Dec. 10, 1940. J. PLEBANSKI 2,224,233

DIRECTIONAL RADIO SYSTEM

Filed May 5, 1938 3 Sheets-Sheet 1

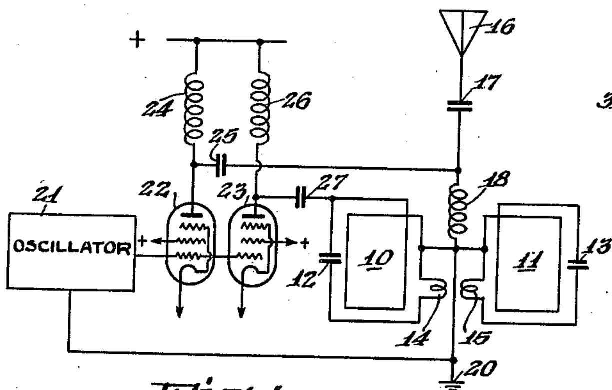

Fig. 1

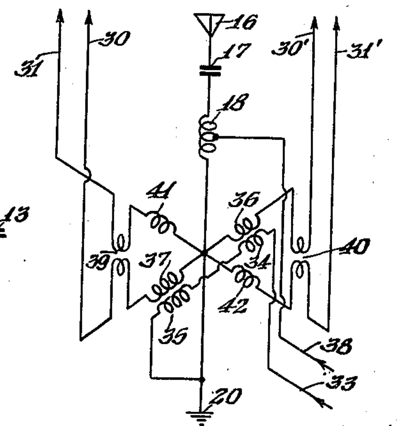

Fig. 4

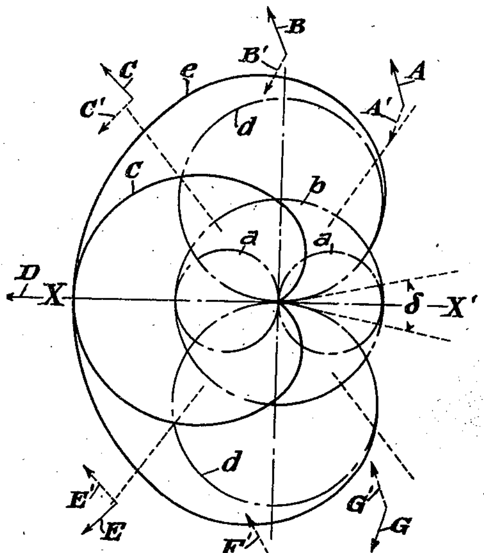

Fig. 3

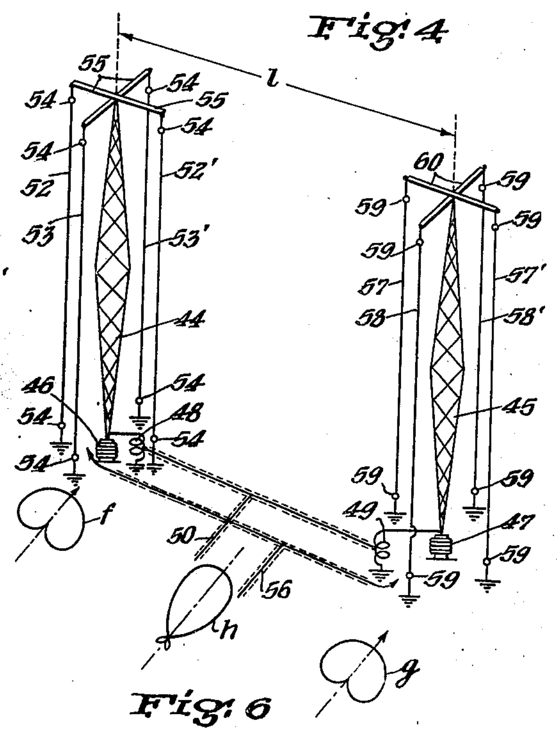

Fig. 6

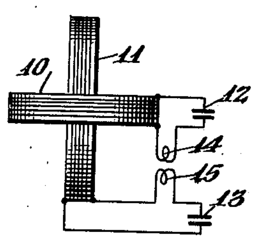

Fig. 2

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DIRECTIONAL RADIO SYSTEM

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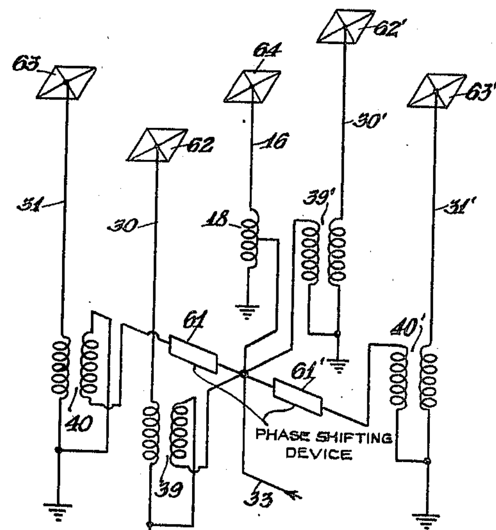

