May 19, 1942. A. G. KANDOIAN 2,283,677

LOCALIZER BEACON

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FIG.3.

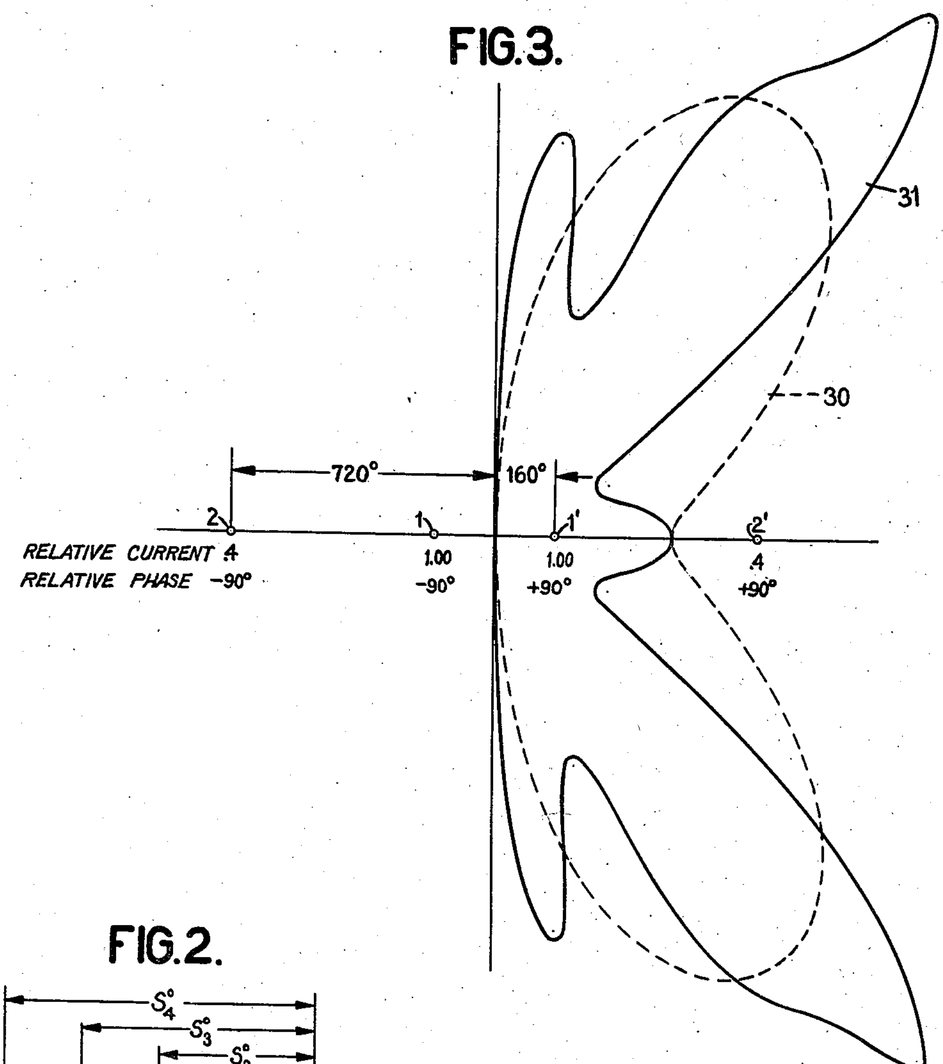


FIG.2.

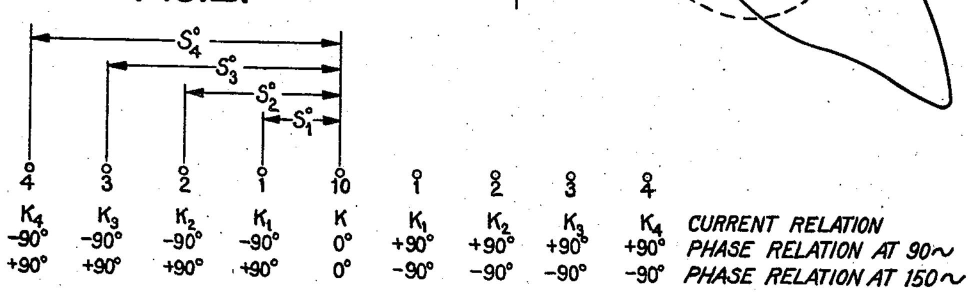
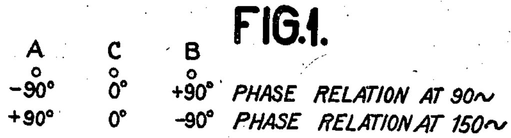


FIG.1.



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LOCALIZER BEACON

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FIG. 4.

