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Wild

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[54] **GENERATION OF SCANNING RADIO BEAMS**

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Feb. 7, 1972 Australia 7882/72

[52] **U.S. Cl.** .... **343/108 M;** 343/779; 343/840; 343/854

[51] **Int. Cl.** **G01s 1/16**

[58] **Field of Search** .... 343/779, 854, 108 M, 840

[56] **References Cited**

UNITED STATES PATENTS

2,437,281	3/1948	Tawney	343/777
3,267,472	8/1966	Fink	343/854
3,317,912	5/1967	Kelleher	343/840
3,406,401	10/1968	Tillotson	343/779
3,534,365	10/1970	Korvin et al.	343/854

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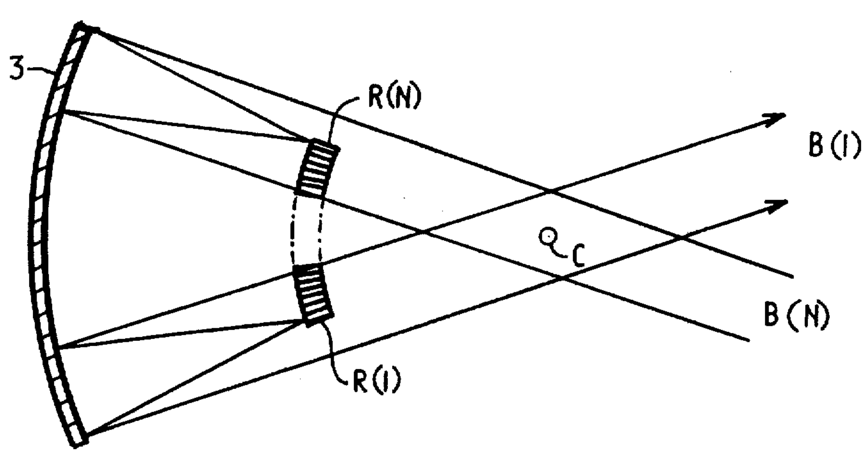
Attorney, Agent, or Firm—Ladas, Parry, Von Gehr, Goldsmith & Deschamps

[57] **ABSTRACT**

A radio aerial is disclosed by which planar beams can be swept through wide angles in space without the need for moving aerials, and which may be used in radio location systems using scanning beams and in radio navigation systems. The aerial consists of a reflector the surface of which is, or approximates part of, a surface produced by the rotation of a generating curve of finite length about an axis, and a plurality of radiating elements disposed about an arc centred on the axis of rotation which are excited sequentially. In its simplest form the reflector is part of a right circular cylinder and the radiating elements are located at the half radius of the cyliner.

