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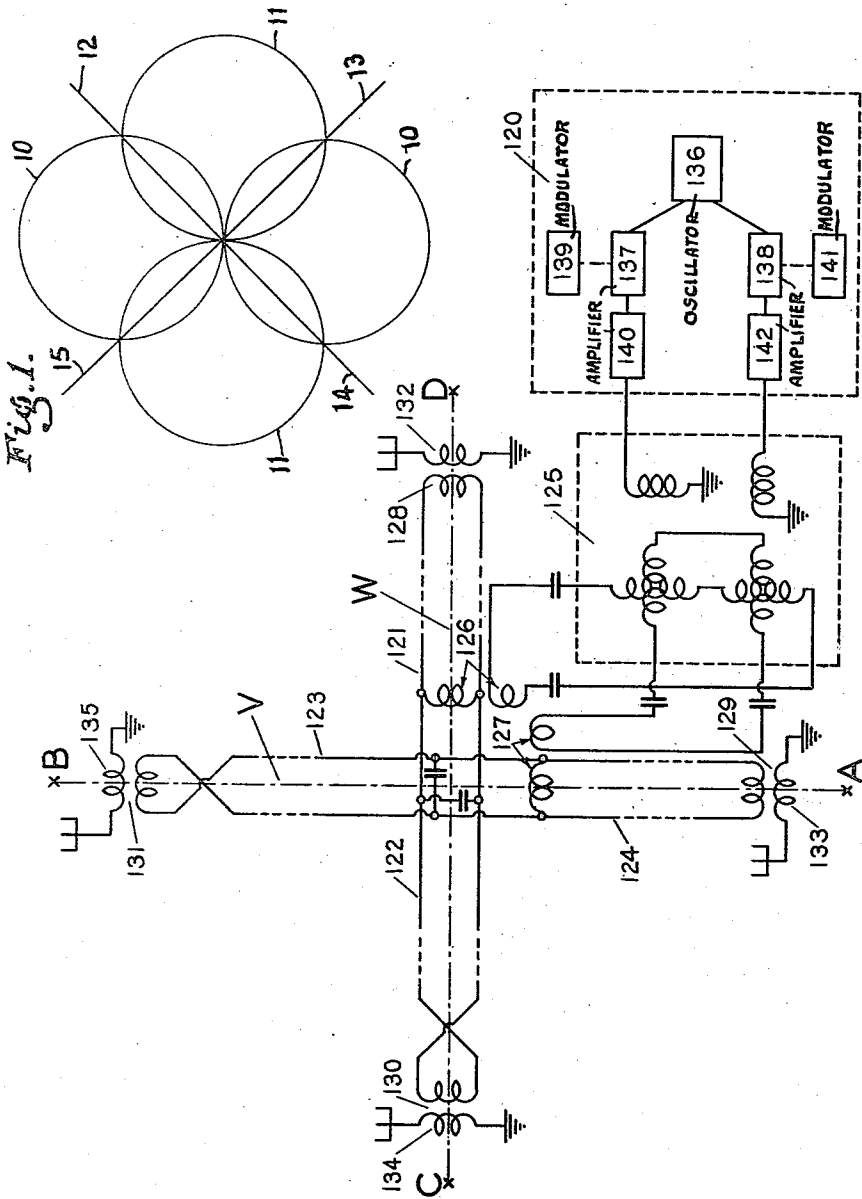
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2,190,037

STABILIZING METHOD AND DEVICE

Filed Nov. 25, 1936

4 Sheets-Sheet 1



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4 Sheets-Sheet 3

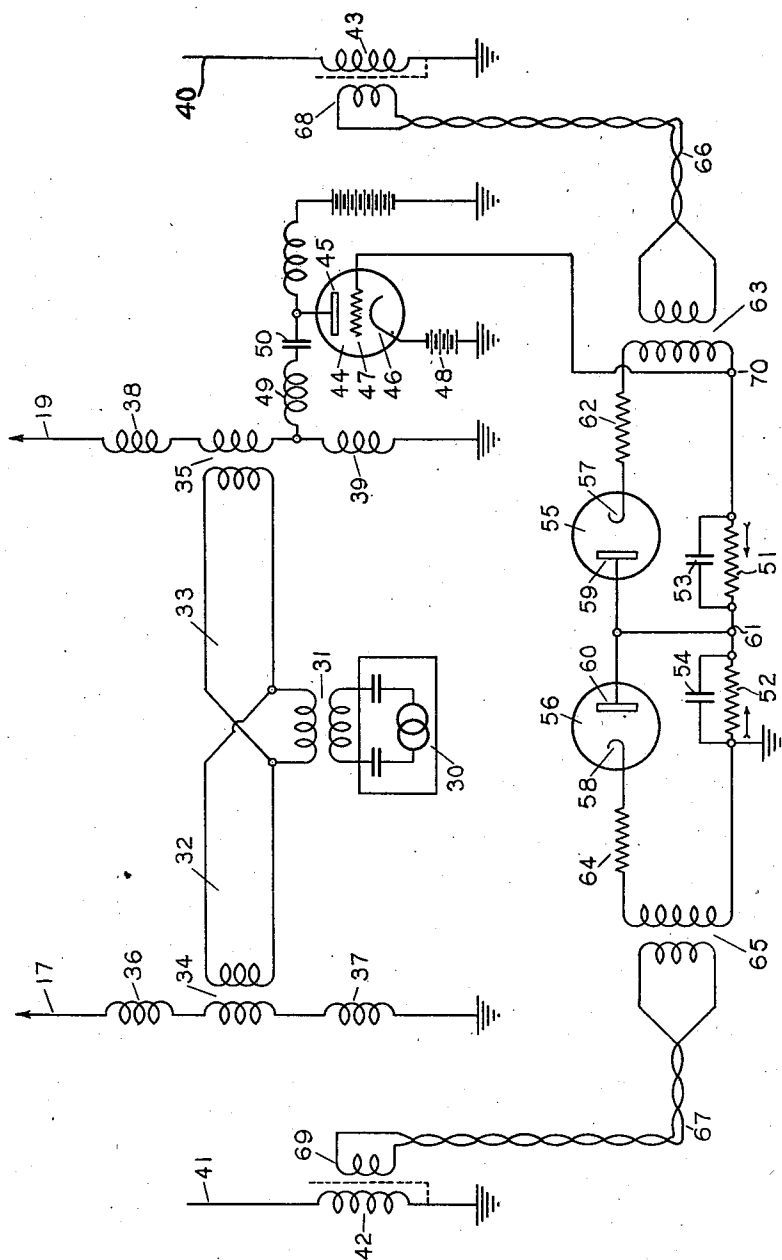


Fig. 3.