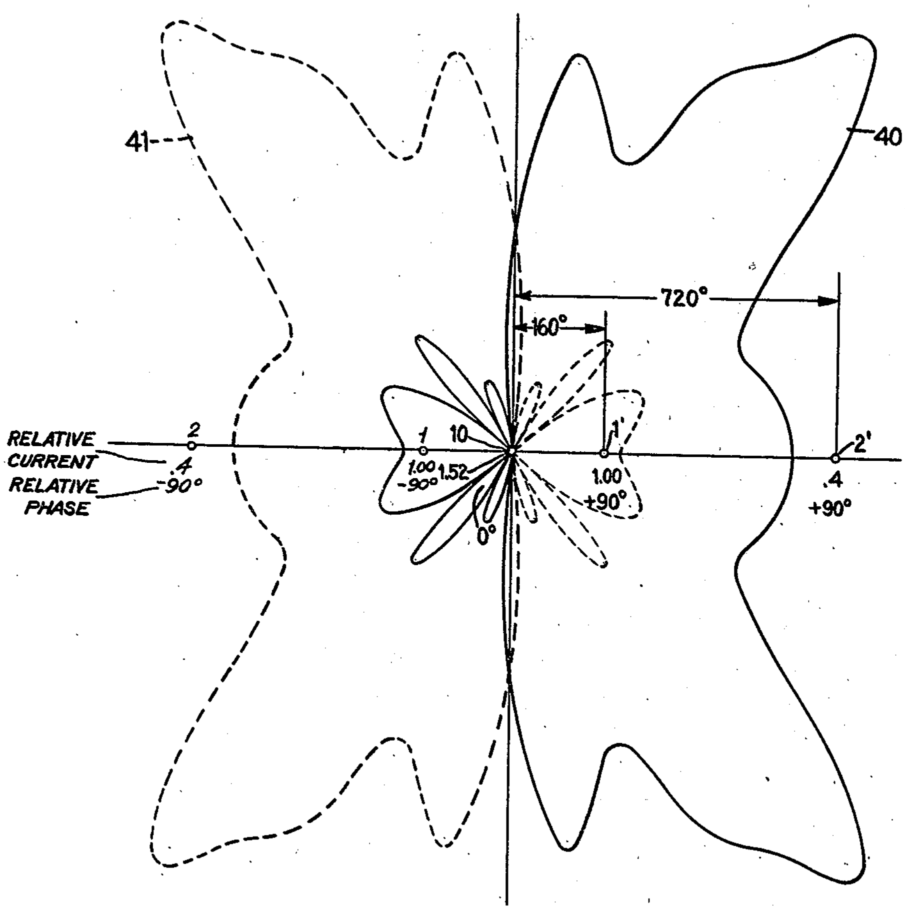

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FIG.5.

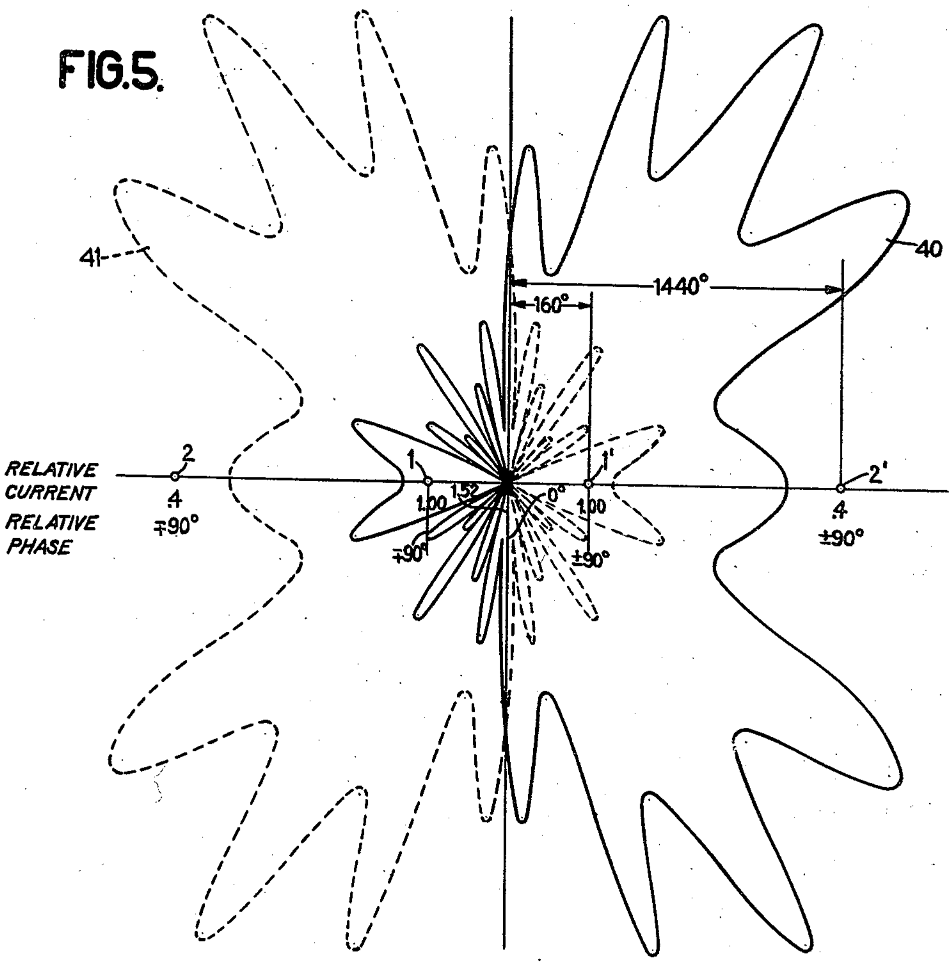

FIG.7.

