ELECTRONICALLY SCANNED TACAN ANTENNA

Filed May 2, 1968 4 Sheets-Sheet 1

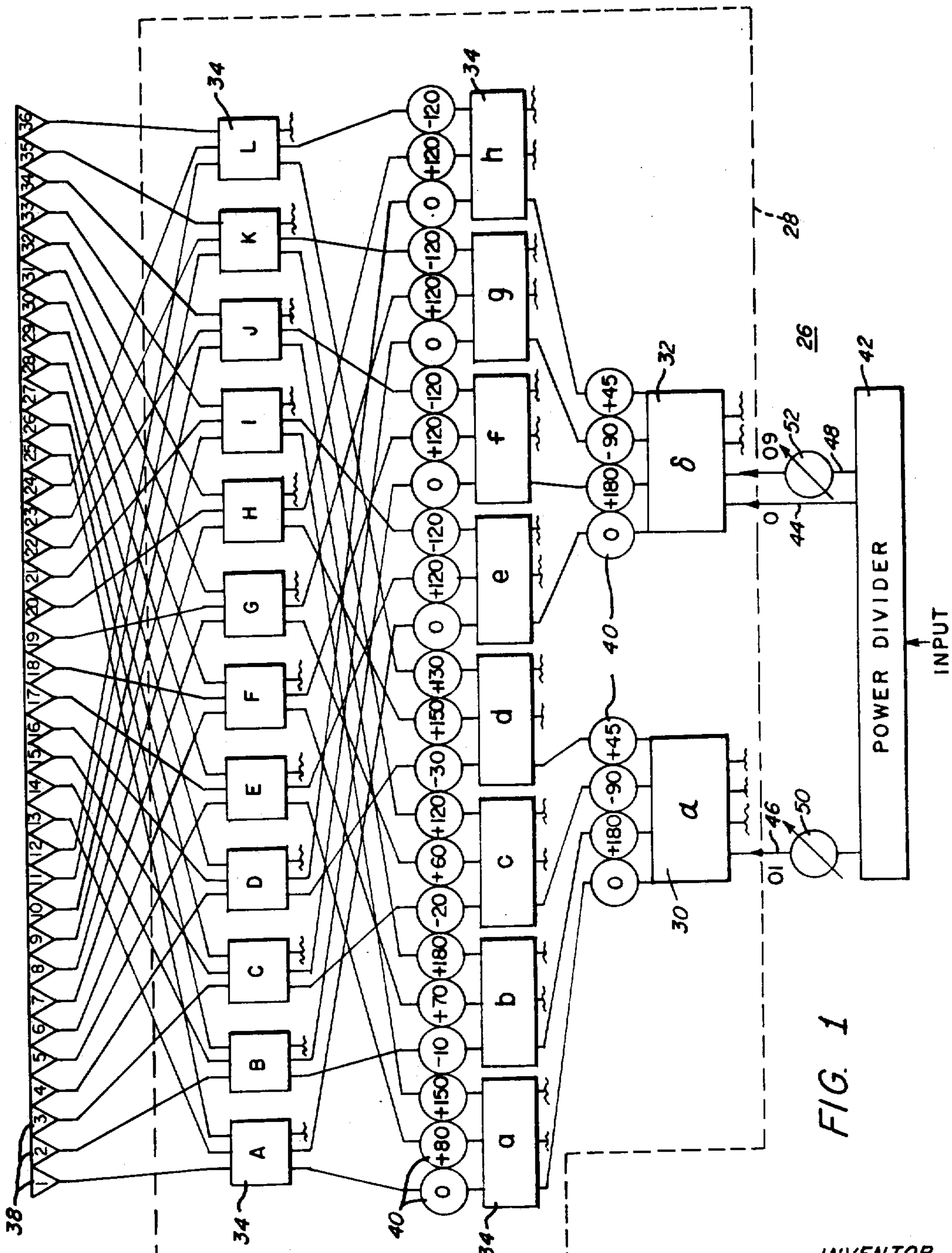

FIG. 1

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FIG. 2

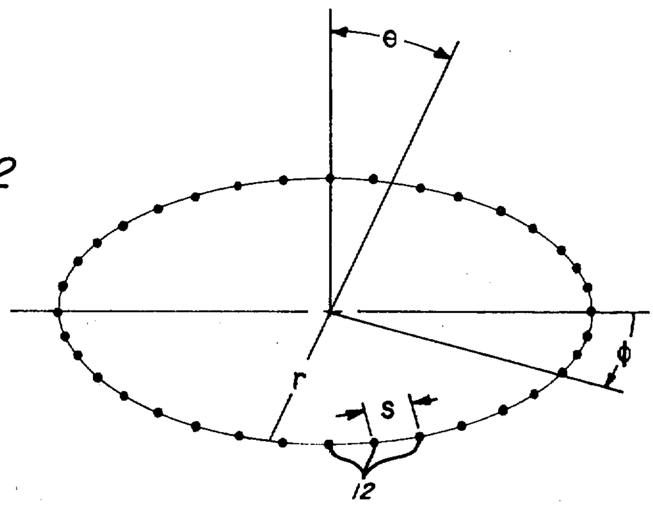
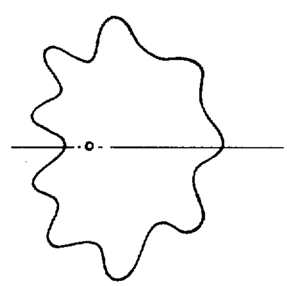


FIG. 3



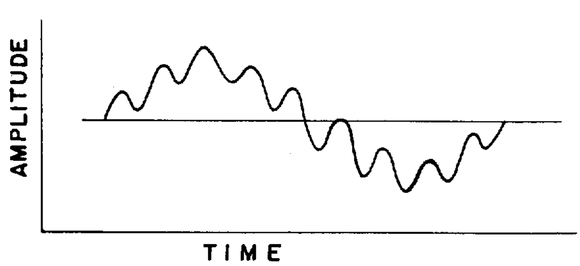


FIG. 4

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ELECTRONICALLY SCANNED TACAN ANTENNA

FIG. 5A

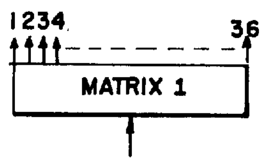


