

Jan. 18, 1966

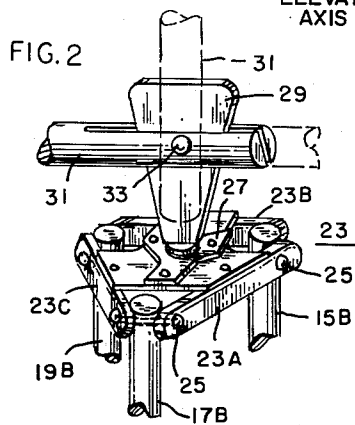
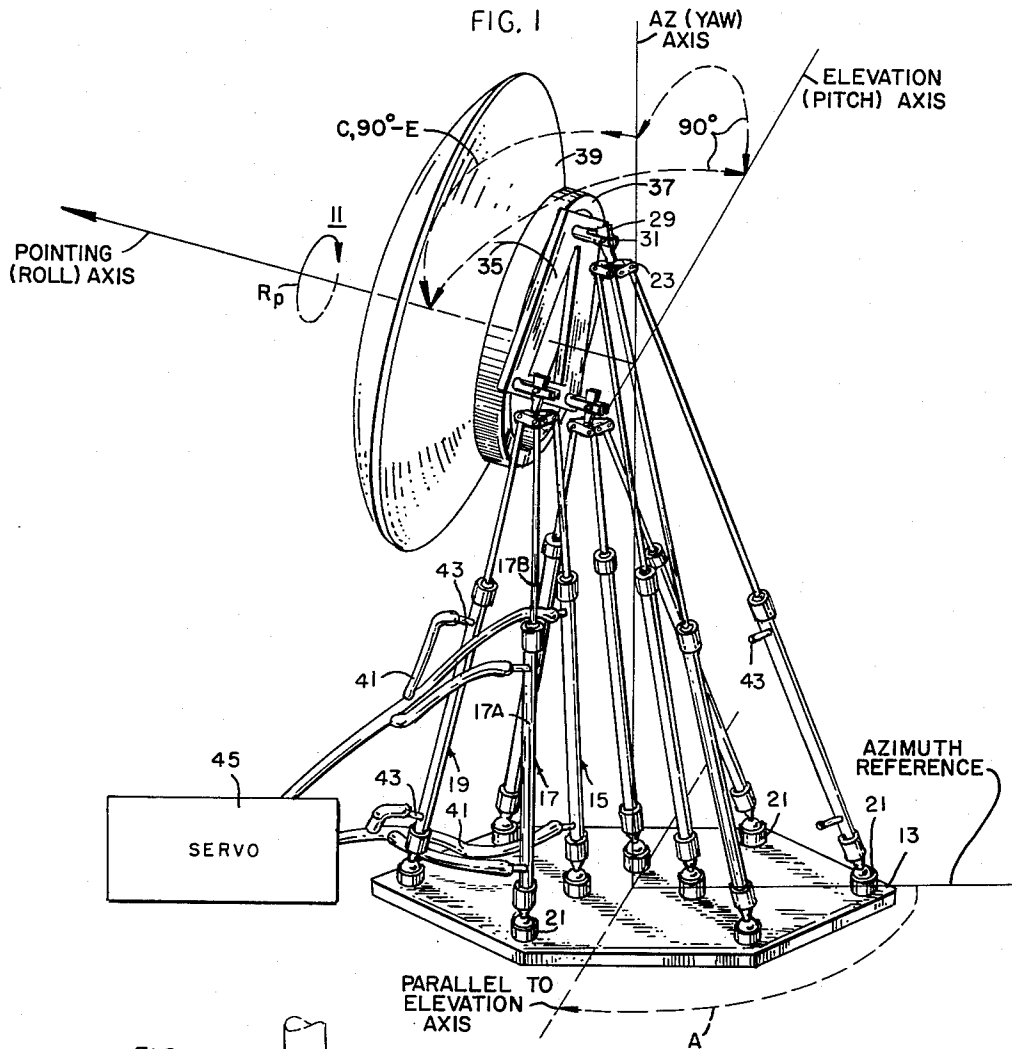
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3,229,941

