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(54) **ON-VEHICLE RADAR DEVICE**

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G01S 13/93	(2006.01)
H01Q 1/48	(2006.01)
H01Q 21/24	(2006.01)

(52) **U.S. Cl.**
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(58) **Field of Classification Search**
CPC H01Q 1/32; H01Q 1/48; H01Q 21/24
USPC 343/713
See application file for complete search history.

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(57) **ABSTRACT**

In an on-vehicle radar device, a receiving antenna part includes a first antenna array with a plurality of receiving antennas arranged in a first direction perpendicular to a predetermined reference direction, and a second antenna array with three or more receiving antennas arranged in a second direction perpendicular to the reference direction and different from the first direction. A computing part computes the elevation angle of an object, using a first detection angle formed by the reference direction and a direction of the object acquired using the first antenna array in a plane parallel to the reference direction and the first direction, a second detection angle formed by the reference direction and a direction of the object acquired using the second antenna array in a plane parallel to the reference direction and the second direction, and a relative inclination angle formed by the first and second directions.
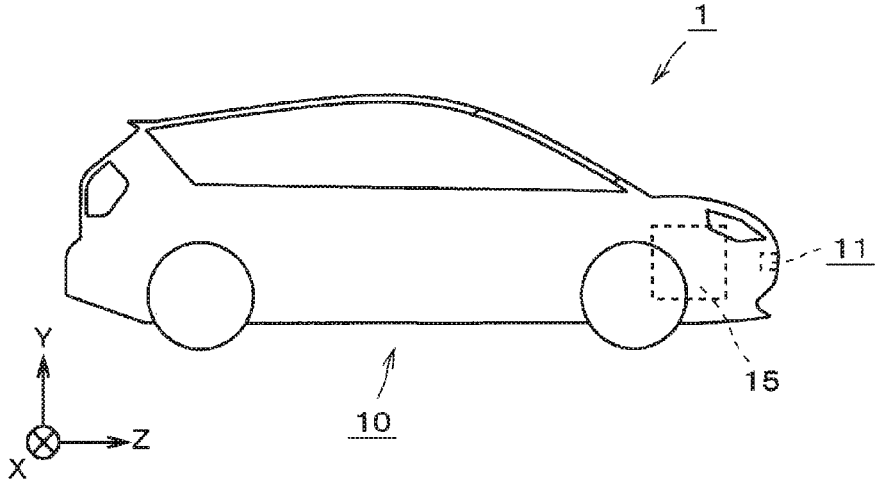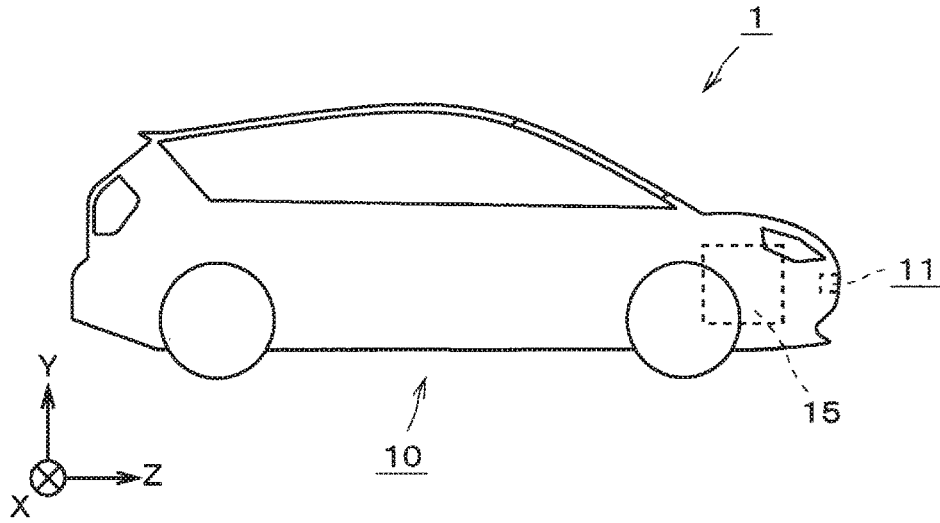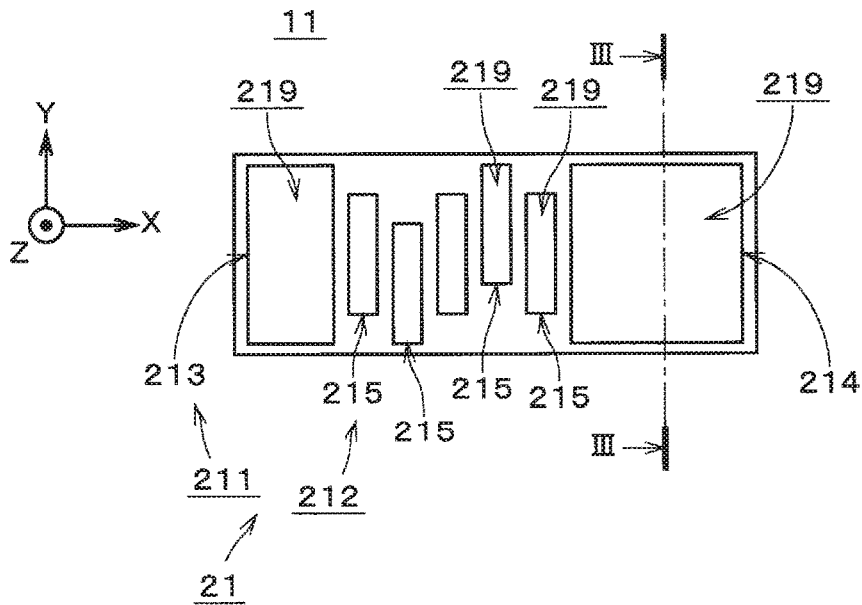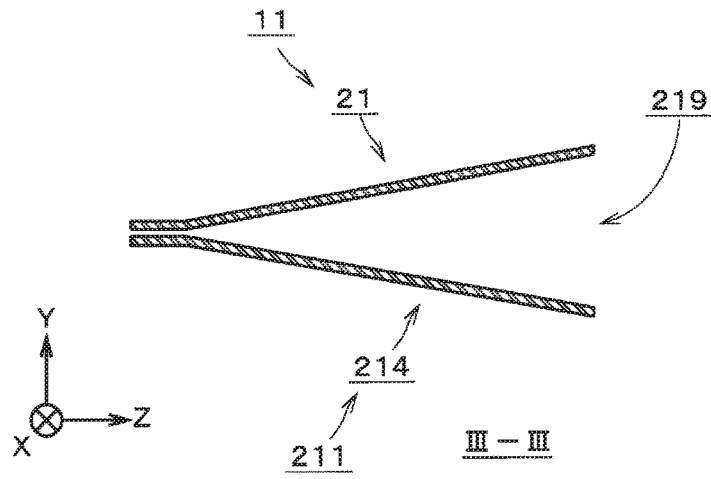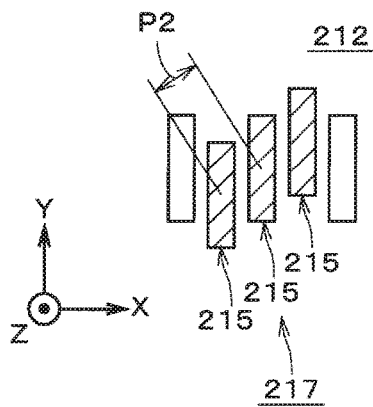
20 Claims, 8 Drawing Sheets