FIG. 5B

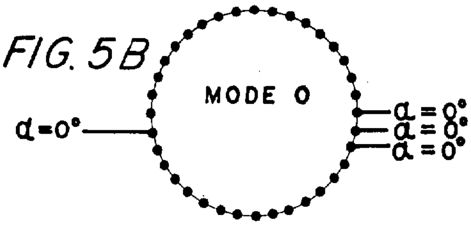


FIG. 5C

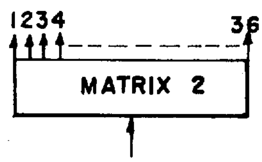


FIG. 5D

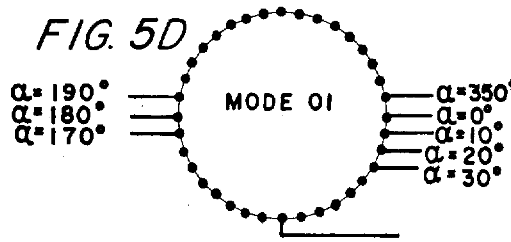


FIG. 5E

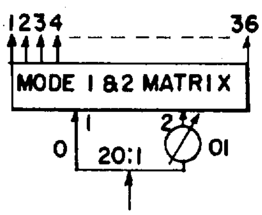
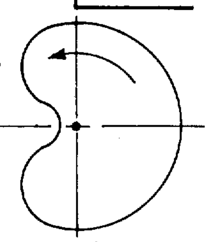


FIG. 5F



COMPOSITE PATTERN 1 + 2

FIG. 5G

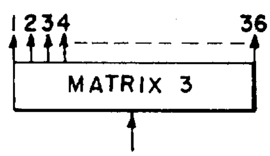


FIG. 5H

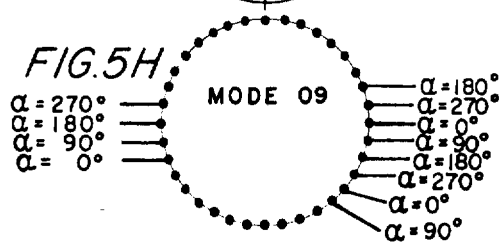


FIG. 5I

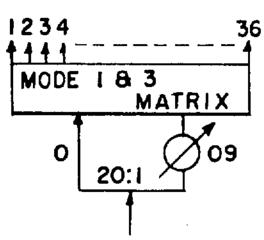
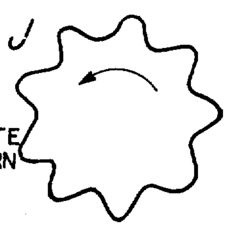


