Feb. 4, 1969 N. B. HAI ET AL 3,426,351

DUAL BEAM ANTENNA FOR SATELLITES

Filed Nov. 12, 1965 Sheet 1 of 3

PRIOR ART

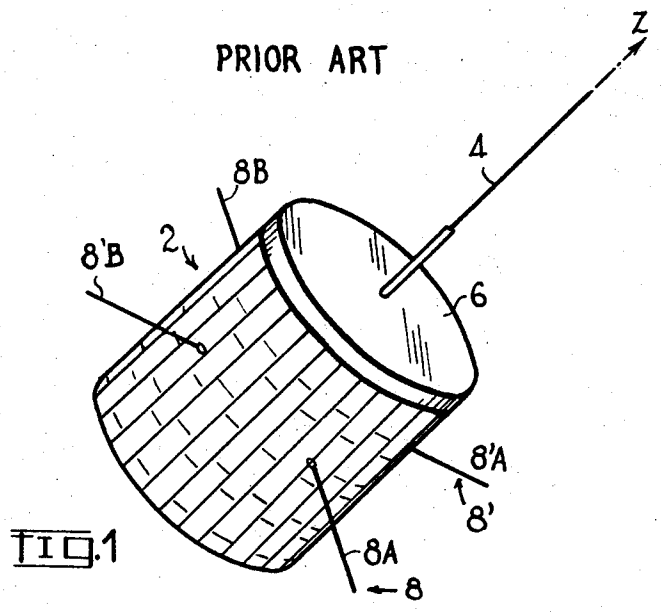


FIG. 1

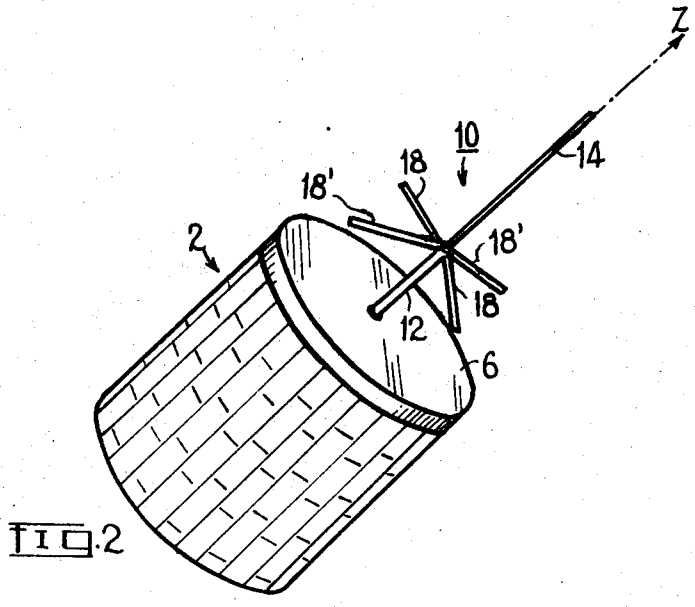


FIG. 2

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Fig. 3

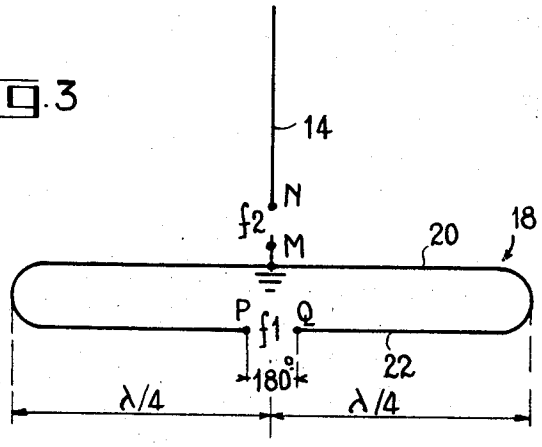
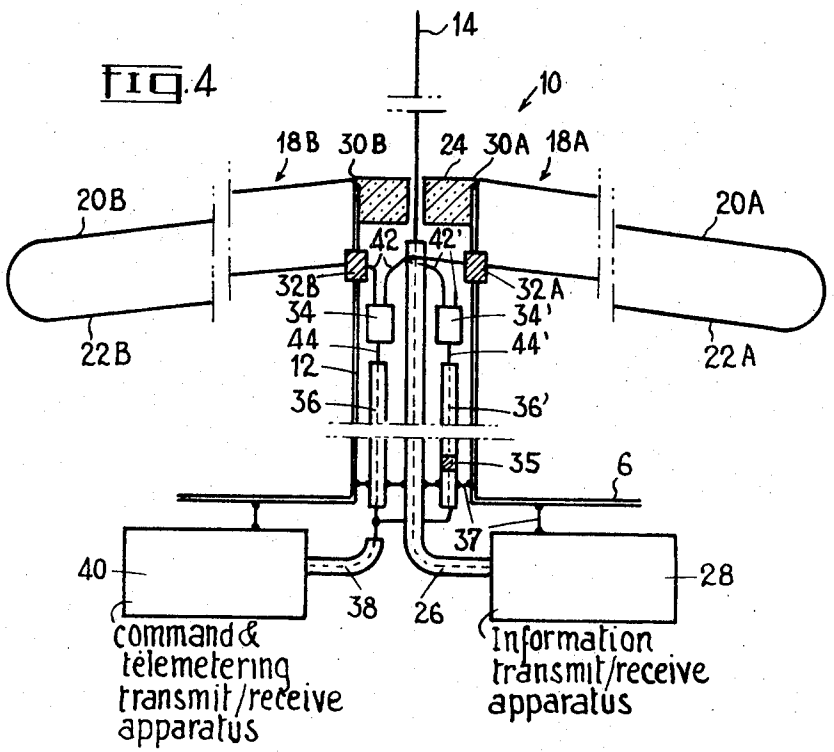

14
N
f2
M
20
18
P
f1
Q
22
180°
λ/4
λ/4

Fig. 4


14
10
18B
30B
24
30A
18A
20B
20A
42
42'
32B
32A
34
34'
44
44'
12
36
36'
35
6
37
40
38
26
28
command & telemetering transmit/receive apparatus
Information transmit/receive apparatus

DUAL BEAM ANTENNA FOR SATELLITES

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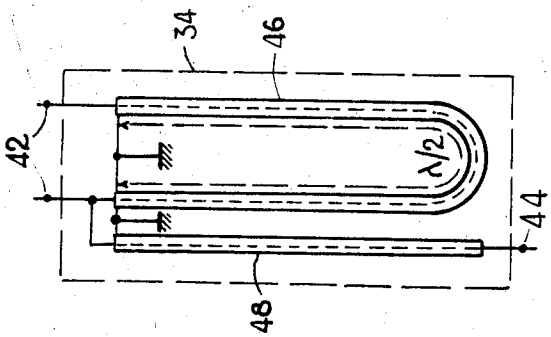


