Sept. 12, 1939. H. DIAMOND 2,172,365

DIRECTIVE ANTENNA SYSTEM

Filed May 5, 1933 3 Sheets-Sheet 1

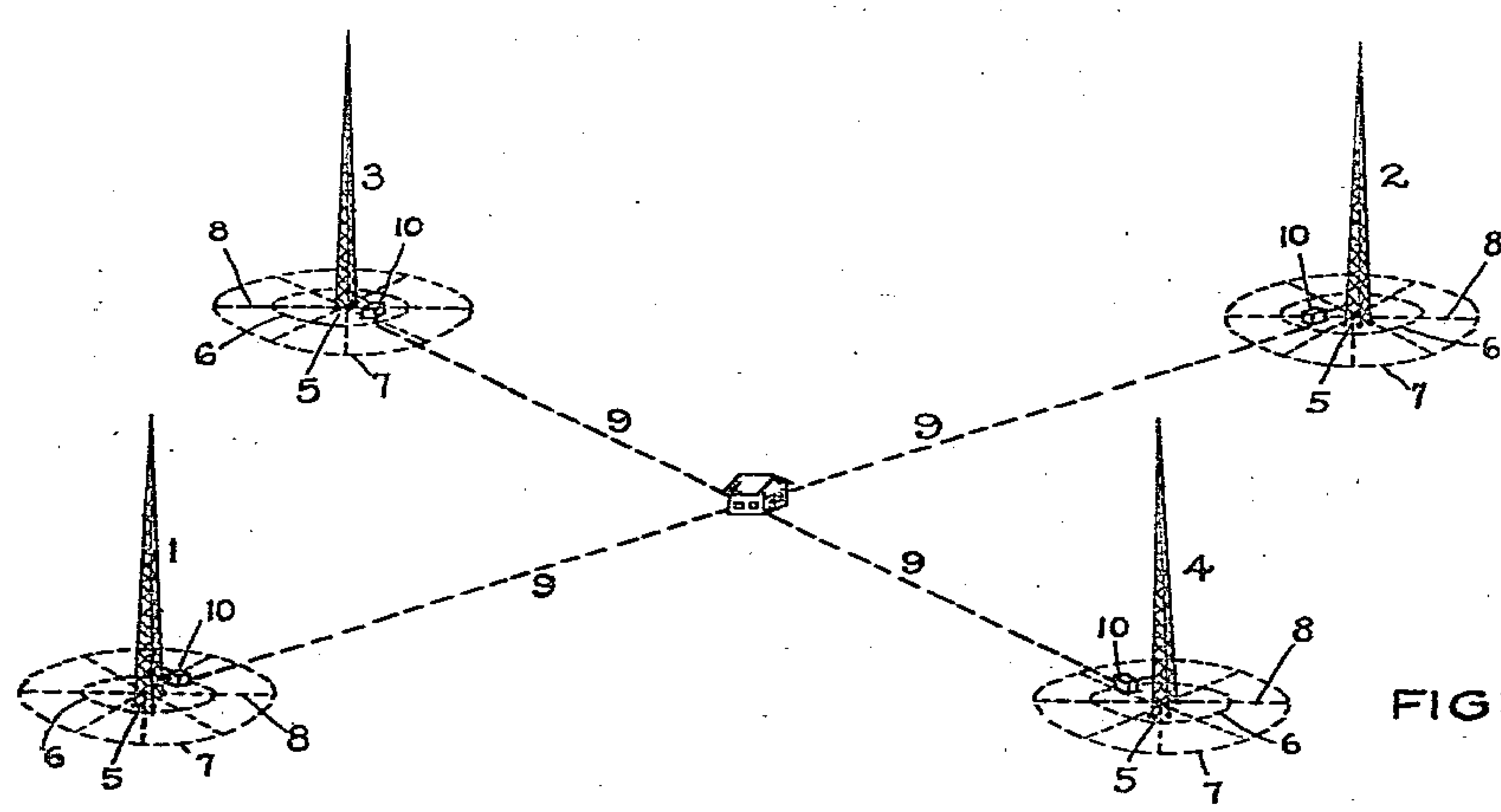


FIGURE 1

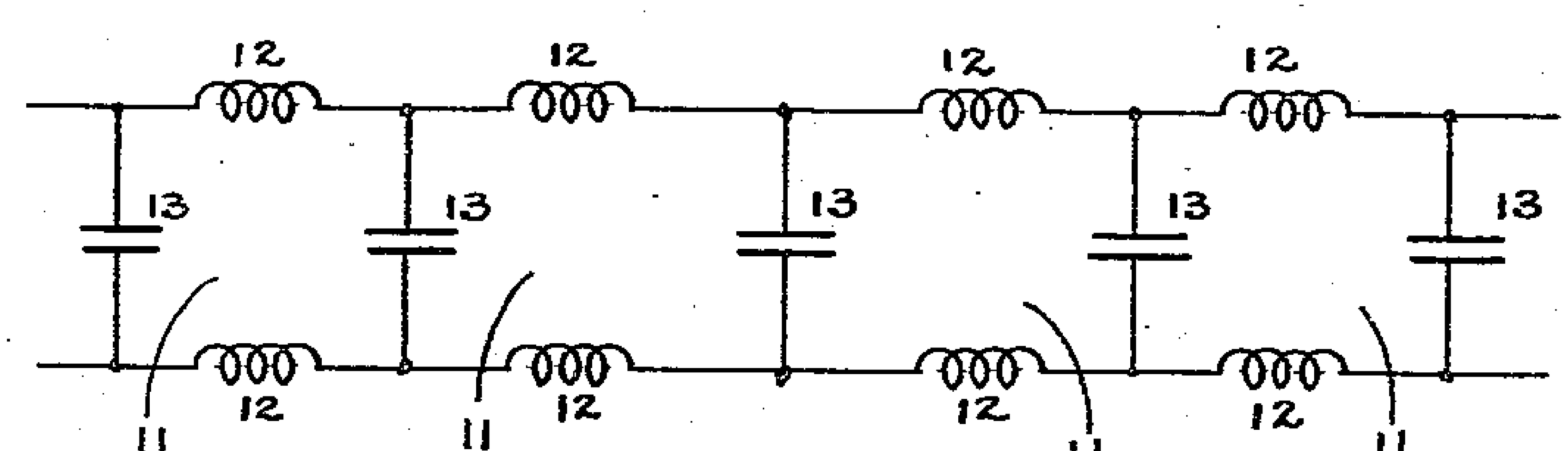
