Sept. 29, 1970 H. A. ROSEN ET AL 3,531,803

SWITCHING AND POWER PHASING APPARATUS FOR AUTOMATICALLY FORMING AND DESPINNING AN ANTENNA BEAM FOR A SPINNING BODY

Filed May 2, 1966 7 Sheets-Sheet 1

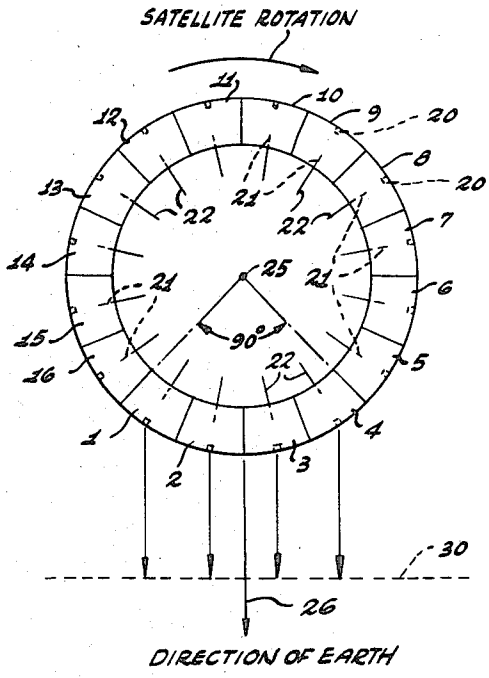


Fig. 1

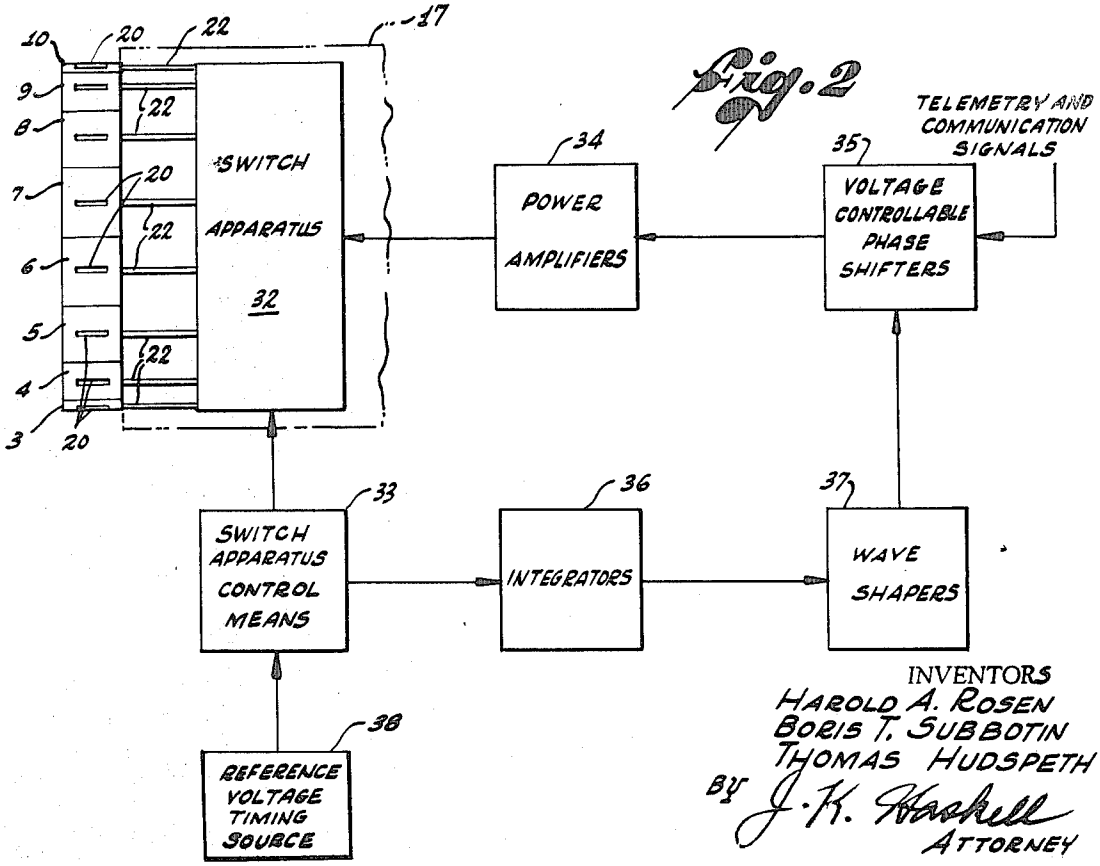


Fig. 2

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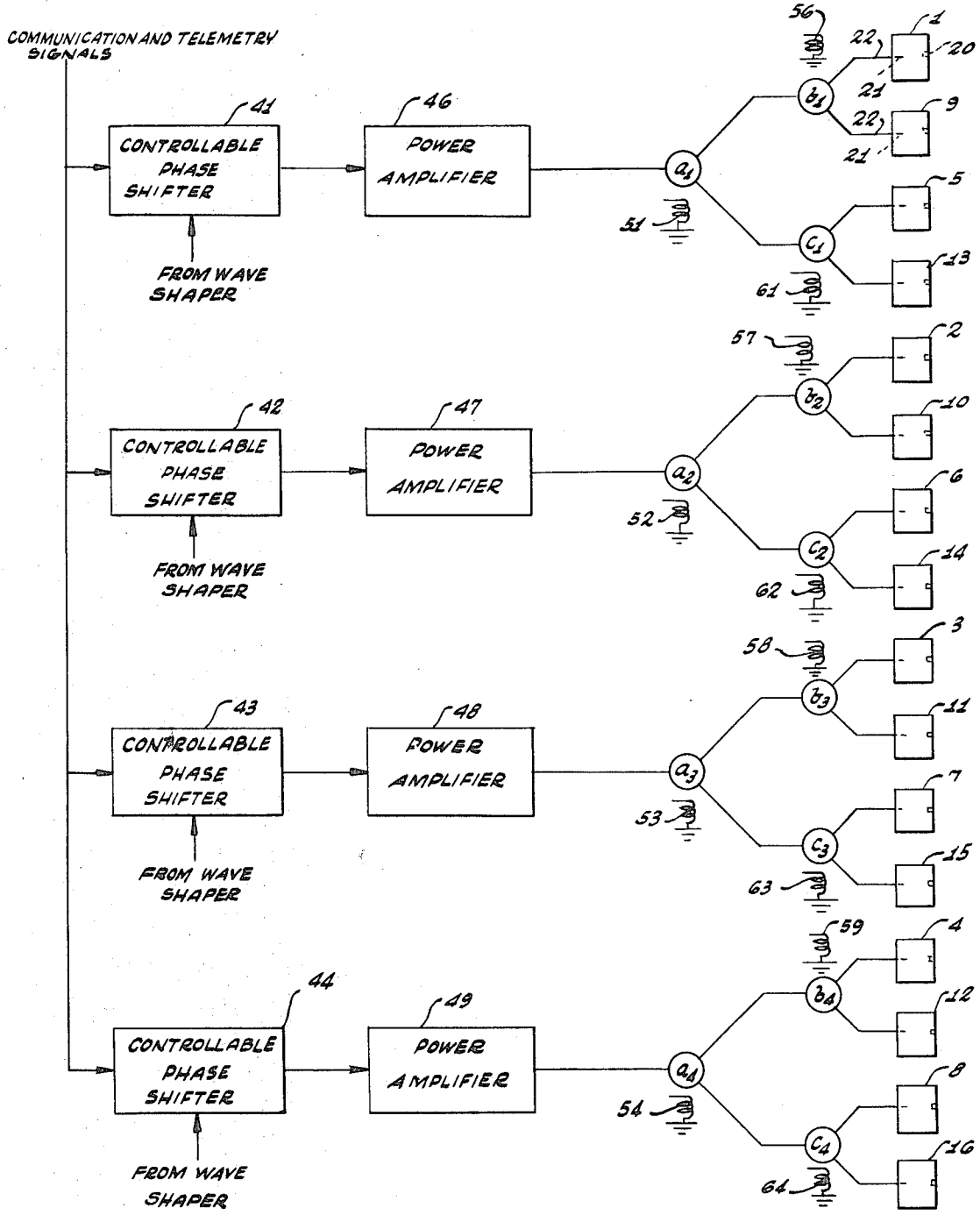


