July 1, 1969 E. T. PHILLIPS **3,453,633**

BEAM POINTING AND GAIN CORRECTION OF LARGE SPHERICAL ANTENNAS

Filed May 3, 1966 Sheet 1 of 2

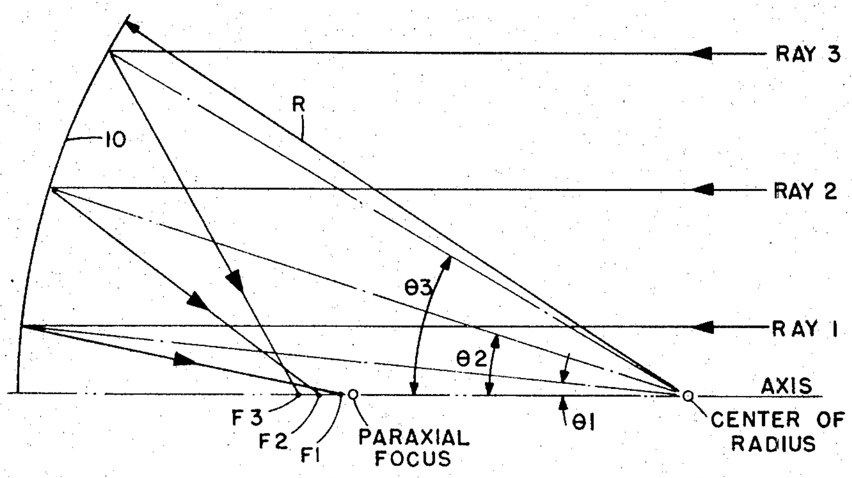

Fig. 1

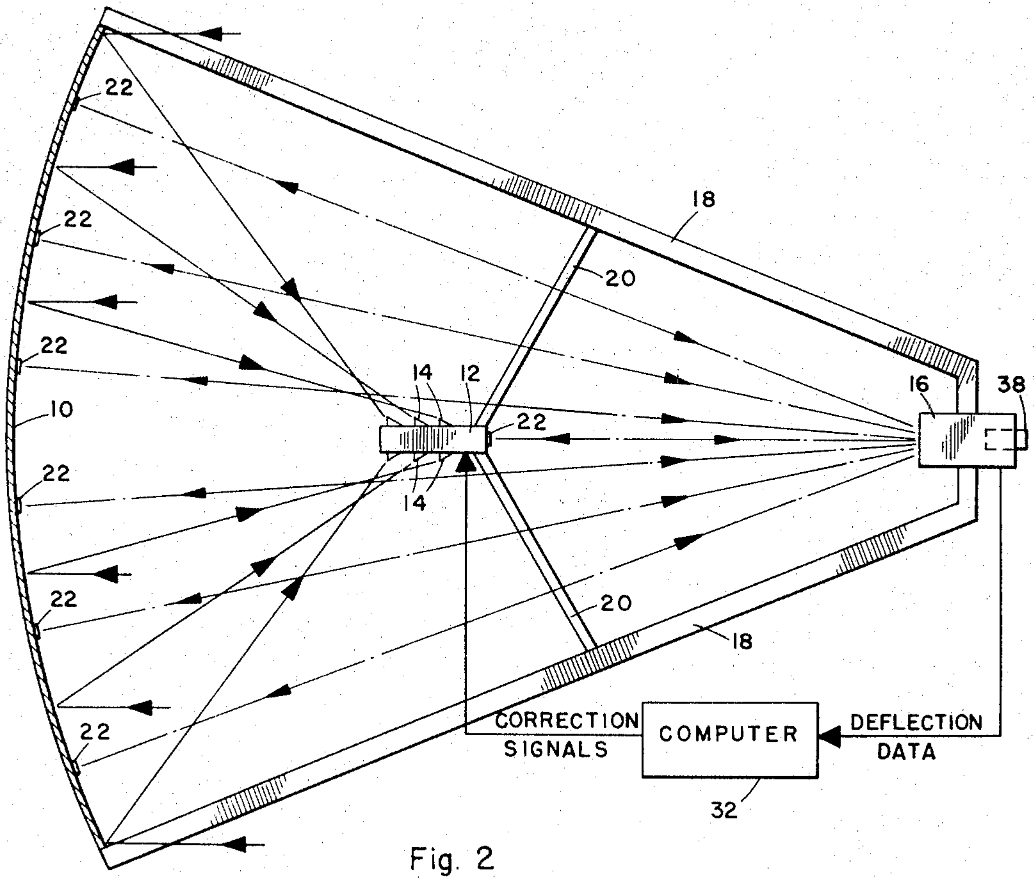

Fig. 2

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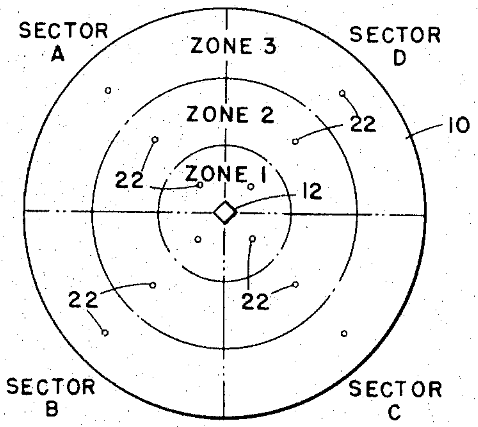

Fig. 3