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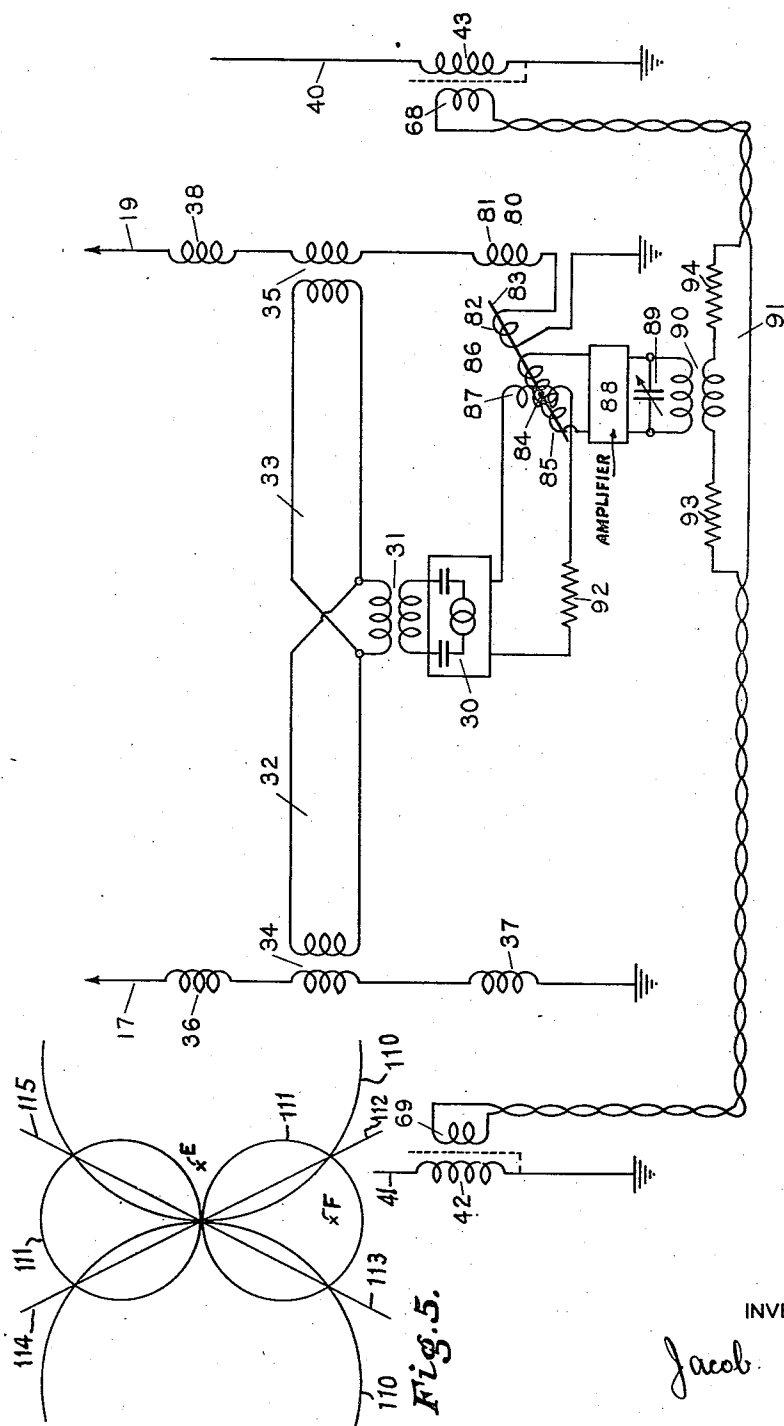


Fig. 4.

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UNITED STATES PATENT OFFICE

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STABILIZING METHOD AND DEVICE

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This invention relates to a method and means for maintaining stable patterns of antenna systems.

In the recent times considerable attention has been given to the problem of maintaining a stable pattern in directive antennas both in the broadcast field and in the radio range beacon transmission.

In the broadcast field antenna arrays which would transmit all their power in one or more directions and will present no radiation in another direction can be utilized to eliminate interference between adjacent transmitting stations and would increase the number of stations which would operate on a single channel. This necessitates the maintenance of correct phase and amplitude relations between the currents in the various antennas of the array. Such relationships are subject to many perturbing effects and a great difficulty has been experienced in the prior art in maintaining the directivity of antennas within allowable tolerance.

In the radio range beacon transmission where the safety of an aircraft is involved the requirements for maintaining a stable antenna pattern are much more rigorous than in the broadcast field, and I shall therefore illustrate my invention as applied to the beacon antennas. It is however well understood that my invention is equally applied to broadcast antennas and to any other antennas and I desire to claim all novelty inherent in the invention as broadly as the prior art permits.

In systems commonly employed for aligning airways the on course zones are determined by the intersection of two space patterns from two independent antenna groups. Any change in one antenna group will change the intersection and shift the course indication. Consequently, it is necessary that the phase relations between the currents be maintained to a considerable accuracy in order to assure the stability of the two space patterns. Considerable difficulty, has been experienced, however, in the past maintaining this accuracy within the allowable limits. It has been recognized that a minute change of tuning in one of the antennas for any reason, such as the effect of nearby poles, faulty insulators, etc. during wet weather, will result in a change in phase angle between the antenna currents. This causes unintentional shifting of the airway courses and may impair considerably the safety of an aircraft.

It has also been found some time ago that frequently considerable shifts in course took place

which have been caused by conditions other than those resulting from the detuning of an antenna. In such cases the plane of polarization of horizontal field components which was due to the horizontal parts in the loop antenna was shifted during the night on account of reflection from ionized layers in the atmosphere.