9 Claims, 9 Drawing Figures



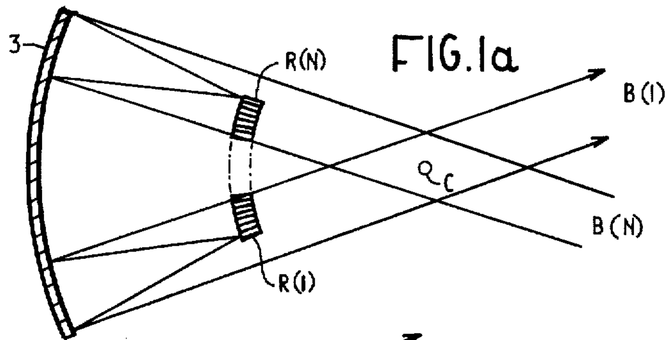


FIG.1a

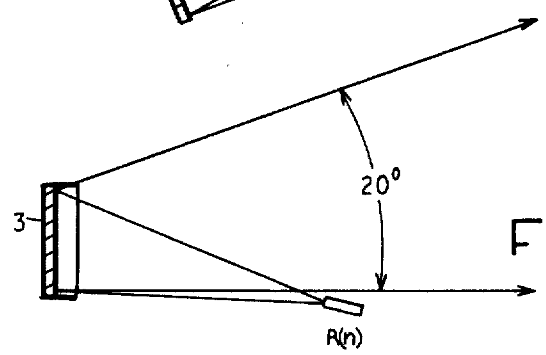


FIG.1b

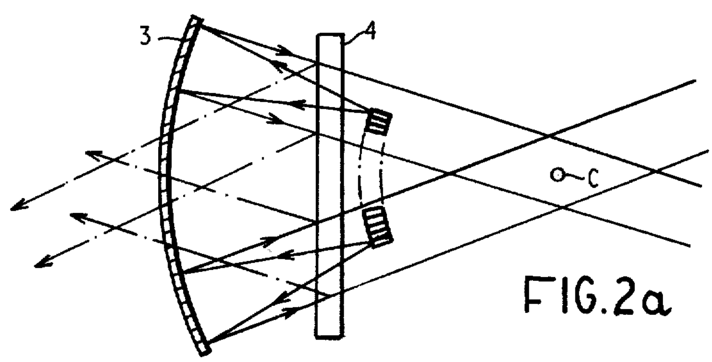


FIG.2a

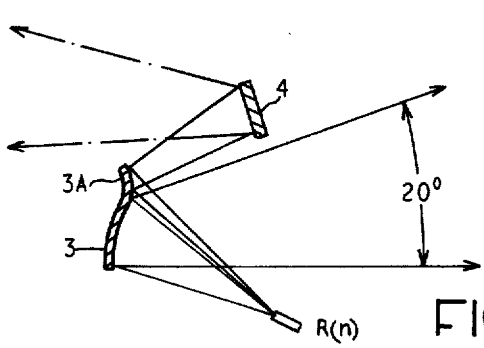


