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(54) ANTENNA DEVICE AND RADAR APPARATUS

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(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**
G01S 7/28 (2006.01)

(52) **U.S. Cl.** **342/175**; 342/157; 342/158; 342/371

(58) **Field of Classification Search** .... 342/175, 342/81, 157, 158, 368–374; 343/700 MS
See application file for complete search history.

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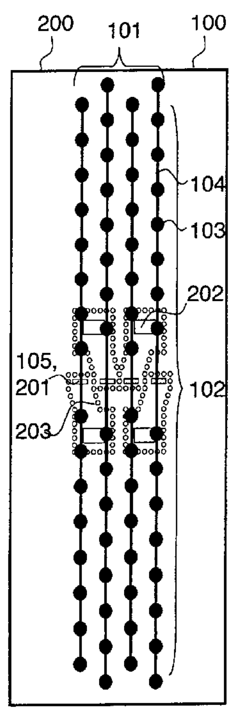
(57) **ABSTRACT**

An antenna device includes an antenna substrate and a feed line substrate. The antenna substrate includes subarray antennas, feeding interfaces and a back surface. The subarray antennas are arranged parallel with an interval on a plane. Each subarray antenna includes antenna elements and first feed lines. The first feed lines feed signals from the feeding interface on back surface to the antenna elements. The feed line substrate is attached along back surface and includes second feed lines, first and second mode transformers. Each second feed line has one and other ends portions. Other end portion has wider width than one end portion. Each first mode transformer is located in one end portion and connected to the feeding interface. Each second mode transformer is located in other end portion. One end portions are arranged in a line with interval, and other end portions are alternately arranged across one end portions.