ANTENNA SUPPORT

Filed June 4, 1962

2 Sheets-Sheet 1



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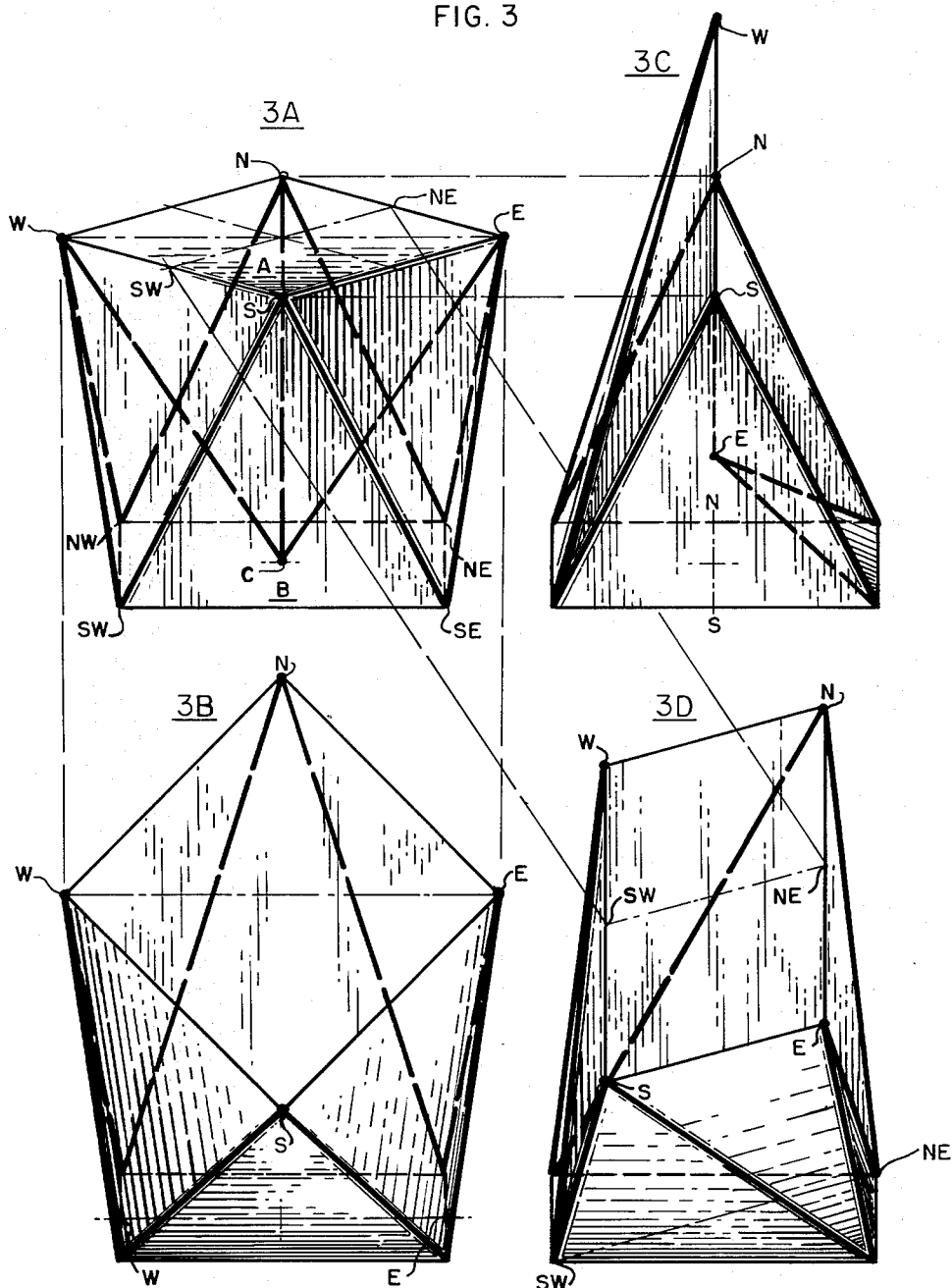
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FIG. 3



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ANTENNA SUPPORT

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The present invention relates to a support and positioning structure for antennas and the like.

