Feb. 26, 1935. H. DIAMOND 1,992,197

METHOD AND APPARATUS FOR A MULTIPLE COURSE RADIOBEACON

Filed March 9, 1932 5 Sheets-Sheet 1

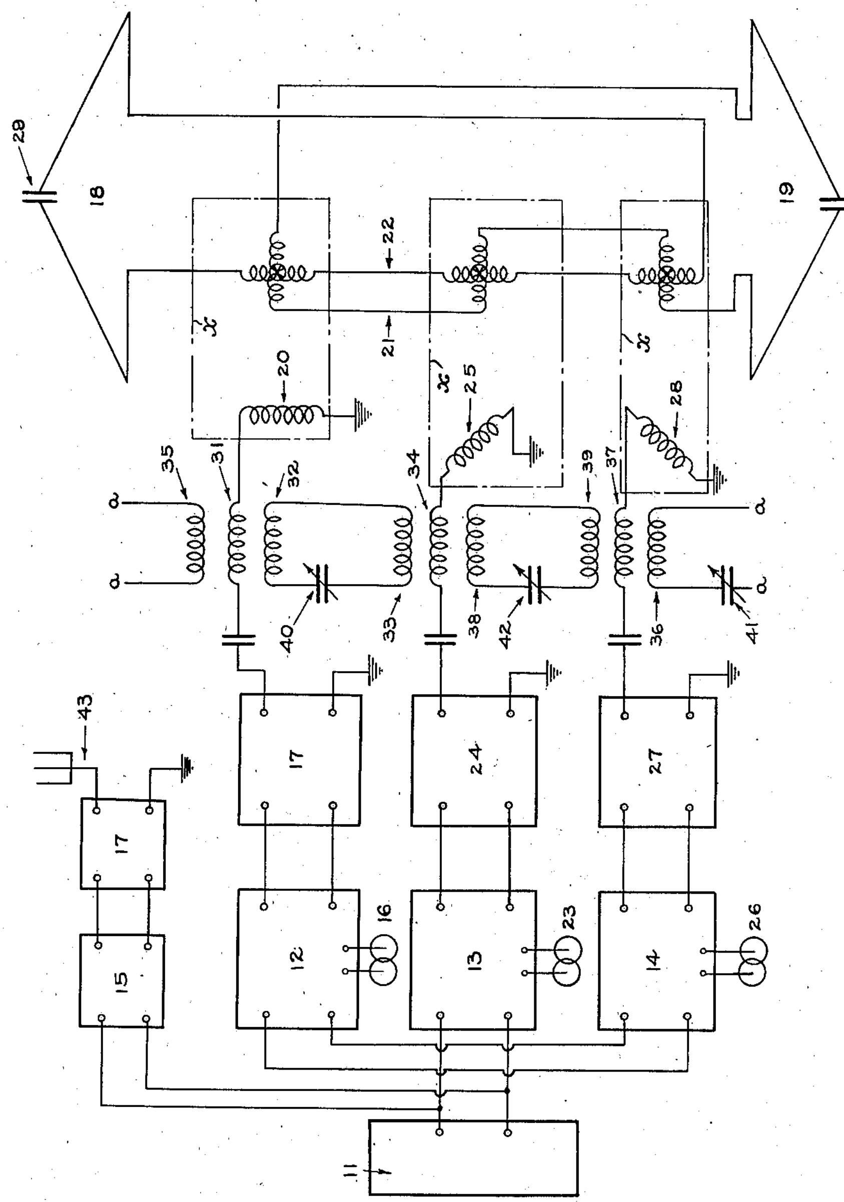

FIGURE 1

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METHOD AND APPARATUS FOR A MULTIPLE COURSE RADIOBEACON

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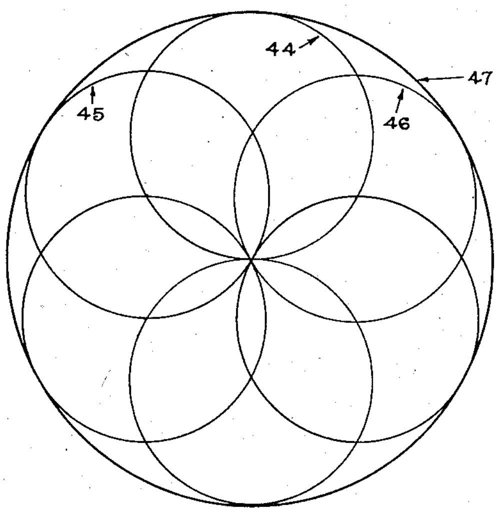

