March 11, 1941. D. G. C. LUCK 2,234,828

RADIO BEACON

Filed Aug. 18, 1937 2 Sheets-Sheet 1

FIG-1

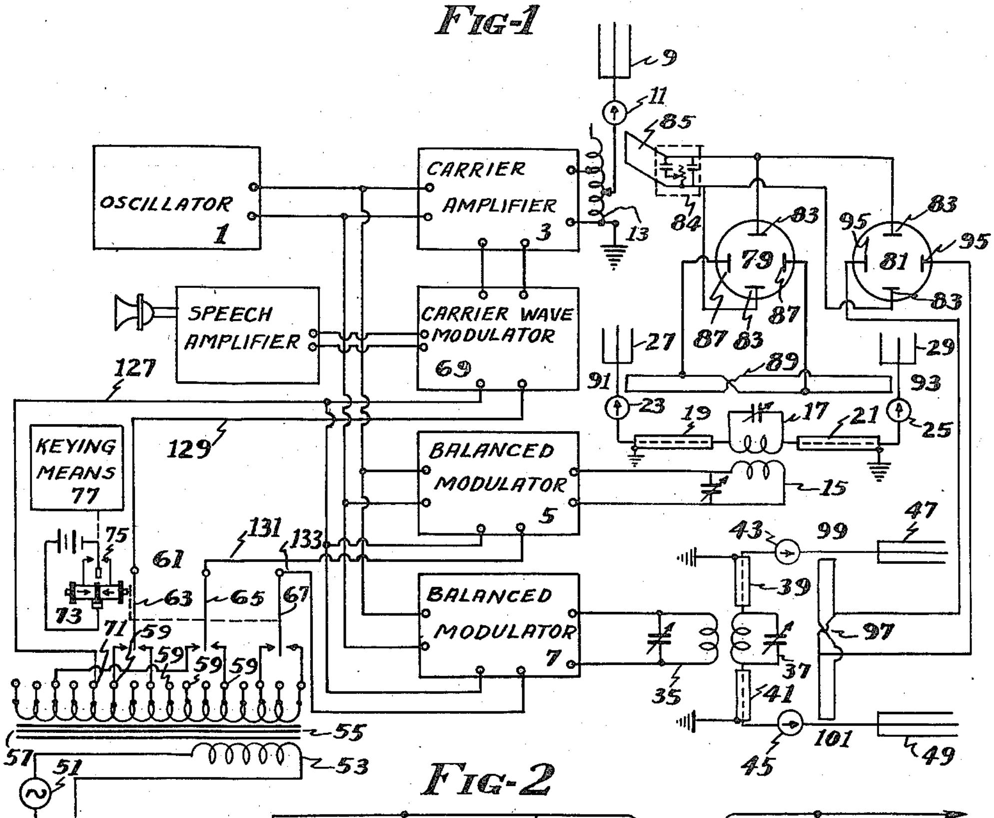

FIG-2

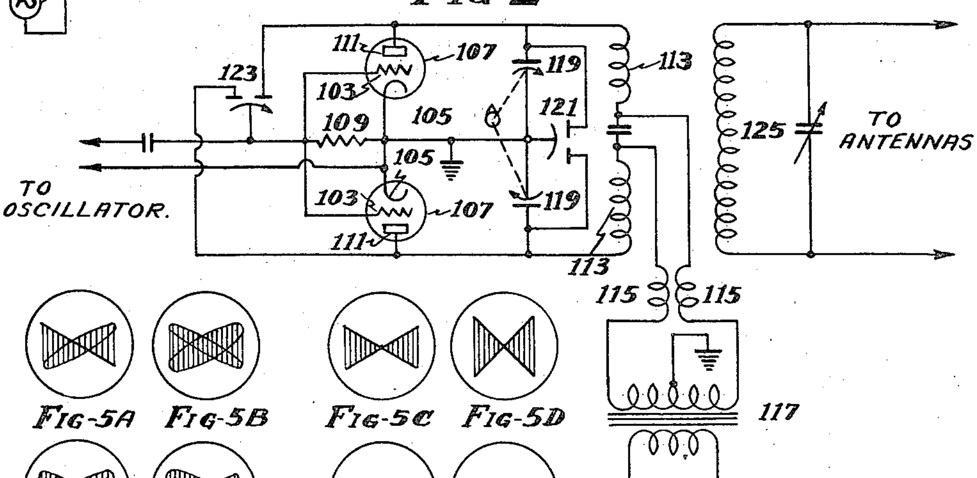

FIG-5A FIG-5B FIG-5C FIG-5D

FIG-6A FIG-6B FIG-6C FIG-6D

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RADIO BEACON

Filed Aug. 18, 1937 2 Sheets-Sheet 2

FIG-3A

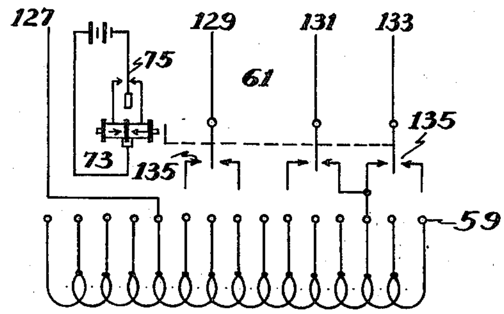


FIG-3B

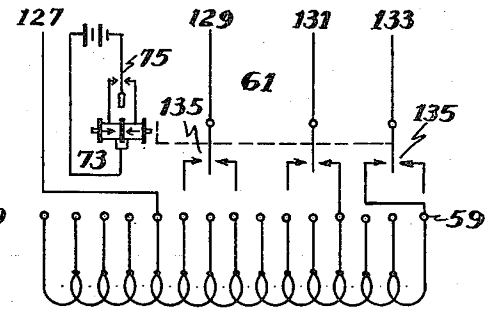


FIG-4A

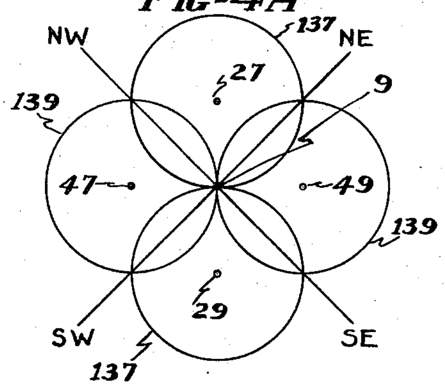


FIG-4B

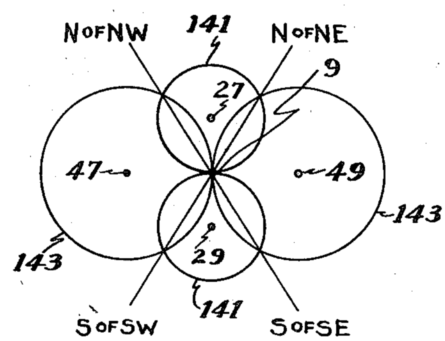


FIG-3C

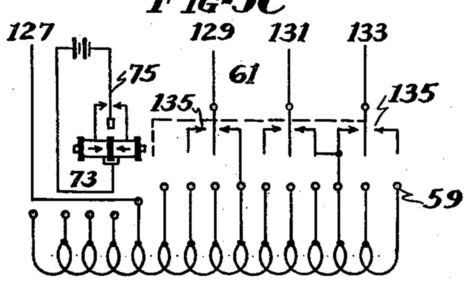


FIG-3D

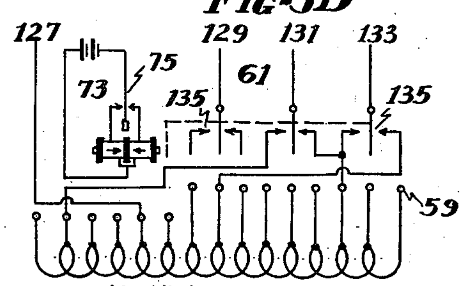


FIG-4C

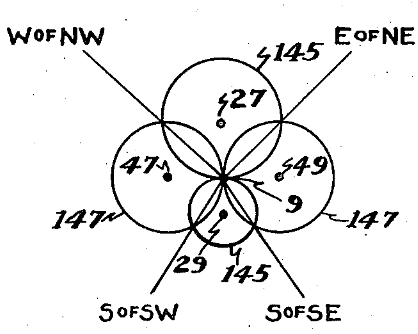
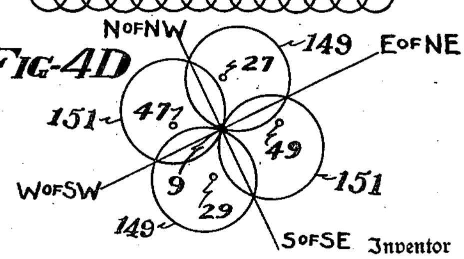


FIG-4D



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UNITED STATES PATENT OFFICE

2,234,828

RADIO BEACON

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Application August 18, 1937, Serial No. 159,661

13 Claims. (Cl. 250—11)

My invention relates to radio beacons of the type in which a plurality of fixed courses are established. More specifically, my invention provides an improved means for and method of obtaining and adjusting a plurality of radio courses of the so-called A—N type. The A—N type of beacon is one in which two intersecting radio frequency fields are respectively and alternately modulated by the telegraphic code signals corresponding to A and N. The intersection of these fields forms a radio frequency field modulated by a steady signal, which indicates the desired course.

