

[54] ANTENNA PATTERN GENERATOR AND SWITCHING APPARATUS

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[52] U.S. Cl. 343/854; 343/876; 333/7 D; 333/31 R

[51] Int. Cl.² H01Q 3/26

[58] Field of Search..... 343/853, 854, 876; 333/7 D, 31 R

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Primary Examiner—Eli Lieberman

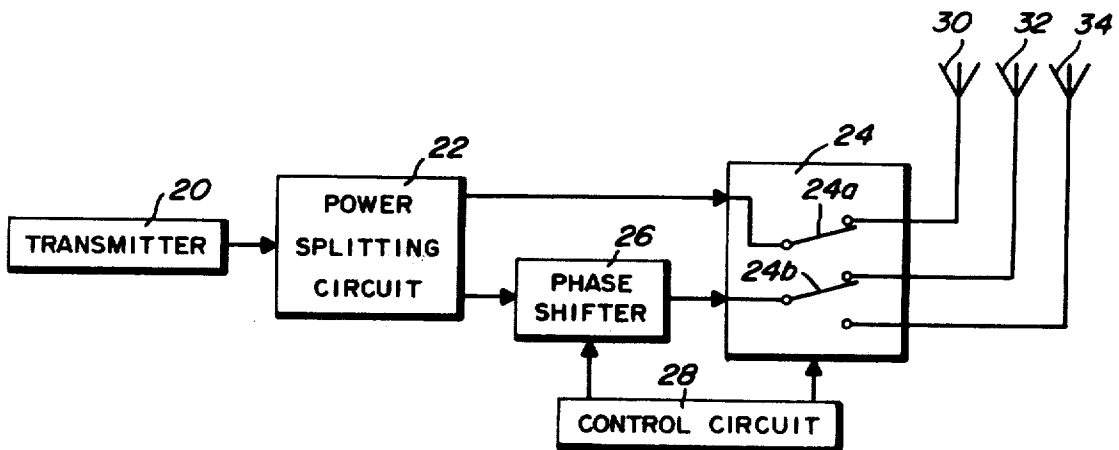
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[57]

ABSTRACT

A variable pattern antenna system including a plurality of radiating elements, a switching circuit for selectively applying signals to various ones of the radiating elements, a phase shifting circuit for shifting the phase of the signals applied to the elements, and a control circuit for operating the switching circuit and phase shifting circuit to cause variable phase signals to be applied to predetermined radiating elements for changing the pattern of the antenna, and a drive wave-shaping circuit to prevent abrupt switching and the spectrum spreading interference commonly known as "splatter" that would occur.