FIGURE 2

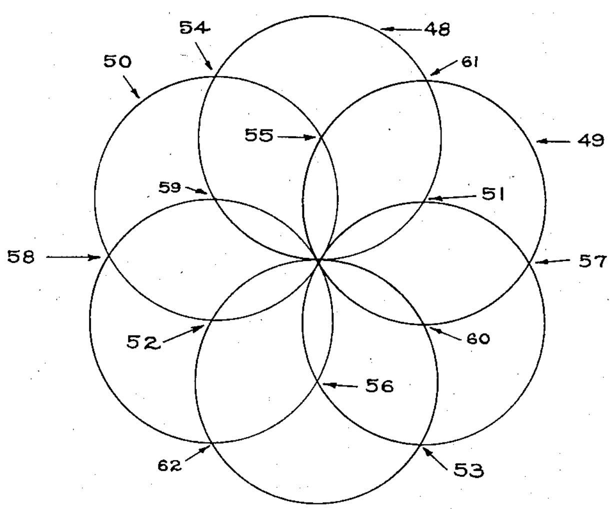

FIGURE 3

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METHOD AND APPARATUS FOR A MULTIPLE COURSE RADIOBEACON

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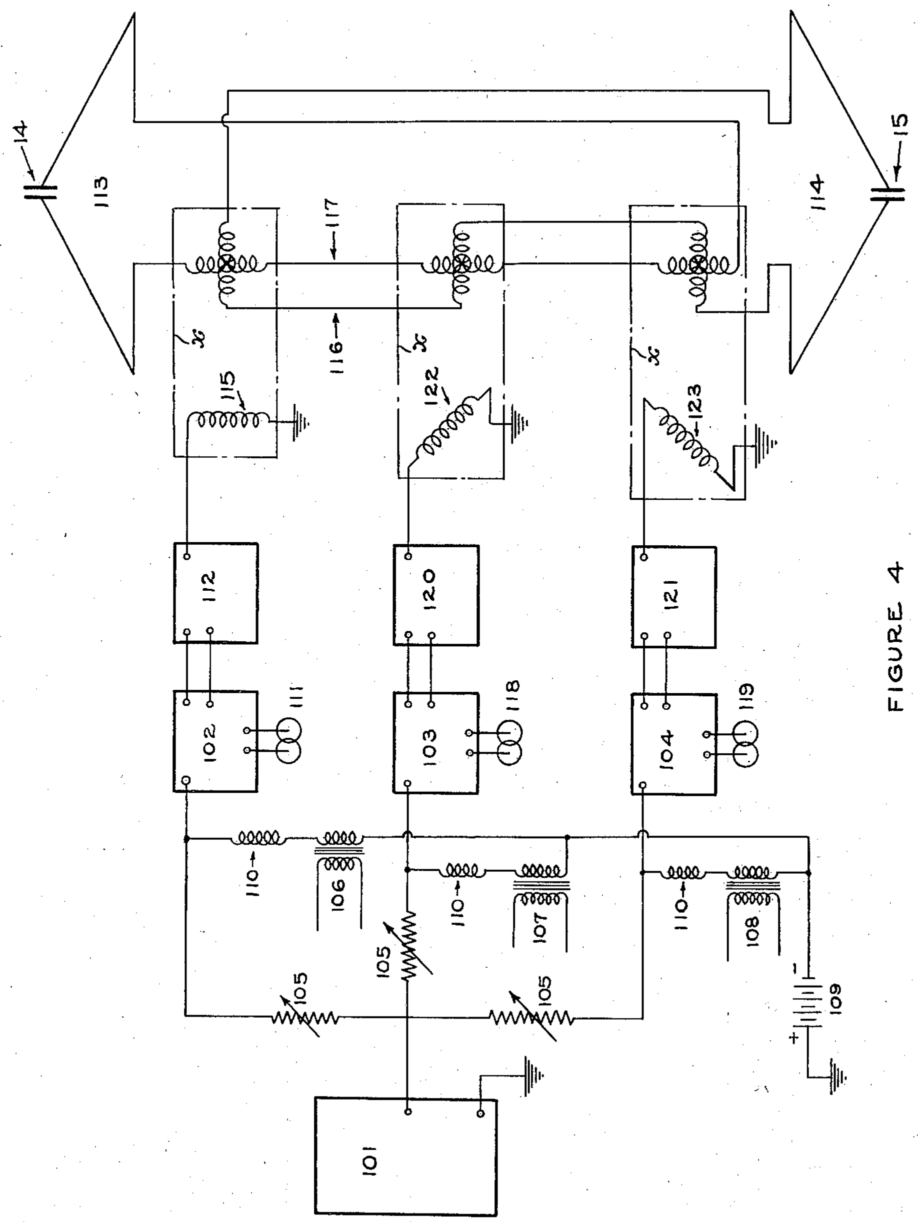

