July 19, 1966 W. W. MACALPINE 3,262,115

PHASE AND AMPLITUDE CONTROL OF ANTENNA ARRAY

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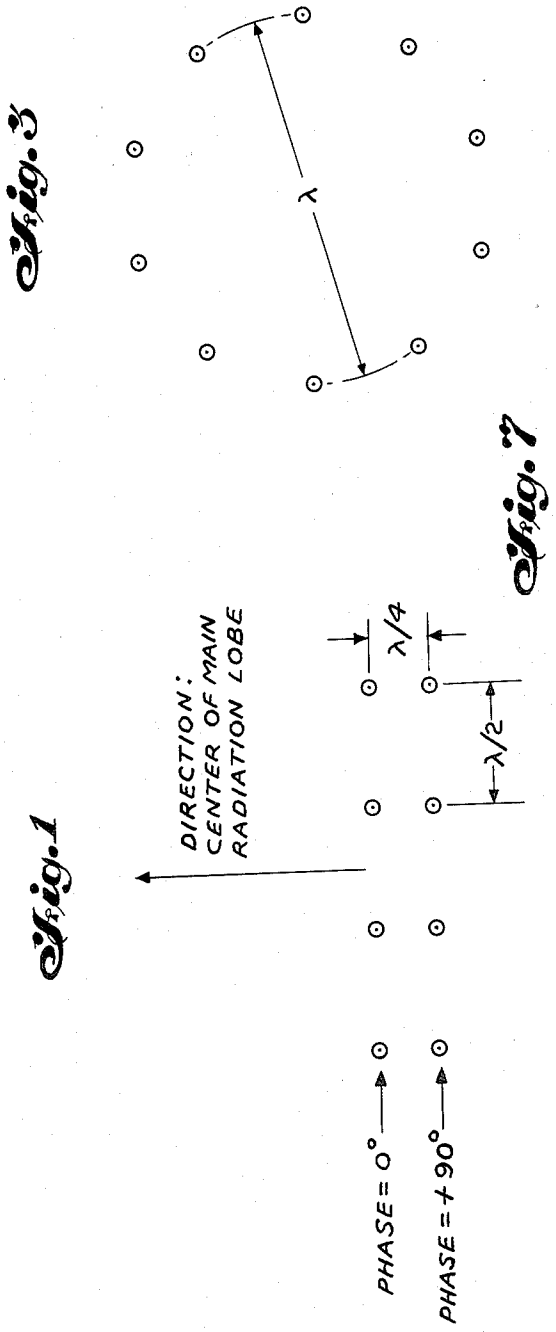


Fig. 1

Fig. 3

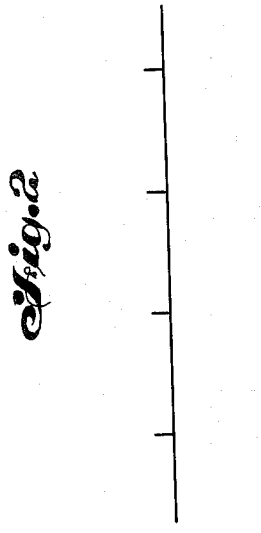


Fig. 7

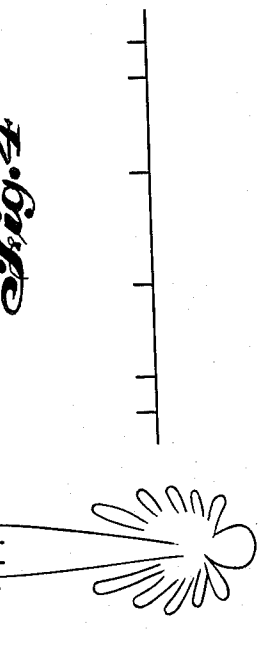


Fig. 4

Fig. 2

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PHASE AND AMPLITUDE CONTROL OF ANTENNA ARRAY

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Fig. 5

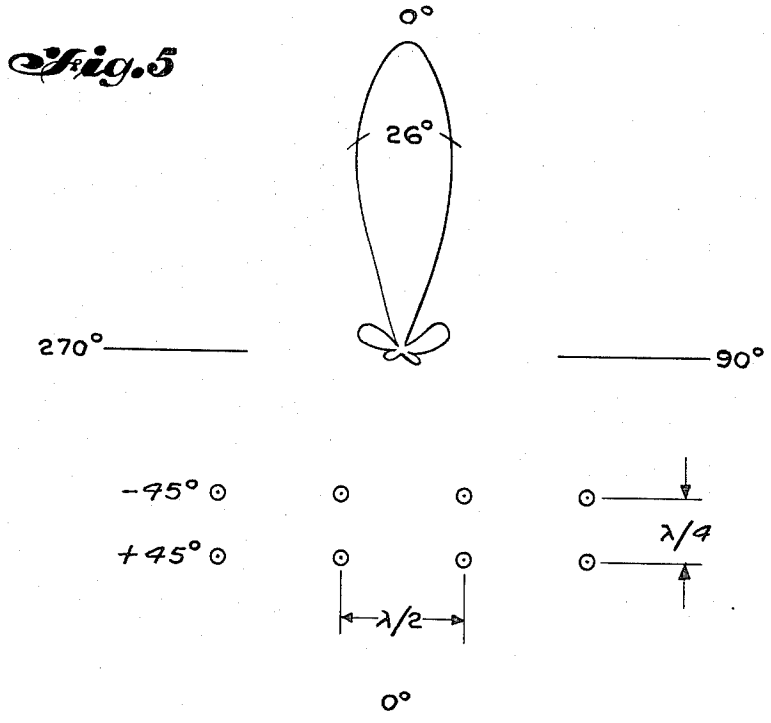
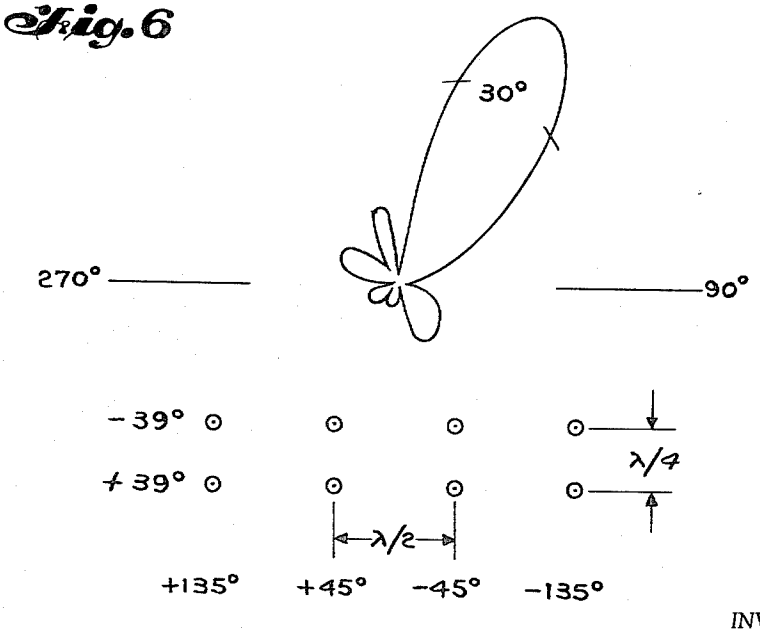