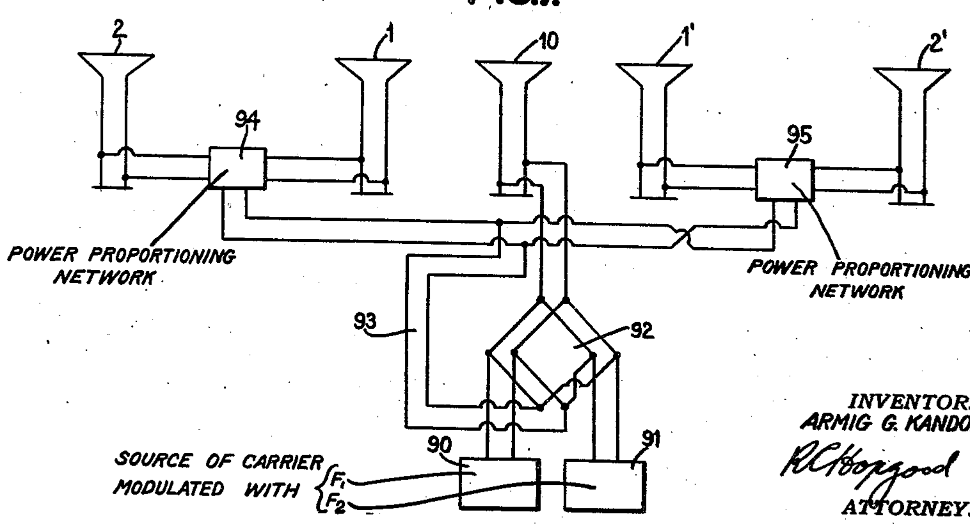

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FIG.6.

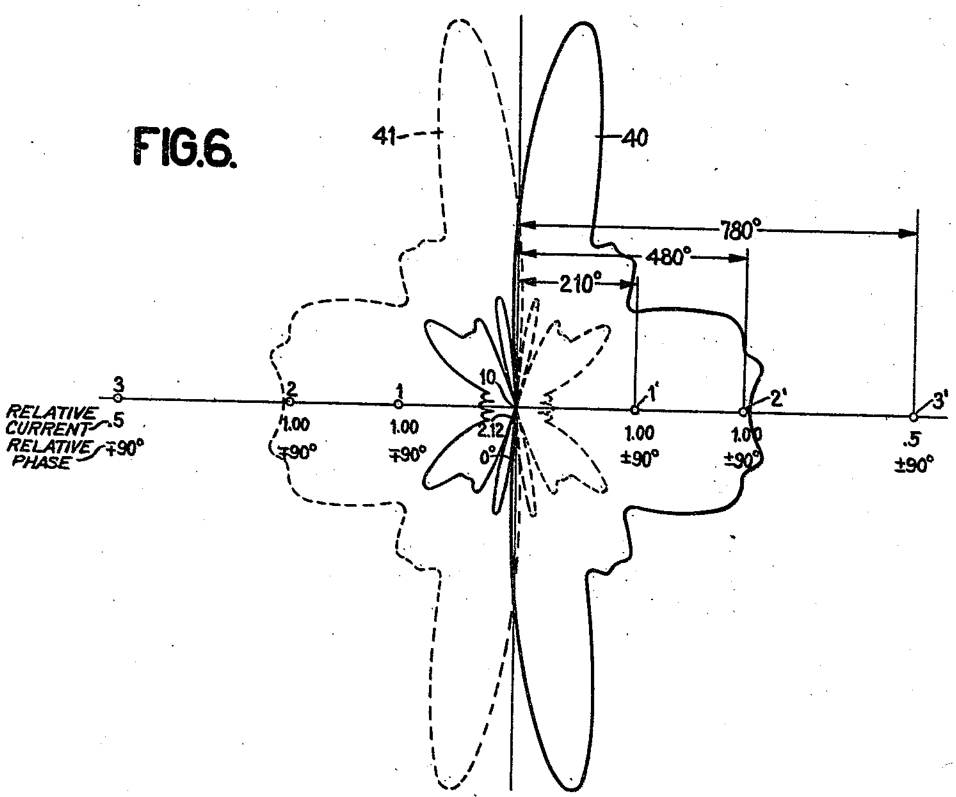
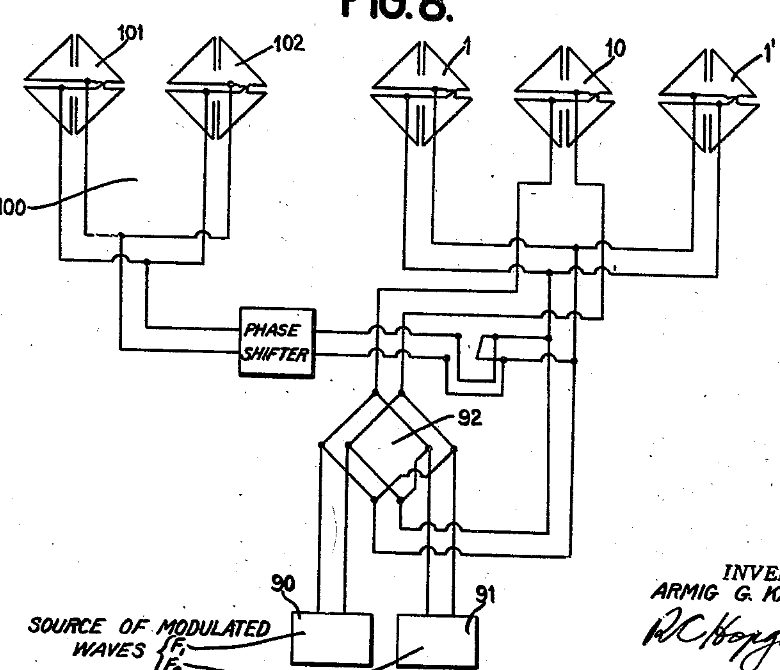