Fig: 5

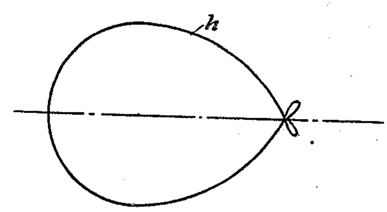

Fig: 7

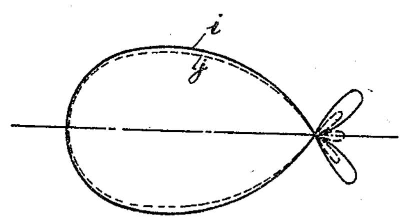

Fig: 8

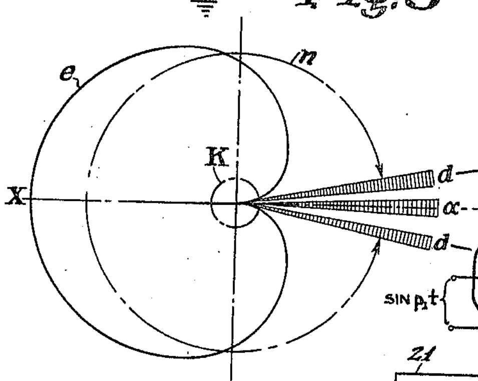

Fig: 10

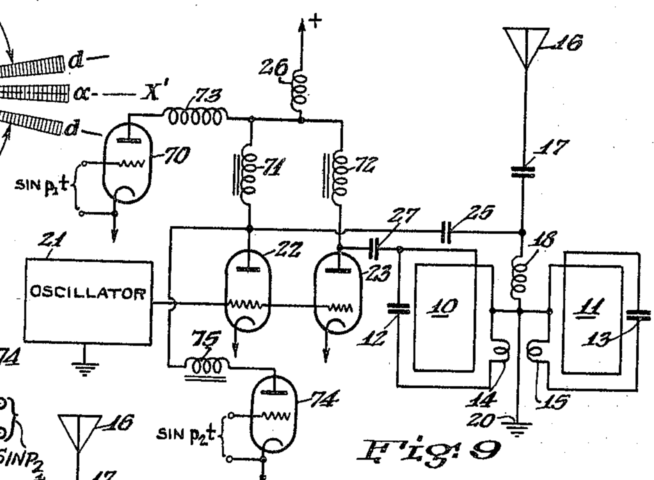

Fig: 9

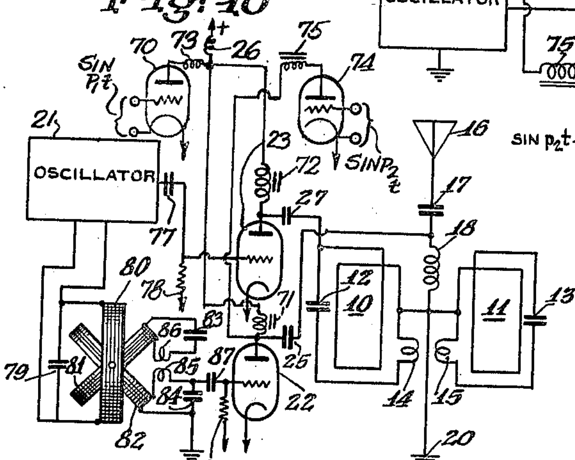

Fig: 11

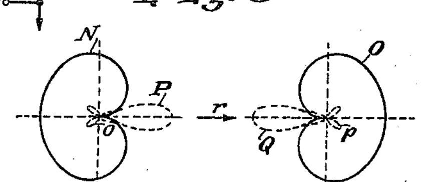

Fig: 15

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DIRECTIONAL RADIO SYSTEM

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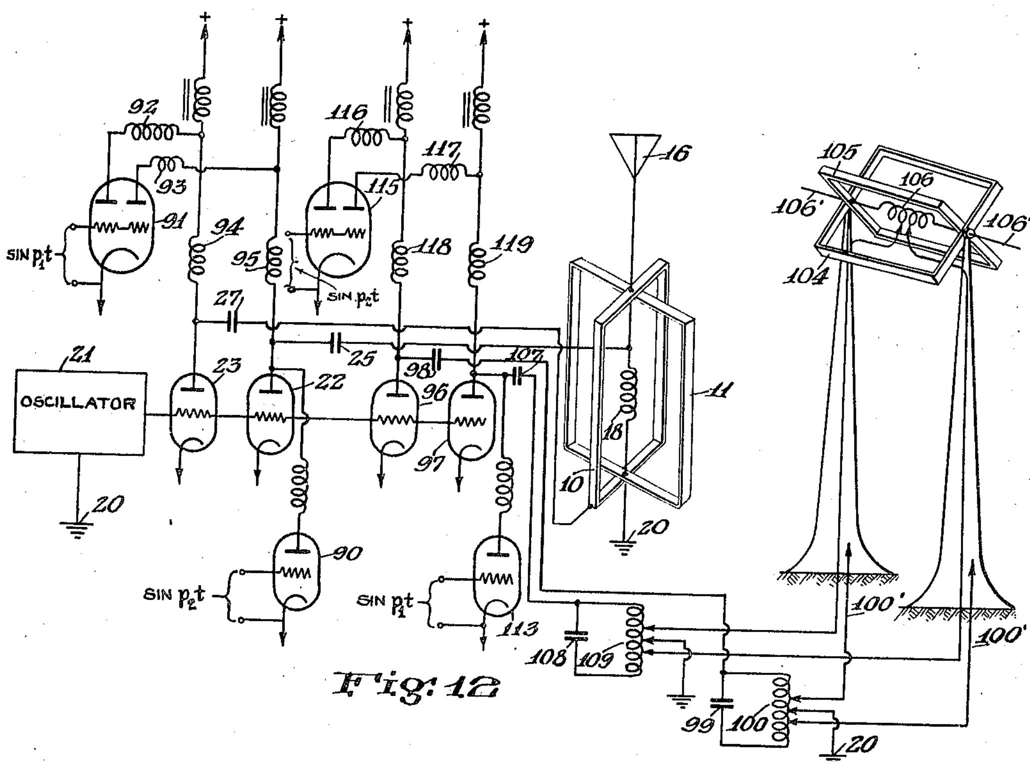

Fig: 12

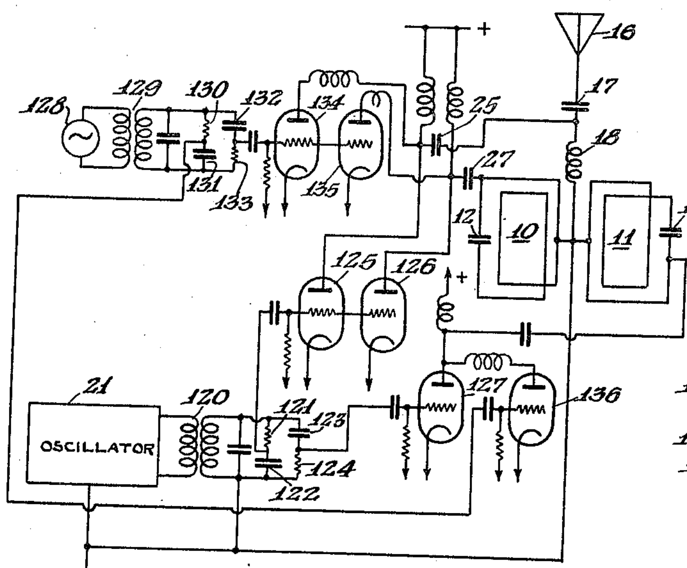

Fig: 13

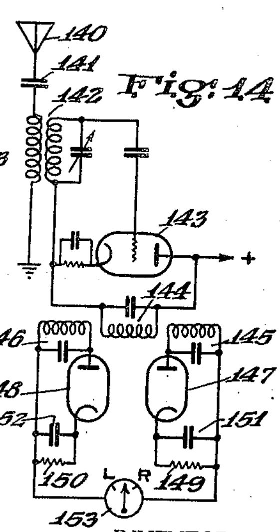

Fig: 14

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Patented Dec. 10, 1940

2,224,233

UNITED STATES PATENT OFFICE

2,224,233

DIRECTIONAL RADIO SYSTEM

Jozef Plebanski, Warsaw, Poland, assignor to Radio Patents Corporation, New York, N. Y., a corporation of New York

Application May 5, 1938, Serial No. 206,141
In Poland June 22, 1937

10 Claims. (Cl. 250—11)

The present invention relates to directional radio systems and methods of operating the same such as for transmitting and/or receiving intelligence, for guiding moving craft, and for other purposes well known.