10 Claims, 12 Drawing Sheets



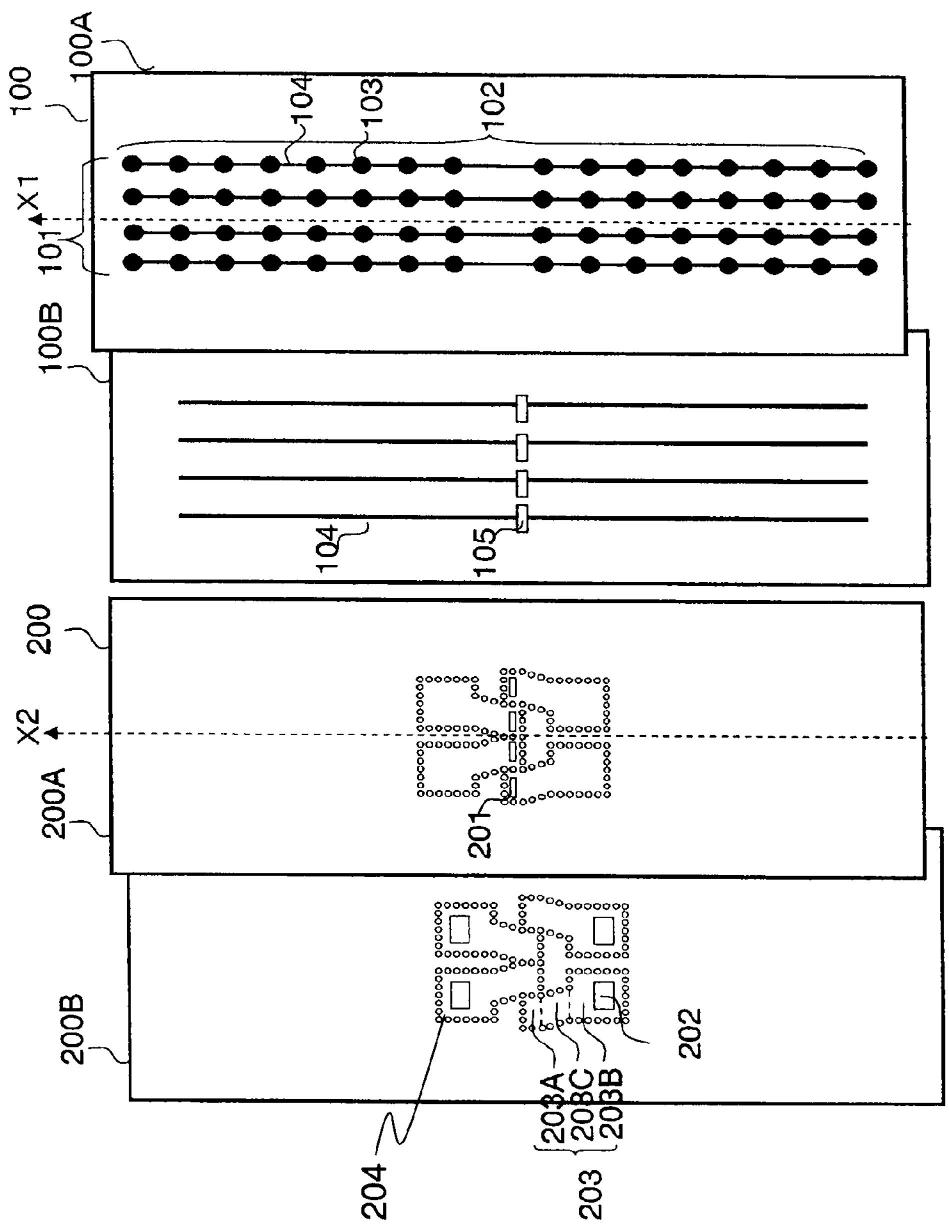

100A
100
104
103
102
X1
101
100B
104
105
200
X2
200A
201
200B
202
203A
203C
203B
203
204

FIG.2A

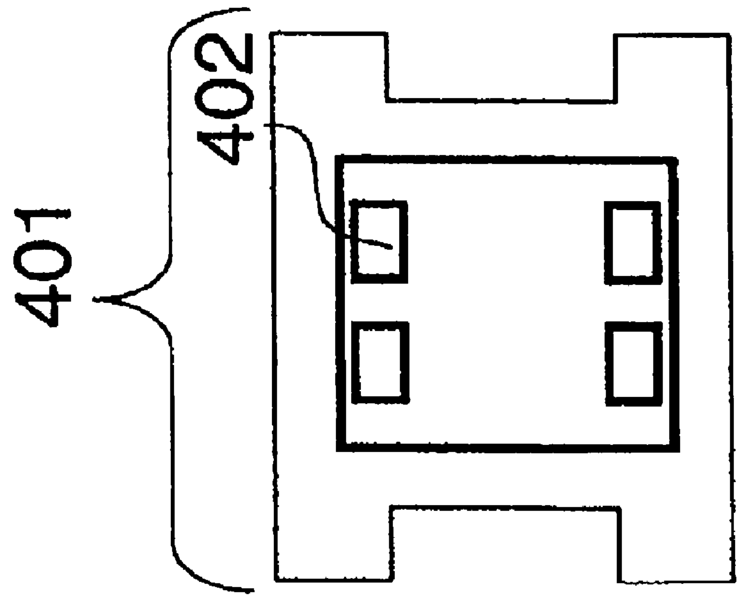