FIG.2b

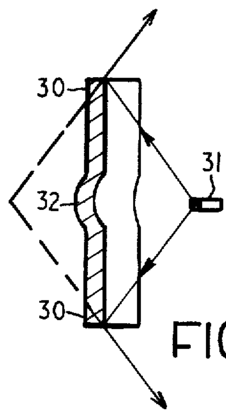


FIG.3a

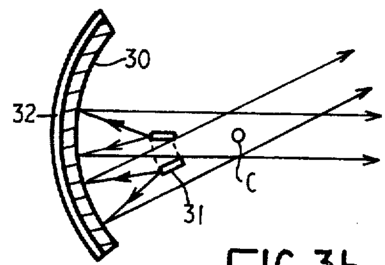


FIG.3b

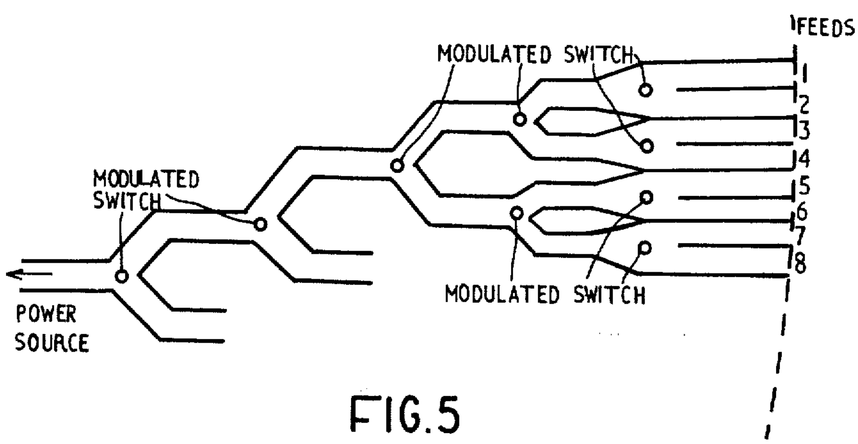
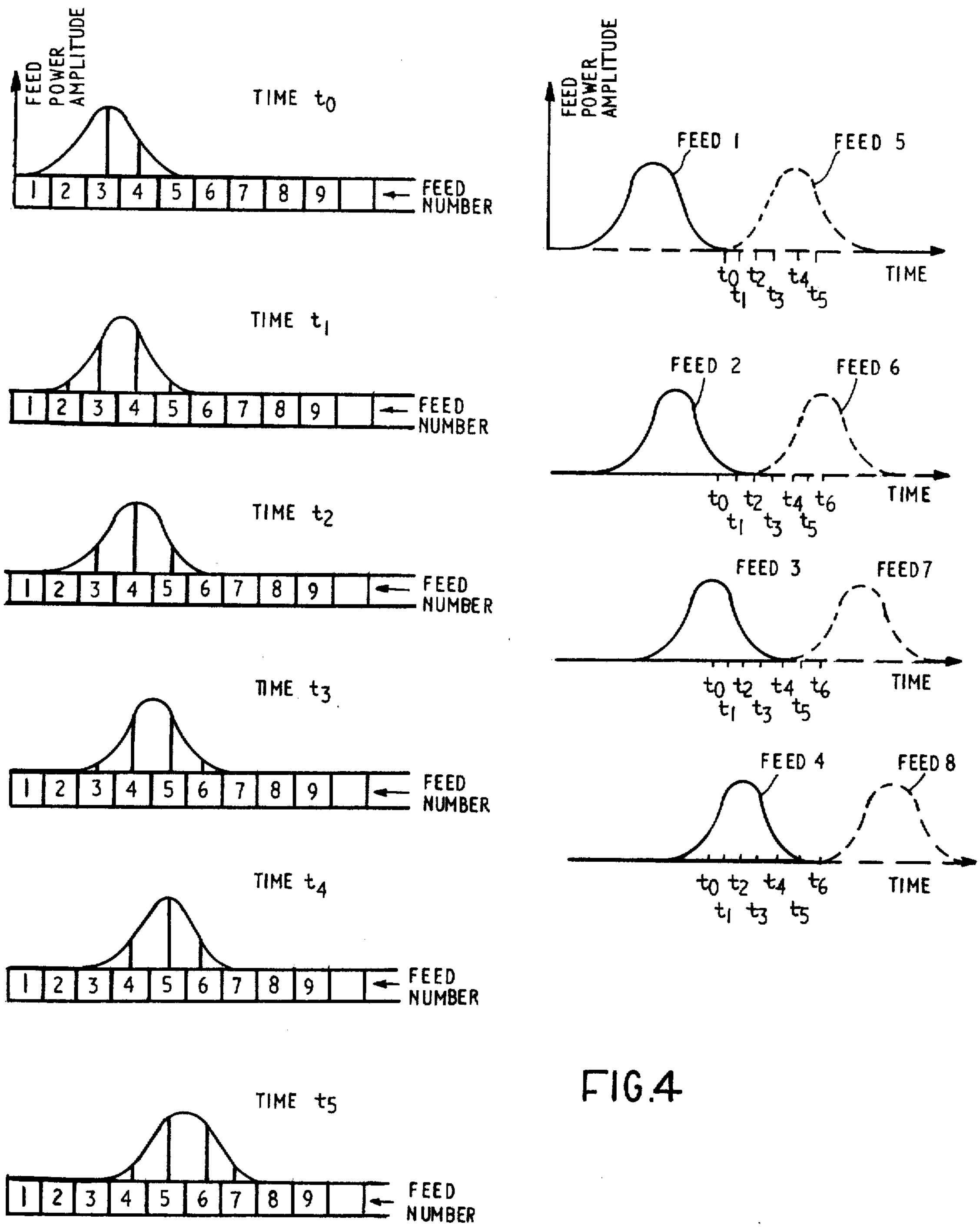


