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ANTENNA APPARATUS

Abstract

An antenna apparatus includes a board, an integrated circuit chip including a transmitting antenna and a receiving antenna and mounted on the board, a waveguide having a first aperture provided on the board side and surrounding the transmitting antenna and the receiving antenna in aperture view, a second aperture provided on a rear side with respect to the first aperture in a radiation direction of the transmitting antenna, and a first inner wall surface connecting the first aperture and the second aperture, a radio wave lens fixed to the second aperture, and a first radio wave absorber disposed on the first aperture side in a space surrounded by the first inner wall surface. At least part of the first radio wave absorber is located inside a first path of a first direct wave, and the first radio wave absorber is located outside a second path of a second direct wave.

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Background/Summary

CLAIM OF PRIORITY [0001] This application is a Continuation of International Application No. PCT/JP2023/036405 filed on Oct. 5, 2023, which claims benefit of Japanese Patent Application No. 2022-200579 filed on Dec. 15, 2022. The entire contents of each application noted above are hereby incorporated by reference.

BACKGROUND OF THE INVENTION
1. Field of the Invention
[0002] The present disclosure relates to an antenna apparatus.
2. Description of the Related Art
[0003] A known lens antenna includes a first horn (conical horn) comprising a metal conductor, a second horn comprising a plastic material having radio wave absorption properties, and a lens that controls power distribution at an aperture of the second horn. The inner wall of the first horn has no radio wave absorber attached; therefore, nothing shields the microwaves nor does it affect the power density distribution at the lens aperture (see Japanese Unexamined Patent Application Publication No. 10-284931, for example).
[0004] If the antenna gain is increased to improve the receiver sensitivity in transmitting and receiving radio waves, in some cases, Equivalent Isotropically Radiated Power (EIRP) of radio waves in transmission may exceed the upper limit of EIRP regulated by the Radio Law or other regulations, whereas if the antenna gain is decreased to suppress the increase in EIRP, sufficient receiver sensitivity may not be achieved.
SUMMARY OF THE INVENTION
[0005] An antenna apparatus capable of suppressing an increase in EIRP and achieving good receiver sensitivity is provided.
[0006] An antenna apparatus according to an aspect of the disclosure includes a board, an integrated circuit chip including a transmitting antenna and a receiving antenna, the integrated circuit chip being mounted on the board, a waveguide having a first aperture provided on the board side and surrounding the transmitting antenna and the receiving antenna in aperture view, a second aperture provided on a rear side with respect to the first aperture in a radiation direction of the transmitting antenna, and a first inner wall surface connecting the first aperture and the second aperture, a radio wave lens fixed to the second aperture, and a first radio wave absorber disposed on the first aperture side in a space surrounded by the first inner wall surface. At least part of the first radio wave absorber is located inside a first path of a first direct wave that is radiated from the transmitting antenna, directly reaches the radio wave lens, and passes through the radio wave lens, and the first radio wave absorber is located outside a second path of a second direct wave that passes through the radio wave lens and directly reaches the receiving antenna.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0007] FIG. **1**A is a schematic view of an antenna apparatus according to an embodiment;
[0008] FIG. **1**B is a schematic view of an antenna apparatus according to an embodiment;

[0009] FIG. **1**C is a schematic view of an antenna apparatus according to an embodiment;
[0010] FIG. **1**D is a perspective view of a radio wave absorber in an antenna apparatus according to an embodiment;
[0011] FIG. **2**A is a cross-sectional view taken along line IIA-IIA, IID-IID in FIG. **1**A;
[0012] FIG. **2**B is a schematic view of an example location of an inner wall surface of a radio wave absorber in an antenna apparatus according to an embodiment;
[0013] FIG. **2**C is a schematic view of a radio wave absorber absorbing reflected waves in an antenna apparatus according to an embodiment;
[0014] FIG. **2**D is a schematic view of an example of a first path and a second path in the cross-sectional view taken along line IIA-IIA, IID-IID in FIG. **1**A;
[0015] FIG. **3**A illustrates an example of radiation characteristics of a comparative antenna apparatus;
[0016] FIG. **3**B illustrates an example of radiation characteristics of a comparative antenna apparatus;
[0017] FIG. **3**C illustrates an example of radiation characteristics of an antenna apparatus **100** according to an embodiment;
[0018] FIG. **3**D illustrates an example of radiation characteristics of the antenna apparatus **100** according to the embodiment;
[0019] FIG. **4**A illustrates an example structure of an antenna apparatus according to a first modification of the embodiment;
[0020] FIG. **4**B illustrates an example structure of the antenna apparatus according to the first modification of the embodiment;
[0021] FIG. **5**A illustrates an example structure of an antenna apparatus according to a second modification of the embodiment;
[0022] FIG. **5**B illustrates an example structure of the antenna apparatus according to the second modification of the embodiment;
[0023] FIG. **5**C illustrates an example structure of the antenna apparatus according to the second modification of the embodiment;
[0024] FIG. **5**D illustrates an example structure of the antenna apparatus according to the second modification of the embodiment;
[0025] FIG. **6**A illustrates an example structure of an antenna apparatus according to a third modification of the embodiment;
[0026] FIG. **6**B illustrates an example structure of the antenna apparatus according to the third modification of the embodiment; and
[0027] FIG. **6**C illustrates an example structure of the antenna apparatus according to the third modification of the embodiment.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0028] Hereinafter, an embodiment of an antenna apparatus according to the disclosure will be described.

EMBODIMENT

<Structure of Antenna Apparatus **100**>

[0029] FIG. **1**A, FIG. **1**B, and FIG. **1**C are schematic views of the antenna apparatus **100** according to the embodiment. FIG. **1**D is a perspective view of a radio wave absorber **140** in the antenna apparatus **100** according to the embodiment. FIG. **1**A is a perspective view, FIG. **1**B is a diagram of a half section of a portion, and FIG. **1**C is a front view. FIG. **2**A is a cross-sectional view taken along line IIA-IIA, IID-IID in FIG. **1**A, and illustrates a cross-section obtained by cutting a waveguide **110** in a YZ plane including an optical axis of a radio wave lens **130**. Here, as long as not specifically mentioned, a structure of the antenna apparatus **100** will be described with reference to FIG. **1**A, FIG. **1**B, FIG. **1**C, FIG. **1**D, and FIG. **2**A.
[0030] In the following description, an XYZ coordinate system is defined and described. For the

sake of convenience, a −Z direction side denotes a lower side or bottom, and a +Z direction side denotes an upper side or top. However, this does not represent a universal vertical relationship. Viewing an XZ plane is referred to as plan view. In addition, viewing an aperture in XZ plane is referred to as aperture view.

[0031] The antenna apparatus **100** includes a board **101**, the waveguide **110**, a transmission/reception unit **120**, the radio wave lens **130**, the radio wave absorber **140**, and a radio wave absorber **150**. The radio wave absorber **150** is an example first radio wave absorber and the radio wave absorber **140** is an example second radio wave absorber. The antenna apparatus **100** may not include the radio wave absorber **140**; however, here, a structure of the antenna apparatus **100** that includes the radio wave absorber **140** is described.

[0032] The antenna apparatus **100** is an apparatus that transmits and receives radio waves, and it narrows down a radiation pattern of transmitted waves using the radio wave lens **130** and focuses received radio waves using the lens to increase the receiver sensitivity. The antenna apparatus **100** attenuates transmitted waves using the radio wave absorber **150** to suppress an increase in EIRP and absorbs multiple reflected waves caused by multiple reflection inside using the radio wave absorber **140**.

[0033] Such an antenna apparatus **100** may be used, for example, as a radar apparatus that measures a distance to a measurement target by receiving reflected waves of transmitted waves reflected by the measurement target and returned. Based on the time from the transmission of radio waves as transmitted waves to the reception of the radio waves as reflected waves, the distance to the measurement target can be measured.