FIG. 1

FIG. 2

FIG. 3

FIG. 4A
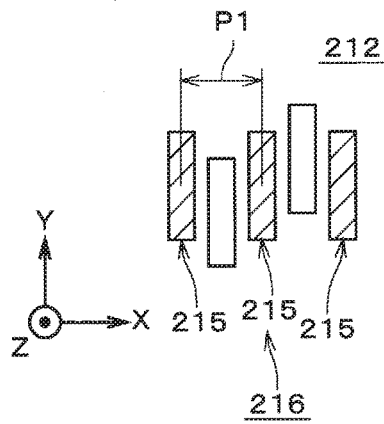
FIG. 4B

FIG. 5
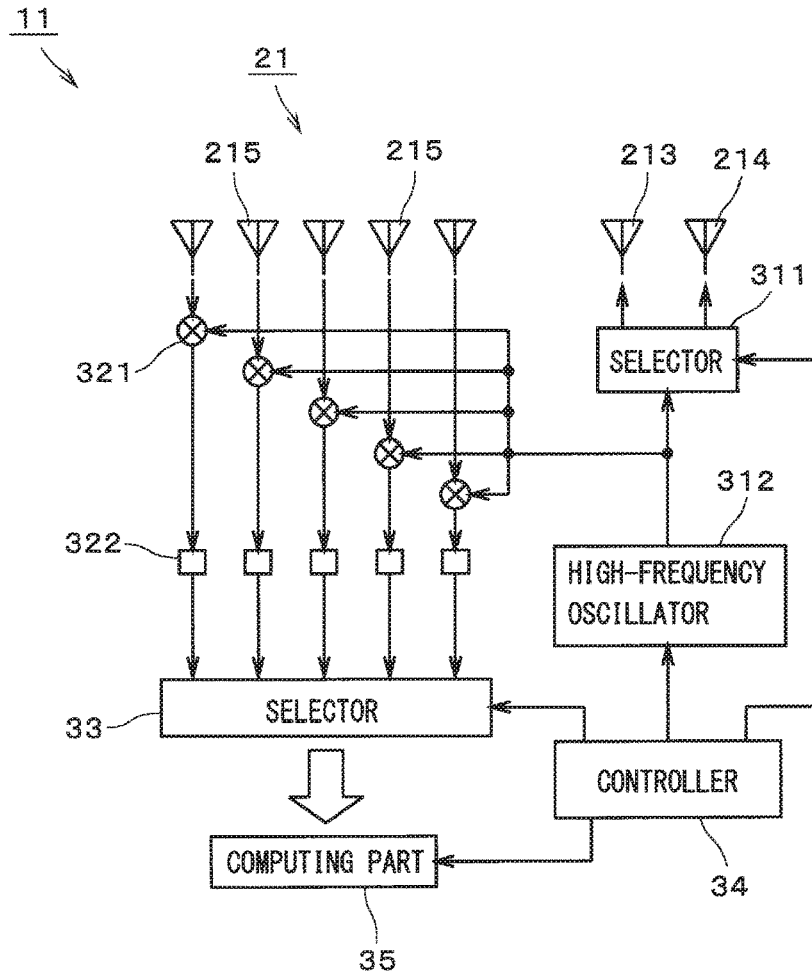
FIG. 6A
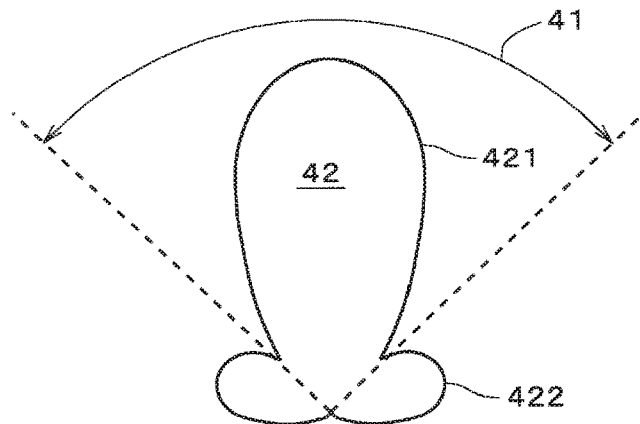
FIG. 6B
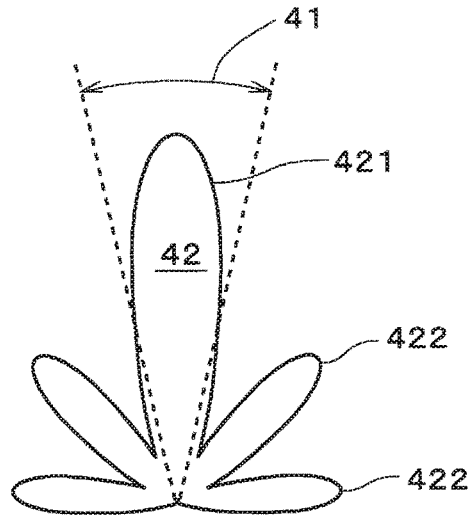
FIG. 7
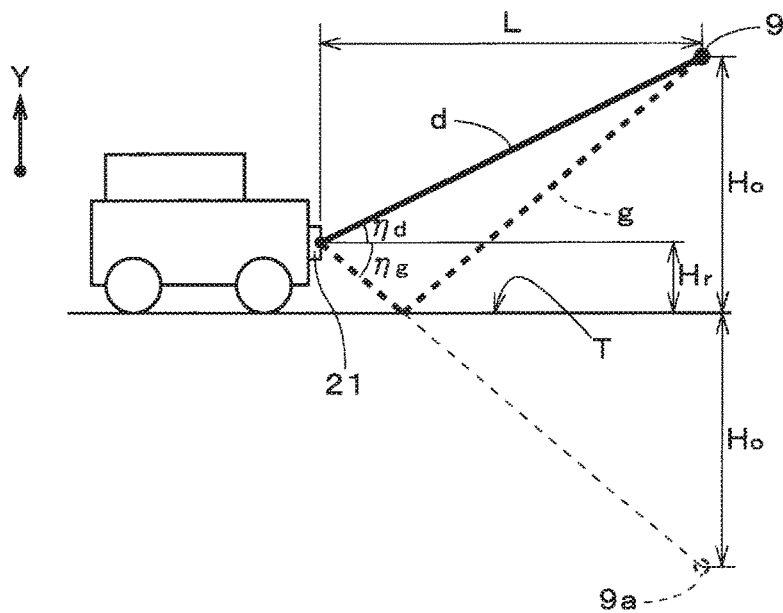
FIG. 8
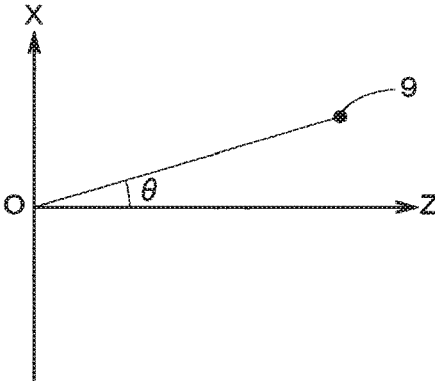
FIG. 9
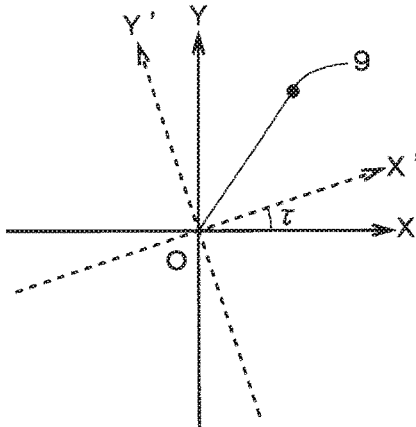
FIG. 10
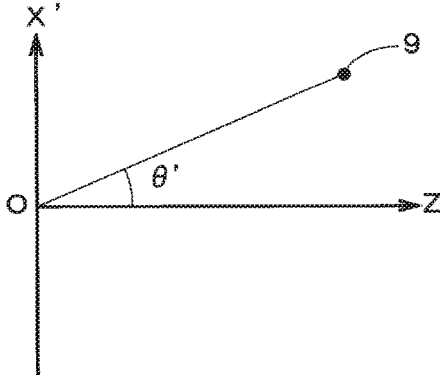
FIG. 11A

