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Karikomi [45] July 25, 1972

[54] ANTENNA DEVICE

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[73] Assignee: **Nippon Telegraph and Telephone Public Corporation**, Tokyo, Japan

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[30] **Foreign Application Priority Data**

Nov. 28, 1969 Japan....................................44/94962

[52] **U.S. Cl.**..............................**343/758,** 343/761, 343/781, 343/839, 343/914
[51] **Int. Cl.**..**H01q 19/14**
[58] **Field of Search**..................343/781, 837, 839, 840, 758, 343/761, 914

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Primary Examiner—Eli Lieberman
Attorney—Flynn & Frishauf

[57] **ABSTRACT**

An antenna device comprising a main spherical reflector; a sub-reflector for reflecting electromagnetic waves to said main reflector so as to compensate for the spherical aberration of said main reflector, a primary radiator, plane reflectors and a parabolic reflector wherein the sub-reflector and plane reflectors are interlocked with each other so as to cause plane waves to be brought from the primary radiator to the sub-reflector through the plane reflectors and parabolic reflector.

6 Claims, 14 Drawing Figures

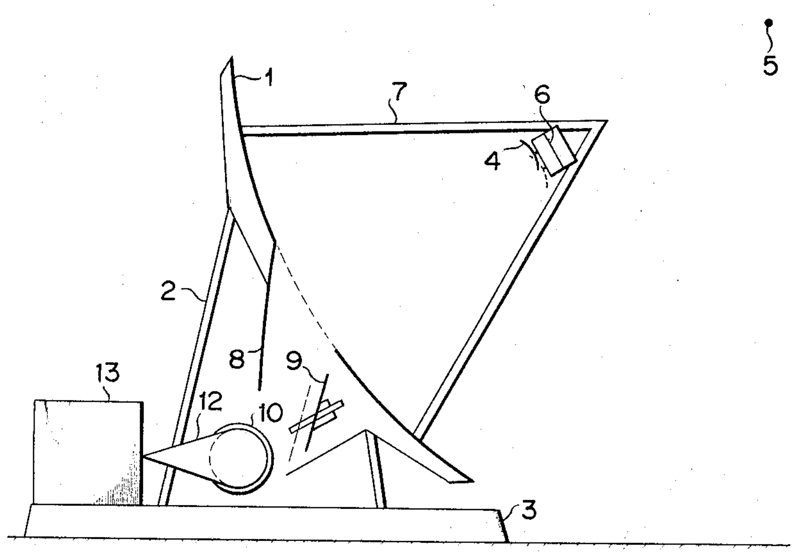


FIG. 1

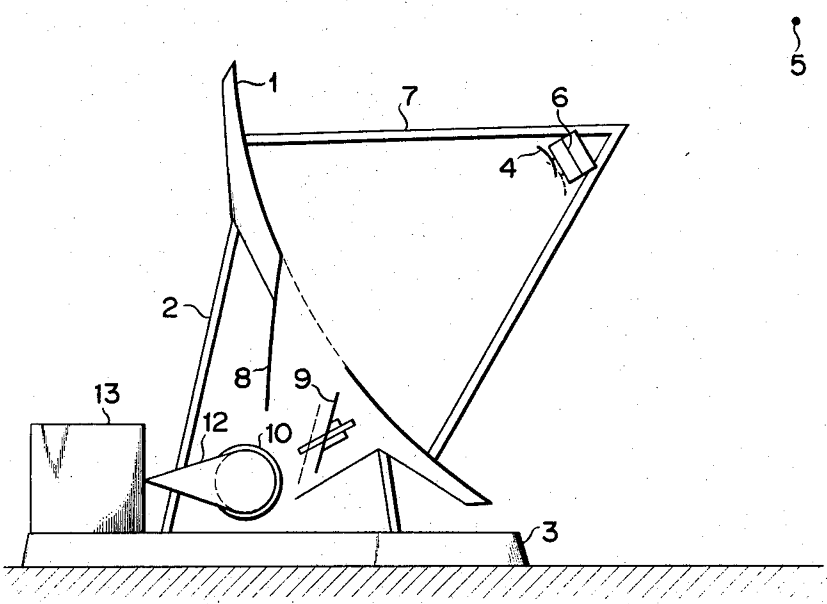


FIG. 3

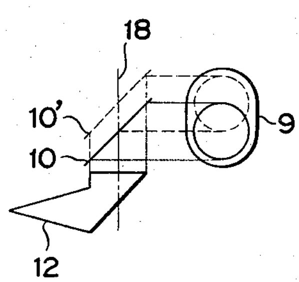


FIG. 2

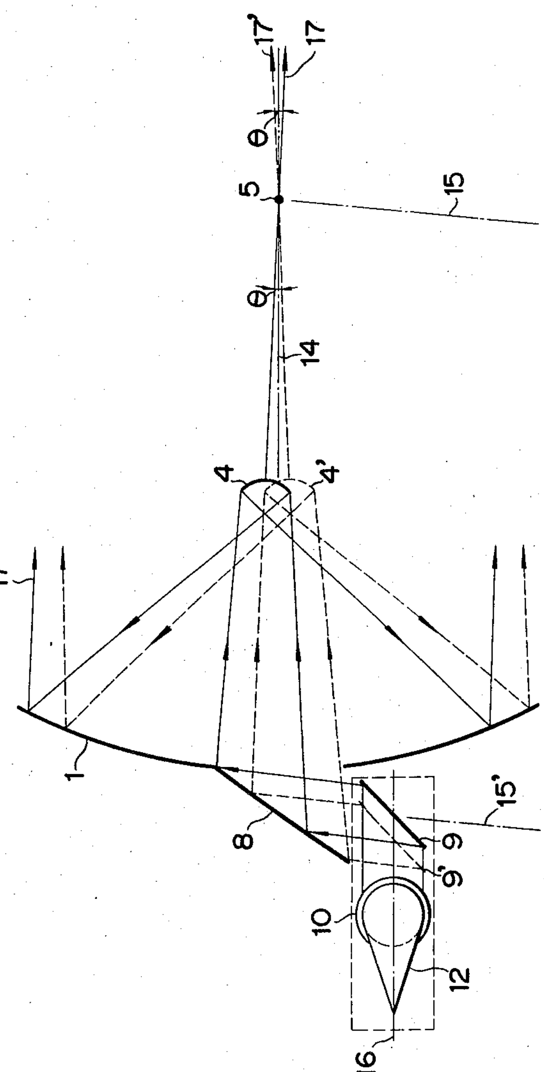
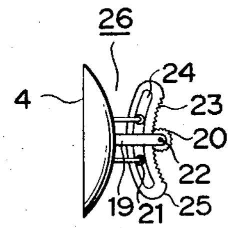


FIG. 4



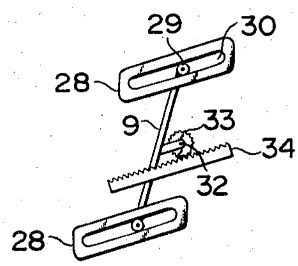


FIG. 5

FIG. 6

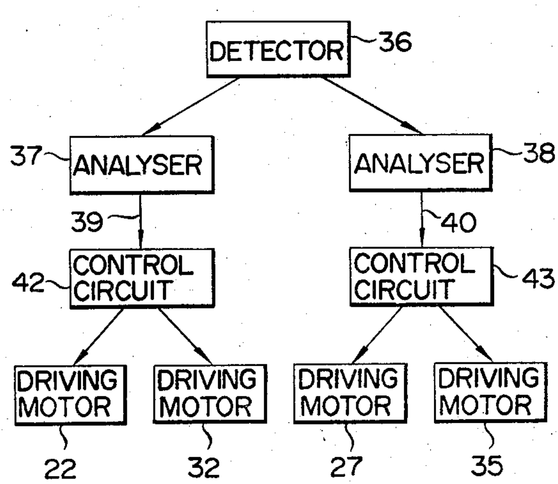


FIG. 8

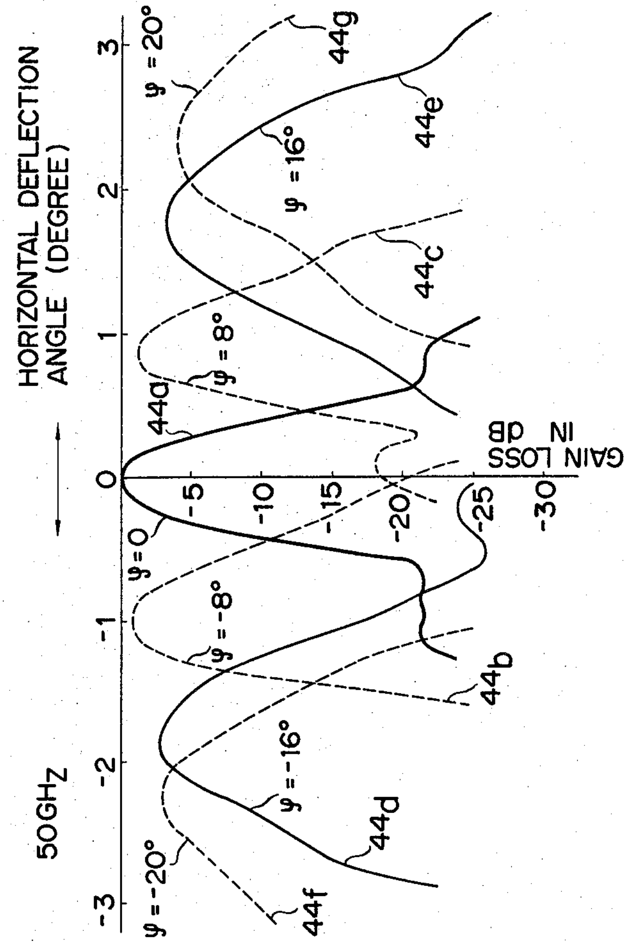

HORIZONTAL DEFLECTION ANGLE (DEGREE)
GAIN LOSS IN dB
50GHz
φ=0
φ=8°
φ=-8°
φ=16°
φ=-16°
φ=20°
φ=-20°
44a
44b
44c
44d
44e
44f
44g
-3
-2
-1
0
1
2
3
-5
-10
-15
-20
-25
-30