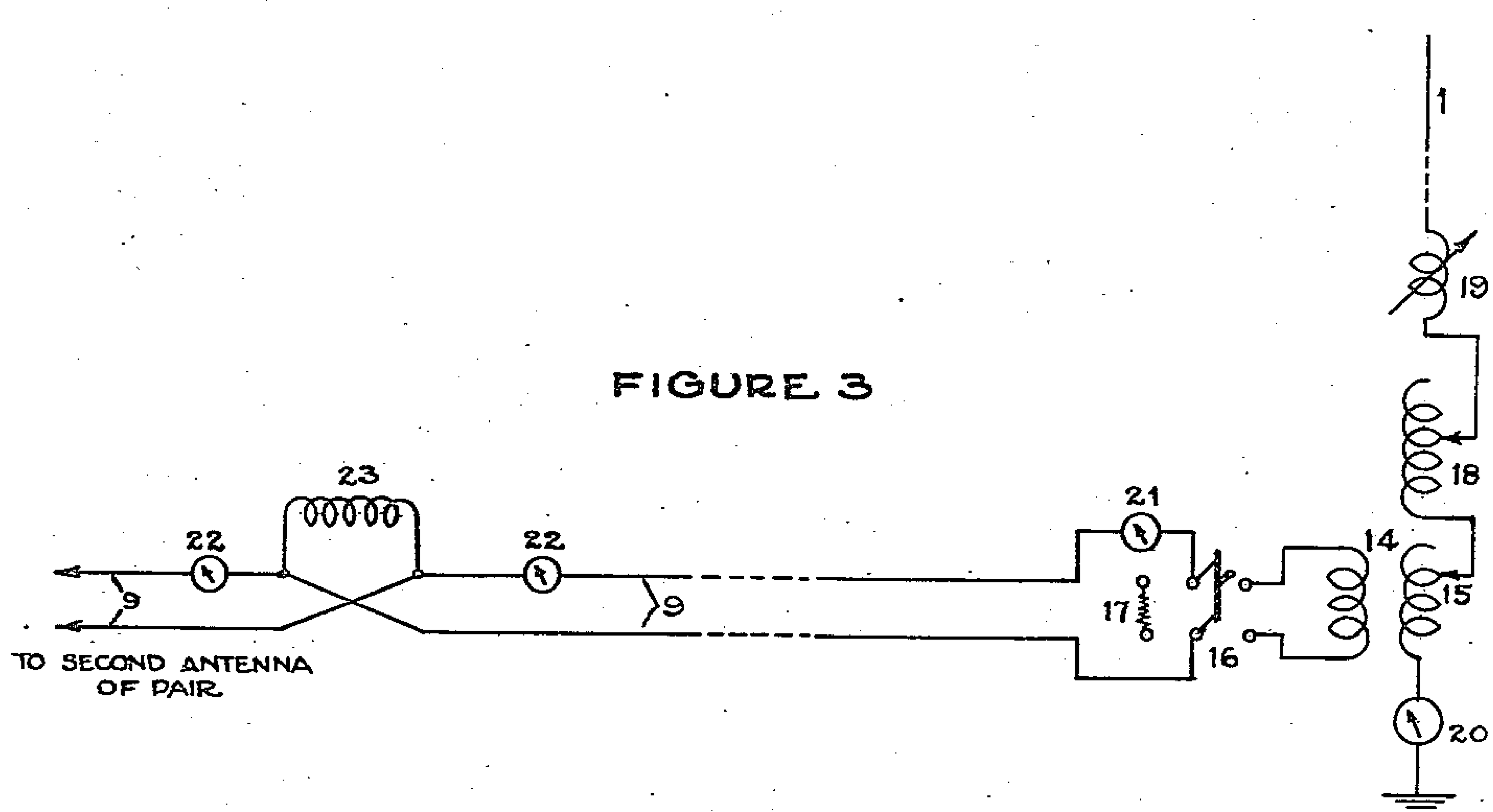


FIGURE 2

FIGURE 3



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Sept. 12, 1939. H. DIAMOND 2,172,365