FIG. 11B

FIG. 12A

FIG. 12B

212b

P2

Y

Z →X

215 215 215

217

FIG. 12C

212b

P2

Y

Z →X

215 215 215

217

FIG. 13
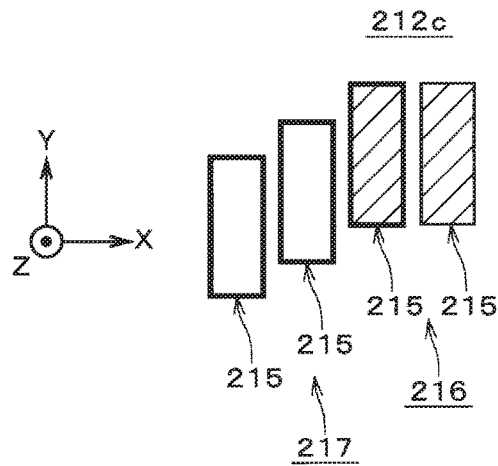
212c

Y

Z →X

215 215 215

217 216
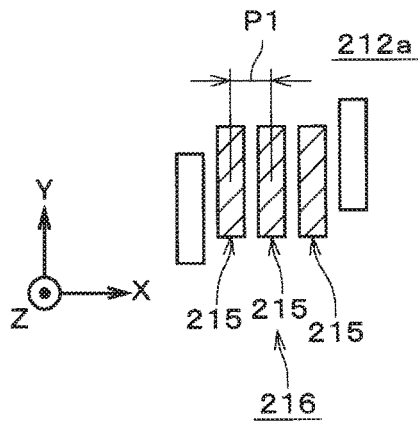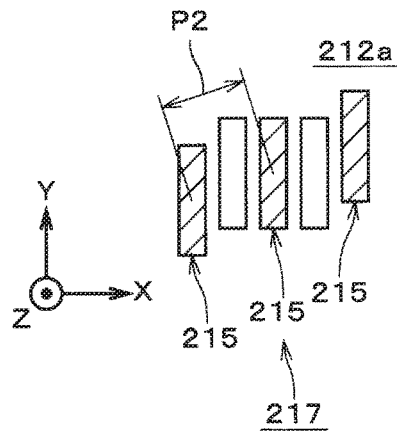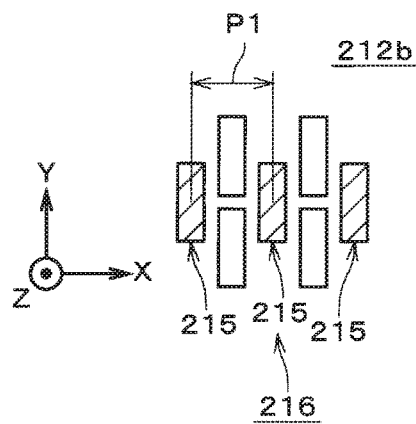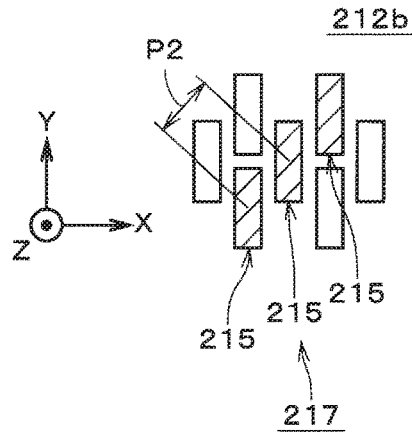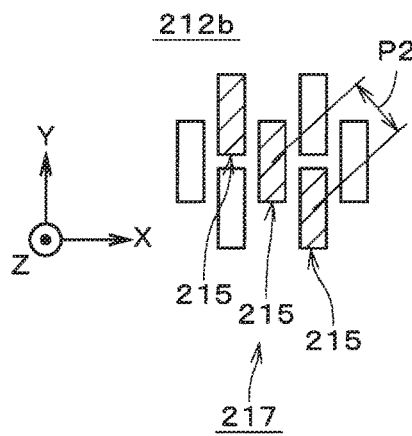
FIG. 14

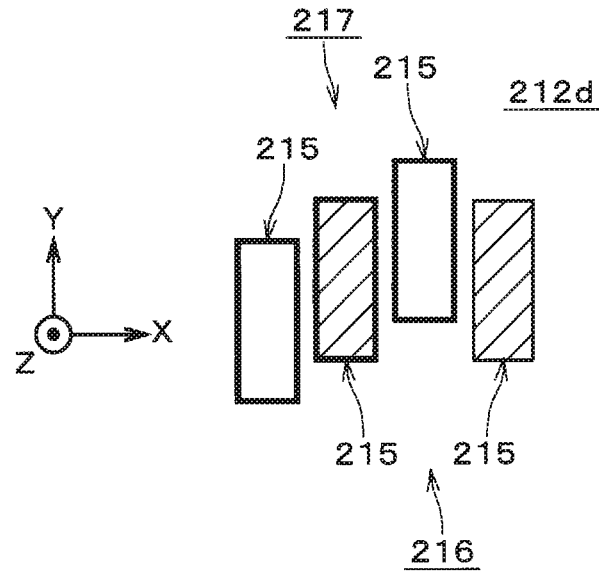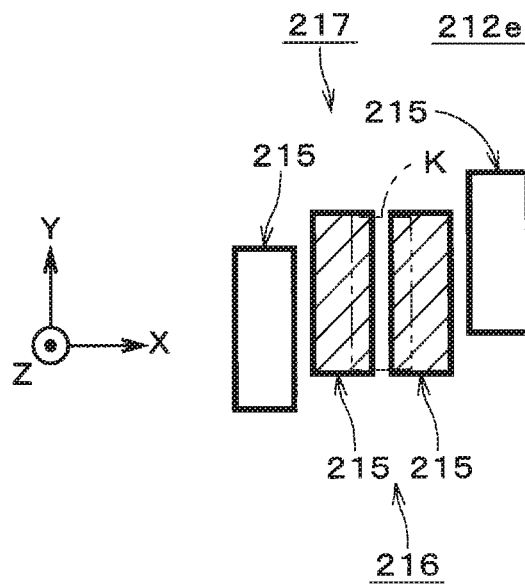*FIG. 15*

ON-VEHICLE RADAR DEVICE

TECHNICAL FIELD

The present invention relates to an on-vehicle radar device.

BACKGROUND ART

Research on areas such as collision avoidance, driving assistance, and automatic driving has been conducted in recent years, using technology for detecting objects around a vehicle with radar. For example, a radar device is provided in the front part of a vehicle and near the ground surface and detects the distance to and azimuth angle of an object. Sometimes the elevation angle of an object may also be required to be detected. Japanese Patent Application Laid-Open No. 2011-27695 discloses a radar device that can also detect the position of an object in the up-down direction. The radar device includes three element antennas arranged in the right-left direction, with the middle element antenna deviated in the up-down direction. The middle element antenna and the right-side element antenna detect the angle of an object in a first oblique direction, and the left-side element antenna and the middle element antenna detect the angle of the object in a second oblique direction. The detected two angles are used to obtain the position of the object in the up-down direction.

An on-vehicle radar device receives aground reflected wave and a direct wave by its receiving antennas, the ground reflected wave reaching the receiving antennas via a ground surface from an object, and the direct wave reaching the receiving antennas directly from the object. The radar device disclosed in Japanese Patent Application Laid-Open No. 2011-27695 detects two angles in the first and second oblique directions from a combined wave of the ground reflected wave and the direct wave and uses these angles to calculate the position of the object in the up-down direction. This requires complicated processing such as obtaining an average and variance of the positions in the up-down direction of the object that are measured for a predetermined period of time and then obtaining a corrected position of the object in the up-down direction.

The elevation angle of the object may be easily obtained by arranging a plurality of receiving antennas two-dimensionally. However, narrowing an existence range of the receiving antennas in a predetermined direction is also necessary because a vehicle has only limited available space for mounting the radar device.

SUMMARY OF INVENTION

The present invention is intended for an on-vehicle radar device, and it is an object of the present invention to easily obtain the elevation angle of an object while narrowing the existence range of receiving antennas in a predetermined direction.

An on-vehicle radar device according to an exemplary embodiment of the present invention includes a transmitting antenna part for transmitting a transmission wave, a receiving antenna part for receiving a reflected wave arising from the transmission wave, and a computing part for receiving a signal from the receiving antenna part. The receiving antenna part includes a first antenna array with a plurality of receiving antennas arranged in a first direction perpendicular to a predetermined reference direction, and a second antenna array with three or more receiving antennas arranged in a

second direction that is perpendicular to the reference direction and different from the first direction. When the first direction is a horizontal direction in a state in which the on-vehicle radar device is fixed to a vehicle body of a vehicle, the number of the plurality of receiving antennas included in the first antenna array is two or more, and when the first direction is not a horizontal direction, the number of the plurality of receiving antennas is three or more. When the receiving antenna part is viewed in the first direction, at least part of an existence range of each receiving antenna included in the second antenna array in a direction perpendicular to the reference direction overlaps with the first antenna array. The computing part computes an elevation angle of an object with respect to a horizontal plane, using a first detection angle, a second detection angle, and a relative inclination angle. The first detection angle is an angle formed by the reference direction and a direction of the object acquired using the first antenna array in a plane that is parallel to the reference direction and the first direction. The second detection angle is an angle formed by the reference direction and a direction of the object acquired using the second antenna array in a plane that is parallel to the reference direction and the second direction. The relative inclination angle is an angle formed by the first direction and the second direction.

According to the present invention, the receiving antenna part can easily obtain the elevation angle of an object while narrowing the existence range of the receiving antennas in a direction perpendicular to the reference direction and the first direction.