In the utilization of equipments that are used for far distant tracking, the need has arisen for extremely large antennas. Such antennas in turn require large pedestal and positioning equipments which use rotary motion in one, two, or three planes to provide the necessary degree of freedom. The use of conventional designs makes for extremely large and bulky supports, complexity of drive and control systems and resultant high initial and maintenance costs. It has further been found that such equipments when providing accurate motion around several axes, require precision bearings, gears, motors and the like with resultant rise in costs of maintenance. A three axis pedestal and positioning support is required to use all three axes to accomplish a search or tracking operation. As a result such support is confronted with accelerations, inertia forces, etc. in three planes. In addition, it will be obvious that a three channel servo system is required for operating such equipments. It has often been found that large torsional and bending moments are created in pedestals used for supporting conventional, or in special instances antennas of over 60 feet diameter. For such large systems operating in high winds, these moments can be considerable and become the limiting factors in the design and manufacture of such pedestals.

A major consequence of the various short comings, such as indicated above, is that available pedestals, as off the shelf or short delivery items are limited to antennas of up to about 24 feet in diameter and having a restricted performance range. Antenna pedestals which have to be custom engineered and built, even if conventional designs are utilized, require considerable delivery time because of this complexity, size, weight and precision requirements. In addition large pedestals pose serious transportation problems because of their complexity and size and possibility of damage to precision bearings and gears.

The primary object of the present invention is to provide a support and positioning device for an antenna that includes no heavy castings or forgings, no large bearings or gears, and no complex mechanisms.

An important feature of the invention lies in the provision of a support in which accurate, fast and precise control of the motion of the support can be realized.

Another feature of the invention is that in its operation, the antenna support can be moved from one position to another using angular motion in one plane. In the symmetrical and simplest such motion the antenna mount changes in elevation (or its complement the co-elevation, more commonly called co-altitude, C , having zero value at Zenith) without rotation about its pointing "axis." Considering only plane geometry this would seem to avoid any such rotation. However, in spherical geometry it becomes apparent that a tilt from Zenith to the Horizon at different points results also in a different part of antenna being nearest the ground; therefore change in azimuth along the Horizon involves a rolling motion or rotation about the pointing axis at the tracking rate. This compares favorably to the rotation about pointing axis near Zenith (and Nadir) in conventional Az El mounts, which rotation may often be much faster than tracking rate and also in a region where target tracking

rates themselves are usually faster than near Horizon. However, analysis of possible operation of the present mount below Horizon reveals more rapid rotation, becoming even worse near the Nadir where a conventional mount would have merely the same problem as at the Zenith; thus the present mount may be considered to have traded the pole or Zenith problem of prior mounts for an increased theoretical Nadir problem, of no actual importance since tracking rarely extends appreciably beyond a hemisphere anyway. As in other mounts the new mode of operation is applicable equally to search or tracking.

Ordinary polar spherical coordinates as in prior mounts involve, besides the radius, primary and secondary angles, while polar space coordinates involve three equally significant angles (obviously not independent variables since there is an extra dimension); the very unusual if not entirely new angular coordinates involved in the present mount are both equally significant, truly " x , y " in the same sense involved in usual rectangular coordinates. This is particularly apparent near the Zenith; in Horizon and Nadair regions the rotation becomes more significant. The actual magnitude may be determined by considering the following relations:

(a) Azimuth or "Az" component dA_t of tracking rate equals only Az rate dA times $\sin C$; that is, Az rate dA equals Az tracking rate dA_t times $\csc C$, variable from unity at horizon to infinity at either Zenith or Nadir.

(b) In plane geometry interior polygon angles add to $\Pi (n-2)$ or 180° for triangle, 360° for square, etc. If more simply considered by the complementary angles or amount of bend at each corner, the total bend B is 360° for any polygon, including a curve or circle of infinite sides and corners. Any discrepancy is considered as angular closing error, as in plane surveying. However, in spherical geometry and surveying such discrepancy, known as "spherical excess," above such $\Pi (n-2)$ is recognized as actually the area in spherical radians; considering the total bend angles B this would be an equal deficiency below 2Π for spherical area of any shape, or:

$$A = 2\Pi - B$$

Thus, the perimeter of each hemisphere has zero total bend or the entire 2Π deficiency, a 90° lune 180° bend or Π deficiency (the remainder 3Π by changing algebraic sign), etc. The same applies to any area greater or less than hemisphere (observing signs properly), of which circles about the pole are of immediate interest.

