United States Patent

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[72] Inventor Leonard L. Blaisdell
Medway, Mass.
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[73] Assignee Sylvania Electric Products Inc.

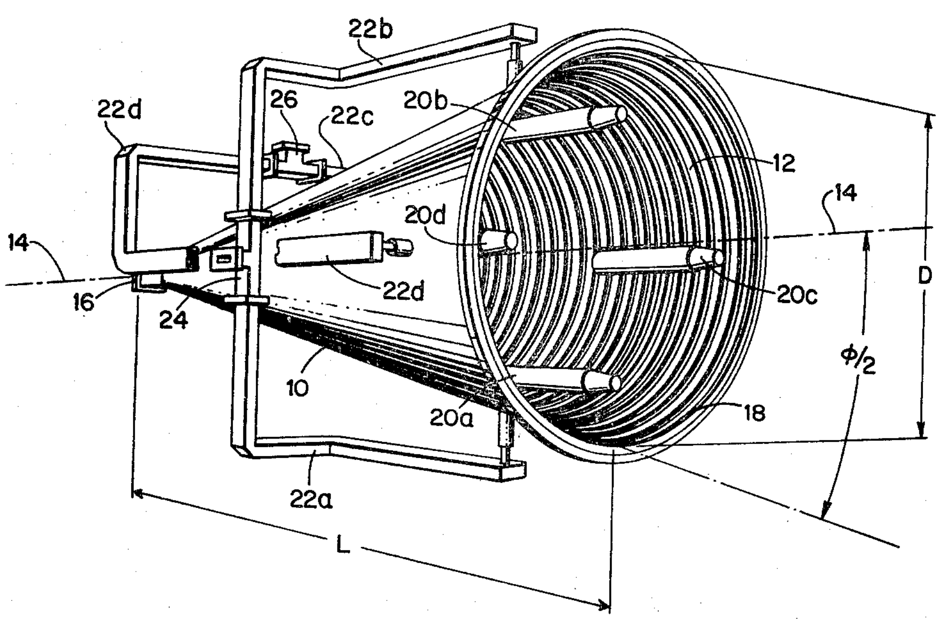
[54] **MULTIMODE ANTENNA FEED SYSTEM HAVING A PLURALITY OF TRACKING ELEMENTS MOUNTED SYMMETRICALLY ABOUT THE INNER WALLS AND AT THE APERTURE END OF A SCALAR HORN**
5 Claims, 7 Drawing Figs.

[52] U.S. Cl. 343/725, 343/786, 343/895, 343/781
[51] Int. Cl. H01g 21/00, H01g 13/00, H01g 1/36
[50] Field of Search 343/725, 729, 781, 786, 840, 895

[56] References Cited
UNITED STATES PATENTS
2,863,148 12/1958 Gammon et al. 343/895
3,274,603 9/1966 Kay 343/786X
3,482,251 12/1969 Bowes 343/786X
3,500,419 3/1970 Leitner et al. 343/781X

Primary Examiner—Herman K. Saalbach
Assistant Examiner—T. Vezeau
Attorneys—Norman J. O'Malley, Elmer J. Nealon and David M. Keay

ABSTRACT: An antenna feed system employing a plurality of tracking elements mounted symmetrically about the inner walls and at the aperture end of a scalar horn. The tracking elements have a single axis of directivity coincident with the axis of directivity of the scalar horn.