These and other objects, features, aspects and advantages of the present invention will become more apparent from the following detailed description of the present invention when taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF DRAWINGS

FIG. **1** is a simplified side view of a vehicle;
FIG. **2** is a front view of an antenna part;
FIG. **3** is a cross-sectional view of the antenna part;
FIG. **4A** illustrates a receiving antenna part;
FIG. **4B** illustrates the receiving antenna part;
FIG. **5** is a block diagram schematically illustrating a configuration of a radar device;
FIG. **6A** illustrates a near-field monitoring mode;
FIG. **6B** illustrates a far-field monitoring mode;
FIG. **7** illustrates the routes of reflected waves from an object to an antenna part;
FIG. **8** illustrates a first detection angle;
FIG. **9** illustrates a relative inclination angle;
FIG. **10** illustrates a second detection angle;
FIG. **11A** illustrates another example of the receiving antenna part;
FIG. **11B** illustrates another example of the receiving antenna part;
FIG. **12A** illustrates yet another example of the receiving antenna part;
FIG. **12B** illustrates yet another example of the receiving antenna part;
FIG. **12C** illustrates yet another example of the receiving antenna part;
FIG. **13** illustrates yet another example of the receiving antenna part;
FIG. **14** illustrates yet another example of the receiving antenna part; and

FIG. **15** illustrates yet another example of the receiving antenna part.

DESCRIPTION OF EMBODIMENTS

FIG. **1** is a simplified side view of a vehicle that includes an on-vehicle radar device **11** (hereinafter, referred to as a "radar device") according to an exemplary embodiment of the present invention. In FIG. **1**, X, Y, and Z directions that are orthogonal to one another are indicated by arrows. The X, Y, and Z directions correspond respectively to width, up-down, and lengthwise directions of the vehicle **1**. The same applies to drawings described below. The following description is based on the condition that the vehicle **1** is disposed with its width and lengthwise directions being horizontal. That is, the X and Z directions are horizontal directions. The Z direction is a direction of travel of the vehicle **1** moving straight ahead, and is thus hereinafter also referred to as a "reference direction."

The vehicle **1** includes a vehicle body **10**, a drive mechanism **15** for moving the vehicle body **10**, and the radar device **11** that is fixed to the vehicle body **10**. The radar device **11** is used for purposes such as collision avoidance, driving assistance, and automatic driving. For example, the radar device **11** is provided in the front part of the vehicle **1** and near the ground surface. The drive mechanism **15** includes, for example, an engine, a steering mechanism, a power transmission mechanism, and wheels.

FIG. **2** is a front view of an antenna part **21** of the radar device **11**. FIG. **3** is a cross-sectional view of the antenna part **21** taken at the position indicated by arrows III in FIG. **2**. FIGS. **2** and **3** illustrate the antenna part **21** fixed to the vehicle body **10** of the vehicle **1**, and X, Y, and Z directions in FIGS. **2** and **3** are the same as those in FIG. **1**.

The antenna part **21** of the radar device **11** includes a transmitting antenna part **211** and a receiving antenna part **212**. The transmitting antenna part **211** transmits transmission waves. The receiving antenna part **212** receives reflected waves arising from the transmission waves. The transmitting antenna part **211** includes a first transmitting antenna **213** and a second transmitting antenna **214**. The first transmitting antenna **213** and the second transmitting antenna **214** are horn antennas, each having an aperture **219** parallel to an XY plane. The apertures **219** of the first transmitting antenna **213** and the second transmitting antenna **214** have rectangular shapes whose sides are parallel to the X and Y directions. The apertures **219** of the first transmitting antenna **213** and the second transmitting antenna **214** have the same length in the Y direction. The width in the X direction of the aperture **219** of the first transmitting antenna **213** is smaller than the width in the X direction of the aperture **219** of the second transmitting antenna **214**. Thus, the first transmitting antenna **213** transmits a first transmission wave that has a wide range in radiation angle, and the second transmitting antenna **214** transmits a second transmission wave that has a different radiation pattern from the first transmission wave and has a narrower range in radiation angle than the first transmission wave has. That is, the transmitting antenna part **211** can transmit both the first transmission wave and the second transmission wave.

The receiving antenna part **212** includes a plurality of receiving antennas **215**. In the example in FIG. **2**, the receiving antenna part **212** includes five receiving antennas **215**. Each receiving antenna **215** is a horn antenna and has an aperture **219** parallel to an XY plane. The aperture **219** of each receiving antenna **215** has a rectangular shape whose

sides are parallel to the X and Y directions. The apertures **219** of the plurality of receiving antennas **215** have the same shape to one another. The length in the Y direction of the aperture **219** of each receiving antenna **215** is larger than the width in the X direction of the aperture **219** of the receiving antenna **215**. That is, the longitudinal direction of the aperture **219** corresponds to the up-down direction.

The five receiving antennas **215** are arranged approximately in the X direction. Among the five receiving antennas **215**, three receiving antennas **215** at both ends and in the middle in the X direction are arranged such that the centers of their apertures **219** are accurately aligned in the X direction. In the following description, a group of these three receiving antennas **215** is referred to as a "first antenna array," and the direction of alignment of receiving antennas **215** included in the first antenna array is referred to as a "first alignment direction." In FIG. **4A**, the three receiving antennas **215** included in the first antenna array **216** are marked with diagonal hatching. The first alignment direction is perpendicular to the Z direction and parallel to the X direction. The three receiving antennas **215** in the first antenna array **216** are aligned with a constant first pitch P1 in the first alignment direction.

Among the five receiving antennas **215**, the remaining two receiving antennas **215** and the one receiving antenna **215** in the middle are arranged such that the centers of their apertures **219** are accurately aligned in a direction (hereinafter, referred to as a "second alignment direction") that is inclined with respect to the X direction. The second alignment direction is perpendicular to the Z direction and inclined with respect to the X direction. In the following description, a group of these three receiving antennas **215** aligned in the second alignment direction is referred to as a "second antenna array." In FIG. **4B**, the three receiving antennas **215** included in the second antenna array **217** are marked with diagonal hatching. The three receiving antennas **215** in the second antenna array **217** are aligned with a constant second pitch P2 that is different from the first pitch P1 in the second alignment direction. The second pitch P2 is smaller than the first pitch P1. The first antenna array **216** and the second antenna array **217** share the middle receiving antenna **215**. That is, one receiving antenna **215** included in the first antenna array **216** serves also as one of the receiving antennas **215** in the second antenna array **217**.

Each horn antenna of the antenna part **21** is electrically or spatially connected to the structure for transmitting and receiving signals in the order of a monolithic microwave integrated circuit (MMIC), a transmission line (specifically, a micro-strip line, a transducer, and a waveguide), and a horn.

The aperture **219** of each receiving antenna **215** is regarded as an existence area in which the receiving antenna **215** exists. When the receiving antenna part **212** is viewed in the first alignment direction, the existence ranges in the Y direction of the two receiving antennas **215** in the second antenna array **217**, excluding the middle receiving antenna **215**, overlaps partially with the first antenna array **216**. The existence range in the Y direction of the middle receiving antenna **215** overlaps entirely with the first antenna array **216**. Thus, when the receiving antenna part **212** is viewed in the first alignment direction, at least part of the existence range in the Y direction of each receiving antenna **215** in the second antenna array **217** overlaps with the first antenna array **216**.

FIG. **5** is a block diagram schematically illustrating a configuration of the radar device **11**. The first transmitting antenna **213** and the second transmitting antenna **214** are

connected to a selector **311**. The selector **311** is connected to a high-frequency oscillator **312**. This allows switching between the connection of the high-frequency oscillator **312** and the first transmitting antenna **213** and the connection of the high-frequency oscillator **312** and the second transmitting antenna **214**. Thus, high-frequency electric power is supplied to either the first transmitting antenna **213** or the second transmitting antenna **214**. That is, the transmission of the first transmission wave and the transmission of the second transmission wave are switchable. The present embodiment adopts a frequency-modulated continuous wave (FMCW) system that uses a relatively narrow frequency band, and the frequency of high-frequency signals received from the high-frequency oscillator **312** will fluctuate.

Each of the five receiving antennas **215** is connected to a mixer **321** and an AD converter **322** in this order. The AD converters **322** are connected to a selector **33**. The receiving antenna **215** receives a reflected wave as a result of the transmission wave being reflected by an external object. A signal of the reflected wave obtained by the receiving antennas **215** and a circuit associated with the antennas is input to the mixer **321**. The mixer **321** also receives input of a signal from the high-frequency oscillator **312** and combines the obtained signals to acquire a beat signal that indicates a difference in frequency between the transmission wave and the reflected wave. The beat signal is converted into a digital signal by the AD converter **322** and input to the selector **33**.