(c) Area or surface, S , of such circles in spherical radians is also:

$$\begin{aligned} S &= \Pi (2 \sin C/2)^2 = \Pi - B \\ &= 4\Pi \sin^2 C/2 \\ &= 4\Pi (1 - \cos C/2) \\ &= 2\Pi - 2\Pi \cos C = 2\Pi - B \end{aligned}$$

Thus

$$B = 2\Pi \cos C$$

corresponding to the rotation of an Az El mount antenna about its pointing "axis." This is:

- (1) Equal to Az at Zenith,
- (2) Zero at Horizon,
- (3) Opposite to Az at Nadair,

and easily calculated for intermediate values.

(d) In the present mount designated as "Anpod," the antenna does not rotate about its pointing axis at the Zenith, but does so rotate at the Horizon, as would be observed in rolling together like cones or bevel gears on the antenna and Nadir axes. The actual rotation R_p about the pointing axis may be shown for a full circle as:

$$R_p = B - 2\Pi = 2\Pi \cos C - 2\Pi = 2\Pi (\cos C - 1)$$

This is the combination of the same rotation as a conventional Az El mount and a rotation opposite in magnitude to the Az, obtained by subtracting the absolute values, and is:

- (1) Zero at Zenith,
- (2) Opposite to Az at Horizon, still of moderate value;
- (3) Double and opposite to Az at Nadir.

(e) Now combining (a) with (c) and (d), and including tracking rate Az components A_t the net rotations are:

$$2IIdR_p = BdA_t Csc C v = 2IIdA_t Csc C \cos C, \\ (=2IIdA_t \cot C)$$

for Az El mounts, which is:

- (1) Infinity at Zenith,
- (2) Zero at horizon,
- (3) Minus infinity at Nadir; and

$$2IIdR_p = (B-2IId) dA_t Csc C = 2IIdA_t Csc C (\cos C - 1), \\ (=2IIdA_t (\cot C - Csc C))$$

for Anpod mount, which is:

- (1) Zero at Zenith;
- (2) Opposite to Az (rate and tracking rate) at horizon;
- (3) Minus (double) infinity at Nadir, but in a region rarely used in tracking anyway. The two polar problems at Zenith and Nadir of ordinary mount have been both transferred to the Nadir, and a resulting moderate rotation at Horizon does not involve any real problem.

The following illustrative values show the relations between operation of Az El and "Anpod" mounts. The simple $Csc C$ factor in both varies from 1 to the value infinity, which tends to determine the maximum of antenna rotation rates. The simple $\cos C$ and fairly simple $\cos C - 1$ factors vary over a total range from 1 to -2 including the value zero, which actually determines the minima. The clearly dominant factors of each product and the products showing problem regions are underlined, while the suitable regions are emphasized by asterisks; the dominance of the $Csc C$ factor is affected by the other factor.

C-----	Az El			Anpod		
	Csc C Cos C	Csc C	Cos C	Cos C-1	Csc C	Csc C (cos C-1)
0-----	<u>∞</u>	<u>∞</u>	1.0	0	∞	*0.000
5-----	<u>11.4</u>	<u>11.5</u>	.996	<u>-0.004</u>	11.5	*-0.046
45-----	*1.0	1.4	.7	-0.3	1.4	*-0.42
90-----	*0	1.0	0	-1.0	1.0	*-1.0
135-----	-1.0	1.4	-.7	-1.7	1.4	-2.38
175-----	<u>-11.4</u>	<u>11.5</u>	<u>-.996</u>	<u>-1.996</u>	<u>11.5</u>	<u>-23.</u>
180-----	<u>∞</u>	<u>∞</u>	-1.0	-2.0	∞	<u>∞</u>

In the forms used above only approximate Csc values are needed to observe the trends in the values at any range of angles, but the difference between $\cot$ and Csc values yields the same results; at very small angles accurate tables would be needed, or a very close approximation can be used instead, either $\sin C/2$ or $(\sin C)/2$.

The co-altitude component of tracking rate may now be combined to determine entire motion, only one rotation about the current elevation "axis" for such co-altitude, one rotation about a normal to such "axis" and actual pointing axis for Az, these two inherent in any tracking, and another about pointing axis itself for Az, dependent on the particular form of mount.