It is customary to establish radio courses by radiating in different directions a pair of modulated fields of figure 8 shape. The junctions of the figure 8 fields form the desired courses. One of the fields is modulated by a signal which forms a dot space dash or telegraphic signal

A (. —)

The other field is modulated by a dash space dot, or telegraphic signal

N (— .)

If the space intervals are of the same duration as the dot signals and if the dash of the N terminates on the start of the dot of the A, the resultant signal will be a continuous dash; e. g., dash-dot-dot-dash

(— . . —)

If the major axis through the eight of one field intersects the major axis of the other field at right angles, and if the fields are of uniform strength, four similar courses intersecting at right angles will be established. As a practical matter, it is difficult to establish even simple courses of the type described because the amplitudes and phases of the antenna currents must be not only calculated and measured, but checked in elaborate field tests. The problem becomes increasingly difficult, when the courses are not symmetrically arranged about the beacon.

The disadvantages of the prior art radio beacons and the advantages of the present invention may be stated as follows: In prior art A—N beacon systems, course adjustment is made entirely by means of radio frequency circuit variation. The necessary adjustments are thoroughly interdependent and their effects are not easy to measure. In the system of the present invention, however, all radio frequency adjustments are definite, independent and easily checked; all course adjustments are made by choosing taps on a power frequency transformer and