DIRECTIVE ANTENNA SYSTEM

Filed May 5, 1933 3 Sheets-Sheet 2

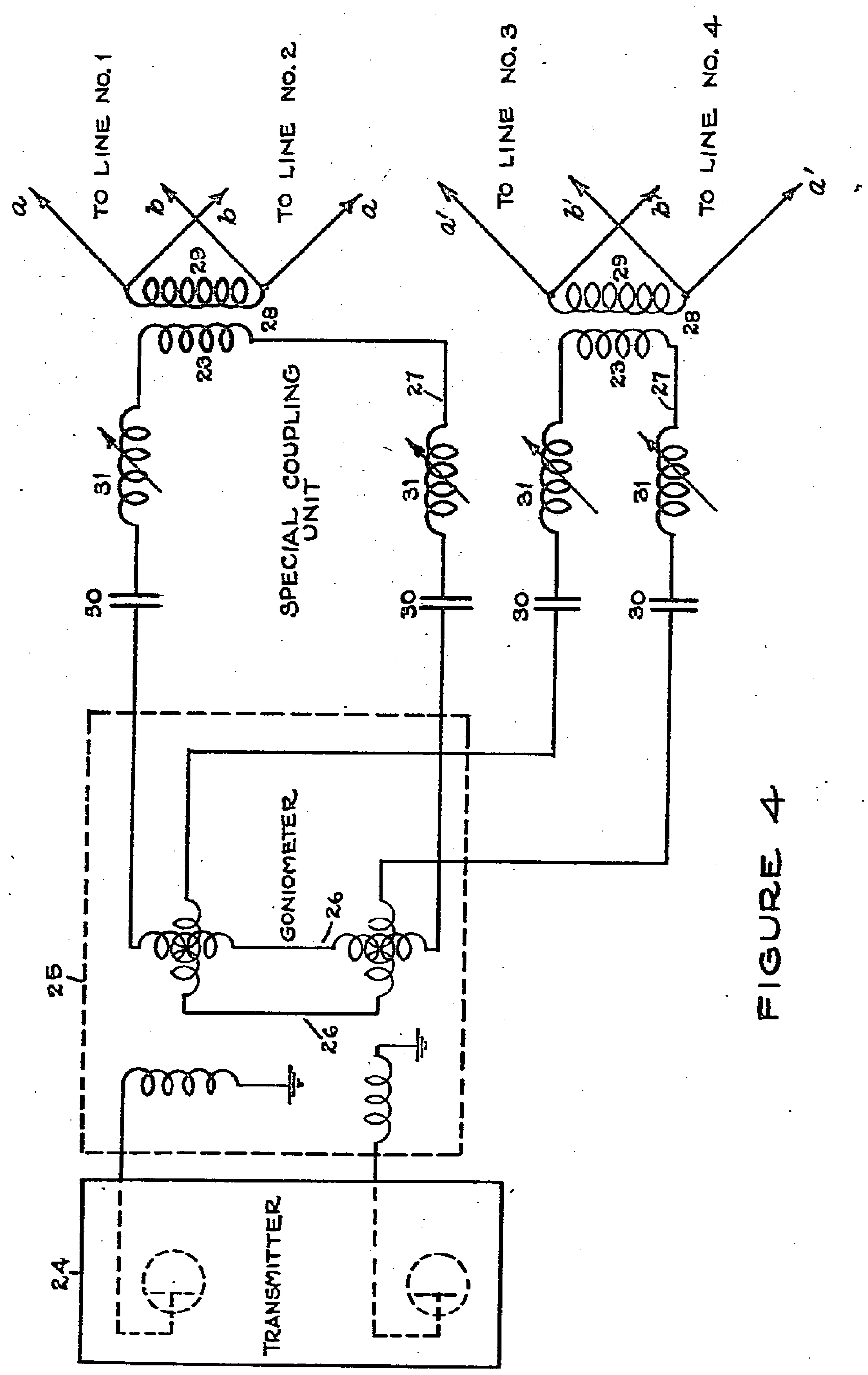

FIGURE 4

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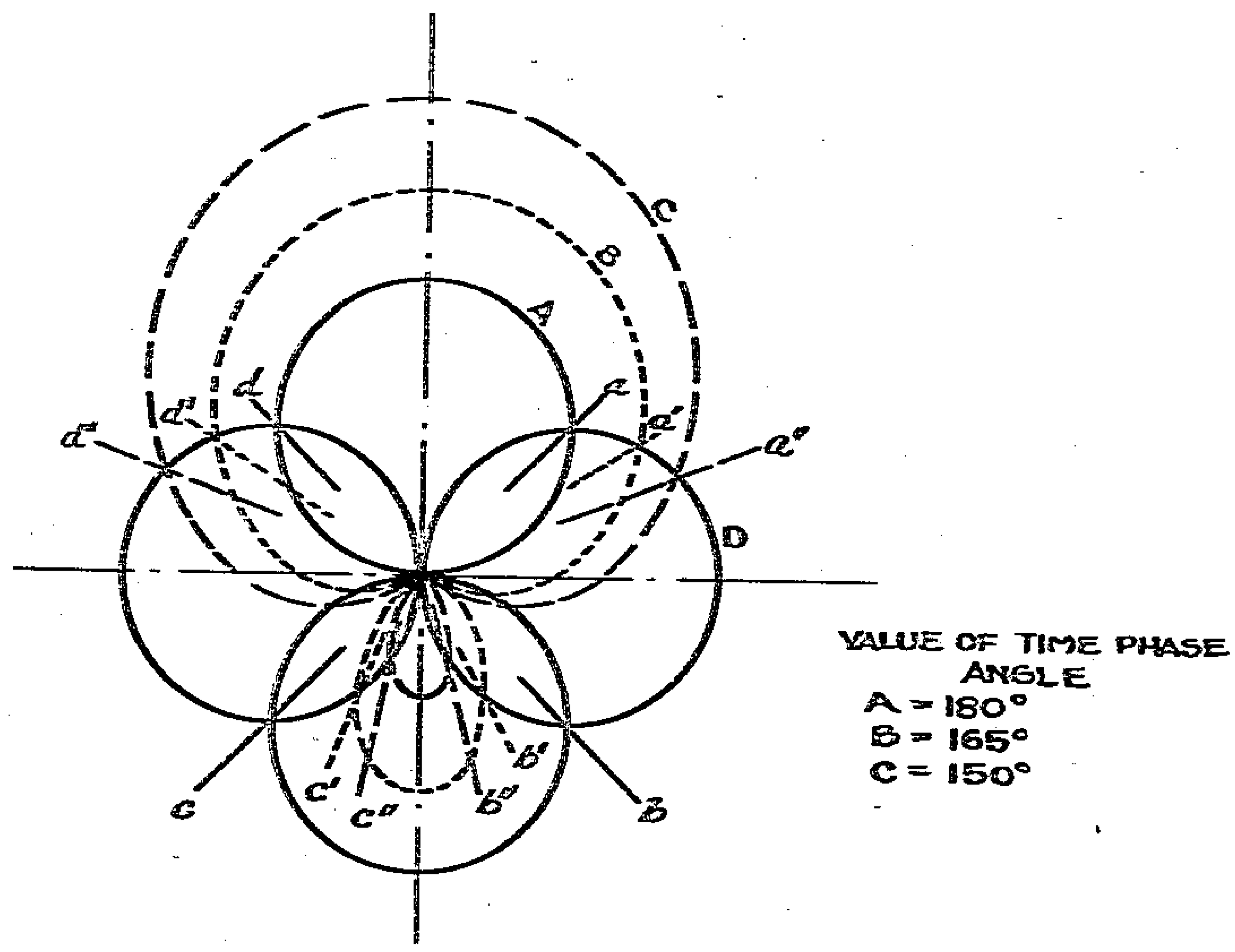