FIG. 5J



COMPOSITE PATTERN 1 & 3

FIG. 5K

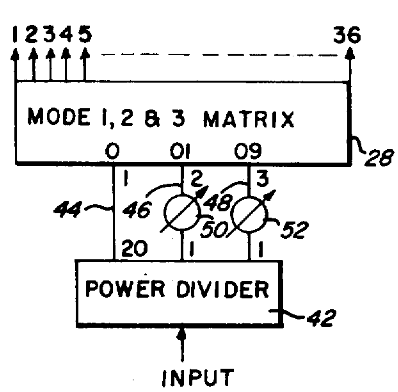
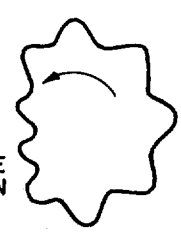


FIG. 5L



COMPOSITE PATTERN 1,2, & 3

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Oct. 21, 1969 L. MELANCON 3,474,447

ELECTRONICALLY SCANNED TACAN ANTENNA

Filed May 2, 1968 4 Sheets-Sheet 4

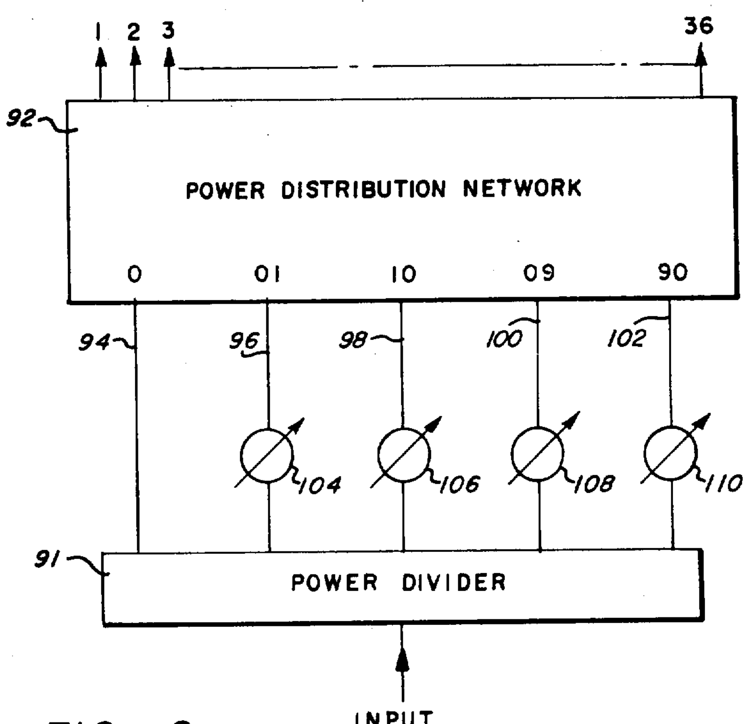

FIG. 6

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United States Patent Office

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ELECTRONICALLY SCANNED TACAN ANTENNA

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Int. Cl. H04b 7/02
U.S. Cl. 343—100 5 Claims

ABSTRACT OF THE DISCLOSURE

An electronically scanned antenna is provided which is capable of producing a desired amplitude modulation in space. The antenna includes a ring array of 36 radiators, a power distribution network and only two variable phase shifters. The power distribution network consists of a 36 by 36 port Butler matrix. While all 36 output ports are used, only three of the input ports are utilized. Transmitting power is divided unequally three ways for feeding into the three inputs. A variable phase shifter is inserted into two of the three input ports. When the phase shifters are activated, the desired modulation is produced at all 36 outputs. All of the input power is radiated except for normal transmission line losses.

Background of the invention

TACAN is a tactical air navigational system which provides bearing and range information on direct reading instruments located in an aircraft. The heart of the system lies in the ground beacon antenna which generates a certain amplitude modulation in space in all azimuth directions to provide bearing information. Essentially, this is a shaped beam in the horizontal plane which rotates in this plane. Coarse bearing information is generated by a rotating limacon-shaped pattern which results in a 15 cycle-per-second amplitude modulation. Fine bearing information is generated by a nine-lobed radiation pattern which is superimposed on the limacon pattern. To provide vertical coverage, the pattern is shaped siimlar to a cosecant-squared pattern.

In order to better understand the design of an array for TACAN, the existing antenna design and its operation will be described briefly. At the present time there are two similar antenna designs, one for the lower half of the frequency band and one for the upper half. Each antenna consists of a stationary centray array of two dipoles stacked vertically to give an omnidirectional pattern in the azimuth plane. This is the only active element in the antenna. All other elements are parasitically excited.