Fig. 3

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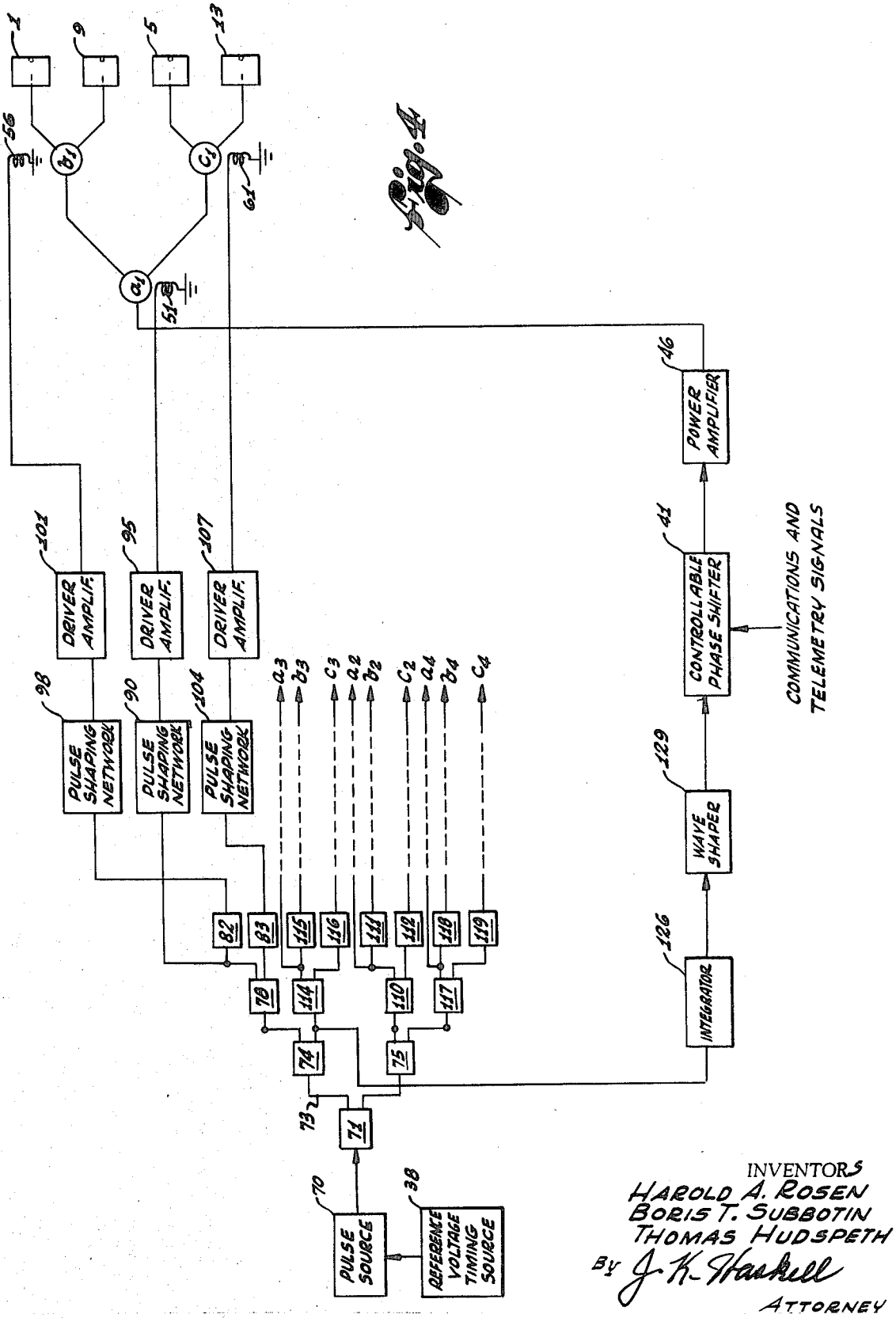


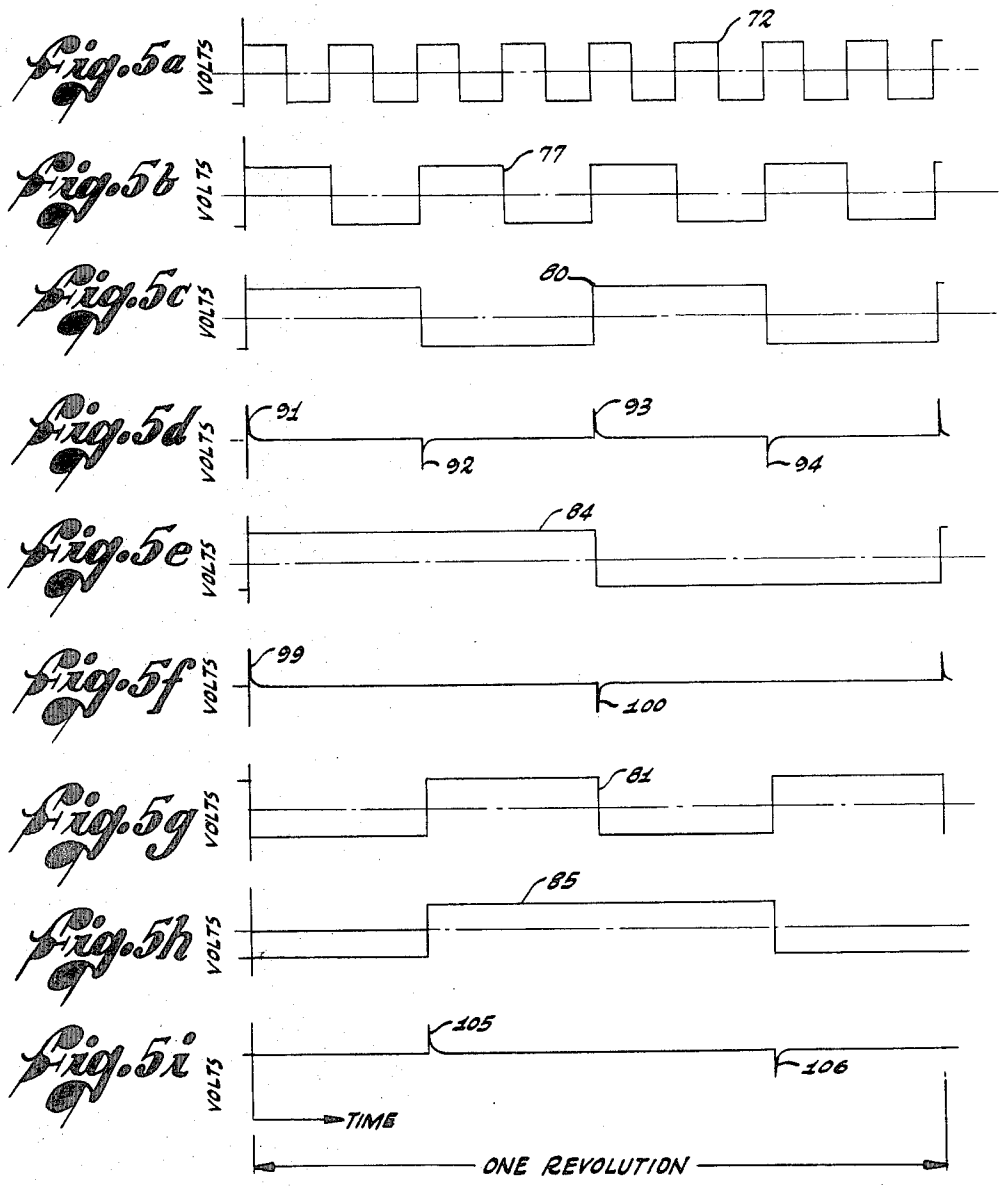
Fig. 4

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SWITCHING AND POWER PHASING APPARATUS FOR AUTOMATICALLY FORMING AND DESPINNING AN ANTENNA BEAM FOR A SPINNING BODY