[0034] Regarding EIRP of transmitted waves, in Japan, the upper limit is specified by the Radio Law. This is similar in other countries with international guidelines provided. Here, in a known antenna apparatus, when radio waves are transmitted and received, the antenna gains of the transmitted waves and received waves are equal. Accordingly, if the antenna gain is increased to improve the radio wave receiver sensitivity in the known antenna apparatus, in some cases, EIRP of the transmitted waves may exceed the upper limit specified by the Radio Law, whereas if the antenna gain is decreased to suppress EIRP, sufficient receiver sensitivity may not be achieved. The antenna apparatus **100** according to the embodiment solves such a problem by attenuating transmitted waves by using the radio wave absorber **150** to suppress an increase in EIRP and increase receiver sensitivity.

[0035] In addition, the detection accuracy of a radar apparatus for measuring a distance to a measurement target generally decreases due to the effects of multiple reflection as the measurement target becomes closer. This is because the closer the measurement target is, the shorter the round-trip time becomes, making it harder to distinguish between the received waves that have not undergone multiple reflection and the multiple-reflected waves. As detection accuracy decreases, the minimum detectable distance (minimum detection distance) increases. The antenna apparatus **100** according to the embodiment solves such a problem by using the radio wave absorber **140**.

[0036] The multiple-reflected waves refer to radio waves that are reflected two or more times within a space surrounded by the board **101**, the waveguide **110**, the transmission/reception unit **120**, the radio wave lens **130**, and the radio wave absorber **140**. For example, radio waves that are transmitted in the +Y direction from the transmission/reception unit **120** may be reflected by a surface of the radio wave lens **130** on the −Y direction side without passing through the radio wave lens **130** and cause multiple-reflected waves. For example, radio waves that pass through the radio wave lens **130** to the −Y direction side may be reflected by an inner wall surface **110**A of the waveguide **110** or the like without directly reaching the transmission/reception unit **120** and cause multiple-reflected waves.

[0037] These radio waves transmitted and received by the antenna apparatus **100** are, for example, radio waves in the millimeter wave band. The millimeter waves are radio waves in the frequency band of 30 GHz to 300 GHz, and behave in a similar way to light. Note that the radio waves transmitted and received by the antenna apparatus **100** may be radio waves of frequencies that belong to bands other than the millimeter wave band.

<Structure of Board **101**>

[0038] The board **101** is a board on which the transmission/reception unit **120** is mounted, and for example, a wiring board complying with the Flame Retardant type 4 (FR-4) standard may be used. The board **101** is fixed to the −Y direction side of the waveguide **110**.

<Structure of Waveguide **110**>

[0039] The waveguide **110** is, for example, a cylindrical, hollow circular waveguide. The waveguide **110** has an aperture **111**, an aperture **112**, the inner wall surface **110**A, and an attachment section **115**. The inside of the waveguide **110** serves as a waveguide through which radio waves propagate. The inner wall surface **110**A is an example first inner wall surface, the aperture **111** is an example first aperture, and the aperture **112** is an example second aperture. The −Y direction side of the waveguide **110** is an example first aperture side, and the +Y direction side is an example second aperture side. The +Y direction is an example radiation direction of a transmitting antenna **120**Tx of the transmission/reception unit **120**.

[0040] In FIG. **1**A, FIG. **1**B, FIG. **1**C, and FIG. **2**A, the origin of the XYZ coordinate system is aligned with a center of the aperture **111**, and a central axis C of the waveguide **110** is aligned with the Y-axis. The central axis C is also aligned with an optical axis of the radio wave lens **130**. In the drawings, for ease of viewing, the central axis C and the Y-axis are shifted.

[0041] The inner wall surface **110**A is an inner wall surface of the cylindrical, hollow circular waveguide **110**. The waveguide **110** has, for example, a cylindrical shape in which an aperture diameter of the aperture **111** and an aperture diameter of the aperture **112** are equal. Accordingly, the inner wall surface **110**A has a cylindrical shape with a constant diameter. Note that the aperture diameter of the aperture **111** may be larger than the aperture diameter of the aperture **112**, and the aperture diameter of the aperture **112** may be larger than the aperture diameter of the aperture **111**.

[0042] The aperture **111** is an aperture located at an end of the waveguide **110** on the −Y direction side. The aperture **111** is circular in aperture view. The aperture **112** is an aperture located at an end of the waveguide **110** on the +Y direction side. A section that functions as the waveguide **110** through which radio waves propagate is a section between the aperture **111** and the aperture **112**. The aperture **112** is circular in aperture view. The aperture diameter of the aperture **112** is, for example, equal to the aperture diameter of the aperture **111**. The radio wave lens **130** is attached to the aperture **112** by an attachment section **117**.

[0043] The attachment section **115** is a section that extends outward in plan view at the end of the waveguide **110** on the −Y direction side, and for example, has a square outer edge in plan view. The attachment section **115** is provided to attach the board **101** to the waveguide **110**. The outer edge of the attachment section **115** in plan view is held by a frame portion **105**B of a cover **105** that covers a rear side (−Y direction side) of the board **101**. The attachment section **115** is, for example, made of resin.

[0044] The attachment section **117** is a frame-shaped member for attaching the radio wave lens **130** to the waveguide **110** at the end of the waveguide **110** on the +Y direction side. The attachment section **117** is circular in plan view, and is fitted onto an outer circumferential surface of the waveguide **110** on the +Y direction side. The attachment section **117** holds the radio wave lens **130** at a position on the +Y direction side of the aperture **112**. In a state in which the radio wave lens **130** is held by the attachment section **117**, the optical axis of the radio wave lens **130** is aligned with the central axis C of the waveguide **110**. The attachment section **117** is, for example, made of resin.

[0045] In a state in which the radio wave lens **130** is attached to the waveguide **110** by using the attachment section **117** as described above, a focal point of the radio wave lens **130** is positioned at a center of the aperture **111** in aperture view. In other words, the length of the waveguide **110** in the extending direction of the central axis C is set such that the focal point of the radio wave lens **130** is positioned on the aperture surface of the aperture **111**.

<Structure of Transmission Reception Unit **120**>

[0046] The transmission/reception unit **120** is mounted on a surface of the board **101** on the +Y direction side. The transmission/reception unit **120** is an example integrated circuit chip. The transmission/reception unit **120** includes a substrate **121**, the transmitting antenna **120**Tx, and a receiving antenna **120**Rx. The substrate **121** is smaller than the board **101** in plan view and is square, for example. The substrate **121** is disposed at a central portion of the aperture **111** in plan view. More specifically, the substrate **121** is disposed such that a center of the substrate **121** is positioned on the central axis C. The position of the surface of the substrate **121** on the +Y direction side in the Y direction is aligned with the position of the aperture **111** in the Y direction.

[0047] The transmitting antenna **120**Tx and the receiving antenna **120**Rx are spaced apart in the Z direction on the surface of the substrate **121** on the +Y direction side. The transmitting antenna **120**Tx and the receiving antenna **120**Rx are, for example, antennas that have the same shape and the same size. The transmitting antenna **120**Tx transmits radio waves through the waveguide **110**, and the receiving antenna **120**Rx receives radio waves through the waveguide **110**.

[0048] The transmitting antenna **120**Tx and the receiving antenna **120**Rx are disposed to be symmetrical in plan view with respect to the central axis C. Viewing the transmitting antenna **120**Tx and the receiving antenna **120**Rx in plan view is equivalent to viewing the transmitting antenna **120**Tx and the receiving antenna **120**Rx in aperture view (plan view) of the aperture **111**.