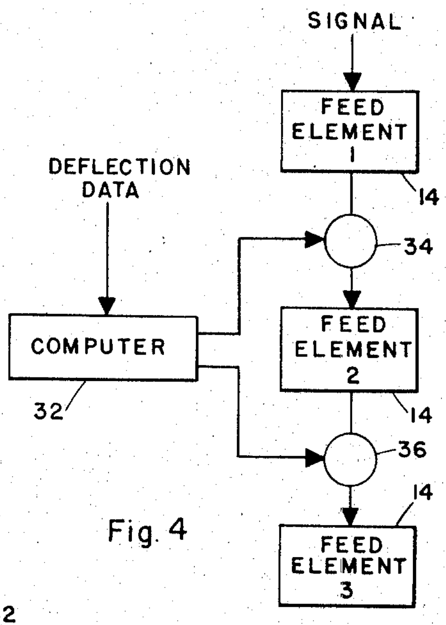

Fig. 4

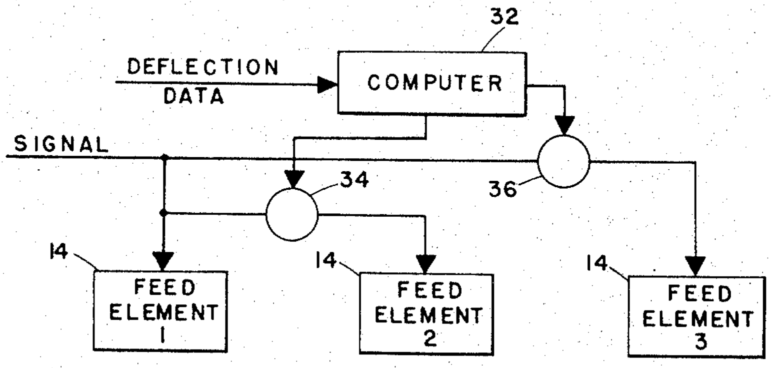

Fig. 5

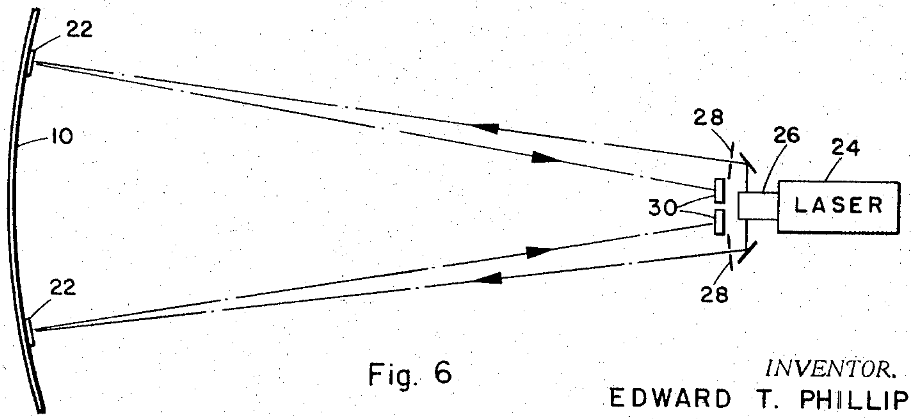

Fig. 6

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BEAM POINTING AND GAIN CORRECTION OF LARGE SPHERICAL ANTENNAS

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U.S. Cl. 343—779 **6 Claims**

