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(54) **MAIN BEAM ALIGNMENT VERIFICATION
FOR TRACKING ANTENNAS**

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455/115.1–115.4, 226.1–226.4; 343/703,
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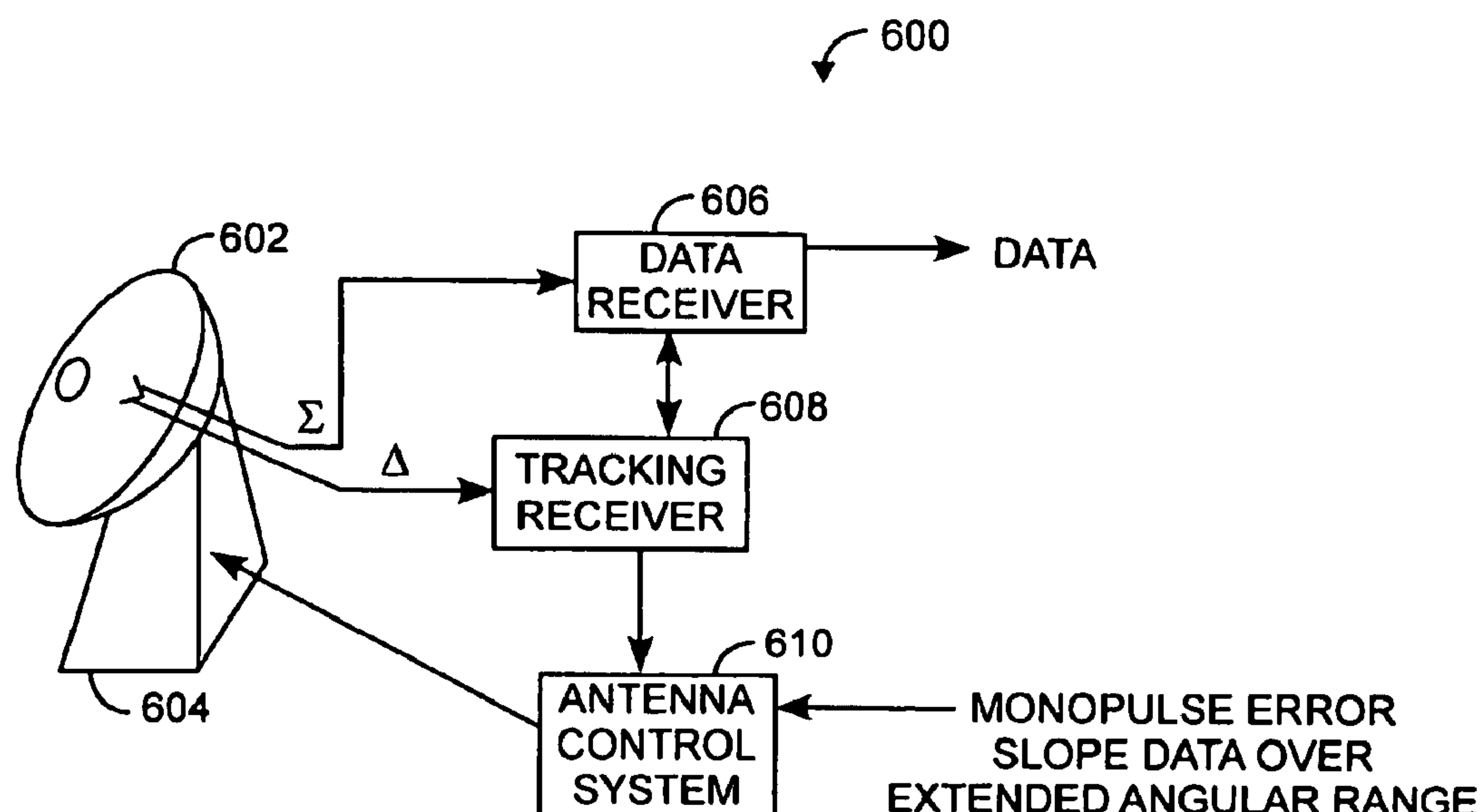
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(57) **ABSTRACT**

A method for main beam alignment verification includes providing data pertaining to one or more patterns associated with an antenna, measuring power levels of a signal acquired by the antenna, and comparing the measured power levels with the data to determine whether a direction of the signal is incident upon a main beam of the antenna.

49 Claims, 5 Drawing Sheets



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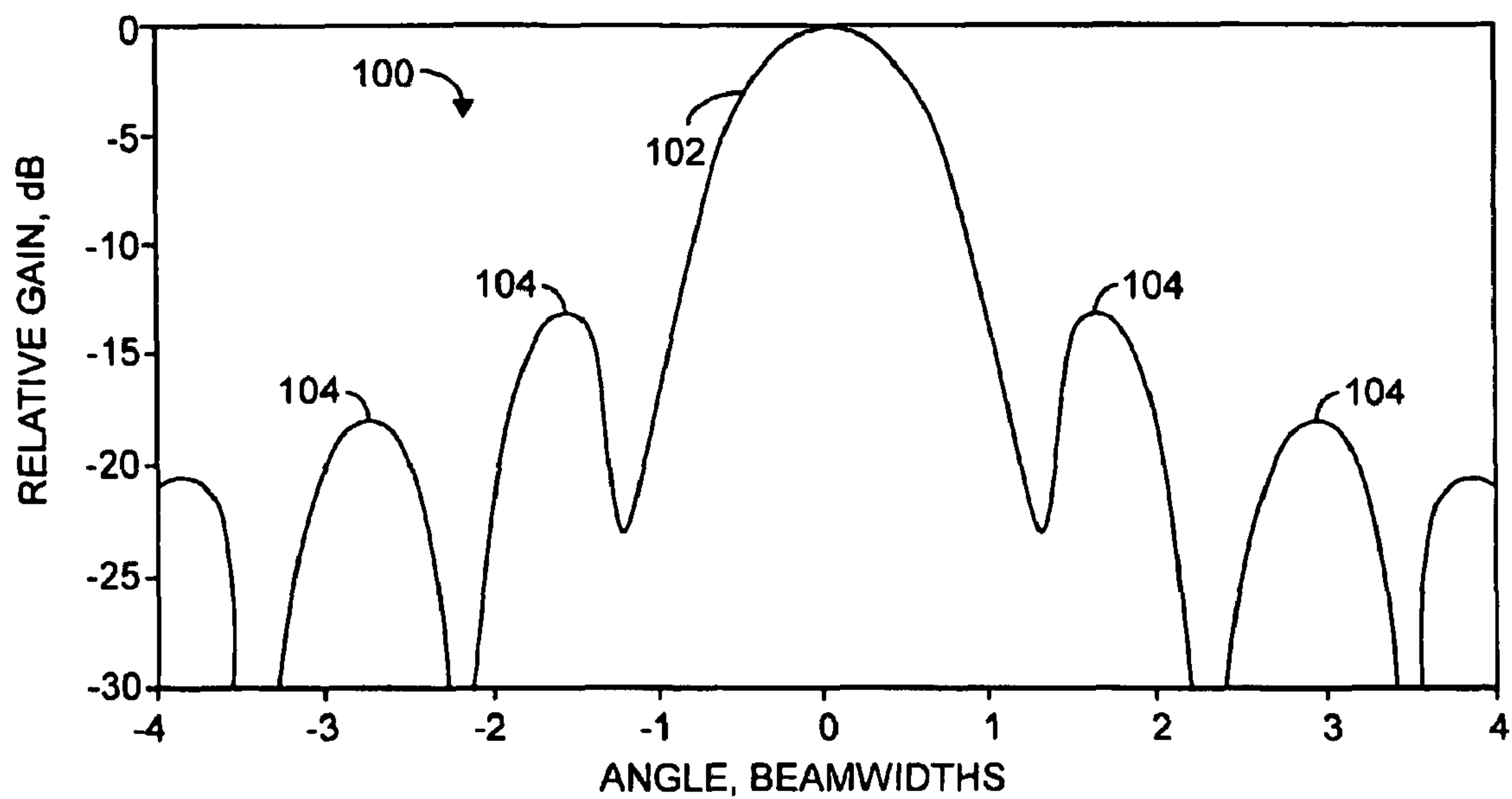