FIG. 6
PRIOR ART

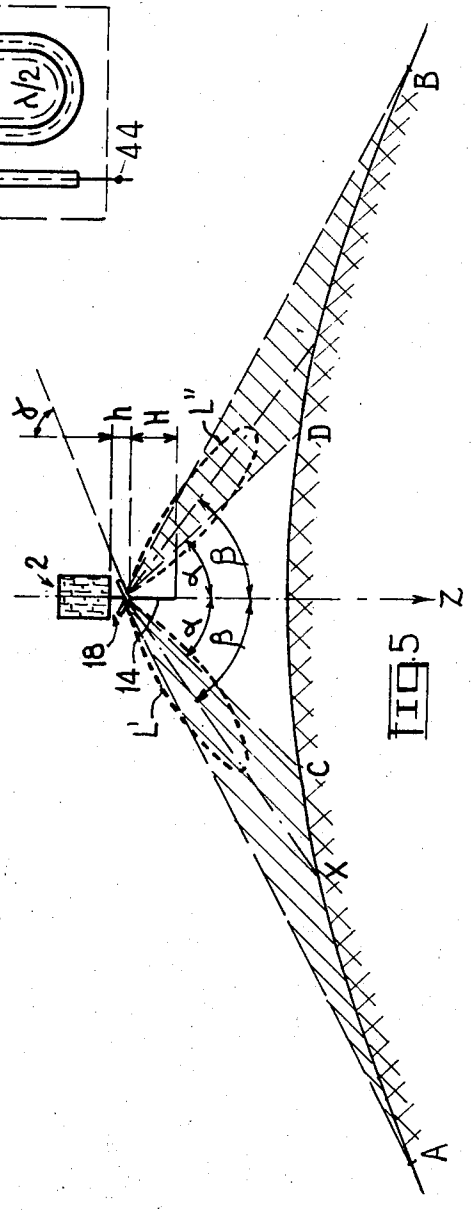


FIG. 5

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3,426,351

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3,426,351

DUAL BEAM ANTENNA FOR SATELLITES

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Claims priority, application France, Nov. 13, 1964, 994,959

U.S. Cl. 343—705 5 Claims

Int. Cl. H01q 1/28

ABSTRACT OF THE DISCLOSURE

A pair of radiating elements are arranged, next to each other, on the space craft which forms a chassis, a second one of the elements constituting a ground plane for the first, the first element, taken in conjunction with the ground plane, having a predetermined directional radiation pattern and being connected to data information transmit-receive apparatus, and the second element, having an omnidirectional transmit-receive pattern being connected to telemetering and control channels, so that control of the satellite, regardless of attitude stabilization, can be transmitted by way of the second radiator element, and, upon stabilization in attitude, the directional antenna will provide communication of sensed data, or information relating thereto, with a maximum of antenna gain.

This invention provides an improved multi-purpose antenna system capable of simultaneously radiating radio signals from different sources with different directional and other characteristics. The invention was developed for use in spacecraft, particularly satellite, communication systems and will accordingly be set forth herein with primary reference to such application; it is to be understood however that the invention is applicable to other uses in the field of radio communications.

Communications with satellites and other types of spacecraft raise serious problems, due chiefly to the considerable number of different communication links that have to be provided and transmitting signals of different characteristics as to carrier frequency, polarization and direction, coupled with the extremely cramped conditions and limited load-carrying capacity of the craft. Present satellites generally require the simultaneous provision of three different types of radio link:

(1) a main link for the transmission and reception of information,

(2) a telemetering link for transmission of measurements performed aboard the satellite, and

(3) a remote control link, for the reception of command signals to actuate various relays controlling the operation of the satellite equipment. Different radio-frequency bands are assigned by international agreement to each of the above links.

Some of the radio communications involved in the above links may have to be transmitted (and received) directionally, while others may have to be transmitted (and received) omnidirectionally. Thus, the above-mentioned main or information link is generally only placed in operation after the satellite has been placed on its prescribed orbit and, furthermore, has been stabilized in attitude on the orbit so that it constantly presents the same side towards the Earth. In these conditions, it is highly advantageous to transmit the information signals by way of a directional antenna such as an axial radiator pointing vertically towards the Earth, since this permits an appreciable gain in radiating efficiency. On the other hand, other types of information, such as the telemetering and command signals referred to above as links (2) and

(3), cannot usefully be transmitted through a directional antenna since the transmission of these signals may have to commence before the satellite has been stabilized, and while it is whirling randomly in space.

The above is illustrative of a situation where a spacecraft antenna system is required to cater for both directional and omnidirectional transmission and reception of different signals. It is to be understood that other situations where a generally similar requirement is present may well occur.

Heretofore, to the best of applicants' knowledge, no effort has been made to provide a unitary or integrated multi-purpose antenna system that would be capable of simultaneously radiating one signal directionally and another signal omnidirectionally. It is therefore a primary object of this invention to fill this gap and provide such an integrated, multi-purpose antenna system.