Still another feature of the invention resides in the use of a support or mounting ring for the antenna thereby eliminating the need for any support brackets, beams or

yokes. The use of such mounting ring provides for more rigidity between the antenna and its supporting structure.

The ability of the supporting legs of the supporting device to be collapsed, as hereinafter described to less than full extension allows for easier storage of the supporting structure. This same feature makes such supporting structure less subject to wind loads.

The invention can best be understood from the following description to be read in view of the accompanying drawing in which

FIGURE 1 is a view in perspective of the support and positioning device of our invention as used to support an antenna;

FIGURE 2 is a view in perspective showing details of the construction of one end of one of the tripod assembly supports; FIG. 3A, B, C, D are purely diagrammatic views to illustrate successive positions and therefore the movement involved in tracking.

Referring particularly to FIGURE 1, the antenna support and positioning device is designated generally at 11 shown mounted on a base 13. In the specific embodiment of the invention shown herein at FIGURE 1, the support device includes three tripod assembly supports. It is to be understood however that three or more such tripod assemblies may be used to support an antenna, and the number of such supports may be varied dependent upon specific requirements. Since all three tripod assemblies are identical, only one such tripod will be described.

Each tripod assembly includes three extendible and retractable legs 15, 17, 19. As each leg of the tripod assembly is identical, only one need be described. Thus for example leg 17 includes a tubular portion 17A and a movable piston-like portion 17B that is slidably engageable in the tubular portion. The base or lower end of the tubular portion 17A terminates in a ball which is engageable in a socket on the base 13 to provide a ball and socket joint 21. By such arrangements the leg 17 is permitted free motion in any direction as is true of legs 15 and 19. At its other end each tripod assembly terminates in a triangular shaped framework 23 made of three similar sized arms 23A, 23B and 23C. The arms are slightly spaced from each other and linked by pivot pins, one of which is shown in dotted outline at 25. Pivotaly mounted on each one of the three pins 25 is the end of one of the piston like sections of the legs 15, 17, and 19.

The framework 23 further includes a bearing plate 27 which serves to support a flat plate 29 the bottom end of which is adapted to rotate in the bearing plate 27. The plate 29 is further in pivotal engagement with an arm 31 about a pin 33 which extends through said arm and plate. Each of the legs can be adjusted in height in unison or separately, as hereinafter described, so that a wobble like motion can be imparted thru the framework 23 to the pin 33 considered as a control point of the antenna. As can be seen in FIG. 2, which represents a tripod top as used in a working model to illustrate the possibilities of the new mode of tracking, the plate 29 is accommodated within a U-shaped slot at the end of said arm. The other end of the arm 31 is confined in a bearing at one apex of a triangular shaped frame 35 to permit freedom of movement of said arm to rotate relative to

said frame. In the same manner the corresponding arms 31 of the other two tripod assemblies are also separately joined in bearings to the discrete apices of the frame 35. Affixed to the frame 35 is mounting ring 37 which serves to support an antenna 39. In a very general sense there is a common center at pin 33 from which the leg lengths can be measured. The most familiar strong, truly common-center, wide-angle, free-moving joint structure is the universal joint normally used only at narrow angles as a drive coupling between only two shafts; however further shafts can be connected at or reasonably close to the same center without unduly hampering the freedom of motion. Considered entirely disconnected from the antenna, equally increasing all leg lengths increases tripod height, but if in or near balance as a tall tripod, increasing only one leg length mainly controls horizontal position; if out of balance height may vary directly or inversely with length, and in widely variable ratio depending on the particular leg considered and the degree of unbalance. This type of tripod movement has been used previously in 3-dimensional positioning servo-mechanisms as illustrated by Cailloux Patent No. 2,545,258 for microscope slide positioning, also using an analog tripod input device for control, somewhat similar to the long familiar 2-dimensional "Telautograph" used for writing train arrival times.

Ordinarily the mere change in tripod height is enough to control direction, particularly in pointing near the Zenith. However, in approaching the horizon the plane of the antenna control points passes thru a tripod. In the case of a three tripod mount as shown only two points would then be controllable or even stable to determine the position of such plane. If more than three tripods are used the chance of such loss of control is reduced. In any case separate control of each leg as noted above avoids the problem, and also can be used to overcome gradual tipping of the entire assembly.