11 Claims, 9 Drawing Figures



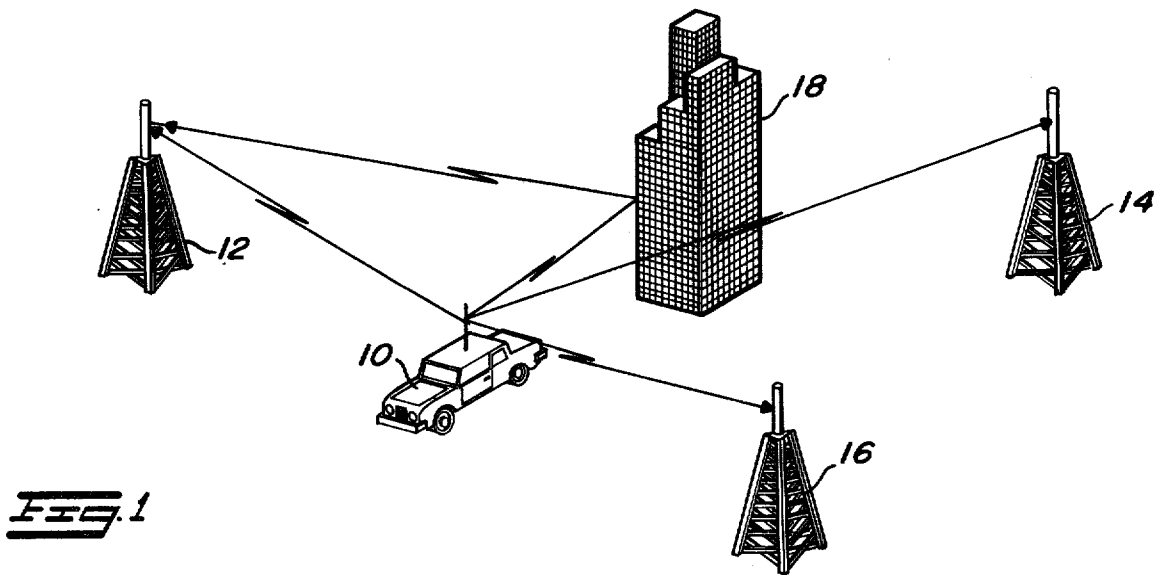


FIG. 1

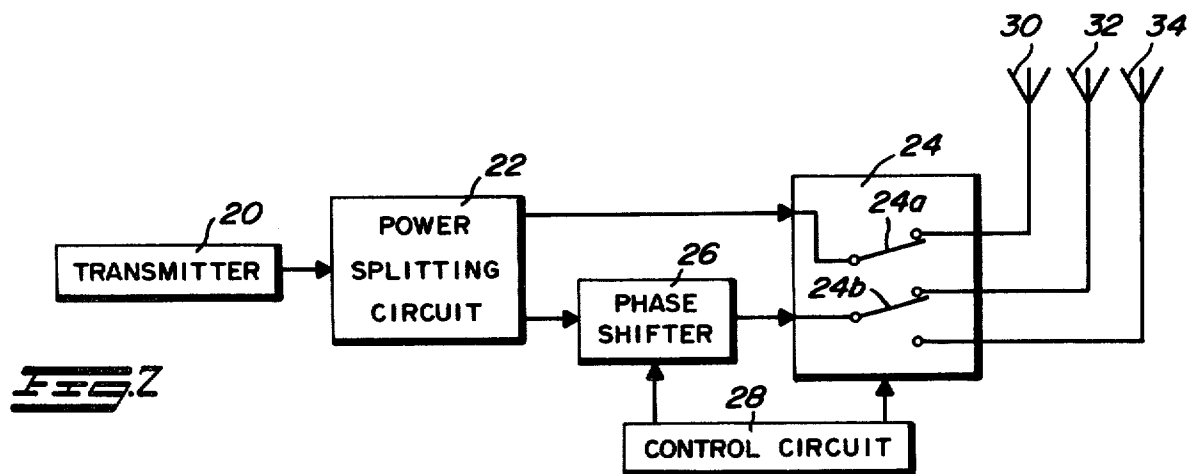


FIG. 2

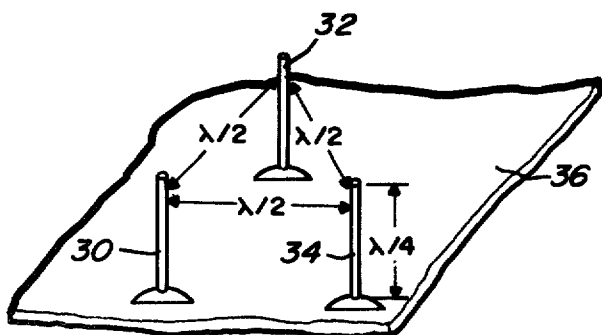
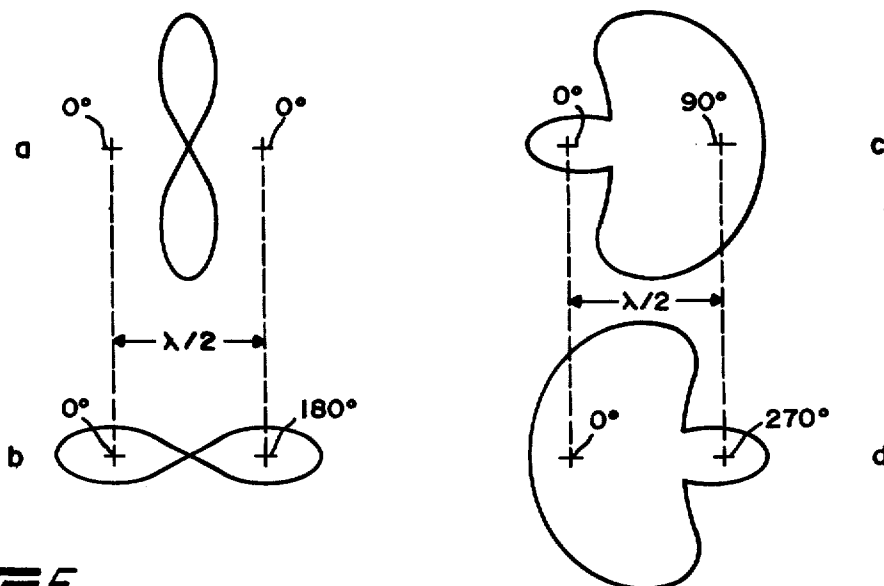
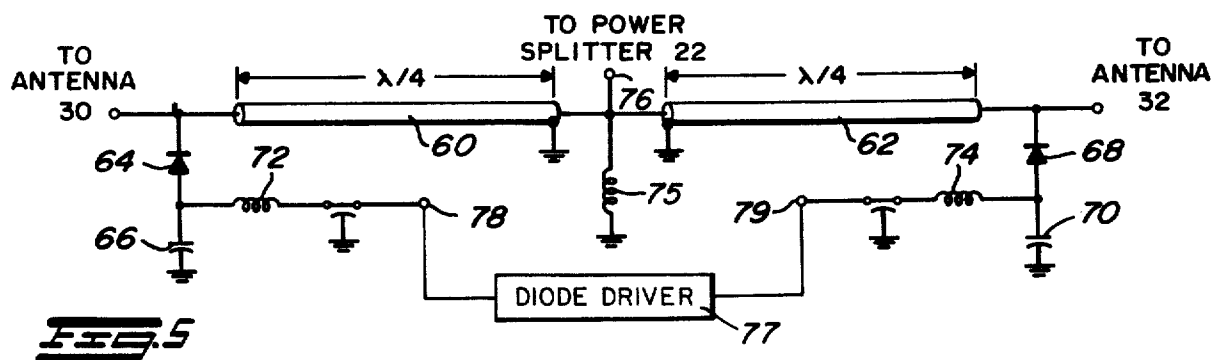
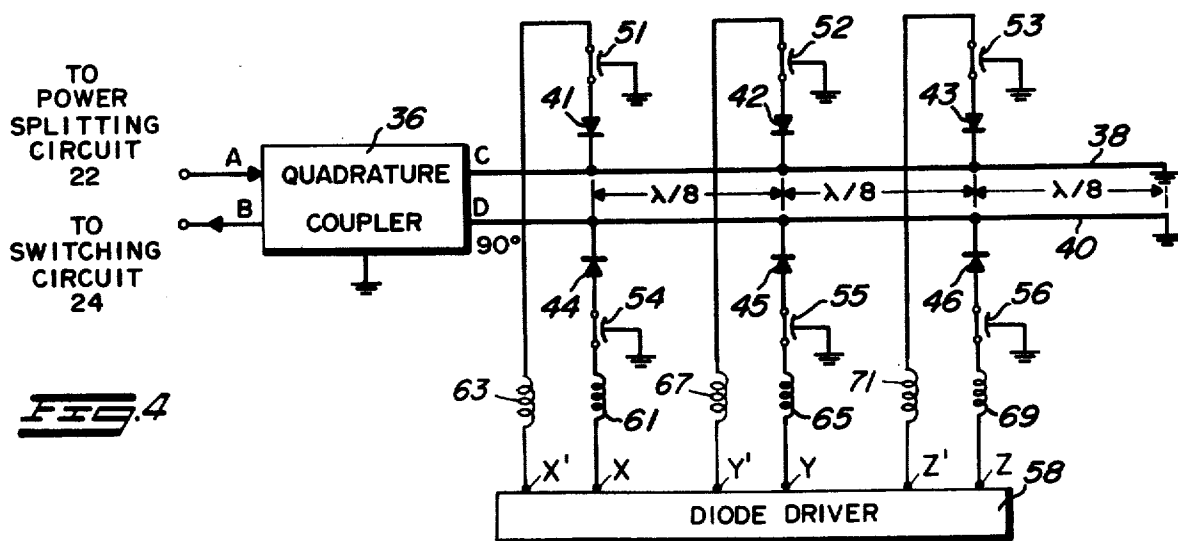