FIG. 1

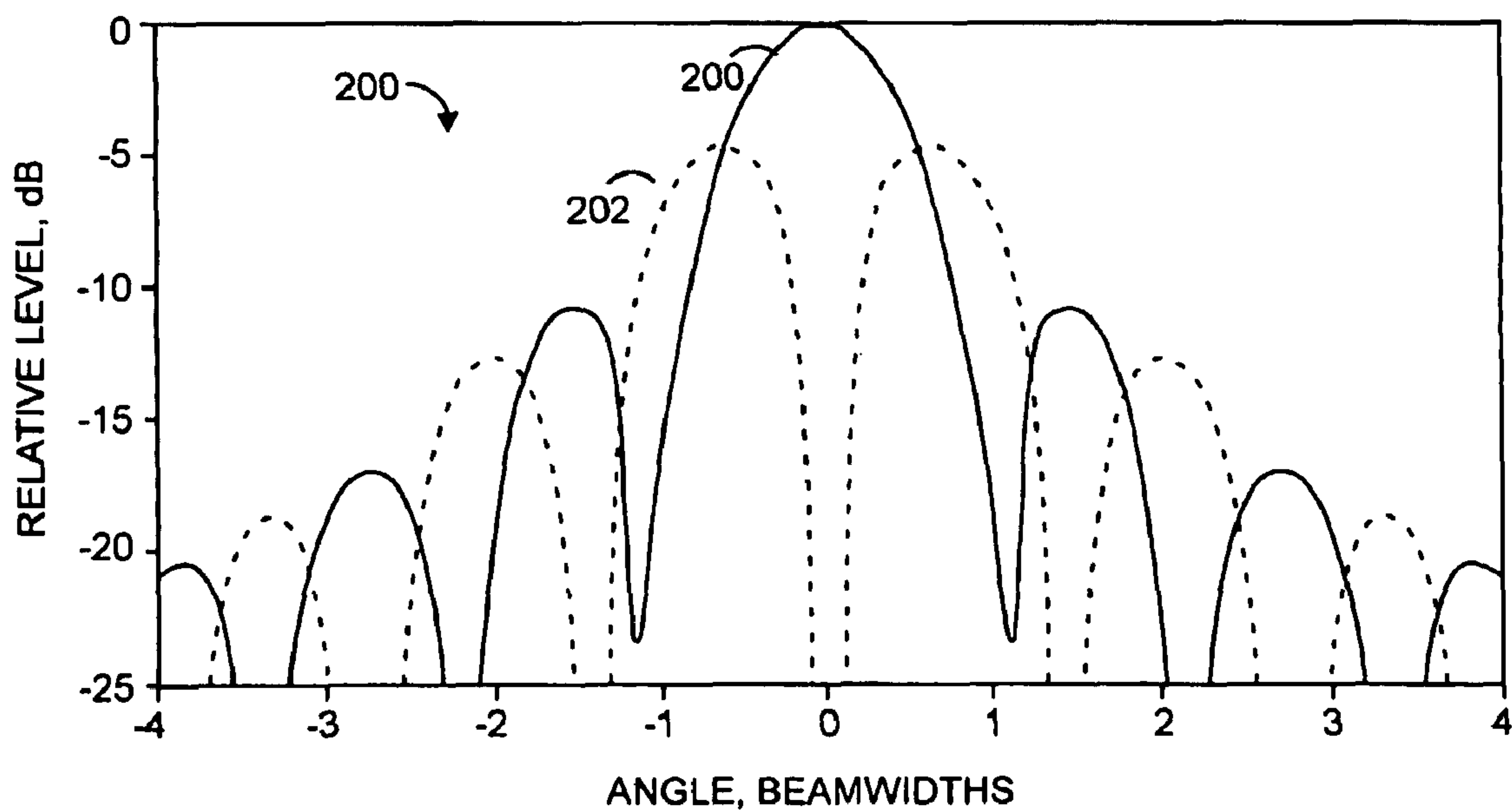


FIG. 2

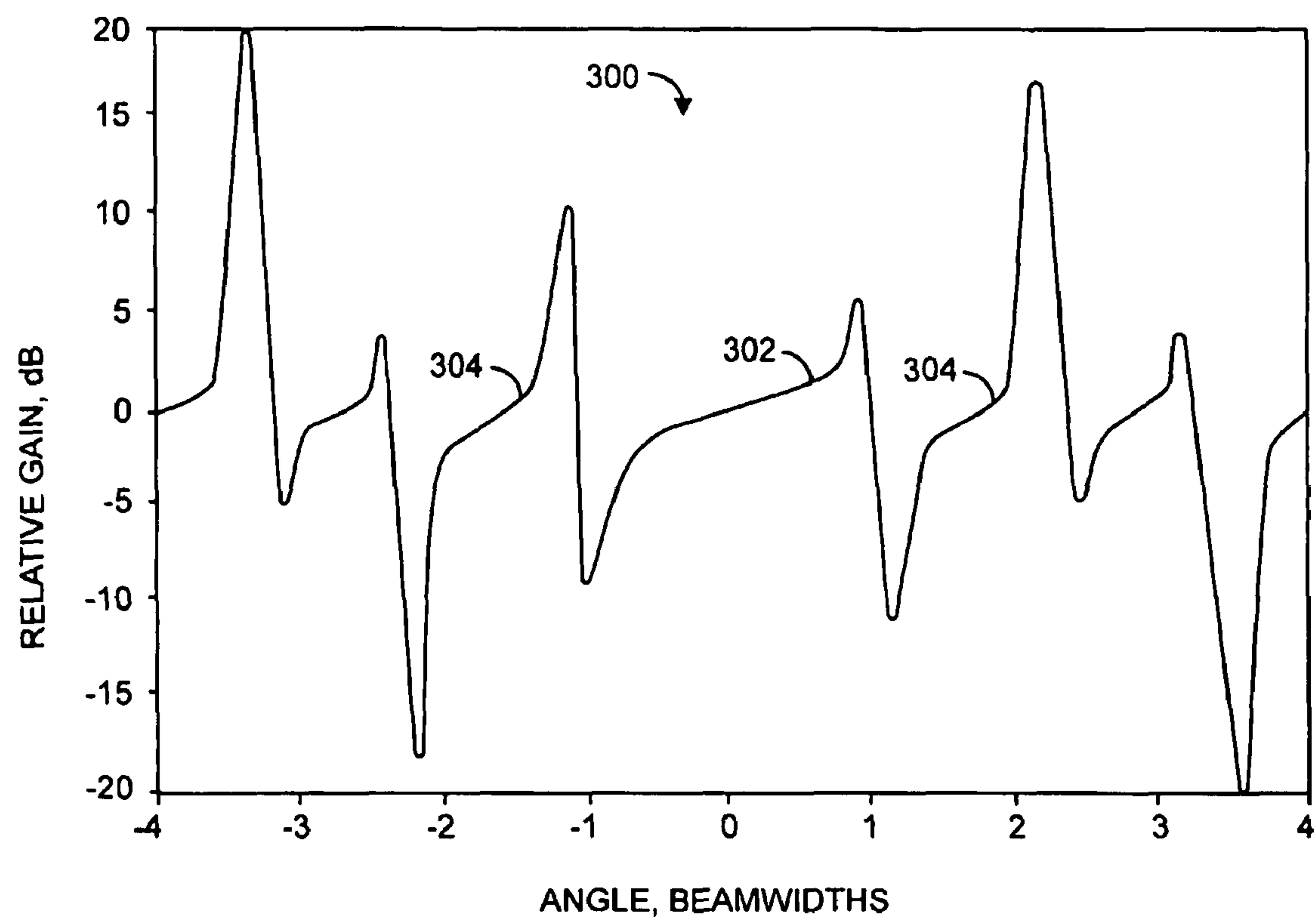


FIG. 3

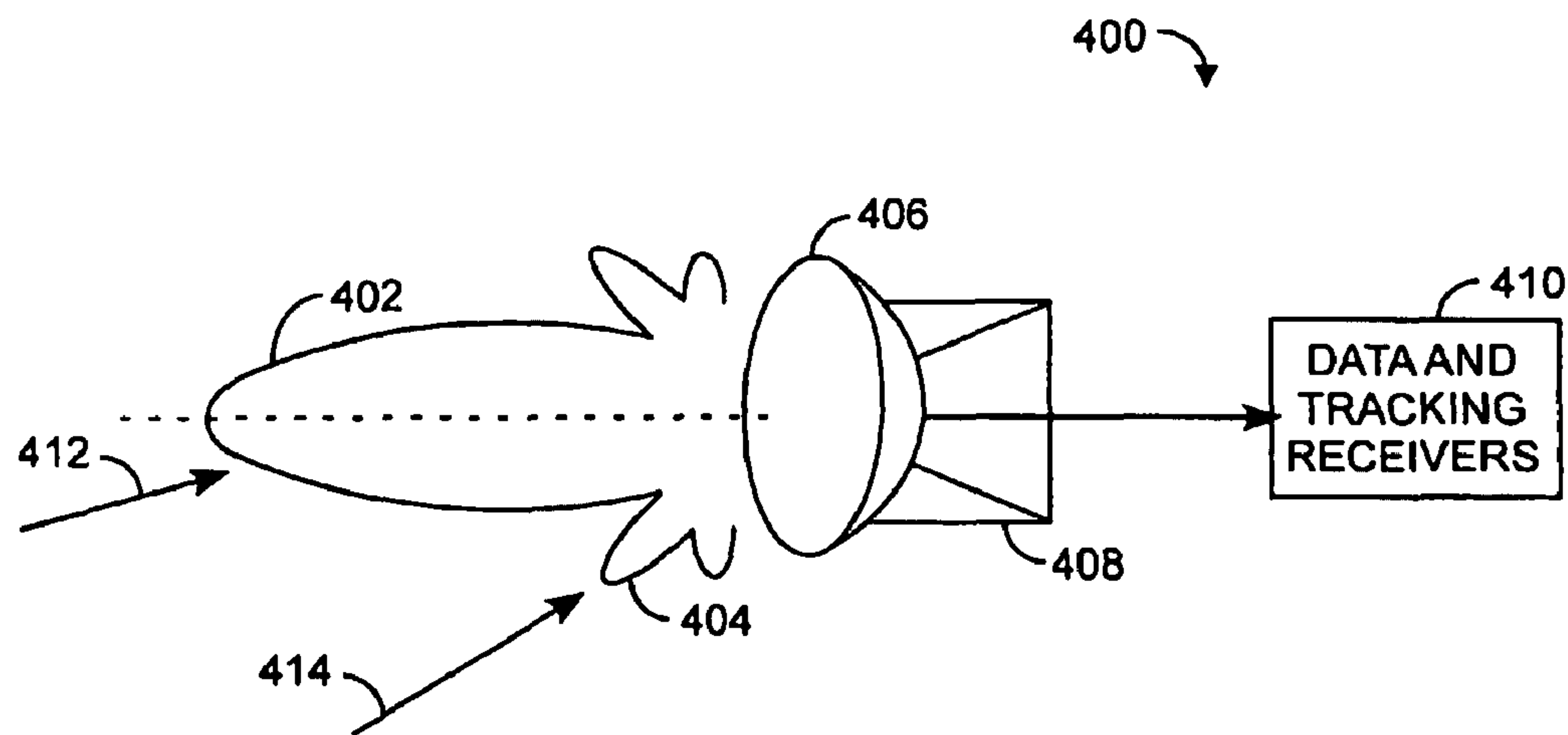


FIG. 4

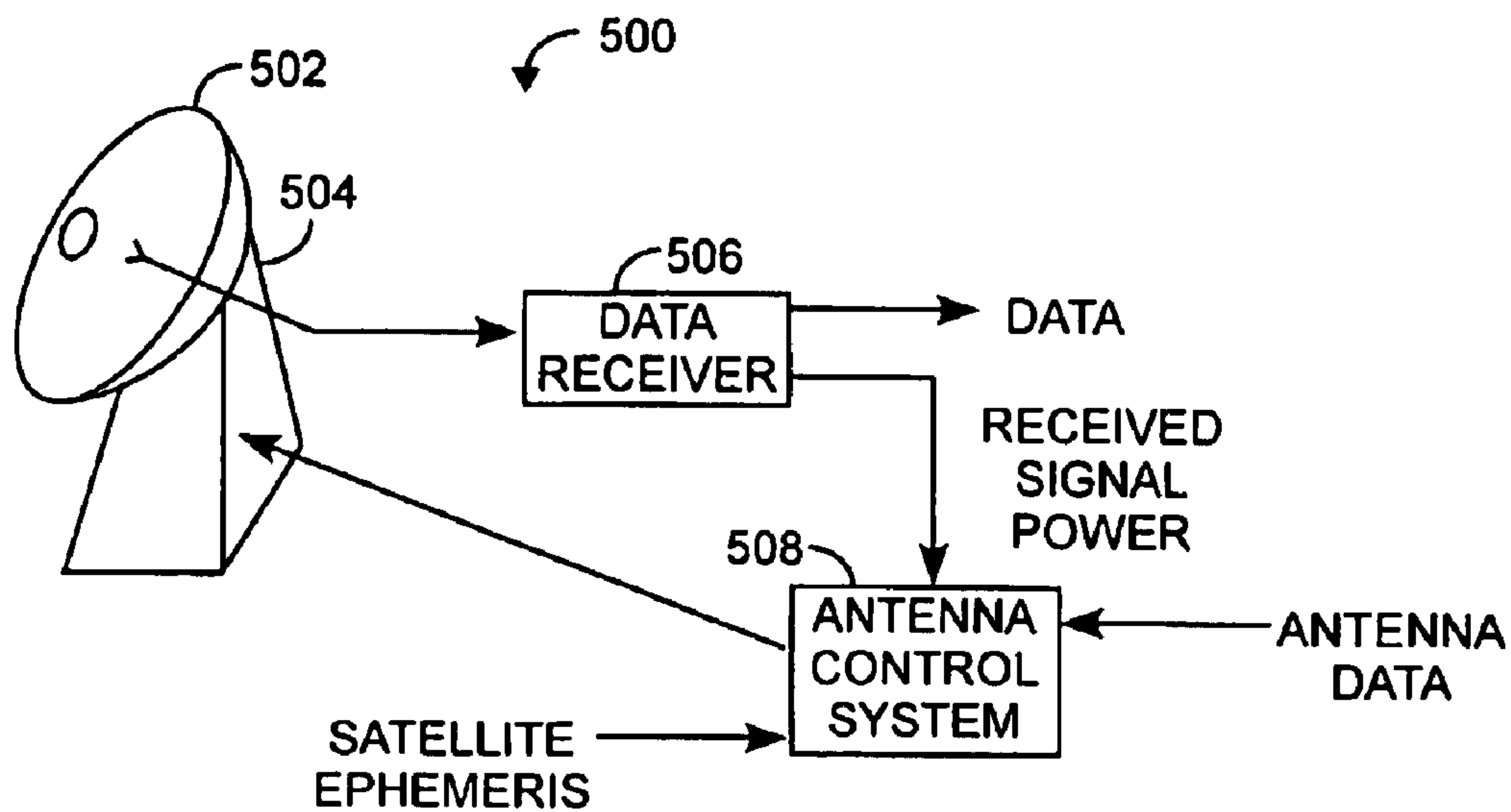


FIG. 5

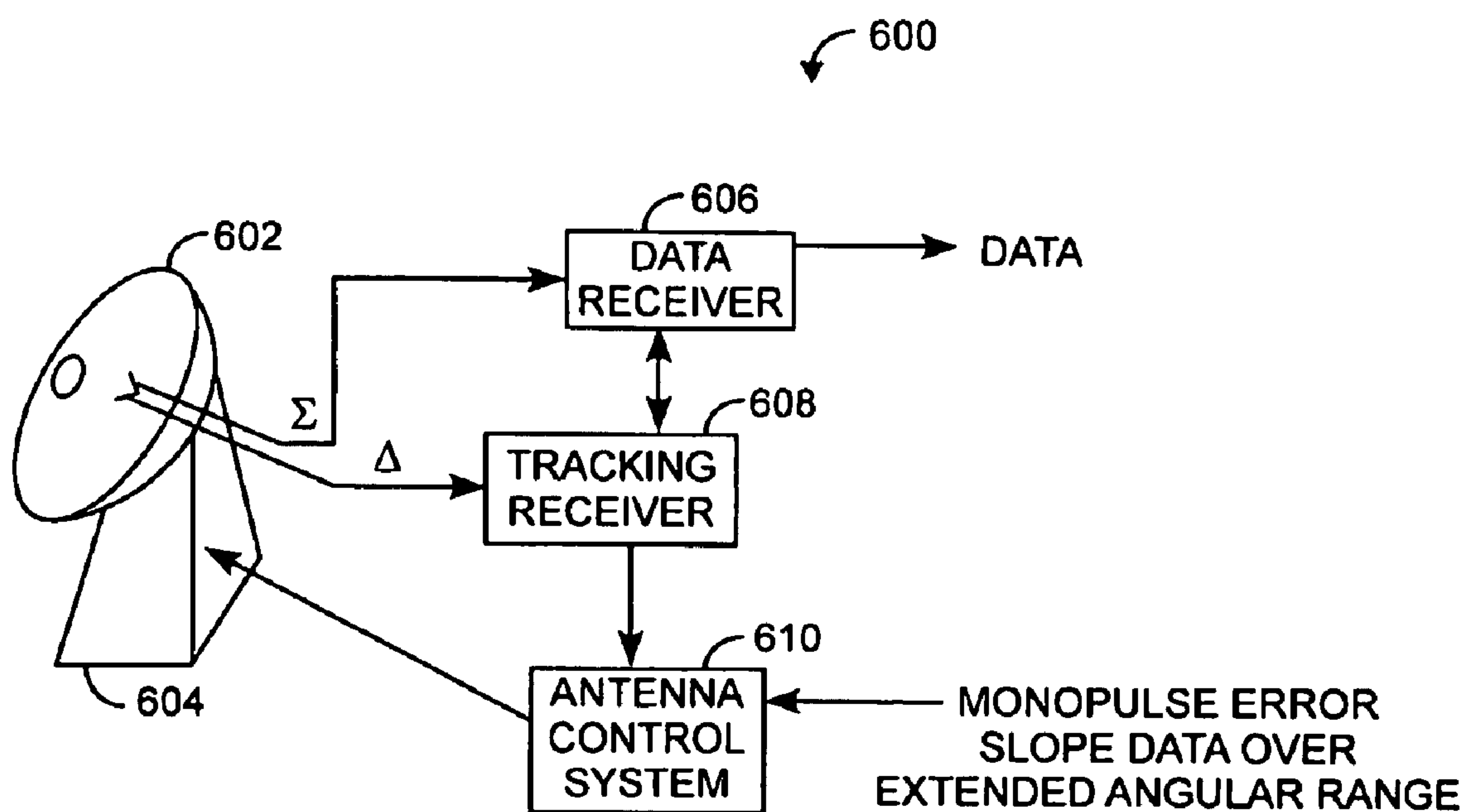


FIG. 6

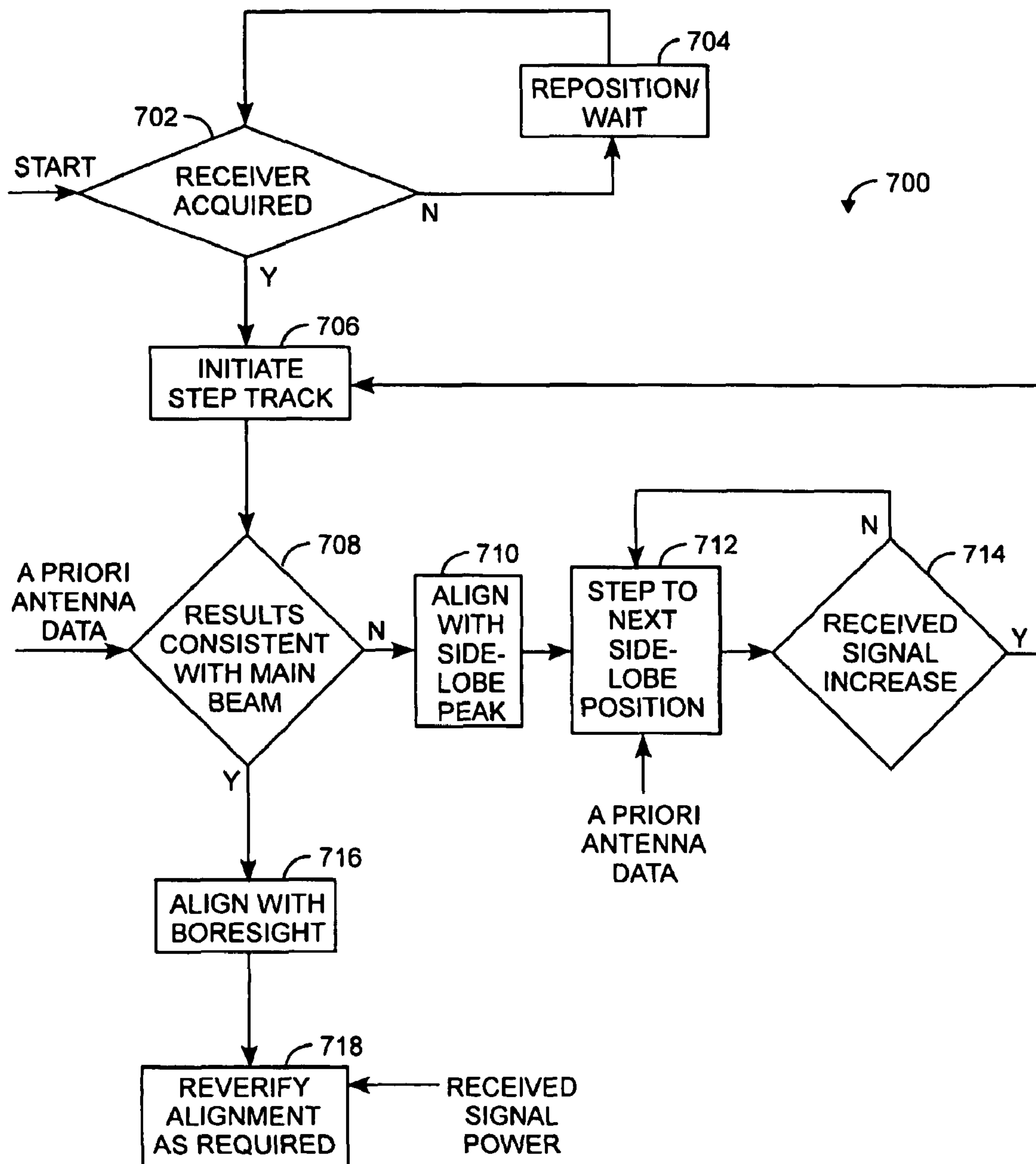


FIG. 7

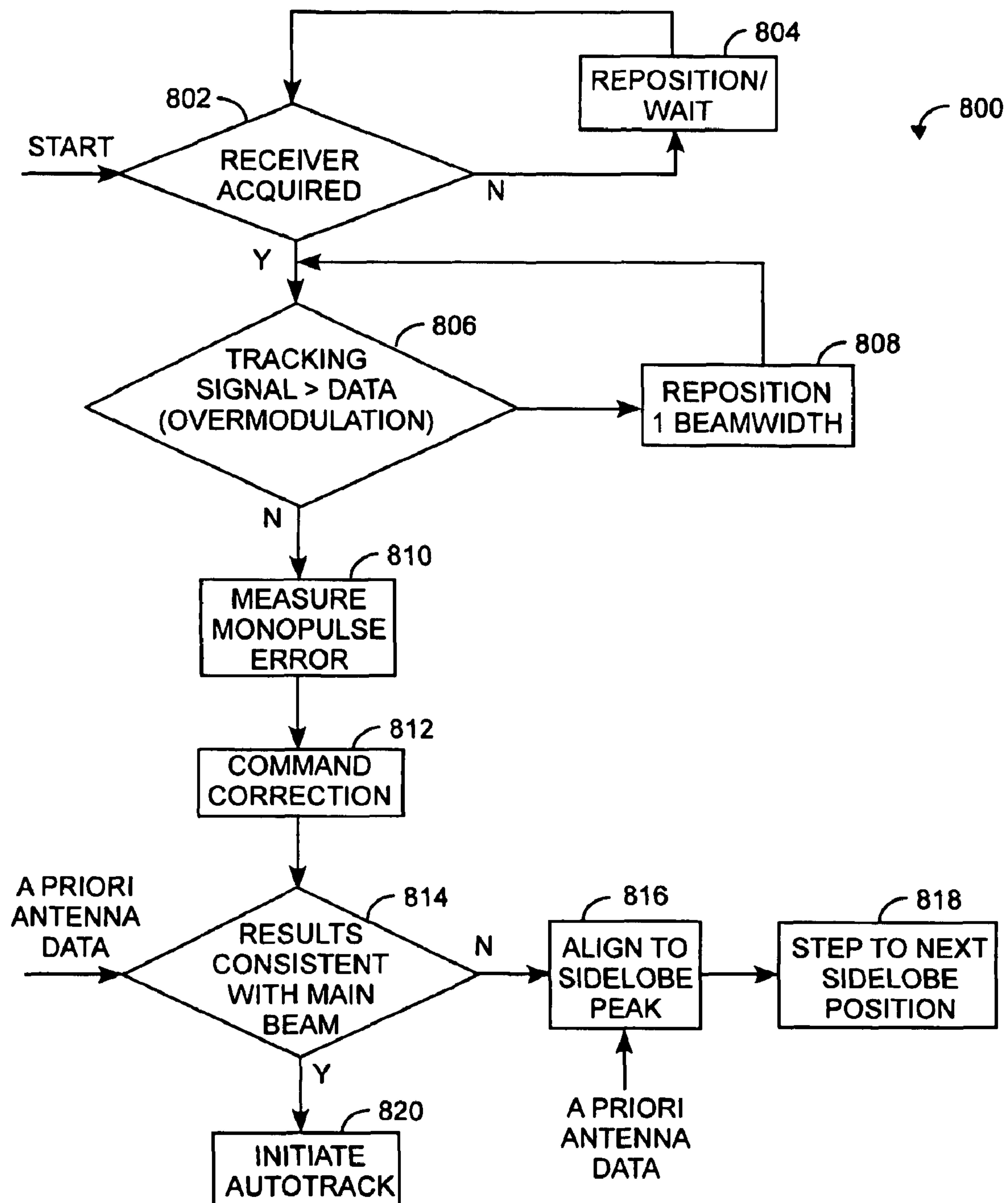


FIG. 8

MAIN BEAM ALIGNMENT VERIFICATION FOR TRACKING ANTENNAS

Matter enclosed in heavy brackets [] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

TECHNICAL FIELD

The invention relates generally to antenna tracking and, in particular, to main beam alignment verification for angle tracking antennas.

BACKGROUND ART