the effect of each adjustment on the courses laid down is simple and straightforward. Prior art systems perform the A—N keying in a radio frequency link circuit, sometimes of very low impedance, while the present invention reduces this operation to one of power supply switching. The type of signal provided by the range beacon of the present invention may be received on the same equipment used in the prior art receivers.

I propose as one of the objects of my invention to provide means for and a method of creating, adjusting and monitoring radio beacon courses to thereby improve the existing means and methods.

Another object of my invention is to provide means for establishing a uniform radio frequency field, and carrier suppressed modulated fields of figure 8 pattern and predetermined strength to thereby establish radio courses in desired directions about a radio beacon.

A further object is to provide means for monitoring and adjusting the direction of a plurality of radio beacon courses.

My invention may be best understood by reference to the accompanying drawings in which

Figure 1 is a schematic circuit diagram of one embodiment of my invention,

Figure 2 is a circuit diagram of a balanced modulator of the type employed in my invention,

Figures 3A, 3B, 3C and 3D represent details of the keying and modulating circuit connections,

Figures 4A, 4B, 4C and 4D represent the courses obtained by the circuit connections respectively illustrated in Figs. 3A, 3B, 3C and 3D, and

Figures 5A, 5B, 5C, 5D and 6A, 6B, 6C, 6D represent cathode ray patterns of the types obtained in adjusting the several antenna currents.