An object of the invention is the provision of a directional antenna system having a greatly improved cardioid type directional characteristic compared with the directional patterns of similar type obtainable with the systems and methods known in the prior art.

Another object is to provide a directional radio system comprising spaced antenna units wherein the spacing of the individual units may be greatly reduced compared with conventional systems of this type for obtaining a given directional pattern or characteristic.

A further object is to provide a radio beacon system simultaneously transmitting a plurality of different signals, each signal being receivable in a different predetermined zone or sector only.

Still a further object is the provision of a radio range beacon transmitting a characteristic signal within a narrow angular zone or sector.

Another object is to provide a sharply defined narrow radio signal beam which can be adjusted in any desired direction.

Another object is to provide a three-dimension radio beam system for guiding moving craft in both elevational and azimuthal directions.

Still a further object is to provide a radio range beacon and a visual left-right indicator cooperating therewith at the receiving end.

The above and further objects and aspects of the invention will become more apparent from the following detailed description taken with reference to the accompanying drawings forming part of this specification and wherein;

Figure 1 illustrates a basic circuit constructed in accordance with the invention comprising a pair of crossed loop aerials and an open or omnidirectional antenna for producing an improved cardioid shaped polar directional diagram,

Figure 2 is a top view of a structure with concentric loop aerials according to Figure 1,

Figure 3 shows the polar characteristic or directional pattern obtained with a system according to Figure 1,

Figure 4 illustrates a modified system of the type according to Figure 1,

Figure 5 shows a modification of an antenna system of the type shown in Figure 4,

Figure 6 represents a directional antenna system comprising spaced antenna units of the type according to the invention,

Figures 7 and 8 show directional diagrams obtainable with antenna systems shown in Figure 6,

Figure 9 illustrates a radio beacon system employing the principles of the invention,

Figure 10 shows the directional diagram explanatory of the function of the system shown in Figure 9,

Figure 11 shows a modification of the system according to Figure 9,

Figure 12 illustrates a pair of radio signal beacons according to Figures 10 and 11 for direction finding in both horizontal and vertical planes,

Figure 13 illustrates a radio beacon system according to the invention with improved features embodied therein,

Figure 14 illustrates a receiver for visual left-right indication cooperating with a range beacon shown in Figure 13,

Figure 15 illustrates the invention as applied to point to point or secret communication.

Similar reference characters identify similar parts throughout the different views of the drawings.

Referring to Figures 1 and 2 wherein there is shown a transmitting system with an improved cardioid shaped directional characteristic, items 10 and 11 represent a pair of crossed loop aerials arranged with their planes perpendicular to each other. The loops may be spaced or coaxial as shown in Figure 2. Both loops are shunted by tuning condensers 12 and 13 in series with induction coils 14 and 15, respectively. The latter are arranged in inductive coupling relation whereby the loop circuits are mutually coupled. Numeral 16 represents an open or omni-directional aerial connected to an inductance or loading coil 18 through a coupling condenser 17. The upper terminals of the coupling coils 14 and 15 and the lower end of the loading coil 18 are connected to ground 20 as shown. The loop 10 and the open antenna 16 are energized from an oscillator or source of carrier currents 21 through individual amplifying valves 23 and 22, respectively. To this end the anode of valve 22 is connected to the upper side of the antenna loading coil 18 through a coupling condenser 25, a coupling inductance 24 being inserted in the supply lead from the anode to the positive pole of a high potential supply source indicated by the plus sign. Similarly the anode of valve 23 is connected to the upper side of tuning condenser 12 for the loop 10 through a coupling condenser 27, an output or coupling inductance 26 being inserted in the lead from the anode of this valve to the positive pole of the high tension supply source. The loop 11 receives its energy indirectly from the loop 10 through the coupling between coils 14 and 15. Any other coupling such as a capacitative coupling may be employed between the loop circuits in place of the inductive coupling illustrated, as will be understood from the following.