Fig. 6



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PHASE AND AMPLITUDE CONTROL OF ANTENNA ARRAY

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Fig. 8

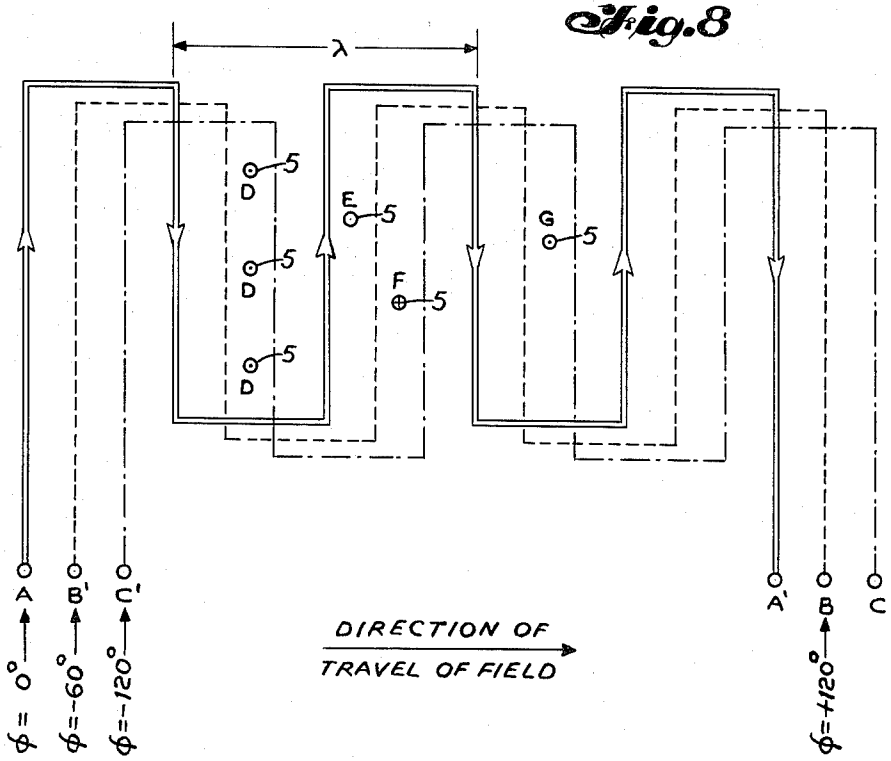
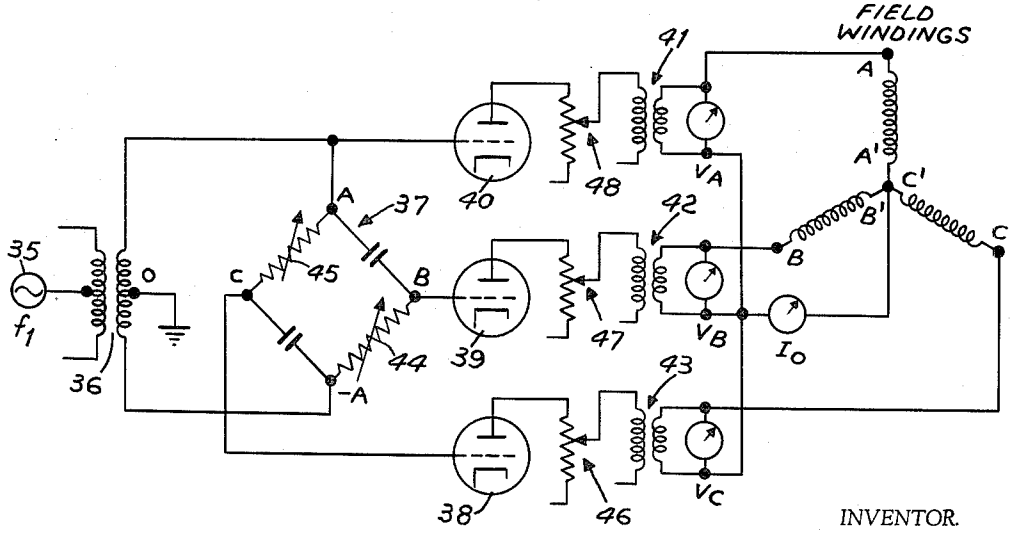


Fig. 9



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PHASE AND AMPLITUDE CONTROL OF ANTENNA ARRAY

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Fig. 10

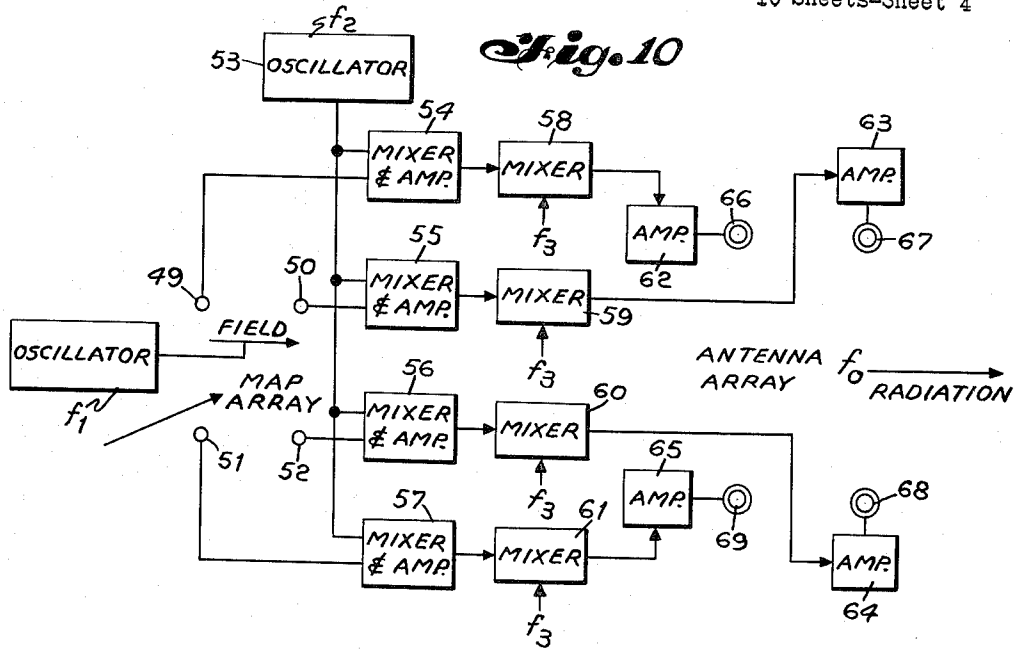
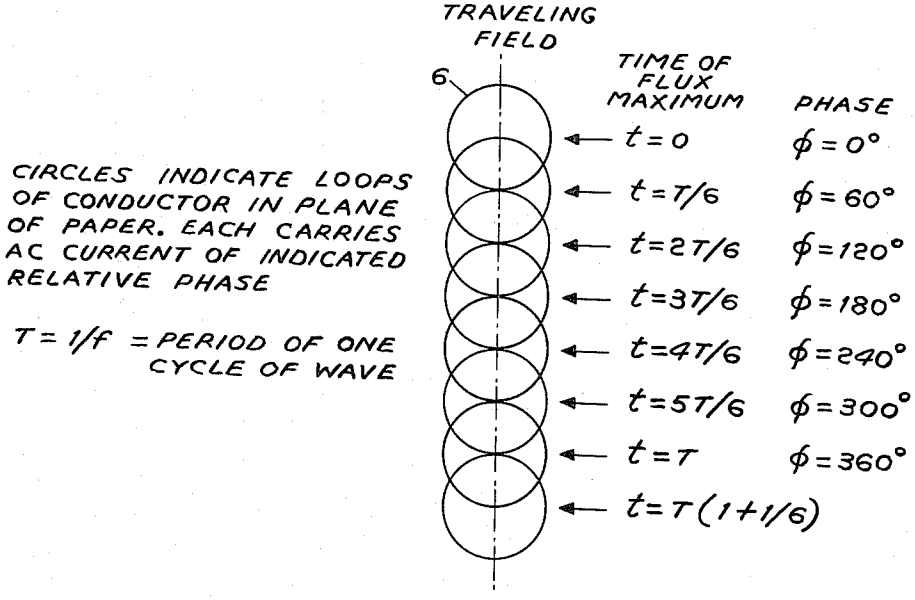