Referring to Fig. 1, a generator 1 of carrier frequency oscillations is connected to a carrier frequency amplifier 3, and a pair of balanced modulators 5, 7. The carrier amplifier 3 is connected to a non-directional vertical antenna 9. The antenna 9 may include a current indicator 11 and any suitable coupling and current phasing means, such as an autotransformer 13.

The output from one balanced modulator 5 is connected through a circuit 15 to a tunable circuit 17. The tunable circuit is connected through transmission lines 19, 21 and meters 23, 25 to a pair of vertical antennas 27, 29. The second balanced modulator 7 is connected through a circuit 35 to a tunable circuit 37. The tunable circuit 37 is connected through transmission lines

39, 41 and meters 43, 45 to a second pair of vertical antennas 47, 49.

The pairs of antennas 27, 29, 47, 49 are uniformly spaced with respect to the nondirectional antenna 9 and preferably, although not necessarily, uniformly spaced with respect to each other. In the preferred arrangement, the pairs of antennas are located at the corners of a square. Each pair is diagonally disposed. The nondirectional antenna is located at the center of the square. The radio frequency fields which are established by the currents in the several antennas will be hereinafter described.

The modulating currents are created by a generator 51 which, by way of example, may generate currents having a frequency of one thousand cycles per second. The generator 51 is connected to a primary 53, transformer 55, which may be an autotransformer. The secondary 57 of the transformer 55 includes a plurality of taps 59. The taps 59 are connected in pairs to the fixed contacts of a differential relay 61. The movable blades 63, 65, 67 of the relay are connected respectively to a carrier wave modulator 69 which is connected to the carrier amplifier 3 and to the first 5 and second 7 balanced modulators. A common terminal 71 of the secondary 57 is connected to the carrier wave modulator 69 and to the pairs of balanced modulators 5, 7. The field magnet 73 of the differential relay is connected to a two-way switch or key 75, which may be operated by an automatic keying means 77.

The monitoring or phase indicating means includes a pair of cathode ray tubes 79, 81. The vertical deflecting electrodes 83 of these tubes are connected together and to a transformer, represented by the reference numeral 85, which is coupled to the nondirectional antenna 9. The horizontal deflecting electrodes 87 of the cathode ray tube 79 are connected by a suitable transposed line 89 to transformers 91, 93 which are respectively included in the antennas 27, 29. The horizontal deflecting electrodes 95 of the cathode ray tube 81 are connected to a transposed line 97 which terminates in transformers 99, 101. The pairs of transformers 91, 93 and 99, 101 are connected in opposed relation to minimize the effect of currents induced by the nondirectional antenna in the pairs of antennas.

The balanced modulator circuit is shown in Fig. 2. The output from the oscillator 1 (see Fig. 1) is impressed between the grid and cathode electrodes 103, 105 of thermionic tubes 107. The grid and cathode electrodes are connected together by means of a resistor 109. The anode electrodes 111 are connected through a split transformer primary 113 and chokes 115 to a power source 117. The power source includes the keying mechanism of Figs. 1, etc. The split transformer primary 113 is shunted by a pair of gang tuned capacitors 119 and an adjustable differential capacitor 121. Neutralization of the capacity between grid and anode electrodes, disturbed by adjustment of capacitor 121, may be restored by a differential capacitor 123. The primary 113 is coupled to a tunable circuit 125 which is symmetrically connected between the pairs of antennas, such as 27, 29 or 47, 49.

The several circuits illustrated in Figs. 3A, 3B, 3C and 3D correspond to some typical connections which may be made from the differential relay 61 to the transformer 55. The leads 127, 129, 131 and 133 may be connected as shown in Fig. 1, but the leads from the fixed relay contacts 135 to the transformer taps 59 are connected as actually shown in the several figures to obtain the corresponding field patterns illustrated in Figs. 4A, 4B, 4C and 4D. The leads which are not connected between the fixed relay contacts 135 and the transformer taps 59 are not needed to obtain the patterns as aforesaid.