FIGURE 4

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METHOD AND APPARATUS FOR A MULTIPLE COURSE RADIOBEACON

Filed March 9, 1932 5 Sheets-Sheet 4

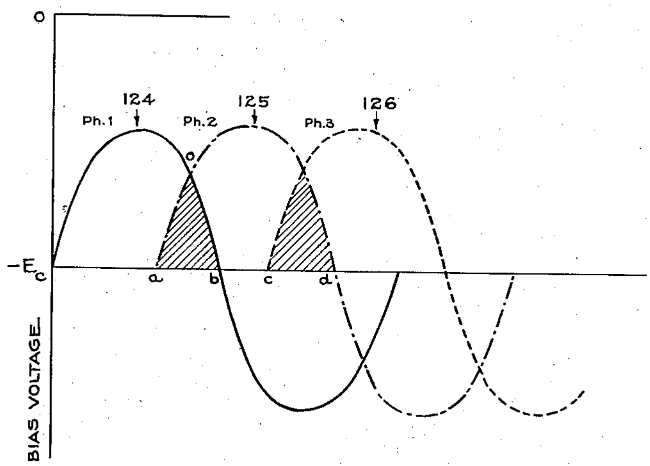

FIGURE 5

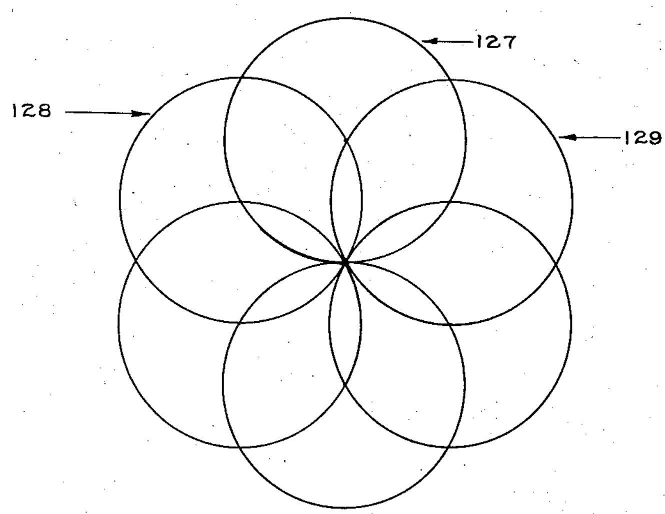

FIGURE 6

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METHOD AND APPARATUS FOR A MULTIPLE COURSE RADIOBEACON

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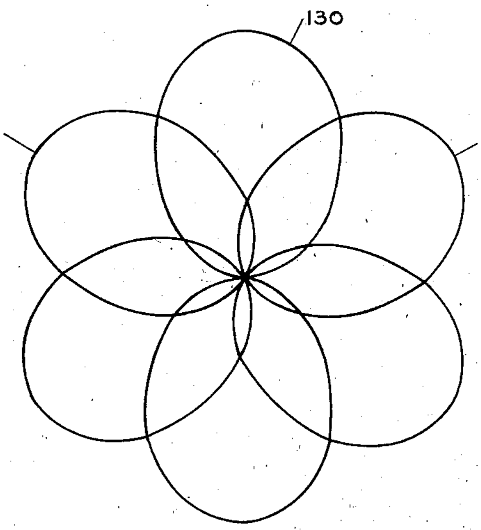