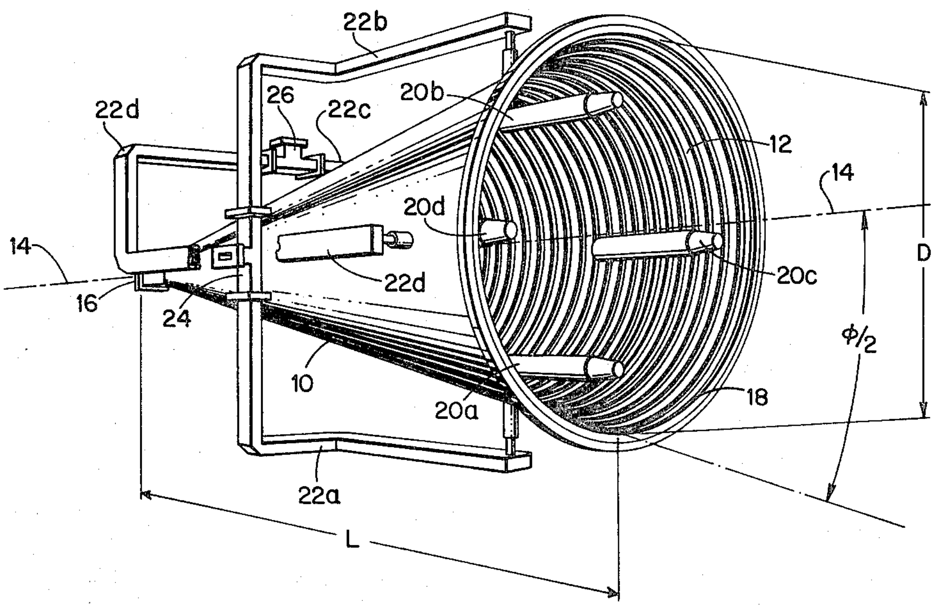


Fig. 1.

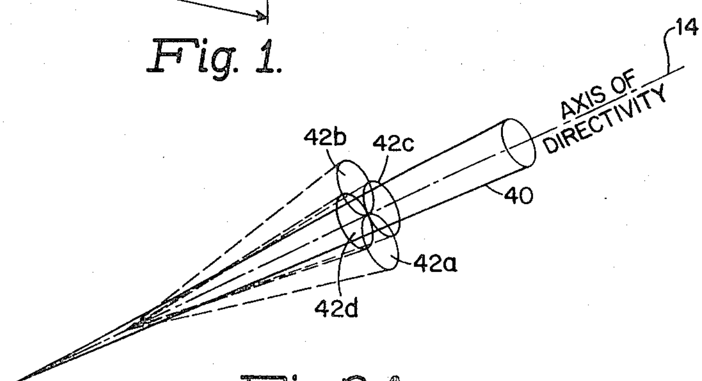


Fig. 2A.

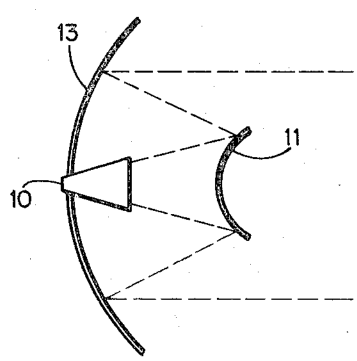


Fig. 2B.