[0049] The phrase that the transmitting antenna **120**Tx and the receiving antenna **120**Rx are symmetrical in plan view with respect to the central axis C means that a center of the transmitting antenna **120**Tx in plan view and a center of the receiving antenna **120**Rx in plan view are symmetrical in plan view with respect to the central axis C. The center of the transmitting antenna **120**Tx in plan view and the center of the receiving antenna **120**Rx in plan view are both located on the Z-axis. The central axis C is aligned with the optical axis of the radio wave lens **130**, and the transmitting antenna **120**Tx and the receiving antenna **120**Rx are disposed to be shifted from the optical axis of the radio wave lens **130**.

[0050] Since the center of the transmitting antenna **120**Tx in plan view and the center of the receiving antenna **120**Rx in plan view are both located on the Z-axis, and are disposed to be symmetrical in plan view with respect to the central axis C, in a cross-section obtained by cutting the waveguide **110** in the YZ plane including the optical axis of the radio wave lens **130**, the transmitting antenna **120**Tx and the receiving antenna **120**Rx are disposed to be symmetrical in the +Z direction and the −Z direction with respect to the central axis C.

[0051] It is not possible to dispose the transmitting antenna **120**Tx and the receiving antenna **120**Rx on the central axis C (optical axis of the radio wave lens **130**), and thus the transmitting antenna **120**Tx and the receiving antenna **120**Rx are disposed in this manner to have the same transmission and reception characteristics. The transmitting antenna **120**Tx and the receiving antenna **120**Rx may be implemented by using, for example, loop antennas, patch antennas, monopole antennas, dipole antennas, or other antennas.

[0052] Since the length of the waveguide **110** in the extending direction of the central axis C is set such that the focal point of the radio wave lens **130** is positioned on the aperture surface of the aperture **111**, the positions of the transmitting antenna **120**Tx and the receiving antenna **120**Rx on the optical axis (central axis C of the waveguide **110**) of the radio wave lens **130** in the extending direction are equal to the position of the focal point of the radio wave lens **130**. In addition, a position of the substrate **121** on the surface on the +Y direction side in the Y direction is aligned with the position of the aperture **111** in the Y direction. Accordingly, the focal point of the radio wave lens **130** is aligned with a center (point on the central axis C) of the centers of the transmitting antenna **120**Tx and the receiving antenna **120**Rx on the surface of the substrate **121** on +Y direction side.

[0053] The strength of the radio waves (transmitted waves) radiated from the transmitting antenna

120 Tx is strongest in a direction connecting the center of the transmitting antenna **120**Tx and the center of the radio wave lens **130**, and the strength of the radio waves (received waves) received by the receiving antenna **120**Rx is strongest in the direction connecting the center of the receiving antenna **120**Rx and the center of the radio wave lens **130**. The center of the radio wave lens **130** is, on the optical axis (central axis C of the waveguide **110**) of the radio wave lens **130**, positioned at a center of the thickness of the radio wave lens **130** in the Y direction.

<Structure of Radio Wave Lens **130**>

[0054] The radio wave lens **130** is a lens that can bidirectionally focus radio waves transmitted and received by the transmitting antenna **120**Tx and the receiving antenna **120**Rx, and for example, the radio wave lens **130** is a circular biconvex lens in plan view. However, the radio wave lens **130** may be a plano-convex lens. Such biconvex lens and plano-convex lens are example convex lenses. Alternatively, the radio wave lens **130** may be a flat lens such as a flat lens having a Fresnel zone or a flat lens comprising metamaterial; however, here, an example of a biconvex lens will be described.

<Structure of Radio Wave Absorber **140**>

[0055] The radio wave absorber **140** is disposed in approximately half of a space on the −Y direction side in the inside of the waveguide **110**. The radio wave absorber **140** is, for example, a component made by molding resin mixed with magnetic or dielectric powder or the like, and is a component that causes radio wave loss. The radio wave absorber **140** has an aperture **141**, an aperture **142**, and an inner wall surface **143**. The aperture **141** is an example third aperture, the aperture **142** is an example fourth aperture, and the inner wall surface **143** is an example second inner wall surface.

[0056] The radio wave absorber **140** is disposed such that a central axis, which is parallel to the Y axis in a substantially truncated conical space surrounded by the inner wall surface **143** between the aperture **141** and the aperture **142**, is aligned with the central axis C of the waveguide **110**. The central axis C of the waveguide **110** is aligned with the optical axis of the radio wave lens **130**, and thus the central axis of the radio wave absorber **140** is aligned with the central axis C of the waveguide **110** and the optical axis of the radio wave lens **130**.

[0057] The aperture **141** is provided on the aperture **111** side, is smaller than the aperture **111** and the board **101** in aperture view of the aperture **111**, and is an aperture that surrounds the transmitting antenna **120**Tx and the receiving antenna **120**Rx. The aperture **141** is smaller than the aperture **142** in aperture view, and is provided concentrically. A position of the aperture **141** in the Y direction is, for example, aligned with the aperture **111** of the waveguide **110** (see FIG. **2**A), and centers of the aperture **141** and aperture **111** are aligned in aperture view.

[0058] The aperture **142** is provided on the rear side (aperture **112** side) with respect to the aperture **141** in the radiation direction, and is an aperture larger than the aperture **141**. The aperture **142** is larger than the aperture **141** in aperture view and is provided concentrically. The position of the aperture **142** in the Y direction is, as illustrated in FIG. **2**A, slightly closer to the +Y direction side than the middle of the apertures **111** and **112** of the waveguide **110**. The length of the radio wave absorber **140** between the apertures **141** and **142** may be determined depending on the length of the waveguide **110** in the Y direction, the shape of the inner wall surface **143**, and other factors.

[0059] The inner wall surface **143** is an inner wall surface that connects the aperture **141** and the aperture **142**. The inner wall surface **143** has, from the −Y direction side to the +Y direction side, inner wall surfaces **143**A, **143**B, **143**C, **143**D, **143**E, and **143**F. An end of the inner wall surface **143**A on the −Y direction side is the aperture **141**, and the inner wall surface **143**A is a cylindrical wall surface (wall surface corresponding to an inner circumferential surface of a cylinder) having a constant diameter, and the inner wall surface **143**B is connected to an end on the +Y direction side.

[0060] The inner wall surface **143**B is a wall surface (wall surface corresponding to an outer circumferential surface of a truncated cone) extending conically from the end of the inner wall surface **143**A on the +Y direction side, and the inner wall surface **143**C is connected to an end on the +Y direction side. The inner wall surface **143**C has a plane parallel to the XZ plane and is circular in aperture view. The end of the inner wall surface **143**B on the +Y direction side is connected to a center of the inner wall surface **143**C as an aperture in aperture view of the radio wave absorber **140**. The inner wall surface **143**D is connected to an outer edge of the inner wall surface **143**C.

[0061] The inner wall surface **143**D is a side surface that extends conically from the end of the inner wall surface **143**C on the +Y direction side, and the inner wall surface **143**E is connected to an end on the +Y direction side. The inner wall surface **143**E is a side surface that extends cylindrically from the end of the inner wall surface **143**D on the +Y direction side, and has a constant diameter in the Y direction. The inner wall surface **143**F is connected to an end of the inner wall surface **143**E on the +Y direction side.

[0062] The inner wall surface **143**F is a side surface that extends conically from the end of the inner wall surface **143**E on the +Y direction side, and an end of the inner wall surface **143**F on the +Y direction side is the aperture **142**.

[0063] The radio wave absorber **140** has the space surrounded by the above-described inner wall surface **143** such that a primary radiation wave radiated from the transmitting antenna **120**Tx in the +Y direction (radiation direction) does not come into contact with the inner wall surface **143**. In other words, the inner wall surface **143** is located outside the radiation path of the primary radiation wave that is radiated from the transmitting antenna **120**Tx. The primary radiation wave is a direct wave that is radiated from the transmitting antenna **120**Tx and passes through the radio wave lens **130** without being reflected. The radiation path of the primary radiation wave radiated from the transmitting antenna **120**Tx is the same as a first path P1 (see FIG. **2**D) through which a first direct wave, which will be described below, passes, and the primary radiation wave radiated from the transmitting antenna **120**Tx is the same as the first direct wave, which will be described below. Such a structure will be described in detail with reference to FIG. **2**B.