Fig. 11



CIRCLES INDICATE LOOPS OF CONDUCTOR IN PLANE OF PAPER. EACH CARRIES AC CURRENT OF INDICATED RELATIVE PHASE

$T = 1/f$ = PERIOD OF ONE CYCLE OF WAVE

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PHASE AND AMPLITUDE CONTROL OF ANTENNA ARRAY

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Fig. 12

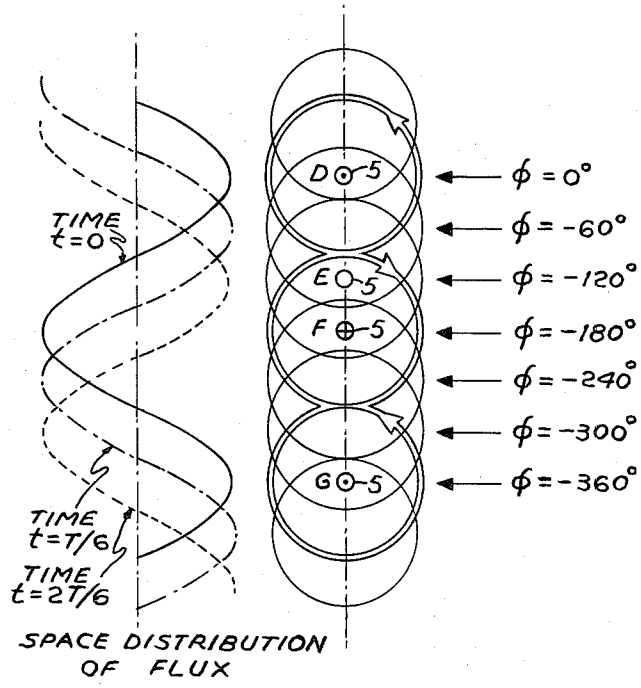
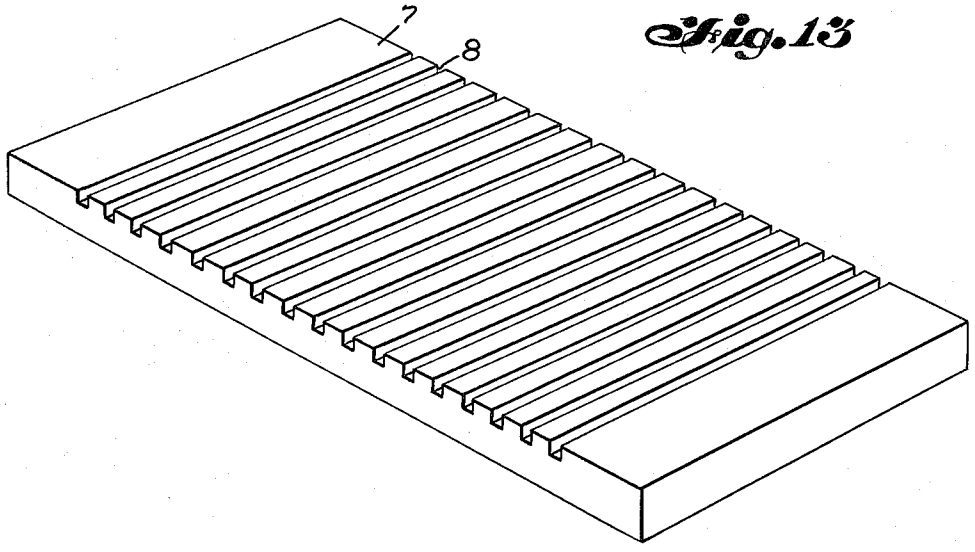