FIGURE 5

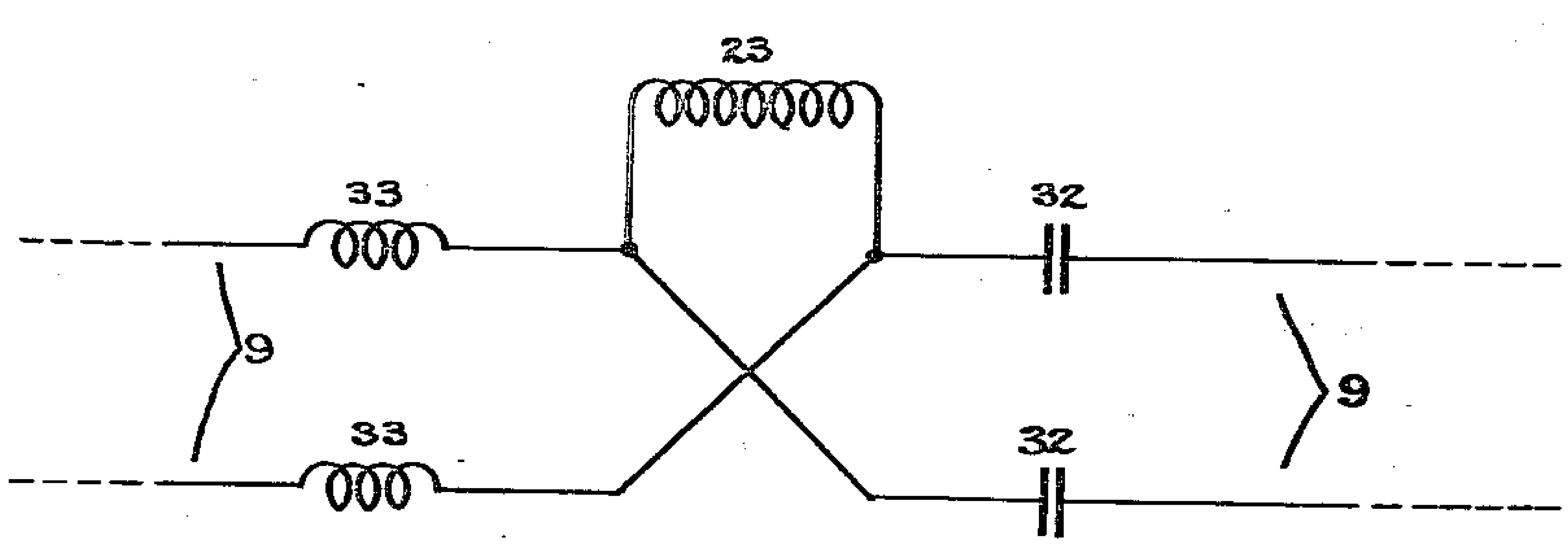

FIGURE 6

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UNITED STATES PATENT OFFICE

2,172,365

DIRECTIVE ANTENNA SYSTEM

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Application May 5, 1933, Serial No. 669,539

9 Claims. (Cl. 250—11)

(Granted under the act of March 3, 1883, as amended April 30, 1928; 370 O. G. 757)

The invention described herein may be manufactured and used by or for the Government of the United States for governmental purposes only, without the payment of any royality thereon.

This system applies generally to radio range-beacon systems, and more particularly to an antenna system for improving the reliability of the radio range-beacon. The radio range-beacon system has been in active use on the civil airways of the United States for nearly four years. The system is also in extensive use in Canada, and in some use in Europe, notably France. Two types of range-beacons are employed, the aural type and the visual type. Without doubt, the system has demonstrated its utility as an aid to air navigation along fixed airway routes. Unfortunately, a phenomenon has been encountered, namely night errors, which seriously limits the use of the range-beacon system at night (particularly over mountainous terrain). This phenomenon takes the form of erroneous indications of the range-beacon courses, so that an airplane following the true course will receive large "off-course" indications to the right, "on-course" indications and large "off-course indications to the left in varying and erratic proportion. Since the magnitude and direction of the errors in course indication vary in an irregular manner with time, it becomes impossible for the pilot to determine his position with respect to the true course, even though a large number of successive course indications be averaged. Unfortunately it is precisely at night and over mountainous terrain that the guidance to aircraft afforded by the radio range-beacon service is most needed. Consequently this limitation to the use of the system hereinbefore described, is of vital importance to the safety of commercial aviation.

My invention comprises a transmitting antenna system for use at the range-beacon station (in place of the conventional loop antenna system hitherto employed) whereby the components of the transmitted wave which result in the phenomeon of night errors are eliminated. My invention therefore prevents the occurrence of erroneous range-beacon course indications at night, and permits the use of this valuable aid to air navigation wherever and whenever needed.

The following brief description is given to indicate the theory underlying the occurrence of night errors. These errors are due to the radio wave reflected from the Kennelly-Heaviside layer and depend upon the state of polarization of this wave when reaching the receiving point. Considering transmission from a loop antenna, the vertical members of the loop antenna set up a vertically polarized field which is proportional to the cosine of the azimuth angle of direction of the wave (taking the plane of the loop antenna as zero angle). The horizontal members of the loop antenna (or members having a horizontal component) set up a horizontally polarized electric field which is proportional to the sine of the azimuth angle of direction of the wave and also to the sine of the angle of elevation of the receiving point with respect to the loop antenna. At any given receiving point having a substantially small angle of elevation with respect to the transmitting point, only the vertically polarized field is received during the daytime, while both the horizontally and vertically polarized fields are received whenever a reflected wave is present (for example, at night). The horizontally polarized waves correspond to high-angle radiation from the transmitter which is reflected down to the receiving point from the Kennelly-Heaviside layer. The transmission characteristic as determined at any given receiving point is therefore a cosine function in the daytime and a function intermediate between a cosine and sine function during the night. The net result during the night time is a virtual rotation in space of the transmission characteristic. The magnitude and direction of the rotation varies irregularly with time as the ratio of horizontally polarized electric field to vertically polarized electric field at the receiving point varies.