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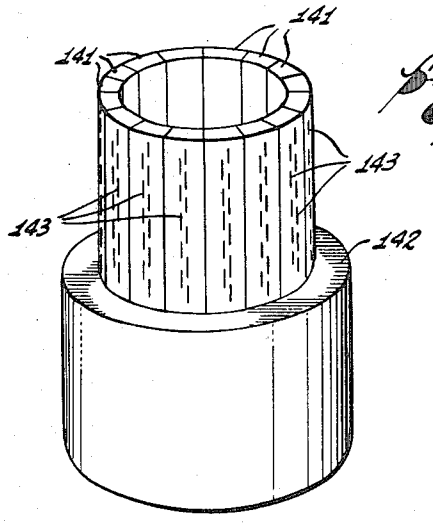


Fig. 7

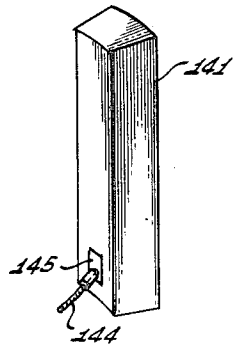
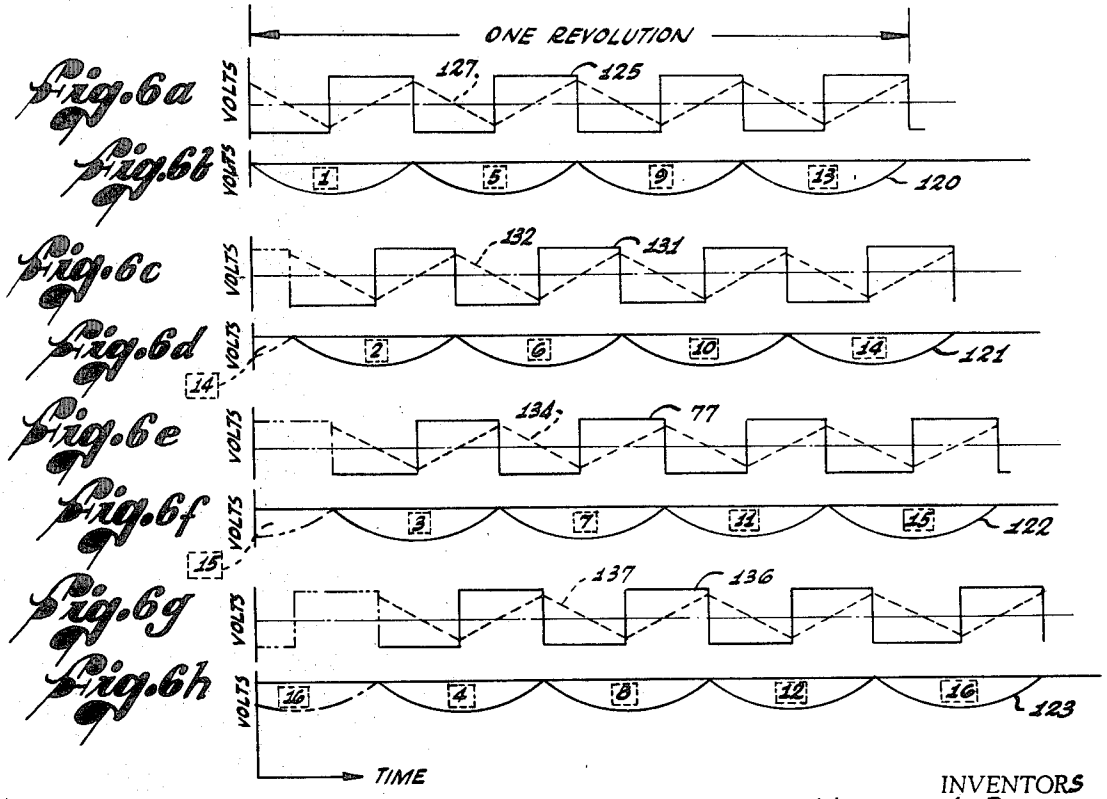


Fig. 8



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Fig. 9

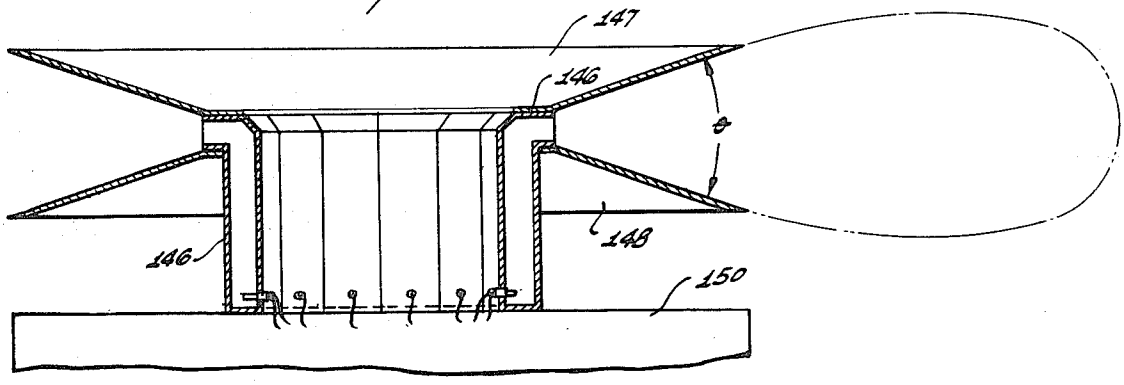
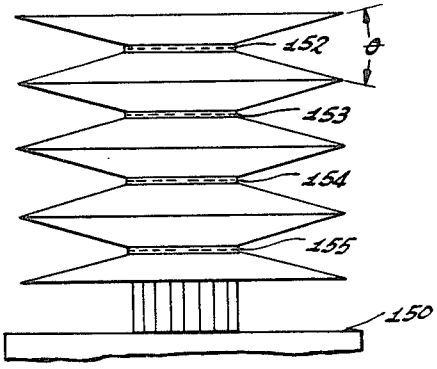


Fig. 10



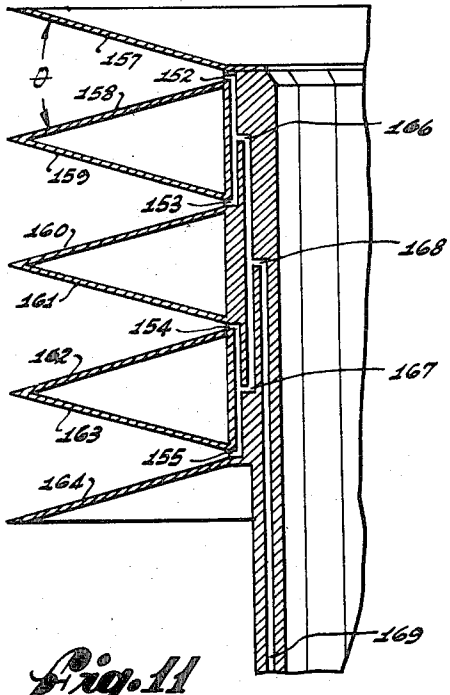


Fig. 11

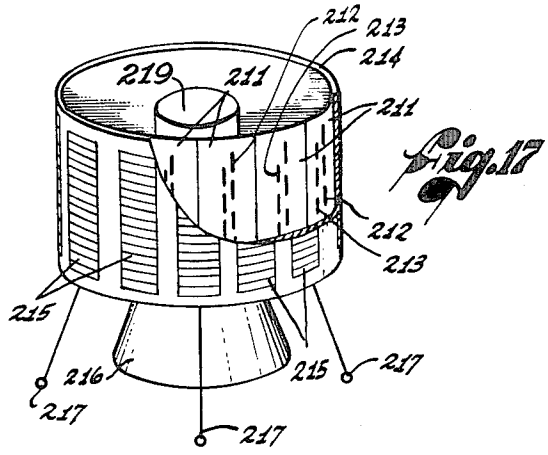


Fig. 17

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Filed May 2, 1966 7 Sheets-Sheet 7