FIG.5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TIME t_0
TIME t_1
TIME t_2
TIME t_3
TIME t_4
TIME t_5
1 2 3 4 5 6 7 8 9
FEED NUMBER
FEED 1
FEED 5
FEED 2
FEED 6
FEED 3
FEED7
FEED 4
FEED 8
t_0 t_1 t_2 t_3 t_4 t_5 t_6
TIME

FIG.4

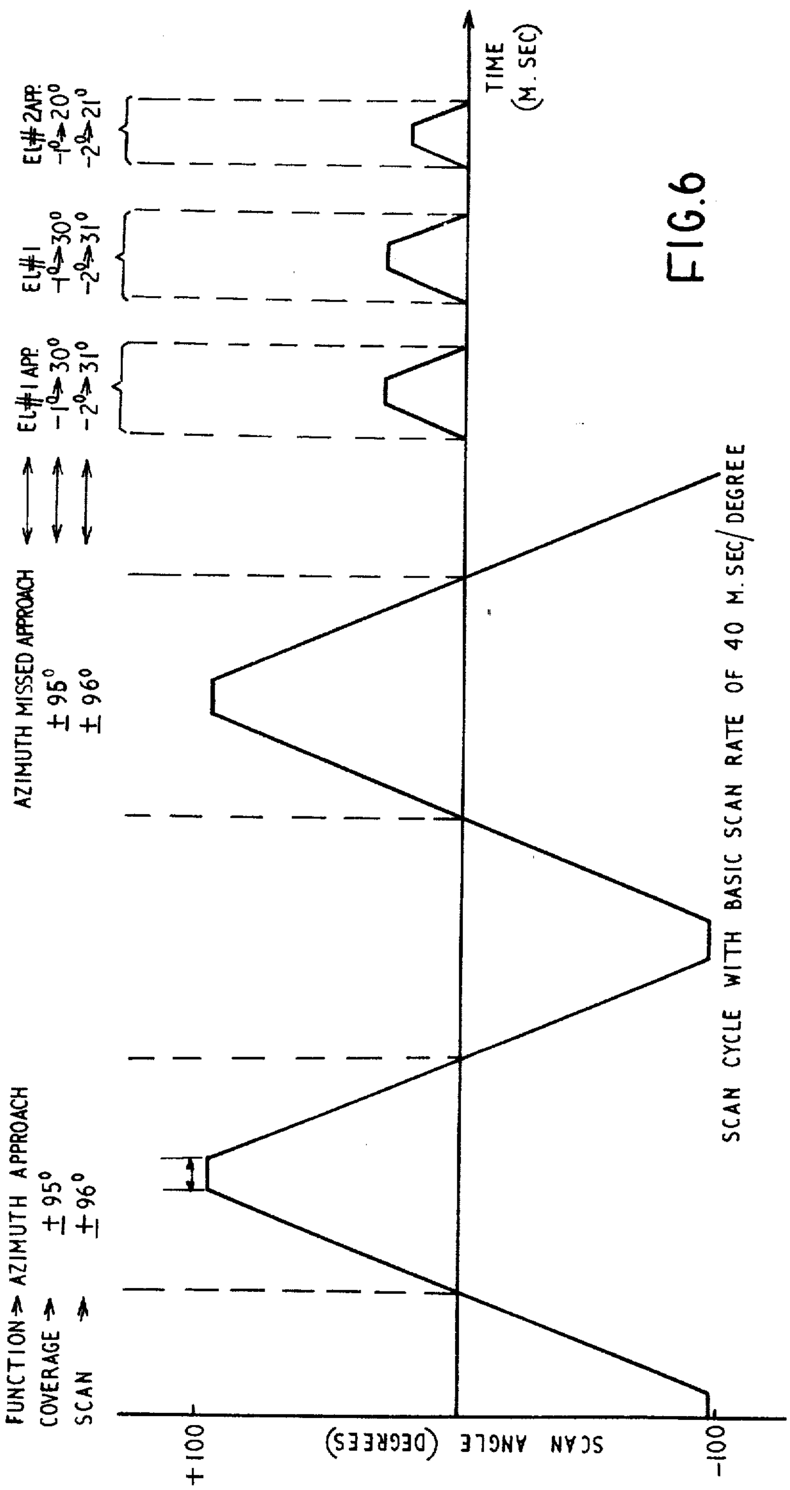
FUNCTION → AZIMUTH APPROACH
COVERAGE → ±95°
SCAN → ±96°
AZIMUTH MISSED APPROACH
±95°
±96°
EL#1 APP.
−1°→30°
−2°→31°
EL#1
−1°→30°
−2°→31°
EL#2 APP.
−1°→20°
−2°→21°
TIME
(M. SEC)
SCAN CYCLE WITH BASIC SCAN RATE OF 40 M. SEC/DEGREE
+100
SCAN ANGLE (DEGREES)
-100

FIG. 6

GENERATION OF SCANNING RADIO BEAMS

This invention is concerned with the generation of radio beams and, more particularly, seeks to provide improved means by which planar beams can be swept through wide angles in space without the need for moving aerials. The invention therefore has application in radio location systems using scanning beams and in radio navigation systems in which a wide ranging pattern of 'signals in space' is established for the guidance of aircraft and ships. Although the present invention is not confined to air navigation systems (other applications include radar and communication systems), the requirements of such systems are most demanding and, for the purpose of illustration, the invention will be described in relation thereto.

The Radio Technical Commission for Aeronautics (RTCA) of the United States has called for the design of a ground base transmitter system which will provide a pattern of signals in space so that aircraft approaching a runway from an azimuth angle of up to 60° on either side of the runway center line and an elevation of up to 20° can be guided by the pattern. Some azimuth back-cover of 40° on either side of the runway is also desirable for use by aircraft which abort their landing; in addition, the renewal of information in the aircraft by the system should be equivalent to at least five updatings per second. After examining available systems, the RTCA concluded that, until a satisfactory electronically scanned system for producing a pattern of planar beams could be devised, large mechanically rotated aerials would have to be employed. In particular, a system including two aerials, up to 20 feet across, mounted back-to-back and rotated mechanically at 2½ revs per second (5 revs per second if a back-to-back configuration is not used) was preferred. Such a system produces a planar beam but does not have the geometrical precision required to enable a time coded system (the simplest) to be used and is therefore restricted to transmitting an azimuth controlled frequency coded signal which is extravagant in its use of bandwidth and requires elaborate signal processing in the aircraft.

One example of a non-mechanical technique for generating signals in space is the 'Doppler' system in which the separate aerial elements — typically about 100 — of a linear array are sequentially excited to simulate a moving radiator. Each element is excited in turn and a different frequency is seen at each angle from the array. However, this system demands the maintenance of a precise RF phase relationship between individual elements and, since conical beams are produced, in order to simulate a planar beam system, a second linear array perpendicular to the first is required and data from the two arrays must be processed by an airborne computer carried in each aircraft using the system.