Fig. 13

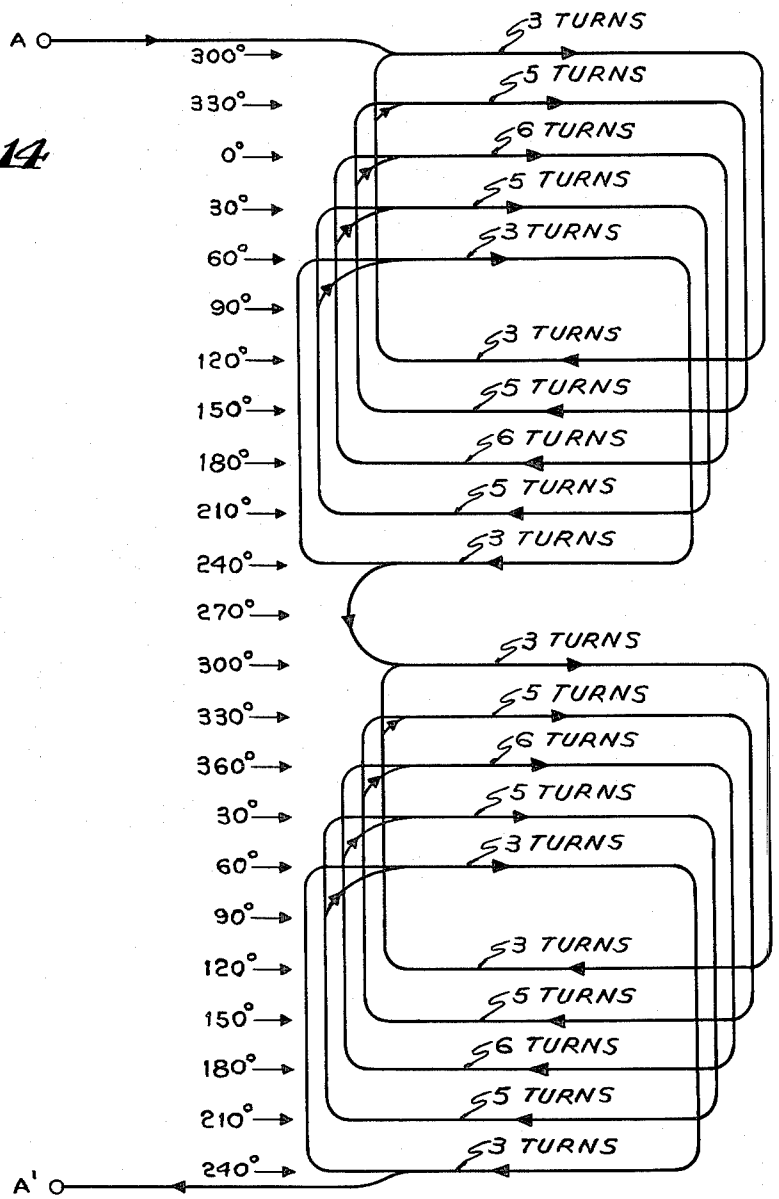


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PHASE AND AMPLITUDE CONTROL OF ANTENNA ARRAY

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Fig. 14



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PHASE AND AMPLITUDE CONTROL OF ANTENNA ARRAY

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Fig. 15

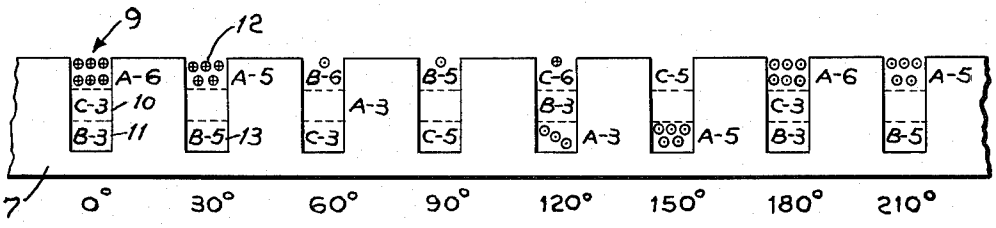


Fig. 16

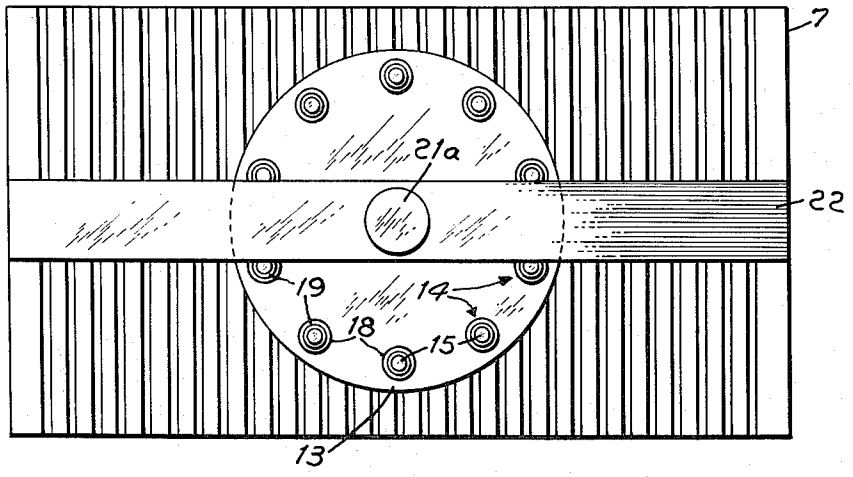
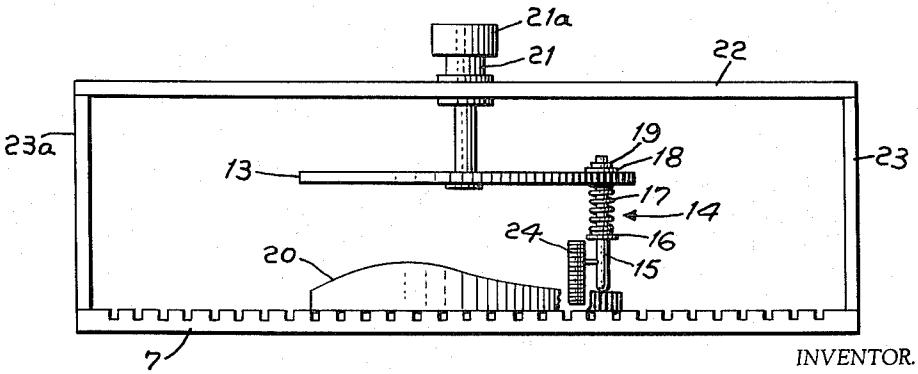


Fig. 17



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PHASE AND AMPLITUDE CONTROL OF ANTENNA ARRAY

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Fig. 18

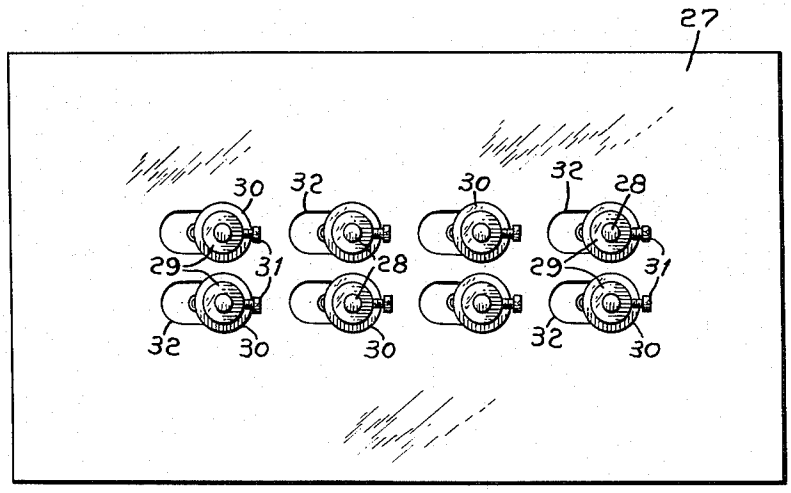
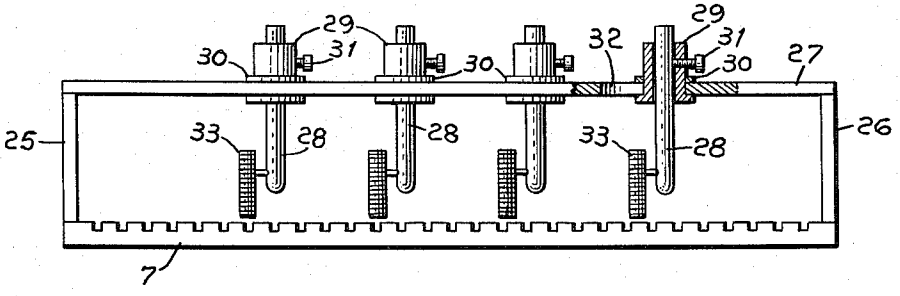


Fig. 19



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PHASE AND AMPLITUDE CONTROL OF ANTENNA ARRAY

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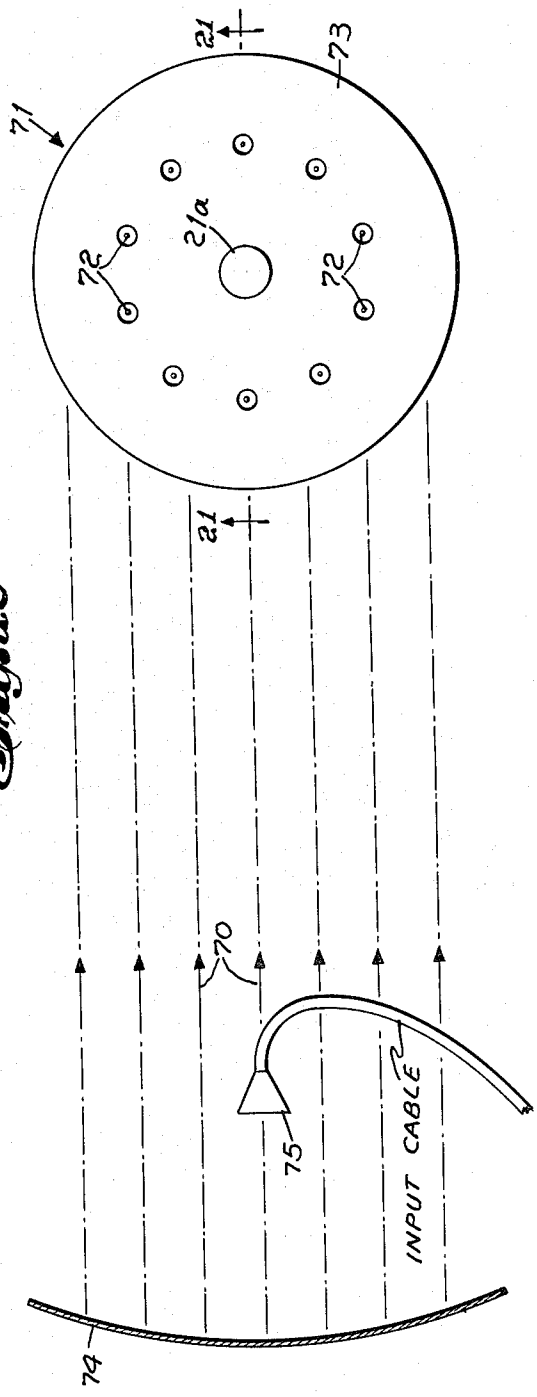