FIG.2B

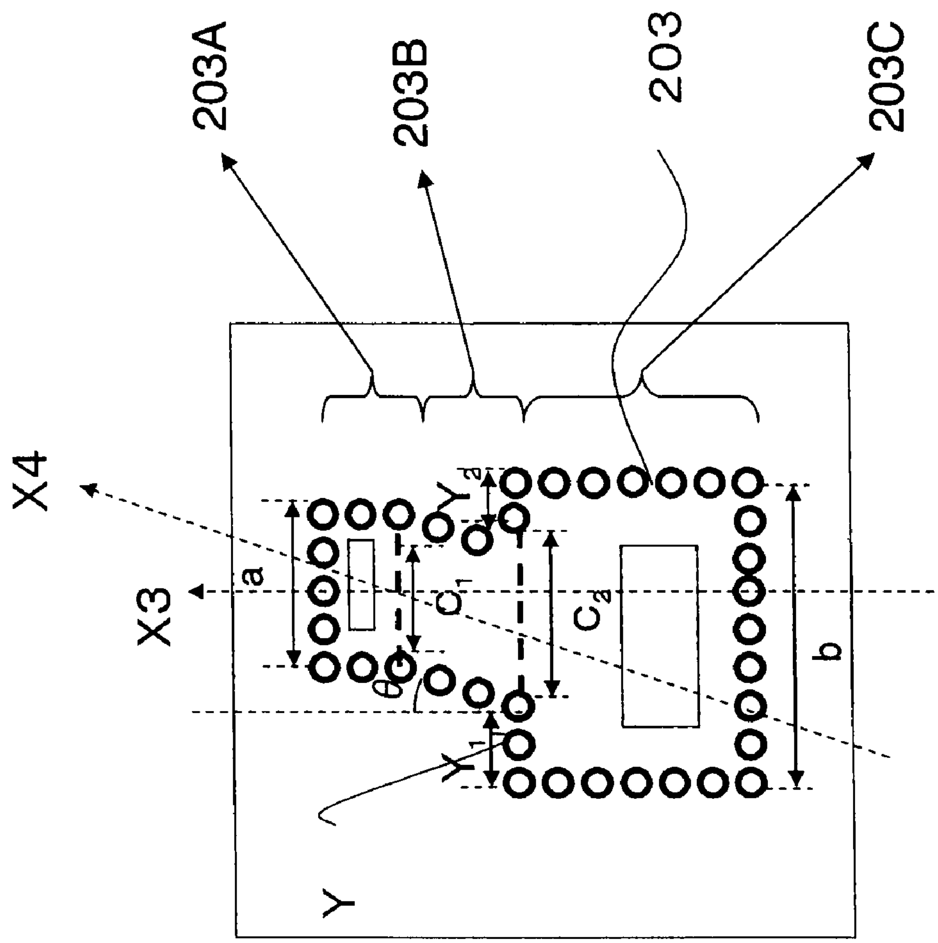


FIG.3

FIG.4

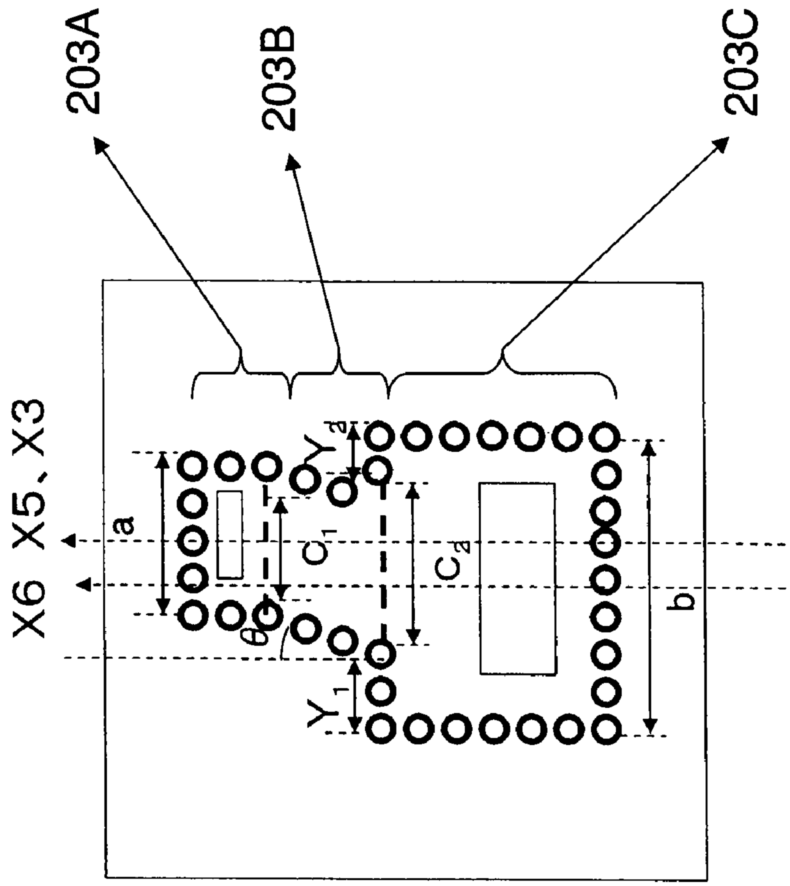
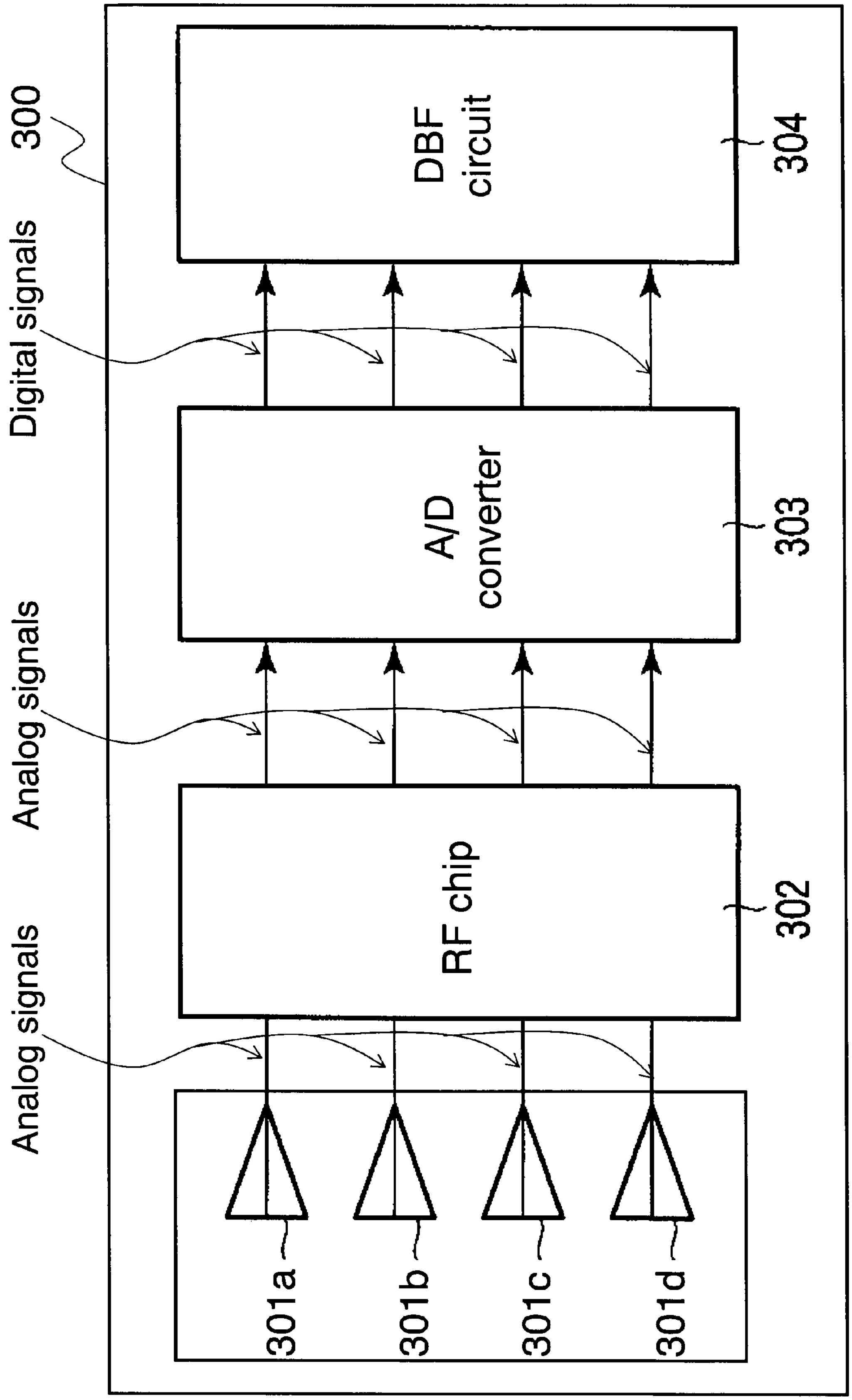
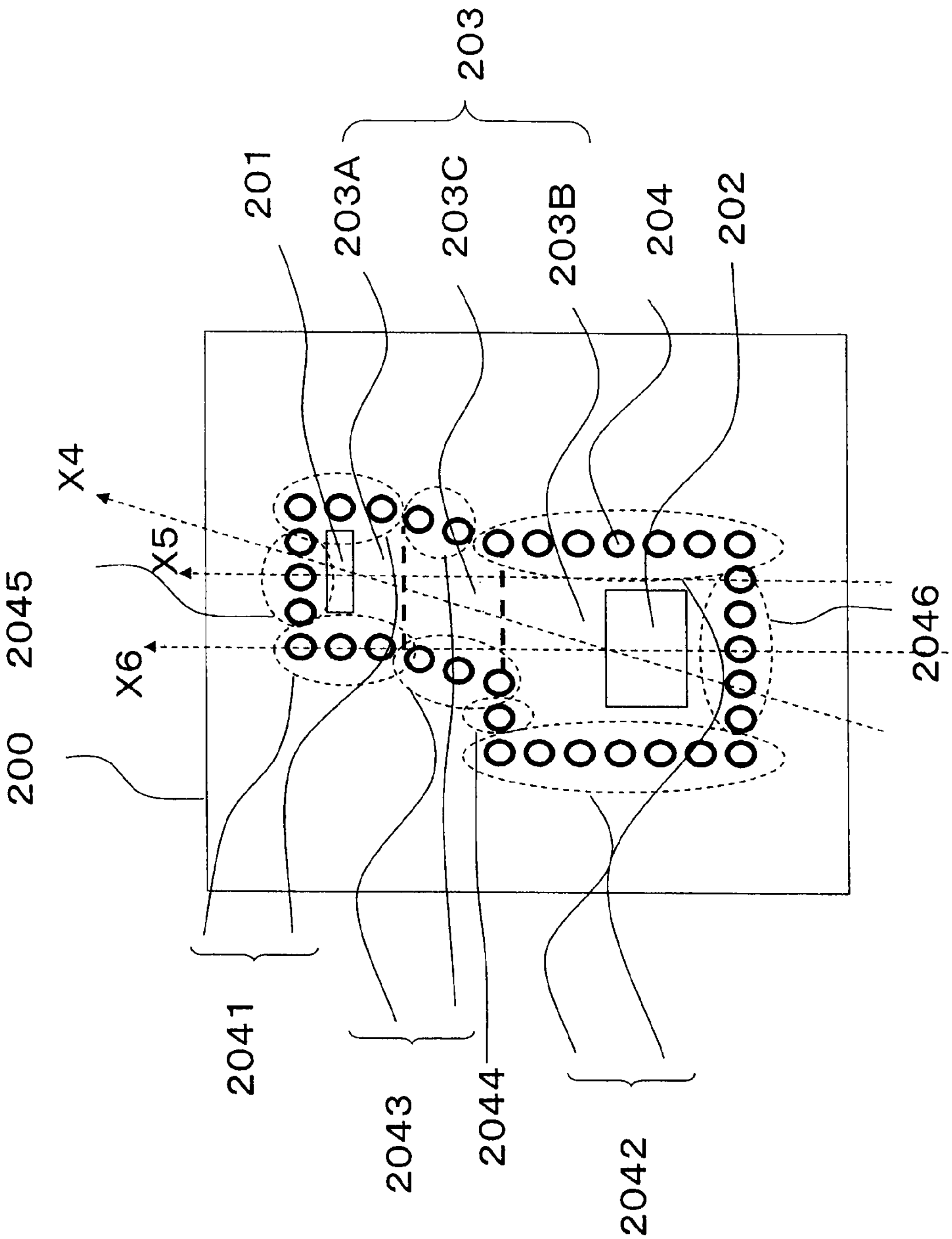