FIG.8.



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Patented May 19, 1942

2,283,677

UNITED STATES PATENT OFFICE

2,283,677

LOCALIZER BEACON

Armig G. Kandoian, New York, N. Y., assignor to International Telephone & Radio Manufacturing Corporation, a corporation of Delaware

Application September 27, 1940, Serial No. 358,677

6 Claims. (Cl. 250—11)

My invention relates to radio beacons and more particularly to two course beacons of controllable sharpness for defining a course line or landing direction.

Systems of antennae are known wherein a central radiator provided with other radiators on either side thereof are used to define a course. In these systems the central radiator provides an on course signal and the side radiators provide the identifying patterns on either side of the course, this latter pattern being termed the "clover leaf" pattern since it is generally of a four lobe shape. In this known system the sharpness which can be obtained is limited by the permissible spacing of the side radiators as these must be so chosen that the signal does not reduce to zero at any point except on course, as otherwise other points of equal signal intensity of "cross-overs" will occur giving rise to false courses.

In accordance with my invention I provide a system of two course beacons generally of the same type as that described above, and in addition provide other side radiators to increase the sharpness of the course signals. This may be accomplished by varying the number of radiators, changing the relative energization of the various side radiators with respect to one another or by varying the energization of the central radiator with respect to the side or clover leaf radiators.

It is accordingly a principal object of my invention to provide a beacon wherein the desired degree of sharpness may be obtained.

It is a further object of my invention to provide a two course or localizer beacon having a high degree of sharpness and a reduced radiation in undesired directions.

It is a still further object of my invention to provide a beacon system using an auxiliary radiator or radiators for controlling the sharpness of the beacon.

Other objects and advantages of my invention will be apparent from a particular description thereof made in connection with the accompanying drawings in which

Fig. 1 is a diagram for explaining the operation of a radio beacon of known type.

Fig. 2 is a diagram of a beacon array used to explain the general principle of my invention.

Figs. 3 and 4 are patterns produced by the side radiators alone and the combination of side radiators and the central radiator, respectively, using two extra side radiators in accordance with my invention.

Fig. 5 shows a modified beacon pattern produced by a system using wider spacing of the added side radiators.

Fig. 6 shows a further modified system using additional side radiators.

Fig. 7 shows an arrangement for supplying energy to the systems in accordance with my invention, and

Fig. 8 shows a modified arrangement wherein the pattern adjusting effect is produced by a single radiator or array.

In Fig. 1 is shown a beacon array comprising a central radiator C and two equally spaced side radiators A and B. This represents a previously suggested system wherein the central radiator is energized preferably with signal modified carrier energy the signals being either modulation or keying signals which are used to define the course patterns. These signals may be, for example 90 cycle and 150 cycle frequencies or interlocking Morse code signals such as A—N. The side radiators are then energized, for example, so that for the 90 cycle side band currents A and B are applied at $-90°$ and $+90°$ phase, respectively, with respect to C and for the 150 cycle side band current A and B are energized at $+90°$ and $-90°$ phase, respectively, with respect to C. While above it is implied that side band energy only is fed to radiators A and B, carrier energy may also be applied to these radiators. This arrangement produces a beacon having a static distribution which may be expressed:

$$F(\theta)=1+2\mu \cos (S_1° \sin \theta)\pm 2K_a \sin (S_1° \sin \theta) \quad (1)$$

where $F(\theta)$ is a function varying with angular displacement θ about the center of symmetry, generally termed the primary radiation function of antenna array, $S_1°$ is the spacing in electrical degrees from the outer radiator to the center radiator, K_a is the current intensity in antennae A and B assuming unity current in C, and μ is the ratio of induced current in side radiators to primary current in center radiators, θ is the horizontal angle from the normal to the axis of the radiator.