In the operation of the radio frequency portion of the system illustrated in Fig. 1, the oscillator 1 supplies carrier frequency currents which are amplified by the carrier amplifier 3 and impressed on the nondirectional vertical antenna 9. Thus, a radio frequency field is uniformly established about the nondirectional antenna. The carrier frequency currents are also impressed on the balanced modulators 5, 7, which suppress the carrier currents but produce side band frequency currents which are fed to the circuits 15 and 35. The side band currents in these circuits are impressed on the tuned circuits 17 and 37 and hence on the pairs of antennas 27, 29 and 47, 49.

In practice, each modulator must be carefully balanced to obtain output currents in 180° phasal relation and the suppression of carrier frequency currents. These conditions may be readily determined by observing the cathode ray deflections in the cathode ray tubes 79, 81 as the neutralizing, tuning and differential capacitors 123, 119 and 121 are adjusted.

The phases of the radio frequency currents in the directional antennas are so determined that the currents in the two antennas of each directional pair are in 180° relation. The current in the non-directional antenna is then adjusted so that it is in phase quadrature with the currents in the directional antennas. This 90° phasal condition may be observed in the cathode ray tubes 79, 81.

The cathode ray patterns illustrated by Figs. 5A, 5B, 5C and 5D represent typical patterns obtained on the screens of cathode ray tubes 79 and 81 when the balanced modulators are being adjusted. For example, in Figs. 5A and 5B the elliptical portion of the patterns indicate that neither of the modulators 5, 7 are in proper balance. Suitable adjustments of the differential capacitors 121 of each modulator will gradually narrow the elliptical traces until single pairs of crossed lines appear as are shown in Figs. 5C and 5D, respectively. The phase of the reference voltage derived from the central antenna may be slightly varied, by means of a phasing circuit 84, for each differential capacitor setting to determine whether the patterns of Figs. 5C and 5D are attainable, and thus to determine if the best condition of modulator balance has been obtained.

It is also necessary to observe the relative phases of the radio frequency currents in the directive antennas 27, 29 and 47, 49 and the central antenna 9. The currents in the central antenna should be in quadrature phase with the currents in the pairs of directive antennas. This condition is determined by disconnecting the phasing circuit 84. The monitoring voltages applied to the cathode ray tubes 79, 81 will generally have the effect of producing two pairs of elliptical traces such as are shown in Figs. 6A and 6B. By suitably adjusting the phases, as by slightly detuning the carrier wave amplifier 3, single elliptical traces will be obtained such as shown in Figs. 6C and 6D, respectively. The single traces indicate that the currents in the pairs of directive antennas 27, 29 and 47, 49 are in quadrature phase with the currents in the central antenna 9.

If the diagonals of the antenna square are

N—S and E—W, the phases of the currents are as stated above, and the modulation connections of Fig. 3A are used to produce equal currents in the pairs of antennas **27, 29, 47, 49,** two radio frequency fields **137, 139** of the figure **8** patterns of Fig. 4A will be obtained. The regions of equal intensity of the figure **8** fields determine radio courses NW, NE, SE and SW, as shown. A radio receiver positioned or moving along the course will receive a steady modulation note. If the radio receiver is slightly to the right or left of the course, the

A (. —)

or the

N (— .)

signal, as the case may be, will predominate. If the receiver is entirely off the course, only an A or N signal will be received.

Since the foregoing courses depend upon the equality of the modulated field strengths, it follows that, if the relative strengths of the modulated fields are varied, the courses will be varied. In Fig. 3B, the connections **131** and **133**, instead of being made to the same transformer taps, as is the case in Fig. 3A, are made to different taps. Thus, in the case of Fig. 3B, the modulation currents applied to the first modulator **5** will be less than those applied to the second modulator **7**. This relative change in modulation diminishes the field strength about the first pair of antennas **27, 29** and increases the field strength about the second pair of antennas **47, 49**, as indicated by the respective field patterns **141, 143**. The intersection of the fields **141** and **143** determines the radio courses N of NW, N of NE, S of SE and S of SW. This type of course adjustment has been termed "course squeezing."