A rotating sub-assembly is placed around this dipole array to distort the omnidirectional pattern into a scalloped pattern which is shaped to produce two amplitude modulations when viewed from a distance. This sub-assembly consists of two coaxial plastic cylinders or radomes which are rigidly held to each other and rotated at the controlled speed of 15 cycles-per-second. In turn, these coaxial cylinders are concentric with the inner central feed array which is stationary. Two biconical horns, which are stacked vertically, are fastened between the inner and outer rotating plastic cylinders and thus rotate with them. These two biconical horns are fed by the two dipoles of the stationary array. The purpose of the horns is to shape the antenna pattern in the vertical plane. In other words these horns determine the shape of the primary radiation pattern in the vertical plane and so determine the vertical coverage.

The heart of the amplitude modulating mechanism lies in the small parasitic radiators which are securely fastened to the two rotating cylinders. Without these parasitic radiators the antenna pattern is essentially omnidirectional in the azimuth plane; i.e., there is no amplitude modulation. A single parasitic reflecting element in the form of fine wires is cemented on the inner cylinder. By placing these wires in the electric field radiating from the dipoles, the omnidirectional pattern is distorted into a more directional one. The shape of this distorted pattern is that of a limacon. Nine parasitic elements uniformly spaced at 40-degree intervals are cemented on the outer rotating cylinder. Again placed in the electric field of the dipoles the azimuth plane pattern is distorted by the re-radiated energy from these parasitic wires. With the absence of parasitic wires on the inner cylinder, the pattern resulting from the nine parasitics is that of a nine-lobed one.

These two dielectric cylinders with their parasitic elements are rotated at the controlled speed of 15 cycles-per-second. Because of the radiation pattern distortion, the radiated energy goes through periodic variations in amplitude when viewed from any point in space. The amplitude variation produced by the single parasitic on the inner cylinder can be represented as a sine wave. Obviously the frequency of this modulation is 15 cycles-per-second. The amplitude variation produced by the nine parasitic elements on the outer cylinder also produces a sine wave. Because the pattern is nine-lobed, the frequency of this modulation is nine times 15 or 135 cycles-per-second. With the simultaneous modulation by both sets of parasitics, the nine-lobed pattern is superimposed on the limacon pattern. The resultant wave radiated by the antenna contains two modulating frequencies, 15 and, its ninth harmonic, 135 cycles-per-second.

Great interest has arisen for an electronically scanned TACAN antenna. The apparent reasons for this interest are the siting problems and the low reliability of the bearings in the prior art designs which rotate continuously at 900 r.p.m. An electronically scanned antenna will have longer life and higher reliability.

Various approaches have been considered for an electronically-scanned antenna. Three such approaches are: (1) use of a bank or banks of plasma tubes which can be lighted in sequence to simulate antenna rotation; (2) use of a shaped parabolic torus with a rotating feed assembly, relatively small in diameter, to illuminate the reflector; and (3) a Wullenweber array.

In the plasma tube approach if an omnidirectional radiator is surrounded by a cylindrical array or arrays of plasma tubes, it should be possible to produce the required amplitude modulation by firing the tubes sequentially. This would simulate antenna rotation. This approach is appealing because it requires only an on-off switching arrangment. Unfortunately this approach requires the development of the basic component, the plasma tube. Stringent specification for reflection and absorption characteristics would be required. Also the design would have to be such that the tubes would extinguish in the presence of high RF power levels. This is not only an expensive but also a high risk approach.

A toroidal reflector and a circular line source is another approach. This approach offers very little advantage because of its special geometry problem of producing modulation at high elevation angles. An unacceptably large diameter is required. The antenna is very large, 20 feet in diameter and 15 feet high. This technique has the added disadvantage of still requiring rotating parts which might also have short lift and reliability problems. In addition, if an expensive electronically-scanned circular array is required, it is far more practical to feed vertical arrays from this array than to feed a large toroidal reflector.

Still another approach involves a modification of the Wullenweber array where every element is switched and possibly could produce the desired patterns. The switching might be implemented electronically. However, this appears to be an extremely complex brute force type of approach requiring a large number of elements to simulate continuous scanning. Its reliability is also questionable.