For simplicity of discussion the radiation pattern from the central radiator may be considered as circular which means μ equals 0, so that the first term of Equation 1 reduces to unity. Then Equation 1 reduces to the simplified form:

$$F(\theta)=1\pm 2K_a \sin (S_1° \sin \theta) \quad (2)$$

With this form of beacon there will be two courses without any "cross-overs," that is points intermediate the course line where the signals of the two sides pass the unity relation so long as $0<S_1°<180°$. This, however, imposes a limit on the degree of sharpness of course definitions that may be obtained.

It is known that in this type of beacon the sharpness of the course is largely dependent upon the so-called "clover leaf" radiation pattern produced by the side radiators. Accordingly, my invention provides for a system of increasing the sharpness of the course by the use of a multiple clover leaf or side radiator assembly of n radiators on each side of the central radiator.

In Fig. 2 is illustrated such a system wherein n is made equal to four.

Neglecting for the time being the radiation from the central radiator **10**, the pattern produced by radiators **1**, **2**, **3**, **4** . . . n energized as indicated by currents of intensities K_1, K_2, K_3, K_4 . . . n may be expressed by the equation:

$$f_2(\theta)=[K_1 \sin (S_1° \sin \theta)+K_2 \sin (S_2° \sin \theta)+K_3 \sin (S_3° \sin \theta)+K_4 \sin (S_4° \sin \theta)+ \dots K_n \sin (S_n° \sin \theta)]2 \quad (3)$$

in the form of a series which may be extended indefinitely, wherein, K_1, K_2 . . . K_n represent the relative current intensities in the radiators, and $S_1°$, $S_2°$ . . . S_n represent the spacing in degrees of the respective units from the point of symmetry of the system.

For the sake of simplicity a system using just two sets of side radiators may be taken for purposes of illustration. Then

$$f_2(\theta)=2[K_1 \sin (S_1° \sin \theta)+K_2 \sin (S_2° \sin \theta)] \quad (4)$$

Substituting in Equation 2 to obtain the entire beacon pattern

$$F(\theta)=1\pm 2[K_1 \sin (S_1° \sin \theta)+K_2 \sin (S_2° \sin \theta)] \quad (5)$$

The general equation for the total field pattern may be expressed

$$F(\theta)=f_1(\theta)\pm f_2(\theta) \quad (6)$$

Where $F(\theta)$ equals the total field intensity, $f_1(\theta)$ equals the field due to the central radiator, and $f_2(\theta)$ equals the field due to the side or "clover leaf" radiators.

The requirements for the beacon or localizer based on this general formula may then be expressed as follows:

1. To prevent cross-overs or false course, due to primary radiations

$$f_2(\theta)>0, \quad 0°<\theta<180° \qquad (7)$$
$$f_2(\theta)<0, \quad 180°<\theta<360°$$

2. To define sharpness i. e. ratio of right to left signal at a specified angle θ_0, in M decibles equivalent to m ratio of intensities

$$m=\frac{f_1(\theta)+f_2(\theta)}{f_1(\theta)-f_2(\theta)} \text{ reducing to} \quad (8)$$

$$f_2\theta=f_1(\theta_a)\left(\frac{m-1}{m+1}\right)=\text{for } \theta=\theta_0$$

3. To define a minimum ratio of right and left signals for θ_d not in the vicinity of the course expressed at P decibels or a p ratio of intensities

$$\frac{f_1(\theta)+f_2(\theta)}{f_1(\theta)-f_2}\geqq p$$

reducing to

$$f_2(\theta)\geqq\left(\frac{p-1}{p+1}\right)f_1(\theta) \quad (9)$$

for

$1.5°<\theta_d<178.5°$ for a two course beacon
$1.5°<\theta_d<88.5°$ for a four course beacon

4. The minimum signal, on course 6 volts per meter

$$f_1(\theta)\pm f_2(\theta)=6 \quad (10)$$

normally $f_2(\theta)=0$ on course and $f_1(\theta)\geqq 6$ for $\theta=0$

By using the values derived in Equations 6 to 10, it is readily possible to design a beacon having a desired sharpness and without cross-overs. Furthermore, if the structure is made symmetrical an experimental check of the pattern shape may be made readily by measurements on the ground at relatively small distances and accordingly with considerable accuracy.

A further advantage lies in the fact that since the added side radiators are generally spaced quite a large distance from the center of the beacon they may be used to introduce a minimum or virtual null at a desired angle to reduce reflection from external objects.

Reradiation from objects in the field of the beacon may cause errors in the course indication. This error results from reradiation of energy from the side radiators only as can be seen by the following discussion.

Suppose a reflecting object reradiates some signal toward the course and that this reradiated signal is

$$K/D[(f_1(\theta_1)\pm f_2(\theta_1)]$$

K/D representing the energy reradiated from an object at D distance and $f_1(\theta)$, $f_2(\theta)$ have the same significance as given above. On course, the normal signal is $f_1(\theta)$ since $f_2(\theta)$ equals zero. Since the amounts of 90 and 150 cycles in $f_1(\theta)$ are equal, we have an "On course" indication. The reradiated K/D $f_1(\theta)$ will obviously change the signal on course depending upon the phase in which it arrives. However, both the 90 and 150 cycle modulations react exactly the same way, that is, they are either both reduced or both increased. There is, therefore, no change in course indication.