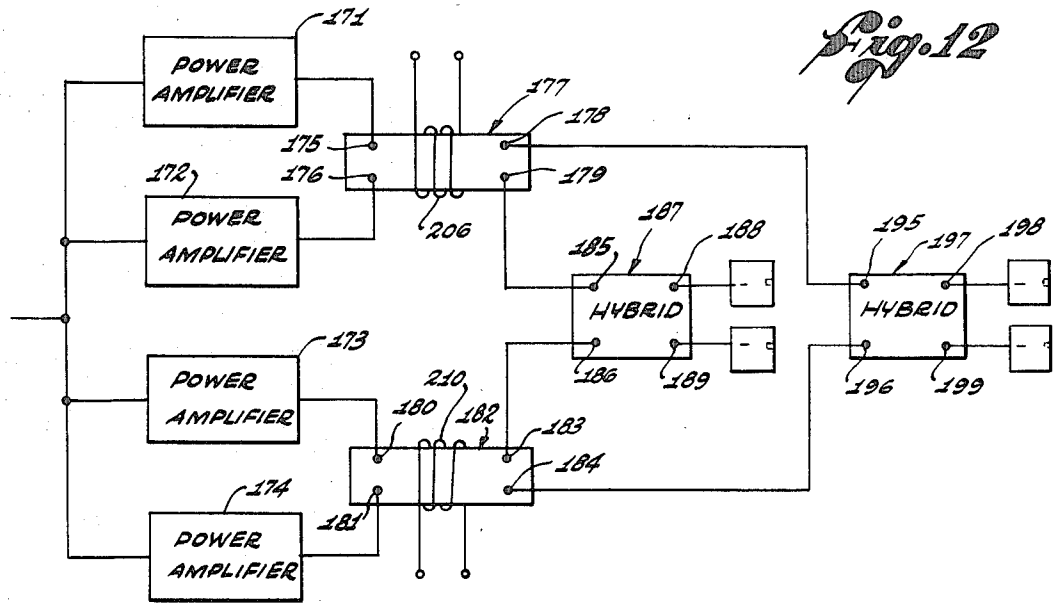


Fig. 12

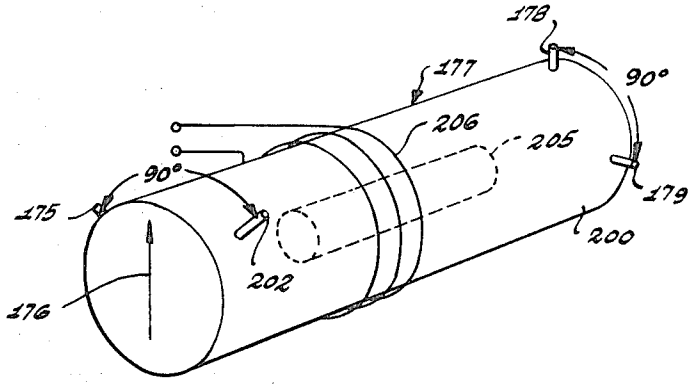


Fig. 13

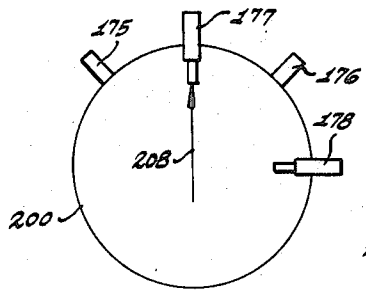


Fig. 14

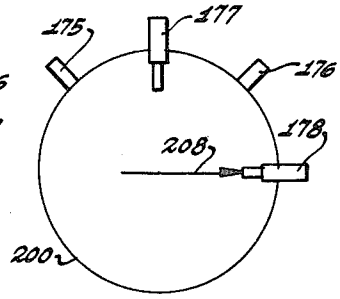


Fig. 15

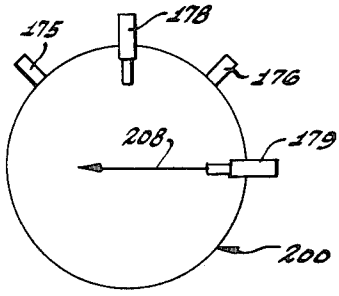


Fig. 16

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United States Patent Office

3,531,803
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3,531,803

SWITCHING AND POWER PHASING APPARATUS FOR AUTOMATICALLY FORMING AND DESPINNING AN ANTENNA BEAM FOR A SPINNING BODY

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Int. Cl. H04b 7/00
U.S. Cl. 343—100 6 Claims

ABSTRACT OF THE DISCLOSURE

A system operable on a spinning body providing a plurality of individually excitable antenna elements with means for both switching and phasing power to individually operable elements so as to develop optimum gain and directivity. Selected power amplifiers are switched to a selected number of adjacent elements during each predetermined fraction of the spacecraft revolution. As the body rotates, phase shifters adjust the RF phase so that the main beam is pointed in the same direction. After the body has revolved the predetermined fraction, one of the power amplifiers is switched to another element at a time when the RF phase shift is proper for continuous operation.

This invention relates to directive radio and antenna systems for spinning bodies, and more particularly to apparatus for developing a stationary radiation beam from a plurality of rotating directive antenna elements.

It is desired to provide a spinning body, such as a communication satellite, with a highly directive radiation pattern, such that any desired area of the globe can be illuminated therefrom. Typical of highly directional antenna elements are slotted and open-ended waveguides. Although it has been known that a circular array of such antenna elements can be arranged on a spinning body, there has heretofore been no apparatus for applying R-F excitation currents to such elements so as to establish and maintain a radiation pattern in a fixed direction.

It is an object of this invention to provide a rotatable body with a plurality of individually excitable antenna elements, and means for exciting such elements so that a radiation pattern in a predetermined direction is established and maintained.

It is another object of this invention to provide electrical means for switching and phasing power to individually operable antenna elements on a spinning body so as to provide optimum antenna gain and directivity.

A further object of this invention is to provide a communication satellite having individually operable directive antenna elements capable of giving a radiation pattern of any desired elevational and azimuthal dimensions.

Still another object of this invention is to provide a communication satellite with highly directive, individually excitable antenna elements, which satellite is characterized as a rugged construction of a minimum number of component parts of simple, lightweight design.

The above and other objects and advantages of this invention will become apparent from the following description taken in conjunction with the accompanying drawings of illustrative embodiments thereof, in which:

FIG. 1 is a top plan view of a circular array of waveguides carried on a spinning satellite, wherein only those waveguides are excited which at any instance are within a sector that is subtended by an angle that includes the line toward the earth;

FIG. 2 is a block diagram of the system of this invention for switching power to different waveguides and phasing the power to each waveguide;

FIG. 3 is a combined block and schematic diagram showing one arrangement of switches through which power is supplied to the individual waveguides;

FIG. 4 is a block diagram of switching apparatus for controlling the switches of FIG. 3;

FIGS. 5*a*–5*i* illustrate a series of waveforms to aid in explaining the operation of the switching apparatus of FIG. 4;

FIGS. 6*a*–6*h* illustrate a series of waveforms to aid in explaining the phasing of power applied to the waveguides through the switching apparatus;

FIG. 7 is a perspective view of a circular array of waveguides of a form to provide a radiation pattern of greater elevation than with the array of FIGS. 1 and 2;

FIG. 8 is a perspective view of one of the waveguides of FIG. 7;

FIG. 9 is a side elevation view, partly in section, of a biconical arrangement of open-ended waveguides for operation in accordance with our invention;

FIG. 10 is a side elevation view of a stacked bicone arrangement of our invention;

FIG. 11 is an enlarged, fragmentary sectional view of the stacked bicones of FIG. 10, showing the feed to corresponding waveguides of each bicone;

FIG. 12 is a schematic diagram of another switching apparatus for applying power from several amplifiers to a single antenna element;

FIG. 13 is a perspective view of one of the magnetically operable traveling wave switches employed in the switching arrangement of FIG. 12;

FIGS. 14–16 are end views of the switch of FIG. 13, to aid in explaining the operation thereof; and

FIG. 17 is a perspective view of a satellite in which the body and antenna are coextensive.