FIGURE 7

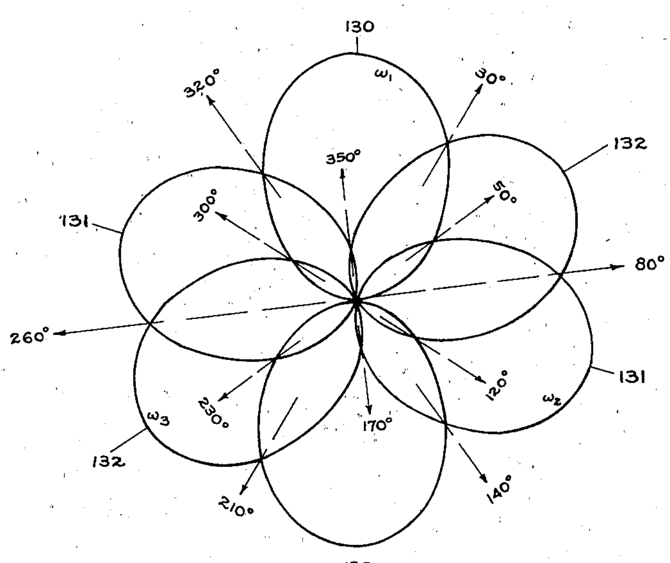

FIGURE 8

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Patented Feb. 26, 1935

1,992,197

UNITED STATES PATENT OFFICE

1,992,197

METHOD AND APPARATUS FOR A MULTIPLE COURSE RADIOBEACON

Harry Diamond, Washington, D. C., assignor to the Government of the United States as represented by the Secretary of Commerce

Application March 9, 1932, Serial No. 597,757

11 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 without the payment of any royalty thereon.

The invention relates to methods of and apparatus for producing directive radio beacon signals, and has for its general object the provision of a signal transmitting apparatus capable of serving more than four courses simultaneously. Another object is to provide means for aligning the radio beacon courses with the fixed airways.

The rapid increase in the number of airways emanating from the more important airports has created a need for a directive radio beacon capable of marking out more than four courses. My purpose is to render the beacon more flexible and thus make it suitable for use at cities located at the junction of a large number of airways. To accomplish this object I have developed a beacon capable of serving any number of courses from one to twelve simultaneously. The increase in apparatus over the beacons above described is not great. An additional train of amplifiers and an additional modulating frequency are used, as will be described hereinafter.

A special goniometer is also required, having, in the preferred type of apparatus, three stator coils, one stator coil being connected to each power amplifier tube. The stator coils in the embodiment of my invention are disposed at 120 degrees to each other, but these angles may be deviated from in any manner to obtain certain desired conditions, as will appear hereinafter. The rotor system of this goniometer comprises two coils crossed at 90 degrees, and each connected in series with one loop antenna. For convenience in goniometer design, each rotor coil is made up of three sections and each section is in inductive relationship with one stator.

Since the goniometer stator windings are not at 90 degrees with each other, undesirable intercoupling between the stators will exist, unless certain precautions are taken, resulting in a combined beacon space pattern which can not be used. Direct inductive coupling between stator windings is eliminated by the use of the 3-section rotor system, each stator winding being placed in a separate shielded compartment.

Indirect coupling between stator windings by virtue of their mutual induction with the rotor system, still exists. Methods and means for eliminating the indirect coupling will be described hereinafter.

Although I shall describe this embodiment of my invention, using three coils and capable of serving twelve courses, it is to be understood that a greater number of coils may be utilized to serve a correspondingly greater number of courses, the principle employed remaining the same.