For $\pm$K/D $f_2(\theta)$ this is not the case. Here the plus sign applies to one modulation (say 90 cycles) while the minus sign applies to the other (say 150 cycles). Therefore, if the 90 cycle signal is increased, while the 150 cycle radiation is decreased, the net result is a false indication in favor of the 90 cycles. At another point along the course, depending upon the source of reradiation, the opposite phase relationship may prevail, so that the 150 cycle radiation is favored. This, of course, is the cause of the familiar bends and multiple courses. The magnitude of these undesirable effects depends upon the strength of the reradiated signal from the side radiators and not from the central radiator. In other words, for a localizer having fixed "on course" signal and fixed sharpness, the amount of trouble to be expected due to a given reradiating object is directly proportional to the side radiator intensity in that direction and nothing else.

The above discussion makes it clear that it is the side radiator group which should receive particular attention in the design of a localizer array, for it is this signal which must be reduced in the direction of a reflecting object when the course is unduly disturbed. The central radiator radiation does no harm at all. The only reason for reducing this radiation in directions to the side of the course is to provide a greater ratio between the 90 cycle and 150 cycle signals and to use the energy more favorably.

One particular example of a beacon station built according to the principles of my invention and the field pattern curves thereof is illustrated in Figs. 3 and 4.

In Fig. 3 is shown side or clover leaf radiators only. The two radiators **1**, **1'** are each spaced a distance of 160° from the center of symmetry and the outer center radiators 2, 2′ are each spaced 720° from the center. Using the same symbols, namely, K_1, K_2 to denote the relative current values in radiators 1, 1′ and 2, 2′, the ratio

$$\frac{K_1}{K_2}$$

is chosen equal to .4. With this form of radiator a curve such as shown in solid line curve 31 is produced. The dash line 30 illustrates the clover leaf radiation pattern obtained with only two radiators such as 1, 1′. Only the field pattern on one side of the beacon is shown, it being understood that the pattern on the other side is symmetrically disposed. It can be seen that by the use of the two additional radiators the curve has been greatly sharpened along the zero line. In Fig. 4 the complete field pattern of the beacon adding together the clover leaf pattern of Fig. 3 and a circular central radiation pattern from the central radiator 10 is shown. This pattern is produced using the same specifications for the outer or clover leaf radiators as used in Fig. 3 and energizing the central radiator 10 with current intensity of 1.52 compared to one for the side radiators 1, 1′. The course is defined by the two radiation patterns 40, 41 which overlap at the center zone. It can be readily seen that this arrangement provides a very sharp course beacon, the sharpness of which may be specified as about 4.3 decibels for a 1.5° departure from the course.

To obtain higher degree of sharpness the ratio of

$$\frac{K_2}{K_1}$$

may be made larger. This may be accomplished by increasing the current in radiators 2, 2′ and since they then will add a larger value to the original curve 30 they will clearly provide a sharper course. Increased sharpness may also be obtained by decreasing the current in the central radiator. The limit of this sharpness, however, is reached when the central radiator obtains a value approaching zero. This latter method is not always desirable since it results in considerably less signal on the course. It should be borne in mind that the ratio

$$\frac{K_1}{K_2}$$

should be maintained at a value greater than unity so that the clover leaf pattern will not drop to zero at any point except along the course line. Otherwise, false courses may be defined by the system.

The course may also be sharpened by increasing the spacing S_2, that is, increasing the spacing of the outer radiators 2, 2′, with respect to the center of symmetry. A curve showing the effect of such increased spacing is shown in Fig. 5.

The pattern of Fig. 5 is produced by an array comprising a central radiator 10, and side radiators 1, 2 and 1′, 2′, the current ratio in the central radiator and side radiators is proportioned 1.52, 1, .4 respectively, as indicated. The radiators 1, 1′ are spaced 160° electrically from the central radiator and the outer radiators 2, 2′ are spaced 1440° electrically from the central radiator. With this arrangement a sharpness of 7.7 db. per 1.5° departure from course is obtained. It can be seen, therefore, that a considerable improvement in sharpness is obtained by this increase in spacing. However, the patterns have the characteristics that a relatively great amount of power is radiated at angles to the course line. This generally represents wasted power and furthermore may cause undesirable effects due to reflection from objects located at an angle to the course line. In many cases, however, this added radiation is not objectionable.

The sharpness of the course may also be increased by adding other side or clover leaf radiators as shown in Fig. 6. In this arrangement the central radiator 10 is provided with three auxiliary or side radiators 1, 2, 3, 1′, 2′, 3′, arranged on either side thereof. The pattern like the others discussed is produced using a circular central radiation pattern. The current relation may be expressed, 10, 2.12; 1, 1′, 1; 2, 2′, 1, and 3, 3′, .5, and the spacing in electrical degrees from the central radiator is, 1, 1′, 210°; 2, 2′, 480°, and 3, 3′, 780°.