FIG. 3



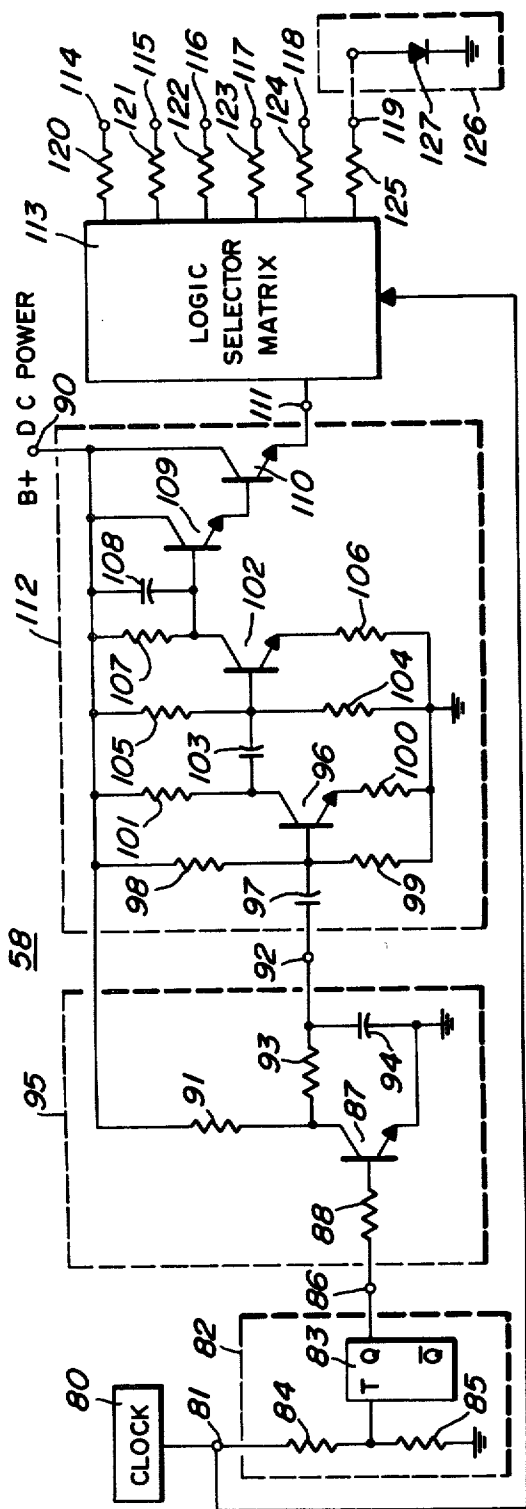


FIG. 7

FIG. 8

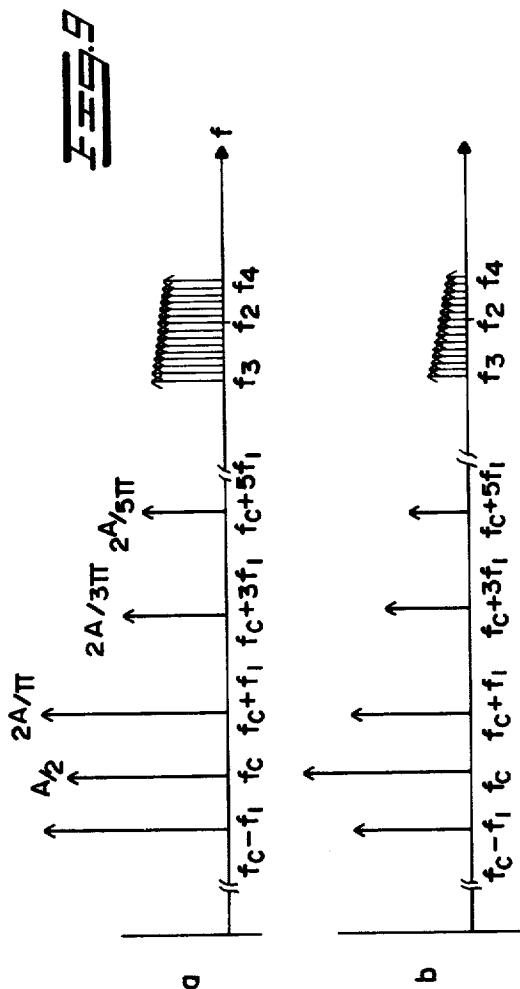
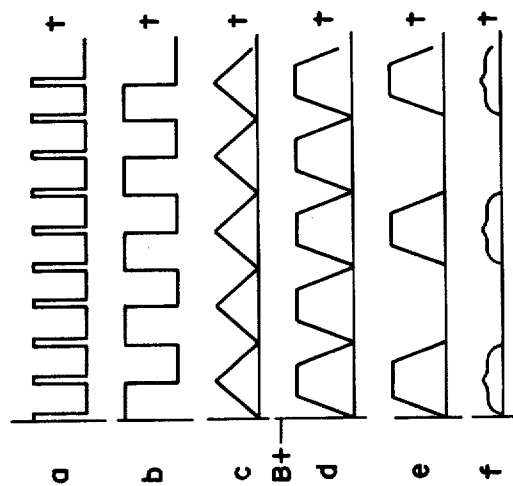


FIG. 9

ANTENNA PATTERN GENERATOR AND SWITCHING APPARATUS

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation in part of copending application Ser. No. 384,328, filed July 30, 1973, now abandoned entitled, "Antenna Pattern Generator," having the same inventor and assignee, and now abandoned.