FIG. 7

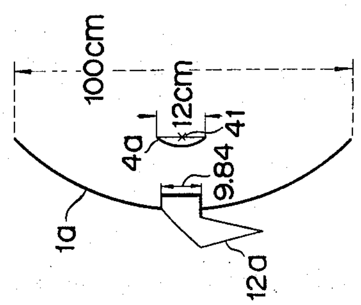

100cm
12cm
9.84
4a
41
1a
12a

FIG. 9

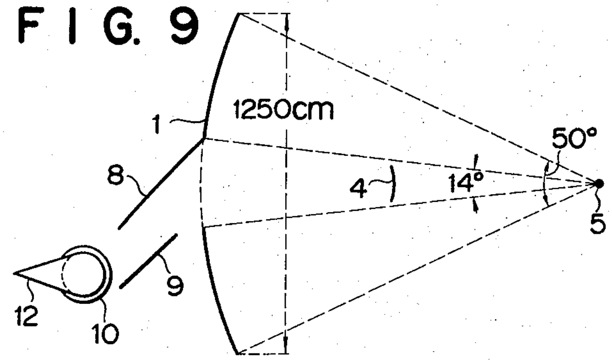


FIG. 10

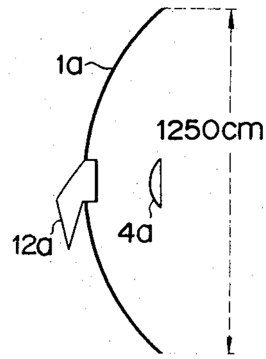


FIG. 11

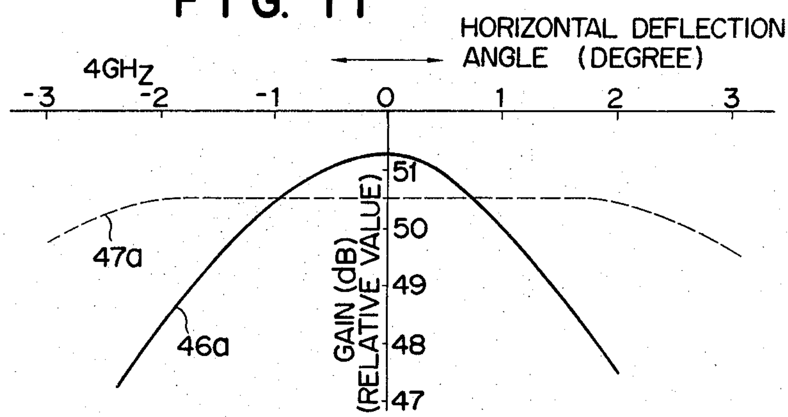


FIG. 12

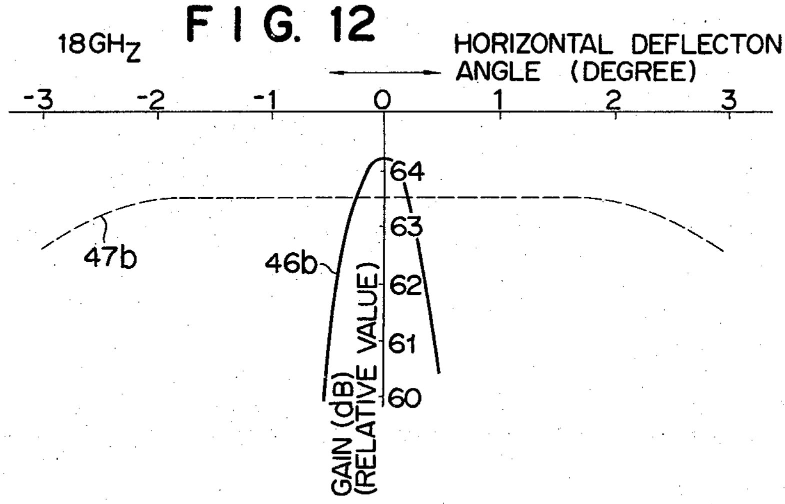


FIG. 13

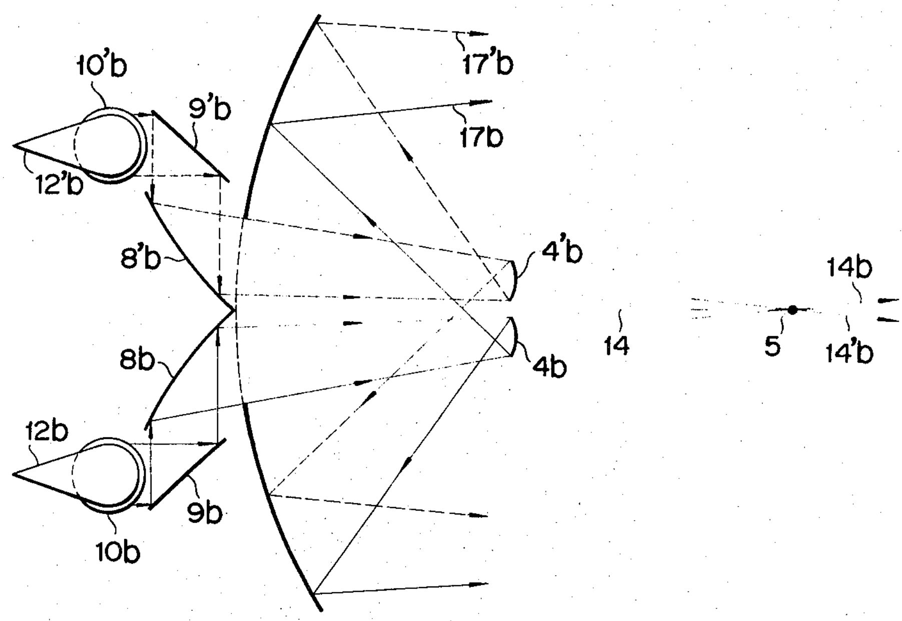
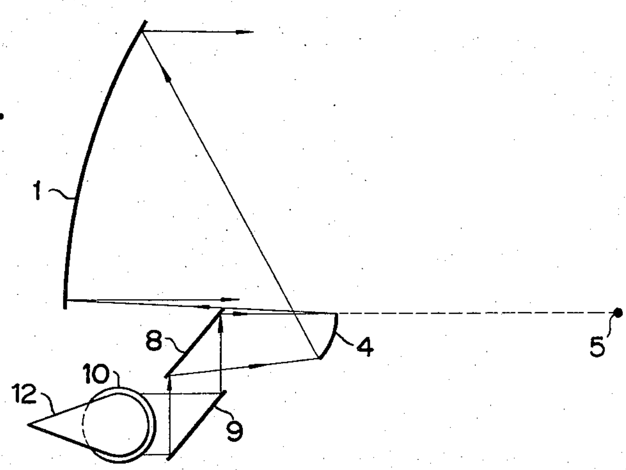


FIG. 14



ANTENNA DEVICE

The present invention relates to an antenna device comprising a main spherical reflector and a sub-reflector for compensating the spherical aberration of the main reflector, and more particularly to an antenna device capable of deflecting electromagnetic waves without moving the main spherical reflector.

Where telecommunication is conducted through a space satellite using signals in a superhigh frequency band (SHF band), the conventional antenna device of a ground station has been so designed as to track an object space satellite by turning the main reflector upward or downward or rotating it in accordance with the movement of said satellite. Even in the case of a stationary satellite, for example, which travels only through an extremely limited angle with respect to the ground station, it has been necessary to operate the whole of an antenna device in tracking such stationary satellite.

Since the main reflector has a considerably large diameter there must be built a gigantic antenna mount with the resulting complicated construction in order to firmly support and drive the main reflector against a certain magnitude of wind force. Obviously, the structure and weight of said main reflector is subject to limitation from the standpoint of constructing said antenna mount.

The aforesaid stationary satellite travels through an extremely minute angle with respect to a ground station, so that beams for tracking the satellite have only to be deflected through a small angle. If, therefore, the antenna device is so designed as to permit the tracking of the stationary satellite simply by deflecting radiated beams within the range of angles through which the satellite travels, with the greater part of the antenna device including the main reflector fixed in place, then the construction of the antenna device will obviously be considerably simplified. Further, if the antenna device is so arranged as to include a single main reflector and separately control the deflections of a plurality of radiated beams without moving said reflector, then it will enable the antenna device to display a more effective action and also offer economic advantage.

A ground station antenna device for satellite telecommunication has heretofore consisted of a Cassegrain type in many cases. There has also been employed a parabola antenna. The Cassegrain antenna device is known to be capable of deflecting radiated beams by inclining a sub-reflector (not intended to compensate spherical aberration) with respect to the main reflector. It is also known that both Cassegrain and parabola antenna devices can radiate a plurality of beams by providing a plurality of primary radiators, using a single main reflector. In either case, however, the opto-geometrical conditions demanded of an antenna device are obstructed with the resulting loss of gain expected therefrom. Therefore, such a process has not yet been practically applied in an antenna device.