FIG.5

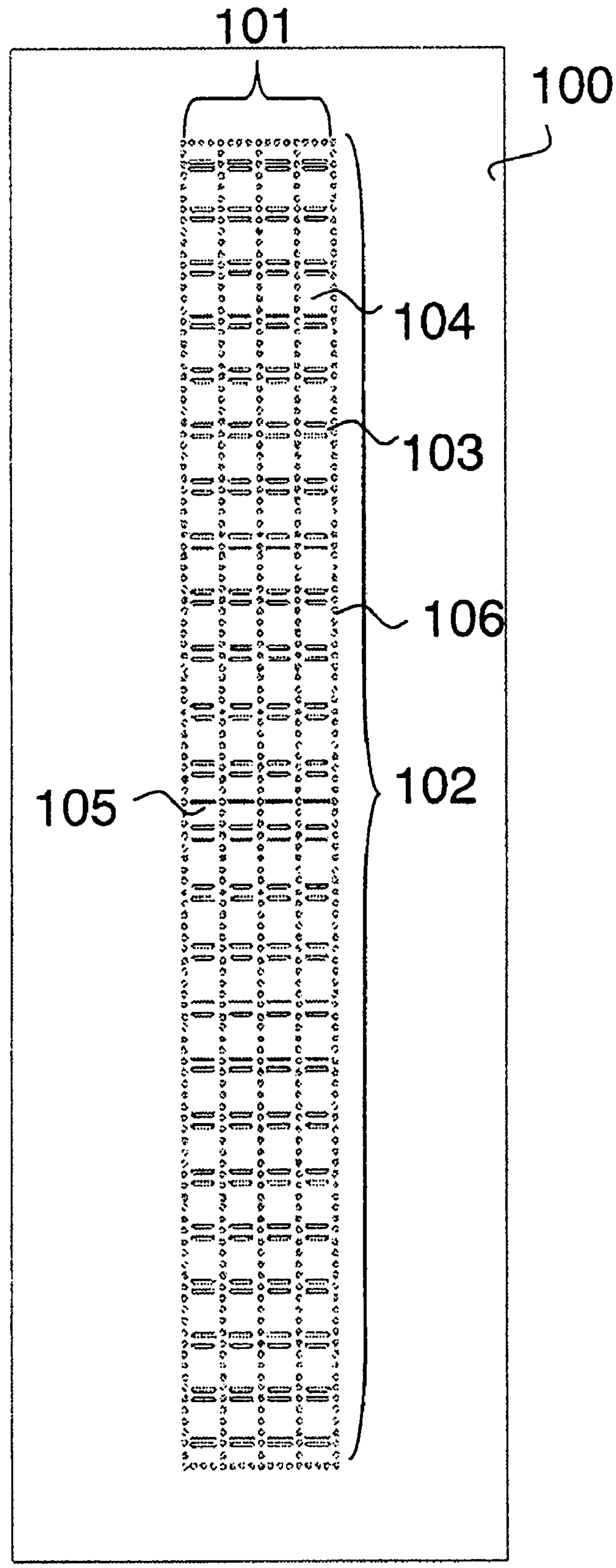

300
DBF circuit
304
Digital signals
A/D converter
303
Analog signals
RF chip
302
Analog signals
301a
301b
301c
301d



203
201
203A
203C
203B
204
202
X4
X5
X6
2045
200
2046
2041
2043
2044
2042

FIG.6

FIG.7



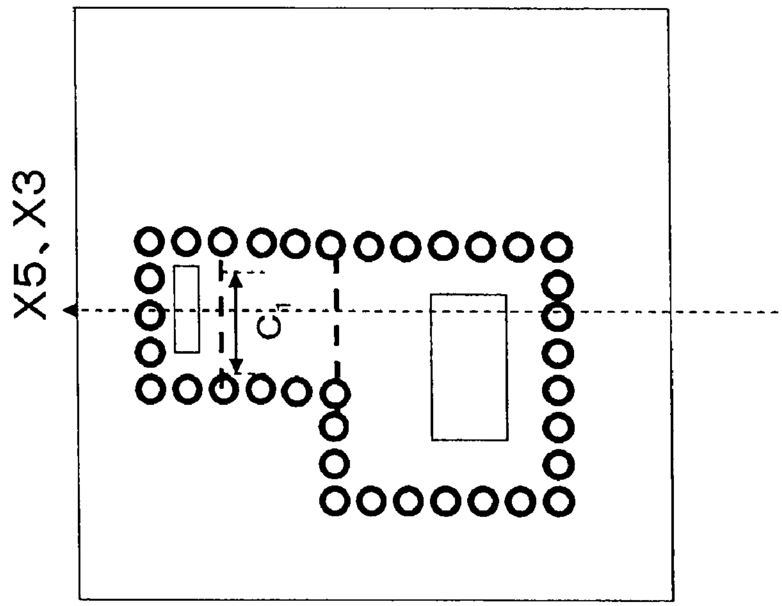


FIG.8A

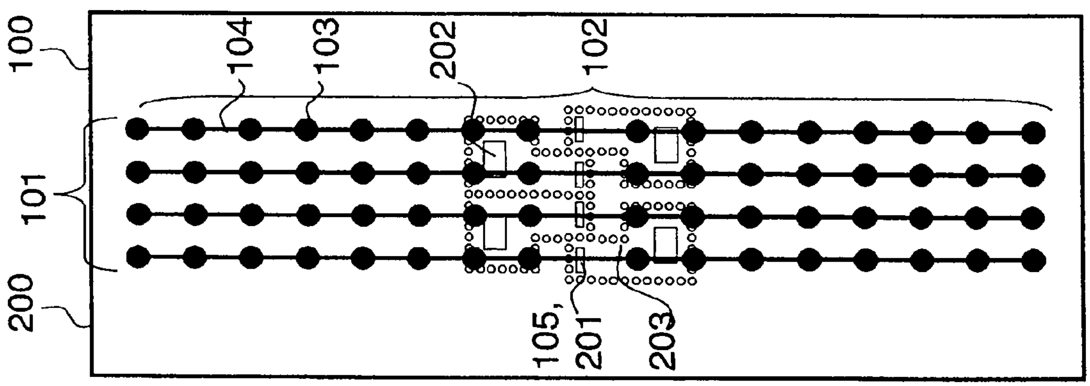


FIG.8B

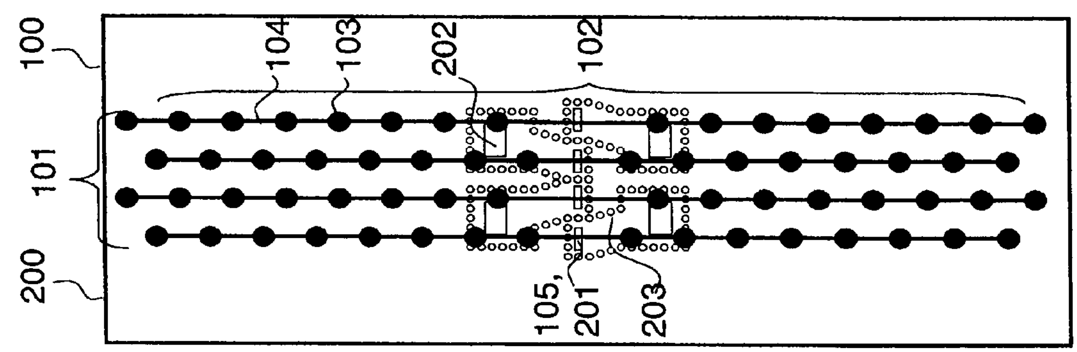
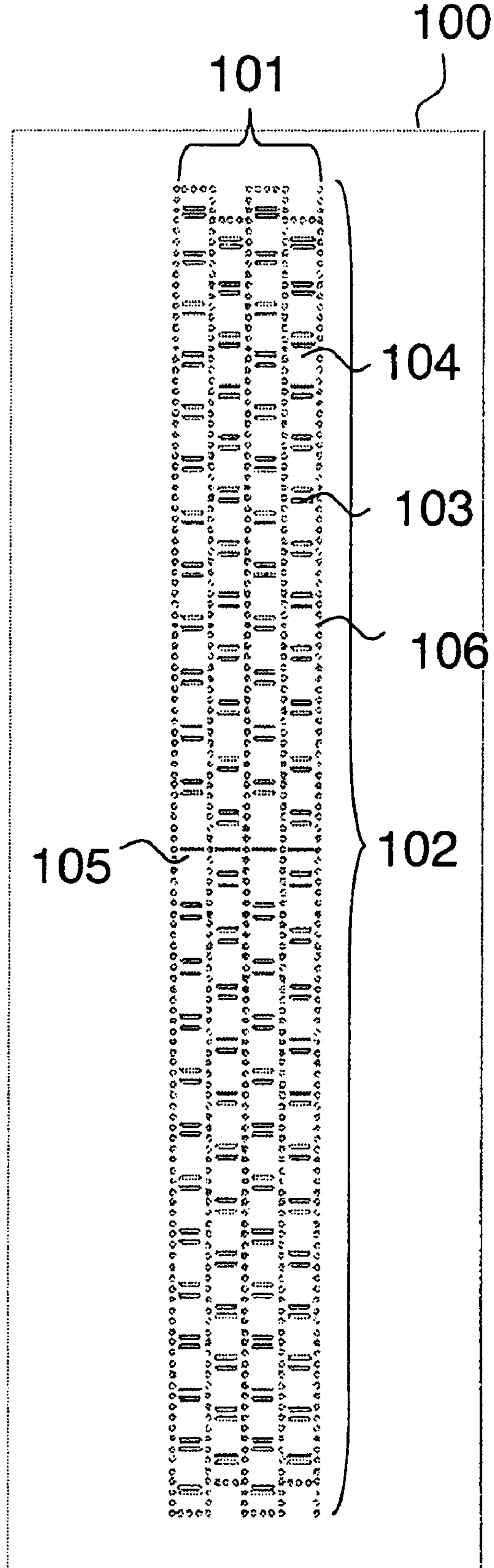


FIG.9

FIG.10



ANTENNA DEVICE AND RADAR APPARATUS

CROSS REFERENCE TO RELATED APPLICATIONS

This application is based upon and claims the benefit of priority from the Japanese Patent Application No. 2009-056259, filed on Mar. 10, 2009, the entire contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an antenna device and a radar apparatus.