BACKGROUND

1. FIELD OF INVENTION

This invention relates to antenna systems, and more particularly to antenna systems having an electronically alterable antenna pattern.

There are many applications wherein it is necessary to provide an antenna system having a readily alterable radiation pattern which can be switched between different radiation pattern states. One such application for such an antenna system is in a vehicle location system of the triangulation or phase ranging type wherein it is necessary to constantly vary the pattern of the vehicle antenna to minimize location errors resulting from reflected and multipath signals. Other applications include diversity transmission and reception systems.

2. PRIOR ART

Several techniques for providing a variable pattern antenna are known. One such system utilizes a mechanically rotatable radiating element which may be rotated to change the antenna pattern. Other such systems utilize mechanical relays or semiconductor switches to selectively switch the radiating elements of an antenna.

Whereas these techniques provide a way to achieve a variable pattern antenna, the first technique requires the use of mechanical components which can be costly and unreliable, and which have an inherent limitation in the maximum rate at which the antenna pattern may be changed. The second technique, while being less costly and capable of higher speed operation, is limited in the variety of patterns that can be readily achieved. The second technique normally has abrupt transitions between each antenna pattern generated and therefore creates undesired frequencies having relatively large amplitudes. The word "transition" as used in this specification refers to the change between two states, and "transition rate" refers to the amount of time required to complete a transition.

SUMMARY

It is an object of the present invention to provide an improved variable pattern antenna system having a wide variety of rapidly alterable radiation patterns.

It is a further object of this invention to provide an improved antenna for a vehicle location system of the phase ranging or triangulation type that minimizes the errors occurring as a result of multipath propagation.

It is a still further objective of this invention to provide apparatus for reducing the amplitude of undesired frequencies created by transmitter switching.

In accordance with a preferred embodiment of the invention, a plurality of radiating elements, such as, for example, quarter wave whip antennas are mounted on the roof of a vehicle or other suitable surface. An electronic switch selectively connects a predetermined one of the radiating elements to a radio apparatus such as a transmitter or receiver, and simultaneously connects

another one of the radiating elements to the radio apparatus through a variable phase shifting circuit. A control circuit is connected to the switching circuit and the phase shifting circuit to vary the phase shift of the phase shifting circuit, and to alter the interconnections between the radiating elements, the phase shifting circuit and the radio apparatus to vary the radiation pattern of the antenna system into a periodic sequence of individually distinct radiation patterns.

Periodic electronic switching in the antenna system, causing transitions between different radiating states, is accomplished by using gradual transitions instead of abrupt transitions. The gradual switching transition reduces the magnitude of undesired frequencies created by the periodic switching of a transmitter antenna system.

DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 is a diagram of a vehicle location system employing an antenna system according to the invention;

FIG. 2 is a block diagram of one embodiment of the antenna system according to the invention;

FIG. 3 is a perspective view of the radiating elements of a preferred embodiment of the antenna system according to the invention mounted on the roof of a vehicle;

FIG. 4 is a more detailed circuit diagram of the phase shifter of FIG. 2;

FIG. 5 is a circuit diagram of an antenna switch usable in the switching circuit of FIG. 2;

FIG. 6 shows several representative radiation patterns obtainable by the system according to the invention utilizing the radiating element layout shown in FIG. 3;

FIG. 7 is a schematic and block diagram of an embodiment of the diode driver shown in FIG. 4;

FIG. 8 is a graph illustrating the waveforms at various points in FIG. 7; and

FIG. 9 is a frequency spectrum plot showing the frequencies created in the system shown in FIG. 2 when different transition rates for the antenna pattern switching are used.

DETAILED DESCRIPTION

Referring to FIG. 1, in a phase ranging or triangulation type vehicle location system, a vehicle 10 transmits signals to a plurality of receiving stations represented by towers 12, 14 and 16. In a representative system, the phases of the signals received by the receiving stations in towers 12, 14 and 16 are compared, and the location of the vehicle 10 is calculated. In practical systems, however, objects capable of reflecting radio signals, such as, for example, building 18, cause reflected signals to be received by the towers 12, 14 and 16. The reflected signals have a different phase delay than the direct signals, and therefore can cause an erroneous calculation of the position of the vehicle 10.

It has been found experimentally that the error in the calculated position of the vehicle resulting from the multiple reflected signals can be minimized by changing the pattern of the transmitting antenna of the vehicle 10 while the vehicle is transmitting. The circuit shown in block diagram form in FIG. 2 provides a system for changing the pattern of the antenna to provide a more accurate calculation of the position of the vehicle 10. Although the antenna system according to the invention is particularly adaptable to vehicle location

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systems, it should be noted that the system according to the invention may be used for other applications, and still fall within the scope of the invention. In the embodiment shown in FIG. 2, the output of a transmitter 20 is connected to a common terminal of a power splitting circuit 22. The power splitting circuit 22 has a pair of output or splitting terminals, one of which is connected to a switching circuit 24, and the other of which is connected to a phase shifting circuit, in this embodiment, a phase shifter 26. The phase shifter 26 is connected to the switching circuit 24 and to a control circuit 28, the latter also being connected to the switching circuit 24. A plurality of radiating elements 30, 32 and 34 are connected to the switching circuit 24.