INVENTOR
LEONARD L. BLAISDELL
BY David M. Keay
AGENT

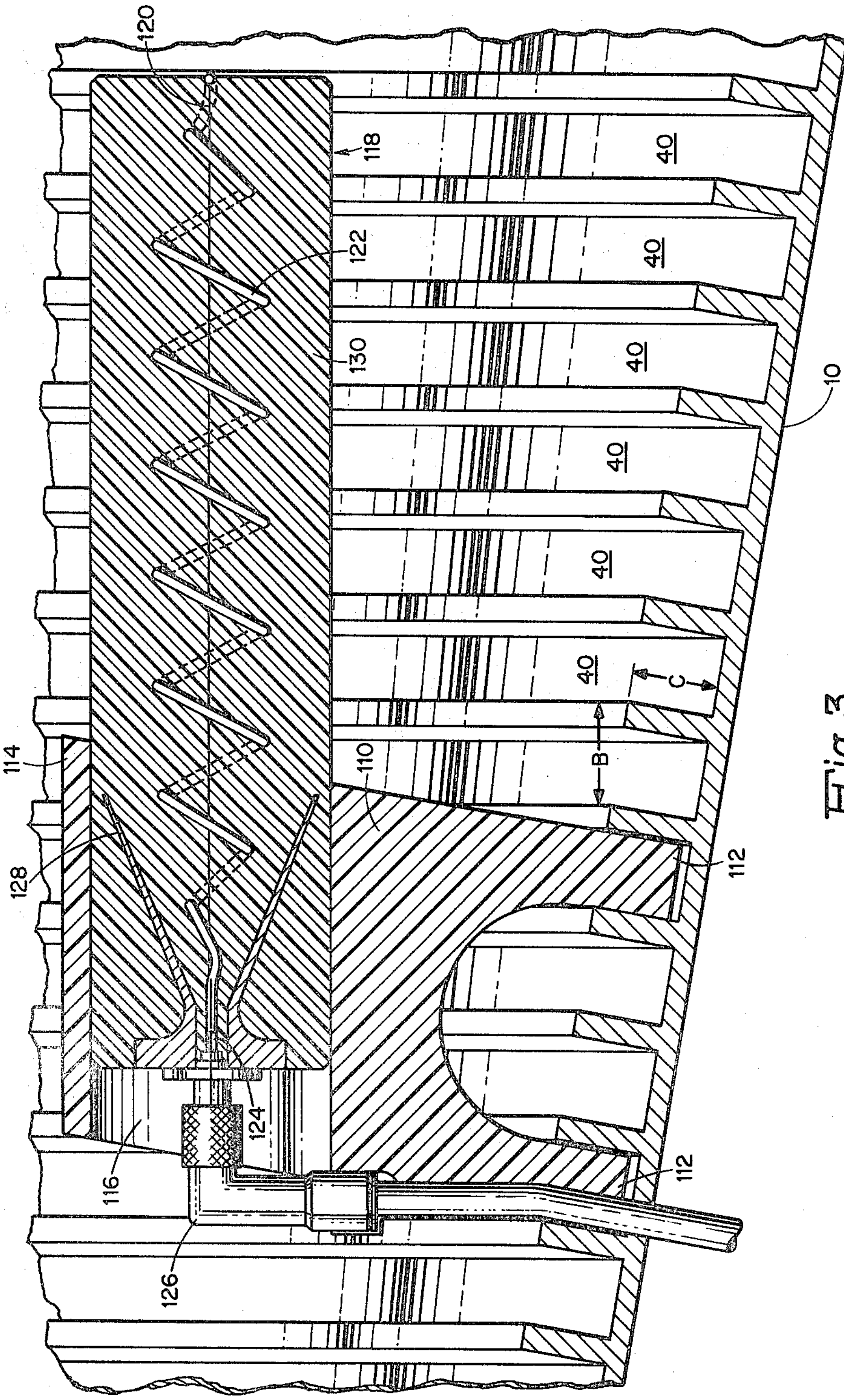


Fig. 3.

INVENTOR
LEONARD L. BLAISDELL
BY David M. Kay
AGENT

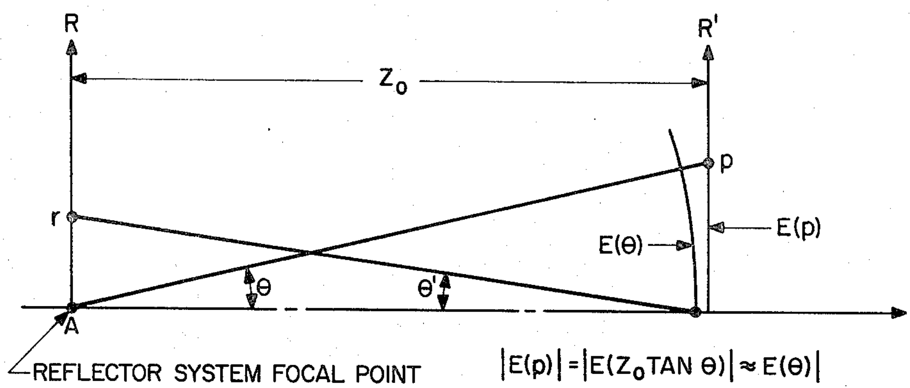


Fig. 4.

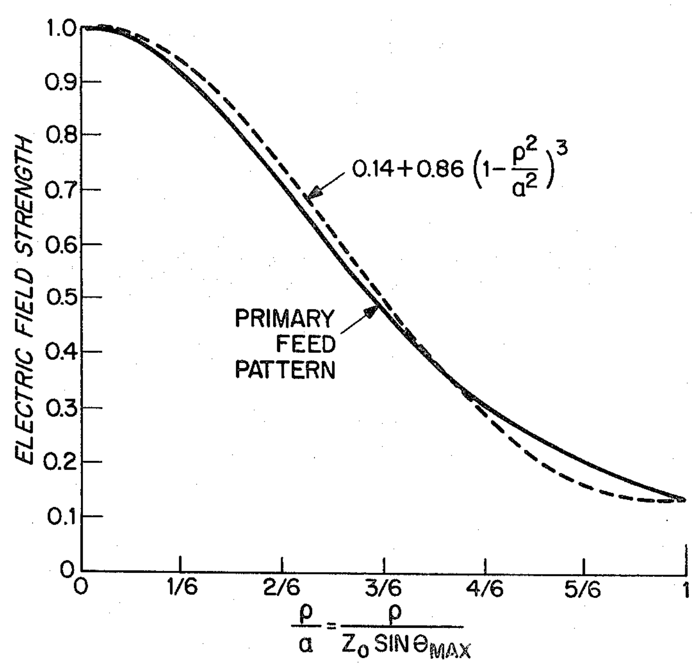


Fig. 5.