On the airplane, the usual indicating vibrating reed arrangement is used as before, but may be provided with three reeds instead of two, by means of which a pilot is enabled to easily determine which of the twelve courses he is on. The manipulation of the usual indicating apparatus for the purpose is not, however, a part of the present invention, and will not be considered in detail. It will be described more in detail in another application for a patent. The construction and mode of operation of my invention will be more particularly understood from the following detailed description taken in connection with the accompanying drawings.

Referring to the drawings:

Figure 1 is a diagram of a triple-modulation direactive radio beacon transmitter and coil antenna system embodying my invention, in one particular arrangement.

Figure 2 is a diagrammatic view illustrating the radiated beacon space pattern of the system shown in Figure 1.

Figure 3 is a diagrammatic view illustrating the corresponding polar pattern as received on the reeds.

Figure 4 is a diagram of a triple-modulation directive radio beacon transmitter and coil antenna system using an alternative arrangement for preventing intercoupling between amplifying branches and goniometer primary coils.

Figure 5 is a diagram showing the resultant biasing voltages on the grid of each intermediate-amplifier stage.

Figure 6 shows the space pattern radiated by the beacon when using the grid biasing arrangement for preventing intercoupling between primary goniometer windings.

Figure 7 shows the received pattern corresponding to the space pattern of Figure 6.

Figure 8 shows the displacement of beacon courses obtained when shifting one stator by 20 degrees from its normal position.

The novel features and details embodied in my invention will now be described. Referring to Figure 1, the numeral 11 shows a conventional form of master oscillator which is connected for supplying radio frequency in predetermined amounts, to the intermediate amplifier tubes 12, 13, 14 and 15. The output of the intermediate amplifier 12 is modulated to, say, 65 cycles, by a modulator 16. The modulated high frequency is then amplified by a power amplifier 17 and transferred to the antennæ 18 and 19 by means of the inductive relation between a stator 20 and the rotors 21 and 22. By a similar transformation the output of the intermediate amplifier tube 13 is modulated by a modulator 23 to, say, 108.3 cycles, and after being amplified by a power amplifier 24, is transferred to the antennæ 18 and 19 by means of the inductive relation between a stator 25 and the rotors 21 and 22. Likewise, the output of the intermediate amplifier tube 14 is modulated by a modulator 26 to, say, 86.7 cycles, and after amplification by a power amplifier tube 27, is transferred to the antennæ 18 and 19 by means of the inductive relation between a stator 28 and the rotors 21 and 22. The antennæ 18 and 19 are tuned to the frequency of the master oscillator by means of the condensers 29 and 30, respectively. The loop antennæ 18 and 19 are in 90 degrees space phase so as to reduce the intercoupling to a minimum.

Each stator coil, acting in conjunction with the two crossed-rotor coils and the two crossed loop antennæ, sets up a system which is electrically equivalent to a single loop antenna. The plane of this phantom antenna coincides with the plane of the stator winding for zero setting of the rotor, but rotates in space as the rotor system is rotated. Since there are three stator coils, placed at 120 degrees with each other, three such phantom antennæ (crossed at 120 degrees) exist. When special precautions are taken in circuit design the combined space pattern consists of a circular carrier with three figures-of-eight sets of side bands crossed at 120 degrees.

An essential precaution is the elimination of intercoupling between the stators 20, 25 and 28, which, if present, would result in a combined space pattern which can not be used. Direct inductive coupling between stator windings is eliminated by the use of the three section rotor system, each stator winding being placed in a separate shielded compartment x. Indirect coupling between stator windings by virtue of their mutual induction with the rotor system still exists. This coupling is somewhat more difficult to eliminate. Several arrangements are possible for preventing this undesirable intercoupling.