2. Description of the Related Art

In radar systems, an array antenna forms a beam to transmit a signal. Then, the array antenna receives an echo signal which is corresponded to the signal in order to measure a target angle. The array antenna includes several subarray antennas and feeding interfaces. Each subarray antenna includes antenna elements and feed lines. The feed lines feed signals to the antenna elements. The antenna element may be any one of a patch, horn, slot antenna. The feed line may be any one of a microstrip line, a triplate line, a waveguide, a dielectric waveguide, and a post-wall waveguide. A waveguide feeding is popular for the antenna in automotive radar systems using the millimeter wave.

One of the waveguide feedings is disclosed in Japanese Patent No. 3843946. In this reference, several waveguide are formed by piling two metal walls. These waveguide provide a choke structure in order to avoid coupling of high frequency signals current in the waveguides.

In the automotive radar systems, interval between the adjacent subarray antennas should be narrow in order to achieve a wide coverage angle. For example, the interval between the adjacent subarray antennas is better to be equal to or smaller than 0.6λ, where λ is a free-space wavelength, in order to achieve the coverage angle of 40-degree.

However, in the case of waveguide feeding, it is difficult to achieve the narrow interval between the adjacent subarray antennas, when all feeding interfaces are formed at the same side of all subarray antennas. Moreover, extra space is required between adjacent subarray antennas in order to keep high isolation between the feeding interfaces.

As a result, the interval between the adjacent subarray antennas becomes wider and size of the antenna device becomes larger.

SUMMARY OF THE INVENTION

According to one aspect of the invention, an antenna device includes

an antenna substrate including

subarray antennas arranged parallel to each other with an interval the interval being less or equal than a free-space wavelength, each subarray antenna including antenna elements and first feed lines, the first feed lines feeding signals to the antenna elements,

an back surface of the antenna substrate including feeding interfaces, each feeding the signals to each of the first feed lines; and

a feed line substrate attached along the back surface, the feed line substrate including

second feed lines, each having one end portion and other end portion, the other end portion having wider line width than the one end portion, the one end portions are arranged in a line to each other with the interval, and the other end portions are alternately arranged across the one end portions,

first mode transformers, each being located in the one end portion, each being connected to each of the feeding interfaces each feeding signals from second feed lines to first feed lines, and

second mode transformers, each being located in the other end portion.

According to other aspect of the invention, a radar apparatus includes

the antenna device of claim **1**, which receives a first signal;

an RF module amplifying the first signal and down-converting a frequency of the first signal to a lower frequency to obtain a second signal;

an A/D converter converting the second signal to a digital signal;

a DBF circuit measuring a target angle based on the digital signal.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a top view of an antenna device;

FIG. **2**A is an exploded view of an antenna device;

FIG. **2**B is a top view of an RF module;

FIG. **3** is a top view of a second feed line;

FIG. **4** is a top view of a second feed line;

FIG. **5** is a block diagram showing a radar apparatus;

FIG. **6** is a top view of a second feed line;

FIG. **7** is a top view of a prototype of an antenna device;

FIG. **8**A is a top view of a second feed line;

FIG. **8**B is a top view of an antenna device;

FIG. **9** is a top view of an antenna device; and

FIG. **10** is a top view of a prototype of an antenna device.

DETAILED DESCRIPTION OF THE INVENTION

The embodiment will be explained with reference to the accompanying drawings.

As shown in FIG. **1**, an antenna device includes an array antenna **101** and a feed line substrate **200**. The array antenna **101** is formed on an antenna substrate **100**. The antenna substrate **100** is piled on the feed line substrate **200**.

FIG. **2**A is an exploded view of the antenna device. The antenna substrate **100** is shown as a top surface **100**A and a back surface **100**B. The feed line substrate **200** is shown as a top surface **200**A and a back surface **200**B. An RF module **401** shown in FIG. **2**B is connected to the antenna device.

The antenna device and the RF module **401** provide a radar apparatus.

The array antenna **101** includes several subarray antennas **102**. Each subarray antenna **102** includes antenna elements **103**, first feed lines **104** and feeding interfaces **105**.

The subarray antennas **102** are arranged along an alignment of the antenna elements **103** parallel to each other on a plane. The subarray antennas **102** provide the array antenna **101**. The subarray antennas **102** are symmetrically arranged about a central axis X1 on the plane. When the number of the subarray antennas **102** is even, the central axis X1 is along with the center of two adjacent subarray antennas **102** arranged at middle of the subarray antennas **102**. As shown in FIG. **1**, the number of the subarray antennas **102** in one side of the central axis X1 is equal to the number of that in other side of the central axis X1.

The first feed lines **104** feeds signals to the antenna elements **103**. The first feed lines **104** may be any one of a waveguide, a dielectric waveguide, a microstrip line, a triplate line, and a post-wall waveguide.

In the case that the first feed line **104** is any one of the waveguide, the dielectric waveguide and the post-wall waveguide, the antenna element **103** may be a slot or horn antenna element. In the case that the first feed line **104** is either of the microstrip line or the triplate line, the antenna element **103** may be a patch antenna element.

The feeding interface **105** is set on the first feed line **104** in the back surface **100**B of the antenna substrate **100**. The back surface **100**B is reverse side of the top surface **100**A on which the array elements **103** are formed. The feeding interface **105** electrically connects a second feed line **203** (described later) of the feed line substrate **200** with the first feed line **104**. The second feed line **203** supplies signals of high frequency to the first feed line **104** through the feeding interface **105**. The feed line substrate **200** is attached along the back surface **100**B. The feeding interface **105** is connected to a first mode transformer **201** (described later).

Shape of the feeding interface **105** depends on the first feed line **104**. Each feeding interface **105** exists in a center of each of the subarray antennas **102**. The number of the antenna elements **103** in one side of the feeding interface **105** is equal to the number of that in other side of the feeding interface **105**.

The distance of the between adjacent subarray antennas **102** (hereinafter, "subarray interval "d"") is following the expression (1) in order to reduce a grating lobe level. In the expression (1), a free-space wavelength of operating frequency is "λ" and a maximum coverage angle is "θm".

$$\frac{d}{\lambda} < \frac{1}{(1 + \sin|\theta_m|)} \tag{1}$$

According to the expression (1), the subarray interval "d" is smaller than the free-space wavelength of operating frequency. For example, the subarray interval "d" should be smaller than 0.6λ to achieve the coverage angle of 40 degrees. The subarray antennas **102** are arranged along alignment of the antenna elements **103** parallel to each other according to the expression (1).