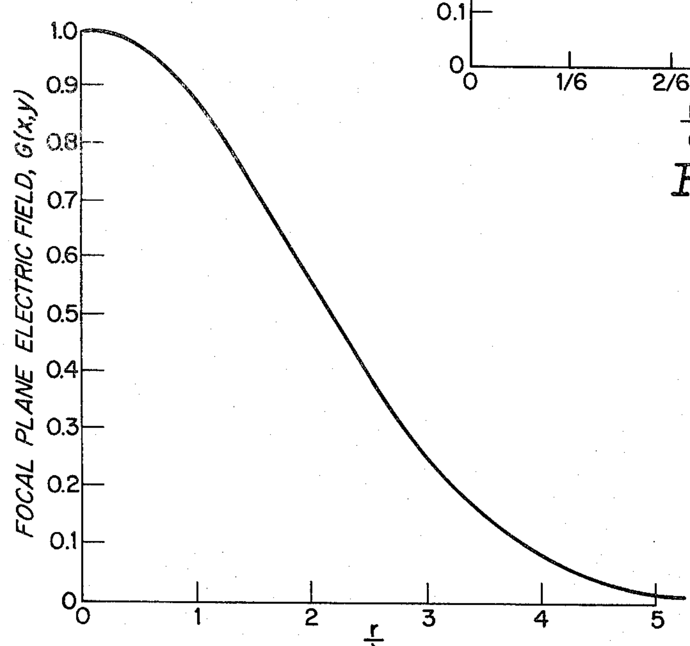


Fig. 6.

INVENTOR
LEONARD L. BLAISDELL
BY David M. Keay
AGENT

MULTIMODE ANTENNA FEED SYSTEM HAVING A PLURALITY OF TRACKING ELEMENTS MOUNTED SYMMETRICALLY ABOUT THE INNER WALLS AND AT THE APERTURE END OF A SCALAR HORN

BACKGROUND OF THE INVENTION

This invention is concerned with antenna systems and, in particular, with a radiofrequency antenna feed system useful, for example, in communication and tracking antenna systems.

As is well known, a Cassegrain antenna includes a feed assembly located at the vertex of a parabolic reflector and a subreflector located between the vertex and the virtual focal point of the parabolic reflector. In a receive mode, parallel rays coming from a point are reflected by the parabolic reflector as a converging beam reflected by the subreflector and converge at the vertex (the position of the feed assembly). In a transmit mode, the path direction of a ray is reversed.

The feed assembly must have low loss and stable radiation pattern characteristics over a broadband to result in low-noise antenna performance for broadband communication purposes while at the same time providing the requisite beam patterns for tracking performance.

Conventional feed systems include a four-element monopulse feed which is primarily a tracking feed. Typical values of the feed spillover efficiency (defined as the percent of energy that is radiated by the feed assembly and is intercepted by the subreflector) vary from 65 to 85 percent. If the transmit and receive bands are separated significantly in frequency, as in the commercial satellite communication field, the illumination of the parabolic reflector by the feed is improved in one band only at the expense of performance in the other. In fact, due to the decrease in beam width as a function of frequency, side lobe energy appears in the operation of the parabolic reflector in the higher frequency bands.

Attempts have been made to provide a wideband scalar horn with a tracking capability by use of low excitation at the higher order excitation modes. A scalar born is one which the aperture illumination functions in the two planes are the same resulting in equal *E* and *H* plane beam widths. These higher order modes are generally excited by mode couplers at or near the scalar horn throat and depend upon the particular modes that the associated waveguide is capable of supporting. For example, the two modes that may be excited by mode couplers for tracking in a circular polarized conical horn are the TE_{01} and the TM_{01} modes. These modes each have a null on the axis of directivity and, consequently, radiate a different pattern in which the electric fields are spatially orthogonal. By phasing the two modes to obtain time quadrature between them, a circularly polarized difference pattern is provided. Other tracking modes may be excited by using a four-wave guide feed at the throat of the conical horn.