<Location of Inner Wall Surface **143**>

[0064] FIG. **2**B is a schematic view of an example location of the inner wall surface **143** of the radio wave absorber **140**. In addition to FIG. **2**A, to FIG. **2**B, radio waves (transmitted waves) radiated from the transmitting antenna **120**Tx, radio waves (received waves) received by the receiving antenna **120**Rx, an angular aperture α of the radio wave lens **130**, a diameter D of the radio wave lens **130**, and a focal length FP of the radio wave lens **130** are added. The radio waves (transmitted waves) radiated from the transmitting antenna **120**Tx are a primary radiation wave. Note that in FIG. **2**B, some of the reference numerals are omitted for the sake of clarity.

[0065] An angular aperture α of the radio wave lens **130** is an angular aperture of the radio wave lens **130** as seen from the focal point of the radio wave lens **130**, and is an angle corresponding to a primary radio wave radiation angle of a transmitting and receiving antenna that is a primary radiator when the transmitting and receiving antenna is placed at the focal point of the radio wave lens **130**.

[0066] The angular aperture α of the radio wave lens **130** is expressed by the following Equation (1) when the diameter D of the radio wave lens **130** and the focal length FP of the radio wave lens **130** are used. The angular aperture α depends on the type and specific structure of the transmitting and receiving antenna (the transmitting antenna **120**Tx and the receiving antenna **120**Rx) of the transmission/reception unit **120**.

[00001] $= 2\ .\text{Math. Arctan}(\frac{D}{2\text{FP}})$ (1)

[0067] The inner wall surface **143** of the radio wave absorber **140** is located outside the area represented by the angular aperture α. The area represented by the angular aperture α is included in the radiation path of the primary radiation wave that is radiated from the transmitting antenna **120**Tx and thus the inner wall surface **143** is located outside the radiation path of the primary radiation wave radiated from the transmitting antenna **120**Tx. The radio wave absorber **140** has the inner wall surface **143** of the shape located outside the area represented by the angular aperture α so as not to obstruct the radiation path of the primary radiation wave radiated from the transmitting antenna **120**Tx. In addition, the radio wave absorber **140** is located outside the area represented by the angular aperture α so as not to obstruct the path of the radio waves (received waves) that pass through the radio wave lens **130** from the outside of the antenna apparatus **100** and are received by the receiving antenna **120**Rx. Accordingly, the antenna apparatus **100** can detect a measurement target with high accuracy without a decrease in detection sensitivity caused by the attenuation of transmitted waves and received waves in the radiation path.

[0068] In FIG. **2**B, radio waves (transmitted waves) as a primary radiation wave radiated from the transmitting antenna **120**Tx are indicated by thick broken lines, and a radio wave (received wave) received by the receiving antenna **120**Rx is indicated by thick alternating long and short dashed lines. The primary radiation wave is radiated within the range of the angular aperture α of the radio wave lens **130** and passes through the radio wave lens **130** without reaching the inner wall surface **143**, as indicated by the thick broken lines. The received wave is focused when passing through the radio wave lens **130** and reaches the receiving antenna **120**Rx without reaching the inner wall surface **143**, as indicated by the thick alternating long and short dashed lines.

[0069] In FIG. **2**B, when viewed from the focal point of the radio wave lens **130**, the angular aperture of the radio wave lens **130** is smaller than the angular aperture of the aperture **112** of the waveguide **110**. However, when viewed from the focal point of the radio wave lens **130**, when the angular aperture of the aperture **112** of the waveguide **110** is smaller than the angular aperture of the radio wave lens **130**, the inner wall surface **143** may have a shape that is located outside an area obtained by the following equation (2) represented by an angular aperture R of the aperture **112**.

[0070] In FIG. **2**B, the position of the focal point of the radio wave lens **130** is an intersection of the optical axis of the radio wave lens **130** and the surface of the substrate **121** of the transmission/reception unit **120**. Accordingly, the angular aperture β of the aperture **112** viewed from the intersection of the optical axis of the radio wave lens **130** and the surface of the substrate **121** of the transmission/reception unit **120** satisfies the following Equation (2), wherein the diameter of the aperture **112** is Dd, and the distance between the intersection and the center of the aperture **112** is L.

[00002] $= 2\ .Math.\ \mathrm{Arctan}\left(\frac{Dd}{2L}\right)$ (2)

<Absorption of Reflected Wave by Radio Wave Absorber **140**>

[0071] FIG. **2**C is an example of absorption of reflected waves by the radio wave absorber **140**. In FIG. **2**C, the received wave and the dimensions of the corners illustrated in FIG. **2**B are omitted, and some of the reference numerals are omitted. FIG. **2**C illustrates the transmitted wave **1** that is radiated from the transmitting antenna **120**Tx and passes through a central portion of the radio wave lens **130**, and the transmitted waves **2** and **3** that are radiated from the transmitting antenna **120**Tx and passes through outside the central portion of the radio wave lens **130**.

[0072] The transmitted wave **1** passes through the surface of the radio wave lens **130** on the −Y direction side with almost no reflection. The transmitted wave **2** is partially reflected when passing through the outside of the central portion of the radio wave lens **130** and generates a reflected wave **2**. The reflected wave **2** is reflected toward the inner wall surface **110**A of the waveguide **110**, but reaches the inner wall surface **143** of the radio wave absorber **140**, and thus the reflected wave **2** is absorbed by the radio wave absorber **140**. Note that if the radio wave absorber **140** is not provided, the reflected wave **2** is reflected by the surface of the radio wave lens **130** on the −Y direction side and reflected by the inner wall surface **110**A of the waveguide **110** as indicated by the thin broken line, and may reach the transmission/reception unit **120** as a multiple-reflected wave.

[0073] In addition, similarly to the transmitted wave **2**, the transmitted wave **3** is partially reflected when passing through the outside of the central portion of the radio wave lens **130** and generates a reflected wave **3**. The reflected wave **3** is reflected toward the inner wall surface **110**A of the waveguide **110**, but reaches the inner wall surface **143** of the radio wave absorber **140**, and thus the reflected wave **3** is absorbed by the radio wave absorber **140**. Note that if the radio wave absorber **140** is not provided, the reflected wave **3** may be reflected by the surface of the radio wave lens **130** on the −Y direction side and reflected by the inner wall surface **110**A of the waveguide **110** as indicated by the thin broken line, and may reach the transmission/reception unit **120** as a multiple-reflected wave.

[0074] In addition to such transmitted waves **2** and **3**, in some cases, the transmitted wave **1**, which reaches closer to the central portion of the radio wave lens **130** than the transmitted waves **2** and **3**, may be reflected by the surface of the radio wave lens **130** on the −Y direction side, or transmitted waves that reach outside the radio wave lens **130** further than the transmitted waves **2** and **3** may be reflected by the surface of the radio wave lens **130** on the −Y direction side. If the radio wave absorber **140** is not provided, these reflected waves may be further reflected and cause multiple-reflected waves, and in such a case, these waves may reach the transmission/reception unit **120**.

[0075] In addition, if the radio wave absorber **140** is not provided, these reflected waves may be reflected by the surface of the board **101** and cause multiple-reflected waves.

[0076] However, since the radio wave absorber **140** is disposed in reality as illustrated in FIG. **2**C, most of the multiple-reflected waves can be absorbed. As described above, multiple-reflected waves can be absorbed by the radio wave absorber **140** and the receiving antenna **120**Rx can be prevented from receiving multiple-reflected waves.