Calculation of the proper leg lengths for each pointing direction is a matter of straightforward solid or spherical trigonometry, complicated only because of the several steps of each calculation, and the number of possible variables. The same pointing direction can be maintained even if antenna:

- (a) rotates about pointing axis (often changing polarization);
- (b) moves in or out on pointing axis (changing range; or
- (c) moves up or down with pointing axis (changing parallax).

For maximum simplicity in calculating a single set of leg lengths for each pointing direction we might assume no variation of these over entire scan. However, the unavoidable roll noted above requires variation of (a); again for simplicity we might now assume particular movement to or from Zenith without change of (a), and about Zenith with such a change of (a), conforming to the subtraction of angles noted in the general description. Variation from such angle could also be obtained by control of leg length, but would complicate control without any apparent advantages. This is sufficient for operation, maintains symmetry of design, etc., but to minimize leg length, height, and windage, avoid leg interference, provide scan beyond a hemisphere, maintain center of gravity, or for other reasons, some further arbitrary of empirical relation of the declination to variables (b) and (c) may be desirable. For example, to reduce interference among legs and control points the antenna may lean forward as in FIG. 1; again a center (outside plane of such points) would partly simplify calculations. Once calculated and stored in the servo-system the operation would be the same in any case. To compute or store every possible combination of leg lengths for every pointing direction would be hopelessly complex and serve no useful purpose.

Most recent conventional antenna mounts involve a two-fold symmetry; the new mode of tracking merely requires more than two-fold symmetry, three-fold as in FIG. 1, four-fold as in the actual model, six-fold with a center and six peripheral support points (all equally spaced), or any higher order. A higher order involves more legs but provides better distribution of load and does not proportionately increase complexity of the servo system since the tracking hemisphere is divided into a plurality of analogous regions corresponding to the order of symmetry, requiring merely that the calculated leg lengths be assigned to the proper legs for the region involved. The present system requires a servo having outputs corresponding to the number of legs, but the reduction in maximum antenna velocities and more effective drive more than compensates for the number of channels.

As is well-known in structures, for stability the tripod bases should be as wide as possible without interference; the immediately apparent limiting width involves the same foundation point for adjacent legs. An even greater advantage of this arrangement is in simplifying analysis of the geometry involved; the three antenna control points become connected to only three foundation points by six exterior legs, forming six structural triangles about the sides, three with one side along the foundation and three along the antenna, structurally very desirable. The general form corresponds to a "regular" octahedron of eight triangular faces, analogous to the eight 90° spherical triangles used in dividing a terrestrial globe or other sphere. Only four of such triangles would be involved in the tracking hemisphere, and its orientation relative to the above structure is very confusing compared to the situation when four tripods are used. Use of four tripods is also particularly helpful in analyzing the tilting motions, both in simplifying movements of parts, permitting designation by compass points as in the tracking hemisphere, and adaptability to the most familiar four lobe tracking control, all in four-fold symmetry; however three lobe control is also rather old. Such an assembly may be considered as a quasi-regular decahedron of two mutually skewed squares and eight triangles. The operation of a three tripod assembly will thereafter then be easier to explain.

To portray spatial relations in a drawing is difficult at best, particularly with very open structure and when spatial motions are involved. Therefore FIG. 3 A, B, C, and D shows diagrammatically only the essential elements of a four tripod assembly in several different positions. A fixed center in the plane of the antenna control points is assumed merely for simplicity in the geometry. To emphasize the spatial relations the planes defined by these elements are portrayed as opaque surfaces, and elements in back are shown dashed. This sketch involves several different types of lines:

- (a) The actual legs in heavy lines;
- (b) Boundaries of antenna and foundation points in medium lines; and
- (c) Certain dot-dashed axes or center lines, dashed "projections" between different positional views, and shading to bring out the position of the surfaces portrayed as opaque, in light lines.