However, all these conventional antenna feed systems are dependent upon the modes that exist in the particular waveguide system, for example, conical in the case of a conical horn. This fact is a basic limitation that precludes having an optimized wideband communications feed and, at the same time, having an optimized tracking feed as most higher order mode tracking techniques are inherently narrowband. The tracking modes in a conical horn do not lend themselves directly to a rectangular coordinate tracking system as is most commonly required in, for example, elevation or azimuth tracking mounts. Some form of coordinate conversion is required in these cases.

It is, therefore, an object of this invention to provide an antenna feed system which has independent patterns for both the tracking and wideband communication functions.

SUMMARY OF THE INVENTION

An antenna feed system according to the present invention incorporates a plurality of tracking elements, for example, helical tracking elements, mounted symmetrically in the same radial plane on the inner walls at the aperture end of a large flared scalor horn, for example, a conical scalar horn, such that the axis of directivity for the plurality of tracking elements and that for the scalar horn coincide. The present invention does not use the higher order modes or the circular modes of the conical horn for tracking but employs a four-element monopulse tracking array incorporated into the aperture end of the horn.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a pictorial representation in perspective of a feed assembly according to the invention;

FIG. 2A is a pictorial representation of the feed assembly of FIG. 1 in conjunction with a Cassegrain reflector system;

FIG. 2B is a diagrammatic representation of the antenna patterns resulting from the use of the feed assembly of FIG. 1 in an antenna system;

FIG. 3 is a sectional view of a portion of the feed assembly of FIG. 1 illustrating in detail one type of a tracking element;

FIG. 4 is a geometrical diagram useful for calculating the focal plane image necessary to calculate the energy distribution across the antenna feed of FIG. 1;

FIG. 5 is a graphic representation of the primary feed pattern for the embodiment of FIG. 1; and

FIG. 6 is a graphic representation of the focal plane field distribution for the embodiment of FIG. 1 in conjunction with a reflector.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to FIG. 1, an antenna feed assembly according to the present invention includes a scalar horn assembly **10** having a corrugated inner wall **12**, an axis of directivity **14**, a throat end **16**, and an aperture end **18**. Mounted symmetrically along the inner wall **12** and radially outward from the axis of directivity **14** are four tracking elements **20*a*—20*d***, for example, dielectric rods or helical elements. Waveguide conductors **22*a*** and **22*b*** connect respective tracking elements **20*a*** and **20*b*** to a first comparator **24**, typically a magic tee, and waveguide conductors **22*c*** and **22*d*** connect respective tracking elements **20*c*** and **20*d*** to a second comparator **26**.

The scalar horn **10** is excited via any well-known transducer (not shown), for example, an orthomode transducer which supports two orthogonal TE_{11} modes, one of which is employed during transmit operation, the other of which is employed during the receive operation. When used in conjunction with a reflector system, such as the well-known Cassegrain type shown in FIG. 2A, the scalar horn generates the antenna filed pattern **40** of FIG. 2B. The Cassegrain reflector system includes a subreflector **11** and a main reflector **13**. Also shown in FIG. 2B are the resultant field patterns **42*a*—42*d*** for respective tracking elements **20*a*—20*d***. The tracking elements **20*a*** and **20*b*** provide vertically disposed diverging response patterns **40*a*** and **40*b***. The tracking elements **20*c*** and **20*d*** provide horizontally disposed diverging response patterns **40*c*** and **40*d***.

From the antenna patterns shown in FIG. 2B, it can be seen that energy received from a point lying on the axis of directivity **14** will induce signals of equal intensity into each of tracking elements **20*a*—20*d***. The induced signals from the tracking elements **20*a*** and **20*b*** are directed through respective waveguide conductors **22*a*** and **22*b*** to the comparator **24**. Likewise, the induced signals from the tracking elements **20*c*** and **20*d*** are directed through respective waveguide conductors **22*c*** and **22*d*** to the comparator **26**. For the case of a point lying on the axis, the energy at the output of the comparators is zero. Energy received, however, from any point off the axis of directivity causes unequal amounts of energy to be induced into the respective tracking elements in proportion to and in accordance with the degree and sense of angular displacement of the axis of directivity relative to the line of arrival of the incoming signal source.