Referring to FIGS. 1 and 2, there is shown a circular array of waveguides **1–16** carried on a spinning body, indicated in phantom lines at **17**. Each of the waveguides is provided with a slot **20** in its lateral surface, an excitation probe or stub **21** extending into the waveguide, and a connection **22** through which to apply power to the probe. In a conventional manner, the satellite is stabilized so that its spin axis **25** is parallel to the axis of rotation of the earth. In such stabilized position, each of the antenna elements **1–16** rotates past a line **26** in the direction of the earth, which is the direction in which it is desired to radiate a beam.

In the example shown, it is desired to excite only those waveguides which, at any instant, lie within a predetermined angle which is bisected by the line **26**. Such angle is indicated as 90°, but obviously may be smaller or larger. It will be apparent that with a given amount of available power, exciting all of the waveguides simultaneously would result in a generally omnidirectional radiation pattern, most of which would be wasted. However, utilizing all of the available power to excite only those few waveguides within the predetermined sector provides a radiation pattern of high antenna gain and directivity.

At the instant indicated in FIG. 1, the waveguides **1–4** are located within the selected sector. As will be observed, the satellite is rotating clockwise in FIG. 1, which means that further rotation of the satellite carries the waveguide **1** out of the sector, and the waveguide **5** moves into that sector. Accordingly, power that was applied to the waveguide **1** must be switched to the waveguide **5**.

Furthermore, as each of the waveguides moves through the sector, its position relative to the earth is constantly changing, i.e., from a maximum distance as it enters the sector, to a minimum distance when it is on the line **26**,

and back to the maximum distance as it leaves the sector. It is desired to excite each wave-guide as it moves throughout the sector. However, it is essential that all of the excited waveguides be operated so as to produce a plane phase front **30** moving in the direction of the earth.

A system in accordance with this invention for effecting the desired switching and phasing of power applied to waveguides in the designated sector is shown in FIG. 2. The connections **22** to the various waveguides extend from switch apparatus **32**. As shown, the switch apparatus **32** is adapted to be operated by a switch apparatus control means **33**, and to have power for exciting selected waveguides applied from a network of power amplifiers **34**. Phasing of the applied power is effected through controllable phase shifters **35**, which are driven by phase shifter driving means including integrators **36** coupled to the control means **33**, and wave shapers **37** connected between the integrators **36** and phase shifters **35**. Both the switching and the phasing of the applied power are effected from a common reference, shown as a reference voltage timing source **38** that is coupled to the switch apparatus control means **33**.

The reference voltage timing source **38** is one which generates a voltage output which is referenced to a predetermined position of the satellite during each revolution thereof. Examples of suitable reference means for this purpose are disclosed in U.S. Pat. No. 3,133,282, Harold A. Rosen, entitled, "Apparatus Providing a Rotating Directive Antenna Field Pattern Associated With a Spinning Body," issued May 12, 1964.

In operation, the switch apparatus control means **33** operates the switch apparatus **32** so as to connect those waveguides within the selected sector to the power amplifiers **34**. The outputs of the phase shifters **35** are applied through the amplifiers **34** and switch apparatus **32** to those waveguides in such a manner that the power applied to each waveguide is retarded in phase to a degree depending upon its position within the sector. In this connection, and referring to FIG. 1, phase retardation is a maximum when a waveguide is located on the line **26**, and a minimum when such waveguide is located at the extremes of the sector. In this manner, we insure that the radiations from all of the affected waveguides are kept in phase, i.e., the plane phase front **30** is maintained.

Referring to FIG. 3 along with FIG. 2, the phase shifters **35** are shown to comprise four controllable phase shifters **41–44**, and the power amplifiers are shown to include respective power amplifiers **46–49** coupled to the phase shifters **41–44**. The outputs of the power amplifiers **46–49** are connected to the inputs of respective magnetically operable switches a_1–a_4. The respective control coils for the switches a_1–a_4 are indicated at **51–54**.

Examples of the switches a_1–a_4 are conventional ferrite circulator swithces. Such a switch has a pair of output terminals, and its input can be connected to one or the other of the output terminals, depending upon a direction of a current pulse applied to its control coil.

As shown in FIG. 3, the switches a_1–a_4 are arranged so that corresponding output terminals are connected to the input terminals of similar switches b_1–b_4 and c_1–c_4 which also have respective control coils **56–59** and **61–64**. The switch b_1 has one of its output terminals connected to the probe connection **22** of the waveguide **1** and its other output terminal connected to the probe connection **22** of the waveguide **9**. In similar fashion, the switch c_1 has one output terminal connected to the probe connection of the waveguide **5**, and its other output terminal connected to the probe connection of the waveguide **13**.

In this latter connection, the waveguides **1–16** are illustrated in FIG. 3 in positions which simplify the explanation of the wiring to the associated switches. However, it will be recognized that the waveguides are positioned in the circular array as shown in FIG. 1.

With respect to the waveguides **1**, **5**, **9** and **13**, it will be seen that these elements are spaced 90° apart. With reference to FIG. 1, the waveguide **5** enters the sector when the waveguide **1** leaves it; the waveguide **9** enters the sector when the waveguide **5** leaves; and the waveguide **13** enters the sector when the waveguide **9** leaves.

The same arrangement is illustrated for the remaining waveguides. The switch b_2 has its output terminal connected to the probes of the waveguides **2**, **10**; the output terminals of the switch b_3 are connected to the probes of the waveguides **3**, **11**; and the switch b_4 has its output terminals connected to the probes of the waveguides **4**, **12**. In a similar manner, the switch c_2 has its output terminals connected to the probes of the waveguides **6**, **14**; the switch c_3 has its output terminals connected to the probes of the waveguides **7**, **15**; and the switch c_4 has its output terminals connected to the probes of the waveguides **8**, **16**.

Referring to the first group of switches a_1, b_1 c_1, let it be assumed that when the control coil **51** of the switch a_1 is pulsed with a positive pulse, the iput of the switch a_1, is connected to the input of switch b_1. When the coil **51** receives a negative pulse, the input of the switch a_1 is connected to the input of the switch c_1. In like manner, positive and negative pulses applied to the control coil **56** of the switch b_1 switches its input, respectively, to the waveguide **1** and waveguide **9**. In similar fashion, positive and negative pulses supplied to the control coil **61** of the switch c_1 causes its input to be connected, respectively, to the waveguide **5** and the waveguide **13**.

When the waveguide **5** leaves and the waveguide **9** enters the sector, a positive pulse is applied to the control coil **51** of the switch a_1, and a negative pulse is applied to the control coil **56** of the switch b_1, thereby connecting the output of the power amplifier **46** to the waveguide **9**. Then, when the waveguide **9** leaves and the waveguide **13** enters the sector, a negative pulse is applied to the control coil **51** of the switch a_1, and a negative pulse is applied to the control coil **61** of the switch c_1, thereby to connect the probe of the waveguide **13** to the power amplifier **46**.

The same sequence of pulses is generated for the remaining groups of switches, and the associated waveguides are excited in the same manner and in the same sequence. However, the pulses applied to the switches of the second group of switches a_2, b_2, c_2 are generated at times following those for the corresponding ones of the first group of switches which amount to $\frac{1}{16}$ of a revolution of a satellite. Similarly, the pulses applied to the third group of switches are delayed by another $\frac{1}{16}$ of a revolution, and those applied to the fourth group of switches are generated still another $\frac{1}{16}$ of a revolution later.

One means for effecting the desired switching is illustrated in FIG. 4. A pulse source **70** is provided for generating sixteen unidirectional pulses per revolution of the satellite. The power source **70** is triggered by the reference voltage timing source **42**. The pulses are applied to a network of flip-flops, each of which is characterized in that successive positive-going voltages applied thereto cause it to change state and in that it has two outputs in which the voltages vary oppositely, and which will be referred to hereafter as the normal and the conjugate outputs. Referring to FIG. 5, along with FIG. 4, FIG. 5*a* shows the alternating squarewave voltage **72** appearing at one output **73** of the flip-flop **71**.