In FIG. 3A the elements are shown symmetrical for Zenith pointing, with N. to S., E. to W., and intermediate center lines or axes of the antenna control point plane, either point-to-point or side-to-side; interior legs to center of base are shown only in this part of the figure. In FIG. 3B the antenna has been tilted to the South horizon, without any change in the EW axis or its support, the control points showing as a square. The projection lines from FIGS. 3A to 3B serve to emphasize that points E. and W. need not move for this change in pointing. In equivalent FIG. 3C tilt to the East horizon is shown, a similar situation from a different viewpoint, the control points appearing in a line representing the edge of a plane. In FIG. 3D tilt to the South East horizon is shown, without change

in one of the intermediate axes NE. to SW. but changing all the triangles, the square now appearing at about 45°. In each of FIGS. 3B, C, and D, an axis is shown in the foundation plane and is also in the vertical antenna control point plane (extended); also the compass points marked are all in such plane to help portray the orientation of the several members. In FIGS. 3B and C there are re-entrant trihedral corners corresponding to the pointing direction, and in FIG. 3D the line S. to E. defines a re-entrant dihedral angle, while the antenna controle square and two triangles are coplanar. Particularly in FIGS. 3B and 3C it is noted that legs to both upper and lower corners shorten or lengthen together, contrary to Zenith region operation; the computed leg lengths would provide for this effect.

Now overlooking FIG. 3A, FIGS. 3B, D, C portray progressive positions of a horizon scan and reveal the rolling action necessary to such scan, accomplished by continuous adjustment of the several legs. Legs to the uppermost control point or points assure proper control, assuming antenna frame rigid, even when legs to lower points may lose control. The extra interior legs to center of base omitted from FIGS. 3B, C, and D avoid relying on rigidity of antenna frames.

In the case of a triangular top since the axes are point-to-side only, not at right angles, and do not correspond to compass points operation though equivalent is more difficult to portray. To tilt about one such axis assumed as N. to S. the point and center of opposite side are fixed, but the side tilted. To tilt about the center parallel to such side (normal to such axis or E. to W.) entire side is raised and opposite corner lowered twice as much. Thus the three-fold symmetry of structure is unlike the four-fold symmetry of compass points, complicating analysis of the operation, altho not significantly affecting the actual operation.

The raising and lowering of each of the discrete legs of any of the tripod assemblies can be accomplished by any of several well known systems. In the specific embodiment, as shown in FIGURE 1, use is made of a hydraulic system utilizing lines 41 connected to appropriate fittings 43. For purposes of programming such hydraulic system a servo mechanism designated generally at 45 is provided. While use of a hydraulic system is suggested in the specific embodiment shown it is apparent that a system employing pneumatic cylinders or mechanical screws could be used in controlling the movements of the separate legs of the several tripod assemblies.

The use and manner of operation of the antenna support will be evident from the detailed description of the device heretofore set forth. Sequential changes in the length of each tripod leg of any or all of the tripod assem-

blies, in conjunction with the varied pivoting movements of the several legs about the pins 25, and the freedom of rotational movement permitted by the arms 31 and the plates 27, will cause the ring 37 and its associated antenna 39 to move through any desired given pattern from 180° horizon-zenith-horizon sweep to 360° horizon search (at 0° elevation).

What is claimed is:

1. An antenna support comprising a plurality of tripod assemblies, each of said assemblies including three extendible and retractible legs having discrete rotatable base portions and top ends pivotable in a framework, a plate having one end rotatable in said framework and an arm pivotably secured to said plate at its other end and rotatable relative to a ring support to which said antenna is affixed.

2. An antenna support comprising a plurality of tripod assemblies, each of said assemblies including three extendible and retractible legs having discrete rotatable base portions and top ends pivotable in a framework, a plate having one end rotatable in said framework and an arm pivotably secured to said plate at its other end and rotatable relative to a ring support to which said antenna is affixed, and means for separately extending and retracting each of the legs of the various tripod assemblies.

3. An antenna support comprising a plurality of identical tripod assemblies each of said assemblies including three extendible and retractible legs that terminate in base portions that are freely rotatable and wherein the top ends of the three legs of said tripod assembly are discretely and pivotally mounted in a framework, a plate freely rotatable on said framework at one of its ends and having its other end pivotally mounted in an arm that is free to rotate in a ring support to which said antenna is affixed.

4. An antenna support of the kind set forth in claim 3 and further including means for separately extending and retracting each of the legs of the various tripod assemblies.

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