The case of the radio range-beacon system may now be considered. The radio range-beacon has employed hitherto two loop antennas crossed at right angles. In the absence of a reflected wave and for receiving points having small angles of elevation with respect to the transmitting station, the transmission characteristic for the radio range-beacon consisted of two cosine characteristics crossed at 90 degrees (each characteristic being referred to the plane containing its loop antenna as the zero angle). The four points of intersection of the two characteristics constitute the four beacon courses. Now consider what occurs when a reflected wave is present. The horizontally polarized component of the reflected wave combines with the vertically polarized components (both in the reflected and the ground waves) to produce a virtual rotation of the two crossed cosine characteristics and consequently of the entire beacon space pattern. Since this rotation varies irregularly in magnitude and direction, depending upon the variation of the ratio of horizontally to vertically polarized components, the points of intersection of the two crossed cosine characteristics rotate or swing in space thereby producing what I have termed night errors in the indicated direction of the beacon courses. It has hitherto been considered possible to eliminate the effect of the horizontally polarized component through the use of a vertical receiving antenna which does not respond to horizontally polarized electric fields. This has not proved effective, however, since, upon reflection of the indirect wave from the Kennelly-Heaviside layer, a rotation of the components of the indirect wave takes place so that the original horizontally polarized component becomes vertical in part and can affect a vertical receiving antenna.

The theoretical basis of my invention may now be understood. To prevent the irregular rotation of the beacon space pattern and consequent swinging of the beacon courses, it is necessary to eliminate the transmission of horizontally polarized electric fields from the horizontal or inclined members of the transmitting antennas.

The influence of the horizontal elements of a loop antenna upon the production of night errors was determined a number of years ago in application to direction finding systems using loop antennas for reception. An antenna having the same directional properties as the loop antenna but free from the effects of the horizontal elements was described in British Patent No. 130,490 issued to R. E. Ellis in 1919. The application of the same principle to directional transmitting antennas appeared in British Patent No. 198,522 issued to J. Robinson, H. L. Crowther, and W. H. Derriman in 1923. Considerable study and experimental work on the development of this type of antenna system for direction finding purposes and for use with the rotating beacon transmitter has been carried on by Smith-Rose, Thomas and Barfield in England since 1926. The arrangement utilized for the rotating beacon transmitter is disclosed in British Patent No. 363,617 issued to R. L. Smith-Rose and H. A. Thomas in 1932. The principle of the antenna involved in each case is to replace the loop antenna by two vertical antennas so coupled to the transmitter that the current in one antenna is in opposite direction to the current in the other antenna. This corresponds exactly to the conditions in the vertical wires of the loop antenna. The horizontal feeders for supplying current to the vertical antennas are arranged in pairs, the two wires of each pair being parallel to each other and carrying equal currents of opposite phase. In this way the horizontal effect is considerably reduced by neutralization. My invention is based upon the amplification and improvement of means for carrying out this principle, particularly in application to the radio range-beacon system.

One object of my invention is to provide a transmitting antenna system for use at the radio range-beacon station whereby the components of the transmitted wave which produce night errors are eliminated.

A second object of my invention is to provide coupling means for transferring power from the radio range-beacon transmitter and goniometer to four vertical antennas so spaced and excited as to produce two crossed cosine (figure-of-eight) space patterns.

A third object of my invention is to provide a novel horizontal feeder arrangement whereby radiation from the horizontal elements of the antenna system is completely eliminated without requiring the use of delicately adjusted circuits as in the older systems.

Another object of my invention is to provide means for controlling the time phase between the currents in two vertical elements of the antenna system so that the beacon courses produced by the intersection of the two space patterns hereinbefore mentioned may be oriented at arbitrary angles to each other so that they may be aligned with airway routes, converging upon a beacon station at arbitrary angles.

Further objects of my invention will appear from a study of the following description and illustrations wherein—

Fig. 1 is a perspective view showing the general arrangement of my antenna system for eliminating night errors with the radio range-beacon system.

Fig. 2 shows the equivalent circuit for the transmission lines employed for eliminating horizontal radiation.

Fig. 3 shows details of one vertical antenna, its coupling to the transmission line employed for eliminating horizontal radiation and the manner of connection to the transmitting set of the two transmission lines feeding each pair of vertical antennas.

Fig. 4 shows the circuit arrangement employed for connecting the goniometer of the radio range-beacon transmitting set to the four transmission lines which feed the four vertical antennas of the system.

Fig. 5 shows the effect of controlling the time phase angle between the currents in two vertical antennas upon the beacon space pattern and upon the orientation of the four beacon courses.

Fig. 6 shows the circuit arrangement used for controlling the time phase angle between the currents in the two antennas of a pair.

Referring to Fig. 1, four vertical antennas 1, 2, 3 and 4 are located at the corners of a square, the pair (1, 2) working together in place of one loop antenna of the former range-beacon antenna system and the pair (3, 4) in place of the second loop antenna. Special attention is paid to increasing the effective capacitance of each vertical antenna to ground, thereby securing as great an antenna current as possible. To this end, each vertical antenna consists of an insulated steel tower of appreciable cross-section. In practical installations of this system, the towers are 6 feet by 6 feet at the base and 125 feet high, the two towers of a pair being spaced 500 feet apart. To insure a fixed low ground resistance, an individual ground wire system 5 is provided at the base of each vertical antenna. Each ground system consists of two concentric circles 6 and 7, 6 being about 75 feet and 7 about 150 feet in diameter: the two circles are interconnected by eight radial spokes 8, which join directly under the vertical antenna.