The current antenna arrangement customarily used on satellites for the simultaneous transfer of directional and omnidirectional radio waves, simply consists of two different antenna arrays, the one directional and the other omnidirectional, functionally unrelated with one another. Thus, the directional antenna may comprise a single axial conductor projecting from an end surface of the satellite shell and cooperating with said end face as a ground plane to provide a conventional ground-plane directional antenna system. The omnidirectional antenna device that is used concurrently with such a directional radiator, frequently comprises a pair of crossed dipoles constituting a so-called turnstile radiator. In such a set-up, the two radiator systems must be positioned rather far apart if they are not to interfere with each other's functions, and this requires that the turnstile dipoles protrude from the sides of the satellite shell. The resulting arrangement is objectionable because it detracts from the valuable space available for locating solar elements and other external equipment on the outer surface of the satellite shell, complicates wiring, and has other drawbacks later pointed out.

It is an object of this invention to provide a composite antenna unit comprising two radiators capable of radiating energy from different sources and having different directional and other characteristics, which radiators are functionally so interrelated that one radiator serves as a ground plane or counterpoise for the other, thereby imparting desired directional characteristics thereto. Another object is to provide such a composite antenna unit wherein the functional interrelation between the two radiators is such that both radiators can (and indeed must) be positioned close to each other, thereby reducing over-all dimensions, facilitating wiring and providing other advantages of especial benefit in a space-craft. A further object is to facilitate the "shaping" of the radiation characteristic pattern of the directional radiator of the composite antenna. Other objects will appear.

Exemplary embodiments will now be disclosed with reference to the accompanying drawings, wherein:

FIG. 1 is a perspective view of a satellite equipped with separate directional and omnidirectional antenna in accordance with a typical arrangement of the prior art;

FIG. 2 is a similar view of a satellite equipped with the improved, unitary, directional-omnidirectional antenna system of the invention;

FIG. 3 is a simplified view illustrating the basic concept used in the invention, and constituting a basic embodiment hereof;

FIG. 4 is a fragmentary view of the system shown in FIG. 2 in section on a diametric plane of the satellite and illustrating inter alia the feeding means for the antenna elements;

FIG. 5 is a diagrammatic view of the improved satellite after directional stabilization on orbit around the earth and partly showing an advantageous directional radiation

pattern as obtainable with the improved antenna system; in this view the linear dimensions of the satellite are of course greatly exaggerated but angular relationships are substantially preserved, and

FIG. 6 illustrate one type of balun unit usable with the foregoing embodiment of the invention.

In the typical prior-art set-up shown in FIG. 1, an artificial satellite having a body **2** of generally cylindrical shape is provided with a directional antenna comprising a single axial radiator element **4** projecting from the center of a flat end wall **6** of the body normally thereto and is further provided with an omnidirectional antenna of the so-called turnstile type. This turnstile antenna array comprises two dipole elements **8** and **8'** in crossed relation, each dipole being a halfwave resonant conductor having its opposite legs or poles, **8A** and **8B**, and **8'A** and **8'B**, projecting from diametrically opposite points of the cylindrical side surface of the body **2**. In the operation of such a conventional space-craft antenna system, the axial radiator **4** is excited with VHF or UHF energy relative to the metallic shell of body **2** constituting the satellite ground or counterpoise. The axial radiator **4** operates jointly with the ground plane constituted by the end face **6** of the satellite body to radiate the applied energy with a relatively high directional characteristic about the axial direction indicated as Z.

Thus, after the satellite has been placed in orbit and stabilized in attitude, in the conventional manner, so that the direction Z of the axial radiator **4** is pointing vertically earthward, the axial antenna **4** can be used with high efficiency to transmit information signals to the earth.

The turnstile array has its two crossed dipoles **8** and **8'** excited in phase quadrature with VHF or UHF energy from another source at a different frequency from the source serving to excite the axial antenna **4**. In accordance with the known turnstile principle, the dipole array **8–8'** has a radiating pattern that is crudely circular in the plane of the turnstile, and is therefore well-suited for omnidirectional communications. Further, the radiated energy from the turnstile is polarized in a plane normal to the plane of polarization of the energy radiated from the directional antenna **4**. The turnstile antenna **8–8'** can accordingly be used for the exchange of information between the Earth and the satellite before the latter has been placed on orbit and stabilized in attitude, for the transfer of control signals and telemetering indications to and from the satellite. It is to be noted that after the satellite has been stabilized on its orbit the omnidirectional antenna **8–8'** still continues to be utilized for the exchange of such last-mentioned signals concurrently with the operation of the directional antenna **4**.