It is therefore an object of my invention to eliminate all the inconveniences of the prior art and to provide a radio range beacon transmission system in which all unintentional shifting in the direction of the aligned courses will be eliminated.

It is a further purpose of my invention to provide a stable radiation pattern for an antenna system free from various perturbing influences.

It is a further purpose of my invention to maintain automatically predetermined phase relationships between various currents of an electrical system.

It is a further purpose of my invention to maintain automatically predetermined phase and current relationships of an electrical system.

It is a further purpose of my invention to provide a means sensitive to a phase change between two currents and to the direction in which this phase change occurs.

Further purposes appear in the specification and in the claims.

My invention involves both the method and the subjects matter.

In accordance with my invention I provide an arrangement for stabilizing the radiation pattern of an antenna system in which I include two receiving antennas placed in the radiation field at two assigned locations in which the intensities of produced signals bear a certain predetermined relationship one to another. The antennas are mutually connected in a manner as to oppose the effects resulting from the received signal and to produce a combined effect which is zero as long as the radiation pattern is maintained stable. If, however, the radiation pattern changes, the effect derived from one antenna increases while the effect derived from another antenna decreases thus causing the appearance of the combined effect the magnitude and the direction of which represent the change of the radiation pattern. The combined effect is made to act upon one of the parameters of the antenna system in a manner as to counteract the cause which has produced the unintentional change in the radiation pattern and thus to maintain the stability of the pattern.

A better understanding of the invention may be had by referring to the following detailed de-

scription which is accompanied by drawings in which:

Fig. 1 shows a normal space pattern for four beacon courses 90 degrees apart.

Fig. 2 shows the space patterns of a pair of antennas in which currents differ in time phase by various amounts.

Fig. 3 shows an arrangement for stabilizing the radiation pattern of a pair of antennas.

Fig. 4 shows a modified arrangement for stabilizing the radiation pattern of a pair of antennas.

Fig. 5 shows the superposition of two normal figure-in-8 patterns of unequal intensity for four beacon courses in which two sets at 180 degrees are at an angle different from 90 degrees.

Fig. 6 shows schematically the general arrangement of a radio-range beacon transmitting station.

Fig. 7 shows another means for stabilizing the radiation pattern of an antenna system.

Referring now more particularly to Fig. 1, the numerals 10 and 11 represent the usual figure-of-8 transmission characteristic for giving the visual or aural type radio beacon courses 12, 13, 14, 15. The arrangement for producing these courses may preferably take place by means of the transmission line type of antenna system described in the "Bureau of Standards Journal of Research", vol. 10, Jan. 1933, Research Paper #513 entitled: "The cause and elimination of night effect in radio range beacon reception" by Harry Diamond—see particularly under subtitle "V Transmission-Line Antenna System" (pp. 23-33 of the said research paper).

The use of the transmission line antenna system involves the problem of accurate control of the time phase angle between the currents in the antennas of each pair. When the time phase angle is 180 degrees, a true figure-of-8 space pattern is obtained. When it is 180 degrees minus the space phase angle between the two vertical antennas, a cardioid is obtained. For phase angles intermediate to those two values, a space pattern intermediate to the true figure-of-8 and cardioid results. Fig. 2 illustrates the dependence between the phase displacement of currents in two opposite antennas of a pair and the resulting space pattern. In this figure, 10 represents the space pattern corresponding to the difference in phase of 180 degrees between the currents of antennas 17 and 19 respectively; 10-a corresponds to the case in which the current in the antenna 19 leads the current in the antenna 17 by 165 degrees; and 10-b represents the space pattern when the current in the antenna 19 leads the current in the antenna 17 by 150 degrees.

The control of the phase relationships in a pair of antennas provides a method for altering the radiated space pattern to permit alignment of the beacon courses at arbitrary angles. Referring to Fig. 1, if the phase angle between the currents in one pair of antenna be changed from 180 degrees to 165 degrees, the corresponding space pattern changes so that the polar diagram of its intensity is not any more 10 but 10a (see Fig. 2). Superposition of the pattern 10a (instead of 10) and of the pattern 11 will give four equisignal zones different from those designated by 12, 13, 14, 15 in Fig. 1.

The use of the above method of altering the angular direction of the beacon courses in order to align them with airway routes is clearly shown in Fig. 16, p. 30 in the referred research paper by Harry Diamond.

The property of this antenna system which

permits alteration of its radiated space pattern involves a very accurate control of the phase angle between the currents in the two vertical antennas of a pair. Obviously the phase angle between the currents in the two vertical antennas of a pair must be kept constant within rather close limits, or the angular direction of the beacon courses will vary from time to time. It has not been possible in many instances to maintain this constancy of phase within certain preassigned tolerances. Very frequent and unintentional changes in the phase relationships were observed and which were due to various accidental causes of random nature and beyond human control and resulted usually from the effects of nearby poles, faulty insulators during wet weather, etc. Since the safety of an aircraft depends upon a stable pattern such phase changes cannot be tolerated and it is necessary that the phase relations between the currents be maintained at a very great accuracy.

In accordance with my invention I am showing in Fig. 3 one of the embodiments of my invention illustrating a means for maintaining an antenna pattern stable and which has been chosen with a view to simplicity of operation and convenient illustration of the principles involved.

Referring now more particularly to Fig. 3 the schematic diagram illustrated therein represents one half of a complete antenna system required for a range-beacon installation. Numeral 30 represents a transmitter which is connected through the transformer 31 to two-wire parallel-conductor transmission lines 32 and 33 respectively, the transmission lines being of such a nature as not to radiate. The transmission line 32 is used to feed power from the transmitter 30 to the antenna 17 by means of a radio frequency transformer 34 while the transmission line 33 feeds power from the transmitter 30 to the antenna 19 by means of a radio frequency transformer 35. The antenna 17 is provided with a loading coil 36 (to resonate it at the frequency of the transmitter) and a fine tuning coil 37 for more minute adjustments. In a similar manner the antenna 19 is provided with a loading coil 38 and a fine tuning coil 39. Assume now that the current flowing in the antenna 19 leads the current in the antenna 17 by 165 degrees. Consequently the resulting radiation pattern will have the form represented by numeral 10a in Fig. 2. In this radiation pattern the points M and N (shown in Fig. 2) correspond to certain locations at which the strength of the respective signals has a predetermined ratio. Let for instance the signal strength at M be a/b times larger than the signal strength at N. At the referred points M and N are placed receiving antennas which are shown in Fig. 3 and designated respectively by numerals 40 and 41. The receiving antenna 41 is provided with an inductor 42 while the receiving antenna 40 is provided with an inductor 43.