In the antenna of the present invention electronic scanning is achieved by employing a cylindrical ring array with only two active phase shifters. In the preferred embodiment, the signal is divided unequally into three separate paths. No phase modulation of the signal is required in the first path through which approximately 90% of the energy is fed into a power distribution network which is a modified Butler matrix. In each of the other two parallel paths approximately 5% of the signal is fed through a continuous microwave phase shifter, one operating at 15 cycles-per-second, the other at 135 cycles-per-second. The signals from the three parallel paths are recombined in a loss-less network to feed a ring array of 36 elements.

One of the great advantages of the present invention is that only two variable phase shifters are required to scan the ring array. Each phase shifter is required to handle only a small percentage of the input power. The drive and control circuitry is comparatively simple since only two active elements are required. Nowhere in the system is power dumped or dissipated in lossy elements. Energy which cancels in one direction is redirected in another direction. The only losses in the system will be normal transmission line losses and nominal insertion losses in the ferrite phase shifters. The simplicity of this design results in a highly reliable unit and a very economical production unit. Extensive use of strip-line techniques makes the design economical and compact. An extension of the use of strip-line for the radiating elements in a later stage will reduce weight even further.

Summary of the invention

The above advantages and features of the present invention as well as many others are achieved by providing an electronically scanned antenna comprising: a plurality of radiating elements arranged in an array; a power distribution network for feeding the plurality of radiating elements from a source of input signal, the network including a power dividing circuit for dividing the input signal into a predetermined number of separate paths; and means for varying the phase of each of the signals in the separate paths so as to produce a desired amplitude modulated radiation pattern in space.

Brief description of the drawings

FIG. 1 shows the feed matrix comprising the antenna of the present invention;

FIG. 2 shows the geometry of the antenna array of the present invention;

FIG. 3 shows the desired radiation pattern that is required for the antenna of the present invention;

FIG. 4 shows the sinusoidal amplitude modulations produced by rotation of the radiation pattern shown in FIG. 1;

FIG. 5, A–L, show the matrices and the relative phase distributions for each mode utilized in the operation of the present invention;

FIG. 6 shows an alternative embodiment of the antenna of the present invention.

Description of the preferred embodiments

In understanding the present invention some discussion of the theory and basic mathematical foundation underlying the invention would be appropriate. It is possible to build a ring array with N azimuth elements which are fed from a network comprised of N inputs. Each input excites all of the N array elements with equal amplitude but with a phase excitation which varies from element to element. For any one input there is a constant increment

of phase progression from element to element. The possible phase increments are:

$$2\pi/N,\ 2\pi/N-1,\ 2\pi/N-2,\ \ldots\ 2\pi \text{ or } 0°$$

The resultant far-field pattern for any given input is omnidirectional for most of the inputs. The exception occurs when $2\pi/n=\pi$ or a value close to π. For this condition an n-lobed amplitude pattern is generated. This type pattern is not useful for the omnidirectional coverage required.

The expression for the radiation patterns from this ring array can be represented in the form:

$$E(\theta,\phi)=A_0(\theta)+A_1(\theta)e^{j\phi}+A_2(\theta)e^{j2\phi}\ \ldots\ A_{N-1}(\theta)e^{j(N-1)\phi} \quad (1)$$

where A_n is the ninth amplitude excitation coefficient, θ is the elevation angle and ϕ is the angle representing the bearing to the ground station from the point of observation.

The antenna geometry of the present invention is shown in FIG. 2 where a ring array of 36 radiators numbered **12** are shown. The array has a radius r, a spacing s between each radiator **12**, an angle θ which is the elevation angle and an angle ϕ which represents the bearing to the ground station from the point of observation.

The radiation pattern shape in the azimuth plane can best be described by reference to the drawings.

FIG. 3 shows the desired composite azimuth plane pattern for the TACAN antenna. The pattern represents an omnidirectional pattern having an amplitude modulation in space in all azimuth directions. When the composite pattern is rotated, the sinusoidal amplitude modulation of FIG. 4 is produced.

If only three of the input ports are excited, and if the three ports represent the first (0 mode), second (01 mode) and tenth (09 mode) terms of the above Equation 1, then the equation reduces to:

$$E(\theta,\ \phi)=A_0(\theta)+A_1(\theta)E^{j\phi}+A_9(\theta)e^{j9\phi} \quad (2)$$

This is the general expression for producing the type of amplitude-modulated radiation patterns required in the TACAN antenna. By judicious selection of the three coefficients A_0, A_1 and A_9, the desired modulation level will result.