The feed line substrate **200** includes first mode transformers **201**, second mode transformers **202** and the second feed line **203**.

The feed line substrate **200** is formed by a copper-clad laminate. Both top and under surfaces of the copper-clad laminate are covered by the metal foils. The feed line substrate **200** is piled under the antenna substrate **100** as that each feeding interface **105** is connected to each of the first mode transformers **201**. Specifically, the top surface **200**A of the feed line substrate **200** is attached to the back surface **100**B of the antenna substrate **100**.

The first mode transformer **201** includes an aperture opened in an one end portion **203**A of the second feed line **203**. The aperture in the first mode transformer **201** is formed in the top surface **200**A of the feed line substrate **200**.

Shape of the first mode transformer **201** depends on the second feed line **203**. The first mode transformer **201** is connected to the feeding interface **105** and supplies signals from the second feed line **203** to the first feed line **104** through the feeding interface **105**. Each first mode transformer **201** is set to be connected to each of the feeding interface **105**.

The second mode transformer **202** includes an aperture opened in an other end portion **203**B of the second feed line **203**. The aperture in the second mode transformer **202** is formed in the back surface **200**B of the feed line substrate **200**.

Shape of the second mode transformer **202** depends on the line connecting the second mode transformer **202** and the RF module **401**. Each second mode transformer **202** is connected to each of RF ports **402** of the RF module **401**. The second mode transformer **202** supplies signals from the RF module to the second feed line **203**.

As shown in FIG. **3**, the first and second mode transformers **201**, **202** are arranged being shifted against a central axis **X3** to opposite directions respectively. Since the first and second mode transformers **201**, **202** are set at staggered positions each other, they can feed to the subarray antennas **102** with small area. Moreover, the RF ports of the RF module can be arranged close to each other.

The second feed lines **203** are symmetrically arranged about a central axis X**2**. The second feed lines **203** are divided into two groups by the central axis X**2**. Both groups include same number of the second feed lines **203**. The second feed line **203** connects the first mode transformer **201** with the second mode transformer **202**.

Each second feed line **203** is surrounded by through holes **204** and the metal foil of the copper-clad laminate. Therefore, the second feed line **203** is a waveguide like structure. Each subarray antenna has each of the second feed lines **203**. The one end portions **203**A of the second feed lines **203** are arranged in a line with the subarray interval "d" as that the first mode transformer **201** is connected to the feeding interface **105**. On the other hand, the other end portions **203**B of the second feed lines **203** are alternately arranged across the one end portions **203**A as that two other end portions **203**B are not adjacent.

The second feed lines **203** are symmetrically arranged about the central axis X**2**. When the number of the subarray antennas **102** is even (that is the number of the second feed lines **203** is even), the other end portions **203**B which are closest to the axis X**2** are arranged adjacent.

The feeding interfaces **105** are better to be arranged with interval being equal to or smaller than 0.6λ in order to achieve that the subarray interval "d" is equal to or smaller than 0.6λ. We describe how to arrange the feeding interfaces **105** below.

The high frequency signals in the second feed lines can be traveled even though width of the second feed line is equal to or smaller than 0.6λ owing to effect of wavelength shortening in lines filled the dielectric. Moreover, since the second feed line **203** has waveguide like structure, it can keep high isolation regardless of interval of between adjacent second feed lines **203**.

Therefore, since the adjacent second feed lines **203** can be arranged with short interval, the first mode transformer **201** can also be arranged with short interval being equal to or smaller than 0.6λ. As a result, the feeding interfaces **105** connected to the first mode transformer **201** can also be arranged with a interval being equal to or smaller than 0.6λ.

Next, we will describe detail of the second feed line **203**. In the description, we pick up one of the second feed lines **203** to explain. Other second feed lines **203** are same as the description.

As shown in FIG. **3**, the second feed line **203** includes an one end portion **203**A, an other end portion **203**B and a line portion **203**C. The one end portion **203**A has the first mode transformer **201**. The other end portion **203**B has the second mode transformer **202**. The line portion **203**C connects the one end portion **203**A with the other end portion **203**B. Width "b" of the other end portion **203**B is wider than width "a" of the one end portion **203**A ($a<b$). A bend angle θ ($0 \leqq \theta < 90$) is an angle between a central axis X3 and a central axis X4. The central axis X3 is center of the one end portion **203**A and divides the width "a" in half. The central axis X4 is center of the line portion **203**C. The central axis X3 is parallel to the first feed line **104**. On the other hand, the central axis X4 is not parallel to the first feed line **104** and the line portion **203**C is slope to the first feed line **104**.

The central axis X4 slopes to the central axis X3. Therefore, the first mode transformer **201** and the second mode transformer **202** are arranged out of alignment. As a result, the first mode transformer **201** and the second mode transformer **202** can feed to the subarray antenna **102** with small area.

As shown in FIG. **4**, a central axis X5 is center of the one end portion **203**A. A central axis X6 is center of the other end portion **203**B. The other end portion **203**B is arranged as that the central axis X6 is parallel to the central axis X5. A first side Y1 and a second side Y2 are sides of the other end portion **203**B and attached to the line portion **203**C. The first side Y1 is longer than the second side Y2.

As shown in FIG. **6**, length of the second side Y2 may be "0". This means that only the first side Y1 exists. In this case, a corner of the line portion **203**C and a corner of the other end portion **203**B are smoothly continuing. The corner of the other end portion **203**B is closer to the one end portion **203**A than any other corners of the other end portion **203**B.

Hereinafter, we will explain a monopulse radar system. As shown in FIG. **5**, the monopulse radar system **300** includes the antenna device, an RF module **302**, an A/D (Analog/Digital) converter **303**, and a DBF (Digital Beam Forming) circuit **304**. The antenna device includes the subarray antennas **301***a*, **301***b*, **301***c*, **301***d*.

Each subarray antenna **301** receives an analog signal. The antenna device outputs the analog signals from the subarray antennas **301***a*, **301***b*, **301***c*, **301***d* to the RF module **302**. The RF module **302** amplifies the analog signals. Also, the RF module **302** down-converts a frequency of each analog signal to a lower frequency. Then, the RF module **302** outputs the analog signals to the A/D converter **303**. The A/D converter **303** converts the analog signals to digital signals. Then, the A/D converter **303** outputs the digital signals to the DBF circuit **304**. The DBF circuit **304** measures the target angle by using the digital signals. Explain of the detail to measure the target angle is skipped because it is same as conventional methods.

(Example of the Second Feed Line **203**)

As shown in FIG. **6**, each second feed line **203** is surround by the through holes **204**.

The through holes **204** provide a first through holes line **2041**, a second through holes line **2042**, a third through holes line **2043**, a first through holes group **2044**, a second through holes group **2045** and a third through holes group **2046**.

The first through holes line **2041** includes two lines of through holes which are set parallel to the central axis X5 of the one end portion **203**A. The one end portion **203**A exists between the two lines of through holes of first through holes line **2041**.

The second through holes line **2042** includes two lines of through holes which are set parallel to the central axis X6 of the other end portion **203**B. The other end portion **203**B exists between the two lines of through holes of the second through holes line **2042**.

The third through holes line **2043** includes two lines of through holes which are set parallel to the central axis X4 of the line portion **203**C. The line portion **203**C exists between the two lines of through holes of the third through holes line **2043**.