The selector **33** selects at least some of the five beat signals and inputs the selected signals to a computing part **35**. The computing part **35** converts the beat signals using Fourier transform and performs arithmetic processing on the transformed signals to obtain, for example, the position and speed of the object. The arithmetic processing performed by the computing part **35** will be described later. The selector **311**, the high-frequency oscillator **312**, the selector **33**, and the computing part **35** are connected to a controller **34**. The controller **34** controls these constituent elements to implement detection operations performed by the computing part **35**.

The operations of the controller **34** involve a near-field monitoring mode and a far-field monitoring mode. FIG. **6A** illustrates the near-field monitoring mode, and FIG. **6B** illustrates the far-field monitoring mode. In FIGS. **6A** and **6B**, the bottom side corresponds to the antenna side, and the top side corresponds to the forward side of the vehicle **1**. A range **41** indicates the range of radiation of transmission waves. The first transmitting antenna **213** and the second transmitting antenna **214** have side lobes that are sufficiently smaller than the main lobe. A pattern **42** indicates an antenna pattern of the receiving antenna part **212**. Reference numeral **421** indicates the main lobe, and reference numeral **422** indicates the side lobes other than the main lobe **421**.

In the near-field monitoring mode, the first transmitting antenna **213** transmits the first transmission wave under the control of the controller controlling the selector **311**. Meanwhile, the signals derived from the three receiving antennas **215** included in the second antenna array **217** (see FIG. **4B**) are input to the computing part **35** under the control of the controller **34** controlling the selector **33**. A range of the main lobe **421** of the receiving antenna part **212** is widened by using the signals from the three receiving antennas **215** arranged with the relatively narrow second pitch P**2**. As a result, the near-field monitoring mode has lower azimuth resolution and a wider effective azimuth detection range than the far-field monitoring mode, which will be described

later. As described previously, the first transmission wave has a wider range **41** in radiation angle than the second transmission wave has. Thus, the near-field monitoring mode can detect a wide range of objects.

In the far-field monitoring mode, the second transmitting antenna **214** transmits the second transmission wave under the control of the controller **34** controlling the selector **311**. Meanwhile, among the five receiving antennas **215**, only signals derived from the three receiving antennas **215** included in the first antenna array **216** (see FIG. **4A**) are input to the computing part **35** under the control of the controller **34** controlling the selector **33**. A range of the main lobe **421** of the receiving antenna part **212** is narrowed by using only the signals from the three receiving antennas **215** arranged with the relatively wide first pitch P**1**. On the other hand, the side lobes **422** become larger.

The second transmission wave is, however, not transmitted in the directions of the side lobes **422**, as illustrated in FIG. **6B**, because the second transmission wave has a narrow range **41** in radiation angle. In other words, in order to detect objects located far forward in the front side, radio waves are not radiated in directions deviating from the front side and thus requiring no monitoring. This achieves detection of reflected waves with the main lobe **421** while suppressing the influence of the side lobes **422**. The far-field monitoring mode has high azimuth resolution and a narrow effective azimuth detection range. The far-field monitoring mode achieves detection of a remote and narrow range of objects.

For example, the near-field monitoring mode and the far-field monitoring mode are switchable at high speeds. That is, the first transmission wave and the second transmission wave are alternately transmitted under the control of the controller **34**. Alternatively, an operation that involves two fixed-time transmissions of the first transmission wave and two fixed-time transmissions of the second transmission wave may be repeated. In this way, the first transmission wave and the second transmission wave are transmitted while being switched in a predetermined order.

Next is a description of the arithmetic processing of the computing part **35** for computing the elevation angle of an object. FIG. **7** illustrates the routes of reflected waves from an object **9** to the antenna part **21**. A plane that includes line segments connecting the object **9** and the antenna part **21** is shown in FIG. **7**. The reflected waves from the object **9** enter the antenna part **21** along a route d indicated by the bold solid line and a route g indicated by the bold broken line in FIG. **7**. The reflected wave along the route d from the object **9** directly reaches the antenna part **21**, and is thus hereinafter referred to as a "direct wave." The reflected wave along the route g reaches the antenna part **21** after travelling from the object **9** to the ground surface T and being reflected by the ground surface T, and is thus hereinafter referred to as a "ground reflected wave."

In FIG. **7**, the ground surface T is perpendicular to the Y direction and horizontal. The elevation angle of the object **9** to be obtained by the computing part **35** is an angle η_d formed by the route d of the direct wave and a horizontal plane perpendicular to the Y direction. An angle η_g that is formed by the route g of the ground reflected wave in the vicinity of the antenna part **21** and the horizontal plane is a depression angle of a virtual object **9a**, which may be set as will be described later. The depression angle η_g is assumed to be negative in the following description.

As described previously, the first alignment direction of the first antenna array **216** is perpendicular to the Z direction, i.e., the reference direction, and parallel to the X

direction. Thus, the computing part **35**, by using the first antenna array **216**, acquires a first detection angle θ that is formed by a direction from the antenna part **21** to the object **9** and the Z direction in a plane parallel to the Z and X directions as illustrated in FIG. **8**. FIG. **8** and FIGS. **9** and **10**, which will be described later, define the position of the antenna part **21** as the origin O. The first detection angle θ that goes counterclockwise about the origin O from the Z axis in FIG. **8** is positive, and the first detection angle θ that goes clockwise is negative. The same applies to a second detection angle, which will be described later. When viewed in the Y direction, the route d of the direct wave and the route g of the ground reflected wave in FIG. **7** overlap each other, and therefore the first detection angle for the direct wave and the first detection angle for the ground reflected wave are almost the same angle θ. Typically, one first detection angle θ is acquired. Two distances acquired using the first antenna array **216**, i.e., the length of the route d of the direct wave and the length of the route g of the ground reflected wave, are different from each other.

The second alignment direction of the second antenna array **217** is perpendicular to the Z direction and inclined with respect to the X direction. That is, the second alignment direction is inclined with respect to a horizontal plane. Assuming that the second alignment direction is the X' direction and the direction perpendicular to the Z and X' directions is the Y' direction, the X' and Y' direction are inclined by an angle τ with respect to the X and Y directions as illustrated in FIG. **9**. The angle τ is an angle formed by the first alignment direction and the second alignment direction and hereinafter referred to as a "relative inclination angle." The relative inclination angle τ is greater than 0° and less than 90°.

As illustrated in FIG. **10**, the computing part **35**, by using the second antenna array **217**, acquires a second detection angle θ' that is formed by the direction from the antenna part **21** to the object **9** and the Z direction in a plane parallel to the Z and X' directions. In actuality, the second detection angle for the direct wave and the second detection angle for the ground reflected wave are different from each other because the route d of the direct wave and the route g of the ground reflected wave in FIG. **7** do not overlap each other when viewed in the Y' direction. FIG. **10** illustrates the second detection angle θ' for the direct wave. In the following description, the second detection angle for the direct wave is referred to as a "second detection angle θ'_d" and the second detection angle for the ground reflected wave is referred to as a "second detection angle θ'_g" to distinguish them. Using the second antenna array **217** that includes the three receiving antenna **215** allows the computing part **35** to simultaneously and separately detect the second detection angle θ'_d for the direct wave and the second detection angle θ'_g for the ground reflected wave.