Fig. 20

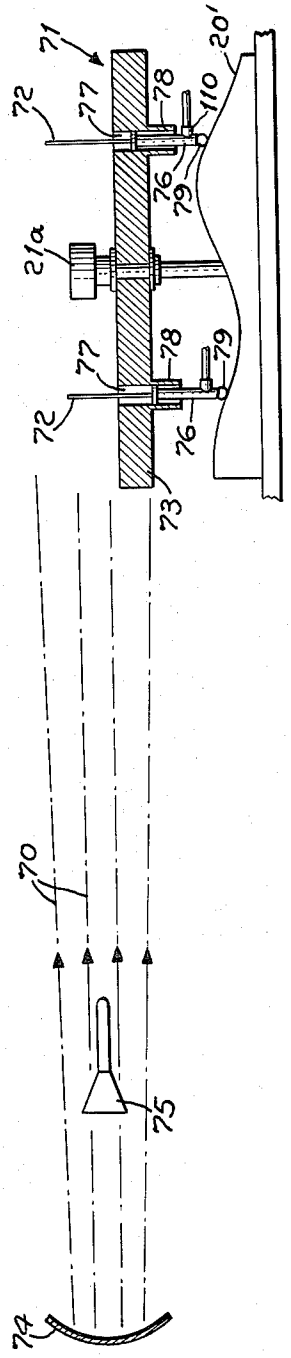


Fig. 21

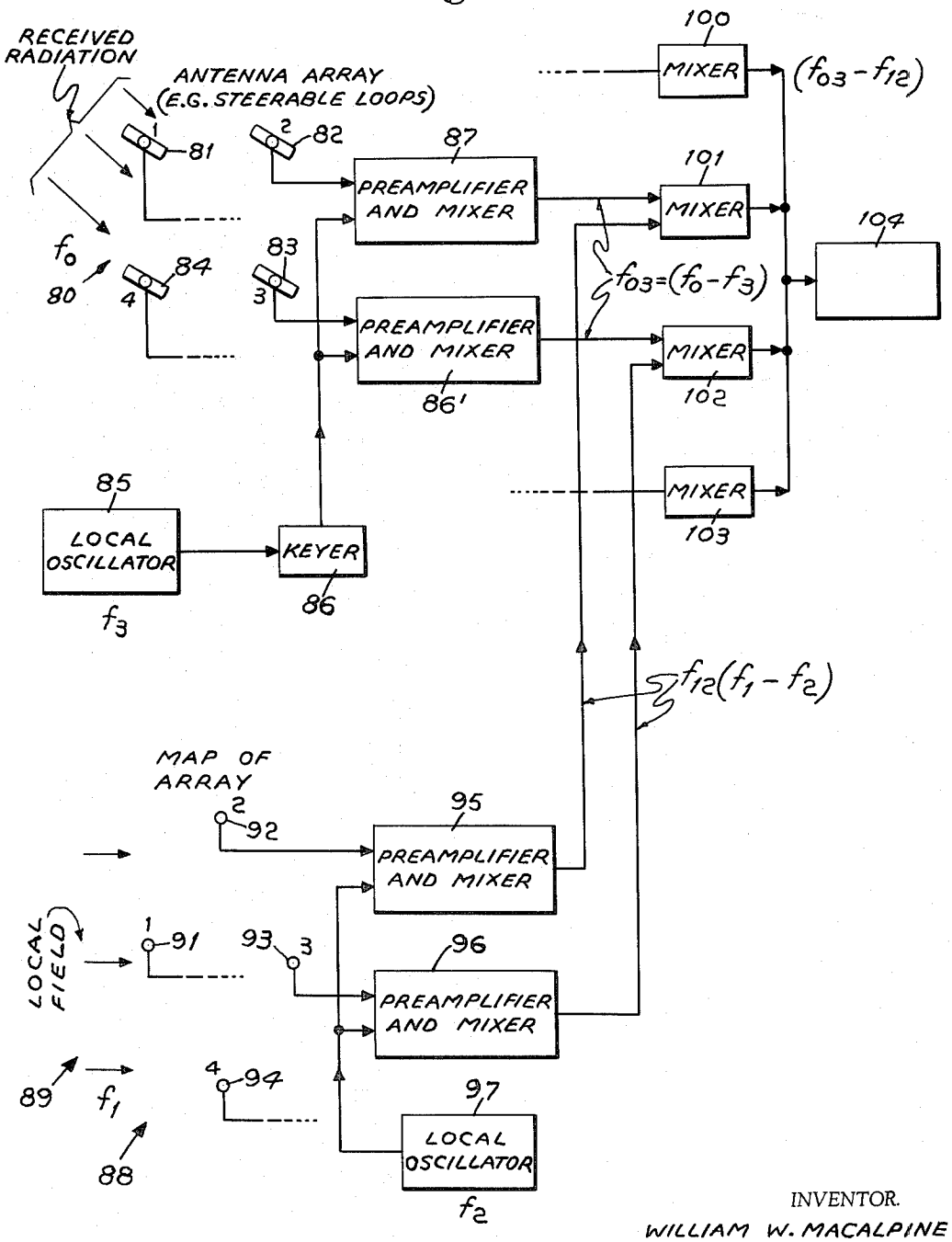
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PHASE AND AMPLITUDE CONTROL OF ANTENNA ARRAY

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Fig. 22



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United States Patent Office 3,262,115 Patented July 19, 1966

3,262,115

PHASE AND AMPLITUDE CONTROL OF ANTENNA ARRAY

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Filed Apr. 15, 1963, Ser. No. 273,109
10 Claims. (Cl. 343—100)

This invention refers to antenna arrays and more particularly to phase and amplitude control of antenna arrays.

By combining appropriate antennas into an array with suitable spacing between the antenna elements and feeding power to them simultaneously, it is possible to make the radiated field from the individual elements add in the favored direction thus increasing the field strength in that direction as compared to that produced by one antenna element alone. In other directions fields will more or less oppose each other, giving a reduction of field strength. Thus a power gain in the desired direction is secured at the expense of a power reduction in other directions. Besides the spacing between the elements, the amplitude and the instantaneous direction or the phase of current flow in the individual elements determines the directivity and power gain. The prior art has many means of feeding phase and amplitude different currents to the elements of the antenna array. It is desirable to have a system for driving the elements of an antenna array in the proper phase and amplitude which is both simple, economical and easy to control.

It is an object of this invention to provide a phase and amplitude control system for an antenna array which is simple, economical and easy to operate.

It is a further object of this invention to provide the phase and amplitude control system for an antenna array which simulates the antenna array in miniature.

A feature of this invention is a control system for an antenna array comprising a replica of the antenna array, a source of energy, means coupling the replica array to the source of energy and means responsive to the output of the replica array to control the transmission and reception of signals by said antenna array.

Another feature of this invention is a control system for an antenna array comprising a replica of the antenna array, a source of energy, means coupling the replica array to the source of energy and means responsive to the output of the replica array to control the phase and amplitude excitation of the antenna array.

Another feature of this invention is that a traveling electromagnetic field is established on a plane surface and a map of the antenna array is produced on that surface which consists of coils representing the position of the elements of the antenna array.

Still another feature of this invention is that in another embodiment a very low frequency beam is formed to illuminate the map of the antenna array and thus provide the phase and amplitude control for the antenna array.

Another feature of this invention is that the replica array may be rotated to provide a controlled change in the direction of the transmitted or received beam.