If the two loop aerials 10 and 11 and the antenna 16 are tuned to the frequency of the oscillations supplied by the source 21, a directional radiation diagram or polar pattern will be obtained as shown in Figure 3. In the latter, *a—a* represents the well known "figure of eight" directional diagram for the loop 10, *b* represents the circular diagram for the open or omni-directional antenna 16. Both diagrams combined result in the conventional cardioid shaped radiation pattern shown at *c*. Curve *d—d* represents the "figure of eight" pattern for the second loop 11 receiving its energy indirectly from the loop 10 whereby the currents in the two loop circuits are phase shifted with respect to each other by exactly 90°. The radiation from the loop 11 may be made greater, equal, or smaller than the radiation from the loop 10 such as by varying the number of turns in the two loops or in any other known manner. For the purposes of this invention, especially in connection with the arrangements illustrated in Figure 6, it is advantageous to provide for an increased radiation from the loop 11, preferably about twice or more compared with the radiation from the loop 10, as shown in the example illustrated.

Taking into consideration the fact that the current in the loop 11 ("figure of eight" diagram *d—d*) is in phase quadrature with respect to the current in the loop 10 ("figure of eight" diagram *a—a*) and the open antenna (circle diagram *b*), an over-all directional characteristic for the entire system is obtained as shown by the curve *e* in Figure 3. This curve represents a distorted cardioid having a substantially reduced non-receptive angle in the direction of the *x—x'* axis compared with an ordinary cardioid such as shown at *c*. At pattern of this type further differs from the conventional cardioid by the fact that the phases of the space waves radiated are no longer equal in all directions as in the conventional cardioid radiation pattern but differ from each other in the different directions. This type of cardioid will therefore be referred to as a "phase cardioid" for the purpose of this specification to distinguish from the regular cardioid pattern. The phases depend upon the sense or relative phase of the upper and lower circles of the pattern for the loop 11. Thus, for instance, if the phase of the currents for the cardioid *c* (loop 10 and antenna 16) is assumed to be 180° with respect to a zero phase or line and the phase of the current for the upper circle *d* for the loop 11 to be 90° with respect to said zero phase, then the phases of the space waves in different directions will be as shown by the solid arrows A, B, C, D, E, F, G, in Figure 3 for various directions. If the phase for the upper circle *d* of the diagram for the loop 11 is reversed (270°), then the phases of the radiated waves shall be as shown by the dotted arrows A', B', C', D', E', F', G' for the various directions.

There is thus shown and described by the invention a directional radio system comprising a first loop aerial and an open or omni-directional aerial to yield a cardioid shaped directional pattern and a second loop aerial with its plane or direction of maximum receptivity at right angles to the plane of the first loop aerial and excited by currents being in phase quadrature to the currents in the first loop aerial and open antenna. By combination of the cardioid shaped diagram and the "figure of eight" diagram of the second loop aerial, a resultant "phase cardioid" diagram with substantially improved directional characteristics is obtained.

In place of two crossed loops and an open antenna, a system comprising five open antennae such as wires may be employed to obtain a similar pattern in accordance with the invention, as illustrated in Figure 4. In the latter, the grounded aerial wires 30—30', and 31—31', may be of the Marconi-Adcock or any other known type. The aerials 30—30' are energized from a carrier source through a feeder line 33 including the primaries 34 and 35 of a pair of feeding transformers whose secondaries 36 and 37 are connected in series with the antenna wires. The antenna 16 is energized through a feeder 38 connected to a suitable tap point of the loading inductance 18. In order to effect the necessary 90° phase shift in the antenna 31—31', there are provided transformers 39 and 40 mutually coupling the antenna systems in a manner substantially similar to Figure 1. The feeder lines 33 and 38 may be connected to a transmitter or oscillator such as to separate power amplifying valves 22 and 23 as shown in Figure 1. There are further shown inductance coils 41 and 42 connected in series with the aerials 31 and 31', respectively, for tuning the aerials to the same wave length to which aerials 30 and 30' are tuned by the inductances 37 and 36.