SCALAR HORN

The construction and operation of flared scalar horns are well known and described in literature, for example, E. J. Simmons, A. F. Kay, "The Scalar Feed—A High Performance Feed for Large Paraboloid Reflectors," IEEE, May 1966, Large Antenna Symposium Conference Record. The flared scalar horn provides low spillover, equal E and H plane patterns, a wide frequency bandwidth, and a stable beamwidth versus frequency characteristic. The beamwidth varies inversely in accordance with the length L of the flare divided by the wavelength, λ, of the energy. The larger this ratio becomes, the more well defined the horn beam becomes. When the flare length, L, is sufficiently large that the diameter, D, of the horn aperture is much larger than the wavelength, λ, then

$$D = 2L \sin \Phi/2 \qquad (1)$$

where Φ is the feed flare angle.

To provide equal E and H plane patterns, the walls **12** of the horn **10** are corrugated. Without the corrugations, the edges of the horn are strongly illuminated in the E plane. This E plane illumination is reduced by means of capacitance chokes in the form of annular grooves **40** perpendicular to inner wall **12** as shown in FIG. **3**. The aperture B of the annular grooves is chosen to be large enough to avoid cutoff of the dominant mode and small enough to avoid exciting a higher order mode thereby preventing illumination of the rim of the horn at the feed aperture. The grooves are closely spaced compared to a wavelength, λ, typically between a quarter and a half wavelength. The chokes must be capacitive in order to simulate the same boundary condition in the E plane as in the H plane, causing the electric field to be zero at the horn walls in both planes. Hence the depth, C, of the chokes must be between a quarter and a half wavelength.

TRACKING ELEMENTS

The four tracking elements **20*a*—20*d*** are excited directly by the electric field incident upon them and not by the field of the modes that exist in the scalar horn **10** as in the prior art devices. This excitation limits the distance from the aperture end of the scalar horn that the tracking elements can be located. For example, the tracking elements are located away from the throat end **16** of the horn **10** to preclude mode coupling into the elements from the fields that exist in the horn. However, the phase center of the tracking feed configuration should be as close to that of the horn to provide acceptable focusing of the tracking elements when used in a common reflector antenna system. The location of the tracking elements is, therefore, a compromise between competing requirements, which requirements are balanced by the judicious placement of the tracking elements in accordance with the structure and analysis described hereinbelow.

The gain of the individual tracking elements and the diameter of the horn on which they are located are a tradeoff between tracking system performance and horn performance. The tracking element gain determines the electrical size of the tracking element, and the diameter of the circle for mounting determines the field strength incident on the tracking elements at the horn aperture. The smaller the circle diameter and the greater the tracking element gain, the greater the blocking effect of the tracking feed configuration is on the horn aperture.

MATHEMATICAL ANALYSIS OF THE TRACKING FEED

Referring to FIGS. **2**, **4**, **5**, and **6**, when the communications port of the horn is excited, an electric field distribution $E(\theta)$ (circular symmetry assumed) is incident upon the subreflector **11** of a Cassegrain antenna system. The subreflector **11** intercepts a portion of the incident energy. The subreflector **11** and the main reflector **13** are shaped to maximize the field at infinity on the focal axis. That is, given an incident field distribution on the subreflector, the reflector system is designed to maximize the power picked up by a far-field probe on the focal axis. Conversely, if the far-field probe is radiating, the reflector system maximizes the power which will be picked up by a large antenna near the subreflector having an aperture field distribution $E(\theta)$. Thus, by analogy with matched filters, the field distribution coming off the subreflector **11** in the receive mode is the complex conjugate of $E(\theta)$. Since the reflector system is designed assuming the feed has a perfect phase center, $E(\theta)$ has a constant phase on the surface of a sphere whose center is the focal point of the reflector system. The focal plane image may now be computed from $E(\theta)$ using the geometry of FIG. 4.

It can be shown that with θ and λ reasonably small, the focal plane field distribution is approximately the Fourier Transform of the field at R'. That is

$$E(r) \approx E(Z_o \sin \theta) \approx \int_0^a |E(p)| J_o(kp \sin \theta') p\,dp \qquad (2)$$

where $a = Z_o \sin \theta_{max}$, k is the free space propagation constant, θ_{max} is the subreflector half angle, and circular symmetry has been assumed. In equation (2), the absolute magnitude of $E(p)$ is taken because the phase of $E(p)$ is the right amount to account for the path length variation of Δp as a function of p. A plot of $E(p)$, which is identical to the primary feed or horn pattern for which the subreflector is shaped, is shown in FIG. **5**. The pattern illustrated in FIG. **5** ignores the effects of blocking and tolerances.