The present invention relates to antennas and specifically to beam pointing and gain correction of large spherical antennas.

Large dish type antennas are presently used for radar, space vehicle tracking, satellite communications, radio, astronomy and other uses, requiring accurate control of beam pointing and maximum gain efficiency. Some steerable antennas are as large as 250 feet in diameter and fixed antennas on the order of 1000 feet in diameter have been built, the latter having beam direction changed by physical or electrical adjustment of the feed. Such large structures are subject to distortion from temperature changes, wind, structural sag or bending, earth movements and other causes. All these distortions change the beam alignment and focal characteristics of an antenna and cause a decrease in efficiency, inaccurate beam pointing, or both.

From a structural aspect, a parabolic antenna of such a large size is very difficult and expensive to build with sufficient accuracy. A spherical reflector is more desirable, since the curvature is constant and all portions can be made with the same tooling, and surface checking is simplified. Due to spherical aberration, however, the antenna feed must be distributed along a portion of the spherical axis of the reflector in order to utilize the entire reflector surface. While gain changes and beam deflection of this arrangement may not be as pronounced as with a parabolic reflector having a single focal point, any deviations from the optimum are undesirable.

The primary object of this invention, therefore, is to provide means for detecting distortion in a large spherical reflector type antenna and compensating for the distortions by adjusting the antenna feed to maintain beam alignment and gain.

Another object of this invention is to provide distortion compensating means which is operable continuously and is responsive to all distortions in the antenna structure which would affect the accuracy and efficiency.

Another object of this invention is to provide distortion compensating means which is coupled directly to the adaptive line source type feed developed for spherical reflectors.

A further object of this invention is to provide distortion compensating means which is extremely simple and can be made without moving parts, and is mounted in such a manner as to utilize the antenna boresight axis as the basic alignment reference.

The system and its application to a typical antenna are illustrated in the drawings, in which:

FIGURE 1 is a diagram showing the spherical aberration and reference geometry of a spherical reflector;

FIGURE 2 is a diagram of the distortion detecting and compensating system incorporated in an antenna;

FIGURE 3 is a view of the antenna face indicating various zones referred to;

FIGURE 4 is a block diagram of a series type phase adjusting means for the feed;

FIGURE 5 is a block diagram of a parallel type phase adjusting means; and

FIGURE 6 is a diagram of a portion of the direction detecting system.

In FIGURE 1 it is seen that in a spherical reflector **10** of radius R, the paraxial focus, or theoretical focus of rays parallel to the axis, is at a distance of one half of the radius from the reflector. Due to spherical aberration, however, all reflected rays do not intersect the paraxial focus, as indicated by three rays at different radial spacings from the axis. Ray **1**, near the axis, intersects the axis at focus **F1** very close to the paraxial focus on the side toward the reflector. Ray **2**, at a register radial spacing from the axis, has a focus at **F2** closer to the reflector. The focus **F3** of ray **3**, spaced further from the axis, is even closer to the reflector. Thus the actual focus of energy striking the reflector parallel to its axis is distributed along a portion of the axis.