Another beam-generating system which has been proposed for aircraft navigation involves the use of a phased array. In this system a linear array of aerial elements is excited by a common source, but a different and progressive time delay is inserted between the elements and the source. The time delays can be changed to produce scanning beams but, again, a very precise RF phasing is required and the beam is conical rather than planar.

A further system that has been proposed for the generation of scanned narrow beams of radiation has been effected by irradiating a mirror having the form of part of a sphere (which is sufficiently similar in shape to a paraboloid over a limited aperture to produce effective focusing), the beam being scanned by physically moving the focal radiating element around a focal arc centered on the centre of the circle. An example of this technique for generating plane wavefront, scanned beams is found in the paper by J. Ashmead and A. B. Pippard in *J. Inst. Elec. Eng.* 93, part 3A, pages 627–632, 1946.

The present invention similarly depends on the focusing power of a mirror of circular cross section but scanning is achieved by simulating the physical movement of the radiating element by the use of many closely spaced radiating elements around an arc which are progressively excited. Also instead of using a spherical mirror, which produces a narrow pencil beam, the present invention employs a cylindrical or nearly cylindrical mirror so as to produce a narrow fan (planar) beam.

One object of the present invention is to provide an aerial for the generation of scanning planar radio beams, and also to provide a method for the generation of such radio beams. In addition, it is an object of a development of the present invention to provide systems, such as aircraft navigation systems (including instrument landing systems), which incorporate scanned planar radio beams. In a particular example, the present invention provides an instrument landing system which complies with the minimum requirements proposed by the RTCA and which can utilise a time coded arrangement for angle measurement.

According to the present invention, an aerial for producing a scanning beam comprises:

a. a reflector having a surface the shape of which is or approximates part of the surface produced by the rotation of a generating curve of finite length about an axis, the reflector being so mounted that the said axis is the axis of rotation of the said beam, and

b. a plurality of radiating elements disposed around an arc centred on the axis of rotation, each element being arranged to radiate towards the reflector, which radiation is reflected from a portion thereof, whereby, by exciting the elements sequentially, a beam of radiation transmitted from the aerial scans through a range of angles.

Depending on whether the angular width of the primary radiation from the radiating elements is small or relatively large, the secondary (reflected) radiation will comprise a pencil beam or a planar fan beam. The curve of the reflector may be a parabola or circle, or any other shape. In its simplest form the generating curve is a straight line, i.e., the reflector is a right cylindrical surface. In many instances, however, particularly with horizontally (azimuth) scanning beams where it is desirable to shape the beam in the vertical plane, it is necessary to shape the curve to distribute the energy of the reflected beam in a desired angular distribution. For example, enhanced sensitivity in low elevations, yet avoiding ground reflections, can be achieved if the reflector is shaped so that the power polar diagram of the secondary beam approximates to a cosecant-squared pattern. (Some relevant results on the geometry of such mirrors have been reported by L. J. Dolan, in report No. RADC-TR-59-231 of the Radiation Engineering Laboratory, dated December 1, 1959.)

In a preferred form of elevation signal generation aerial, the reflector is essentially a right circular cylindrical shape, but with a modified, for example, parabolic, central portion.

If the curve which is rotated about an axis to produce the reflector surface shape is substantially a straight line, the feed elements are preferably located a distance from the reflector which is approximately equal to the half radius of the circle of rotation of the line.

A step-scanned planar beam is produced by actuating each feed element in turn. In a preferred form of the invention, a quasi-continuous scanning by the planar beam is obtained by concurrently exciting several, e.g. four, adjacent feed elements in a particular modulation. It has been found that modulating the excitation of each feed element so that its transmitted power varies with time according to a class of functions such as cosine-squared, will produce quasi-continuous scanning.

The present invention also includes a method for generating and scanning a radio beam through space about a given axis, which method comprises sequentially exciting a series of fixed aerial feed elements arranged about the said axis so as to initiate a series of primary beams, and reflecting said primary beams from respective portions of a common reflector aerial element having a shape which is part of the surface defined by the rotation of a curve about the said axis.

Insofar as the aerial and method of the present invention may be used in radar systems, communication systems and the like, the feed elements may be replaced in part or entirely by receiving elements.

The number of radiation feed elements is preferably greater than 10; for a system in which the beamwidth is 1° there are typically 64 elements per 45° angle (i.e., the angular separation of feeds is about 0°.7). The feeds will generally be located on an arc of a circle (for special purpose aerials they could be otherwise located). In an azimuth signal generating system they are conveniently off-set to be out of the path of the radiation from the reflector. In an elevation generating system it may not be possible to employ off-set feeds and it may be desirable to compensate for the blocking of the radiation by the feed by procedures to be described below.