Instead of determining $E(r)$ directly from equation 2, it is convenient to approximate $E(p)$ by

$$E(p) = 0.14 + 0.86\left(1 - \frac{p^2}{a^2}\right)^3 \qquad (3)$$

which is shown by the dashed lines in FIG. **5**. The focal plane is then

$$E(\mu) = 0.14\Lambda_1(\mu) + \frac{0.86}{4}\Lambda_4(\mu)$$

where:

$$\mu = \frac{2\pi}{\lambda} Z_o \sin \theta_{max} \sin \theta' = \frac{2\pi}{\lambda} \sin \theta_{max} r \qquad (4)$$

and the approximation $r = Z_o \sin \theta'$ has been made. The focal plane image is plotted in FIG. 6. *E H L L, D L* where

The received voltage from any aperture-type antenna may be written as

$$V = \frac{K}{\sqrt{\int\int E(x,y)^2 dx\,dy}} \int\int E(x,y) G(x,y)\,dx\,dy \qquad (5)$$

where K is the constant of proportionality, $E(x,y)$ is the field distribution in the aperture with the input port excited by 1 volt, and $G(x,y)$ the field existing across the antenna aperture with the antenna receiving. Thus, if $G(x,y)$ is constant and equal to unity (the incident field is a plane wave), the output voltage is proportional to the square root of the aperture area.

To compute the received signal from the scalar horn throat and since $E(x,y)$ is not known, another method of computing the output voltage V_c must be used. The maximum voltage occurs if $E(x,y)$ equals the complex conjugate of $G(x,y)$. This voltage is

$$V_{max} = \frac{K\int\int |G(x,y)|^2 dx\,dy}{\sqrt{\int\int |G(x,y)|^2 dx\,dy}} = K\sqrt{\int\int |G(x,y)|^2 dx\,dy} \qquad (6)$$

Evaluating equation 6 numerically using FIG. 6, V_c max = 3.14. In practice, however, $E(x,y)$ does not match $G(x,y)$. In fact, from pattern data, it is known that 10 percent of the available power is not picked up, due to spillover past the subreflector. Hence $V_c \approx .9\ V_{c\ max} = 2.98$ (7)

The output voltage from a single tracking element will now be computed, assuming the focal plane image is as shown in FIG. 6 (the incident plane wave is along the focal axis). This computation will be done at 4.0 GHz.

Data indicates that a typical tracking element optimized to reduce aperture blocking has 11.5 db gain. It is located 11 inches (3.72λ) off the focal axis. For convenience, the field distribution in the tracking element aperture is assumed constant over a 1.06λ square (the effective size of the aperture). The exact field distribution will have little effect upon the results for small apertures.

The voltage output of one tracking element is obtained from equation 5 as the average value of $G(x,y)$ over the tracking element aperture times the square root of the aperture area.

$$V_T = 1.06 \times 0.060 = 0.0635 \qquad (8)$$

The tracking comparator output voltage is equal to zero, since the diametrically opposite tracking element receives the same voltage.

DIFFERENCE PATTERN SLOPE

The slope of the difference pattern is computed by assuming that the incident plane wave makes an angle with the focal axis of approximately one-tenth the 3—db—sum beam width. A squint angle is assumed to be in the plane containing diametrically opposite tracking elements, and the difference of the output voltages is a measure of the difference pattern slope. This slope is identical to that which would be obtained if the plane wave is off the focal axis in one of the principal planes, and all four tracking elements are used to form the difference pattern.

If the plane wave makes an angle of $.1\lambda/D_1$ with the focal axis, where D_1 is the main reflector diameter, the focal plane image moves approximately 0.25λ normal to the focal axis. Hence, the output voltages of two tracking elements, one located 3.47λ and the other 3.97λ from the peak of the focal plane image, are:

$$V_{T1} = 1.06 \times 0.155 = 0.163 \quad V_{T2} = 1.06 \times 0.085 = 0.085 \qquad (9)$$

Hence, the tracking voltage slope in terms of volts per λ/D_1, assuming that the communications channel output voltage to be unity, is.

$$\text{SLOPE} = 0.163 - 0.085/(.1\lambda/D_1)(2.98) = 0.262/(\lambda/D_1\text{a-}) \qquad (10)$$

converting equation 10 to volts per degree, it is approximately 1.85 volts per degree-volts normalized slope.