The beacon sharpness produced by this arrangement is 8.58 db. per 1.5° departure from course. Furthermore this arrangement has the advantage over the arrangement shown in Fig. 5 in that additional lobes are not produced thereby and the pattern may be made much more smooth throughout. Furthermore, by properly adjusting the spacing of these additional radiators the pattern may be so adjusted as to have a substantial minimum or null in a particular direction so as to avoid harmful reflections from outside objects.

It is clear that the antenna arrangements disclosed in Figs. 3 to 6, inclusive, may be made up of single radiators of any form, for example, vertical dipoles or antennae designed for producing horizontally polarized waves as disclosed in the application of Andrew Alford, Ser. No. 270, 173, filed April 26, 1939. However, it is also clear that each of the radiators may be made directional if desired, it being merely necessary in this case to substitute the desired values for the direction parameters of the system in the various equations when calculating the curves. Moreover, the central radiator may be composed of more than one unit, it being merely necessary that this radiator be maintained symmetrical with respect to the clover leaf pattern.

A symmetric arrangement showing a preferred constructional arrangement for a five-element beacon, such as shown in Fig. 4, is illustrated in Fig. 7. In this figure the central radiator 10 and the side radiators 1, 1′, 2, 2′ are shown as antennae for producing horizontally polarized waves. Two sources of carrier modulated with frequencies F_1, F_2, respectively, are shown at 90, 91. It is clear that these two sources may comprise modulators fed from a common transmitter of high frequency. These sources 90, 91 are connected over a bridge network 92 so as to supply the carrier and both modulating side bands to the central radiator 10 in phase. From the opposite side of the network leads 93 convey the side band energization containing modulators F_1 and F_2 to the antennae 1, 1′, 2, 2′. The energy from source F_1 is supplied so as to be in phase opposition in units 1, 2, and 1′, 2′ and the line is adjustable so that these currents are 90° ahead and 90° behind the corresponding component in unit 10. The carrier F_2 is supplied to the same radiators but with phase reversed with respect to the energy of F_1. Power proportioning networks 94, 95 are provided so as to properly proportion the energy in radiators 1, 2, 1′, 2′ with respect to the energy in radiator 10. With this system a complete control of the beacon arrangement so as to obtain the desired ratio of currents may be readily achieved.

From these particular examples illustrated, it is clear that by using the principles of my invention the degree of sharpness of a beacon may be controlled at will by selecting the desired number of elements and arranging their spacing and energization. By adding still further elements to the system shown in Fig. 6, for example, even greater sharpness may be obtained. In general in the system shown the energization ratio

$$\frac{K_2}{K_1}$$

etc., should not exceed unity between any two elements of the array. However, particularly when a large number of elements are used this particular condition need not be satisfied for all the elements.

In the system described above, each of the arrangements shown have consisted of a symmetrical arrangement of antennae elements. A sharpening of the course may be obtained if desired by providing only one set of antenna elements spaced on one side of the main beacon radiator, these elements being energized so as to carry both the modulation frequencies. Such an arrangement is disclosed in Fig. 8. In this figure a network similar to that shown in Fig. 7 supplied from sources **90**, **91**, is shown, furnishing the energy for a central radiator **10** and two side radiators **1**, **1'**. In place of the additional side radiators **2**, **2'**, however, a single unit **100** is provided composing in this case two antenna elements **101**, **102**. Energy is supplied to these units from sources **90**, **91**, in such phase relation that the signals from F_1 will add to those components on the left side of the beacon course and subtract from the right side thereof and the energy from F_2 will add to those components on the right side of the course and subtract from the left side thereof. Thus, a symmetrical pattern is produced having the desired increase in sharpness similar to that shown in the arrangement of Figs. 3 and 4.

For this unsymmetrical system the total radiation $T(\theta)$ at any angle θ is given by the equation

$$T(\theta) = F^2(\theta) + G^2(\theta) \pm 2G(\theta)\ F(\theta)\ \sin\ (d^o \sin\ \theta)$$

in which $F(\theta)$ is the primary radiation function, that is, the radiation from the principle antenna, $G(\theta)$ is the auxiliary radiation function, that is from the auxiliary radiator system, and d^o is the spacing between the main and the auxiliary radiators.

This system has the advantage of economy in structure over the prior systems, since it requires only one additional radiating unit instead of units on each side of the array. This system produces a great increase in sharpness of the course indiction but has the disadvantage that the field pattern cannot be readily determined by ground measurements except at large distances from the beacon since there is no symmetrical arrangement of units. Furthermore, with this arrangement the clover leaf radiating pattern no longer has a zero component along the course line, but has a slight component along the line. An arrangement such as shown in Fig. 8 has been constructed and proven quite satisfactory in operation.

In this system the spacing between the central radiator **10** and the side radiators **1**, **1'** was substantially 165° and the spacing between the center of the radiator and the auxiliary radiator **100** was made substantially 24' at 109 megacycles corresponding to about 2.8 wavelengths. Energy was supplied for radiator **100** from the supply leads feeding the other side radiators. With this arrangement a sharpness of substantially 5 decibels per degree and one-half departure from course was obtained. This is a substantial improvement compared with previous arrangements wherein a sharpness of 2.28 decibels per degree one-half has been obtained.