It is accordingly an object of the present invention to provide an antenna device capable of deflecting beams within a prescribed range of angles satisfying the opto-geometrical conditions without moving a main reflector.

Another object of the present invention is to provide an antenna device capable of radiating a plurality of beams whose deflection can be controlled independently, using a single main reflector.

SUMMARY OF THE INVENTION

The antenna device of the present invention comprises a main spherical reflector for reflecting electromagnetic waves; a sub-reflector disposed between the curvature center and reflecting surface of the main reflector so as to compensate for the spherical aberration of the main reflector; a parabolic reflector whose focal point is coincident with the curvature center of the main spherical reflector so as to reflect electromagnetic waves to the sub-reflector; a plane reflector for reflecting electromagnetic waves to the parabolic reflector; a primary radiator conducting plane waves to the plane reflector; means for rotating said sub-reflector around an axial line passing through said curvature center of said main spherical reflector, with the central axis of said sub-reflector directed to said curvature center; and means for moving said plane reflector in interlocking relationship with the rotation of said sub-reflector so as to cause the plane electromagnetic waves to be conducted from said primary radiator to said sub-reflector through said parabolic reflector.

The reflecting surface of the main spherical reflector is faced to its center side. When there are brought to said effective surface plane waves parallel with a main axial line connecting the center of the reflecting surface and the curvature center, then the resulting reflected waves are not converged exactly at a focal point due to the spherical aberration of the main reflector. If, however, the path of electromagnetic waves is made to have a fixed length and there is provided a sub-reflector having its mirror curve so calculated as to satisfy the opto-geometrical law of reflection, then compensation of the aforesaid spherical aberration will be accomplished. Said compensation is conducted in such a manner that electromagnetic waves reflected by the sub-reflector may be deemed as spherical waves from the curvature center. The aforementioned compensatory means is based on opto-geometrical considerations, so that, strictly speaking, there may be required some correction by taking into consideration the concept of wave mechanics. With an antenna device whose main spherical reflector has a much longer diameter than the wavelength of electromagnetic waves brought thereto, the above-mentioned opto-geometrical consideration will fully serve the practical purpose.

The present invention will be more fully understood from the following description taken by reference to the appended drawings, in which:

FIG. 1 is an elevation of an antenna device according to an embodiment of the present invention, showing the schematic arrangement of its major parts;

FIG. 2 is an elevation of the antenna device of FIG. 1, indicating the relationship of the reflector system and the direction in which there are reflected electromagnetic waves;

FIG. 3 is a plan view showing the positional relationship of the primary radiator and the plane reflector used in FIG. 2;

FIG. 4 is an elevation of a mechanism for rotating the sub-reflector of FIG. 1 in a vertical plane;

FIG. 5 is an elevation of a mechanism for causing the pane reflectors of FIG. 1 to move parallel with their respective original positions;

FIG. 6 is a block diagram of a beam deflection control system for causing the mechanisms of FIGS. 4 and 5 to be electrically driven in interlocking relationship by signals for detecting errors in defining the deflection of electromagnetic waves;

FIG. 7 illustrates the arrangement of a Cassegrain antenna device using a parabola reflector and a primary radiator;

FIG. 8 represents the directional characteristics of electromagnetic waves in the horizontal plane of the antenna device using the reflector system of FIG. 7;

FIGS. 9 and 10 respectively are elevations of the reflector systems of the present antenna device and the conventional Cassegrain antenna device using a parabola reflector;

FIG. 11 is a diagram comprising the gains of the antenna devices of FIGS. 9 and 10 for a frequency of 4 GHz;

FIG. 12 is a diagram comparing the gains of the antenna devices of FIGS. 9 and 10 for a frequency of 18 GHz;

FIG. 13 illustrates the arrangement of reflectors in an antenna device according to another embodiment of the invention; and

FIG. 14 shows the arrangement of reflectors in an antenna device according to still another embodiment of the invention.

Referring to FIGS. 1 and 2, a main spherical reflector 1 having a prescribed curvature radius is fixed on a mount 3 by a support 2. Between the curvature center 5 and the reflecting surface of the main reflector 1 is disposed a sub-reflector 4 for compensating the spherical aberration of the reflecting surface. Means 6 for driving the sub-reflector 4 is held by supports 7 fixed to the main reflector 1 so as to rotate the sub-reflector 4 in the later described direction. At the center of the main reflector 1 is positioned part 8 of a parabolic reflector whose focal point is constituted by the curvature center 5 of the main spherical reflector 1. Numerals 9 and 10 are plane reflectors each so designed as to move parallel with its original position. Numeral 12 is the conical horn reflector of the primary radiator fixed at a prescribed point. This horn reflector 12 is connected to a stationary transmission and reception apparatus and radiates plane waves. The horizontal positional relationship of the horn reflector 12, and the plane reflectors 9 and 10 of FIG. 2 is presented in FIG. 3. Referring to FIG. 2, numeral 14 denotes a central axial line connecting the center of the reflecting surface of the main spherical reflector 1 and its curvature center 5, 15 the central axial line of the parabolic reflectors 8 and 16 the central axial line of the conical horn reflector 12.