The conventional antenna system thus described with reference to FIG. 1 possesses a number of inconveniences. The positioning of the turnstile antenna elements **8–8'** requires objectional perforations to be made through the skin of the satellite body. The valuable surface area available around the body for the positioning of solar battery elements and other equipment is appreciably reduced, while the over-all radial dimensioning of the satellite is undesirably increased by the protruding turnstile dipoles. Electrical circuit connections between the various antenna elements and the internal electronic equipment are difficult to wire up because of the wide-spaced points at which the antenna elements connect with the body and in view of the cramped and crowded conditions of the equipment within the satellite. Also, objectionable capacitance effects are created by the side surface of the body **2** which interfere with the operating efficiency of the antenna array.

In the satellite antenna system of this invention illustrated in FIG. 2, the above deficiencies are eliminated. As shown, the antenna system of the invention, generally designated **10**, is provided in the form of an integrated, unitary array positioned entirely beyond an end face of the satellite body. This array **10** is mounted on a tubular support **12** protruding axially from the center of the end face **6**, and includes a directional radiator **14** projecting axially from support **12**, and an omnidirectional array comprising the pair of crossed, folded dipole elements **18** and **18'**, projecting laterally from the outer end of the tubular support.

Before describing the construction of the improved antenna arrangement in detail with reference to FIG. 4, the basic principle of the invention which renders such an arrangement feasible will be explained. FIG. 3 diagrammatically illustrates a composite antenna unit according to the invention as basically consisting of an axial radiator element **14** and a folded dipole element **18** disposed transversely to element **14** and adjacent its lower or excitation end N. The folded dipole element **18** as well-known per se, can be considered as a wavelength-long conductor so folded, as shown, as to include an unbroken upper leg **20** extending one quarter-wavelength to each side of a midpoint M, and another leg **22**, parallel to and closely spaced from leg **20**, which is interrupted at its midpoint to provide the pair of feed terminals PQ. Radio energy of frequency f_1 is fed to the feed terminals PQ in such a manner that the current values at terminals P and Q are in phase opposition, as shown by the indication "180°." The over-all current distribution along the folded dipole conductor then assumes a configuration such that the net current is zero at the midpoint M of the unbroken leg of the folded dipole.

Because of the absence of current it becomes possible to connect the midpoint M of the dipole radiator element to the same ground conductor, in this instance of the satellite body **2**, as the ground conductor used for the axial radiator element **14**, and feed energy to this latter element across the terminals MN at a frequency f_2 different from f_1. In the arrangement thus produced, it will be seen that the upper leg **18** of the folded dipole will serve as a ground plane for the directional axial radiator **14**, eliminating the necessity of using the end face **6** of the satellite body to perform this function, as was required in the conventional antenna system of FIG. 1. At the same time the folded dipole element **18** can be used to radiate energy at a different frequency and with a different polarization from the energy radiated by axial radiator **14**, that is the two radiators **14** and **18** can be used for transmission (and of course reception) purposes simultaneously with and independently from one another.

In the basic antenna system shown in FIG. 3, it will be understood that the single folded dipole radiator **18** possesses directional properties, in that it has a maximum of radiation in the plane normal to its main dimension. This property may be of interest in certain applications of the invention, where it may be desired to transmit simultaneously different information in different directions. However, a particularly important aspect of the invention as earlier explained herein, deals with the case where the folded dipole radiator associated with the axial radiator is to possess an omnidirectional rather than a directional characteristic. To achieve this, it is simply necessary to supplement the basic system of FIG. 3 by adding another folded dipole element **18'** normal to element **18**, as shown in FIG. 2, the additional folded dipole being fed from the same energy source as the first dipole element **18** but in phase quadrature therewith in order to provide a modified form of turnstile array having an omnidirectional radiation pattern.

This important application of the invention will now be described in greater detail with reference to FIGS. 2 and 4.

As shown in FIG. 4, the axial radiator element **14** of the composite antenna system is passed through an axial aperture in a plug **24** of insulating material fitted in the outer end of tubular support **12** and is connected with the central conductor of a coaxial line **26**. Line **26** is passed through tubular support **12** and is connected within the satellite shell **2** to first transmitting-receiving equipment of any suitable conventional type generally designated **28**.