Tracking antenna systems dynamically follow changes in a direction of a received signal, and position a tracking antenna to align the signal with the peak level of the main beam of the tracking antenna. Such signal alignment results in coincidence of the signal and a portion of the main beam that provides maximum antenna gain and thus system sensitivity.

Various approaches to antenna tracking involve aligning the main beam peak of an antenna with the signal by using open commanding and relative power measurements. One example, referred to as "step track," involves positioning an antenna in a nominal direction, and commanding the antenna in equal but opposite angular offsets and measuring received signal power at each offset position. If the received signal power levels are equal, the antenna is correctly aligned. If the received power levels are unequal, the difference in the power levels can be used to correct the antenna alignment. The process is repeated in the orthogonal plane. The step track technique is periodically repeated to validate correct antenna alignment and to follow any changes in the direction of the signal.

Other approaches to antenna tracking involve a closed loop technique referred to as "monopulse." Two types of antenna patterns are used in such techniques. The first type of pattern has a maximum gain value that is coincident with the axis of the antenna, and is used for data reception. The second type of pattern has a null on the axis of the antenna and, to first order, has a linear variation with displacements from the axis and typically a phase difference between the data pattern and the tracking pattern that coincides with the azimuth angle of the signal direction. This behavior, the linear increase with deviation from axis and the phase difference, is used by an antenna control unit as an error signal, thereby permitting implementation of a closed loop tracking system that dynamically follows changes in the direction of the signal.

Unfortunately, these angle-tracking techniques depend upon initial antenna pointing (prior to initiation of antenna tracking) to align the signal within the main beam angular extent of the antenna. In some cases, however, such alignment is not assured.