Referring again to Fig. 3, the numeral 44 designates a three electrode tube provided with an anode 45, cathode 46 and a grid 47. The anode 45 is connected to one end of the tuning coil 39 of the antenna 19 by means of an arrangement including an inductance 49 in series with a by pass capacitor 50 (of substantially zero reactance). The cathode 46 is connected to another end of the tuning coil 39 and to ground through a biasing battery 48. The grid is connected to ground by means of a path which consists of resistors 51 and 52 in series and shunted by the

capacitors 53 and 54. Rectifiers 55 and 56 are provided which contain cathodes 57, 58, and two anodes 59, 60 respectively. The anodes 59, 60 have a common terminal 61 with the resistors 51 and 52. The cathode 57 is connected to the resistor 51 by means of a path including the resistor 62 and the secondary winding of the transformer 63. The cathode 58 is connected to the resistor 52 by means of a path including the resistor 64 and the secondary winding of the transformer 65. The primary windings of the transformers 63 and 65 are included in the circuits 66 and 67 respectively. The circuit 66 is inductively coupled to the receiving antenna 40 by means of a winding 68 and the circuit 67 is inductively coupled to the receiving antenna 41 by means of a winding 69.

The operation and performance of this arrangement can be explained as follows:

In order to eliminate the radiation from the transmission lines 32 and 33 the input impedances of the radio frequency, transformers 34 and 35 must be respectively equal to the surge impedances of the lines. If the terminating impedance is not equal to the corresponding line impedance, part of the wave reaching the terminating impedance will be absorbed by it and part of the wave will be reflected along the line. This in part sets up standing waves and causes radiation from the line. The radio frequency transformers 34 and 35 employed for coupling the transmission lines 32 and 33 to the vertical antennas 17 and 19 are accordingly designed so that the input impedance of each is equal to the surge impedance of the respective transmission line. In this way radiation from transmission line is eliminated. The proper adjustments necessary in order to insure the equality between the surge impedance of the line and the input impedance are described in the referred research paper by Harry Diamond, chapter V, pages 32-33.

The variable inductors 37 and 39 shown in series with the vertical antennas 17 and 19 serve for minute tuning of the antenna to the radio frequency of the transmitting set. It has been recognized, however, that due to various perturbing effects, an antenna 19 (or 17) when tuned to the frequency of oscillation does not remain tuned after it has been once adjusted by the variable inductance 39, but drifts away from the tuning conditions to which it has been set.

A slight change in tuning of one antenna will cause a decided shift of phase between the currents of two opposite antennas and consequent shifting of the course. If it is arbitrarily said that the maximum allowable shift of course shall be ± 2 degrees, then the phase of the currents must be correct to within ± 2 degrees. A shift of such magnitude can occur with a very slight change in antenna constants. To consider a specific case (see F. G. Kear: "Phase Synchronization in Directive Antenna Arrays with Particular Application to the Radio Range Beacon," Bureau of Standards Research Paper RP581, p. 126) assume a vertical tower 125 feet high with a resistance of 10 ohms and a capacitance of 500 mmf. The phase angle between the current and voltage is zero when the antenna is exactly in tune. For an angle of 2 degrees a change in capacity of 1.2 mmf. is all that is necessary. Such a change could readily be caused by the effect of rain or snow. It is apparent, therefore, that some means of phase control must be provided.

In order to maintain constant the phase differ-

ence between the currents in the antennas 17 and 19 it is necessary to introduce an effect which will tend to overcome any change in tuning condition and which will be controlled by the departure from the said tuning conditions. The controlling element which will counteract the detuning will be in this particular case the vacuum tube 44 which is included in a circuit across the inductance 39. The plate circuit of the vacuum tube 44 acts as a resistance and the magnitude of this resistance is controlled by the grid voltage. As can be seen a variation in plate resistance of the vacuum tube 44 will cause a change in tuning of the antenna 19. This is due to the fact that the equivalent inductive component of the circuit including the inductance 39, the inductance 49 and the tube plate resistance of the tube 44 will change with a variation in the magnitude of the plate resistance of the tube 44. It is thus seen that a variation in the grid bias of the tube 44 will modify the tuning conditions of the antenna 19 and change the phase between the current of the antenna 19 and the antenna 17. On the other hand the grid voltage of the tube 44 is dependent upon the departure of the antenna 19 from its predetermined and assigned tuning conditions. So that any variation in the tuning condition of the antenna 19 is immediately counteracted by the effect introduced by the tube 44. This counteraction is caused by the following sequence of actions. When the predetermined phase difference between the antennas 17 and 19 is maintained and no "drifting action" is noticed the radiation pattern of the antennas 17 and 19 is stable and the intensity of the radiation field is shown schematically on the polar diagram 10a of Fig. 2. Then the intensity of the field in point M is a/b larger than in the point N and consequently the voltage induced across the inductor 43 of the antenna 40 is a/b times larger than the corresponding voltage across the inductor 42 of the antenna 41. The voltage across the inductor 43 is transmitted by means of the circuit 66 to the secondary winding of the transformer 63. This voltage causes a unidirectional current to pass through the path which includes the plate 59, cathode 57, resistor 62, primary winding of the transformer 63 and resistor 51. The steady part of this current passes through the resistor 51 in the direction indicated by the arrow and causes a drop of potential between the terminals of this resistor. Similarly, the alternating voltage across the inductor 42 of the antenna 41 is transmitted by means of the circuit 67 to the secondary winding of the transformer 65. This voltage causes a unidirectional current to pass through the path including the plate 60, cathode 58, resistor 64, primary winding of the transformer 65 and resistor 52. The steady part of the current flowing through this circuit passes through the resistor 52 in the direction indicated by the arrow and causes a drop of potential between the ground and the terminal 61.