In FIG. 4, only one folded dipole element, **18**, of the dual turnstile array is shown, it being understood that the

companion element **18'** is positioned in a plane normal to the plane of the drawing and that its general arrangement is similar to that of element **18**. For reasons that will be given later, the two sides, **18A** and **18B**, of the folded dipole **18** (and of dipole **18'**) are preferably angled symmetrically with respect to each other to the axis of the system, in directions towards the satellite body, as shown. The upper branches **20A** and **20B** of the two sides of the element **18** have their inner ends **30A** and **30B** soldered to diametrically opposed points of the upper rim of tubular support **12**, whereby they are mechanically supported and electrically interconnected to provide the grounded midpoint designated M in FIG. 3. The lower branches **22A** and **22B** have their inner ends mechanically supported in tubular support **12** but electrically insulated from it, by being passed through insulating inserts **32A**, **32B** mounted in diametrically opposed openings of the tubular support. These inner ends of branches **22A** and **22B** are connected within support **12** to the balanced terminals **42** of a balance-unbalance converter, or "balun," unit **34**, and similarly the inner ends of the lower branches of element **18'**, not shown in FIG. 4, are connected to the corresponding terminals **42'** of another balun **34'**. The unbalanced terminals **44**, **44'** of baluns **34** and **34'** are connected to the central conductors of respective coaxial lines **36** and **36'** whose central conductors are combined and connected through a line **38** to a second transmitter-receiver apparatus **40**. As previously disclosed, the inner terminals of the lower branches such as **22A** and **22B**, of each folded dipole, which terminals constitute the feed terminals designated P and Q in FIG. 3, must be fed in 180° phase-displaced relation. This result is conveniently achieved by using baluns **34** and **34'** of the so-called thornbone type, shown in greater detail in FIG. 6. The coaxial lines **36** and **36'** feeding the respective folded dipoles **18** and **18'** differ approximately one quarter wavelength in their electric lengths, as schematically indicated by a phase shift insert **35** in line **36'**. As earlier indicated, the folded dipoles **18** and **18'** when thus fed in phase quadrature have an over-all radiation pattern that is substantially of equal intensity in all azimuths, and thus constitute an omnidirectional array.

As indicated at **37**, the outer conductors of all the coaxial lines are connected to the common ground provided by the shell of the satellite.

Referring to FIG. 6, a balun **34** or **34'** usable according to the invention for feeding either of the folded dipoles includes a line **46** having an electric length corresponding to about one halfwave length of the feed energy, connected at its ends to the balanced terminals **42**. The unbalance terminal **44** is connected by a line **48** to one of the balanced terminals.

In one application of the invention, the signal fed from transmitter **28** to axial radiator **14** is 400M c.p.s., a standard frequency band for satellite information communication links. The turnstile **18–18'** is fed from transmitter **40** with either one of two frequencies, one in the 148M c.p.s. band standard for satellite control links and the other in the 136–138M c.p.s. band assigned to telemetering links. The corresponding wavelengths are λ_1=2.03 m. and λ_2=2.19 m. respectively. The combined length of each of the folded dipoles **18** or **18'** is then selected at a value L intermediate the half wavelength values of the two signals fed to the turnstile array, i.e.

$$L=\frac{1}{2}\sqrt{\lambda_1\lambda_2}$$

or 1.056 m., so as to cater for both frequencies to be transmitted omnidirectionally. It is noted that the folded dipole turnstile array has a relatively broadband characteristic, so that efficient rediation is had for both frequency ranges.

The above value L=1.056 meters approximately represents the overall transverse dimension of the improved antenna unit.

An additional advantage of the invention arises out of the fact that the folded dipoles provide an unexpectedly convenient means of modifying or "shaping" the radiation pattern of the axial antenna.