One prior method for verifying this alignment involves using a smaller guard antenna together with the larger main antenna that is used for data reception. In practice, the smaller antenna is about $\frac{1}{10}$ the diameter of the main antenna to obtain the required gain and pattern characteristics to envelope the sidelobes of the main antenna. The signal levels received by the main antenna and the guard antenna are then compared. If the signal level of the main antenna exceeds the signal level of the guard antenna, the antenna is aligned within the main beam where the main antenna gain is higher than the gain of the guard antenna. If the signal level of the main

antenna is comparable or less than the signal level of the guard antenna, then the signal is aligned with sidelobes of the main antenna.

In addition to requiring a second antenna, another short-fall of this technique is that the boresight of the guard antenna needs to be maintained coincident with the main antenna. Moreover, the smaller guard antenna needs to be mechanically isolated from the main antenna to avoid deforming the main antenna and its patterns, and the mechanical balance of the assembly needs to be maintained. When the received signal level fluctuates, as commonly occurs with multipath at low elevation angles, the guard antenna requires a second tracking receiver so that the signal levels in the guard and main antennas can be simultaneously measured. Aside from the expense of an additional tracking receiver, the two receivers need to be reliably calibrated so that the same received power level results in the same indicated signal levels. This calibration is needed so that the signal level comparison can be used to reliably verify main beam alignment. Additionally, for large antennas that require a protective radome to avoid pointing errors caused by wind loading, a larger radome that envelops both the main and guard antennas is significantly more expensive than a radome for the main antenna alone.

Thus, it would be useful to be able to provide a main beam alignment verification alternative to the prior approaches. It would also be desirable to be able to provide a cost effective method for verifying the main beam alignment of received signals. It would also be useful to be able to provide a mechanism for verifying main beam alignment without imposing additional hardware capabilities, i.e., using existing antenna hardware.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a plot showing a typical antenna pattern for a data channel;

FIG. 2 is a plot showing examples of data (sum) and tracking (difference) patterns;

FIG. 3 is a plot of an example monopulse error response;

FIG. 4 illustrates an example of an antenna tracking system and signals arriving at different angles relative to a main beam and a side lobe, which are shown in cross-section;

FIG. 5 illustrates an example open loop antenna tracking system;

FIG. 6 illustrates an example closed loop antenna tracking system;

FIG. 7 is a flowchart of an example method for open loop antenna tracking; and

FIG. 8 is a flowchart of an example method for closed loop antenna tracking.

DISCLOSURE OF INVENTION

Various methods for verifying main beam alignment according to the present invention generally involve measuring the width of the lobe containing the received signal. As shown in FIG. 1, in a typical antenna pattern 100 for a data channel, the angular width of the main beam 102 of the antenna is roughly twice the angular width of the sidelobes 104 of the antenna. In an example embodiment, open loop commanding is used to measure the width of the lobe containing the received signal and provides a mechanism for verifying main beam alignment. By way of example, such an embodiment can be used with antenna tracking methods that utilize open loop techniques.

As discussed below, various embodiments can be implemented with existing antenna hardware operated in conjunc-

tion with appropriate software controls and received power measurements. Furthermore, the methods described herein do not require a guard antenna and, therefore, do not require the additional aperture needed for the guard antenna or an additional tracking receiver to measure the signal levels received by the guard antenna.

FIG. 4 illustrates an example of an antenna tracking system 400 and signals arriving at different angles relative to a main beam 402 and a sidelobe 404. The antenna tracking system 400 include an antenna 406 (e.g., a reflector antenna), an antenna positioner 408 and data and tracking receivers 410 as shown. In this example, an arrow 412 indicates a signal arrival direction incident upon the main lobe 402 as shown. An arrow 414 indicates a signal arrival direction incident upon the sidelobe 404 as shown.

Referring to FIG. 5, an example open loop antenna tracking system 500 exploits the circumstance that the angular width of the main beam is roughly twice that of the sidelobes. In this embodiment, the difference in the angular widths of the main beam and the sidelobes is used to verify main beam alignment.

The example open loop antenna tracking system 500 includes an antenna 502, a positioner 504, a data receiver 506 and an antenna control system 508, configured as shown. The antenna control system 508 is provided with a received signal power input from the data receiver 506. In this example embodiment, satellite ephemeris and antenna data inputs are also provided to the antenna control system 508.

In operation, after the data receiver 506 acquires the signal, a signal level measurement is made. A typical received signal level indication is the automatic gain control (AGC) voltage of the receiver. The antenna 502 is then offset in equal angular increments in opposite directions and the received power levels at each offset position are measured using a step track procedure, for example. In this example embodiment, the measured power levels are used for an additional purpose. The three measured power levels, at the initial acquisition point and the two angularly displaced positions, are then compared to the a priori known main beam shape and the sidelobe shape of the antenna 502. The a priori antenna data and the measured power levels are processed by the antenna control system 508 which includes, for example, a main beam search algorithm in firmware and step track decision logic for sidelobe determination. Because the angular width of the sidelobes is less than that of the main beam, the power level changes at the angular offset positions are more drastic than those at the main beam. By this comparison of the three power levels with the a priori antenna pattern data, decisions are made as to main beam alignment or sidelobe alignment. In this example embodiment, the process is then repeated in an orthogonal direction.

FIG. 7 shows an example open loop antenna tracking method 700. At step 702, a determination is made as to whether the receiver has acquired a signal. If the determination is negative, at step 704, the antenna is repositioned and acquisition reattempted until successful. At step 706, step track is initiated to make the power measurements as discussed above. At step 708, the measured power levels are compared to the a priori antenna data and a determination is made as to whether a received signal appears to be incident upon the main beam. If this determination is negative, then at step 710 the antenna is aligned with the sidelobe peak. Once aligned with the sidelobe peak, at step 712 the antenna is stepped to the next sidelobe peak using an open loop command. In this example embodiment, the a priori antenna pattern is used for this process, and typically the antenna step size is about one and one-half beamwidths between sidelobe peak

positions. At step 714, a determination is made as to whether the received signal increases in strength and step 712 is repeated until this determination is affirmative. If the open loop repositioning command encounters the main beam of the antenna, the antenna will not be aligned with the main beam peak but will be sufficiently high on the main beam to provide a clear indication of main beam alignment. At step 716, the received signal is aligned with boresight. At step 718, this alignment is re-verified using, for example, either a step track or a monopulse monitoring technique.

In an example embodiment, open loop commanding techniques are used to find the main beam. By using an open loop command to the next sidelobe peak and/or the main antenna beam, there may be sufficient received signal power to maintain receiver acquisition, and therefore it will not be necessary to move the antenna and try to reacquire the receiver. If the tracking receiver has not acquired, a two-dimensional raster scan (e.g., in azimuth and elevation) can be used. In such a case, once the tracking receiver has acquired, the open loop commanding for antenna repositioning can be used.

Other information can be used in the above search process. For example, in some cases, an estimate of the nominal signal level may be available. Also by way of example, when an acquisition at low elevation angles is being performed, the search for the main beam can exclude those antenna positions where the main beam would be positioned below the horizon.