Consider the case when the phase difference between the antennas 17 and 19 is maintained exactly at predetermined value of 165 degrees and consequently the voltage developed across the inductor 43 is a/b times larger than the voltage across the inductor 42. The resistors 51 and 52 have been, however, so proportioned that the voltage drop in one of them equals the voltage drop in another. Now since these voltages are opposite in sign and in series the resulting voltage which is equal to their sum and is applied between the ground terminal and the grid 47 of the

tube 44 is zero. Thus the effect upon the grid voltage of the tube 44 is equally zero and the tuning condition of the antenna 19 remains unaltered.

Now suppose that due to an external influence such as mentioned above, the inductance of the antenna 19 slightly increases. Consequently a certain lag of α degrees appears between the current in the antenna 19 and the voltage in the antenna 19. Under normal conditions the currents in the antenna 19 leads the current in the antenna 17 by 165 degrees. At present, however, due to the detuning the phase angle becomes $165-\alpha$ degrees and this changes the space pattern in such a manner that the intensity of field at point M (see Fig. 2) becomes stronger while the intensity of field at point N becomes weaker. This causes an increase of voltage across the inductor 43 and a decrease of voltage across the inductor 42.

Now the voltage across the inductor 43 is larger than a/b times the voltage across the inductor 42. Consequently the voltage across the resistor 51 will be larger than the voltage across the resistor 52. Since the resistors 51 and 52 are in series and the referred to voltage drops are in opposite directions the resultant voltage between the earth terminal and the point 70 will be equal to the difference between the absolute value of the voltage drop across the resistor 51 and the voltage drop across the resistor 52 and the polarity will be such that the point 70 will become positive with respect to the ground terminal. Now since the point 70 is connected to the grid 47 of the tube 44, the potential of the grid of the tube 44 becomes more positive. This has an effect such as to reduce the negative grid bias between the grid and cathode of the tube 44 (this negative grid bias being supplied by the battery 48). The tube 44 is operating in a circuit the constants of which are such that the operation is over a curved portion of its grid voltage-plate current characteristic (the lower knee of the curve) in such a manner that increasing the grid potential positively decreases the A. C. plate cathode resistance of the tube 44. As it is shown in the figure this A. C. resistance forms a shunt of the inductor 39 and influences the tuning conditions of the antenna 19 in such a manner that if the A. C. resistance of the tube decreases the inductive reactance of the antenna also decreases. Consequently, any tendency to cause the increase of the inductance in the antenna 19 is immediately counteracted. It can be shown similarly that any tendency to decrease the inductance 19 is correspondingly counteracted by the reverse action of the same auxiliary circuit. This means that the auxiliary circuit represented by the numerals 51 to 70 inclusive has an effect on the antenna arrangement which is stabilizing as to the phase variations. That is, any tendency to cause the drift in phase of the current in the antenna 19 with respect to the current in the antenna 17 in the lagging direction is immediately counteracted by the action of the said auxiliary circuit.

It can be shown similarly that any tendency to cause the drift of the current in the antenna 17 with respect to the current of the antenna 19 in the leading or in the lagging direction is correspondingly counteracted by the reverse action of the same auxiliary circuits. That is any change or any tendency to change the tuning conditions from the resonance conditions with respect to the transmitter frequency in either of the antennas 17, 19 is corrected and counteracted and conse-

quently the phase difference between the current in the antenna 17 and the current in the antenna 19 is maintained constant.

It is apparent that the effectiveness of the control of the associated circuits depends upon the circuit constants, the amplification factor of the tube 44, the rectification efficiency of the tubes 55 and 56, etc., and approaches as a limit the ideal condition. Its action is such that it only reduces the amount of drift, but usually does not reduce it to zero. It is apparent to those skilled in the art, that the degree of effectiveness of the circuit is controlled by the circuit constants and can be increased at will to approach as nearly as desired to the ideal limit of zero drift. It is well understood by those skilled in the art that should additional rigor of control be desired it can readily be obtained by use of an amplifier to increase the potential changes applied to the grid of the tube 44, or by other suitable means.

Another method of producing an electrical effect responsive to a change in the antenna pattern in which the electrical effects produced by the two receiving antennas referred to in the description of Fig. 3 are directly subtracted one from another without rectification can be effected by means of a "dynamometer" type electric meter. In this arrangement the voltages across the two receiving antennas are added in series opposing and then impressed across one of the coils of a "dynamometer" type meter, the other coil of the meter having impressed across it part of the voltage being carried by the main oscillator. The motion of the needle of the "dynamometer" will then be a measure of the amount of detuning both in magnitude and in direction. Now, as it has been described previously, after an electrical effect has been produced which is a measure of the detuning the said effect can be made to act upon one of the antennas in a manner so as to stabilize its tuning and to counteract any drifting. One method of acting upon the tuning of the antenna has been in the description of Fig. 3 the said method was entirely electrical in nature. It is, however, possible and sometimes convenient to act upon the antenna mechanically in a manner so as to change its tuning conditions. This variation of its tuning conditions is accomplished by the changing of the value of one of the reactive parameters of the antenna tuned circuit. This can be accomplished by means of some electromechanical device such as small motor or solenoid or electromagnet which will act mechanically upon the capacitance or inductance of the antenna in response to the electric currents or voltages which measure the amount of drift in the tuning. For example, a small variometer, or other variable inductance or a small condenser with one movable plate. The mechanical displacement and consequently the electrical magnitude of this variable reactance can be controlled by the electrical voltage or current which is a measure of the amount of drift in tuning the antenna and can be made to vary the said reactance so as to counteract or tend to counteract the said drift. The mechanical displacement of the variometer coil or the condenser plate can be conveniently combined with means for indicating visually the exactness of tuning. The displacement of the variable inductance or variable capacitance can be controlled either by the difference in the rectified voltages of the auxiliary circuits described in connection with Fig. 3 or could be controlled directly by the difference of the two voltages by means of the suitably ar-

ranged "dynamometer" type meter described above. The circuit shown in Fig. 4 illustrates diagrammatically in greater detail the system in which a mechanically movable arm is made to control the tuning of the antenna.