In Fig. 3C, the modulator connections **131** and **133** are the same as those of Fig. 3A and, in addition thereto, the connection **129** is made whereby the two balanced modulators are supplied with equal modulation currents and the carrier wave is also modulated. The effect of the connections is to simultaneously radiate side band currents nondirectionally and with figure **8** directivity. The resulting field is approximately indicated by the lines **145**. The second modulator **7** is modulated when the carrier is unmodulated. The resulting field is indicated by **147**. The intersection of the fields **145** and **147** determines the courses W of NW, E of NE, S of SE and S of SW. This type of course adjustment has been called "course bending."

One obvious method for rotating several courses would be to rotate the entire beacon. However, it is more practical to vary the modulation as indicated by the connections in Fig. 3D. The modulators **5, 7** are simultaneously modulated by differing amounts of currents which are alternately applied. That is, the first modulator is modulated by a relatively large and then by a relatively small amount of current at the respective times when the smaller and when the larger modulation currents are applied, in reversed phase with respect to the first modulator modulation currents, to the second modulator. This method of modulation of the currents in the pairs of antennas **27, 29, 47, 49** establishes fields **149, 151** and courses N of NW, E of NE, S of SE, and W of SW, as shown in Fig. 4D. These courses may be said to be rotated with respect to the courses of Fig. 4A.

While the foregoing description is limited to several special types of courses, any desired set of four courses, from a beacon with the antennas at the cardinal compass points, N, S, E and W, may be arranged by "bending," "squeezing" and "rotation." If courses I, II, III and IV with bearings respectively designated as K_1, K_2, K_3 and K_4 are desired, the normal NE, SE, SW and NW courses may be rotated through an angle

$$R=\frac{K_1+K_2+K_3+K_4}{4}-180^\circ$$

the courses I—II and III—IV may be squeezed toward each other through an angle

$$S=45^\circ-\frac{(K_2-K_1)+(K_4-K_3)}{4}$$

the courses I and III may be bent toward course II by the angle

$$B=90^\circ-\frac{(K_3-K_1)}{2}$$

degrees, and courses II and IV may be bent toward course III by the angle

$$C=90^\circ-\frac{K_4-K_2}{2}$$

degrees, so that the desired four courses are composed as follows:

$$K_1=45^\circ+R+S+B \qquad K_2=135^\circ+R-S+C$$

$$K_3=225^\circ+R+S-B \qquad K_4=315^\circ+R-S-C$$

If the first course to the east of north be chosen always as K_1, the above set of courses may be realized by setting the relative modulation depths according to the following table:

Keying condition	Relative N-S antenna modulation	Relative E-W antenna modulation	Relative nondirectional antenna modulation
N signal	$\sin(S+45)\cos R$, or $-\frac{1}{2}\cos\frac{K_4+K_2}{2}-\frac{1}{2}\cos\frac{K_3+K_1}{2}$	$\sin(S+45)\sin R$, or $-\frac{1}{2}\sin\frac{K_4+K_2}{2}-\frac{1}{2}\sin\frac{K_3+K_1}{2}$	$\frac{1}{2}\sin C+\frac{1}{2}\sin B$, or $\frac{1}{2}\cos\frac{K_4-K_2}{2}+\frac{1}{2}\cos\frac{K_3-K_1}{2}$
A signal	$-\cos(S+45)\sin R$, or $-\frac{1}{2}\cos\frac{K_4+K_2}{2}+\frac{1}{2}\cos\frac{K_3+K_1}{2}$	$\cos(S+45)\cos R$, or $-\frac{1}{2}\sin\frac{K_4+K_2}{2}+\frac{1}{2}\sin\frac{K_3+K_1}{2}$	$\frac{1}{2}\sin C-\frac{1}{2}\sin B$, or $\frac{1}{2}\cos\frac{K_4-K_2}{2}-\frac{1}{2}\cos\frac{K_3-K_1}{2}$