The voltage **72**, which will be recognized as an 8-cycle wave as referenced to a revolution of satellite, is applied to a similar flip-flop **74**. The conjugate squarewave voltage is also applied to another flip-flop **75**. FIG. 5*b* illustrates a squarewave voltage **77** in the normal output of flip-flop **74** that is formed in response to the voltage **72**. As shown, the voltage **77** is of half the frequency of the voltage **72**.

The voltage **77** is applied to the input of a flip-flop **78** which similarly develops normal and conjugate squarewave voltages **80**, **81** (FIGS. 5*c* and 5*e*) and these in

turn are applied to flip-flops **82**, **83** to develop further squarewaves **84**, **85** (FIGS *5f*, *5h*).

With reference to FIG. *5c*, it will be seen that two cycles of the voltage **80** occur during each revolution of the satellite. This normal output of the flip-flop **78** is applied also to a pulse-shaping network **90** (FIG. 4) which differentiates the voltage **80** and develops alternate positive and negative pulses **91–94** (FIG. *5d*). The output of the pulse-shaping network **90** is applied through a driver amplifier **95** to the control coil **51** of the switch a_1. Thus, in accordance with the sequence previously mentioned, positive and negative pulses are alternately applied to the control coil **51** to alternately switch a_1 between its output terminals, i.e., alternately connecting the input of switch a_1 to the inputs of the switches b_1, c_1.

Again referring to FIG. *5*, and particularly to FIGS. *5f* and *5h*, one cycle of each of the voltages **84**, **85** occurs during each revolution of the satellite. However, the voltages **84**, **85** are 90° out of phase, the voltage **85** lagging the voltage **84** by 90°. The voltage **84** from the flip-flop **82** is applied to a pulse-shaping network **98** which differentiates the voltage **84** and develops alternate positive and negative pulses **99**, **100** (FIG. *5f*). These pulses are applied through a driver amplifier **101** to the control coil **56** of the switch b_1. Thus, the positive pulse **99** is applied to the control coil **56** of the switch b_1 when the positive pulse **91** is applied to the control coil **51** of switch a_1 thereby connecting the power amplifier **46** to the waveguide **1**. A half revolution later, when the positive pulse **93** is applied to the control coil **51** of the switch a_1, the negative pulse **100** is applied to the control coil **56** of the switch b_1, thereby connecting the amplifier **41** to the waveguide **9**.

The voltage **85** from the flip-flop **83** is applied to a pulse-shaping network **104**, which differentiates the wave and develops alternate positive and negative pulses **105**, **106**. Like the pulses **99**, **100**, the pulses **105**, **106** are spaced a half revolution apart. However, as with the voltages from which they were developed, the pulse **105** is spaced a quarter of a revolution from the pulse **99**, and the pulse **106** is spaced a quarter of a revolution from the pulse **100**.

The output of the pulse-shaping network **104** is applied through a driver amplifier **107** to the control coil **61** of the switch c_1. Accordingly, it will be seen that when the negative pulse **92** is applied to the control coil **51** of the switch a_1, the positive pulse **105** is applied to the control coil **61** of the switch c_1, thereby connecting the power amplifier **46** to the probe of the waveguide **5**. Similarly, when the negative pulse **94** is applied to the control coil **51** of the switch a_1, the negative pulse **106** is applied to the control coil **61** of the switch c_1, thereby connecting the amplifier **46** to the prove of the waveguide **13**.

The same arrangement of flip-flops, pulse-shaping networks and driver amplifiers is employed for pulsing the remaining groups of switches so that each of the waveguides served thereby is connected to its power amplifier for the portion of each revolution in which it is moving through the sector. In this connection, the input to a flip-flop **110** is connected to the normal output of the flip-flop **75**, and flip-flops **111**, **112** are connected to the outputs of the flip-flop **110**, all in the same manner as the flip-flops **78**, **82**, **83**. Inasmuch as the 8-cycle voltage applied to the flip-flop **75** is the conjugate of the voltage **72** of FIG. *5a*, the waveform of the voltage applied to the flip-flop **110** is the same as that of the voltage **77** of FIG. *5b*, but displayed by 1/16 of a revolution. Since the outputs of the flip-flops **110–112** are connected through pulse-shaping networks and driver amplifiers to the control coils of the switches a_2, b_2, c_2 in the same manner as the first group of switches, the associated waveguides **2**, **6**, **10**, **14** are excited in the same sequence for a quarter of a revolution, but at times 1/16 of a revolution after the corresponding waveguides in the first group **1**, **5**, **9**, **13** are excited.

The conjugate voltages from flip-flops **74**, **75** are utilized in the same manner for operating the remaining groups of switches a_3, b_3, c_3 and a_4, b_4, c_4. For example, the inverted voltage from the flip-flop **74** is applied to the input of a flip-flop **114**, the outputs of which are applied to similar flip-flops **115**, **116**. The conjugate voltage from the flip-flop **74** is displaced by 1/16 of a revolution from the normal voltage from the flip-flop **75**. Since the flip-flops **114–116** are connected through pulse-shaping networks and driver amplifiers to the control coils of the switches a_3, b_3, c_3, in the same manner as previously described for the first group of switches, the switches a_3, b_3, c_3, are operated to connect the associated waveguides **3**, **7**, **11**, **15** to the associated power amplifier in the same sequence.

Rounding out the foregoing, the conjugate output of the flip-flop **75** is connected to the input of a flip-flop **117**, the outputs of which are connected to similar flip-flops **118**, **119**. As will now be apparent, the flip-flops **117–119** operate in the same manner as the flip-flops **114–116**, thereby to cause the switches a_4, b_4, c_4 to be operated for connecting the associated waveguides **4**, **8**, **12**, **16** to the associated power amplifier in the same sequence.

As previously explained in connection with FIGS. 2 and 3, the phase shifters **41–44** are adapted to retard the phase of the *r-f* currents applied to each excited waveguide as it moves through the sector. Referring to FIG. 6 along with FIG. 4, there is illustrated a squarewave voltage **120** which, during each quarter of a revolution, decreases from zero to a minimum, and back to zero. The voltage **120** is applied to the phase shifter **41**, which responds thereto to variably retard the phase of the power applied to each of the waveguides **1**, **5**, **9**, **13** as it moves through the sector. The point of maximum phase retardation occurs at the midpoint of each of the excursions of the voltage **120**. In this connection, each of the waveguides **1**, **5**, **9**, **13** is shown adjacent the lobe of the voltage **120** applied to that waveguide.

In similar fashion, FIGS. *6d*, *6f* and *6h* illustrate the voltage waveforms **121–123** applied to the phase shifters **42–44** for changing the phase of the power applied to each associated waveguide as it moves through the sector.

Referring to FIG. 4, along with FIG. 6, the phasing voltages **120–123** are obtained from the outputs of the flip-flops **74**, **75**. In this connection, FIG. *6a* shows the voltage waveform **125** that is the conjugate output of the flip-flop **74**. The voltage **125** is applied to an integrator **126** which develops an integrated output voltage, indicated as a dotted waveform **127** in FIG. *6a*. The integrated voltage **127** is applied to a wave shaper **129** to develop the voltage **120** of FIG. *6b*. In response to such voltage, as previously explained, the phase shifter **41** functions to vary the phase of the *r-f* currents applied to the respective waveguides **1**, **5**, **9**, **13** served thereby.

As will now be apparent, the voltages **121–123** are derived in similar fashion. FIG. *6c* shows the conjugate voltage wave **131** from the flip-flop **75**, and a corresponding integrated voltage **132** from which the voltage wave **121** of FIG. *6d* is derived. To this end, it will be obvious from inspection of FIG. 4 that the conjugate output of the flip-flop **75** is applied to an appropriate integrator and wave shaper coupled to the phase shifter **42** of FIG. 3.

FIG. *6e* shows the normal output voltage **77** from the flip-flop **74** (which is the same voltage shown in FIG. *5b*). This voltage is similarly integrated to obtain the integrated voltage **134**, and thence the voltage **122** of FIG. *6f*. In like manner, FIG. *6g* shows the normal output voltage **136** of the flip-flop **75**, and integrated voltage **137** derived therefrom, from which the voltage **123** is obtained.