In FIG. 5 the satellite **2** is shown after stabilization on its orbit so that axial antenna **14** is directed vertically earthward. The radiation pattern (and, of course, the pattern of directional characteristic of reception, for convenience referred to herein also as the radiation pattern) of antenna **14** as modified by the ground plane constituted by the unbroken legs (designated **20** in FIG. 3) of the folded dipoles **18** and **18'** is indiciated as including the major lobe shown in dotted lines at L', L'' it being understood that the two shapes shown separately as L' and L'' actually represent a vertical cross section through a common solid of rotation about the vertical Z, the solid being hereinafter termed as the lobe L. It will further be understood that the radiation pattern includes minor lobes or ears, omitted from FIG. 5 for clarity. The geometric configuration of such a radiation pattern can be characterized by two angles, such as the angles α and β, which jointly define both the angular deflection of the bisector axes (such as X) of main field intensity from the vertical, and the angular width of the lobe L. Specifically, β is the angle between the lobe bisector X and the vertical Z, and α is the angle between the vertical and the generatrix (such as C) of a cone approximately tangent to the inner surface of the lobe L. It is desirable, in many satellite communication programs, to provide a directional radiation pattern from the satellite having a general configuration as shown in FIG. 5, that is, with a lobe of relatively narrow width (i.e. with the magnitude $2(\beta-\alpha)$ relatively small) and so inclined to the vertical that a cone approximately tangent to the outer surface of the lobe L will be substantially tangent to the Earth's surface, as indicated at A and B. Such a radiation pattern includes a "dead area" defined by inner cone CD of substantial extent and results in a high concentration of received energy available in the remaining useful area between the inner and outer cones CD and AB, making possible a corresponding reduction in the power requirements of the satellite sending equipment.

The values required for angles α and β in order to produce such a pattern depend, of course, on the mean altitude of the satellite. With directional antenna systems of the prior art as typified in FIG. 1, the parameters susceptible of adjustment in controlling the angles α and β and thereby providing a radiation pattern of desired shape (for given values of altitude and radiated frequency) were two in number: the length of axial antenna **4** and its distance from the ground plane constituted by end face **6**. With the limited possibilities of control thus available it was not always feasible to obtain an optimum configuration for a specified satellite altitude and a specified signal frequency.

The antenna system of the invention makes available an additional parameter whereby the "shaping" of the radiation pattern of the directional antenna of the satellite is considerably facilitated. This additional parameter is the inclination of the sides of the dipole elements **18** and **18'**, that is, the angle γ formed by either side branch such as **18A** or **18B** of each dipole with respect to the axial direction of antenna **14**. It is found that the additional degree of freedom introduced into the design of the antenna system by this additional parameter γ, when taken together with parameters H (length of the axial radiator **14**) and h (height of the dipole assembly above the satellite end face), makes it possible to obtain the desired directional radiation characteristics in practically all important instances.

Thus, in the practical application referred to herein, it was determined that substantially optimal communication conditions would be had if the angles α and β in FIG. 5 could be made respectively equal to 45° and 54° (the angular width of the main radiation lobe then being

about 2(54—45)=18°). The mean altitude of the satellite as resulting from the selected orbit was specified as about 780 kilometers. The specified frequency for the information signals to be transmitted from directional antenna **14** was 400M c.p.s. as indicated above. It is calculated that the requisite directional characteristic having the above-specified values of α and β is obtained with the following values of the parameters:

$$H=590 \text{ mm.}; \quad h=140 \text{ mm.}; \quad \gamma=78°$$

The combined length of each of the dipole elements, as earlier determined, is 1.056 mm.

With the directional pattern specified by the above given values of α and β, it is calculated that the concentration of beamed energy in the useful area (cross hatched in FIG. 5) is such as to yield a gain of about 5 db over what would be obtained with an isotropic directional pattern, i.e. with approximately uniform radiation intensity over the entire cone defined between the tangents at A and B to the Earth's surface. This permits a corresponding reduction in the power supply of the radio equipment aboard the satellite.