Width of the second through holes line **2042** is wider than the first through holes line **2041**. Therefore, the central axis X5 of the first through holes line **2041** and the central axis X6 of the second through holes line **2042** are different.

The first through holes group **2044** connects the first through holes line **2041** with the third through holes line **2043**.

The second through holes group **2045** connects the two lines of through holes of the first through holes line **2041**. One ends of the two lines of the first through holes line **2041** are connected to the second through holes group **2045**. Other ends of the two lines of the first through holes line **2041** are connected to the third through holes line **2043**.

The third through holes group **2046** connects the two lines of through holes of the second through holes line **2042**. One ends of the two lines of the second through holes line **2042** are connected to the third through holes group **2046**. Other end of one of the two lines of the second through holes line **2042** is connected to the first through holes group **2044**. Other end of other one of the two lines of the second through holes line **2042** is connected to the third through holes line **2043**.

The end portion **203**A, the other portion **203**B and the line portion **203**C may be formed as one structure to provide the second feed line **203**.

Next, an example of array antenna **101** is described with reference to FIG. **7**. In the example, the array antenna **101** is provided by post-wall waveguide slotted subarray antennas. The antenna substrate **100** is made of a dielectric substrate. Both top and under surfaces of the dielectric substrate are covered by metal foils. The first feed line **104** is a portion surrounded by through holes **106**. The through hole **601** is through the antenna substrate **100**. The through hole **106** shorts between the metal foils of the top and under surfaces of the dielectric substrate. Each post-wall waveguide is provided by alignment of the through holes **106**. The adjacent post-wall waveguides share one alignment of the through holes **106** corresponding to a narrow wall of waveguide. The antenna element **103** is formed by opening a slot by etching. The post-wall waveguide slotted subarray antenna acts as a slot array antenna of a waveguide which is filled with dielectric material. Each slot may be formed parallel to an axis of the waveguide. The axis of the waveguide is parallel to the alignment of the through holes **106**. Or, each slot may be formed longitudinal or 45-degree to the axis of the waveguide. Moreover, the post-wall waveguide slotted subarray antenna may have the through holes inside of the post-wall waveguide.

The feeding interface **105** is formed by etching.

As described above, since the second feed line **203** is formed on the feed line substrate **200** which is different from the antenna substrate **100** in the antenna device, the second feed line **203** can connect the RF module **401** and the array antenna **101** with short distance. Therefore, the antenna device achieves small size.

Moreover, one ends of the second feed lines **203** (which are connected to the array antenna **101**) are arranged parallel to each other. Other ends of the second feed lines **203** (which are connected to the RF module **401**) are symmetrically arranged about the one ends arranged parallel to each other. Specifically, the other ends are alternately located at a furthest end of the second feed lines **203** from the other end of the adjacent second feed lines **203**. Therefore, the second feed lines **203** are arranged in the small area. In general, size of the second mode transformer **202** is larger than that of the first mode transformer **201** because the feed interfaces of RF module **401** are hollow waveguides which are larger than waveguide filled dielectric. In the antenna device according to the embodiment, the second mode transformers **202** are alternately arranged at different sides of the first mode transformers **201**. Therefore, the other ends of adjacent second feed lines **203** are not adjacent. As a result, line connecting the first mode transformer **201** in the one end and the second mode transformer **202** in the other end of the second feed lines **203** achieves shorter length compared with the case that the second mode transformers in the other ends are arranged parallel to each other.

Since the feeding interface **105** is arranged at a middle of the first feed line **104**, distance from feed interface **105** to each antenna element **103** can be shorter than when the feeding interface **105** is arranged at a end of the first line **104**. Therefore, errors in a traveling wave phase of the signals in the first feed line **105** due to manufacturing error are accumulated a little. As a result, beam tilt due to manufacturing error can be reduced. Moreover, since the antenna elements **103** are symmetrically arranged about the feeding interface **105**, the antenna elements **103** cancel the beam tilt due to manufacturing error. Accordingly, the beam tilt is more reduced.

Since width of the other end portion **203**B is wider than width of one end portion **203**A, impedance of the second feed line **203** can be smaller. Therefore, width of the second mode transformer **202** formed in the other end portion **203**B becomes wider.

Since the first side Y**1** is longer than the second side Y**2** in the second feed line **203**, the bend angle of the second feed line **203** becomes smaller. As a result, bandwidth of the second feed line **203** becomes wider.

Modified Example 1

In the above description, the central axis X**4** of the line portion **203**C is formed transverse to the central axis X**3** of the subarray antenna **102**. As shown in FIGS. **8**A and **8**B, the central axis X**4** may be formed parallel to the central axis X**3**. In this case, the bend angle can be smaller. Therefore, bandwidth is achieved keeping wider.

Modified Example 2

In the above description, the antenna elements **103** are arranged at same positions every subarray antenna **102**. As shown in FIG. **9**, the antenna elements **103** may be arranged at different positions every subarray antenna **102**. In this case, phases of signals can be sifted in each subarray antenna **102**. FIG. **10** shows a prototype of the antenna device using the post-wall waveguide slotted array antenna. The antenna elements **103** in FIG. **10** are arranged at different positions in the alternate subarray antennas **102** comparing to them in FIG. **7**.

In the above description, the antenna device adopts the post-wall waveguide slotted array antenna. The antenna device may adopt a horn array antenna or a patch array antenna with a triplate line. In the case of the horn array antenna, the antenna device does not include the antenna substrate **100** but the horn array antenna acts as the antenna. The horn array antenna or the patch array antenna includes subarray antennas. The subarray antennas includes antenna elements, a first feed line which feeds to the antenna elements, and feeding interface which feeds signals to the first feed line. The feeding interface of the horn array antenna or the patch array antenna is formed on the same side on which the horn array antenna or the patch array antenna is formed.

In the antenna device of FIG. **7**, apertures of the first and second mode transformers are opened parallel to the antenna elements **103**. The apertures of the first and second mode transformers may be opened longitudinal or transverse to the antenna elements **103**. Each second feed line **203** may have several apertures of the first mode transformer and several apertures of the second mode transformer. Moreover, in the above description, each aperture has rectangle-shape. Each aperture may have hook-shape or cross-shape. The first and second mode transformers may include aperture and conductive pin.

Additional advantages and modifications will readily occur to those skilled in the art. Therefore, the invention in its broader aspects is not limited to the specific details and representative embodiments shown and described herein. Accordingly, various modifications may be made without departing from the spirit or scope of the general inventive concept as defined by the appended claims and their equivalents.

What is claimed is:

1. An antenna device comprising:

an antenna substrate having subarray antennas,

arranged parallel to each other with an interval, the interval being less or equal than a free-space wavelength, each subarray antenna including antenna elements and first feed lines, the first feed lines feeding signals to the antenna elements,

feeding interfaces, each feeding the signals to each of the first feed lines

a back surface of the antenna substrate having the feeding interfaces;

and

a feed line substrate attached along the back surface, the feed line substrate including

second feed lines, each having one end portion and other end portion, the other end portion having wider width than the one end portion, the one end portions are arranged in a line to each other with the interval, and the other end portions are alternately arranged across the one end portions,

first mode transformers, each being located in the one end portion, each being connected to each of the feeding interfaces, and

second mode transformers, each being located in the other end portion.