The "on-course" resultant modulation depths are, respectively:

$$M_1=\tfrac{1}{2}\sin C+\tfrac{1}{2}\cos(2S+B)=\tfrac{1}{2}\cos\frac{K_4-K_2}{2}-\tfrac{1}{2}\cos\left(K_1-\frac{K_4+K_2}{2}\right)$$

$$M_2=\tfrac{1}{2}\sin B-\tfrac{1}{2}\cos(2S-C)=\tfrac{1}{2}\cos\frac{K_3-K_1}{2}-\tfrac{1}{2}\cos\left(K_2-\frac{K_3+K_1}{2}\right)$$

$$M_3=\tfrac{1}{2}\sin C-\tfrac{1}{2}\cos(2S-B)=\tfrac{1}{2}\cos\frac{K_4-K_2}{2}+\tfrac{1}{2}\cos\left(K_1-\frac{K_4+K_2}{2}\right)$$

$$M_4=\tfrac{1}{2}\sin B+\tfrac{1}{2}\cos(2S+C)=\tfrac{1}{2}\cos\frac{K_3-K_1}{2}+\tfrac{1}{2}\cos\left(K_2-\frac{K_3+K_1}{2}\right)$$

Maximum "off-course" modulation depths are relatively:

$$M_n=\sin(S+45)+\tfrac{1}{2}\sin C+\tfrac{1}{2}\sin B$$

$$M_a=\cos(S+45)+\tfrac{1}{2}\sin C-\tfrac{1}{2}\sin B$$

In general, the degree of modulation corresponding to a given ratio of directional antenna current to nondirectional antenna current, when the latter is unmodulated, must be measured in the field. However, with highly efficient antenna and ground systems, the diagonal of the antenna square being A electrical degrees, the peak modulation will be

$$m=4 \sin \frac{A}{2} \cdot \frac{Id}{Im}$$

where both currents are expressed as root-mean-square values. Interaction with speech modulation sets an upper limit, of the order of 0.3 to 0.5, to the peak directive modulation that may safely be used. Allowing the modulation on the most intensely modulated course to fall in this range, the actual current ratios required to give the needed relative modulation depths may be determined; these ratios may then be realized by suitable choice of taps **59** on the transformer secondary **57**. The depth of modulation on the nondirectional antenna may be measured directly and may likewise be set to the required values by proper choice of taps.

Thus I have described a radio beacon in which the courses are set by adjusting the tap connections on the modulator power supply transformer. The proper phasal relation of the currents in the several antennas may be monitored or adjusted by observing the cathode ray deflections in a pair of oscillographs connected to the several antennas. The amount of currents in the pairs of directional antennas can be determined by the meters in the antenna circuits. The A—N keying may be arranged by connecting an automatic keying device in the generator or relay circuit. Speech modulation may be applied to the carrier wave by means of a microphone and speech amplifier. The invention is not limited to any particular type of antennas, provided the radiators or antennas establish the required nondirectional and figure **8** field patterns.

I claim as my invention:

1. A radio beacon including a generator of carrier frequency currents, a nondirectional antenna, means for impressing said carrier frequency currents on said nondirectional antenna to thereby establish a uniform field, a pair of balanced modulators, a pair of directional antennas, means for impressing said carrier currents on said modulators, a source of modulation currents, means for impressing said modulation currents on said balanced modulators to obtain side band currents, means for impressing said side band currents on respective directional antennas to thereby establish a pair of intersecting modulated fields of figure **8** pattern, and selective means for alternately varying the amplitude of said modulation currents in accordance with a signal, to thereby determine the direction of lines of equal amplitude of said modulated fields.