In the above-mentioned antenna device, the central axial line 17 (shown in a solid line) of the sub-reflector 4 assumes a position rotated about the curvature center 5 in a vertical plane (that is, a plane parallel with the surface of the drawing sheet) through an angle θ with respect to the first mentioned central axial line 14. Said sub-reflector 4 is so designed as to compensate the spherical aberration of the main spherical reflector 1, with respect to, for example, electromagnetic waves introduced in the direction of the central axial line 17. On the other hand, plane waves from the conical horn reflector 12 are reflected, as indicated in solid lines, by the plane reflectors 10 and 9 in turn. The plane waves thus reflected are conducted to the parabolic reflector 8 in parallel with a line 15' which is also parallel with the central axial line 15. The parabolic reflector 8 has a focal point 5 on said central axial line 15, so that electromagnetical beams brought to said reflector 8 are so reflected as to be focussed at said focal point 15. The beams are further reflected by the sub-reflector 4 and main reflector 1, rearranged in phase in the direction of the central axial line 17, and emitted in the form of beams having a sharp directivity in said direction.

There will now be described the case where radiated waves are deflected without moving the main reflector 1. When, there are emitted beams in the direction 17' in a vertical plane, the central axial line 17 is made to rotate about point 5 so as to be aligned with the line 17'. In this case, the sub-reflector 4 is inclined to a position indicated by 4'. At the same time the plane reflector 9 is moved up to point 9' parallel with its original position along the axial line 16. In this case, electromagnetic waves are conducted through a route indicated by dotted lines, that is, plane waves from the conical horn reflector 12 are reflected by the plane reflector at point 9' and parabolic reflector 8, and advance to the focal point 5 or the curvature center of the main reflector 1, again reflected by the sub-reflector at point 4' and main reflector 1 and emitted in the form of waves fully rearranged in phase in the direction of the central axial line 17'.

Next where radiated waves are deflected in a horizontal plane (that is, a plane perpendicular to the surface of the drawing sheet), then the plane reflector 10 is brought, as shown in FIG. 3, to point 10' parallel with its original position along the axial line 18, a direction in which there are conducted plane waves from the horn reflector 12, and the sub-reflector 4 is made to rotate about the focal point 5 in a plane perpendicular to the surface of the drawing sheet.

There have been described the cases where radiated waves are deflected in vertical and horizontal planes. If, in this case, the plane reflectors 9 and 10 and sub-reflector 4 are made to move in interlocking relationship according to the direction in which electromagnetic waves are to be deflected, such deflection can be effected in a state fully meeting the opto-geometrical conditions involved with respect to any direction in which said electromagnetical beams pass through a conical region having a half vertical angle θ which is disposed about the central axial line 14. Accordingly, the antenna device of the present invention can track a stationary satellite without moving the main reflector and reducing the radiation property.

There will now be described means for causing the sub-reflector 4 and plane reflectors 9 and 10 to interlock with each other. The sub-reflector 4 has, as shown in FIG. 4, a rotary shaft 19 extending in the direction of the axial line 17 and engaged with a gear 20, which in turn is rotated by a motor 22. For the sub-reflector 4 there is also provided a movable guide member 25 comprising a toothed section 23 engaged with said gear 20 which jointly act as a sort of rack-pinion mechanism, and a groove 24 through which there are guided two rollers rotatably fitted to two supports respectively which are fixed to the back of the sub-reflector 4. As seen from FIG. 4, rotation of the motor 22 causes the sub-reflector 4 to be inclined in a vertical plane. In this case, the axial line 17 of the sub-reflector 4 is so designed as to be deflected through an angle θ at maximum with respect to the central axial line 14. To incline the sub-reflector 4 in a horizontal plane, it is only required to deflect the entire assembly 26 of FIG. 4 in a horizontal plane through an angle θ at maximum about point 5 of FIG. 2. A drive mechanism used in such case may consist of a horizontally disposed guide member 25', a gear 20' engaged with the toothed section 23' of said guide member 25' and a motor 27 (FIG. 6) for driving said gear 20' (20', 23', 25', are not shown). In this case the guide member 25' is fixed to the support member 7 of FIG. 1.