Signal level fluctuations can have an impact on open loop antenna tracking techniques. Multipath is a common cause of such fluctuations that occurs at low elevation angles. For step track, the fluctuations can be reduced by dwelling at each angular position for a sufficient amount of time to average the power measurements. Averaging at low elevation angles may have limited effectiveness in cases where the multipath has a strong specular component. Averaging, particularly in the elevation coordinate, is less effective since the average of the direct signal and the multipath component has a non-zero mean value. It is generally more effective to average in the azimuth coordinate. An alternative approach is to wait until the satellite has increased in its elevation angle and the spatial filtering of the pattern of the receive antenna reduces multipath. When the satellite is higher above the horizon, a further search for the main beam can be conducted at the anticipated position of the satellite at that time. The main beam acquisition verification method described above can be used for open loop tracking designs using step track techniques or with closed loop monopulse-based tracking designs.

In an example embodiment, a method for main beam alignment verification includes providing data including main beam and sidelobe angular widths for an antenna, measuring power levels of a signal acquired by the antenna at multiple antenna positions, and comparing the measured power levels with the data to determine whether a direction of the signal is incident upon a main beam of the antenna.

In another example embodiment, a method for main beam alignment verification includes providing data pertaining to one or more patterns associated with an antenna, measuring power levels of a signal acquired by the antenna, and comparing the measured power levels with the data to determine whether a direction of the signal is incident upon a main beam of the antenna.

Various methods for verifying main beam alignment according to the present invention involve examining monopulse error response. Referring to FIG. 6, an example closed loop antenna tracking system 600 exploits a monopulse-based design and includes an antenna 602, a positioner 604, a data receiver 606, a tracking receiver 608 and an antenna control system 610, configured as shown. In an

5

example embodiment, a monopulse error response is examined and serves as a basis to decide whether the antenna is aligned within the main beam. By way of example, such an embodiment can be used to verify main beam alignment prior to initiating a closed loop tracking operation. Also by way of example, such an embodiment can be used with antenna tracking methods that utilize monopulse-tracking techniques.

FIG. 2 is a plot showing examples of a data (sum) pattern **200** and a tracking (difference) pattern **202** (in dashed lines) for a typical antenna. In this example, the main beam peak of the data pattern **200** is coincident with the null of the tracking pattern **202**. Referring to FIG. 3, over the same angular region, a monopulse error response **300** results from dividing the tracking pattern **202** by the data pattern **200**. The actual values depend on the difference in the path loss between the data and tracking channel and the coupler coefficient.

In an example embodiment, a determination is made as to whether a measured monopulse output is consistent with the main beam. By way of example, the monopulse error response is determined a priori by measurements and/or analyses of the tracking system for the antenna. In an example embodiment, the monopulse error response is determined over the linear error response of the main lobe (which for practical antenna designs is typically somewhat less than the width of the main beam as shown in FIG. 3) and also out into the sidelobe regions; this extended response provides a data base that is used to verify main beam alignment. A common implementation couples a small portion of the tracking signal onto the data signal. The tracking signal is switched to quadrature positions and when added to the data signal, produces an amplitude modulation indicating antenna misalignment that is acted on by the antenna control system.

In an example main beam alignment method, a determination is made as to whether indicated tracking error behavior corresponds to variations that result in the main beam of the antenna. FIG. 8 shows an example closed loop antenna tracking method **800**. At step **802**, a determination is made as to whether the receiver has acquired a signal. If the determination is negative, at step **804**, the antenna is repositioned and acquisition reattempted until successful. As shown in FIG. 2, the data and tracking antenna patterns indicate regions within the sidelobe response of the antenna where the tracking pattern **202** can exceed the data pattern **200** and overmodulation occurs. At step **806**, a determination is made as to whether modulation values are within a range resulting from antenna positions within the main beam. If an overmodulation is present, at step **808** the antenna is repositioned (e.g., one beamwidth) until a modulation condition is detected. If the modulation level lies within a range that is credible for the antenna, the antenna can be open loop commanded to a position that corresponds to the boresight location for the main beam. In this example embodiment, at step **810** the monopulse error is measured, and at step **812** the position correction is commanded. At step **814**, if the open loop repositioning results in the expected reduction of the modulation from the tracking channel consistent with the a priori antenna data for the main beam of the antenna, then the system does indeed have alignment within the main beam. As shown in FIG. 3, the error slope within the main beam region **302** is less than the error slope when a linear region exists within the sidelobe regions **304** of the antenna. If the determination at step **814** is negative, a sidelobe of the antenna is aligned with the signal. Then, at step **816** the a priori antenna data is used to align the antenna to the sidelobe peak, and the antenna is stepped to the next sidelobe position until the results of the

6

determination made in step **814** are consistent with main beam positioning. Then, at step **820** closed loop operation (e.g., autotrack) is initiated.

As discussed above, open loop pointing techniques can be used to realign the antenna with the main beam. The monopulse error response can also be used to realign the antenna to its main beam of the data pattern. As with the open loop tracking technique, measurement and/or analyses can be used to determine the monopulse error response and knowledge of this response can be used in open loop commanding to determine the realignment. Linear regions of the monopulse error response also coincide with the sidelobe peaks, and open loop commanding can be used to reposition the antenna to realign the antenna. Open loop commanding can be used in conjunction with determining whether an error slope corresponds to a value within the main beam or within the sidelobes. If the system has a closed loop monopulse-based tracking system, a combination of the approaches described herein can be used to obtain a further assurance of main beam acquisition.

In an example embodiment, a method for main beam alignment verification includes providing data including monopulse error responses for a main beam region and sidelobe regions of an antenna, measuring power levels of a signal acquired by the antenna at multiple antenna positions, and comparing the measured power levels with the data to determine whether a direction of the signal is incident upon a main beam of the antenna.

Although the present invention has been described in terms of the example embodiments above, numerous modifications and/or additions to the above-described embodiments would be readily apparent to one skilled in the art. It is intended that the scope of the present invention extend to all such modifications and/or additions.

We claim:

1. A method for main beam alignment verification, comprising:

[providing data pertaining to one or more patterns associated with an antenna;]

measuring, *at at least one data receiver*, power levels of a signal acquired by [the] *an* antenna; [and]

comparing, *at at least one antenna control system*, the measured power levels with [the] *data pertaining to one or more patterns associated with the antenna*; and

[to determine] *determining, at the at least one antenna control system*, whether a direction of the signal is incident upon a main beam of the antenna *based on the comparison*.

2. The method for main beam alignment verification of claim 1, wherein the one or more patterns include a data pattern.

3. The method for main beam alignment verification of claim 1, wherein the one or more patterns include data and tracking patterns.

4. The method for main beam alignment verification of claim 1, wherein the data includes main beam and sidelobe angular widths for the antenna.

5. The method for main beam alignment verification of claim 1, wherein the data includes monopulse error responses for a main beam region and sidelobe regions of the antenna.

6. The method for main beam alignment verification of claim 1, wherein the data is a priori.

7. The method for main beam alignment verification of claim 1, wherein multiple samples of the measured power levels at a common antenna position are averaged.

7

8. The method for main beam alignment verification of claim 1, wherein power levels measured in the azimuth coordinate are averaged.

9. A method for main beam alignment verification, comprising:

[providing data including main beam and sidelobe angular widths for an antenna;]

measuring, *at at least one data receiver*, power levels of a signal acquired by [the] *an antenna* at multiple antenna positions; [and]

comparing, *at at least one antenna control system*, the measured power levels with [the] *data pertaining to one or more patterns associated with the antenna*; and

[to determine] *determining, at the at least one antenna control system*, whether a direction of the signal is incident upon a main beam of the antenna *based on the comparison*.

10. The method for main beam alignment verification of claim 9, wherein the data is a priori.

11. The method for main beam alignment verification of claim 9, wherein multiple samples of the measured power levels at a common antenna position are averaged.