One arrangement consists of neutralizing this coupling by introducing inductive coupling between stator windings of opposite sense, as shown in Figure 1. Thus the stator 20 is coupled to the stator 25 by coils 31; 32; 33; 34 and to the stator 28 by coils 31; 35; 36; 37. Similarly the stator 25 is coupled to the stator 20 as noted and to the stator 28 by coils 34; 38; 39; 37. The link circuits 32, 40; 33 and 35; 41; 36 and 38; 42; 39 in which 40; 41 and 42 indicate variable condensers, are each tuned to the beacon carrier frequency. It is evident that by virtue of these link circuits a current flowing in any stator induces in each of the other stators an E. M. F. 180 degrees out of phase with that current. On account of the indirect coupling between stators by way of the rotor system, a current flowing in any one stator induces in each of the other stators a voltage exactly in phase with that current. By properly adjusting the amount of coupling due to the link circuits, an exact neutralization may be obtained.

The carrier-frequency currents in the stators 20; 25 and 28 have been assumed to be in time phase. Since the stator windings are displaced by 120 degrees space phase, the resultant carrier transmitted is zero. A circuit carrier can, however, be supplied by the use of a vertical antenna 43 extending along the beacon tower and coupled through a train of amplifying tubes to the master oscillator of the beacon transmitting set.

The combined space pattern which consists of three figure-of-eight side band characteristics and a circular carrier is shown in Figure 2. 44 indicates the figure-of-eight side band characteristic from stator 20 modulated at 65 cycles, 45 indicates a similar characteristic from the stator 25 modulated at 108.3 cycles, and 46 indicates a similar characteristic from the stator 28 modulated at 86.7 cycles. 47 indicates the circular carrier radiated from the vertical antenna.

The corresponding polar pattern, assuming square law detection, is shown in Figure 3, in which 48 shows the figure-of-eight reed amplitude characteristic due to the 65-cycle modulation, 49 and 50 show similar characteristics for the reed amplitudes at 86.7 and 108.3 cycles, respectively. Now assume that a pilot is equipped with three vibrating-reed course indicators of the two-reed type, the first tuned to 65 and 108.3 cycles, the second to 86.7 and 108.3 cycles, and the third to 86.7 and 108.3 cycles, respectively. Using the first indicator, he will find four courses at 51; 52; 53; and 54. With the second course indicator he will observe four courses at 55; 56; 57 and 58. Similarly, with the third reed indicator, four courses at 59; 60; 61 and 62 will be obtained. Two of each set of four courses (for example, 51 and 52) have an equisignal zone of 1 to 1.5 degrees wide, while the width of this zone for the other two courses, (viz. 53 and 54) is from 2 to 3 degrees.

The use of link circuits to eliminate coupling between stator windings and the need for supplying an auxiliary carrier to replace the one suppressed by the goniometer system may both be precluded if means are provided for exciting but one stator winding at a time. A circuit arrangement accomplishing this desired result is shown in Figure 4, in which the numeral 101 is a conventional form of master oscillator supplying radio-frequency power to the three intermediate power amplifier tubes 102; 103; and 104 at, say, 290 kc, through the medium of balancing resistors 105 and conductors attached thereto. 106; 107 and 108 denote transformers, one terminal of the secondary of each is connected to the direct current biasing voltage 109, the other terminal is connected to the grid of an intermediate amplifier tube through the medium of a radio-frequency choke 110. The primary of each transformer is connected to one phase of a 3-phase 300-cycle supply. The choice of this frequency is of importance in the operation of the system.

The output of the intermediate amplifier tube 102 is modulated to, say, 65 cycles, by means of modulator 111 and after amplification by the power amplifier tube 112 is transferred to the antennæ 113 and 114 through the inductive relations between the stator 115 and the rotors 116 and 117. In a similar manner, the output of the intermediate amplifier tubes 103 and 104 is modulated to, say, 108.7 and 86.7 cycles, respectively, by means of modulators 118 and 119, amplified by power amplifiers 120 and 121 and transferred to the antennæ 113 and 114 through the inductive relations of the stators 122 and 123 and the rotors 116 and 117.

The direct current biasing voltage applied to the grids of the intermediate-amplifier tubes is of such magnitude that (in the absence of the three-phase 300-cycle supply) no power is transmitted through these tubes. In series with this common direct current biasing voltage, each grid circuit has induced in it one of the phase voltages of the three-phase 300-cycle supply. The resultant biasing voltages impressed on the grid of each of the three intermediate amplifying tubes is indicated by curves 124, 125 and 126, respectively, of Figure 5.