One method for distributing power to the radiating elements separately and simultaneously utilizes the well known "Butler" matrix. Originally, the Butler matrix was limited to 2^n number of ports. However, an article entitled, "Multiple Beams From Linear Arrays," IRE Transactions on Antennas and Propagation, March 1961, extended the theory and showed that element numbers equal to $2^l\ 3^m\ 4^n$ are possible if six-port and eight-port couplers are used. This means that in the range of number of elements of interest for this application 18, 24, 27, 32, 36, 48 and 54 elements are all possible choices.

Since a nine-lobed pattern is desired for the preferred embodiment of the present invention and since the resultant amplitude pattern is the combination of the three modes discussed above, the logical conclusion is that the number of array elements should be a multiple of nine. This limits the selection to 18, 27, 36, 45 and 54 elements. For reasons of simplicity and economy it is desirable to utilize a minimum number of elements. One of the requirements of this technique is that all three mode radiation patterns be omnidirectional. It is known that mode 09 for $N=18$ is a nine-lobed pattern since the phase increment is π. This is an unacceptable pattern. Also because of the 120° phase increment in mode 9 for $N=27$, the radiation pattern will not be omnidirectional. The ripples in the patterns are expected to be sufficiently deep as to cause a change in modulation with change in bearing. For these reasons both 18 and 27 elements are considered unusable. FIGS. 5A–L, show the matrices and the relative phase distribution for all three modes for $N=36$.

FIG. 5A shows the matrix with the 36 output radiating elements and FIG. 5B shows the phase distribution for the 0 mode. FIG. 5C illustrates the matrix and FIG. 5D the pase distribution for the 01 mode. The matrix and the composite radiation pattern for the combined 0 and 01 modes is depicted in FIGS. 5E and 5F respectively while FIG. 5G represents the matrix and FIG. 5H the phase distribution for the 09 mode. FIG. 5I shows the matrix and FIG. 5J the composite radiation pattern for the combined 0 and 09 modes. Finally, the composite pattern derived from combining the 0, 01 and 09 modes and the required matrix are shown in FIGS. 5L and 5K respectively.

In this case good omnidirectional patterns can be achieved for all of the three required modes. Of course good omnidirectionality can be achieved only by judicious selection of radiating element design and array diameter.

The feed matrix of the present invention employs a modified version of a Butler matrix. A 36 x 36 port Butler matrix is a lossless 36 element feed distribution matrix which is matched at all ports. It consists of nine eight-port couplers, 24 six-port couplers and various phase shifters. Phase shifters are provided in conjunction with each of the couplers to provide both phase delays and phase advances whichc merely is indicative of relative path lengths. In practice, lengths of transmission line provide phase delay. Since line lengths are frequency sensitive, additional compensating filters in the form of open circuited sections of transmission lines are required in series with the phase shifters for broadband operation.

The 36 x 36 Butler matrix has 36 inputs to the matrix which correspond to different modes 0, 01, 10, 02, 20, etc. Energy into any one of the input ports will divide equally between the 36 output ports. Energy into the port corresponding to the 0 mode will have a 0° phase increment. Energy into the port corresponding to the 01 mode will have a −10° phase increment when looking at the array from the left to right. Energy into the port corresponding to the 10 mode will have a +10° phase increment, etc. Energy into the port corresponding to the 09 mode will have a −90° phase increment.

In the present invention, the desired inputs are the 0, 01, and 09 modes. These three input modes are connected to only two of the nine eight-port couplers of a standard 36 x 36 Butler matrix. Since the other seven eight-port couplers are not utilized they can be replaced with matched loads. In a like manner, other couplers of the standard 36 x 36 Butler matrix can be replaced with matched loads. The result is the simplified feed matrix of the present invention shown in FIG. 1. It must be pointed out that the replacement of couplers with matched loads involves neither a change in performance nor a loss in energy. This modified Butler matrix network **26** of the present invention is a lossless reciprocal network (i.e. exclusive of normal transmission line losses). The antenna structure of FIG. 1 shows a matrix having only two eight-port couplers **30**, which has the 01 input, and 32, which has the 0 and 09 inputs. Couplers **30** and **32** are connected to 20 six-port couplers **34** which are connected to the radiators **38**. Various phase shifters **40** are connected to the couplers **34**.