The above-mentioned and other features and objects of this invention will become more apparent by reference to the following description taken in conjunction with the accompanying drawings, in which:

FIGURE 1 is a plan view of a linear antenna array;

FIGURE 2 is a side elevation view of the linear array of FIGURE 1;

FIGURE 3 is a plan view of a circular antenna array;

FIGURE 4 is a side elevation view of the circular array;

FIGURE 5 is the radiation pattern for the linear array;

FIGURE 6 is the radiation pattern of the linear array steered 30 degrees;

FIGURE 7 is the radiation pattern of the circular array;

FIGURE 8 is a map of the circular array with the traveling-field winding;

FIGURE 9 is a circuit for the excitation of the traveling-field winding;

FIGURE 10 is a block diagram of the excitation of the VLF antenna array;

FIGURES 11 and 12 illustrate the phase relationship existing on the map array;

FIGURE 13 is an isometric view of a field plate for the traveling electromagnetic field arrangement;

FIGURE 14 is a diagram of the distributed winding of one phase in the field plate;

FIGURE 15 is a side elevation diagrammatic view of the three-phase winding distribution in the field plate;

FIGURES 16 and 17 are respectively plan and elevation views of one embodiment of the map of this invention;

FIGURES 18 and 19 are respectively plan and elevation views of another embodiment of the map;

FIGURES 20 and 21 are plan and elevation views respectively of still another embodiment of this invention; and

FIGURE 22 is a block diagram of a receiving system utilizing the invention.

This invention provides a means of driving the individual element of an antenna array in the proper phase and amplitude. In this system, it is easy to steer the beam direction, with the phase and amplitude excitation of the arrayed elements following their correct relationships automatically. The controlling device can be located in a building at a convenient place; it may be at the center of the array.

Two types of antenna arrays can be used to attain the desired directional pattern. If the direction of the radiation maximum is to be fixed or steerable within plus or minus 30 degrees of a given azimuth, then a rectangular array of four or eight antennas can be used as shown in FIGURES 1 and 2. On the other hand, if the beam is to be steerable over 360 degrees, a circular array, such as shown in FIGURES 3 and 4, is preferred. FIGURES 1 and 2 show the rectangular array with eight elements. Four antenna units represented by the circles are located at half wavelength spacings on a line broadside to the direction of the main radiation lobe. A quarter wavelength behind them are erected four similar antenna units. The front line units are driven in phase with each other, as are the rear line units but the phase of the rear line leads the phase of the front line by 90 degrees. Radiation to the rear and the side is far below that in the forward direction. The radiation pattern can be steered to any azimuth when a circular array of antenna units is used as shown in FIGURES 3 and 4. If 10 or more antennas, the elements of which are represented by the circles in FIGURES 3 and 4, are used, the pattern changes only slightly as the azimuth is varied. The antenna elements, of course, are spaced equally around the perimeter of the circle. The diameter of the circle is one wavelength, more or less. The antenna element can be any suitable antenna for effectuating the desired radiation. The design of the antenna element itself is not the subject of this invention. The radiator may be a 500 foot vertical tower insulated from the ground and driven at the base through a loading coil or it may be any other suitable design.

With reference to FIGURE 8, there is shown a traveling electromagnetic field established on a plane surface. The three-phase winding is shown in the simplest elementary form of only one winding for each phase. The three-

phase winding is distributed along the surface in a manner analogous to that used to produce the rotating field in the stator of a three-phase motor or alternator. The material of the plate carrying the windings can be a dielectric, either non-magnetic or possibly a ferrite material. The magnetic field flux lines are perpendicular to the plane of the plates and travel from left to right, for example, with a wavelength λ as shown in FIGURE 8. The three-phase windings which are placed in slots on the plane plate as will be described in more detail later on, are analogous to the stator winding of a three-phase motor and produce a traveling sinusoidal field just as the motor stator produces a rotating field. λ is the wavelength of field distribution on the plane plate and is much shorter than the free-space wavelength of the exciting currents. Disposed in the field are plan views of pickup coils. The there coils D are spaced in line along the X axis, coil E is spaced apart from D along the X axis as also are F and G which are also spaced apart from each other in the X axis. Each of the circles **5** indicates a coil with an axis perpendicular to the plane. The disposition of the coils here is not to be compared to the antenna array which will be described later on, but is used for the purpose of illustrating the phase relationship between the induced voltages in the pickup coils D, E, F, and G as are noted on FIGURES 11 and 12. In FIGURE 11, the circles **6** indicate loops of the conductor in the plane of the paper. Each loop carries A.C. current of indicated relative phase at the time shown. The magnetic flux of the field is normal to the plane of the paper. In FIGURE 12, there is shown the relationship of the pickup coils, the axes of which are perpendicular to the plane of the field generating winding and the relative phase of the induced voltages in the different pickup coils D, E, F, and G. All of the pickup coils D have the same relative phase induced in them at any particular time since they are in the same position along the direction of travel of the field. Coils E, F, and G spaced apart from D have induced voltages of different phase relationship as shown in the figure. The induced voltage in pickup coils D (FIGS. 8 and 12) is in time phase 0°. The induced voltage in the E coil will lag that in the D coil by 120 degrees. F coil lags D coil by 180 degrees and G lags D by 360 degrees, that is to say, it is in phase with the voltage in D.

The field plate for carrying the windings and the map of the antenna array is illustrated in FIGURE 13. It consists of a plate **7** of dielectric, non-magnetic or magnetic material, such as ferrite. A plurality of slots **8** are cut in the plate in a direction perpendicular to the long axis of the plate. These slots are used to hold the windings which are fed into the slots and disposed therealong and come out at the end of the slots and then fed back into the appropriate slot. The typical distributed winding of phase A is shown in FIGURE 14. The number of conductors per slot, that is to say, per coil, is approximately proportional to the cosine ϕ. As shown in the figure, phase A is connected into the coil, as an example, at ϕ equals 300° and for ϕ equals 300° and 120° where it makes the complete coil, the number of turns is 3. Then at the end of 3 turns, the winding continues into the slot indicating ϕ equals 330° and is wound to the slot around the outside of the field plate **7** into the slot indicating 150° and then back again until 5 turns have been completed. Then from there the winding continues into the slot where ϕ equals 0° wound therethrough around the outside of the field plate **7** and into the slot where ϕ equals 180°. This is repeated as shown in the illustration for the number of slots indicated there. This is taken as a way of example and is not to be construed as otherwise limiting the invention. Where cosine ϕ equals zero, that is, 90° and 270°, no windings of course are inserted into the slots. The windings for phases B and C are spaced at 120° to phase A; or phase B winding is displaced 60° to the right of phase A and connected in reverse and phase C is displaced 120° to the right of phase A and connected in the same polarity. The length of the conductor in the complete winding, all the coils being in series, for each phase is very short compared to the quarter wavelength in free space at the excitation frequency. With reference to FIGURE 15, there is shown the disposition of the windings of the several phases. Several turns of each phase can be wound in each slot. For each phase the number of conductors in each slot is approximately proportional to the absolute value of cosine ϕ where ϕ is the electrical angle along the field plate. If we look at the side elevation view of field plate **7** in FIGURE 15, the first slot shows 6 windings of phase A indicated by the numeral **9** and $\phi=0$ for phase A, 3 windings of phase C indicated by the numeral **10** and $\phi=240°$ for phase C and 3 windings of phase B indicated by the numeral **11** and $\phi=120°$ for phase B. The second slot where for phase A ϕ equals 30° shows 5 windings **12** of phase A and 5 windings **13** of phase B. There are no windings of phase C for at that point ϕ for phase C is equal to 270°. The distribution of the windings in the other slot follows in the same manner as shown with reference to the winding plan of FIGURE 14. This distributed winding thus gives a better approximation to a sinusoidal distribution of magnetic flux along the field plate **7**.