An array of directive antenna elements as heretofore described can be provided in any desired number, and the sector in which waveguides are excited can be made as large or as small as necessary to establish the desired beam coverage on the earth. In this connection, and re-

ferring to FIGS. 1 and 2, waveguides with as narrow a sector as necessary are excited to provide an azimuthal beam of wide coverage, e.g., half the globe. The single aperture waveguides also provide broad elevation (i.e., north-south) coverage. However, while waveguides in a large sector can be excited to provide extremely narrow azimuthal coverage, the single-aperture waveguides of FIGS. 1 and 2 are limited to broad elevation coverage.

FIGS. 7–11 illustrate circular arrays of waveguides to obtain narrow coverage in both azimuth and elevation. Referring to FIG. 7, a circular array of antenna elements is formed of elongated waveguides **141** carried on a satellite **142**. Along its length, each of the waveguides **141** has a plurality of slots **143** formed in its outer wall. The slots **143** may be formed in any desired shape and arrangement, e.g., two rows of staggered rectangular slots as indicated in the example shown. Elongated stationary waveguides having a plurality of slots therein are well known in the art. As is conventional, however, the slots **143** are arranged, e.g., one wavelength vertical spacing between slots in each row and suitable spacing, e.g., one-eighth, between the rows of each pair, and the spacing and arrangement is such as to insure that the radiations therefrom are in phase along the length of the waveguide. As shown in FIG. 8, each of the waveguides **141** is provided with means to excite it individually, e.g., a coaxial connection **144** leading to a connector **145** for an internal probe (not shown).

With the elongated array of antenna elements **141** of FIG. 7 substituted for the waveguides **1–16** of FIGS. 1 and 2, it will be seen that, while the elements **141** are excited individually as previously described, the resulting elevation beam width is considerably narrower. With waveguides **141** of sufficient length, which may be of the order of ten wavelengths, a resulting antenna pattern may be obtained in which coverage is confined to a small area on the globe.

FIG. 9 illustrates another antenna construction for a satellite in accordance with our invention. The construction shown in FIG. 9 is a bicone antenna, wherein a circular array of antenna elements is formed of open-ended waveguides **146**. As shown, each of the waveguides **146** is formed as an elongated element having its open end bent at right angles. The resulting circular array of waveguide mouths is located between the small ends of oppositely facing frusto-conical reflectors **147, 148**. In this connection, the diameters of the inner ends of the conical elements **147, 148** are the same as the outer diameter of the circle formed by the mouths of the waveguides **146**.

The waveguides **146** are shown to be supported at their lower ends by the body of the satellite **150**. With this antenna arrangement substituted for that in FIGS. 1 and 2, the radiation pattern obtained is one in which the reflectors **147, 148** provide broad coverage in elevation. However, such coverage is considerably narrower than is obtainable without the reflectors. In this connection, the flare angle, θ, between the diverging reflectors, together with the outer diameters of the large ends of the reflectors, determines the gain and directivity of the beam.

Our invention also includes the feature of stacked bicone antenna arrangements of the type shown in FIG. 9. Referring to FIGS. 10 and 11, there is shown a stack of four such bicones supported by the satellite body **150**, and in which four circular arrays of open-ended waveguides **152–155** are located between respective pairs of diverging frusto-conical reflectors **157–158, 159–160, 161–162, 163–164**. The open ends of the wave guides in the stack are aligned, and each aligned set is connected to a common feed. To this end, a coaxial or waveguide fed may be employed. For example, as best seen in FIG. 11, a corporate waveguide feed may be employed in which aligned openings **152, 153** in the upper pair are connected at **166**, aligned openings **154, 155** in the lower pair are connected at **167**, the connections **166, 167** are connected at **168**, and the connection **168** is connected at **169** to an energizing source (not shown). The input **169** to this feed corresponds to a probe connection **22** in FIGS. 1 and 2.

With such a stacked bicone antenna arrangement substituted for the array of waveguides in FIG. 2, it will be seen that we obtain a radiation field pattern which is extremely narrow both in elevation and in azimuth. With such a stacked bicone arrangement, for an equivalent beamwidth the various reflectors employed may be considerably smaller in diameter than those required where only a single bicone arrangement (as in FIG. 9) is used.

It will be apparent to persons of ordinary skill in the art that a variety of the switching schemes may be employed for the switching apparatus, and that our invention is not limited to the particular switching scheme above described. Additionally, our invention embraces the use of switching devices other than the ferrite circulator switches previously described, and means for applying increased power to each directive antenna element as it moves through the predetermined sector.

FIGS. 12–16 illustrate one switching arrangement of the type referred to, and in which different switch mechanisms are employed, and in which power from a plurality of amplifiers is applied to a single waveguide as it moves through the predetermined sector. Referring to FIG. 12, there is shown two pairs of power amplifiers, **171, 172** and **173, 174** having a common input, as from one of the phase shifters heretofore described. The outputs of the amplifiers **171, 172** are connected to the input terminals **175, 176** of a switch **177** from which all of the power from both amplifiers **171, 172** is made to appear at either of a pair of output terminals **178, 179**. In similar fashion, the outputs of the amplifiers **173, 174** are applied to corresponding input terminals **180, 181** of a similar switch **182**, which is operable to cause the power from both amplifiers **173, 174** to be applied to either of a pair of output terminals **183, 184** of the switch **182**.

As shown, respective output terminals **179, 183** of the switches **177, 182** are connected to respective input connections of a conventional hybrid element **187** which has respective output terminals **188, 189** connected to the probes of respective waveguides **1, 9**. In the same manner, the remaining output terminals **178, 184** of the switches **177, 182** are connected to input terminals **195, 196** of a similar hybrid element **197**, from which respective outputer terminals **198, 199** are connected to the probes of respective waveguides **5, 13**.

Referring to the hybrid **187**, it is a passive element which functions so that when the power from the amplifiers **171, 172** is applied to the hybrid input terminal **185** and the power from the amplifiers **173, 174** is applied to the hybrid input terminal **186**, the power from all four amplifiers appears at either the output terminal **188** or the output terminal **189**, depending upon whether the power appearing at the input terminals **185, 186** is in phase or 180° out of phase.

The hybrid **197** operates in the identical manner of the hybrid **187**. Accordingly, if the combined outputs of the amplifiers **171, 172** are made to appear at the input terminal **195**, and the combined outputs of the amplifiers **173, 174** are made to appear at the input terminal **196**, the combined power from all of the amplifiers is made to appear at the output terminal **198** or the output terminal **199**, depending upon whether the power inputs at the terminals **195, 196** are in phase or 180° out of phase.

FIGS. 13–16 illustrate the general construction of switches **177, 182**, and their mode of operation. Referring to FIG. 13, which depicts the switch **177**, the device employs a tube **200** having power input terminals **175, 176** at one end which are displaced 90°. Positioned at the opposite end of the tube are output probes **178, 179** which are also displaced 90°. However, the output probes

178, 179 are angularly displaced about 45° from the input probes 175, 176, such that one of the output probes 178 is located midway between the input probes 175, 176.

Disposed within the tube 200 is a ferrite element 205, and surrounding the tube intermediate the ends of the element 205 is an energizing coil 206.

With the arrangement illustrated in FIG. 13, the application of equal, in phase power to the input probes 175, 176 causes a field to be established in the tube 200 which is represented by an electric vector, indicated by arrow 208, that is centered between the input probes 175, 176. Referring to FIG. 14, along with FIG. 13, the wave thus estabilshed travels through the tube 200, and is coupled to one or the other of the output probes 178, 179, depending upon the application or absence of a current in the coil 206. For example, if no current is applied to the coil 206, the wave travels through the tube without being shifted, in which case the arrow 208 (FIG. 14) indicates that all of the power is coupled to the upper output probe 178.

Current in one direction through the coil 206 causes the field to be rotated 90°, and the direction of such rotation will depend upon the direction of current flow through the coil. In either case, all of the power is coupled into the other output probe 179.

In this latter connection, FIG. 15 illustrates a situation in which current is fed through the coil 206 in one direction, and FIG. 16 illustrates the situation in which such current is in the opposite direction. In FIGS. 15 and 16, the arrow 208 is shown in reversed positions, although aligned with the output probe 179, to illustrate the 180° phase shift resulting from current flow in opposite directions through the coil 206.