The significant element of the system is the particular means employed to confine the radiation to the four vertical antennas. A 2-wire parallel-conductor transmission line 9 is used to feed power from the goniometer to each vertical antenna. As will be shown, these transmission lines are of such a nature as not to radiate. The efficient means for eliminating horizontal radiation thus provided makes it feasible to reduce the residual night errors to much smaller values than was possible with any adaptation of the arrangements hitherto disclosed. Moreover, this degree of elimination of horizontal radiation is readily obtained through the normal use of the transmission lines and does not depend upon the critical adjustment of balanced circuits as in the arrangements previously employed. The use of transmission lines also affords efficient transfer of power from the goniometer to the vertical antennas; this is quite important.

Housed in each of a plurality of small boxes 10, shown at the base of each vertical antenna, are antenna loading coils for tuning each antenna to the radio frequency used and also the coupling transformers for coupling the antennas to their respective transmission lines. These boxes are provided with complete shielding to prevent stray horizontal radiation. The transmission lines 9 (Figs. 1 and 3) may consist of ordinary 2-conductor cable with or without a lead sheath and may be buried below the ground surface, if desired. If a lead sheath is used for mechanical protection, it is important that the sheath (particularly that portion near the antenna end) is not electrically connected to the ground wire system except by way of its continuous connection with the earth; otherwise the ground return currents from the antennas concentrate along the sheath thereby re-introducing night errors.

The theory of transmission line operation is well known. The two parallel wires comprising the transmission line may be considered to form a finite series of unit sections 11—see Fig. 2. In each of said units an inductor 12 represents the self-inductance of each wire of the unit section, and each condenser 13 represents the capacitance between the two wires of the unit section. The square root of the ratio of each of the self-inductances 12 to a corresponding capacitance 13 is equal to the surge impedance of the line. If the load end of the transmission line is terminated by a resistor equal to the surge impedance of the line or its equivalent and a voltage applied at the sending end, an electric wave is transmitted along the line and is entirely absorbed by the load resistor. No radiation from the transmission line occurs. This is the desired condition of operation for the radio range-beacon since all radiation is then confined to the four vertical elements of the antenna system.

In marked contrast to the methods for preventing horizontal radiation hitherto disclosed, this arrangement requires no delicate adjustment of circuits. The terminating impedance may depart considerably from the surge impedance of the line without causing undue reflection back along the line and consequent horizontal radiation. The lead sheath, when employed, and also burying the transmission line underground, provide a partial shielding of the line so that residual radiation due to mismatch at the load end is still further reduced.

The circuit arrangement employed for coupling each vertical antenna to the load end of its transmission line is shown in Fig. 3. This figure also shows the arrangement for tuning each antenna, the comparator arrangement to insure proper load termination for the transmission line and finally the connection at their input ends of the transmission lines feeding the two vertical antennas of each pair. Each of the four vertical antennas 1, being selected for illustration, is coupled to a transmission line 9 by means of a coupling transformer 14. The secondary winding of this transformer is provided with a tapped connection 15 to permit accurate matching of its input impedance to the transmission-line surge impedance. A double pole double throw switch 16 permits termination of the transmission line by either the primary of the transformer 14, or by a resistor 17, equal to the surge impedance of the line.

During the adjustment of each antenna the transmission line to the second antenna of the pair is terminated by a similar resistor 17. With the switch 16 thrown to connect the transmission line to the antenna transformer, a loading coil 18 and a fine tuning coil 19 are adjusted for maximum antenna current as read on an ammeter 20. The line current is now read on a special ammeter 21, and the tap 15 is adjusted until this reading is equal to the reading corresponding to resistance termination, the antenna being retuned for each adjustment of the tap 15. The input impedance to the transformer 14 is now equal to the resistor 17, in magnitude but not in phase. This may be observed by the fact that the input current to the line, as read on one of a plurality of ammeters 22, is not the same for resistance and transformer termination of the line. The required correction for phase is made by detuning the antenna slightly, through the addition of inductance in 18 or 19, until 22 reads the same for both positions of the switch 16. The same set of adjustments is repeated for the second antenna, say 2, the switch 16 being now always connected to the resistor 17. After this adjustment is completed the two antennas can be excited together without disturbing the adjustment of either.

In Fig. 3 the connection of the two transmission lines 11 to a coil 23 should be noted. The connections of one of the lines are reversed with respect to those of the second line, thereby causing the currents in the two vertical antennas of a pair to flow in opposite directions, as required. The coil 23 forms part of the equipment for connecting the transmission lines to the beacon transmitter. The complete circuit arrangement for connecting the transmission lines to the range-beacon transmitting set is given in Fig. 4. Transmitting set 24 and goniometer 25 are unaltered. The change required over hitherto existing installations using loop transmitting antennas lies in the addition of means for transferring the radio-frequency power from the rotor windings of the goniometer to the transmission lines. (With the loop transmitting antenna system each rotor winding 26 of the goniometer is connected directly to one of the two loop antennas.) Referring to Fig. 4, each rotor winding 26 is connected in a tuned series circuit 27, which, in conjunction with a radio-frequency transformer 28, has two functions: (*a*) to transfer power from the rotor winding to a pair of transmission lines, and (*b*) to match the impedance of the rotor winding 26 of the goniometer to the impedance of the two transmission lines in parallel. Each tuned rotor circuit 27 comprises the rotor winding 26 in circuit with two condensers 30, two inductors 31, and the primary winding 23 of the coupling transformer 28. The letters a, b, a' and b' on the leads from the secondary transformer winding 29 to the transmission lines indicate the reversal of the connections to one line of each pair in order to obtain phase opposition for the currents in the two antennas of each pair. From the above it is evident that the additional equipment required to change a radio range-beacon from loop antenna transmission to the new antenna system is quite simple.