Since E_c is the cutoff voltage, each tube passes power only during the positive half-cycle of its alternating current biasing voltage. As a result no two amplifier tubes transmit power simultaneously except during the small intervals of time *a*—*b*, *c*—*d*, etc. as shown in Figure 5.

The proportion of power transmitted during these intervals is less than the ratio of shaded area *aob* to total area of transmission per cycle for one tube E_c *ob*, since the tube is then operating on the knee of its characteristic curve. The amount of coupling still present may be further reduced by increasing the common direct current bias voltage, but this results also in a decrease of total power transmitted. In practice this further reduction is unnecessary, the beacon performance proving satisfactory without it.

Neglecting the small amount of coupling present, the beacon space pattern becomes as shown in Figure 6, in which 127 denotes the radiation intensity of the carrier and side bands modulated at 65 cycles from stator 115, 128 and 129 denote similar characteristics, modulated at 108.3 and 86.7 cycles, respectively, from the stators 122 and 123.

Note that since but one stator winding is excited at a time, there are three independent carrier waves in the beacon space pattern. Assuming square-law detection, the polar pattern as received on the reeds is shown in Figure 7, in which 130 shows the reed amplitude corresponding to the 65-cycle modulated carrier. Similarly, 131 and 132, show the reed amplitudes corresponding to the 108.3 and 86.7-cycle modulated carriers, respectively.

The choice of frequency of the three-phase alternator used for the grid bias switching is important. The fundamental and second harmonic of this frequency must not be closer than approximately 20 cycles to any of the harmonics of the modulation frequencies used in the beacon. To illustrate the reason for this requirement assume that a frequency of 262 cycles were chosen for the three-phase alternator. The fourth harmonic of 65 cycles and the third harmonic of 86⅔ cycles are each 260 cycles. Under this condition a beating of the reed indicator at the difference frequency of 2 cycles is obtained.

The same means are available for shifting the beacon courses from their 30 degree space relationship (in order to align them with the airways emanating from a given airport) as has been previously employed in connection with the four-course beacon. A simpler method applicable only to the 12-course beacon is, however, preferable. This method consists of displacing the stator windings from their normal 120 degree positions.

Since the stators are excited one at a time, displacement of a given stator results in an equivalent displacement of the field pattern due to that stator. Thus, Figure 8 is the received polar pattern when stator 122 is displaced by 20 degrees from its normal position. The pattern due to 122 is similarly displaced. (Compare with Figure 7.) The eight courses formed by the intersection of the pattern due to stator 122, with the patterns due to 115 and 123 are all shifted by 10 degrees in the direction of displacement of 122 while the four courses due to the patterns of 115 and 123 remain fixed in their normal positions. A greater variation of the angles between courses may be obtained by displacing two of the three stators in equal amounts, but in opposite directions.

Using this method of attack, it becomes possible to align the beacon courses with the airways at a great number of airports. In certain special cases, however, it may become necessary to resort to other methods of course shifting already known to the art.

What I claim is:

1. A method for producing a directive radio beacon providing more than four beacon courses, which includes generating more than two modulated waves having the same carrier frequency but each modulated by a different selected audio-frequency modulation signal, interrupting said modulated waves so that they occur singly at successive intervals of time, adjusting the rate of interruption so that each of said modulation signals are continuous in effect upon reception, and combining said interrupted modulated waves in a pair of directional radiation sources so that the resultant radiated waves contain figure-of-eight space patterns corresponding to each of said modulated waves, the axes of said space patterns intersecting at predetermined angles with each other.

2. A transmitter and antenna system comprising two loop antennæ arranged at right angles to each other, a source of radio-frequency carrier, three amplifying branches each provided with one or more amplifying tubes, an automatic switching circuit for exciting one amplifier branch at a time by means of a multi-phase alternating current supply in series with a common direct current biasing voltage, each grid circuit having induced in it one of the phase voltages of the multi-phase alternating current supply.