If a different slope is desired, the gain and the radial position of the tracking elements can be varied and a new slope calculated in accordance with the above equations. The final radial positioning of the four tracking elements inside the scalar horn is a tradeoff between tracking performance and horn performance. For example, to increase the slope of the difference pattern, the gain of the individual elements can be increased. The exact radial position is determined by varying the tracking element gain and position around values which optimize the desired tracking system performance until a condition which provides tracking with minimum effect upon horn performance is achieved. By locating the tracking elements at the aperture end of the feed horn assembly **10**, a tracking pattern which is substantially independent of the horn pattern is provided, and the excitation mode at the throat **16** is effectively undisturbed.

Referring again to FIG. **3**, one embodiment of a tracking element such as a helical tracking element is shown and includes a mounting base **110** fixedly mounted at one end **112** between two of the corrugations **40** of the scalar horn assembly **10**. The other end **114** has a cylindrical opening **116**, the axial centerline of which is parallel to the axis of directivity **14** (focal axis) of the horn assembly **10**. Fixedly mounted within the cylindrical opening **116** is a helical antenna assembly **118** having a longitudinal axis **120** coincident with the centerline of the cylindrical opening **116**. The helical antenna assembly **118** includes a helical element **122** having one end electrically connected to the center conductor **124** of the coaxial cable **126** and the other end tapered to achieve an impedance match of the helical element to free space. Disposed symmetrically about the one end of the helical element **122** is a conically shaped ground plate **128**. The combination of the helical element **122** and its associated conically shaped ground plate are encapsulated in a low loss dielectric **130** typically a low density foam.

The operation of a helical antenna is well known and is described in detail in "Antenna Engineering Handbook" by Henry Jasic, a McGraw-Hill Book Company publication. The expressions for gain and beamwidth are repeated herein for convenience. The half-power beamwidth, B, and the gain, G, can be expressed as follows:

$$B = \frac{52}{\frac{C}{\lambda}\sqrt{\frac{ns}{\lambda}}} \qquad (11)$$

$$G = 15\left(\frac{C}{\lambda}\right)^2 \frac{ns}{\lambda} \qquad (12)$$

where:

λ = free-space wavelength
s = spacing
c = circumference and
n = number of turns

It has been shown that an antenna feed system having substantially independent tracking and communication directional zones has been developed.

I claim:

1. In an antenna system including a reflector assembly, an antenna feed apparatus comprising:

a scalar feed horn assembly positioned in an electromagnetic wave propagation arrangement with the reflector assembly and having a throat end and an aperture end, said feed horn assembly being operative in response to an input signal at said throat end to illuminate said reflector assembly and to generate a first confined field having an axis of directivity;

a plurality of tracking elements for providing a second confined field in response to an input signal, said confined field having a plurality of directional zones; and

means for mounting said plurality of tracking elements symmetrically about the inside wall and at the aperture end of said scalar horn assembly with the axis of directivity of said second confined field coincident with the axis of directivity of said scalar horn assembly.

2. An antenna feed apparatus according to claim **1** further including means connected to a pair of said plurality of tracking elements for combining substantially in phase opposition a radiofrequency signal received from opposing zones thereby to produce a resultant energy signal for each pair of opposing zones.

3. An antenna feed apparatus according to claim **1** wherein said plurality of tracking elements includes four helical antenna elements each having a predetermined gain.

4. An antenna feed apparatus according to claim **3** wherein means for mounting includes for each of said plurality of tracking elements a base member of a low loss dielectric material having one end fixedly mounted to the inner wall of said scalar horn assembly and the other end having a cylindrical opening, the centerline of which is parallel to the axis of directivity of said plurality of helical antenna elements and the diameter of which is sufficient to accept one of said helical tracking elements, said base member extending radially inward such that the centerline of the cylindrical opening is a predetermined distance from the axis of directivity of the first confined field of said horn assembly.

5. An antenna feed apparatus according to claim 4 wherein the predetermined gain for each of said helical antenna elements is substantially 11.5 db and wherein the predetermined distance that the centerline of the cylindrical opening is located from the axis of directivity of said scalar horn assembly is substantially equal to 3.72λ where λ is the free space wavelength of the input signal.