12. The method for main beam alignment verification of claim 9, wherein power levels measured in the azimuth coordinate are averaged.

13. The method for main beam alignment verification of claim 9, further including using the data to reposition the antenna.

14. The method for main beam alignment verification of claim 9, further including using the data to reposition the antenna after a determination has been made that the signal is not incident upon the main beam.

15. The method for main beam alignment verification of claim 9, further including using the data to reposition the antenna to align the signal with a sidelobe of the antenna.

16. A method for main beam alignment verification, comprising:

[providing data including monopulse error responses for a main beam region and sidelobe regions of an antenna;]

measuring, *at at least one data receiver and at least one tracking receiver*, power levels of a signal acquired by [the] *an antenna* at multiple antenna positions; and

comparing, *at at least one antenna control system*, the measured power levels with [the] *data pertaining to one or more patterns associated with the antenna and including monopulse error responses for a main beam region and sidelobe regions of the antenna*; and

[to determine] *determining, at the at least one antenna control system*, whether a direction of the signal is incident upon a main beam of the antenna *based on the comparison*.

17. The method for main beam alignment verification of claim 16, wherein the monopulse error responses are determined from data and tracking patterns of the antenna.

18. The method for main beam alignment verification of claim 16, wherein the data is a priori.

19. The method for main beam alignment verification of claim 16, further including using the data to reposition the antenna.

20. The method for main beam alignment verification of claim 16, further including using the data to reposition the antenna after a determination has been made that the signal is not incident upon the main beam.

21. The method for main beam alignment verification of claim 16, further including using the data to reposition the antenna to align the signal with a sidelobe of the antenna.

8

22. A system for determining main beam and sidelobe alignment, comprising:

an antenna for acquiring a signal and outputting a received signal;

a positioner for rotating the antenna to offset positions;

a data receiver for receiving the received signal and outputting data and power of the received signal; and

an antenna control system for controlling the positioner and for processing outputs of the data receiver and a priori data,

wherein the offset positions of the antenna are spaced apart in opposite directions and with equal angular widths, and the system is configured to measure received signal power upon initially acquiring the signal and at each of the offset positions, compare the measured received signal powers with a priori antenna data, and determine main beam and sidelobe alignment based on the comparison.

23. The system of claim 22, wherein the a priori antenna data is a main beam shape and a sidelobe shape.

24. The system of claim 23, wherein the a priori antenna data further comprises satellite ephemeris data.

25. The system of claim 22, wherein the received signal power is measured at each of the offset positions and when the signal is initially acquired with a step track procedure.

26. The system of claim 25, wherein the antenna control system further comprises logic for the step track procedure.

27. The system of claim 22, wherein an automatic gain control signal of the data receiver provides the received signal power.

28. A system for determining main beam and sidelobe alignment comprising:

an antenna for acquiring a signal and outputting a received sum signal and received difference signal;

a positioner for rotating the antenna to offset positions;

a data receiver for outputting data and power of the received sum signal;

a tracking receiver for tracking the received difference signal and outputting power of the received difference signal; and

an antenna control system for controlling the positioner and for processing outputs of the tracking receiver and a priori antenna data,

wherein the offset positions of the antenna are spaced apart in opposite directions with equal angular widths and, received sum signal power is measured upon initially acquiring the signal and at each of the offset positions, the measured received sum signal powers are compared with the a priori antenna, and main beam and sidelobe alignment are determined based on the comparison.

29. The system of claim 28, wherein the a priori antenna data is monopulse error slope data over extended angular range.

30. The system of claim 28, wherein the received sum signal power at each of the offset positions and upon acquiring the signal is measured with a step track procedure.

31. The system of claim 30, wherein the antenna control system further comprises logic for the step track procedure.

32. A non-transitory computer-readable medium containing executable instructions that, when executed by a machine, cause the machine to implement a method for main beam alignment verification, comprising:

receiving measured power levels of a signal acquired by an antenna;

accessing data pertaining to one or more patterns associated with the antenna;

comparing the measured power levels with the data pertaining to one or more patterns associated with the antenna;

determining whether a direction of the signal is incident upon a main beam of the antenna based on the comparison; and

commanding the antenna to be repositioned based on whether the direction of the signal is incident upon the main beam of the antenna.

33. The computer-readable medium of claim 32, wherein the one or more patterns include a data pattern.

34. The computer-readable medium of claim 32, wherein the one or more patterns include data and tracking patterns.

35. The computer-readable medium of claim 32, wherein the data includes main beam and sidelobe angular widths for the antenna.

36. The computer-readable medium of claim 32, wherein the data includes monopulse error responses for a main beam region and sidelobe regions of the antenna.

37. The computer-readable medium of claim 32, wherein execution of the instructions further comprises averaging multiple samples of the measured power levels at a common antenna position.

38. The computer-readable medium of claim 32, wherein execution of the instructions further comprises averaging power levels measured in the azimuth coordinate.

39. A non-transitory computer-readable medium containing executable instructions that, when executed by a machine, cause the machine to implement a method for main beam alignment verification, comprising:

receiving measured power levels of a signal acquired by an antenna at multiple antenna positions;

accessing data pertaining to one or more patterns associated with the antenna;

comparing the measured power levels with the data pertaining to one or more patterns associated with the antenna;

determining whether a direction of the signal is incident upon a main beam of the antenna based on the comparison; and

commanding the antenna to be repositioned based on whether the direction of the signal is incident upon the main beam of the antenna.

40. The computer-readable medium of claim 39, wherein execution of the instructions further comprises averaging of multiple samples of the measured power levels at a common antenna position.

41. The computer-readable medium of claim 39, wherein execution of the instructions further comprises averaging of power levels measured in the azimuth coordinate.

42. The computer-readable medium of claim 39, wherein execution of the instructions further comprises generating a positioner signal to reposition the antenna.

43. The computer-readable medium of claim 39, wherein execution of the instructions further includes generating a positioner signal to reposition the antenna after a determination has been made that the signal is not incident upon the main beam.

44. The computer-readable medium of claim 39, wherein execution of the instructions further comprises generating a positioner signal to reposition the antenna and to align the signal with a sidelobe of the antenna.

45. A non-transitory computer-readable medium containing executable instructions that, when executed by a machine, cause the machine to implement a method for main beam alignment verification, comprising:

receiving measured power levels to form measured error responses at multiple antenna positions;

accessing data pertaining to one or more patterns associated with the antenna and including monopulse error responses for a main beam region and sidelobe regions of an antenna;

comparing the measured error responses with the data pertaining to one or more patterns associated with the antenna and including monopulse error responses for a main beam region and sidelobe regions of the antenna;

determining whether a direction of the signal is incident upon a main beam of the antenna based on the comparison; and

commanding the antenna to be repositioned based on whether the direction of the signal is incident upon the main beam of the antenna.

46. The computer-readable medium of claim 45, wherein execution of the instructions further comprises determining the monopulse error responses from data and tracking patterns of the antenna.

47. The computer-readable medium of claim 45, wherein execution of the instructions further comprises generating a positioner signal to reposition the antenna.

48. The computer-readable medium of claim 45, wherein execution of the instructions further comprises generating a positioner signal to reposition the antenna after a determination has been made that the signal is not incident upon the main beam.

49. The computer-readable medium of claim 45, wherein execution of the instructions further comprises generating a positioner signal to reposition the antenna and to align the signal with a sidelobe of the antenna.

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