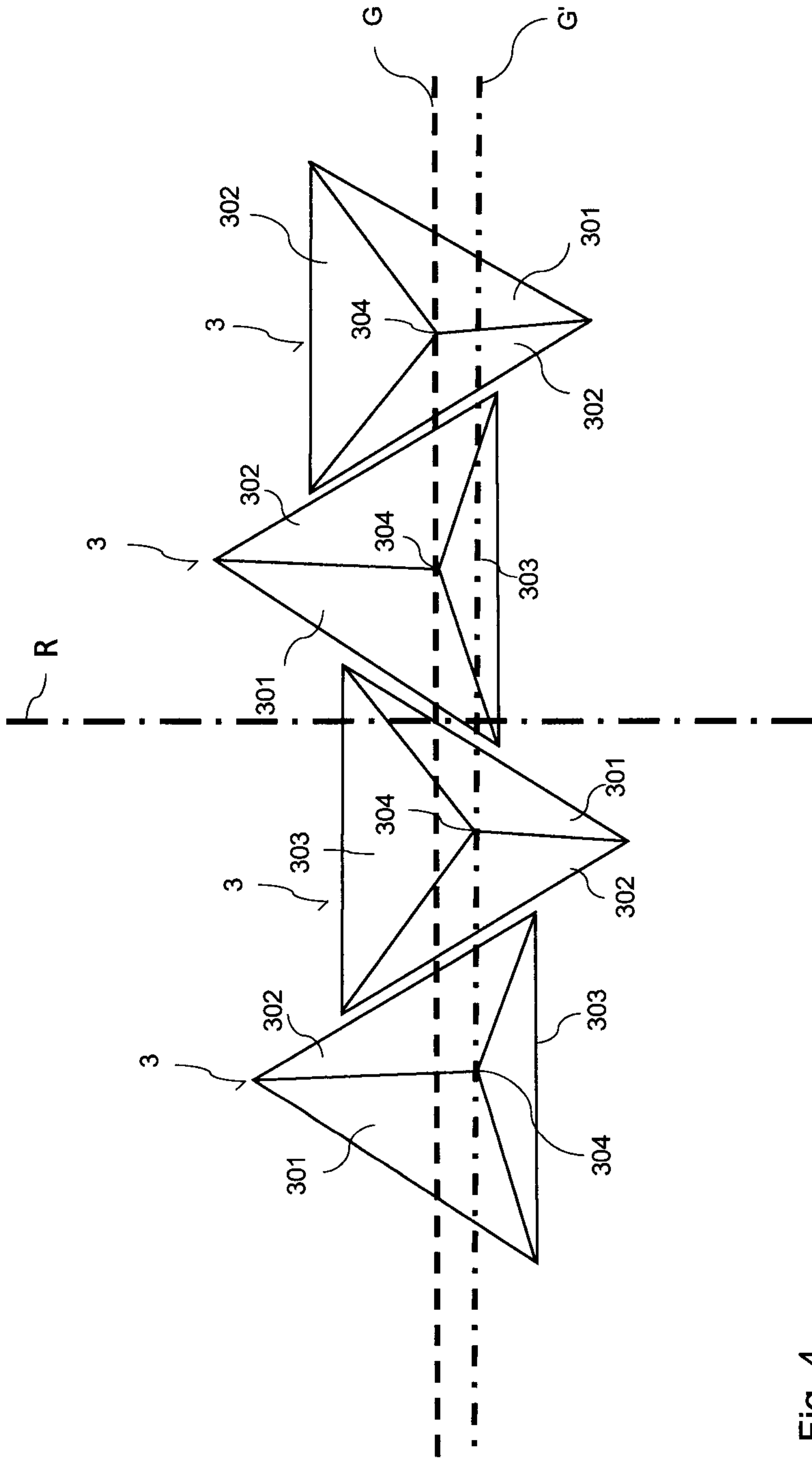


Fig. 3


G
G'
R
3
3
3
3
301
301
301
301
302
302
302
302
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303
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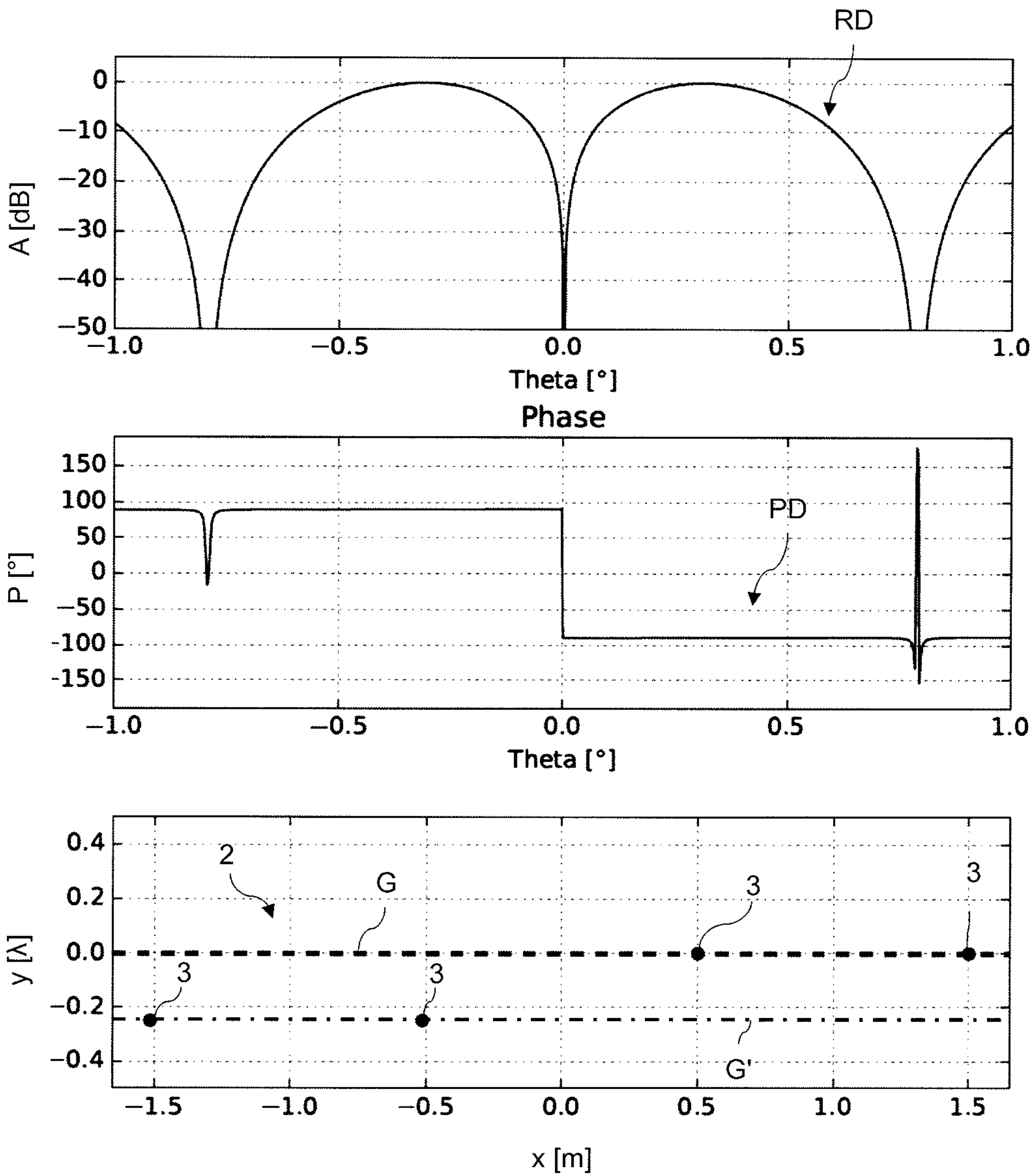
303
304
304
304
304

Fig. 4



RD
0
−10
−20
−30
−40
−50
A [dB]
−1.0
−0.5
0.0
0.5
1.0
Theta [°]
Phase
150
100
50
0
−50
-100
-150
P [°]
PD
−1.0
−0.5
0.0
0.5
1.0
Theta [°]
0.4
0.2
0.0
−0.2
−0.4
y [λ]
2
G
3
3
3
3
G'
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
x [m]

Fig. 3