The dotted block **28** corresponds to each of the matrix blocks shown in FIGS. 5A–K. The input signal to the matrix **26** is fed to a power dividing circuit **42** which separates the input signal into three separate input paths—the 0, 01 and 09 input lines labelled **44**, **46** and **48** respectively. The 01 input line **46** includes a variable microwave phase shifter **50** which is set to operate at 15 cycles-per-second. The 09 input line **48** includes a variable microwave phase shifter **52** which is set to operate at 135 cycles-per-second. No phase modulation of the signal is required on the 0 input line **44** through which approximately 90% of the energy is fed into the power distribution system. Approximately 5% of the energy is fed through each of the 01 and 09 input lines **46** and **48** respectively. The three input signals are then recombined in the lossless power distribution network to feed the ring array of 36 elements **38**.

As mentioned previously, the far field pattern for each of the three inputs is omnidirectional. To understand the operation of the antenna reference should again be made to FIGS. 5A–K. If a two-way power divider is used to feed inputs 0 and 01 simultaneously, it is evident that in one direction the RF fields will add vectorially to give increased gain in this direction. Looking in directions away from this reference direction there is a continuous decrease in gain as the two vectors rotate away from each other, until these vectors are 180° out of phase and cancel completely when looking in the opposite direction. The resultant far field pattern, as well as the excitation amplitude, is of the shape of a cardioid not shown.

Now if a continuous type of phase shifter is inserted in either one of the feed lines, the radiation pattern will rotate one revolution for each 360° of phase shift. Viewed from a fixed point in space this will appear as 100% amplitude modulation. If instead of dividing the power equally between inputs, a 20:1 power divider is used then there will be less of an increase in gain in the reference direction and incomplete cancellation in the opposite direction. The matrix as described is shown in FIG. 5E and the resultant far field pattern is a limacon type pattern as shown in FIG. 5F. When viewed from a point in space this will appear as a sinusoidal amplitude modulation of approximately 20%. The expression for the radiation pattern from this antenna is of the form:

$$E(\theta\phi)=A_0(\theta)+A_1(\theta)e^{j\phi} \quad (3)$$

In a similar manner the 0 and 09 inputs can be excited simultaneously with a two-way power divider. In this case there are nine directions in which the RF fields will add to give increased gain and nine directions in which they cancel to give a lower gain. As in the previous case, with a 20:1 power divider and a phase modulator, the nine-lobed pattern will rotate 360/9 or 40° for each 360° of phase shift thus appearing as a sinusoidal amplitude modulation of approximately 20% when viewed from a fixed point in space. The matrix is seen in FIG. 5I and the resultant pattern is shown in FIG. 5J.

As a final step all three modes 0, 01 and 09 can be excited simultaneously with the three-way power divider **42** as seen in FIG. 5K. It follows that the far field pattern, as well as the excitation amplitude, will be the vector sum of the three separate mode inputs. The resultant pattern shown in FIG. 5L is precisely the shape for the TACAN system where a fundamental and ninth harmonic are required. In order to rotate the radiation pattern with no change in shape it is necessary to phase modulate the 09 mode at nine times the frequency of the 01 mode. The reason being that the nine-lobed pattern rotates at one-ninth the speed of the limacon pattern. The expression for the combined radiation pattern is the Equation 2 above. As shown in FIG. 5K, a 15 cycle-per-second phase shifter **50** is required in series with the 01 input line **46** and a 135 cycle-per-second phase shifter **52** in the 09 input line **48**.

This system is very simple requiring only two variable phase shifters to produce the desired patterns. It is unencumbered with elaborate control mechanisms ordinarily required to control phases or amplitudes for every antenna element. The only requirement is that the 15 and 135 cycle modulation be maintained constant and this would also be required with any other antenna technique. The choice of variable phase shifters might include mechanical, diode or ferrite devices.

Although the preferred embodiment has been described using two variable phase shifters, the antenna might also be designed for operation with five inputs using four variable phase shifters. This alternative is shown in FIG. 6. In the embodiment of FIG. 6, the input is fed to a power divider **91** which divides the input into five separate paths, four of which have variable phase shifters. The five paths include the 0, 01, 10, 09 and 90 modes and are fed into a power distribution matrix **92** on lines **94**, **96**, **98**, **100** and **102** respectively.