The elements which are common to Fig. 4 and to Fig. 3 have been denoted by the same numerals; their performance has been described above and need not to be explained here. Briefly, numeral 30 indicates the transmitter, 32, 33, transmission lines feeding the current into the antennas 17 and 19. Numerals 36 and 38 represent the loading coils of antennas 17 and 19 respectively. The antenna 19 is provided also with a tuning coil 80 having a form of a variometer and including a stationary winding 81 and a rotatable winding 82. The rotatable winding 82 is mounted on an arm 83, the said arm being capable of rotating about point 84 representing an axis perpendicular to the drawing. Fastened to the arm 83 is a coil 85 which constitutes the moving coil of the dynamometer arrangement 86. The fixed coil of the dynamometer arrangement designated by 87 receives the current from the transmitter 30. The moving coil 85 is connected across the output terminals of the amplifier 88. The input circuit of the amplifier 88 is coupled through the transformer 90 to a circuit 91. The circuit 91 includes resistors 93, 94 and windings 63, 69. The windings 63, 69 are respectively coupled to the receiving antennas 40 and 41.

The operation of the circuit is as follows:

Suppose that the phase difference between the currents in the antennas 17 and 19 is correctly adjusted in order to give the desired space pattern. Under these conditions the voltage induced by the antenna 40 in the circuit 91 through the winding 63 is equal to the voltage induced by the antenna 41 in the circuit 91 through the winding 69. These induced voltages are in opposition, and consequently their effects are mutually cancelled and there is no current flowing in the circuit 91. Under these conditions there is obviously no current which would be forwarded to the amplifier 88 from the circuit 91 and which would be subsequently transmitted to the coil 85. Consequently the current through the coil 85 will be zero. The coil 87, however, is energized directly from the transmitter 30 and the current through it is determined by the current limiting resistor 92. Since however the current through the coil 85 is substantially zero, there will be practically no magnetic interaction between the two coils and the coil 85 will remain in its position of rest. Now suppose that because of the various exterior causes which have been previously described the antenna 19 becomes detuned by a slight increase of its reactance. Consequently, a certain lag of α degrees appears between the current in the antenna and the voltage in the antenna 19. Under normal conditions the current in the antenna 19 leads the current in the antenna 17 by 165 degrees. At present, however, due to the detuning the phase angle becomes $165-\alpha$ degrees and this changes the space pattern in such a manner that the intensity of field at point M (see Fig. 2) becomes stronger while the intensity of field at point N becomes weaker. This causes an increase of voltage across the inductor 43 and a decrease of voltage across the inductor 42. This will result in the increase of voltage induced in the circuit 91 by the antenna 43 and in the decrease of voltage induced in the circuit 91 by the antenna 41. These two voltages are impressed in the circuit 91 in the opposite directions and cause a

current to flow. This current is amplified in the amplifier 88 and applied to the movable dynamometer coil 85. Now the winding directions of coils 85 and 87 are such that due to their magnetic interaction there is a force acting. This force causes a rotational movement of the arm 83 to which the coil 85 is fastened. Consequently, the inductance of the variometer 80 is varied in such a manner as to oppose the slight increase in the antenna inductance which was the cause of the detuning. Now in the case when the inductance of the antenna 19 decreases the action of this arrangement is very similar in the fact that the balance of the voltages induced in 91 by the antennas 40 and 41 is disturbed. However, in the case of decrease of inductance it is the voltage induced by the antenna 42 that is increased and the voltage induced by the antenna 40 that is decreased. So that the voltage impressed upon the amplifier 88 is of opposite phase of the voltage which would be caused by the increase of inductance in the antenna 19. Consequently, the current flowing through the movable coil 85 of the dynamometer mechanism 86 is of an opposite phase to that in the previously described case. The operation is otherwise analogous but in opposite sign as the magnetic interaction between the coils 85 and 87 is such that the coil 85 tends to move away from its position of rest in a direction opposite to that which it had previously.

It is evident therefore that the stabilizing influence of the circuit arrangement is equally efficient in the case of the phase drift in the lagging or in the leading direction between the currents in the antennas 17 and 19. The action of the arrangement being such that at any instant if an influence acts upon the antenna so as to change the phase of the current flowing through this antenna in relation to the current flowing in another antenna then immediately the circuit acts in a manner so as to counteract and neutralize the said drift.

It is therefore obvious that I have provided a means for maintaining a course alignment independent of various accidental and unintentional effects.

In general, various conditions for course alignment exist. One condition corresponds to the normal space pattern for a given beacon (see Fig. 1). The two sets of 180 degrees courses 12, 14 and 13, 15 are at right angles. Another condition corresponds to a change from 180 degrees relationship of both sets of courses. This condition can be effected by superposing at right angles of the normal figure-in-8 pattern as designated by 11 in Fig. 1 with a distorted pattern as designated by 10a in Fig. 2. Still another condition may be secured in which the two sets of 180 degrees are at an angle different from 90 degrees. This condition is illustrated in Fig. 5 in which the four beacon courses 112, 113, 114, 115, are formed by a superposition of two normal figure-in-8 patterns 110 and 111 of unequal intensity, the pattern 110 being more intense than the pattern 111.

The general arrangement for producing a pattern as shown in Fig. 5 for a double modulation radio-range beacon is shown in Fig. 6. Referring now more particularly to Fig. 6 the dotted block denoted by the numeral 120 designates a transmitting set which is coupled into the transmission lines 121, 122, 123, 124, through a goniometer included in the dotted rectangle 125 and coupling coils 126 and 127. The transmission lines are in turn coupled through the transformers 128, 129, 73

130, 131, into the vertical antennas 132, 133, 134, 135. The transmitting set contained in the dotted rectangle 120 includes a master oscillator designated by block 136, delivering radio frequency oscillations which are respectively transmitted to the amplifiers 137 and 138. The amplifier 137 receives the modulating frequency (for instance 60 cycles) from the block 139 and transmits the modulated carrier to the power amplifier 140. The amplifier 138 receives the modulating frequency (for instance 86 $\frac{2}{3}$ cycles) from the block 141 and transmits the modulated carrier to the power amplifier 142.