3. In a beacon transmitter, the combination with means for producing in rapid succession three modulated waves each of the same carrier frequency but having a different selected audio-frequency modulation, of means for transferring said modulated waves to two directive antennæ whereby said modulated waves are transmitted in predetermined directions to produce a twelve-course radio beacon space pattern, and means for varying said transfer means whereby the entire beacon space pattern may be rotated in space or fixed at any desired orientation.

4. A goniometer comprising three primary windings placed at predetermined angles to each other, two secondary windings crossed at right angles each in inductive relationship with said primary windings, of means for shielding said primary windings from each other to prevent direct intercoupling, and auxiliary means for intercoupling said primary windings whereby the indirect coupling between said windings by virtue of their inductive relationship with the secondary windings is exactly neutralized.

5. In a beacon transmitter, the combination with a source of radio frequency energy, of three amplifying branches for amplifying said radio frequency energy, three equivalent tuned circuit loads fed by said amplifying branches, and means for rapidly switching said radio-frequency energy successively to each of said tuned loads comprising a source of three-phase substantially low frequency, alternating voltage and a source of negative direct voltage applied to the input circuit

of each of said amplifying branches in series with one of the phase voltages of said three-phase alternating voltage whereby each of said power amplifying branches passes said radio frequency energy only during a portion of the positive half-cycle of the alternating low-frequency voltage applied to its input circuit.

6. In a beacon transmitter, the combination with means for producing a plurality of modulated waves each of the same carrier frequency but having a selected modulation frequency differing from each of the other waves, of means for suppressing said carrier frequency in each of said modulated waves, means for transferring the resultant sets of side band frequencies to two directive antennæ whereby said sets of side band waves are transmitted in predetermined directions, means for radiating in all directions a carrier wave of identical frequency with the suppressed carriers and of proper phase to combine with said sets of side band waves to produce a multi-course radio beacon space pattern, and means for varying the directions of transmission of said side band waves whereby said beacon space pattern may be rotated in space or fixed at any desired orientation.

7. A goniometer comprising three primary windings placed at predetermined angles to each other, means for electrically shielding said primary windings from each other, two secondary windings crossed at right angles and each in mutual inductive relationship with all of said primary windings, and means for rotating said secondary windings with respect to said primary windings whereby the mutual inductance between each of said secondary windings and each of said primary windings is varied in substantially sinusoidal relation.

8. In a beacon transmitter, the combination with a source of radio frequency energy, of a plurality of amplifying branches for amplifying said radio frequency energy, two directive antennæ crossed at right angles, and a goniometer comprising more thatn two primary windings placed at predetermined angles to each other and each fed from a corresponding one of said amplifying branches, said primary windings being in mutual inductive relationship with two mutually perpendicular secondary windings each of which is connected to one of said directive antennæ, whereby the same radiated space pattern may be produced as from a system of directive antennæ equal to in number and placed in the same angular relationship as said primary windings of said goniometer and coupled directly each to a corresponding one of said amplifying branches.

9. A method for producing a multi-course directive radio beacon which comprises transmitting simultaneously in definite directions a plurality of radio-frequency fields each with a different selected audio-frequency modulation and from each of which the carrier frequency has been suppressed and resupplying the carrier wave in proper time phase relationship by radiation from a non-directional antenna.

10. A goniometer comprising three primary windings located in separate shielded compartments and placed at predetermined angles to each other, two secondary windings crossed at right angles, each of said secondary windings consisting of three separate sections in mutual inductive relationship with corresponding ones of said primary windings, and means of intercoupling said primary windings whereby the indirect coupling between said windings by virtue of their inductive relationship with said secondary windings is exactly neutralized.

11. A goniometer comprising three primary windings located in separate shielded compartments and placed at predetermined angles to each other, two secondary windings crossed at right angles, each of said secondary windings consisting of three separate sections in mutual inductive relationship with corresponding ones of said primary windings, and means for rotating said secondary windings with respect to said primary windings whereby the mutual inductance between each of said secondary windings and each of said primary windings is varied in substantially sinusoidal relation.

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