The 0 mode input line **94** feeds approximately 90% of the energy into matrix **92** and requires no phase modulation. Each of the other input lines **96**, **98**, **100** and **102** each feed approximately 2½% of the energy to the matrix **92** and each requires a variable phase shifter to produce the desired amplitude modulation. Input line **96** has a variable phase shifter **104** which is set at 15 cycles-per-second for retarding the phase of the 01 input. Input line **98** has a variable phase shifter **106** set at 15 cycles-per-second for advancing the phase of the 10 input. A retarding variable phase shifter **108** is provided with the 09 input line **100** and is set at 135 cycles-per-second while the 90 input line **102** has a variable phase shifter **110** set at 135 cycles-per-second for advancing the phase of the signal. The alternative shown in FIG. 6 results in the same radiation pattern as shown in FIGS. 3 and 5L for the embodiment of the invention shown in FIG. 1, except that the phase of the far field pattern remains constant for all azimuth angles.

It should be pointed out that although the preferred embodiments of the present invention have been described as providing an omnidirectional radiation pattern, the antenna of the present invention may be operated to yield other patterns. By changing the relationship of the phase of the various inputs, the resultant radiation pattern may be changed. Such changes can be made to produce certain types of directional radiation patterns. For example, instead of the nine-lobed omnidirectional pattern desired for TACAN systems, it is possible to produce a nine-lobed directional pattern for uses other than in a TACAN system by using the antenna of the present invention.

I claim:

1. An electronically scanned ground beacon antenna for use in a tactical air navigational system comprising:
- a plurality of radiating elements arranged in a ring array;
- a lossless power distribution network for feeding the plurality of radiating elements from a source of input signal; said network including a power dividing circuit for dividing the input signal into a predetermined number of separate paths; and
- a variable phase shifter located in each of the separate paths except one for producing the required phase modulations in each path for obtaining a desired amplitude-modulated radiation pattern in space.

2. An electronically scanned ground beacon antenna for use in a tactical air navigational system comprising:
- a plurality of radiating elements arranged in a ring array;
- a lossless power distribution network for feeding the plurality of radiating elements from a source of input signal; said network including a power dividing circuit for dividing the input signal into a predetermined number of separate paths; and
- a variable microwave phase shifter located in each of the separate paths except one for producing the required phase modulations in each path for obtaining an omnidirectional radiation pattern being amplitude-modulated in space in all azimuth directions.

3. An electronically scanned ground beacon antenna for use in a tactical air navigational system comprising:
- a plurality of radiating elements arranged in a ring array;
- a lossless power distribution network for feeding the plurality of radiating elements from a source of input signal, said network including a plurality of couplers and phase shifters connected in such a manner as to produce a desired modulation at all the radiating elements;
- a power dividing circuit coupled to the power distribution network for dividing the input signal into a predetermined number of separate paths; and
- a variable microwave phase shifter located in each of the separate paths except one for producing the required phase modulations in each path for obtaining an omnidirectional radiation pattern being amplitude-modulated in space in all azimuth directions.

4. An electronically scanned ground beacon antenna for use in a tactical air navigational system comprising:
- a ring array comprising 36 radiating elements;
- a lossless power distribution network for feeding the plurality of radiating elements from a source of input signal, said network including a plurality of couplers and phase shifters connected in such manner as to produce a desired modulation at all the radiating elements;
- a power dividing circuit coupled to the power distribution network for dividing the input signal into three separate paths;
- a variable phase shifter located in one of said paths for producing a 15 cycle-per-second phase modulation; and
- another variable phase shifter located in another of said paths for producing a 135 cycle-per-second phase modulation;
- said path without a phase shifter feeding approximately 90% of the energy to said power distribution network while approximately 5% of the energy passes through each of the other paths to said network whereby a desired nine-lobed omnidirectional radiation pattern being amplitude-modulated in space in all azimuth directions is produced.

5. An electronically scanned ground beacon antenna for use in a tactical air navigational system comprising:
- a ring array comprising 36 radiating elements;
- a lossless power distribution network for feeding the plurality of radiating elements from a source of input signal, said network including a plurality of couplers and phase shifters connected in such manner as to produce a desired modulation at all the radiating elements;
- a power dividing circuit coupled to the power distribution network for dividing the input signal into five separate paths;
- two of said paths each having a variable phase shifter set at 15 cycles-per-second, one producing a retarding and the other an advancing phase modulation; and
- two other of said paths each having a variable phase shifter set at 135 cycles-per-second, one producing a retarding and the other an advancing phase modulation;
- said path without a phase shifter feeding approximately 90% of the energy to said power distribution network while approximately 2½% of the energy passes through each of the other paths to said network, whereby a desired nine-lobed omnidirectional radiation pattern being amplitude-modulated in space in all azimuth directions and whose far field pattern remains constant for all azimuth angles.

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