Here, the position of the antenna part **21** is assumed to be the origin O, and coordinates of the object **9** in a coordinate system defined by X, Y, and Z axes (hereinafter, referred to as an "XYZ coordinate system") are expressed as (x, y, z). The coordinates (x, y, z) of the object **9** is expressed by Formula 1, where ρ is the length of the route d of the direct wave in FIG. **7**, i.e., the direct distance between the object **9** and the antenna part **21**, η is the elevation angle η_d, and θ is the first detection angle.

$$z=\rho\cos\eta\cdot\cos\theta$$

$$x=\rho\cos\eta\cdot\sin\theta$$

$$y=\rho\sin\eta \qquad \text{[Formula 1]}$$

Also, the position of the antenna part **21** is assumed to be the origin O, and coordinates of the object **9** in a coordinate system defined by X', Y', and Z axes (hereinafter, referred to as the "X'Y'Z coordinate system") are expressed as (x', y', z). The coordinates (x', y', z) of the object **9** are expressed by Formula 2, where is the angle formed by the route d of the direct wave and a plane perpendicular to the Y' direction, and θ' is the second detection angle θ'_d for the direct wave. In the X'Y'Z coordinate system that is an inclined coordinate system, the distance ρ between the object **9** and the antenna part **21** is the same as in the XYZ coordinate system that is a horizontal coordinate system.

$$z=\rho\cos\eta'\cdot\cos\theta'$$

$$x'=\rho\cos\eta\cdot\sin\theta'$$

$$y'=\rho\sin\eta \qquad \text{[Formula 2]}$$

The variables x and y' in Formula 2 are expressed by Formula 3 using the variables x and y and the relative inclination angle τ.

$$x'=\rho\cos\eta'\cdot\sin\theta'=x\cos\tau+y\sin\tau$$

$$y'=\rho\sin\eta'=-x\sin\tau+y\cos\tau \qquad \text{[Formula 3]}$$

The equation of x' in Formula 3 is transformed into Formula 4 using the equation of z in Formula 2.

$$x'/z=\tan\theta'=x/z\cos\tau+y/z\sin\tau \qquad \text{[Formula 4]}$$

Formula 4 is transformed into Formula 5 using Formula 1.

$$\tan\theta' = \tan\theta\cdot\cos\tau + \frac{\tan\eta}{\cos\theta}\sin\tau \qquad \text{[Formula 5]}$$

Solving Formula 5 for η yields Formula 6.

$$\eta = \tan^{-1}\left(\frac{\tan\theta'\cdot\cos\theta - \sin\theta\cdot\cos\tau}{\sin\tau}\right) \qquad \text{[Formula 6]}$$

While the direct wave is described using Formulas 1 to 6, the same applies to the ground reflected wave. More specifically, the virtual object **9a** is set at a position that is symmetric to the position of the object **9** on the ground surface T in FIG. **7**. Coordinates (x, y, z) of the virtual object **9a** in the XYZ coordinate system are expressed by Formula 1, where ρ is the length of the route g of the ground reflected wave, i.e., the direct distance between the virtual object **9a** and the antenna part **21**, η is the depression angle η_g of the virtual object **9a**, and θ is the first detection angle. Coordinates (x', y', z) of the virtual object **9a** in the X'Y'Z coordinate system are expressed by Formula 2, where η' is the angle formed by the route g of the ground reflected wave in the vicinity of the antenna part **21** and a plane perpendicular to the Y' direction, and θ' is the second detection angle θ'_g for the ground reflected wave. Formulas 3 to 6 are transformed in the same way as described above.

Accordingly, substituting the second detection angle θ'_d of the direct wave for θ' in Formula 6 after substituting the values of the first detection angle θ and the relative inclination angle τ into Formula 6 yields the elevation angle η_d of the object **9** as η. Also, substituting the second detection angle θ'_g of the ground reflected wave for θ' in Formula 6 yields the depression angle η_g of the virtual object **9a** as η.

In actual processing, the computing part **35** acquires two second detection angles by using the second antenna array **217** and calculates η from each second detection angle by using Formula 6. The calculated value η that is positive is regarded as the elevation angle η_d of the object **9**, and the calculated value η that is negative is regarded as the depression angle η_g of the virtual object **9a**.

As described above, the receiving antenna part **212** includes the first antenna array **216** of three receiving antennas **215** arranged in the first alignment direction, and the second antenna array **217** of three receiving antennas **215** arranged in the second alignment direction different from the first alignment direction. The receiving antenna part **212** receives both the ground reflected wave and the direct wave as reflected waves. The computing part **35** obtains the elevation angle of the object **9** with respect to a horizontal plane by using the first detection angle acquired using the first antenna array **216**, the second detection angle acquired using the second antenna array **217** on the basis of the direct wave, and the relative inclination angle. This allows the computing part **35** to easily obtain the elevation angle of the object **9** without the need to perform complicated processing such as correction processing.

When the receiving antenna part **212** is viewed in the first alignment direction, at least part of the existence range of each receiving antenna **215** included in the second antenna array **217** in the Y direction perpendicular to the Z direction overlaps with the first antenna array **216**. This narrows the existence range in the Y direction of the receiving antennas **215** in the directions of the apertures **219** of all the receiving antennas **215** included in the receiving antenna part **212** intersect with the first alignment direction and the second alignment direction and all are the same direction. This increases aperture areas of the receiving antennas **215** while narrowing the pitches of the receiving antennas **215** and reducing grating lobes.

In the receiving antenna part **212**, the first pitch P1 of the receiving antennas **215** in the first antenna array **216** is different from the second pitch P2 in the second antenna array **217**. This achieves both the monitoring mode with low azimuth resolution and a wide effective azimuth detection range, and the monitoring mode with high azimuth resolution and a narrow effective azimuth detection range. The near-field monitoring mode and the far-field monitoring mode can be achieved with the transmitting antenna part **211** transmitting both the first transmission wave with a wide radiation range and the second transmission wave with a narrow radiation range.

The arrays of the receiving antennas **215** in the receiving antenna part **212** may be modified in various ways. For example, a receiving antenna part **212a** illustrated in FIGS. **11A** and **11B** includes five receiving antennas **215** among which receiving antennas **215** at both ends are deviated respectively on the +Y and −Y sides. As indicated by diagonal hatching in FIG. **11A**, three receiving antennas **215** that are sandwiched between the deviated receiving antennas **215** at both ends are aligned as a first antenna array **216** in a first alignment direction parallel to the X direction. As indicated by diagonal hatching in FIG. **11B**, three receiving antennas **215** at both ends and in the middle are arranged as a second antenna array **217** in a second alignment direction that is inclined with respect to the X direction. The first pitch P1 in the first antenna array **216** is smaller than the second pitch P2 in the second antenna array **217**.

A receiving antenna part **212b** illustrated in FIGS. **12A** to **12C** includes seven receiving antennas **215**. As indicated by diagonal hatching in FIG. **12A**, three receiving antennas **215**

at both ends and in the middle in the X direction are arranged as a first antenna array **216** in a first alignment direction parallel to the X direction. As indicated by diagonal hatching in FIG. **12B**, the middle receiving antenna **215** and two receiving antennas **215** that are located in the upper right and lower left of the middle receiving antenna **215** are arranged as a second antenna array **217** in a second alignment direction that is inclined with respect to the X direction. As indicated by diagonal hatching in FIG. **12C**, the middle receiving antenna **215** and two receiving antennas **215** that are located in the upper left and lower right of the middle receiving antenna **215** are arranged as another second antenna array **217** in another second alignment direction that is inclined with respect to the X direction. The two second antenna arrays **217** have the same second pitch P2. The first pitch P1 in the first antenna array **216** is larger than the second pitch P2 in each second antenna array **217**.

In the receiving antenna parts **212a** and **212b** described above, the first antenna array **216** and the second antenna array(s) **217** each include three receiving antennas **215**. When the receiving antenna part is viewed in the first alignment direction, at least part of the existence range in the Y direction of each receiving antenna **215** included in the second antenna array(s) **217** overlaps with the first antenna array **216**. This allows the elevation angle of the object to be easily obtained while narrowing the existence ranges in the Y direction of the receiving antennas **215**. Using the different first and second pitches P1 and P2 achieves both the monitoring mode with low azimuth resolution and a wide effective azimuth detection range, and the monitoring mode with high azimuth resolution and a narrow effective azimuth detection range.

In general, an antenna array requires (N+1) receiving antennas to separately detect N reflected waves, where N is an integer of two or more. Thus, importantly each of the first antenna array **216** and the second antenna array(s) **217** include three or more receiving antennas **215** in order to simultaneously and separately detect the detection angle for the direct wave and the detection angle for the ground reflected wave.

As described previously, the first detection angle for the direct wave and the first detection angle for the ground reflected wave are the same when the first alignment direction of the first antenna array **216** is a horizontal direction. In this case, the number of receiving antennas **215** included in the first antenna array **216** may be two or more. In other words, it is possible to use receiving antenna parts **212c** to **212e** that include four receiving antennas **215** as illustrated in FIGS. **13** to **15**. In FIGS. **13** to **15**, receiving antennas **215** included in a first antenna array **216** are marked with diagonal hatching, and receiving antennas **215** included in a second antenna array **217** are indicated by rectangles in thick lines.