In an elevation generating system the horizontal angle of coverage of the fan-like beam can be increased by increasing the horizontal length of the cylinder. To reduce this length for a given horizontal angular coverage, the reflector may be convexly curved (as viewed from the focal side) though this procedure may introduce some degradation of the beamwidth. Alternatively a secondary reflector or lens may be used in the path of the radiation from the primary reflector to expand the fan angle of the planar beam.

The frequency of radiation may be any suitable value, but C-band or K_u-band frequencies are thought to be most appropriate in the case of instrument landing systems. Switching of feed elements may be performed by known electronic means, for example diode switching or switching using ferrite devices. The beam may be identified by a timed system or any other suitable code. With a time identified arrangement, stepped or continuous scanning may be used to effect beam rotation, and in either case, one-way or two-way scanning can be utilised.

A plane mirror may be used with the azimuth aerial to provide overshoot information for an instrument landing system.

The present invention also encompasses instrument landing systems and other aircraft navigation systems, tracking systems, radar and communication systems which include the scanning aerial and method of this invention. In particular the present invention provides an instrument landing system which, in a simple example has a first aerial of the form described above which is adapted to produce a planar beam which scans in azimuth, and a second aerial of the form described above which is adapted to produce a second planar beam which scans vertical angular elevations, the generation of the planar beams being such that they may be utilised by aircraft for navigation and/or landing purposes.

A description of embodiments of the present invention will now be given with reference to the accompanying drawings, in which:

FIGS. **1***a* and **1***b* are, schematically, a plan and elevation, respectively, of an azimuth signal generating aerial of a type which can be used in an instrument landing system,

FIGS. **2***a* and **2***b* are a schematic plan and elevation, respectively, of a modified azimuth signal generating aerial which incorporates a back-reflecting arrangement,

FIGS. **3***a* and **3***b* are, respectively, a schematic plan view and elevation of an elevation signal generating aerial,

FIG. **4** illustrates how power may be supplied to excited feeds at sequential time intervals to obtain quasi-continuous scanning,

FIG. **5** depicts one form of modulator configuration that may be used for feed power modulation, and

FIG. **6** shows an example of cycle of time-shared functional operations in a landing system suitable also for an area navigation system.

Referring to FIG. **1***a*, a reflector **3**, shown in section, has an axis of symmetry C. Radiation feed elements R(**1**), R(**2**), . . . R(n) . . . R(N) are located at the half radius of the circle of generation of the reflector and are adapted to beam radiation to a segment of the reflector **3**. Because the geometry of the circle and parabola are essentially the same over small angles, a well-collimated parallel beam of radiation is reflected from the surface of reflector **3**. The angular dispersion of the beam in a vertical direction will depend upon the shape of the reflector **3** in the vertical plane. In FIG. **1b**, this shape is a straight line, but as indicated above, and as shown for example in FIG. **2**, it may be any desired shape. By switching each radiator feed element R(**1**) . . . R(n) . . . R(N) on in turn, a beam is set up which scans from one extreme position to another, i.e., from beam B(**1**) to beam B(N) in FIG. **1***a*. For example, in an instrument landing system providing azimuth beams which are 1° wide and scanned over 120°, about 200 feed elements R(n) will be required for satisfactory performance.

As shown in FIGS. **1***b* and **2***b*, the feed elements are preferably offset below the reflector so that they do not obstruct the beam.

In the embodiment of FIGS. **2***a* and **2***b* the reflector **3** has an optional additional reflector portion **3A** formed atop it (it could, in other embodiments, be located below it), so shaped that radiation incident on it from a feed element R(n) is reflected above the aircraft approach elevation (generally about 20°) on to a mirror **4**, typically a plane mirror, so positioned above the main beam that it reflects its incident radiation backwards at an angle extending from the horizontal to an elevation determined by the shape of portion 3A. Such azimuth information is required for aircraft which overshoot the landing position and cannot land. This embodiment, however, can only be used when the combined height of the primary reflector **3** and the back reflector **4** is such that the maximum obstacle height for the airport is not exceeded. In general, the preferred arrangement for providing overshoot information is to have two azimuth transmitting aerials, one at each end of the runway, each directed along the runway.