In the previous embodiments shown in Fig. 3 and Fig. 4 means were provided for maintaining the space distribution of a pair of antennas in such a manner that the phase displacement between the currents in these antennas was automatically kept at 165 degrees and consequently the polar diagram 10a (see Fig. 2) was maintained invariant. It is well understood, however, by those skilled in the art that when the patterns of two pairs of antennas are superposed one upon another in order to align the courses it may not always be possible to maintain the direction of the courses constant by maintaining the invariability of each of the said patterns. In many cases various accidental and unintentional changes occur in the relative strengths of the two superposed patterns and this causes shifts in the direction of courses and impairs considerably the conditions of safety of an aircraft.

In this embodiment I am therefore providing means of maintaining constant the direction of the aligned courses resulting from the superposition of two patterns by maintaining the form of each of the patterns invariant and also by maintaining their relative strengths constant.

Consider again the space pattern shown in Fig. 5. In order to eliminate any accidental and unintentional shifting of the courses 112, 113, 114, 115, a provision should be made for the following:

1. The space pattern radiated by the pair of antennas 133 and 135 (Fig. 6) must maintain stable its normal figure-in-8 pattern.
2. The space pattern radiated by the pair of antennas 130 and 132 (Fig. 6) must maintain stable its normal figure-in-8 pattern.
3. The relative strength of the pattern 110 with regard to the pattern 111 (Fig. 5) must be constant.

In order to satisfy the conditions (1) and (2) means are employed which are similar to those explained above in connection with Fig. 3 or Fig. 4.

For instance, the pattern radiated by the antennas 133 and 135 is maintained stable by means of two receiving antennas placed at points A and B respectively. The points A and B are preferably located in the vertical plane which passes through the antennas 133 and 135 and intersects the plane of the figure along the line V. Under normal conditions the voltage induced in the receiving antenna placed at point A bears a certain predetermined relationship to the voltage induced in the receiving antenna placed at point B. These two voltages are transmitted to an auxiliary circuit arrangement which is substantially similar to the one designated by the numerals 51 to 70 inclusive in Fig. 3 and operates in the manner explained above. Briefly, if the phase relationship between the currents in the transmitting antennas 133 and 135 are correctly adjusted the voltages which appear at the receiving antennas located at points A and B respectively and which are transmitted to the said

auxiliary arrangement oppose their effects and produce a combined effect which is zero as long as the parameters of the antennas 133 and 135 maintain their values constant. If, however, due to weather conditions, wind, temperature, etc., the parameter of one of the antennas, for instance of the antenna 135 changes slightly its value, the pattern radiated by this antenna becomes distorted. Then the voltage transmitted by the receiving antenna at A to the auxiliary circuit changes its relative value with regard to the voltage transmitted by the receiving antenna at B to the said auxiliary circuit and the combined effect is no longer zero; its magnitude and direction represent the change of the radiation pattern. This combined effect is made to act upon the parameter of the antenna 135 in a manner as to counteract the cause which has produced the unintentional change in the radiation pattern.

In a similar way any unintentional variation of a parameter in the antennas 132 and 134 may be counterbalanced by an effect which is derived from two receiving antennas placed at points C and D respectively. The points C and D are located preferably on the axis in the vertical plane which passes through antennas 132, 134, and intersects the plane of the figure along the line W. The receiving antennas placed at points C and D act in the same manner as the antennas placed at points A and B upon an auxiliary arrangement which is similar to the arrangement which is designated by the numerals 51-70 in Fig. 3. If the phase relationship between currents in the antennas 132 and 134 slightly changes its value due to the drift of one of the parameters the said auxiliary arrangement is made to act on a parameter in one of the antennas 132, 134, in such a manner as to counteract the said change in the value of the parameter and to maintain the corresponding space pattern in its normal, figure-in-8 form.

In order to satisfy the condition (3) consisting in maintaining the relative strength of the pattern 110 with regard to the pattern 111 constant an auxiliary arrangement is provided which contains means similar to those represented by the numerals 51-70 in Fig. 3. This arrangement is shown in Fig. 7 which should be examined in connection with Fig. 5 and Fig. 6. Referring now more particularly to Fig. 7, numerals 200 and 201 represent two receiving antennas which have been appropriately placed at the points E and F respectively (see Fig. 5) in the space pattern of the antennas 132, 133, 134, 135. In the Fig. 7 the rectangular block 202 includes an auxiliary arrangement which is similar to the one designated by the numerals 51-65 inclusive in Fig. 3. In this auxiliary arrangement the elements which correspond to those of Fig. 3 have been designated by the same numerals with the difference that to the numerals designating the elements of Fig. 7 the subscript *a* has been added. Thus a resistor 51*a* in Fig. 7 corresponds to the resistor 51 in Fig. 3, the rectifier tube 55*a* in Fig. 7 corresponds to the rectifier tube 55 in Fig. 3, etc.

The rectangular block 203 includes the radio frequency amplifier in which the modulation is produced and which has been designated by the numeral 137 in Fig. 6. Numeral 204 designates a fragment of a power amplifier which has been designated by the block 140 in Fig. 6. Block 139 designates the arrangement in which the modulating frequency is produced and which has been designated by the same numeral in Fig. 6. The

amplifier is connected to the power amplifier 204 by means of a coupling 205. The coupling 206 designates the connection between the master oscillator and the amplifier 203. The master oscillator is not shown in the Fig. 7. The coupling 207 connects the block 139 with the block 203.

The block 203 represents an amplifier which is suitable for the so-called plate modulation. It includes a tube 208 provided with cathode 209, grid 210 and anode 211. The numeral 212 designates a self-biasing arrangement in the grid circuit of the tube 208. The plate circuit of the tube 208 includes an oscillatory circuit 213, a secondary winding of the transformer 214, a resistor 215 in series with a battery 216. The resistor 215 and battery 216 are shunted by a tube 217. The tube 217 includes a cathode 218, a grid 219, and anode 220. The grid voltage of the tube 217 is the sum of the voltage delivered by the battery 221 and the voltage resulting from the potential drop across the resistors 52a and 51a.