In the receiving antenna part **212c** illustrated in FIG. **13**, the receiving antenna **215** furthest to the +X side and the receiving antenna **215** adjacent on the −X side to the receiving antenna **215** furthest to the +X side are treated as a first antenna array **216** in a first alignment direction that is a horizontal direction. Three receiving antennas **215**, excluding the receiving antenna **215** furthest to the +X side, are arranged as a second antenna array **217** in a second alignment direction that is inclined with respect to the first alignment direction. In the example in FIG. **13**, the two receiving antennas **215** included in the first antenna array **216** are used to acquire the first detection angle for the combined wave of the direct wave and the ground reflected wave. The first detection angle for the combined wave is the

same as the first detection angle for the direct wave and the first detection angle for the ground reflected wave, and therefore the first detection angle for the direct wave and the first detection angle for the ground reflected wave are substantially acquired using the first antenna array **216**.

In the receiving antenna part **212d** illustrated in FIG. **14**, the first and third receiving antennas **215** from the +X side toward the −X direction are arranged as a first antenna array **216** in a first alignment direction that is a horizontal direction. The arrangement of receiving antennas **215** included in a second antenna array **217** is the same as in the example in FIG. **13**. In the example in FIG. **14**, the pitch of the two receiving antennas **215** included in the first antenna array **216** is greater than that in the first antenna array **216** in FIG. **13**, and the effective azimuth detection range is narrower.

In the receiving antenna part **212d**, the maximum value of deviation in the Y direction between the receiving antennas **215** included in the second antenna array **217** and the receiving antennas **215** included in the first antenna array **216** is smaller than that in the receiving antenna part **212c** in FIG. **13**. Thus, in cases such as where an object is located far away and the elevation angle of the object is so small that it is difficult or unnecessary to acquire, all of the four receiving antennas **215** may be used to obtain the azimuth angle of an object, for example. In this case, various types of arithmetic processing are performed, assuming that the four receiving antennas **215** are located at the same position in the Y direction, i.e., the four receiving antennas **215** are regarded as an antenna array arranged in a horizontal direction. This improves radar performance such as resolution, as compared with the case of using only the two receiving antennas **215** included in the first antenna array **21**. The other receiving antenna parts may also use the above-described technique in which when the acquisition of the elevation angle of an object is unnecessary, the receiving antennas **215** included in only the second antenna array **217** are used together with the receiving antennas **215** included in the first antenna array **216** to obtain the azimuth angle in a horizontal direction. In the case of using this technique, the accuracy of detection increases as the amount of deviation in the Y direction of the receiving antennas **215** decreases.

In the receiving antenna part **212e** illustrated in FIG. **15**, receiving antennas **215** at both ends, among the four receiving antennas **215**, are deviated respectively on the +Y and −Y sides. Two receiving antennas **215** that are sandwiched between the receiving antennas **215** at both ends are arranged as a first antenna array **216** in a first alignment direction that is a horizontal direction. In the example in FIG. **15**, a phase signal at a virtual receiving antenna indicated by a rectangle K with a chain double-dashed line can be acquired by obtaining a complex sum of signals received by the two receiving antennas **215** in the first antenna array. In the receiving antenna part **212e**, therefore, the two receiving antennas **215** included in the first antenna array **216** also serve as a receiving antenna **215** in a second antenna array **217**. It can also be said that, in the second antenna array **217**, the receiving antennas **215** at both ends and the virtual receiving antenna (see the rectangle K) are arranged in a second alignment direction that is inclined with respect to the first alignment direction.

As described previously, the examples in FIGS. **13** to **15** are based on the assumption that the first alignment direction of the first antenna array **216** is a horizontal direction. If the first alignment direction is not a horizontal direction, the first detection angle for the direct wave and the first detection angle for the ground reflected wave are different and therefore, importantly, the first antenna array **216** includes three

or more receiving antennas **215**. The number of receiving antennas **215** is preferably high in order to improve radar performance. From this viewpoint, even if the first alignment direction is a horizontal direction, the first antenna array **216** preferably includes three or more receiving antennas **215**.

In FIG. **7**, Formula 7 holds true, where H_o is the distance from the ground surface T to the object **9**, i.e., the height of the object **9** in the Y direction, H_r is the height of the antenna part **21**, and L is the horizontal distance from the antenna part **21** to the object **9**. The depression angle η_g is negative.

$$H_o - H_r = L \tan \eta_d$$

$$H_o + H_r = -L \tan \eta_g \qquad \text{[Formula 7]}$$

Deleting H_o from the two equations in Formula 7 and solving for η_g yields Formula 8.

$$\eta_g = -\tan^{-1}\left(\tan \eta_d + \frac{2H_r}{\rho \cos \eta_d}\right) \qquad \text{[Formula 8]}$$

As described previously, substituting the two second detection angles acquired using the second antenna array **217** into Formula 6 yields the elevation angle η_d that is positive and the depression angle η_g that is negative. Formula 8 above expresses the relationship between the elevation angle η_d of the object **9** and the depression angle η_g of the virtual object **9a** corresponding to the object **9**. Alternatively, depending on the processing performed by the computing part **35**, only the depression angle η_g of the virtual object **9a** may be first obtained, and then the elevation angle η_d of the object **9** may be obtained using the depression angle η_g and Formula 8.

The radar device **11** may be configured to be able to detect the elevation angles of two objects. In this case, the first antenna array **216** and the second antenna array **217** each typically include five or more receiving antennas **215** in order to separately detect direct waves and ground reflected waves from the two objects. The first antenna array **216** acquires a first detection angle θ_{Ad} for the direct wave and a first detection angle θ_{Ag} for the ground reflected wave for one of the objects, and also acquires a first detection angle θ_{Bd} for the direct wave and a first detection angle θ_{Bg} for the ground reflected wave for the other object. Similarly, the second antenna array **217** acquires a second detection angle θ'_{Ad} for the direct wave and a second detection angle θ'_{Ag} for the ground reflected wave for one of the objects, and also acquires a second detection angle θ'_{Bd} for the direct wave and a second detection angle θ'_{Bg} for the ground reflected wave for the other object. At this time, it is unclear which of the two objects corresponds to each of the four second detection angles and which of the two waves, direct wave and ground reflected wave, corresponds to each of the four second detection angles. The same applies to the four first detection angles.

The first detection angle θ_{Ad} and the first detection angle θ_{Ag} are approximately of the same value, and the first detection angle θ_{Bd} and the first detection angle θ_{Bg} are approximately of the same value. Thus, typically two first detection angles are acquired. In this case, the four second detection angles θ'_{Ad}, θ'_{Ag}, θ'_{Bd}, and θ'_{Bg} are respectively combined with one of the first detection angles to obtain four angles η from Formula 6. The four second detection angles θ'_{Ad}, θ'_{Ag}, θ'_{Bd}, and θ'_{Bg} are respectively combined with the other first detection angle to obtain four angles η from Formula 6.

As described previously, angles η that are positive are regarded as elevation angles η_d of objects, and angles η that are negative are regarded as depression angles η_g of virtual objects. Thus, four angles η are identified as candidates for the elevation angles η_d of the two objects, and four angles η are identified as candidates for the depression angles η_g of the two virtual objects. At this time, a plurality of candidates for the direct distance ρ between each of the two objects and the antenna part 21 are also acquired. Accordingly, each combination of the four candidates for the elevation angle η_d, the four candidates for the depression angle η_g, and the candidates for the direct distance ρ are substituted into Formula 8, and a combination that satisfies Formula 8 is acquired as the elevation angle η_d, the depression angle η_g, and the direct distance ρ for each object. This allows the elevation angles of the two objects to be easily obtained. The radar device 11 may also be configured to be able to detect the elevation angles of three or more objects.

The radar device 11 and the vehicle 1 may be modified in various ways.

The first alignment direction may be inclined with respect to a horizontal direction. In this case, Formula 6 is appropriately modified so that the elevation angle of an object with respect to a horizontal plane can be easily obtained using the first detection angle, the second detection angle, and the relative inclination angle.

The receiving antenna part 212 may completely separate receiving antennas 215 included in the first antenna array 216 and receiving antennas 215 included in the second antenna array 217. However, from the viewpoint of efficiently using the receiving antennas 215, one receiving antenna 215 included in the first antenna array 216 preferably serves also as a receiving antenna 215 in the second antenna array 217.

In the second antenna array 217 of the receiving antenna part 212 illustrated in FIGS. 12A to 12C, the existence range in the Y direction of the receiving antennas 215 slightly increases because the receiving antennas 215 at both ends are away from each other in the Y direction. In order to further reduce the existence range in the Y direction of the receiving antennas 215, when the receiving antenna part is viewed in the first alignment direction, the existence ranges in the Y direction of all receiving antennas 215 included in the second antenna array 217 preferably overlap partially with one another.

The transmitting antennas 213 and 214 and the receiving antennas 215 may be antennas other than horn antennas.