There will now be described a mechanism (FIG. 5) whereby one plane reflector 9 is made to move parallel with its original position along the axial line 16 of FIG. 2. In this case, there are provided two guide members 28 disposed at a prescribed position with respect to the main reflector 1, each of said guide members 28 having a guide groove 30 through which there slides one of the two rollers 29 rotatably fitted to the plane reflector 9 so as to cause it to move parallel along the axial line 16 of FIG. 2. The plane reflector 9 is fitted with a gear 33 driven by a motor 32 and engaged with a toothed guide member 34 fixed at a prescribed position, said gear 33 and toothed member 34 jointly acting as a sort of rack-pinion mechanism. Accordingly, rotation of the motor 32 enables the plane reflector 9 to move parallel along the axial line 16.

When the other plane reflector 10 is made to move parallel along the axial line 18, there is used the same drive arrangement as that of FIG. 5 though it is fitted in a different direction. The gear 33' (not shown) of the drive arrangement for the plane reflector 10 is driven by a motor 35 (FIG. 6).

There will now be described means for causing the sub-reflector 4 and the plane reflectors 9 and 10 to be moved in interlocking relationship. As shown in FIG. 6, there is provided a detector 36 for finding errors in deflecting radiated beams or waves. As used herein, the term "errors" means those degrees of an angle through which the radiated beam should be deflected in order to properly track a space satellite which has happened to shift its position. Error signals are supplied to a generator or an analyzer 37 for generating signals indicating errors occurring in a vertical plane (EL plane) and also to another generator 38 for producing signals representing errors in a horizontal plane (AZ plane), thereby obtaining control signals 39 and 40 respectively. These control signals 39 and 40 are conducted to a circuit 42 for controlling the rotation of motors 22 and 32, namely, a circuit for driving said motors 22 and 32 so as to eliminate errors in the EL plane and also to a circuit 43 for controlling the rotation of motors 27 and 35, namely, a circuit for driving said motors 22 and 32 so as to eliminate errors in the AZ plane so as to actuate the servo motors of these circuits. Now the motors 22, 32, 27 and 35 are driven by outputs from said circuits 42 and 43. Thus detection signals from the detector 36 can vary the angle at which there are radiated electromagnetical beams in the EL plane and such angle in the AZ plane separately, so that electromagnetical beams can be collectively deflected in an arbitrary direction passing through the previously mentioned conical region having a half vertical angle θ which is disposed about the central axial line 14.

There will now be described the deflection characteristics of electromagnetic waves radiated by the antenna device of the present invention in comparison with those obtained with the conventional Cassegrain antenna device using a parabola reflector. FIG. 7 represents a Cassegrain antenna device comprising a parabola reflector **1***a* 100 cm in outer diameter, sub-reflector **4***a* 12 cm in outer diameter and a conical horn reflector **12***a* having a beam hole 9.84 cm in diameter. The sub-reflector **4***a* is so designed as to be deflected through an angle ϕ with respect to its original axis about point **41**. FIG. **8** indicates the directional characteristics and gain loss of electromagnetic waves having a frequency of **50** GHz which were radiated by said prior art antenna device. The abscissa denotes the actual inclination (in a horizontal plane) of electromagnetic waves with respect to the direction of the beams which were radiated when the sub-reflector 4a was inclined at angle $\phi = 0$. The ordinate indicates gain loss by −dB as against a gain of 51.2 dB in the case of the aforesaid inclination at angle $\phi = 0$ of the sub-reflector **4***a*. Curves **44***a* to **44***h* represent the directional characteristics of electromagnetic wave radiated when the inclination of the sub-reflector **4***a* assumed angles of 0, −8, +8, −16, +16, −20 and +20. As seen from FIG. **8**, a 1° to 2° inclination in either way of the radiated beams from the standard direction causes an appreciable decline in their directional characteristics.

FIG. **9** shows the reflector system of the present invention used in an antenna device and FIG. **10** that of the conventional Cassegrain antenna device using a parabola reflector. The experimentally determined directional characteristics of radiated beams when the main reflectors of both antenna devices were alike **125** cm in center diameter are compared in both FIGS. **11** and **12**. FIG. **11** represents the case where there were used beams having a frequency of **4** GHz and FIG. **12** 18 GHz. Throughout these figures, the abscissa denotes the deflection of radiated beams in a horizontal plane with respect to the axis of the main reflector, and the ordinate the antenna gain as measured on a comparative basis. The curves **46***a* and **46***b* show the directional characteristics of electromagnetic waves radiated from the conventional antenna device of FIG. **10** and the curves **47***a* and **47***b* those obtained with the present antenna device. Here it should be noted that all these curves were drawn by joining the peaks of curves representing the directional characteristics of radiated beams, that is, the points of highest gain. As apparent from FIGS. **11** and **12**, the antenna device of the present invention displays a substantially fixed gain when radiated beams are deflected through an angle falling within a range of ±2°, and, what describes particular notice, presents a prominently increased gain as radiated beams have a higher frequency. The aforementioned favorable characteristics of radiated beams prove that the antenna device of the present invention is well adapted for space satellite telecommunication.