In operation, the transmitter 20 provides a signal to the power splitting circuit 22, which in turn applies a portion of the power to the switching circuit 24 and another portion to the phase shifter 26. The power splitting circuit may be of conventional design, and in a preferred embodiment may be a 3db or Wilkinson coupler, well known in the art, which provides one-half of the power applied to its common terminal to each of its output terminals. However, any splitting circuit may be used, and the power applied to the switching circuit 24 need not be equal to the power applied to phase shifter 26, but the power may be divided in any ratio to provide various antenna patterns. The power applied to the switching circuit 24 from the power splitting circuit 22 is, in this embodiment, applied to one of the radiating elements 30 and 32, while the power applied to the switching circuit 24 by the phase shifter 26 is applied to another one of the radiating elements. The control circuit 28 provides signals to the phase shifter 26 to periodically change the phase shift thereof, control signals are also provided to the switching circuit 24 to cause the circuit 24 to alternately connect one of the radiating elements 30 and 32 to the power splitting circuit and another one of the radiating elements to the phase shifter 26 to change the radiation pattern of the antenna system. It should further be noted that although the antenna system according to the invention has been illustrated for use with the transmitter 20, because antenna systems display reciprocity, the system according to the invention may also be used for other purposes with a receiver or other radio apparatus. In addition, either the power splitting circuit 22 or the phase shifter 26 may be alternately connected to any one of the radiating elements 30, 32 and 34 to provide additional antenna patterns.

Referring to FIG. 3, there is shown a preferred structure of the radiating elements 30, 32 and 34. In the embodiment of FIG. 3, each of the three radiating elements is a quarter wavelength whip antenna, similar to standard quarter wave whip antennas used in conjunction with mobile communications equipment. The three quarter wave antennas 30, 32 and 34 are arranged in an equilateral triangle and spaced one-half wavelength apart on a ground plane 36, such as the roof of a vehicle. When two thusly spaced antennas are simultaneously energized, one with a signal from the power splitting circuit 22 and the other with a phase shifted signal from the phase shifter 26, a wide variety of patterns can be obtained by changing the phase shift provided by the phase shifter 26 and the particular antennas energized. Other patterns may be obtained by utilizing other antenna spacing and geometry. A more detailed discussion of the obtainable antenna patterns is included in a subsequent portion of the specification.

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The phase shifter 26 of FIG. 2 can be readily synthesized using the circuitry shown in FIG. 4. Referring to FIG. 4, a quadrature coupler 36 has an input port A connected to the power splitting circuit 22 and an isolated port B connected to the switching circuit 24. A pair of output ports C and D of the quadrature coupler 36 are connected to a pair of $3/8$ wavelength transmission lines 38 and 40, respectively. Three diodes 41-43 have cathodes connected to the transmission line 38 at points spaced apart from each other by $1/8$ wavelength. Similarly, the cathodes of the diodes 44-46 are connected to the transmission line 40 at points spaced $1/8$ wavelength apart. The anodes of the diodes 41-46 are connected to a ground or common terminal through capacitors 51-56, respectively, which resonate out the lead inductance of the diodes 41-46. The anodes of the diodes 41 and 44 are connected to an output point X and X' of a diode driver 58, which comprises part of the control circuit 28 of FIG. 2, through isolating chokes 61 and 63, respectively. Similarly, the anodes of the diodes 42 and 45 are connected to an output point Y and Y' through chokes 65 and 67 respectively, and the anodes of the diodes 43 and 46 are connected to an output point Z and Z' of the diode driver 58 through chokes 69 and 71 respectively. Although a specific number of diodes and specific line lengths have been recited, any combination may be used depending on the desired phase shift.

A quadrature hybrid coupler, such as the quadrature coupler 36 is a device having properties such that when the input port A and the output ports C and D are matched or operated into a load having an impedance equal to the impedance of the quadrature coupler, then any power applied to the input port A is equally distributed between the output ports C and D, and no power is applied to the isolated port B. However, if either of the output ports C or D is mismatched, then power is applied to the isolated port B. The magnitude and phase of the voltage applied to the isolated port B is dependent upon the degree of mismatch at the output ports C and D. As a result, the phase shift provided by the quadrature coupler 36 between the ports A and B can be varied by adjusting the impedance of the load connected to the output ports C and D.

In the embodiment shown in FIG. 4, the variable impedance loads connected to the output ports C and D are provided by the $3/8$ wavelength transmission lines 38 and 40, respectively. The characteristic impedance of each of the lines 38 and 40 is equal to the impedance of the respective ports C and D, and the remote end of each of the transmission lines is short circuited or grounded. Hence, when none of the diodes 41-46 are rendered conductive, the load on each of the output ports C and D is a $3/8$ wavelength shorted transmission line stub. The $3/8$ wavelength shorted stubs result in a phase shift of 270° between the ports A and B. When the diodes 43 and 46 are rendered conductive by the diode driver 58, the transmission line 38 is shorted to ground through the diode 43 and capacitor 53, and the transmission line 40 is shorted to ground through the diode 46 and capacitor 56. As a result, each transmission line is shortened by $1/8$ wavelength or 45 electrical degrees. This results in a 90° reduction in phase shift between the ports A and B, thereby reducing the phase shift between the ports A and B to 180° . Similarly, rendering the diodes 42 and 45 conductive shortens the length of each of the transmission lines to $1/8$ wavelength and reduces the phase shift between ports A and

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B to 90°. Rendering the diodes 41 and 44 conductive places a substantial short circuit at the output ports C and D and reduces the phase shift between the ports A and B to 0°.

Referring to FIG. 5, there is shown a radio frequency single pole, double throw switch suitable for use as the switch 24a of the switching circuit 24. A pair of quarter wavelength transmission lines 60 and 62 connect the power splitter 22 to the antennas 30 and 32, respectively. A diode 64 connects the antenna end of the transmission line 60 to ground through a capacitor 66 which is used to resonate out the lead inductance of the diode 64. Similarly, the antenna end of the transmission line 62 is connected to ground through the series combination of the diode 68 and capacitor 70. Control switching voltages are applied to the diodes 64 and 68 through a pair of RF chokes 72 and 74, respectively. An RF choke 75 is connected between a junction 76 of the transmission lines 60 and 62 and ground to complete the control voltage paths. A diode driver 77 is connected to terminals 78 and 79 which supply diode control voltages through chokes 72 and 74 respectively. Diode driver 77 is part of the control circuit 28 shown in FIG. 2.