In FIGURES 16 and 17 there is shown a complete assembly of the phase and amplitude control system of this invention. This embodiment shows the map for the circular array disposed over the field plate **7**. On a plate **13** which is disposed over the field plate **7** are mounted pickup coils **14**. There are shown 10 such pickup coils equally spaced on a circle about the center. These pickup coils **14** are supported on a rod **15** which is carried by the plate **13**, each of the coils being so supported. The rod **15** carries a washer **16** and a spring **17** disposed intermediate the washer **16** and the lower surface of the plate **13**. The rod **15** is movably retained on the plate **13** by means of a washer **18** and a nut **19**. This method of fastening is shown for illustration though it is to be understood that other means of securing the rod in a movable fashion to the plate **13** may also be used. Disposed over the windings on the field plate **7** is a cam **20** which is disposed in coactive association beneath the **13** to be engaged by the rods **15** which are essentially cam followers. Plate **13** is supported above the field plate **7** by means of a shaft **21** which is rotatably coupled to a support plate **22** which in turn is supported above the field plate **17** by means of end members **23** and **23***a*. Fastened to the shaft **21** is a knob **21***a*. By means of knob **21***a* and the capability of the shaft **21** to rotate in the plate **22**, the plate **13** can be rotated about the center of the field plate and the cam followers **15** to which are attached the respective pickup coils will then move up or down according to the contour of the cam **20**. The pickup coils **24** will of course follow the movement of the cam followers **15**. As the pickup coils **24** are moved higher or lower in relation to the field plate **7**, the interaction of the magnetic flux of the traveling field with the pickup coil will vary proportionately with the distance of the coil from the surface of the field plate **7**. This thus produces amplitude differences that may be desired in the signal. Also, as the plate **13** with the pickup coils is rotated, the phase of the induced voltages in the pickup coils vary with the position of the coils in the field. Thus, the radiation pattern for the circular array as shown in FIG. 7 can be shifted 360° by varying the phase and the amplitude of the signal by rotating it in cooperation with the cam. The cam **20** should be preferably of a non-magnetic material as are the other plates and support members utilized in the map control. If it is desired to have a rotating beam, then it is obvious that instead of manual rotation of the mounting plate **13** a motor can be used to drive the shaft **21** to secure the constant rotation of the plate **13**. In FIGS. 18 and 19, there is shown

the plan and side elevation view of the linear array map and control arrangement. In this case, the field plate **7** supports above it by virtue of two side members **25** and **26** a support plate **27**. Shown as mounted on the support plate is a map of the eight element linear array. A rod **28** is movably supported in a bushing **29** which is fastened to the support plate **27** by means of a nut **30**. The position of the rod **28** within the bushing **29** can be changed vertically and secured to the desired position by a screw **31**. The position of the coil **33** can be varied longitudinally by moving the bushing **29** in a slot **32**. The rod **28** can be moved axially along the support plate **22** by releasing the nut **30** which fastens the bushing **29** to the support plate **27** whereby the bushing **29** can be moved axially through the slot **32**, thus changing the phase position of the pickup coil **33** with relation to the field plate **7**. It is thus seen that by virtue of the fact that the rod **28** which carries the pickup coil **33** can be moved up and down and also to and fro along the axis, the phase and amplitude of the induced voltage in the pickup coil **33** can be varied as desired. Once the steering of the beam of the linear array, such as shown in FIGURE 5 and FIGURE 6, is accomplished, then the pickup coil is securely fastened into that position. The beam may, alternatively, be steered by providing means for rotating plate **27** with respect to field plate **7** in a manner analogous to that for the circular array of FIGS. 16 and 17. FIGS. 18 and 19 depict a map arranged for an end-fire array. For a broadside radiation pattern, the sets of four elements would be lined up parallel to the winding slots on plate **7**.

The means of exciting the traveling field windings is shown in FIGURE 9. Some suitable frequency f_1 which is the output of a generator **35**, is chosen for the control field either lower or higher than the frequency to be radiated by the antenna array. The generator **35** by means of transformer **36** supplies a phase bridge **37** having the connection 0, A, B, —A, C. Voltages nominally equal in amplitude and at 120° relative phase are picked off from the bridge **37** to drive vacuum tubes **38, 39, 40** and thence through transformers **41, 42** and **43** to the three field windings A, A′; B, B′; C, C′. The phase is controlled by adjustment of the two resistive arms **44** and **45** of bridge **37**. Small external loading of the bridge and tube inequalities, etc. will cause the voltages to be somewhat unequal and three potentiometers **46, 47, 48** are provided in the tube output circuits. The correct three-phase current relationships are secured when volt meters V_a, V_b and V_c show equal voltages and the return current I_0 in the neutral line is zero. It is necessary, of course, that the voltmeter calibrations be matched.

With reference to FIGURE 10, there is shown the excitation means of the antenna array. For purposes of illustration, only four pickup coils numbered **49, 50 51** and **52** are shown. A source of signals of frequency f_2, **53** is used to mix with the output of the pickup coils **49** to **52** in the electronic units **54, 55, 56** and **57** and the resultant signals after passing through amplifiers and phase compensators therein are fed to mixers **58** to **61**, inclusive, where they are mixed with the carrier frequency f_3. The output at frequency f_0 of mixers **58, 59, 60** and **61** are then fed to power amplifiers **62, 63, 64** and **65** and are radiated from the respective antennas **66, 67, 68** and **69**. The phase relationship between the pickup coil and the antenna has a definite value. Since this value will not usually be the same for various antennas due to different path lengths, etc., phase compensating means can be provided. This, of course, can be adjusted and locked to the value indicated by field monitoring tests. If the beam is not to be steered, the phase compensator is unnecessary. The phase corrections as above explained can be obtained directly by shifting the position of each pickup coil over the control field plane. The arrangement of coils need not then be in the form of a map of the array but can be made to produce any desired distribution of phase and amplitude between the elements of the array. The mixing frequencies f_2 and f_3 provide the frequency change to prevent feedback to the pickup coils from the antennas. Keying or other modulation can be impressed upon f_2 or f_3 or by any other modulation system.

Referring now to FIGURES 20 and 21, there is shown an embodiment of the invention where a UHF beam **70** is used to illuminate a map **71** of the antenna array made of miniature dipoles **72** mounted on a copper ground plate **73**. The dipoles **72** pick up signals in the relative phase and amplitude required by a large array to produce the desired beam direction. The spacing of the elements of the map measured in wavelengths of the illuminating beam is the same as the spacing of the actual array in wavelengths of the signal to be radiated. The beam can be formed by a parabolic reflector **74** sufficiently wide and far enough away from the map to give effective collimation. The radiating horn **75**, of course, is mounted at the focus of the parabola. The beam and the map can be erected in the open or in an anechoic chamber. In this embodiment, if the frequency f_1 is 300 megacycles, then the spacing of the dipoles is one meter diameter of the circle around which the dipoles are mounted provided the transmitting antennas are on a circle of diameter one wavelength at the transmitting frequency. f_2 can then be set at 290 megacycles, f_3 at 9 megacycles and f_0 can be made 1 megacycle for transmission. The plate **73** can be a copper ground plane and is made rotatable in the same manner as the map array of the pickup coils so that the phase variation in the different dipoles can be secured. To vary the intensity of the signal in each of the dipoles, the dipoles in a conductor can be made movable so that the amount of signal received by each dipole is proportional to the amount of the probe protruding from the pickup. While the dipole arrangement on the circular plate is shown in the simplest form for purposes of describing this embodiment, it is evident that the arrangement described in FIGURES 16 and 17 can be utilized to rotate the dipoles and to vary the length of the dipole protruding above the circular plate **73** and exposed to the radiated field from the horn **75**. The plate **73** is supported from a support plate **73*a*** and is rotatable by means of a knob **21*a***. The pickup probes or dipoles **72** are disposed in coaxial pistons **76** which are slidable in cylindrical wells **77** in contact thereto by sliding ground contacts **78**. The coaxial pistons **76** are thus movable in a vertical direction as the plate **73** is rotated because the cam follower **79** moves along the cam **20′**. A coaxial cable connector **110** is fastened to the coaxial pistons **76** and provides the output cable for the pickup probes **72**.