[0077] When multiple-reflected waves are received by the receiving antenna **120**Rx, it is difficult to distinguish between received waves that pass through the radio wave lens **130** and directly reach the receiving antenna **120**Rx and the received multiple-reflected waves. In such a case, the detection accuracy of received waves that pass through the radio wave lens **130** and directly reach the receiving antenna **120**Rx decreases. As a measurement target is closer, the detection accuracy decreases due to the effects of multiple reflection, and a minimum detection distance becomes longer.

[0078] The antenna apparatus **100** according to the embodiment includes the above-described radio wave absorber **140**, preventing the receiving antenna **120**Rx from receiving multiple-reflected waves. The antenna apparatus **100** according to the embodiment achieves an increased received wave detection accuracy of the receiving antenna **120**Rx, and can realize shortened minimum detection distance and increased detection performance.

<Structure of Radio Wave Absorber **150**>

[0079] The radio wave absorber **150** is described with reference to FIG. **2**D, in addition to FIGS. **1**A to **1**D and FIGS. **2**A to **2**C. FIG. **2**D is a schematic view of an example of the first path P1 and the second path P2 in the cross-sectional view taken along line IIA-IIA, IID-IID in FIG. **1**A.

[0080] The radio wave absorber **150** is provided to attenuate radio waves that are radiated by the transmitting antenna **120**Tx. The radio wave absorber **150** attenuates transmitted waves to regulate the power of the transmitted waves to values less than or equal to the upper limit specified by the Radio Law but does not attenuate received waves, thereby enabling the receiving antenna **120**Rx to achieve high receiver sensitivity. The radio wave absorber **150** is, similarly to the radio wave absorber **140**, for example, a component made by molding resin mixed with magnetic or dielectric powder or the like, and is a component that causes radio wave loss.

[0081] The radio wave absorber **150** is located within the aperture **141** of the radio wave absorber **140** in aperture view of the aperture **111**, and is disposed on an upper (+Z) side of the inner wall surfaces **143**A and **143**B of the inner wall surface **143** of the radio wave absorber **140**. Here, the structure of the radio wave absorber **150** is described with reference to the radial direction of the aperture **141** of the radio wave absorber **140**.

[0082] An outer surface of the radio wave absorber **150** in the radial direction is in contact with the inner wall surfaces **143**A and **143**B. Accordingly, the boundary between the radio wave absorber **150** and the radio wave absorber **140** is curved.

[0083] The radio wave absorber **150** is provided, in the Y direction, from the surface of the radio wave absorber **140** on the −Y direction side to a location between the end on the −Y direction side and the end on the +Y direction side of the inner wall surface **143**B. The location of the surface of the radio wave absorber **140** on the −Y direction side in the Y direction is equal to the location of the aperture **141** in the Y direction. Accordingly, the radio wave absorber **150**, in aperture view of the aperture **111**, overlaps a portion of the board **101**, and overlaps a portion of the transmission/reception unit **120** mounted on the surface of the board **101** on the +Y direction side.
[0084] As illustrated in FIG. **1**C and FIG. **1**D, the radio wave absorber **150** has a C-shape in aperture view of the aperture **111**, and is provided on the upper side of the inner wall surfaces **143**A and **143**B of the inner wall surface **143** in a state in which the C-shape is rotated 90 degrees clockwise. In other words, as illustrated in FIG. **1**C, in aperture view of the aperture **111**, the radio wave absorber **150** is disposed on the upper side to the transmitting antenna **120**Tx, on the oblique upper side to the transmitting antenna **120**Tx on the +X direction side, and on the oblique upper side to the transmitting antenna **120**Tx on the −X direction side.
[0085] As illustrated in FIG. **1**C and FIG. **1**D, the radio wave absorber **150** has a recessed portion **151** that is recessed in the +Z direction over the transmitting antenna **120**Tx in aperture view of the aperture **111**. A surface of the recessed portion **151** facing the central axis C has, for example, three planes. In addition, chamfered portions **151**A are formed between portions of the surface on the +Y direction side of the recessed portion **151** facing the central axis C and the surface of the radio wave absorber **150** on the +Y direction side. The chamfered portions **151**A are diagonally chamfered corners between the surface of the recessed portion **151** facing the central axis C and the surface of the radio wave absorber **150** on the +Y direction side.
[0086] Note that, although the recessed portion **151** has the three planes as illustrated in FIGS. **1**C and **1**D, the structure is not limited to this example and the recessed portion **151** may be curved in a shape of an arc, for example. Alternatively, the radio wave absorber **150** may omit the chamfered portions **151**A.
[0087] Although the radio wave absorber **150** and the radio wave absorber **140** are integrated into one unit as an example, the radio wave absorber **150** may be fabricated separately from the radio wave absorber **140** and attached to the radio wave absorber **140**. When the radio wave absorber **150** is integrally formed with the radio wave absorber **140**, for example, the component may be fabricated by integral molding or machining. In the cross-sectional view in FIG. **2**D, the radio wave absorber **150** and the radio wave absorber **140** are illustrated with different types of hatching to distinguish the radio wave absorber **150** from the radio wave absorber **140**.
[0088] As illustrated in FIG. **2**D, the radio wave absorber **150** is disposed on the aperture **111** side in a space surrounded by the inner wall surface **110**A of the waveguide **110**. This is because the transmitting antenna **120**Tx is disposed on the aperture **111** side. At least part of the radio wave absorber **150** is located inside the first path P1 of a first direct wave that is radiated from the transmitting antenna **120**Tx and directly reaches the radio wave lens **130**. This structure is provided to attenuate the first direct wave. The radio wave absorber **150** is located outside the second path P2 of a second direct wave that passes through the radio wave lens **130** and directly reaches the receiving antenna **120**Rx. This structure is provided to enable the receiving antenna **120**Rx to achieve high and good receiver sensitivity without attenuating the second direct wave.
[0089] The first direct wave is a direct wave that is radiated from the transmitting antenna **120**Tx, directly reaches the radio wave lens **130**, and passes through the radio wave lens **130**. The first path P1 is a three-dimensional path through which the first direct wave can pass between the transmitting antenna **120**Tx and the radio wave lens **130**, and is a three-dimensional spatial area through which the first direct wave can pass. The phrase at least part of the radio wave absorber **150** is located inside the first path P1 means that at least part of the radio wave absorber **150** is located within the three-dimensional spatial area through which the first direct wave can pass through. The first path P1 is the same as a radiation path of a primary radiation wave that is

radiated from the transmitting antenna **120**Tx. The primary radiation wave radiated from the transmitting antenna **120**Tx is the same as the first direct wave.

[0090] The three-dimensional spatial area through which the first direct wave can pass through is a spatial area that connects the outer edge of the radio wave lens **130** and the outer edge of the transmitting antenna **120**Tx. When the aperture **112** of the waveguide **110** is located inside with respect to the outer edge of the radio wave lens **130**, the three-dimensional spatial area through which the first direct wave can pass through is a spatial area that connects the aperture **112** of the waveguide **110** and the outer edge of the transmitting antenna **120**Tx.

[0091] The second direct wave is a received wave that comes from outside (+Y direction side) the radio wave lens **130**, passes through the radio wave lens **130**, and directly reaches the receiving antenna **120**Rx. The second path P2 is a three-dimensional path through which the second direct wave can pass between the receiving antenna **120**Rx and the radio wave lens **130**, and is a three-dimensional spatial area through which the second direct wave can pass. The phrase the radio wave absorber **150** is located outside the second path P2 means that the entire radio wave absorber **150** is located outside the three-dimensional spatial area through which the second direct wave can pass through, and the entire radio wave absorber **150** is not located inside the three-dimensional spatial area through which the second direct wave can pass through.