The use of the new antenna system hereinbefore described provides a simple means for altering the space pattern radiated from a radio range-beacon to permit alignment of the beacon courses with airway routes converging on the beacon station at arbitrary angles with each other. Varying the time phase angle between the currents in the two vertical antennas of each or both pairs accomplishes the desired alignment. When the time phase angle for a given pair is 180 degrees, a true figure-of-eight space pattern is obtained for that pair; when it is 180 degrees minus the space phase angle between the two vertical antennas, a cardioid is obtained. For phase angles intermediate to these two values, a space pattern intermediate to the true figure-of-eight and cardioid results. This affords a convenient means for alignment of the four beacon courses with airway routes converging on an airport at arbitrary angles. Altering the space pattern radiated by one or both of the directional antennas changes the points of intersection of the two patterns and, in consequence, the angular direction of the four equisignal zones or courses. The requirements for a central open-type course bending antenna, such as is employed with the loop antenna system, is thus obviated.

This method of controlling the angles between the beacon courses is best understood from reference to Fig. 5, in which A and D designate the two figure-of-eight space patterns radiated from the two pairs of vertical antennas when the time phase angle between the currents in the two antennas of each pair is 180 degrees. The four beacon courses formed by the intersection of these two space patterns are oriented in space as shown by direction lines *a*, *b*, *c* and *d*, being 90 degrees apart. If the phase angle between the antenna currents for one pair is changed to 165 degrees, the space pattern is changed from A to that shown by B. The orientation of the four beacon courses is now shown by the direction lines *a'*, *b'*, *c'* and *d'*. Similarly, with the time phase angle changed to 150 degrees, the space pattern changes to *c* and the courses are at *a''*, *b''*, *c''* and *d''*. It is understood, of course, that both the original space patterns A and B may be altered by time phase changes in the corresponding pairs of antennas. There is accordingly provided a very flexible method for altering the alignment of the beacon courses without requiring complex auxiliary equipment.

The circuit arrangement for securing the desired control of time phase angle between the currents in the two vertical antennas of a pair is shown in Fig. 6. The time phase angle may be adjusted to any desired value by inserting condensers, **32**, or inductors **33**, of predetermined values in the input circuit of one or other of the two transmission lines **9**. For the purpose of computation of the reactance required for a desired phase angle, the input to each transmission line is considered a pure resistance equal to the surge impedance of the line. The balanced arrangement of condensers or inductors is employed to prevent unbalanced voltages to ground for the two wires of a transmission line. If it is desired to transfer equal currents to the two vertical antennas, half the required reactance is inserted in one transmission line using the condensers **32**, and half in the second line by means of the inductors **33**.

It is to be understood that other means for controlling phase angle are also available and come within the scope of my invention. For example, altering the electrical length of one transmission line with respect to the second will accomplish the same result. This added electrical length may be obtained through increased physical length of line or through the addition of artificial line sections.

Since the time phase angle has such an important effect upon the location of the beacon courses in space, it is necessary to provide special means for quick phase checking. To check the phase for a given pair of antennas, the voltage is removed from the second pair of antennas, and a milliammeter inserted in one of these antennas. This antenna being equidistant from the pair of antennas under test, the current induced in it from the pair depends upon the time-phase angle between the currents in the two antennas of the pair. For 180 degrees phaseangle, the induced current is zero; the greater the departure from 180 degrees, the greater the induced current. The milliammeter reading this current may therefore be calibrated directly in phase angle. Several arrangements are available for bringing this reading into the beacon station so that, if needed, the required adjustment of the phase-control equipment may be made directly.

While I have described and illustrated different examples of my invention, I do not wish to be limited to these specific examples since modifications may be made both in the circuits and apparatus within the scope of my invention.

In the "Air Commerce Bulletin," vol. 4, No. 2, for July 15, 1932, pages 33 to 45, there was published an article under the title "New Type of Transmitting Antenna Developed for Radio Range Beacons" based upon my herein-disclosed invention which was published by the Aeronautics Branch, Department of Commerce, there being no intention to abandon my said invention by this publication.

What I claim is:

1. In a radio range-beacon for setting up a plurality of equisignal courses, means for producing a plurality of radio-frequency voltages having the same carrier frequency but different characteristic signals, means for transferring said voltages in predetermined phase relation to a pair of local auxiliary coupling circuits, four vertical transmitting antennas geometrically arranged about and at appreciable distance from said producing and auxiliary coupling means, four traveling wave mediums for transferring said radio-frequency voltages from each of said auxiliary coupling means to a corresponding pair of said vertical transmitting antennas, means for adjusting the phase of said radio-frequency voltages in the two antennas of each of said pairs to produce a figure-of-eight space radiation pattern for each pair, and auxiliary impedance matching means interposed between said traveling wave mediums and their corresponding vertical antennas to prevent the setting up of standing waves upon said traveling wave mediums, whereby the electric fields radiated are solely from said vertical transmitting antennas and constitute a plurality of differently characterized radio waves in the form of figure-of-eight space patterns at angles to each other, the intersection of any two of said plurality of patterns producing four lines of equisignal which constitute four beacon courses, said beacon courses remaining fixed in azimuth direction in all inclined places having angles of elevation with respect to the transmitting point ranging from zero to ninety degrees.

2. An improved method of varying the orientation of the equisignal courses of a radio range-beacon in order to align them with airway routes

converging upon said radio-beacon at arbitrary angles which comprises transmitting four vertically plane polarized non-directional radio waves from four points geometrically positioned at the corners of a square, one pair of said radio waves radiated from diametrically opposite points of said square being modulated to a selected characteristic signal and the second pair being modulated to a different selected characteristic signal, and varying the time phase angle between the two radio waves of at least one of said pairs to control the shape of the resulting two intersecting space patterns, corresponding to the two characteristic signals, between the limiting shapes of a figure-of-eight and a cardioid so as to fix the azimuth angles of direction of the points of intersection of said space patterns, said points of intersection constituting the radio-beacon courses.