While, in the arrangements described in connection with Fig. 8, the auxiliary radiator **100** has been defined as being energized at 90° with respect to the central radiator, it is clear that this is not a necessary limitation, it being merely necessary that the phase relation of F_1, F_2 leading and lagging, the currents in central radiator **10**, respectively must be equal if symmetrical patterns are to be obtained. Accordingly, the present structure lends itself most readily to an arrangement wherein the 90° relationship is maintained. However, by utilization of suitable phase shifters, other relationships, for example, say 85° leading and 85° lagging may be obtained. In this case the energy is most easily supplied directly from lines interconnecting the sources **90** and **91** with network **92**.

It is evident that the arrangement as disclosed above provides a system whereby a beacon may be calculated to provide the desired sharpness of course as well as reduction of radiation in particular directions.

While I have disclosed by way of example only a few preferred embodiments thereof, it should be distinctly understood that this is not to be considered as a limitation on the scope of my invention. What I consider my invention and desire to protect in this application is set forth in the accompanying claims.

What I claim is:

1. A radio beacon comprising an array of antennae, a source of radio frequency energy, means for modulating said source with signal energy of two distinctive signal characteristics, means for applying said modulated energy to said array to effect a radiation of said energy to produce a course indication by comparison of said distinctive signals, and means for modifying the sharpness of said course indication comprising an auxiliary radiator spaced from said array of antennae, and means for applying energy modulated with both said signals to said auxiliary radiator with an energy level differing from that supplied to the antennae of said array.

2. A radio beacon comprising a central radiating means, radiating means spaced on either side of said central radiating means, two sources of radio frequency energy characterized by distinctive signals, means for applying energy from said sources to said central radiator in a particular phase relation, means for applying signal energy from one of said sources substantially in phase quadrature with respect to said central radiating means and in phase opposition to said other radiating means, means for applying signal energy from the other of said sources to said other radiating means in opposite phase to the energy applied from said one of said sources, whereby a beacon course of predetermined sharpness is defined, and means for increasing the sharpness of said course comprising additional radiating means spaced from said central radiating means and each of said other radiating

means, and means for applying signal energy to said additional radiating means from both said sources with the same phase relation as said spaced radiating means, and with an energy level lower than that applied to said other radiating means.

3. A radio beacon comprising a central radiating means and a plurality of auxiliary radiating means disposed on each side thereof, and means for energizing said central radiating means in a predetermined phase relation and said auxiliary radiating means on one side in phase opposition with respect to those on the other side and in phase quadrature with respect to said central radiating means, said auxiliary radiating means being energized with different current intensities from the current intensity of the central radiating means and with different relative current intensities from one another.

4. A radio beacon comprising a central radiating means, a plurality of auxiliary radiating means spaced on each side of said central radiating means, means for energizing said central radiating means with energy, means for energizing said auxiliary radiating means on opposite sides of said central radiating means in phase opposition with respect to each other and in phase quadrature with respect to said central radiating means, the field pattern being defined by the equation

$$F(\theta)=f_1(\theta)\pm[K_1 \sin (S_1^\circ \sin \theta)+K_2 \sin (S_2^\circ \sin \theta) \ldots +K_n \sin (S_n^\circ \sin \theta)]$$

where θ is the angular relation of the radiation, $F(\theta)$ the resultant total pattern, $f_1(\theta)$ the pattern from the central radiating means, $K_1, K_2 \ldots K_n$ the relative current intensities of the energy in n auxiliary radiating means on each side of center of symmetry of the system, and S_1°, $S_2^\circ \ldots S_n^\circ$ the relative spacing in electrical degrees from the center of symmetry of said respective auxiliary radiators, the energy at the central radiating means being greater than zero.

5. A radio beacon comprising a central radiating means and a pair of auxiliary radiating means disposed on each side thereof and in line therewith, said auxiliary radiators nearest said central radiator being spaced therefrom a distance in the order of one-half a wavelength, means for energizing said central radiating means in a predetermined phase relation and said auxiliary radiating means on one side in phase opposition with respect to those on the other side and in phase quadrature with respect to said central radiating means, and means for energizing said auxiliary radiating means nearest said central radiating means with different current intensities from the current intensity of the central radiating means and said other auxiliary antennae with current intensities different from said nearest auxiliary radiators.

6. A radio beacon comprising a central radiating means, radiating means spaced on either side of said central radiating means a distance in the order of one-half a wavelength, two sources of radio frequency energy characterized by distinctive signals, means for applying energy from said sources to said central radiator in a particular phase relation, means for applying signal energy from one of said sources substantially in phase quadrature with respect to said central radiating means and in phase opposition to said other radiating means, means for applying signal energy from the other of said sources to said other radiating means in opposite phase to the energy applied from said one of said sources, whereby a beacon course of predetermined sharpness is defined, and means for increasing the sharpness of said course comprising additional radiating means spaced from said central radiating means and each of said other radiating means a distance of at least one wavelength from the central radiator, and means for applying signal energy to said additional radiating means from both said sources with the same phase relation as said spaced radiating means, and with an energy level lower than that applied to said other radiating means.

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