[0092] The three-dimensional spatial area through which the second direct wave can pass through is a spatial area that connects the outer edge of the radio wave lens **130** and the outer edge of the receiving antenna **120**Rx. When the aperture **112** of the waveguide **110** is located inside with respect to the outer edge of the radio wave lens **130**, the three-dimensional spatial area through which the second direct wave can pass through is a spatial area that connects the aperture **112** of the waveguide **110** and the outer edge of the receiving antenna **120**Rx.

[0093] The radio wave absorber **150** is disposed on the transmitting antenna **120**Tx side with respect to the central axis C of the waveguide **110** in aperture view of the aperture **111**. The radio wave absorber **150** attenuates radio waves that are radiated by the transmitting antenna **120**Tx, and is not located inside the second path P2 of radio waves received by the receiving antenna **120**Rx, and thus the radio wave absorber **150** is disposed on the transmitting antenna **120**Tx side with respect to the central axis C of the waveguide **110** in aperture view of the aperture **111**. Note that the central axis C is aligned with the optical axis of the radio wave lens **130**.

[0094] In the above description, regarding the radio wave absorber **140**, it has been described that the inner wall surface **143** has the shape the inner wall surface **143** is located outside the area represented by the angular aperture α represented by the equation (1) or the shape the inner wall surface **143** is located outside the area represented by the angular aperture β of the aperture **112** obtained by the equation (2). However, in the radio wave absorber **140**, the inner wall surface **143** may be located outside the first path P1 and the second path P2.

<Simulation Results>

[0095] To verify the effects of the radio wave absorber **150**, simulations were conducted on a comparative antenna apparatus that does not include the radio wave absorber **150** and the antenna apparatus **100** that includes the radio wave absorber **150** according to the embodiment, and radiation characteristics of the transmitting antenna **120**Tx and the receiving antenna **120**Rx were calculated. The comparative antenna apparatus had a structure in which the radio wave absorber **150** was removed from the antenna apparatus **100**.

[0096] FIG. **3**A and FIG. **3**B illustrate examples of radiation characteristics of the comparative antenna apparatus. FIG. **3**C and FIG. **3**D illustrate examples of radiation characteristics of the antenna apparatus **100** according to the embodiment. FIG. **3**A and FIG. **3**C illustrate radiation characteristics in the XY cross-section passing through the central axis C, and FIG. **3**B and FIG. **3**D illustrate radiation characteristics in the YZ cross-section passing through the central axis C. In FIG. **3**A and FIG. **3**D, the central axis C is located on the straight line connecting −90 degrees and 90 degrees.

[0097] The radiation characteristics of the comparative antenna apparatuses illustrated in FIG. **3**A and FIG. **3**B were calculated by setting the receiver sensitivity of the receiving antenna **120**Rx to a desired high level and setting the configurations of the transmitting antenna **120**Tx and receiving antenna **120**Rx to be the same. The radiation characteristics of the transmitted waves are indicated by solid lines, and the radiation characteristics of the received waves are indicated by broken lines.
[0098] In FIG. **3**A, the radiation characteristics of the transmitted wave and the received wave are equal, and the radiation characteristics of the transmitted wave (solid line) and the radiation characteristics of the received wave (broken line) completely overlap, and thus only the radiation characteristics of the transmitted wave indicated by the solid line is illustrated. In FIG. **3**B, it can be confirmed that the radiation characteristics of the transmitted wave on the +Z direction side and the radiation characteristics of the received wave on the −Z direction side do not overlap. This is because the transmitting antenna **120**Tx is located above the central axis C, and the receiving antenna **120**Rx is located below the central axis C.
[0099] The gains (antenna gains) of the transmitted wave and the received wave in the comparative antenna apparatus were both 15.4 dB. The receiving antenna **120**Rx was set to have a desired high level of receiver sensitivity, and thus the power of the transmitted wave (EIRP) exceeded the upper limit of power specified by the Radio Law.
[0100] In FIG. **3**C, it can be confirmed that the radiation characteristics of the transmitted wave and the received wave were different, and the gain of the transmitted wave was smaller than the gain of the received wave. In FIG. **3**D, it can also be confirmed that the gain of the transmitted wave was smaller than the gain of the received wave.
[0101] The gain of the transmitted wave in the antenna apparatus **100** according to the embodiment was 12.1 dB, and the gain of the received wave was 15.3 dB. Although the receiving antenna **120**Rx was set to have the desired high level of receiver sensitivity, the power of the transmitted wave was kept below the upper limit of power specified by the Radio Law. Therefore, it was confirmed that by providing the radio wave absorber **150**, it was possible to achieve high and good receiver sensitivity while the power of the transmitted wave was kept below the upper limit of power specified by the Radio Law.
<Effects>
[0102] The antenna apparatus **100** includes the board **101**, the transmission/reception unit **120** that includes the transmitting antenna **120**Tx and the receiving antenna **120**Rx and is mounted on the board **101**, the waveguide **110** that has the aperture **111** (first aperture) that is provided on the board **101** side and surrounds the transmitting antenna **120**Tx and the receiving antenna **120**Rx in aperture view, the aperture **112** (second aperture) that is provided on the rear side with respect to the aperture **111** (first aperture) in the radiation direction of the transmitting antenna **120**Tx, and the inner wall surface **110**A (first inner wall surface) that connects the aperture **111** (first aperture) and the aperture **112** (second aperture), the radio wave lens **130** fixed to the aperture **112** (second aperture), and the radio wave absorber **150** (first radio wave absorber) that is disposed on the aperture **111** (first aperture) side in the space surrounded by the inner wall surface **110**A (first inner wall surface). At least part of the radio wave absorber **150** (first radio wave absorber) is located inside the first path of the first direct wave that is radiated from the transmitting antenna **120**Tx, directly reaches the radio wave lens **130**, and passes through the radio wave lens **130**, and the radio wave absorber **150** (first radio wave absorber) is located outside the second path of the second direct wave that passes through the radio wave lens **130** and directly reaches the receiving antenna **120**Rx. With this structure, high receiver sensitivity can be achieved without attenuating the received wave while attenuating the transmitted wave.
[0103] Accordingly, the antenna apparatus **100** capable of suppressing an increase in EIRP and achieving good receiver sensitivity can be provided.
[0104] The transmitting antenna **120**Tx and the receiving antenna **120**Rx are disposed across the central axis C (the optical axis of the radio wave lens **130**). This structure enables the first path P1

of the first direct wave and the second path P2 of the second direct wave to be shifted above and below the central axis C, and enables the radio wave absorber **150** to be disposed inside the first path P1 and outside the second path P2. Accordingly, with the positional difference between the first path P1 and the second path P2, the antenna apparatus **100** capable of suppressing an increase in EIRP and achieving good receiver sensitivity can be provided.

[0105] The radio wave absorber **150** (first radio wave absorber) is disposed on the transmitting antenna **120**Tx side with respect to the central axis C (optical axis of the radio wave lens **130**) in aperture view of the aperture **111** (first aperture). Accordingly, by providing the radio wave absorber **150** on the first path P1 side, the antenna apparatus **100** capable of attenuating transmitted waves, suppressing an increase in EIRP, and achieving good receiver sensitivity can be provided.

[0106] The antenna apparatus **100** further includes the cylindrical radio wave absorber **140** (second radio wave absorber) that is provided inside the inner wall surface **110**A (first inner wall surface). The radio wave absorber **140** (second radio wave absorber) includes the aperture **141** (third aperture) that is provided on the aperture **111** (first aperture) side, is smaller than the aperture **111** (first aperture) and the board **101** in aperture view of the aperture **111** (first aperture), and surrounds the transmitting antenna **120**Tx and the receiving antenna **120**Rx, the aperture **142** (fourth aperture) that is provided on the rear side with respect to the aperture **141** (third aperture) in the radiation direction and is larger than the aperture **141** (third aperture) and the inner wall surface **143** (second inner wall surface) that connects the aperture **141** (third aperture) and the aperture **142** (fourth aperture). Accordingly, the antenna apparatus **100** capable of reducing effects of multiple reflection and increasing the detection performance, and also capable of suppressing an increase in EIRP and achieving good receiver sensitivity can be provided.