It will be apparent from the foregoing disclosure that the integrated multi-purpose antenna system of this invention has important advantages. Owing to the close functional interaction present between the two independently-fed radiating sub-assemblies comprising the system, such as a directional axial radiator and an omnidirectional turnstile array with the latter providing, in a part thereof, a groundplane for the former, the two sub-assemblies can be structurally combined into a compact unit easy to mount and wire in a small-sized supporting structure such as a satellite. At the same time such integration of the two radiating components does not detract from the main function of the system which is to radiate radio energy from different sources each having its particular frequency, polarization and directional characteristics. Indeed, the particular type of coaction present between the two radiators introduces an added parameter or degree of freedom which can be taken advantage of in improving the radiation characteristic of the directional radiator, in the manner disclosed.

It will be understood that various modifications may be introduced into the details of the embodiments disclosed herein depending on the requirements of a particular application to which the invention may be put. As earlier mentioned, in certain applications it may be desired that both the radiating components possess directional characteristics, each in a particular direction, and in such cases the omnidirectional turnstile radiator may be replaced with a single directional radiator or with a directional array of spaced radiators such as folded dipoles, arranged for example in an end-fire array. Various other possibilities will occur to those familiar with the art.

What we claim is:

1. A multi-purpose antenna system for installation on a space craft forming a chassis, comprising:

a first radiating element (**14**);

a second radiating element (**18, 18'**) having a point (M) thereof connected to chassis and being positioned adjacent to said first element (**14**) so as to constitute a groundplane therefor, and having a pair of feed terminals (P, Q);

said first radiating element (**14**) and said second radiating element (**18, 18'**) being relatively placed with respect to each other to provide a first predetermined directional radiation pattern characteristic for said first element, and said second element (**18, 18'**) having a second and substantially omni-directional radiation pattern;

said first element, having said directional radiation pattern, being located on the space craft to be substantially directed to earth when the space craft is stabilized in attitude;

first connecting means (**26**) for connecting transmitted/received radio frequency energy from a first apparatus (**28**) between a point (N) on said first element (**14**) and chassis, to radiate/receive energy in accordance with said directional radiation pattern; and

second connection means (**38, 36, 36'**) for connecting transmitted/received radio frequency energy from a second apparatus (**40**) to the pair of feed terminals (P, Q) of said second element to radiate energy in accordance with the omni-directional pattern;

whereby radio frequency energy may be simultaneously and independently transmitted/received by both the first and second apparatus, respectively, and radiated/received with both the respective radiation patterns.

2. An antenna system according to claim **1**, wherein said first radiator element (**14**) comprises an axial conductor (**14**) fed at one end (N), and the second radiating element (**18, 18'**) comprises two folded dipoles having their midpoints (M) connected to chassis and positioned in crossed relation to each other and located with respect to the first radiator element (**14**) so as to extend generally transversely to said axial conductor and with said grounded midpoints thereof adjacent to said feed end of the axial conductor; the terminals (P, Q) of said folded dipoles are closely spaced and connected by said second connection means to said second apparatus (**40**) to be connected in phase quadrature relation with respect to each other.

3. An antenna system according to claim **2**, wherein said second connection means connecting energy between said second apparatus (**40**) and said second radiator element (**18, 18'**) includes an unbalance to-balance converter (**34**) arranged to introduce a 180° phase displacement between the balanced terminals (**42**) thereof connected to the feed terminals (P, Q) of the dipole.

4. An antenna system according to claim **2**, wherein the sides of each folded dipole (**18, 18'**) are bent at a predetermined angle of inclination to a plane normal to the axial conductor (**14**) in a direction away from the axial conductor, and wherein the length of said axial conductor and its frequency of operation are predetermined and so related as to produce said first directional pattern in form of a hollow cone, the angle of said cone having a predetermined value and its axis being in earth direction when the space craft is stabilized in attitude.

5. An antenna system according ot claim **1**, wherein said apparatus (**28**) connected to said radiation element (**14**) having said first directional pattern comprises apparatus for communicating information between space craft and earth relating to sensed data and said second apparatus (**40**) connected to said second radiator element having said substantially omni-directional radiation pattern comprises apparatus responsive to transmission of telecontrol signals from earth to space craft and for transmitting telemetering signals from space craft to earth, even when the space craft is not stabilized in attitude.

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ELI LIEBERMAN, *Primary Examiner.*

U.S. Cl. X.R.

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