Referring again to FIG. 12, the control coil for the switch 182 is indicated at 210. To better understand the combined operations of the switches 177, 182, let it be assumed that no current flows in the coil 210 of the switch 182, thereby causing the combined output of the amplifiers 173, 174 to appear at the output terminal 183, and hence at the input terminal 186 of the hybrid 187. Also, let it be assumed that current is applied to the coil 206 is such a direction as to cause the combined outputs of the amplifiers 171, 172 to appear at the output terminal 179 of switch 177, and hence at the input terminal 185 of the hybrid 187.

For the assumed direction of flow of current through the coil 206, the combined input at the hybrid input terminals 185, 186 is caused to appear at one of its output terminals 188. Reversing the direction of current flow to the coil 206 causes the combined input at 185, 186 to appear at the other output terminal 189.

Operation of the switches 177, 182 to couple the combined outputs of the amplifiers 171–174 to either of the outputs of the hybrid 197 is effected in the same manner. In such case, there is no current in the coil 206 of the switch 177, and there is current in the coil 210 of the switch 182, thereby causing the outputs of the amplifiers 171, 172 to appear at the output terminal 178 and hence the input terminal 195 of the hybrid 197, and causing the outputs of the amplifiers 173, 174 to appear at the output terminal 184, and hence the hybrid input terminal 196. For one direction of current flow through the coil 210, the combined outputs of the four amplifiers are made to appear at one of the hybrid output terminals, e.g., the terminal 198. For the opposite direction of current flow through the coil 210, such combined outputs are made to appear at the other output terminal 199.

In the antenna arrangements heretofore described, it will be noted that the surface area of the total satellite is shared between the antenna array and the satellite body. In this connection, the satellite body in conventional fashion carries on its outer surface a plurality of strips of solar cells, which provide the power for all electrically operated equipment. The major portion of the power provided by such solar cells is used to drive the power amplifiers.

Further in this connection, with the total surface of the satellite shared between the antenna array and the remainder of the satellite—which includes the solar cells—a relatively broad antenna pattern, e.g., sufficient to encompass the globe, can be obtained with relatively small antenna elements. In such case, the bulk of the lateral surface of the satellite can be utilized for solar cells for supplying the desired power.

A larger surface must be occupied by the antenna on a satellite in which a relatively small area of the globe is to be covered by the radiation pattern. Thus, elongated antenna arrays as heretofore described in connection with FIGS. 7–11, result in a small portion of the satellite being available for the solar cells. Accordingly, it will be seen that there are practical limits to the proportions of the satellite volume that can be taken up by the antenna structure and the solar cell supporting structure. As a practical matter, there is a measure of equivalency between antenna aperture and surface area that must be allotted to solar cells sufficient to provide the R-F power necessary for the antenna beam.

Referring to FIG. 17, a satellite in accordance with our invention is shown in which the same surface area is utilized for both the antenna array and the solar cells. There is shown a circular array of elongated directional waveguide elements 211, each of which is provided with parallel rows of staggered slots 212, 213, much as in the antenna array shown in FIGS. 7 and 8. Surrounding this entire array, and coextensive therewith, is an electrically insulating sleeve 214. The sleeve 214 may be formed of any suitable material, such as a plastic or fiberglass material commonly used as substrates on which solar cells are conventionally mounted on satellites, and is transparent to R-F energy.

Attached to the exterior of the sleeve 214 are a plurality of spaced strips 215 of solar cells. As illustrated, each of the strips 215 is located between adjacent rows of slots 212, 213 of adjacent waveguides. The edges of the strips 215 do not extend to the slots, but are spaced therefrom so as to avoid interference with the radiation pattern emitted.

Such an arrangement is one in which approximately 90 percent of the total surface area of the satellite is occupied by solar cells. Moreover, the entire length and diameter of the satellite is available for purposes of establishing a radiation field pattern for obtaining an elevation beamwidth of any desired size. Still further, it will be recognized that the satellite carries within the interior of the waveguide array the electrical equipment heretofore mentioned for obtaining the desired azimuthal beamwidth, including the switching apparatus, control means, power amplifiers, etc. In addition, of course, this composite satellite, in the same manner as conventional satellites, supports within its interior the equipment necessary to perform various physical and electrical functions normally required of such devices. In this latter connection, there is shown in FIG. 17 the nozzle 216 of an apogee motor 219, such motor being mounted in the space defined by the interior walls of the waveguides 211. Also, there is shown extending from the lower end of the satellite structure a number of telemetry and/or command VHF antennas 217.

Connections from the solar cell strips 215 may be led into the interior of the composite satellite of our invention in any suitable manner. For example, such connections may extend around the ends of the antenna elements 211. Alternatively, the may be led into the interior between adjacent elements.

While there have been shown and described certain types of switches and switching schemes, our invention clearly embraces reasonable equivalents thereof. For example, we recognize that analog equivalents of digital switching as described herein may be employed, e.g., a

butter matrix replacing the switching elements and having respective inputs connected to the power amplifiers and respective outputs connected to the antenna elements so as to form the beam. Persons of ordinary skill in the art can readily determine the voltage waveforms necessary for creating the phase shifters for despinning the beam.

Accordingly, we do not intend that the scope of our invention shall be limited, except in accordance with a reasonable interpretation of the appended claims.

What is claimed is:

1. In combination:
a circular array of directive antenna elements adapted to be rotated;
controllable phase shifting means through which to apply power to said antenna elements;
power amplifiers coupled to said phase shifting means;
switching means coupled between said power amplifiers and said antenna elements;
first control means for selectively operating said phase shifting means to cause the power applied to said antenna elements to be so phased that a predetermined radiation pattern is radiated in a selected direction from a predetermined sector of said array through which said antenna elements are rotated;
second control means coupled to said switching means to connect said antenna elements in said sector to said power amplifiers;
and a source of reference signals related to the rotation angle of said circular array and coupled to said second means to switch an antenna element into said sector and antenna element out of said sector at each predetermined fraction of revolution of said array.

2. The combinaton of claim 1, including means having a plurality of bistable means for operating said switching means and coupled to said first means for controlling said phase shifting means in synchronism with said switching means.

3. A communication device comprising:
a body adapted to revolve about an axis and including means to provide a reference signal representing the angular position of said body;
a circular array of directive antenna elements about said axis, each antenna element being adapted to be separately excited and each element representing a predetermined angle of a revolution of said body;
controllable phase shifting means adapted to have power for the antenna elements applied thereto;
switching apparatus coupled between said antenna elements and said phase shifting means;
switch apparatus control means coupled to said phase shifting means and to said switch apparatus, said control means switching said antenna elements in a predetermined sequence to maintain a selected number of excited adjacent elements;
and a reference voltage timing source coupled to said control means, said control means responding to said reference signal to operate said switch apparatus to cause power to be applied to said selected number of antenna elements so that each element passes energy during a predetermined angle of revolution and to operate said phase shifting means to form a selected radiation pattern.

4. A communication device comprising:
a circular array of directive antenna elements, each including means to be individually excited, said array being adapted to be rotated around an axis;
reference means for developing a signal representing the angular position of said device;
exciting means for said antenna elements;
and means responsive to said reference means to connect said exciting means to a predetermined number of said antenna elements by sequentially connecting an antenna element and disconnecting a different antenna element in a direction opposite but equal to said direction of rotation, whereby to cause a stationary antenna filed pattern to be radiated in a selected direction from a predetermined sector through which said array rotates.

5. A communication device as defined in claim 4, wherein said exciting means includes controllable phase shifting means;
means for applying signals to said phase shifting means;
switch apparatus in said connecting means coupled between said phase shifting means and said antenna elements;
and control means for operating said switch apparatus to selectively connect said phase shifting means to said antenna elements so that during each revolution of said array a different element is connected and a different element is disconnected each predetermined fraction of revolution.

6. A communication device as defined in claim 4 wherein said connecting means causes each antenna element to be excited in its movement throughout the predetermined sector and wherein a plurality of antenna elements are located in the predetermined sector at any instant, and wherein said connecting means causes said exciting means to be simultaneously connected to each of said plurality of antenna elements located in said sector.

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