A separate aerial using substantially the same cylindrical optics arrangement and plurality of feeds as the azimuth aerial described above, can be used to generate planar beams which scan vertically. In the RTCA required instrument landing systems, a beam which is horizontally planar and has an angular width of 120° has to be scanned 20° vertically. One form of elevation scanning aerial is shown in FIGS. 3a and 3b. A plurality of wide-angle feed elements **31** are located on the central half-radius of a cylindrical reflector **30**. If the feed elements **31** cannot generate a wide-angle (e.g. 60°) fan-like beam, the reflected beam can be expanded by inserting a lens in the reflected beam. A conventional slatted lens is suitable for this purpose. Alternative possible arrangements for expanding the width of the fan-like beam include shaping the reflector **30** to present a convex surface to the beam from elements **31.**

One problem with using a cylindrical reflector is that the feed elements, if within the path of the reflected beam, obstruct the reflected beam and can give rise to diminished intensity of the secondary radiation in certain directions. Such a situation is undesirable in aircraft navigation systems. It can, however, be avoided by suitable shaping of the reflector **30** at its central station as shown at **32,** so that the resultant reflected beam has a substantially plane wavefront at its central portion, which experiences minimal obstruction by the feed elements.

To obtain optimum accuracy in angle measurements with instrument landing systems, it is important to maintain equal amplitude of the signals in space radiated in different directions. A feature of the aerials of the present invention is that, in use, the centres of the beams produced by the individual feed elements pass through a single point which, in the case of the illustrated arrangements of FIGS. 1a to 3b inclusive, is located on the axis of symmetry, C, of the reflector. A single detector may therefore be installed at this point and coupled to a conventional error corrector to maintain the constant amplitude of the beam radiation.

In use in an instrument landing system, the beams of radiation may be distinguished from each other either by (*a*) exciting beams at different times in a known sequence, particularly a simple progressive sequence causing the beam to rotate about the axis, or (*b*) by applying a code to each beam by modulation or frequency change. In the former case, which here is called a time coded system, continuous or quasi-continuous scanning may be achieved by a progressive excitation of a group of feeds with appropriate modulated intensity. Where continuous scanning is not needed, the simpler stepped scanning may be utilised, with each feed element excited sequentially.

It has been found in practice that continuous or quasi-continuous scanning can be satisfactorily achieved by simultaneously transmitting power from four feed elements, the power being modulated as a suitable function of time (for example, cosine-squared) as shown in FIG. **4.** The quasi-continuous nature of the scanning is caused by the continuous movement of the excitation pattern along the feed system.

The switching system for effecting modulation of the feed element outputs may be any suitable arrangement. Ferrite switches have been found satisfactory but diode switching arrangements may also be used. One layout for modulators for an aerial havng **32** feeds is shown in FIG. **5.** In this layout, all the waveguide interconnections are in the same plane and no right angle bends are necessary. Aperture blocking problems are minimised, but a form of continuous modulation is needed to achieve beam scanning. The power output of the individual feeds is determined by the current waveforms applied to the modulators.

With a time-coded system, a one-way or two-way system of beam rotation can be applied. In a typical one-way system, an omnidirectional reference pulse is emitted at the start of, or a known time before, the scan. The N feed elements (or groups thereof) are then excited from R(1) to R(N). At the end of this sequence, a new reference pulse is emitted and the sequence is repeated.

With a two-way system, the elements are excited from R(1) to R(N) and then the excitation is reversed from R(N) to R(1). No omnidirectional pulse is required as part of the angle-measurement signal, the ambiguity as to which direction a beam is being scanned when a pulse is received by a receiver in the space swept by the beam being avoided by the use of a function identification signal, such as a combination of three FM tones on the scanning beam with a different tone combination for each function, or, in the case where no function identification is required, and the delay between transmissions exceeds the scanning period, by utilising the shortest time between pulses. A preferred signal format is the "to-to-fro" pulsed system, in which the scan is from element R(1) to R(N), then R(1) to R(N) followed immediately by R(N) to R(1). Function identification can be achieved by variation of the lag between the first "to" scan and the second "to" scan. Further information may be encoded by varying this lag from scan to scan.

The azimuth component of an area navigation system for aircraft may be set up using the present invention. Typically three aerials would be required to cover 360° azimuth.

FIG. **6** shows one way in which a cycle of time-shared functional operations for a compound landing system may be constructed. This system provides two azimuth scans of 180° (the second a missed approach, back azimuth signal) followed by three elevation scans, the last of which is a missed approach elevation signal. The updating rate is 20 repetitions per second with a scanning rate of 40 microseconds per degree of scan.

With a one-way timed system, a separate omnidirectional aerial is required for each function to transmit a synchronising pulse as well as reference data. With a two-way system, an omnidirectional aerial is not required except possibly for reference data (in which case, timing is not critical and one omnidirectional aerial could be used for all functions of the entire landing or navigation system). If a rear mirror arrangement is to be used to provide overshoot information, the omnidirectional aerials must be split into two semi-omnidirectional aerials.