In operation, power is applied to the switching circuit at point 76. When it is desired to apply the power to the antenna 32, a positive voltage is applied to the control terminal 78 to forward bias the diode 64 to provide a short circuit termination for the transmission line 60 through the diode 64 and capacitor 66. The short circuit is transformed by the quarter wave transmission line 60 to an open circuit at the junction of the two transmission lines. Hence, any signal applied to the input point 76 will not be affected by the quarter wave transmission line 60, and will be transferred through the transmission line 62 to the antenna 32. Conversely, when the antenna 30 is to be energized, the diode 68 is forward biased to short circuit the transmission line 62. The control signals applied to the points 78 and 79 of diode driver 77 are obtained from the control circuit 28 of FIG. 2, which may be any well known digital logic circuit adapted to switch the diodes in the derived sequence to provide any desired sequence of radiating patterns. A switch similar to that shown in FIG. 5 is used to connect the antenna elements 32 and 34 to the phase shifter 26 and provide the function of the switch 24b of FIG. 2. The switching diodes used in the circuits of FIGS. 4 and 5 may be any diodes compatible with the amplitude and frequency of the signals employed, however, in a preferred embodiment, switching diodes of the PIN type are used. Also, in a preferred embodiment the control signals used to bias the switching diodes shown in FIGS. 4 and 5 have a non-abrupt, gradual waveshape, as will later be explained in detail.

FIG. 6 shows the antenna radiation patterns obtained by applying various phase signals to two of the antennas. The figure shows a top view of two of the antennas, such as, for example, antennas 30 and 32. The antennas are represented as crosses in FIG. 6. Curve a of FIG. 6 shows the pattern obtained when the two antennas are fed with in-phase signals. When the antennas are fed with signals that are 180° out of phase, the pattern is rotated by 90° as shown in curve b. Curve c shows the cardioid pattern obtained when the signals applied to the antennas are 90° out of phase, while curve d shows a similar pattern rotated by 180° resulting from a 270° phase shift between signals. The four patterns shown have been obtained by energizing two of the three an-

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tennas. When three equilaterally spaced antennas as shown in FIG. 4 are employed, and when two of the three antennas are simultaneously energized, each pair of antennas can generate each of the patterns shown in FIG. 6. Hence, twelve different patterns can be generated, four being provided by antennas 30, 32, four by antennas 32, 34 rotated 120° from the patterns provided by antennas 30, 32 and four by the antennas 30, 34 rotated 240° from the original patterns. Three omnidirectional patterns may be provided by energizing each of the three antennas 30, 32 and 34 individually to provide a total of fifteen different patterns, however, more complex switching would be required. More patterns may be provided by using an additional number of antennas, however, it has been found that three antennas provide a good compromise between simplicity and antenna pattern variety. Furthermore, other patterns can be achieved by using phase shift in other than 90° increments.

Waveshaping circuitry such as a low pass filter or a capacitor is provided in the diode drivers to prevent abrupt switching of the diodes, to provide a gradual change in antenna pattern, and to reduce the interference commonly known as "splatter" resulting from rapid switching between individually distinct radiation patterns as will now be explained in detail.

FIG. 7 shows a preferred embodiment of the diode driver 58 shown in FIG. 4. A clock 80 is connected to an input terminal 81 of a squarewave generator 82 (shown dotted) consisting of a bistable flip-flop 83 having a terminal T connected to terminal 81 through a resistor 84 and to ground through a resistor 85, and a terminal Q connected to squarewave output terminal 86.

An NPN transistor 87 has its base connected to terminal 86 through a resistor 88, its emitter directly connected to ground, and its collector connected to a DC power input terminal 90 through a resistor 91 and to a terminal 92 through a resistor 93. Terminal 92 is connected to ground through an integrating capacitor 94. Components 87, 88, 91, 93, and 94 comprise an integrator 95 (shown dotted) having terminal 86 as an input terminal and terminal 92 as an output terminal.

An NPN transistor 96 has: its base connected to the terminal 92 through a coupling capacitor 97, to terminal 90 through a resistor 98, and to ground through a resistor 99; its emitter connected to ground through a resistor 100; and its collector connected to terminal 90 through a resistor 101. An NPN transistor 102 has: its base connected to the collector of transistor 96 through a coupling capacitor 103, connected to ground through a resistor 104, and connected to terminal 90 through a resistor 105; its emitter connected to ground through a resistor 106; and its collector connected to terminal 90 through a resistor 107 in parallel with a capacitor 108. An NPN transistor 109 and an NPN transistor 110 are connected in a Darlington configuration with the common collector terminal connected to terminal 90, the input base terminal of transistor 109 connected to the collector of transistor 102, and the output emitter terminal of transistor 110 connected to an output terminal 111. Components 96 through 110 comprise a multi-stage amplifier 112 (shown dotted) having an input terminal 92 and an output terminal 111.

A logic selector matrix 113 is directly connected to terminals 111 and 81 and is connected to an output terminal 114, 115, 116, 117, 118, and 119 through a resistor 120, 121, 122, 123, 124, and 125 respectively. A load 126 (shown dotted) is shown connected to termi-

nal 119 and consists of a diode 127 having its anode connected to terminal 119 and its cathode connected to ground. The timing signals received by logic matrix 113 from terminal 81 are used to develop internal control signals which select which of terminals 114, 115, 116, 117, 118 or 119 will receive the output signal present at terminal 111. The internal construction of logic matrix 113 therefore consists of standard digital logic circuits such as counters and shift registers and matrix 113 merely sequentially excites in a predetermined manner the logic matrix output terminals with the output signal present at terminal 111. Load 126 represents a typical output load of diode driver 58 such as diode 43 shown in FIG. 4. Terminals 114, 115, 116, 117, 118, and 119 correspond to terminals X, X', Y, Y', Z and Z' in FIG. 4, respectively. In any one state, the logic selector output terminals are actually excited in pairs.