One of the transmitting antennas may include a mechanism for changing the antenna pattern so that the first transmission wave and the second transmission wave are both transmitted from that single transmitting antenna.

The radar device 11 may be provided in the rear part of the vehicle 1 for the purpose of rear monitoring. Alternatively, the radar device 11 may be mounted to the interior of a vehicle.

The vehicle 1 is not limited to a passenger car and may be other vehicles for use in various applications, such as a truck or a train. The vehicle 1 is not limited to a man-driven vehicle, and may be an unmanned operation vehicle such as an automated guided vehicle used in a factory.

The configurations of the above-described preferred embodiments and variations may be appropriately combined as long as there are no mutual inconsistencies.

While the invention has been shown and described in detail, the foregoing description is in all aspects illustrative and not restrictive. It is therefore to be understood that numerous modifications and variations can be devised with-

out departing from the scope of the invention. This application claims priority benefit under 35 U.S.C. Section 119 of Japanese Patent Application No. 2015-251953 filed in the Japan Patent Office on Dec. 24, 2015, the entire disclosure of which is incorporated herein by reference.

INDUSTRIAL APPLICABILITY

The radar device according to the present invention can be mounted on a vehicle for use in various applications.

REFERENCE SIGNS LIST

1 Vehicle
9 Object
10 Vehicle body
11 On-vehicle radar device
35 Operation part
211 Transmitting antenna part
212, 212a to 212e Receiving antenna part
215 Receiving antenna
216 First antenna array
217 Second antenna array
219 Aperture
θ First detection angle
θ' Second detection angle
τ Relative inclination angle
η_d Elevation angle
P1 First pitch
P2 Second pitch
T Ground surface

The invention claimed is:

1. An on-vehicle radar device comprising:
a transmitting antenna part for transmitting a transmission wave;
a receiving antenna part for receiving a reflected wave arising from the transmission wave; and
a computing part for receiving a signal from the receiving antenna part;
wherein the receiving antenna part includes:
a first antenna array with a plurality of receiving antennas arranged in a first direction perpendicular to a predetermined reference direction; and
a second antenna array with three or more receiving antennas arranged in a second direction that is perpendicular to the reference direction and different from the first direction,
when the first direction is a horizontal direction in a state in which the on-vehicle radar device is fixed to a vehicle body of a vehicle, the number of the plurality of receiving antennas included in the first antenna array is two or more, and when the first direction is not a horizontal direction, the number of the plurality of receiving antennas is three or more,
when the receiving antenna part is viewed in the first direction, at least part of an existence range of each receiving antenna included in the second antenna array in a direction perpendicular to the reference direction overlaps with that of the first antenna array, and
the computing part computes an elevation angle of an object with respect to a horizontal plane, using a first detection angle, a second detection angle, and a relative inclination angle, where the first detection angle being an angle formed by the reference direction and a direction of the object acquired using the first antenna array in a plane that is parallel to both the reference direction and the first direction, the second detection

angle being an angle formed by the reference direction and a direction of the object acquired using the second antenna array in a plane that is parallel to both the reference direction and the second direction, and the relative inclination angle being an angle formed by the first direction and the second direction.

2. The on-vehicle radar device according to claim 1, wherein

the receiving antenna part receives a ground reflected wave and a direct wave as the reflected wave, the ground reflected wave reaching the receiving antenna part via a ground surface from the object, and the direct wave reaching the receiving antenna part directly from the object;

the second direction is inclined with respect to the horizontal plane in a state in which the on-vehicle radar device is fixed to a vehicle body of a vehicle; and the computing part acquires the second detection angle for the direct wave and the second detection angle for the ground reflected wave, using the second antenna array.

3. The on-vehicle radar device according to claim 1, wherein

at least one receiving antenna included in the first antenna array serves also as a receiving antenna of the second antenna array.

4. The on-vehicle radar device according to claim 2, wherein

at least one receiving antenna included in the first antenna array serves also as a receiving antenna of the second antenna array.

5. The on-vehicle radar device according to claim 1, wherein

when the receiving antenna part is viewed in the first direction, existence ranges of all receiving antennas included in the second antenna array in a direction perpendicular to the reference direction overlap partially with one another.

6. The on-vehicle radar device according to claim 2, wherein

when the receiving antenna part is viewed in the first direction, existence ranges of all receiving antennas included in the second antenna array in a direction perpendicular to the reference direction overlap partially with one another.

7. The on-vehicle radar device according to claim 3, wherein

when the receiving antenna part is viewed in the first direction, existence ranges of all receiving antennas included in the second antenna array in a direction perpendicular to the reference direction overlap partially with one another.

8. The on-vehicle radar device according to claim 4, wherein

when the receiving antenna part is viewed in the first direction, existence ranges of all receiving antennas included in the second antenna array in a direction perpendicular to the reference direction overlap partially with one another.

9. The on-vehicle radar device according to claim 1, wherein

each receiving antenna included in the first antenna array and each receiving antenna included in the second antenna array have an aperture, a plane on which the aperture exists is perpendicular to the reference direction, and a dimension of the aperture in a direction that intersects with the first direction and the second direction is longer than those in other directions.

10. The on-vehicle radar device according to claim 8, wherein

each receiving antenna included in the first antenna array and each receiving antenna included in the second antenna array have an aperture, a plane on which the aperture exists is perpendicular to the reference direction, and a dimension of the aperture in a direction that intersects with the first direction and the second direction is longer than those in other directions.

11. The on-vehicle radar device according to claim 9, wherein

a longitudinal direction of the aperture corresponds to an up-down direction in a state in which the on-vehicle radar device is fixed to a vehicle body of a vehicle.

12. The on-vehicle radar device according to claim 10, wherein

a longitudinal direction of the aperture corresponds to an up-down direction in a state in which the on-vehicle radar device is fixed to a vehicle body of a vehicle.

13. The on-vehicle radar device according to claim 1, wherein

the plurality of receiving antennas of the first antenna array are arranged with a constant first pitch in the first direction; and

the three or more receiving antennas of the second antenna array are arranged with a constant second pitch that is different from the first pitch, in the second direction.

14. The on-vehicle radar device according to claim 3, wherein

the plurality of receiving antennas of the first antenna array are arranged with a constant first pitch in the first direction; and

the three or more receiving antennas of the second antenna array are arranged with a constant second pitch that is different from the first pitch, in the second direction.

15. The on-vehicle radar device according to claim 12, wherein

the plurality of receiving antennas of the first antenna array are arranged with a constant first pitch in the first direction; and

the three or more receiving antennas of the second antenna array are arranged with a constant second pitch that is different from the first pitch, in the second direction.

16. The on-vehicle radar device according to claim 13, wherein

the transmitting antenna part transmits either a first transmission wave having a wider range in radiation angle or a second transmission wave having a narrower range in radiation angle by switching, the narrower range being narrower than the wider range in radiation angle.

17. The on-vehicle radar device according to claim 14, wherein

the transmitting antenna part transmits either a first transmission wave having a wider range in radiation angle or a second transmission wave having a narrower range in radiation angle by switching, the narrower range being narrower than the wider range in radiation angle.

18. The on-vehicle radar device according to claim 1, wherein

the first direction is a horizontal direction in a state in which the on-vehicle radar device is fixed to a vehicle body of a vehicle, and

the elevation angle η of the object with respect to the horizontal plane is computed by using a formula of:

$$\eta=\tan^{-1}\{(\tan\theta'\cdot\cos\theta-\sin\theta\cdot\cos\tau)/\sin\tau\},$$

where τ is the relative inclination angle, θ is the first detection angle, and θ' is the second detection angle.

19. The on-vehicle radar device according to claim 2, wherein

the first direction is a horizontal direction in a state in which the on-vehicle radar device is fixed to a vehicle body of a vehicle, and

the elevation angle η of the object with respect to the horizontal plane is computed by using a formula of:

$$\eta=\tan^{-1}\{(\tan\theta'\cdot\cos\theta-\sin\theta\cdot\cos\tau)/\sin\tau\},$$

where τ is the relative inclination angle, θ is the first detection angle, and θ' is the second detection angle.

20. The on-vehicle radar device according to claim 3, wherein

the first direction is a horizontal direction in a state in which the on-vehicle radar device is fixed to a vehicle body of a vehicle, and

the elevation angle η of the object with respect to the horizontal plane is computed by using a formula of:

$$\eta=\tan^{-1}\{(\tan\theta'\cdot\cos\theta-\sin\theta\cdot\cos\tau)/\sin\tau\},$$

where τ is the relative inclination angle, θ is the first detection angle, and θ' is the second detection angle.

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