FIG. **13** illustrates another embodiment of the present invention capable of generating a plurality of beams in such a manner that their deflections can be separately controlled using a single spherical reflector. There are provided a pair of parabolic reflectors **8***b* and **8'***b* in symmetrical relationship with respect to the axis **14** of the main spherical reflector **1**, the focal point of said paired parabolic reflectors being constituted by the curvature center **5** of the main reflector **1**. For these paired parabolic reflectors **8***b* and **8'***b* there are provided, as illustrated, the corresponding sub-reflectors **4***b* and **4'***b*, two groups of plane reflectors **9***b*–**9'***b* and **10***b*–**10'***b* and conical horn reflectors **12***b* and **12'***b*. That is, there are used two primary radiator systems each including from the conical horn reflector to the sub-reflector. The arrangement of each primary radiator system and its optical position with respect to the main spherical reflector **1** are the same as in the embodiment of FIG. **2**. Accordingly, when the axis of the sub-reflector **4***b* is deflected from the central axial line **14b** and the plane reflectors **9***b* and **10***b* are moved in interlocking relationship with said deflection by the same means as used in the embodiment of FIG. **2**, then radiated beams **17***b* can be deflected.

Similarly when the axis of the sub-reflector **4'***b* is deflected from the central axial line **14'***b* and the plane reflectors **9'** *b* and **10'***b* are moved in interlocking relationship with said deflection, then radiated beams **17'***b* can be deflected independently of the first mentioned beams **17***b*. Though the embodiment of FIG. **13** includes two primary radiator system the present invention is obviously not limited to said number.

FIG. **14** represents still another embodiment of the present invention wherein there is positioned a primary radiator system in front of a main spherical reflector **1**. Namely, outside of the passage of electromagnetic waves radiated from the main reflector **1**, is disposed a primary radiator system including a sub-reflector **4**. Under this arrangement, it is possible to provide a space satellite tracking antenna device capable of eliminating blocking and radiating a plurality of electromagnetic waves in such a manner that even when there are juxtaposed a plurality of primary radiator systems like that illustrated in FIG. **14**, there does not occur mutual interference.

As mentioned above, the present invention can deflect radiated beams through a specified range of angles without moving the main spherical reflector simply by operating the movable constituent units of the primary radiator system in interlocking relationship, and further can deflect a plurality of electromagnetic waves separately, without degrading the directional characteristics of said waves or beams, so that the antenna device of the present invention is particularly adapted for use in a ground station tracking a stationary space satellite.

What is claimed is:

1. An antenna device comprising:

- a main spherical reflector for reflecting electromagnetic waves;
- a sub-reflector disposed between the curvature center and reflecting surface of the main reflector so as to reflect electromagnetic waves to said surface and having a mirror surface which is arranged to compensate for the spherical aberration of said main spherical reflector;
- a parabolic reflector whose focal point is coincident with said curvature center so as to reflect electromagnetic waves to said sub-reflector;
- a primary radiator for radiating plane electromagnetic waves;
- a plane reflector for reflecting said electromagnetic waves to said parabolic reflector;
- means for rotating said sub-reflector around an axial line passing through said curvature center of said main spherical reflector, with the central axis of said sub-reflector directed to said curvature center; and
- means for moving said plane reflector in interlocking relationship with the rotation of said sub-reflector so as to cause the plane electromagnetic waves to be conducted from said primary radiator to said sub-reflector through said parabolic reflector.

2. An antenna device according to claim **1** wherein said primary radiator, plane reflector, parabolic reflector, sub-reflector, means for rotating said sub-reflector and means for moving said plane reflector are respectively provided in a sufficient number to constitute a plurality of wave radiating and conducting systems and are so as to reflect a plurality of electromagnetic waves to said main reflector in such a manner that the deflections of said electromagnetic waves are separately controllable.

3. An antenna device according to claim **1** wherein a wave radiating and conducting system comprising said primary radiator, plane reflector, parabolic reflector, sub-reflector, means for rotating said sub-reflector and means for moving said plane reflector is positioned outside of the path of electromagnetic waves reflected from said main spherical reflector.

4. An antenna device according to claim **1** wherein said means for moving said plane reflector in interlocking relationship with the rotation of said sub-reflector comprises:

- a detector for detecting deflection errors in radiated waves and for generating error signals corresponding to vertical plane errors and horizontal plane errors; and means responsive to said error signals for selectively rotating said plane reflector so as to reduce said deflection errors.

5. An antenna device according to claim 4 wherein said means responsive to said error signals includes means for generating respective control signals corresponding to said vertical plane and horizontal plane error signals, said plane reflector being selectively rotated in response to said control signals.

6. An antenna device according to claim 5 wherein said means responsive to said error signals further includes motor means responsive to said control signals and coupled to said plane reflector for selectively rotating said plane reflector to reduce said deflection errors.

* * * * *