Thus it will be seen that one form of the present invention comprises an instrument landing system or area navigation system for aircraft, the system having at least one azimuth and one elevation aerial, each having axial symmetry and each fed by a plurality of feeds to produce planar beams, as described above, and each aerial incorporating a signal monitor for intercepting its associated transmitted beam and producing an output controlling an error detector which is operational to ensure a constant amplitude of the transmitted radiation. Additionally the system may include an omnidirectional transmitter for transmitting identification and auxiliary data.

A feature that may be included in airport arrangements is the division of the azimuth signal generator into two aerials, one at either side of the stop end of the runway and operated on alternate scans or on different frequencies. This configuration permits the azimuth part of the proposed landing system to be operated at the same time as an existing Instrument Landing System (ILS) localiser and also provides added integrity because azimuth information is lost only when both aerials fail. It has the further advantage that the aerials may be mounted on towers without violating operational height restrictions and so ease the problem of obtaining adequate signal strength near the touch-down zone at the approach end of the runway. Small aircraft can take the average of the two signals and fly along the centre-line, in the same manner as existing localiser systems are used.

The advantages of systems using the basic aerial of the present invention and the planar (fan-like) beams generated thereby — such as rapid updating and the absence of critical phase adjustment or rotating parts — are also of value in other applications. For example, the present invention can be applied to rapid scanning radar and communications systems using a single azimuth beam (or group of beams) whereby different messages can be almost simultaneously passed to different destinations without risk of confusion. The basic invention described in this specification is, therefore, a tool of considerable value.

What I claim is:

1. An aerial for producing a scanning radio beam comprising:

a. a substantially cylindrical reflector having a surface the shape of which is substantially the surface produced by the partial rotation of a generating curve of finite length about an axis, the reflector being so mounted that the said axis is the axis of rotation of the said beam, and

b. a plurality of radiating elements disposed about an arc centered on the said axis, and of radius substantially half that of the cylindrical reflector, each element being arranged to radiate a beam towards the reflector, which radiation is reflected from the portion thereof,

said beam being divergent in the direction parallel to the axis to produce reflected radiation comprising a planar fan beam, with the plane of the fan parallel to the said axis of rotation, and including means to excite a group of four adjacent elements sequentially, the power to each element being modulated with time in accordance with a cosine-squared function, a detector responsive to the power of incident radiation being located substantially at the axis of symmetry of the reflected radiation to monitor the scanning beam.

2. An aerial as defined in claim 1, in which the output of the monitoring detector is arranged to control an error detector which is operable to ensure a substantially constant amplitude of the transmitted radiation.

3. An aerial as defined in claim 1, in which said means to excite comprises a single power source connected to each element by waveguide connections, and a plurality of modulated ferrite or diode switches to switch power from the source to selected ones of the elements.

4. An aerial as defined in claim 1, in which a second reflecting surface is provided to intercept a portion of the reflected radiation and reflect the intercepted radiation in a direction extending behind the first reflector.

5. An aerial as defined in claim 4, in which the second reflecting surface is a plane reflector.

6. An azimuth aerial comprising two aerials according to claim 1 located at the stop end of an aircraft runway on either side thereof, each of said aerials being arranged to perform a single scanning cycle and then be inactive while the other aerial performs a single scanning cycle.

7. An elevation aerial comprising an aerial according to claim 1, in which the generating curve is a straight line with the central portion thereof shaped to reduce obstruction of the reflected radiation by feed elements which are located in the path thereof.

8. An aerial as defined in claim 7 in which said means to excite comprise a single power source connected to each element by waveguide connections, and a plurality of modulated ferrite or diode switches to switch power from the source to selected ones of the elements.

9. A ground-station aerial for use in a scanning beam instrument landing system of an aircraft navigation system comprising

a. A substantially cylindrical reflector having a surface the shape of which is substantially the surface produced by the partial rotation of a generating curve of finite length about an axis;

b. A plurality of radiating elements facing said reflector and disposed about an arc centered on said axis, the center of each element being spaced from its neighbor by not substantially less than one half wavelength and being arranged to radiate a beam towards a corresponding portion of the reflector, the radius of the arc of radiators being substantially half that of the cylindrical reflector and also not substantially less than the width of reflector illuminated by the primary beam in the plane of the arc; and

c. A single power source connected to each element by branching waveguide or coaxial connections having diode or ferrite switch means to modulate and switch the source of power to excite sequentially a small group of adjacent elements in accordance with a predetermined modulation pattern,

whereby radiation emitted from said elements is after reflection by the reflector, formed into a single narrow and precisely-defined high-quality radio beam which may be continuously and smoothly scanned by the aerial over any selected range of angles about the said axis, the beam being accurately planar with its plane parallel to said axis.

* * * * *