[0107] The radio wave absorber **150** (first radio wave absorber) is integrally formed with the radio wave absorber **140** (second radio wave absorber). Accordingly, the radio wave absorbers **140** and **150** can be fabricated simultaneously, and the number of components can be reduced. In addition, positioning of the radio wave absorbers **140** and **150** with respect to the transmitting antenna **120**Tx and the receiving antenna **120**Rx can be performed simultaneously.

<First Modification>

[0108] FIG. **4**A and FIG. **4**B are diagrams of an example structure of an antenna apparatus **100**M**1** according to a first modification of the embodiment. Here, differences between the antenna apparatus **100** and the antenna apparatus **100**M**1** will be described. Among the components of the antenna apparatus **100**M**1**, the same reference numerals are given to components similar to those in the antenna apparatus **100** and their descriptions will be omitted.

[0109] The antenna apparatus **100**M**1** has a structure in which the radio wave absorber **140** is removed from the antenna apparatus **100**, and the radio wave absorber **150** is attached to the surface of the board **101** on the +Y direction side. The location and size of the radio wave absorber **150** in the antenna apparatus **100**M**1** are the same as the location and size of the radio wave absorber **150** in the antenna apparatus **100**. For example, in a case in which effects of multiple reflection are small, the radio wave absorber **140** may be omitted as in the antenna apparatus **100**M**1**.

[0110] In addition, in the antenna apparatus **100**M**1**, the radio wave absorber **150** is attached to the board **101**, and thus the radio wave absorber **150** that has a higher positioning accuracy with respect to the transmitting antenna **120**Tx can be provided. For example, when the antenna apparatus **100** is mounted on a vehicle or the like, even if misalignments occur between the board **101** and the cover **105**, the waveguide **110**, and other components, the position of the radio wave absorber **150** with respect to the transmitting antenna **120**Tx is not changed, and thus the transmitted wave can be attenuated highly accurately.

[0111] The antenna apparatus **100**M**1** can provide high receiver sensitivity without attenuating received waves while attenuating transmitted waves using the radio wave absorber **150**, and thus the antenna apparatus **100**M**1** with good radio wave receiver sensitivity can be provided. In addition, the positioning accuracy of the radio wave absorber **150** with respect to the transmitting antenna **120**Tx is high, and transmitted waves can be attenuated highly accurately.

<Second Modification>

[0112] FIG. **5**A to FIG. **5**D are diagrams of an example structure of an antenna apparatus **100**M**2** according to a second modification of the embodiment. Here, differences between the antenna apparatuses **100** and **100**M**1** and the antenna apparatus **100**M**2** will be described. Among the components of the antenna apparatus **100**M**2**, the same reference numerals are given to components similar to those in the antenna apparatuses **100** and **100**M**1** and their descriptions will be omitted.

[0113] First, the description will be made with reference to FIGS. **5**A to **5**C. The antenna apparatus **100**M**2** has a structure in which the radio wave absorber **140** is removed from the antenna apparatus **100**, and a radio wave absorber **150**M**2** is attached to the surface of the board **101** on the +Y direction side. The radio wave absorber **150**M**2** is different from the radio wave absorber **150** in the antenna apparatuses **100** and **100**M**1** in that, in aperture view of the aperture **111**, the radio wave absorber **150**M**2** covers the transmitting antenna **120**Tx, and the radio wave absorber **150**M**2** is attached to the surface of the transmission/reception unit **120** with three legs **151**M**2** that protrude toward the −Y direction side. For example, in a case in which effects of multiple reflection are small, the radio wave absorber **140** may be omitted as in the antenna apparatus **100**M**2**.

[0114] For example, when a transmitted wave is attenuated from a state in which the gains of the transmitting antenna **120**Tx and the receiving antenna **120**Rx are the same to reduce the power to less than or equal to the upper limit specified by the Radio Law, in aperture view of the aperture **111**, if it is better to cover the transmitting antenna **120**Tx, the radio wave absorber **150**M**2** that covers the transmitting antenna **120**Tx in aperture view of the aperture **111** may be used.

[0115] In addition, in the antenna apparatus **100**M**2**, the radio wave absorber **150**M**2** is attached to the board **101** similarly to the antenna apparatus **100**M**1**, and thus the radio wave absorber **150**M**2** that has a higher positioning accuracy with respect to the transmitting antenna **120**Tx can be provided. For example, when the antenna apparatus **100**M**2** is mounted on a vehicle or the like, even if misalignments occur between the board **101** and the cover **105**, the waveguide **110**, and other components, the position of the radio wave absorber **150**M**2** with respect to the transmitting antenna **120**Tx is not changed, and thus the transmitted wave can be attenuated highly accurately.

[0116] The antenna apparatus **100**M**2** can provide high receiver sensitivity without attenuating received waves while attenuating transmitted waves using the radio wave absorber **150**M**2**, and thus the antenna apparatus **100**M**2** with good radio wave receiver sensitivity can be provided. In addition, the positioning accuracy of the radio wave absorber **150**M**2** with respect to the transmitting antenna **120**Tx is high, and transmitted waves can be attenuated highly accurately.

[0117] Note that the radio wave absorber **150**M**2** may cover part of the transmitting antenna **120**Tx in aperture view of the aperture **111**. In other words, in aperture view of the aperture **111**, the radio wave absorber **150**M**2** may cover at least part of the transmitting antenna **120**Tx. FIG. **5**D illustrates the radio wave absorber **150**M**2** that covers the upper half of the transmitting antenna **120**Tx in aperture view of the aperture **111**.

[0118] The radio wave absorber **150**M**2** that covers at least part of the transmitting antenna **120**Tx in aperture view of the aperture **111** can attenuate transmitted waves. In addition, by adjusting the length of the radio wave absorber **150**M**2** in the longitudinal direction to adjust the portion of the radio wave absorber **150**M**2** that covers the transmitting antenna **120**Tx, the degree of attenuation of transmitted waves can be set.

<Third Modification>

[0119] FIG. **6**A to FIG. **6**C are diagrams of an example structure of an antenna apparatus **100**M**3** according to a third modification of the embodiment. Here, differences between the antenna apparatus **100** and the antenna apparatus **100**M**3** will be described. Among the components of the antenna apparatus **100**M**3**, the same reference numerals are given to components similar to those in the antenna apparatus **100** and their descriptions will be omitted.

<Structure of Antenna Apparatus **100**M**3**>

[0120] The antenna apparatus **100**M**3** has a structure in which the radio wave absorber **140** in the antenna apparatus **100** is omitted, a waveguide **110**M**3** is included instead of the waveguide **110**, and a radio wave absorber **150**M**3** is fixed to the waveguide **110** using a holder **155**, instead of the radio wave absorber **150**.

<Structure of Waveguide **110**M**3**>

[0121] The waveguide **110**M**3** has the aperture **111**, the aperture **112**, a recessed portion **113**A, an inner wall surface **114**A, an inner wall surface **115**A, and an inner wall surface **116**A. A central axis of each of the aperture **111**, the aperture **112**, the recessed portion **113**A, the inner wall surface **114**A, the inner wall surface **115**A, and the inner wall surface **116**A is positioned on the central axis C.

[0122] The aperture **111** and the aperture **112** correspond to the apertures **111** and **112** of the waveguide **110**.