FIGURE 22 is a block diagram of a receiving system utilizing this invention. The receiving system shown is suitable for communication or for direction finding as will be explained. With reference to FIGURE 22, there is shown a steerable antenna array **80** which in this figure comprises four antennas **81, 82, 83** and **84**, though it is to be understood that any other antenna array having more or fewer antennas is also feasible. The direction of the received radiation f_0 is shown by the arrows. The antennas **81, 82, 83** and **84** are shown diagrammatically as loop antennas oriented in the direction of the incoming radiation for maximum signal strength. A local oscillator **85** generates a signal at a frequency f_3 and is coupled to a keyer **86**. The keyer is required only in a pulse system, such as radar, to disable the receiver when the transmitter is operating. Otherwise, for CW operation it is not necessary. The output of the keyer **86** is coupled to mixers and preamplifiers **86′** and **87** to which are coupled respectively the output of antennas **82** and **83**. It is to be understood that similar mixers are provided for antennas **81** and **84**. The outputs of the mixers and preamplifiers **86** and **87** are in each case $f_{03}=(f_0-f_3)$. The map array **88** with a fixed electromagnetic field directed as shown by the arrows **89** has antenna replicas **90, 91 92** and **93** exposed to the local field of frequency f_1. It is to be noted that

the replica array **88** has been rotated to obtain the same relative field direction as in the antenna array **80**. The outputs of antenna replicas **92** and **93** are coupled to electronic units **95** and **96** respectively, which comprise amplifiers, phase compensators and mixers. A local oscillator **97** generates a signal at frequency f_2 which is fed to the mixers **95** and **96**, the output of which is $f_{12}=(f_1-f_2)$. The outputs of antenna replicas **91** and **94** are likewise coupled to similar electronic units, though not so shown. The signals $f_{12}=(f_1-f_2)$ are fed to second mixers **100**, **101**, **102** and **103** as are the signals $f_{03}=(f_0-f_3)$ and the outputs of the second mixers are combined in phase signals $(f_{03}-f_{12})$ which are fed to receiver **104** that includes all final stages of the receiving system to extract the desired signals. In a communication system where it is known from which direction the signals are coming, the steerable loops of the antenna array **80** are steered to that direction and the antenna replica **88** is rotated to obtain the same relative field direction. The phase of the received signals and the local field signals is coincident and the derived signal strength is maximum. However, in a direction finding system, it is not known from what direction the signals emanate. Therefore, the antenna array loops are steered and the map array is rotated in phase until maximum signal strength occurs and indicates the direction of arrival of the signals. It is necessary to provide a servo system for the loop antennas of the antenna array so that the loop antennas will always maintain the same orientation.

Instead of loop antennas, it is possible to us monopole antennas which can be fixed since they have omnidirectional characteristics. In this case, only the map array would be rotated. In the second mixers, the signals are added and if the map rotation is in the corresponding phase to the direction of signal arrival, then the signal output is maximum and the direction of signal is ascertained.

While I have described above the principles of my invention in connection with specific apparatus, it is to be clearly understood that this description is made only by way of example and not as a limitation to the scope of my invention as set forth in the objects thereof and in the accompanying claims.

I claim:

1. A control system for an antenna array comprising:
- a replica of said antenna array,
- a source of energy for producing an electromagnetic field,
- means coupling said replica array to said electromagnetic field; and
- means responsive to the output of said replica array to control the transmission and reception of signals by said antenna array.

2. A control system for an antenna array comprising:
- a replica of said antenna array,
- a source of radiated electromagnetic energy,
- means for causing said replica array to be illuminated by said source of radiated electromagnetic energy; and
- means responsive to the output of said replica array to control the phase and amplitude excitation of said antenna array.

3. A control system according to claim **1** further comprising means supporting said replica antenna elements in the electromagnetic field of said source of energy and said supporting means include means for moving said replica antenna elements to vary the phase and amplitude of the signal induced in said replica antenna elements by said electromagnetic field.

4. A control system according to claim **3** wherein said supporting means comprise:
- a plane surface,
- a multi-phase winding distributed along said plane surface; and
- means coupling said multi-phase winding to said source of energy whereby a traveling electromagnetic field is produced.

5. A control system according to claim **3** further comprising:
- means for mixing the signal output of said replica antenna elements with signals of a first frequency,
- means for mixing the resultant signals occurring from said mixing of the signal output of said replica antenna elements with signals of a first frequency with a modulating frequency; and
- means for transmitting said modulated resultant signals from said antenna array.

6. A control system for an antenna array consisting of a plurality of antennas comprising:
- a flat member,
- a plurality of parallel slots cut into one side of said flat member transverse to the long axis of said member,
- multi-phase alternating current windings disposed in said slots so that when connected to a source of energy a traveling electromagnetic field is produced,
- a plurality of electrically responsive elements disposed adjacent to and in coactive association with said traveling electromagnetic field in a configuration equivalent to the configuration of said antenna array, the number of said elements being equal to the number of antennas in said antenna array,
- a source of multi-phase alternating current at a first frequency,
- means coupling said multi-phase windings to said source of multi-phase alternating current,
- a first group of mixers,
- a source of signals at a second frequency,
- means coupling the respective outputs of said electrical elements produced by said traveling electromagnetic field to said first group of mixers,
- means coupling said second frequency signal source to said mixers,
- a second group of mixers,
- a source of modulating signals,
- means coupling the respective outputs of said first mixers to the respective ones of said second mixers,
- means coupling said modulating signals to said second mixers,
- and means coupling the output of each said second mixer to a respective one of said antennas of said antenna array whereby the beam direction of the electromagnetic waves radiated from said antenna array is controlled by the position of the elements in said electromagnetic field.

7. A control system according to claim **6** wherein said elements are pickup coils.

8. A control system according to claim **7** further comprising:
- a support member,
- means rotatably disposing said support member above said flat member in substantially parallel relation thereto,
- a plurality of said coils movably disposed on said support member in a circular array,
- means to rotate said support member; and
- means to move each said coil normal to said flat member.

9. A control system for an antenna array comprising:
- a source of radio frequency energy for producing an electromagnetic field,
- a plurality of dipoles equal to the number of antennas in said antenna array,
- means disposing said dipoles in said electromagnetic field in a configuration equivalent to the configuration of said antenna array; and
- means responsive to the output of said dipoles of said equivalent array to control the transmission and reception of signals by said antenna array.

10. A control system for a receiving system having an

antenna array for the reception of electromagnetic signals comprising:

a source of energy at a first frequency,

a replica of said antenna array,

means coupling said replica array to the electromagnetic field of said source of energy,

means to move said replica array in the electromagnetic field to vary the phase and the amplitude of the currents induced in the antennas of said antenna array,

a source of energy of a second frequency,

first means to mix the outputs of said replica antennas with said energy at said second frequency,

a source of energy at a third frequency,

second means to mix the energy received by the antennas of said antenna array with the energy at said third frequency,

third means to mix the respective outputs of said first mixing means with the respective outputs of said second mixing means whereby the respective converted outputs of the antennas of said antenna array are mixed with the converted output of the equivalent antennas of said replica array; and

means to combine the outputs of said third mixing means.

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