To utilize the full reflective surface at maximum efficiency when transmitting or receiving with a spherical antenna, the feed must extend along the portion of the axis encompassing the focal zone of the reflector. This type of feed is known as a line source feed **12** and has multiple, axially spaced feed elements **14**, as in FIGURE 2, to cover different zones of the antenna. For purposes of the present description the reflector is considered to be divided, as in FIGURE 3, three concentric zones **1**, **2** and **3**, each served by a corresponding feed element. The reflector is further divided into four sectors A, B, C and D, of 90 degrees each, the feed **12** having four sides each with three feed elements to cover the reflector surface adequately. It will be evident that any number of sides and elements may be incorporated into the feed, according to the size and performance requirements of the antenna. The feed elements are phased in a particular relationship to each other to realize optimum gain from the antenna. Changes in phasing will change the beam pointing direction of the antenna from its alignment with the axis. This phased or adaptive line source feed is well known as such and reference may be made to a paper by Spencer, R. C., Sletten, C. J., and Walsh, J. E., entitled "Correction of Spherical Aberration by a Phased Line Source," Proc. National Electronics Conference, vol. 5, 1959. Another pertinent reference is a paper by Love, A. W., entitled "Spherical Reflecting Antennas with Corrected Line Sources," I.R.E. Transactions, vol. AP–10, No. 5, September 1962.

With reference to FIGURE 1, the three sample rays **1**, **2** and **3** are representative of the three hypothetical zones of the antenna. The normal of each incident ray and its reflected ray, from the center of radius, subtends an angle θ with the axis. From geometric analysis it can be determined that the path length difference δ_1 between a ray along the axis and ray **1** is:

$$\delta_1=R[(\cos\theta_2-1)+\tfrac{1}{2}(\sec\theta_1-1)]$$

The path length difference δ_2 between ray **1** and ray **2** is:

$$\delta_2=R[(\cos\theta_2-\cos\theta_1)+\tfrac{1}{2}(\sec\theta_2-\sec\theta_2)]$$

Similarly, the path length difference δ_3 between ray **2** and ray **3** is:

$$\delta_3=R[(\cos\theta_3-\cos\theta_2)+\tfrac{1}{2}(\sec\theta_3-\sec\theta_2)]$$

The feed **12** is tuned to the phase and amplitude distribution along the axis of the reflections representative of the different zones. Any distortion in the antenna will result in changes in this distribution.

In the antenna illustrated diagrammatically in FIGURE 2, an alignment head **16** is mounted substantially at the center of radius of reflector **10** on supporting structure **18**. Feed **12** is mounted on the reflector axis on supports **20** from the basic supporting structure **18**. Various types of struts, beams, spiders, or other structure can be used for supports. Distortion can occur from changes in spherical curvature of the reflector, axial displacement of the feed relative to the reflector, radial displacement of the feed, or combinations thereof. These can all be caused by temperature variations affecting the structure, or by bending due to wind or atmospheric disturbances. In a steerable antenna the structure can sag or bend under its own weight as the antenna changes position.

The phase errors in the feed caused by distortions can be summarized as follows:

Type of distortion:	Phase error
Axial displacement of feed, ΔZ	$(-\pi/\lambda)r^2\Delta Z$.
Radial displacement of feed, ΔS	$(-2\pi/\lambda)(r+r^3/6+\ldots\Delta S$.
Error in reflector radius, ΔR	$(\pi/32\lambda)(r^4+r^6/8+\ldots\Delta R$.

where $r=\sin\theta/\sin\theta_{\max}$.

With regard to the error in reflector radius, it has been found that if the errors in the reflected wavefront are not to exceed $\lambda/16$, (an accepted tolerance) then the maximum aperture of a spherical reflector, whose aperture diameter is equal to the radius of curvature, using a simple uncorrected feed at the paraxial focus, is limited to 32 wavelengths of the energy being handled.

In the spherical configuration the ideal point of reference for distortion detection is the center of radius, since the distance from the reference point to the reflector surface is constant and all points on the reflector surfaces are effectively normal to the radius vector. The alignment head **16** thus houses a distortion detecting unit, which is illustrated as optical in nature, although microwave or other energy could be used if necessary. Each sector of each zone of the reflector **10** is provided with a small mirror **22** at a suitable position, as in FIGURE 3. A source of light, indicated in FIGURE 6 as a laser **24**, is mounted in the alignment head **16** and has a beam splitter **26** to direct light through individual slits **28** to the respective mirrors **22**. The slit images reflected from the mirrors are intercepted by photoelectric sensors **30**, one for each mirror **22**. Each sensor **30** is capable of detecting deviation of the reflected light beam caused by distortion and providing an electrical error signal representing the deviation. Optical motion detectors of this type are well known and suitable sensors are available. Multiple light sources could be used, but a single low power, continuous or pulsed laser, with suitable beam splitting, is adequate and constant.