3. In combination with a source of radio-frequency power, a pair of vertical transmitting antennas spaced apart in the horizontal plane by a distance equal to not more than one-half the wave-length of said radio-frequency source, individual tuning means for tuning each of said vertical antennas to the radio-frequency of said source, a pair of two-wire parallel conductor transmission lines for transferring the radio-frequency power from said source, individual coupling means for transferring the radio-frequency power received at the antenna end of each of said transmission lines to a corresponding one of said vertical antennas whereby a figure-of-eight space pattern of vertically plane polarized electric fields is radiated from said pair of vertical antennas, and means for adjusting each of said coupling means so that its input impedance presented to its associated transmission line is equal to the surge impedance of said line thus eliminating the radiation of horizontally plane polarized electric fields from said transmission lines whereby the axis of said space pattern radiated from said vertical antennas remains fixed in azimuth direction in a plurality of inclined planes having varying angles of elevation with respect to the transmitting source.

4. In combination with a source of radio-frequency, a pair of vertical transmitting antennas spaced apart in the horizontal plane by a distance equal to not more than one-half the wave-length of said radio-frequency source, tuning means for tuning said antennas to the radio-frequency of said source, a pair of two-wire parallel-conductor transmission lines, coupling means for transferring radio-frequency power from each of said transmission lines to a corresponding one of said vertical antennas, adjusting means for controlling said coupling means whereby radio-frequency power impressed upon the input ends of said transmission lines will reach said coupling means without causing radiation from the transmission lines, auxiliary coupling means for transferring radio-frequency power to the input ends of said transmission lines from said source, and variable artificial transmission line sections inserted preferably between said auxiliary coupling means and the input ends of said transmission lines whereby the relative phases of the currents in said two vertical antennas may be altered to vary the radiated space pattern from a figure-of-eight through intermediate steps to a cardoioid pattern, the electric fields in said patterns being entirely polarized in the vertical plane of propagation of said electric fields.

5. In combination with a radio range-beacon transmitter, a goniometer receiving radio-frequency power from said transmitter, two local coupling transformers, means for transferring said radio-frequency power from said goniometer to said transformers, four parallel-conductor transmission lines connected in pairs to corresponding ones of said transformers, four vertical transmitting antennas spaced on the corners of a square, four coupling means for connecting each of said vertical transmitting antennas to a corresponding one of said transmission lines and auxiliary adjusting means associated with said coupling means for matching the input impedance of each of said coupling means to the surge impedance of the corresponding transmission line in order that no radiation will occur from said transmission lines, whereby all radiations are confined to said antennas and the intensities of said radiations are at all times fixed functions of the azimuth angle of direction of transmission.

6. In combination with a radio range-beacon transmitter, a goniometer receiving radio-frequency power from said transmitter, four vertical transmitting antennas spaced on the four corners of a square and arranged to have each pair of said antennas on diagonal corners of said square operate together as a directional transmitting antenna, means for transferring power from said goniometer to each of said pairs of antennas whereby the normal space pattern radiated comprises two figure-of-eight patterns each modulated to a different characteristic signal and crossed at right angles, and associated means for controlling the time phase displacement between the two currents in the two vertical antennas of one or the other of said pairs of antennas whereby the space pattern corresponding to the pair of antennas controlled may be altered from the normal figure-of-eight pattern in order that its intersection with the space pattern radiated from the other of said pairs of antennas will produce beacon courses oriented at suitable angles for alignment with airway routes at arbitrary angles.

7. In a radio beacon, the combination of a source of radio frequency electrical oscillations, a plurality of vertical antennas capable of transmitting solely vertically plane polarized electrical waves symmetrically disposed about said source, a plurality of tuning elements, a plurality of coupling elements, one of each of said tuning and coupling elements being completely shielded and disposed at the base of each vertical antenna, a plurality of traveling wave type transmission lines each of which connects one of said coupling elements with said source, and adjustable taps on said coupling elements for matching the impedance presented by said coupling elements to said transmission lines to the surge impedance of said lines, whereby the space pattern radiated from said radio beacon remains constant in directional characteristic both day and night.

8. In a radio range-beacon for setting up a plurality of equisignal courses, means for producing a plurality of radio-frequency voltages having the same carrier frequency but coded to different characteristic signals, means for transferring said voltages in predetermined phase relation to a pair of local auxiliary coupling circuits, four vertical transmitting antennas geometrically arranged about and at appreciable distance from said producing and auxiliary coupling means, four traveling wave mediums for transferring said coded voltages from each of

said auxiliary coupling means to a corresponding pair of said vertical transmitting antennas, means for adjusting the phase of said radio-frequency voltages in the two antennas of each of said pairs to produce a figure-of-eight space radiation pattern for each pair, and auxiliary impedance matching means interposed between said traveling wave mediums and their corresponding vertical antennas to prevent the setting up of standing waves upon said traveling wave mediums, whereby the electrical fields radiated are solely from said vertical transmitting antennas and constitute a plurality of differently coded radio waves in the form of figure-of-eight space patterns at angles to each other, the intersection of any two of said plurality of patterns producing four lines of equisignal which constitute four beacon courses, said beacon courses remaining fixed in azimuth direction in all inclined planes having angles of elevation with respect to the transmitting point ranging from zero to 90 degrees.

9. An improved method of varying the orientation of the equisignal courses of a radio range-beacon in order to align them with airway routes converging upon said radio-beacon at arbitrary angles which comprises transmitting four vertically plane polarized non-directional radio waves from four points geometrically positioned at the corners of a square, one pair of said radio waves radiated from diametrically opposite points of said square being coded to a selected characteristic signal and the second pair being coded to a different selected characteristic signal, and varying the time phase angle between the two radio waves of at least one of said pairs to control the shape of the resulting two intersecting space patterns, corresponding to the two characteristic signals, between the limiting shapes of a figure-of-eight and a cardioid so as to fix the azimuth angles of direction of the points of intersection of said space patterns, said points of intersection constituting the radio beacon courses.

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