The operation of this arrangement can be explained as follows:

Under normal conditions the relative strength of the pattern 110 is maintained at a predetermined value with regard to the strength of the pattern 111. Consequently the voltage transmitted by the antenna 200 to the block 202 bears a predetermined ratio to the voltage transmitted by the antenna 201 to the block 202. These two voltages are subsequently applied through the transformers 63a and 65a to the rectifier 55a and 56a respectively. Consequently, a rectified voltage appears across the resistor 51a and it is equal and is of opposite sign to the rectified voltage which appears across the resistor 52a. Thus the voltage between the ground terminal and the grid 219 of the tube 217 is zero. If, however, the relative strength of the pattern 110 changes with regard to the strength of the pattern 111 (see Fig. 5) the voltage derived from the antenna 200 changes its magnitude with regard to the voltage derived from the antenna 201. Then the rectified voltage across the resistor 51a is not equal to the rectified voltage across the resistor 52a. Consequently the resultant voltage between the earth terminal and the grid 219 is not equal to zero. Its magnitude and direction represents the departure from the relative strength of the pattern 110 with regard to the pattern 111. So that any variation of the relative strength of the pattern 110 with regard to the pattern 111 is immediately counteracted by the effect introduced by the auxiliary arrangement 202. This has an effect such as to change the grid voltage of the tube 217. It is known to those skilled in the art that the change of the grid potential of the tube 217 changes the A. C. plate resistance. Since the tube 217 is inserted across the resistor 215 and the battery 216 in the plate circuit of the tube 208, it follows that the change of the grid potential of the tube 217 changes the plate resistance of the tube 208. Consequently any tendency to change the relative strengths of the pattern 110 and 111 causes a change to the plate voltage of the tube 208 and consequently changes the power output of the modulated amplifier 208.

The radio frequency oscillations are transmitted from the master oscillator (shown in Fig. 6) through the coupling 206 to the grid 210 of the amplifier tube 208 and they appear in the amplified form in the plate circuit of the tube 208. The modulator 139 is coupled to the plate

circuit of the amplifier by means of the transformer 214. Thus the audio frequency voltage transmitted from the modulator to the plate circuit of the amplifier is superposed on the D. C. voltage of the battery 216. Consequently the radio frequency oscillations in the plate circuit of the tube 208 are modulated by the audio voltages induced into the plate circuit through the transformer 214. The modulated R. F. oscillations are in turn transmitted through the coupling 205 to the power amplifier 204. As it is well known by those skilled in the art, the power delivered by the modulated amplifier depends upon the resistance in its plate circuit. It has been explained above that by varying the effective plate cathode resistance of the tube 217 the plate resistance of the tube 213 is varied.

Now, it can be readily understood by those skilled in the art that any variation in the strength of the pattern 110 with regard to the pattern 111 is immediately counteracted by the effect introduced by the auxiliary arrangement 202 (Fig. 7). This counteraction is caused by the following sequence of events: Any slight change in the relative strengths of the patterns 110 and 111 causes a change in the grid voltage of the tube 217 and this in turn causes a variation of the plate resistance of the tube 208 and consequently changes the power output of the amplifier 208. The change in the power output of the amplifier 208 is done in such a manner as to oppose the variation in the relative strengths of the patterns 110 and 111 in order to maintain the direction of the courses invariant.

It is therefore apparent that I have provided a method and means for stabilizing directive properties of antennas by maintaining automatically their current and phase relationships constant.

In view of my invention and disclosure variation and modifications to meet individual whim or particular need will doubtless become evident to those skilled in the art, to obtain part or all of the benefit of my invention without copying the structure shown, and I therefore claim all such in so far as they fall within the reasonable spirit and scope of my invention.

I claim:

1. An aerial layout comprising several antenna systems, in which the intensities and phases of currents are maintained at predetermined relationships for producing a pattern of desired space characteristics, means in the said pattern responsive to a change in the said space characteristics and associated with the said aerial layout for maintaining the intensities of currents at a predetermined relationship and another means responsive to a change in the said space characteristics and associated with the said aerial layout for maintaining the phases of currents at predetermined relationships.

2. In a radio beacon the combination with a source of radio frequency currents of amplifiers for amplifying said currents, modulation devices for modulating currents in each of said amplifiers by a different signal, a goniometer comprising fixed stator windings and rotor windings crossed at predetermined angles and rotatable about a common axis with respect to said stator windings, the said goniometer receiving the outputs of the said amplifiers, transmitting antennas tuned to the radio frequency of the said source and connected to the said goniometer, each of the said transmitting antennas having a parameter which controls individually its radiation

- patterns, a controlling circuit, receiving antennas placed in the radiation patterns of the transmitting antennas and coupled with the controlling circuit, the said controlling circuit being differentially responsive to the outputs of the said receiving antennas and controlling the parameters of the transmitting antennas in order to maintain the radiation pattern of the radio beacon stable.
3. In a radio beacon the combination with a source of radio frequency currents, of amplifiers for amplifying said currents, modulation devices for modulating currents in each of said amplifiers by a different signal, a goniometer comprising fixed stator windings and rotor windings crossed at predetermined angles and rotatable about a common axis with respect to said stator windings, the said goniometer receiving the outputs of the said amplifiers, transmitting antennas tuned to the radio frequency of the said source and connected to the said goniometer, a controlling circuit, receiving antennas placed in the radiation patterns of the transmitting antennas and coupled to the said controlling circuit, the said controlling circuit being differentially responsive to the output of the said receiving antennas, an electronic tube in the plate circuit of one of the said amplifiers, and means for controlling the electronic tube by the said controlling circuit in a direction to continually maintain the same relative magnitudes of the power outputs in the said amplifiers.
4. In a method of aligning beacon courses with a plurality of airways by superposing a plurality of space patterns of a plurality of antenna systems, the step of producing an electrical signal responsive to a change in the strength of a space pattern and applying the said signal for the control of the relative strengths of the said space patterns, the step of producing another electrical signal responsive to a change in the phase of a space pattern and applying the said signal for the control of the relative phases of the said space patterns, the said two steps maintaining the directions of the said courses invariant.

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