[0123] The recessed portion **113**A is provided in the aperture **111** on the −Y direction side and is a portion into which the holder **155** is fitted. The recessed portion **113**A is a cylindrical portion that is recessed from a surface of the waveguide **110**M**3** on the −Y direction side to the +Y direction side. The central axis of the recessed portion **113**A is aligned with the central axis C. The length of the recessed portion **113**A in the radial direction is longer than the radius of the aperture **111**. Accordingly, when the waveguide **110**M**3** is viewed from the −Y direction side in aperture view, the recessed portion **113**A is larger than the aperture **111**.

[0124] The inner wall surface **114**A is a cylindrical wall surface (wall surface corresponding to an inner circumferential surface of a cylinder) having a constant diameter, and is connected to the +Y direction side of the aperture **111**. The diameter of the inner wall surface **114**A is equal to the diameter of the aperture **111**.

[0125] The inner wall surface **115**A is a wall surface (wall surface corresponding to an outer circumferential surface of a truncated cone) extending conically from an end of the inner wall surface **114**A on the +Y direction side, and the aperture **112** is located at an end on the +Y direction side. The inner wall surface **115**A is located outside the area represented by the angular aperture α represented by the equation (1). The inner wall surface **115**A is located outside the first path P1 and the second path P2 illustrated in FIG. **2**D.

[0126] The inner wall surface **116**A is a cylindrical wall surface (wall surface corresponding to an inner circumferential surface of a cylinder) that is provided on the +Y direction side with respect to the aperture **112**, and is larger than the aperture **112** in aperture view of the waveguide **110**M**3**.

<Structure of Radio Wave Absorber **150**M**3** and Holder **155**>

[0127] The radio wave absorber **150**M**3** has a disc shape and has a through hole **151**M**3** that is located on the +Y direction side of the receiving antenna **120**Rx. The through hole **151**M**3** extends through in the Y direction in about half of the radio wave absorber **150**M**3** on the −Z direction side. The through hole **151**M**3** has a cylindrical inner wall surface (wall surface corresponding to an inner circumferential surface of a cylinder) having a constant diameter.

[0128] The radio wave absorber **150**M**3** is, similarly to the radio wave absorber **150**, for example, a component made by molding resin mixed with magnetic or dielectric powder or the like, and is a component that causes radio wave loss. The holder **155** is preferably non-metallic and comprises a dielectric. The holder **155** can be made of, for example, resin or ceramic.

[0129] In a state in which the radio wave absorber **150**M**3** is held by the holder **155**, in aperture view of the waveguide **110**M**3**, the radio wave absorber **150**M**3** covers the transmitting antenna **120**Tx and enables the receiving antenna **120**Rx to be exposed from the through hole **151**M**3**. The inner wall surface of the through hole **151**M**3** is located outside the second path P2 illustrated in FIG. **2**D. Accordingly, while the first direct wave that is output from the transmitting antenna **120**Tx is attenuated by the radio wave absorber **150**M**3**, the second direct wave that reaches the receiving antenna **120**Rx passes through inside the through hole **151**M**3** and thus the second direct

wave is not attenuated by the radio wave absorber **150**M**3**.
[0130] The holder **155** is a disc-shaped component that is larger than the radio wave absorber **150**M**3**, and has a recessed portion **155**A formed along the central axis C from the −Y direction side and an aperture **155**B that is provided on a +Y direction side of the recessed portion **155**A. The recessed portion **155**A and the aperture **155**B are circular with the central axis C as the center when the holder **155** is viewed from the −Y direction side. The recessed portion **155**A has a cylindrical inner wall surface (wall surface corresponding to an inner circumferential surface of a cylinder) having a constant diameter, and the aperture **155**B that has a diameter smaller than that of the recessed portion **155**A is continuous with an end on the +Y direction side. The recessed portion **155**A and the aperture **155**B extend through the holder **155** in the Y direction.
[0131] The radio wave absorber **150**M**3** is fitted into the cylindrical inner wall surface of the recessed portion **155**A. In this state, in aperture view of the aperture **111** of the waveguide **110**M**3**, the aperture edge of the aperture **155**B is located outside the transmitting antenna **120**Tx and the receiving antenna **120**Rx. In other words, the aperture edge of the aperture **155**B is located outside the first path P1 and the second path P2 illustrated in FIG. **2**D.
[0132] As illustrated in FIG. **6**A to FIG. **6**C, the radio wave absorber **150**M**3** can be attached to the waveguide **110**M**3** by attaching the radio wave absorber **150**M**3** to such a holder **155** and fitting the holder **155** into the recessed portion **113**A of the waveguide **110**M**3**.
[0133] In the state in which the radio wave absorber **150**M**3** is attached to the waveguide **110**M**3**, the radio wave absorber **150**M**3** is located inside the first path P1 of the first direct wave that is output from the transmitting antenna **120**Tx, but is located outside the second path P2 of the second direct wave that reaches the receiving antenna **120**Rx. Accordingly, the antenna apparatus **100**M**3** can provide high receiver sensitivity without attenuating the received wave while attenuating the transmitted wave using the radio wave absorber **150**M**3**, and thus the antenna apparatus **100**M**3** with good radio wave receiver sensitivity can be provided.
[0134] In addition, in the antenna apparatus **100**M**3**, the radio wave absorber **150**M**3** is attached to the waveguide **110**M**3**, and thus the positioning accuracy of the waveguide **110**M**3** and the radio wave absorber **150**M**3** can be increased.
[0135] Note that the holder **155** is provided to hold the radio wave absorber **150**M**3** as described above, and the shape is not limited to the disc shape and may be various shapes.
[0136] While the antenna apparatus according to the exemplary embodiment of the disclosure has been described, it is to be understood that the disclosure is not limited to the embodiment disclosed specifically, and various modifications or changes may be made without departing from the scope of the claims.

Claims

1. An antenna apparatus comprising: a board; an integrated circuit chip comprising a transmitting antenna and a receiving antenna, the integrated circuit chip being mounted on the board; a waveguide having a first aperture provided on the board side and surrounding the transmitting antenna and the receiving antenna in aperture view, a second aperture provided on a rear side with respect to the first aperture in a radiation direction of the transmitting antenna, and a first inner wall surface connecting the first aperture and the second aperture; a radio wave lens fixed to the second aperture; and a first radio wave absorber disposed on the first aperture side in a space surrounded by the first inner wall surface, wherein at least part of the first radio wave absorber is located inside a first path of a first direct wave that is radiated from the transmitting antenna, directly reaches the radio wave lens, and passes through the radio wave lens, and the first radio wave absorber is located outside a second path of a second direct wave that passes through the radio wave lens and directly reaches the receiving antenna.
2. The antenna apparatus according to claim 1, wherein the first radio wave absorber covers at least

part of the transmitting antenna in aperture view of the first aperture.

3. The antenna apparatus according to claim 1, wherein the transmitting antenna and the receiving antenna are disposed across an optical axis of the radio wave lens.

4. The antenna apparatus according to claim 3, wherein the first radio wave absorber is provided on the transmitting antenna side with respect to the optical axis in aperture view of the first aperture.

5. The antenna apparatus according to claim 1, further comprising: a cylindrical second radio wave absorber provided inside the first inner wall surface, wherein the second radio wave absorber comprises a third aperture that is provided on the first aperture side, is smaller than the first aperture and the board in aperture view of the first aperture, and surrounds the transmitting antenna and the receiving antenna; a fourth aperture that is provided on the rear side with respect to the third aperture in the radiation direction and is larger than the third aperture; and a second inner wall surface that connects the third aperture and the fourth aperture.

6. The antenna apparatus according to claim 5, wherein the second inner wall surface of the second radio wave absorber is located outside the first path and the second path.

7. The antenna apparatus according to claim 6, wherein the first radio wave absorber is integrally formed with the second radio wave absorber.