The narrow band, high spectral density characteristics of the laser will make the reflected slit images readily identifiable over sunlight or other interfering illumination. In theory the mirrors **22** should ideally be of the same radius as the reflector and can be mounted on or be suitable treated portions of the reflector. With the very narrow beam of the laser and a large radius reflector, however, plane mirrors may be satisfactory.

The error signals from sensors **30** are fed to a computer **32** which provides signals for correcting the phase of the feed elements to compensate for detected distortion. Phase corrections are linear functions of relative feed displacement and reflector radius errors. Thus the computer could be a simple linear mixing matrix with proportional amplifiers to drive the phase correctors. Alternatively, a digital computer could be used, a typical example being the Bunker-Ramo BR–133.

One arrangement is illustrated in FIGURE 4, with computer **32** supplying correction signals to phase shifters **34** and **36** in a series connection with the feed elements. A parallel connected configuration, which might be more desirable for noise characteristics, is shown in FIGURE 5. The phase correctors could utilize varactor diodes, ferrite elements, or other devices with suitable noise characteristics and low loss.

In order to base the distortion on a fixed axis of reference, the alignment head **16** is coaxial with the feed **12** on the spherical axis of reflector **10**. To detect any deviation of the feed relative to the alignment head, an additional mirror **22** is mounted on the feed to reflect a slit image back to a sensor in the optical system.

The reference axis is established in the initial boresighting of the antenna, which is usually accomplished by mounting an optical telescope **38** in axial alignment on the spherical axis of the antenna. The telescope is then pointed at a known substantially point source of combined optical and radio frequency radiation, such as a stellar object. The antenna can then be aligned to the source viewed in the optical telescope, so providing a common axis of reference based on the spherical axis of the reflector, the boresighting technique being well known.

A spherical reflector is simple to construct since all the portions have the same curvature. Tolerances are not especially critical because small deviations from a perfect configuration are compensated for electrically through the system described.

The system provides real-time correction of beam pointing and gain stability, without the need for analysis of distortions or elaborate programming of operations. Structure need not be as rugged as some existing antennas, and no special dome or cover is necessary to protect the antenna from wind and climate changes.

It is understood that minor variation from the form of the invention disclosed herein may be made without departure from the spirit and scope of the invention, and that the specification and drawings are to be considered as merely illustrative rather than limiting.

I claim:

1. In a large antenna having a substantially spherical reflector, with a line source feed mounted on the reflector axis and having a plurality of feed elements directed to selected zones of the reflector, a distortion componensating system, comprising:

a distortion detecting unit mounted substantially at the center of radius of the reflector, said unit having means to observe selected portions of the reflector, detect deviations of the reflector surface relative to the unit and provide error signals corresponding to the deviations;

means to analyze the error signals and provide correction signals representing deviations of the reflector relative to a predetermined reference axis;

and phase adjusting means coupled between said feed elements and actuated by the correction signals to alter the phase relationship of the feed elements to compensate for the distortion.

2. The system according to claim **1** and including means in said distortion detecting unit to detect motion of said feed relative to the unit and provide error signals corresponding to the motion.

3. The system according to claim **1**, wherein said means to observe comprises;

a source of wave energy;

means to direct beams of energy from said source to portions of said reflector;

mirror means on said reflector to reflect individual beams back to said source;

and means at said source to intercept the individual reflected beams and sense the deviation thereof from a predetermined alignment.

4. The system according to claim **3**, wherein each zone of said reflector related to an individual feed element contains at least one of said mirrors.

5. The system according to claim **3** and including means to direct a beam from said source generally axially to said feed, a mirror on said feed to reflect the beam back to said source, and means to receive the reflected beam and sense the radial displacement of said feed relative to the axis of reference.

6. The system according to claim **3**, wherein said source of wave energy is a laser.

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U.S. Cl. X.R.

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