The clock 80 produces periodic timing pulses which are shown in FIG. 8a. These pulses are used by logic selector 113 to generate the predetermined selection of which output terminals (114, 115, 116, 117, 118, or 119) will be excited by the voltage waveform present at terminal 111, and also how long the output terminal will remain excited by the signal present at terminal 111. The clock pulses are also coupled into squarewave generator 82 which generates a corresponding squarewave having twice the time period of the input clock pulses, as shown in FIG. 8b. Resistors 84 and 85 form a resistor divider to reduce the magnitude of the input clock pulses and flip-flop 83 is a standard bistable flip-flop which is triggered into alternating logic states whenever an input pulse is received. Thus the output of the squarewave generator present at terminal 86 is the waveform shown in FIG. 8b.

Integrator 95 receives the squarewave signals from generator 82 and integrates them to produce a ramp function signal having the same period as the incoming squarewave. Transistor 87 is used to present a high input impedance to flip-flop 83 and is also used for gain purposes. The integration is preformed by resistor 93 and integrating capacitor 94. The output of integrator 94 present at terminal 92 is shown in FIG. 8c.

Amplifier 112 consists of two cascade connected transistor amplifiers which shape and amplify the ramp signal present at terminal 92 and thus vary the rate of rise of the signal and insure that a signal, sufficient to forward bias a PIN diode to a desired current level, is present at terminal 111. Transistor 102 is biased such that during a portion of the ramp signal the transistor is cut off. Thus the waveform at the collector of transistor 102 is generally triangular shaped with a truncated upper section. A truncated waveform is not required and a non-truncated waveform is usable and can be obtained by changing the bias or gain of the stage containing transistor 102. Capacitor 108 has a small value and is used to prevent spurious oscillations of transistor 109 which commonly occur in common collector stages. The waveform present at terminal 111, shown in FIG. 8d, is the same as the waveform present at the collector of transistor 102 but shifted downward in voltage by the forward biased base-emitter voltage drops of transistors 109 and 110. The Darlington connection of transistors 109 and 110 is used to minimize loading on the preceding amplifying stages and to produce an amplifier 112 that has a very low output impedance.

When logic selector matrix 113 receives an appropriate control signal, terminal 111 will be directly con-

nected to terminal 119 through resistor 125 and load 126 will be energized. A waveform of the typical current through diode 127 is shown in FIG. 8e and has a generally truncated on cycle, similar to waveform 8d, followed by an off cycle. The voltage waveform that appears across diode 121, shown in FIG. 8f, resembles a severely truncated triangular waveform which has the same initial rate of rise as waveform 8e, but is now truncated at a maximum DC level corresponding to the forward biased diode drop of diode 127. Resistors 120-125 are used for current limiting so that the current through PIN diodes 41-46 will not exceed maximum diode voltages when they are excited. The cycle period of the excitation for load 126 is the same as the cycle period of waveform 8e.

Diode driver 77 in FIG. 5 has circuitry similar to diode driver 58 and preferably only one clock 80, one integrator 95, one amplifier 112, and one large logic selector matrix (which includes matrix 113) will be present in control circuit 28 which includes drivers 58 and 77.

The results of using different excitation functions for PIN switching diodes, which are used to periodically alter the radiation pattern generated by the system shown in FIG. 2, are shown in FIG. 9. If a squarewave voltage waveform, having abrupt step function transitions and having the same period as the waveform shown in FIG. 8e, is used to periodically excite transmitter switching diodes, the resultant frequency spectrum will be as shown in FIG. 9a. The carrier frequency component f_c will have a magnitude of $A/2$ and an infinite number of undesired additional frequency components (collectively called splatter) exist having frequencies equal to the carrier frequency plus and minus the odd harmonics of the switching period frequency f_1 (which is the period of the excitation waveform.) The magnitude of each of the additional frequency components can be calculated by standard Fourier series analysis and will decrease as the odd harmonic number increases. At an upper adjacent channel, extending from f_3 to f_4 and having a center frequency f_2 , the undesired frequency components generated by the periodic switching of the carrier frequency f_c will be picked up by receivers operating in the f_2 frequency band.

In two-way communication systems, the FCC requires a minimum adjacent channel interference and therefore large magnitude undesired frequencies present at the adjacent channel frequency f_2 may violate the FCC regulations. One way of reducing the amplitude of undesired frequency components received in the f_2 frequency channel would be to decrease the frequency (f_1) of the antenna switching so that higher numbered harmonics would be received in the f_2 channel. However, in many systems this is not desirable, such as in a vehicle location system where rapid updating of the vehicle position is desired.

In order to maintain the same period of transmitter switching and still reduce the amplitude of extraneous signals received in the f_2 band, a gradual switching transition is used. FIG. 9b shows the corresponding frequency spectrum when the carrier frequency f_c is switched with a gradual transition, into various transmission states. The resulting frequency spectrum has the same frequency components, but the amplitudes of the frequency components are significantly reduced because of the gradual transition between various transmitting states.

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Thus FIG. 9a represents the frequency spectrum present when an abrupt rapid rise time waveform, such as a square-wave, is used to switch the PIN diodes in the circuit shown in FIGS. 4 and 5. FIG. 9b shows the resultant frequency spectrum when gradual transitions are implemented in switching circuit 24 and phase shifter 26 in FIG. 2.