2. A radio beacon including a generator of carrier frequency currents, a nondirectional antenna, means for impressing said carrier frequency currents on said nondirectional antenna to thereby establish a uniform field, a pair of balanced modulators, a pair of directional antenna systems, means for impressing said carrier currents on said modulators, means for alternately impressing modulation currents on said modulators, means for impressing the modulated carrier currents alternately derived from respective modulators on said directional antennas to establish alternately a pair of intersecting modulated fields of figure **8** pattern, means for adjusting the phase of said carrier currents in said nondirectional antenna with respect to the phase of the currents in said pairs of directional antennas, and means for alternately changing the amplitudes of modulation currents applied to said modulators, whereby said field strengths may be relatively varied to vary the regions of equal intensity of said modulated fields.

3. A radio beacon transmitter including in combination a generator of carrier frequency currents, a nondirectional antenna, means for impressing said carrier frequency currents on said nondirectional antenna to thereby establish a uniform field, a carrier wave modulator, a generator of modulation frequency currents, a transformer having a plurality of taps connected to said modulation frequency generator, a first selective switch operable in accordance with a signal by which said carrier wave modulator may be alternately connected to one or the other of two of said plurality of taps; two pairs of oppositely positioned antennas at the corners of a square of which said nondirectional antenna is the center, a pair of balanced modulators, means connecting each modulator to a pair of said antennas so that currents in opposite antennas of said pair are in phase opposition, a pair of selective switches operable in accordance with said signal by which said balanced modulators may each be connected to one or the other of two of said plurality of taps, whereby the resultant modulated field intensity may be varied to vary the regions of equal intensity of said field.

4. A device of the character described in claim 3 in which said taps are so arranged that one voltage is applied to said first balanced modulator and a different voltage alternately applied to the second balanced modulator whereby the course is squeezed.

5. A device of the character described in claim 3 in which said taps are so arranged that the same voltage is alternately applied to said balanced modulators.

6. A device of the character described in claim 3 in which said taps are so arranged that the same voltage is alternately applied to said balanced modulators, and, in addition, a modulating voltage is applied to said carrier wave modulator during one of said alternations, whereby the course is bent.

7. A device of the character described in claim 3 in which said taps are so arranged that said balanced modulators are simultaneously connected to differing voltages which are alternately applied, whereby the course is rotated.

8. A radio beacon including a source of carrier frequency currents, means for producing separate modulation frequency currents, means for radiating said carrier frequency currents to establish a uniform radiation field, means for combining said carrier and said separate modulation frequency currents to obtain separate side band currents, means for radiating said side band currents to establish two directional radiation fields, and keying means for alternately varying the relative amplitudes of said separate modulation frequency currents to thereby determine the direction of lines of equal field intensity of said directional radiation fields.

9. A system of the character described in claim 8 in which said keying means includes means for causing the amplitude of said modulation frequency currents during one alternate radiation period to be greater than the amplitude of said

modulation frequency currents during the successive radiation period whereby two of said lines of equal field intensity are brought closer to each other.

10. A system of the character described in claim 8 in which said keying means includes means for causing the amplitude of said modulation frequency currents which are used to obtain one of said side band directional radiation fields to be alternately varied while the amplitude of said modulation frequency current which are used to obtain the other of said side band directional fields is similarly varied in an opposite sense to rotate the lines of equal field intensity of said directional fields.

11. The method of establishing radio beacon courses which includes the steps of generating carrier frequency currents, producing separate modulation frequency currents, radiating said carrier frequency currents to establish a uniform omnidirectional radiation field, separately combining said carrier and separate modulation frequency currents to obtain distinct sideband currents, radiating said distinct sideband currents to establish two directional radiation fields, and alternately varying the amplitudes of said separate modulation frequency currents to thereby determine the direction of lines of equal field intensity.

12. A radio beacon including, in combination, means for radiating a uniform field of carrier frequency, a pair of modulating devices, a source of separate modulating voltages, keying means for applying said voltages to said separate modulating devices, means connected to said modulating devices for radiating a pair of bi-directional fields of sideband frequency, and means for adjusting the relative amplitudes of said separate modulating voltages whereby radio courses may be established in predetermined directions in accordance with said adjustments.

13. A system of the character described in claim 8 in which said keying means includes means for causing the amplitude of said carrier frequency currents to vary during alternate variations of said directional fields.

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