2. The antenna device of claim **1**, wherein

the second feed lines are symmetrically arranged about a first central axis, the first central axis is parallel to the second feed lines and divides the second feed lines in two groups.

3. The antenna device of claim **1**, wherein

the number of the second feed lines is even,

two adjacent other end portions which are closest to a first central axis are arranged in same side against the corresponding one end portions,

the first central axis is parallel to the second feed lines and divides the second feed lines in two groups.

4. The antenna device of claim **1**, wherein

each second feed line has a line portion connecting the one end portion and the other end portion,

the other end portion has a first and second sides connected to the line portion, the first side is shorter than the second side.

5. The antenna device of claim **1**, wherein

each second feed line has a line portion connecting the one end portion and the other end portion,

the other end portion has a corner connected to the line portion.

6. The antenna device of claim **1**, wherein

each second feed line has a line portion connecting the one end portion and the other end portion,

the line portion has a second central axis, the second central axis is transverse to a first central axis,

the first central axis is parallel to the second feed lines and divides the second feed lines in two groups.

7. The antenna device of claim **1**, wherein

each of the second feed lines is surrounded by through holes, each through hole is through the feed line substrate.

8. The antenna device of claim **1**, wherein

a central axis of the other end portion is different from a central axis of the one end portion.

9. The antenna device of claim **1**, wherein

the antenna elements are symmetrically arranged about a central axis on a top surface, the central axis divides the subarray antennas in two groups.

10. A radar apparatus comprising:

the antenna device of claim **1**, which receives a first signal;

an RF chip amplifying the first signal and down-converting a frequency of the first signal to a lower frequency to obtain a second signal;

an A/D converter converting the second signal to a digital signal;

a DBF circuit measuring a target angle based on the digital signal.

* * * * *

save damage to other cargo either within the container or in an adjacent container. Although SAW devices have in particular been described, other low power devices using battery or RF power can also be used where necessary. Note, the use of any of the aforementioned SAW devices in connection within or on a vehicle for any purpose other than tire pressure and temperature monitoring or torque monitoring is new and contemplated by the inventions disclosed herein. Only a small number of examples are presented of the general application of the SAW, or RFID, technology to vehicles.

Other sensors that can be designed to operate under very low power levels include microphones **492** and light sensors **493** or sensors sensitive to other frequencies in the electromagnetic spectrum as the need arises. The light sensors **493** could be designed to cause activation of the interior sensor system **481** when the container is being switched from a dark condition (normally closed) to a light situation (when the door or other aperture is opened). A flashlight could also activate the light sensor **493**.

Instead of one or more batteries providing power to the interior sensor system **481**, the communication system **485** and the location determining system **486**, solar power can be used. In this case, one or more solar panels **494** are attached to the upper wall of the container **480** (see. FIG. **57**) and electrically coupled to the various power-requiring components of the monitoring system. A battery can thus be eliminated. In the alternative, since the solar panel(s) **494** will not always be exposed to sunlight, a rechargeable battery can be provided which is charged by the solar panel **494** when the solar panels are exposed to sunlight. A battery could also be provided in the event that the solar panel **494** does not receive sufficient light to power the components of the monitoring system. In a similar manner, power can temporarily be supplied by a vehicle such as a tractor either by a direct connection to the tractor power or though through capacitive, inductive or RF coupling power transmission systems. As above an ultracapacitor can be used instead of a battery and energy harvesting can be used if there is a source of energy such as light or vibration in the environment.

In some cases, a container is thought to be empty when in fact it is being surreptitiously used for purposes beyond the desires of the container owner or law enforcement authorities. The various transducers that can be used to monitor interior of a container as described above, plus others, can also be used to allow the trailer or container owner to periodically monitor the use of his property.

Immediately above, monitoring of the interior of the container is described. If the container is idle, there may not the need to frequently monitor the status of the container interior or exterior until some event happens. Thus, all monitoring systems on the container can be placed in the sleep mode until some event such as a motion or vibration of the container takes place. Other wakeup events could include the opening of the doors, the sensing of light or a change in the interior temperature of the container above a reference level, for example. When any of these chosen events occurs, the system can be instructed to change the monitoring rate and to immediately transmit a signal to a satellite or another communication system, or respond to a satellite-initiated signal for some LEO-based, or geocentric systems, for example. Such an event may signal to the container owner that a robbery was in progress either of the interior contents of the container or of the entire container. It also might signal that the contents of the container are in danger of being destroyed through temperature or excessive motion or that the container is being misappropriated for some unauthorized use.

FIG. **22** shows a flowchart of the manner in which container **480** may be monitored by personnel or a computer program at a remote facility for the purpose of detecting unauthorized entry into the container and possible theft of the contents of the container **480**. Initially, the wakeup sensor **495** detects motion, sound, light or vibration including motion of the doors **484**, or any other change of the condition of the container **480** from a stationary or expected position. The wakeup sensor **495** can be designed to provide a signal indicative of motion only after a fixed time delay, i.e., a period of "sleep". In this manner, the wakeup sensor would not be activated repeatedly in traffic stop and go situations.

The wakeup sensor **495** initiates the interior sensor system **481** to perform the analysis of the contents in the interior of the container, e.g., send waves into the interior, receive waves and then process the received waves. If motion in the interior of the container is not detected at **496**, then the interior sensor system **481** may be designed to continue to monitor the interior of the container, for example, by periodically re-sending waves into the interior of the container. If motion is detected at **496**, then a signal is sent at **497** to a monitoring facility via the communication system **485** and which includes the location of the container **480** obtained from the location determining system **486** or by the ID for a permanently fixed container or other asset, structure or storage facility. In this manner, if the motion is determined to deviate from the expected handling of the container **480**, appropriate law enforcement personnel can be summoned to investigate.

When it is known and expected that the container should be in motion, monitoring of this motion can still be important. An unexpected vibration could signal the start of a failure of the chassis tire, for example, or failure of the attachment to the chassis or the attachment of the chassis to the tractor. Similarly, an unexpected tilt angle of the container may signify a dangerous situation that could lead to a rollover accident and an unexpected shock could indicate an accident has occurred. Various sensors that can be used to monitor the motion of the container include gyroscopes, accelerometers and tilt sensors. An IMU (Inertial Measurement Unit) containing for example three accelerometers and three gyroscopes can be used.

In some cases, the container or the chassis can be provided with weight sensors that measure the total weight of the cargo as well as the distribution of weight. By monitoring changes in the weight distribution as the vehicle is traveling, an indication can result that the contents within the trailer are shifting which could cause damage to the cargo. An alternate method is to put weight sensors in the floor or as a mat on the floor of the vehicle. The mat design can use the bladder principles described above for weighing b vehicle occupants using, in most cases, multiple chambers. Strain gages can also be configured to measure the weight of container contents. An alternate approach is to use inertial sensors such as accelerometers and gyroscopes to measure the motion of the vehicle as it travels. If the characteristics of the input accelerations (linear and angular) are known from a map, for example, or by measuring them on the chassis then the inertial properties of the container can be determined and thus the load that the container contains. This is an alternate method of determining the contents of a container. If several (usually 3) accelerometers and several (usually 3) gyroscopes are used together in a single package then this is known as an inertial measurement unit. If a source of position is also known such as from a GPS system then the errors inherent in the IMU can be corrected using a Kalman filter.

Other container and chassis monitoring can include the attachment of a trailer to a tractor, the attachment of electrical