In a specific case a transmitter carrier frequency (f_c) in the 450 to 470 Mhz range was switched at a period rate of 200 Hz (f_1) and the response near the center frequency (f_2) of an adjacent channel, 25KHz away, was measured. When a truncated triangular ramp function signal (similar to waveform 8e) having a gradual rate of rise of about 5 volts/millisecond was used to bias switching PIN diodes, the amplitudes of frequency translated switching harmonics received in the adjacent channel were about 60db below the carrier frequency amplitude. When a squarewave signal similar to waveform 8e and having the same period but with an abrupt or step transition (having a rate of rise of 500 volts/millisecond or larger) was used to excite the same switching diodes, the received harmonic amplitudes were only 40db down from the carrier frequency. Using a non-truncated triangular excitation waveform having a slower rate of rise, the harmonic amplitudes in the adjacent channel were greater than 70db below the carrier amplitude. Thus by reducing the rate of rise of the PIN diode biasing waveform, a gradual transition of the PIN diode was implemented which resulted in a reduction in the amplitude of undesired frequencies created by periodic switching. The minimum rate of rise usable is determined by the RF power dissipation considerations in the PIN diode, the switching frequency, and the amount of time a diode is to be maintained in an on condition for each switching cycle.

Mechanical relays and abrupt on-off devices cannot create a gradual transition in an antenna pattern or in any radio transmitter switching network. Thus a device which exhibits a continuous gradual impedance change between an off and an on state must be used to create a gradual transition. This device must be excited by a waveform which, in a gradual and progressive manner, moves the device from an off to an on state and vice versa. PIN diodes possess a non-abrupt, gradual continuous impedance between an off and an on state, and the circuitry shown in FIG. 7 comprises a driver apparatus to operate PIN diodes in gradual transition modes, the transitions being sufficiently gradual such that the amplitudes of undesired frequencies created by periodic switching are substantially less (smaller) than the amplitudes of undesired frequencies created by using abrupt transitions to implement periodic switching.

While I have shown and described a specific embodiment of this invention, further modifications and improvements will occur to those skilled in the art. All such modifications which retain the basic underlying principles disclosed and claimed herein are within the scope of this invention.

I claim:

1. An antenna system used with a radio transmitter for creating a periodic sequence of individually distinct radiation patterns including in combination:

- a power splitting circuit having a common terminal for connection to said radio transmitter apparatus and first and second splitting terminals;
- a switching circuit having first and second signal terminals, a control terminal, and a plurality of an-

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tenna terminals, said switching circuit being responsive to signals applied to said control terminal for selectively connecting, in a predetermined manner with a gradual transition, one of said antenna terminals to said first signal terminal and another of said antenna terminals to said second signal terminal, said first signal terminal being coupled to said first splitting terminal;

a variable phase shifting circuit having first and second terminals and a control terminal, said phase shifting circuit having a predetermined phase shift between said first and second terminals and being responsive to signals applied to said control terminal for periodically changing, in a predetermined manner with a gradual transition, said phase shift between said first and second terminals, said first terminal being coupled to said second splitting terminal and said second terminal being coupled to said second signal terminal;

a plurality of radiating elements, each being connected to one of said antenna terminals of said switching circuit; and

a control circuit developing control signals for creating a periodic sequence of radiation patterns and being connected to said control terminal of said switching circuit and said control terminal of said variable phase shifting circuit, said switching circuit being responsive to said control signals for selectively connecting, in a predetermined manner with a gradual transition, one of said radiating elements to said power splitting circuit and another of said radiating elements to said phase shifting circuit,

said gradual transitions of said switching circuit and said variable phase shifting circuit resulting in small amplitudes for the undesired frequencies created by the periodic changes of said switching circuit and said phase shifting circuit.

2. An antenna system as recited in claim 1 wherein; said switching circuit includes PIN diodes for selectively connecting said radiating elements to said power splitting circuit and said phase shifting circuit, and said variable phase shifting circuit includes PIN diodes for changing said phase shift.

3. The antenna system as recited in claim 2 which includes; diode driver means coupled to said PIN diodes for producing a waveform, having gradual changes in amplitude, for biasing said PIN diodes.

4. The antenna system as recited in claim 3 wherein; said driver means includes square wave generating apparatus and an integrating apparatus coupled to said square wave generating apparatus for developing said waveform having gradual changes in amplitude.

5. An antenna system for use with radio apparatus including in combination:

a power splitting circuit having a common terminal for connection to said radio apparatus and first and second splitting terminals;

a switching circuit having first and second signal terminals and a plurality of antenna terminals, said first signal terminal being coupled to said first splitting terminal;

a variable phase shifting circuit having first and second terminals, and a control terminal, said phase shifting circuit having a predetermined phase shift between said first and second terminals and being responsive to control signals applied to said control terminal for altering said phase shift, said first ter-

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minal being coupled to said second splitting terminal and said second terminal being coupled to said second signal terminal, said phase shifting circuit including a quadrature hybrid having an input port, a pair of output ports and an isolated port, said input port being connected to said power switching circuit, and variable impedance means connected to said output ports;

a plurality of radiating elements, each being connected to one of said antenna terminals of said switching circuit; and

a control circuit connected to said switching circuit, said switching circuit being responsive to said control circuit for selectively connecting said radiating elements to said power splitting circuit and said phase shifting circuit in a predetermined manner, said control circuit being further connected to said control terminal of said phase shifting circuit and providing control signals thereto for altering said phase shift in response to said control signals.

6. An antenna system as recited in claim 5 wherein said variable impedance means includes a pair of transmission lines, each line having an end connected to one of said output ports, and means connected to each of said lines for varying the electrical length thereof.

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7. An antenna system as recited in claim 6 wherein said length varying means includes a plurality of diodes, each diode being connected to a predetermined point of one of said transmission lines and coupled to said control circuit, each diode being responsive to said control circuit for alternately providing substantially an open circuit load and a short circuit load to one of said transmission lines.

8. An antenna system as recited in claim 7 wherein said switching circuit includes a transmission line and a diode connected thereto, said diode being further coupled to said control circuit and receiving control signals therefrom.

9. An antenna system as recited in claim 8 wherein said splitting circuit includes a 3db coupler.

10. An antenna system as recited in claim 5 wherein each of said radiating elements is one quarter wavelength long, and wherein said radiating elements are spaced one-half wavelength apart.

11. An antenna system as recited in claim 10 including three radiating elements spaced to form an equilateral triangle, each radiating element defining an apex of the triangle.

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