Instead of using two feeder lines, only one feeder may be provided for energizing all antennae as shown in Figure 5. In the latter the grounded aerials 30—30' and 31—31' are decoupled and energized by currents in phase quadrature from the carrier source through feeding transformers 39, 39' and 40, 40', respectively. The phase shift can be accomplished in any known manner such as by the insertion of phase shifting devices 61 and 61' of any suitable construction in the feeders or by using feeders of different length. The open antenna 16 in this case is fed from the same feeder 33. It is necessary however, that the open antenna be fed with currents of the same phase angle as the antenna 30—30'. In order to improve the vertical radiation characteristic of the system, the individual antennae may be capacity-loaded by means of metallic top structures or conductors as shown at 62—62', 63—63' and 64, respectively. In this manner the radiation of sky waves is minimized resulting in reduction of fading due to interference between signals absorbed from both earth bound and sky bound radiation at a receiving point.

Referring to Figure 6, there is shown an embodiment of the invention applied to a directional antenna array, in the example shown comprising two antenna units each having a "phase cardioid" pattern of the type described previously. An advantage of an arrangement of this type is the fact that the spacing between the individual aerials which in the case of the conventional systems should be one-half the wave length can be considerably reduced to a distance of about one-tenth of the wave length or less, while obtaining substantially the same directional characteristics originally obtainable with known arrangements employing substantially greater spacing distances. This makes it possible to construct directional transmitting aerials for the longer wave lengths in a simple and easy manner including the broadcast waves from 200 to 500 meters wave length.

As is well known, in order to meet the general requirements for broadcasting purposes and to avoid transmitting channel congestion, a solution has been found by using directional broadcasting aerials thereby providing a sufficient coverage for a densely populated surface area and at the same time eliminating interference in other regions. An obstacle to such a solution, however, has been the fact that the construction of directional aerials for wave lengths of the order of 500 meters is costly and complicated when using the known methods requiring spacing distances between the individual antenna units of the order of one-half of the wave length radiated; that is, spacings of the order of 250 meters. Moreover, in order to obtain uni-directional transmission, reflectors have to be provided spaced from the main transmitting antenna by one-quarter of the wave length; that is, by distances of the order of about 125 meters. By the present invention the above difficulties are substantially overcome by enabling a reduction of the spacing distance to as low as one-tenth of the wave length resulting in less bulky and expensive antenna structures. Thus, for a wave length of 500 meters a spacing of the antenna units of only 75 meters will result in a pronounced directional or beam radiation characteristic as described more fully hereafter.

In order to obtain this object of the invention, two or more systems or units having a "phase cardioid" directional pattern are provided in spaced relation and fed from a common carrier source or oscillator.

Referring to Figure 6, such a system comprising two antenna units has been illustrated. Items **44** and **45** are two towers or masts spaced by a distance l equal to about 0.15 of the wave length to be radiated. The masts are insulated from ground by insulators **46** and **47**, respectively, whereby they constitute open aerials corresponding to the aerial **16** in Figures 1, 4 and 5. For this purpose the masts **44** and **45** are connected to ground through tuning or loading coils **48** and **49**, respectively, which latter are energized by a shielded feeder line **50** connected to the output of a carrier source or amplifier such as shown in the previous figures. Each of the mast antennae **44** and **45** has associated therewith a four-wire vertical antenna system of the type shown in Figures 4 and 5. The vertical antennae **52—52′** and **53—53′** for the mast **44** are suspended between supporting cross bars **55** and ground by means of insulators **54** as shown. Similarly the vertical wires **57—57′** and **58—58′** for the mast **45** are suspended between cross bars **60** and ground by means of insulators **59**. The cross bars **55** and **60** mounted at the top of the masts or towers **44** and **45** may be of conductive material to act as capacitative loadings for the open antennae similar to and for the purpose as pointed out above. The vertical antennae associated with each of the open mast antennae **44** and **45** are supplied with oscillating energy through a feeder line **56** from an amplifier or oscillator in a manner substantially similar as shown in the previous figures, the details of the feeding and distribution system having been omitted for simplicity of illustration.

If in a system hereinbefore described, the antenna structure associated with mast **44** is designed to produce a "phase cardioid" type radiation characteristic as shown at f wherein the phases of the waves radiated are as shown at A, B, C, D, E, F, G in Figure 3 and if the antenna structure associated with mast **45** produces a "phase cardioid" type radiation characteristic as shown at g wherein the space phases of the radiated waves are as shown at A′, B′, C′, D′, E′, F′, G′ in Figure 3, then the resultant over-all radiation characteristic of the entire antenna system will be as shown at h in Figure 6, or as more clearly shown in Figure 7. In order to obtain such a characteristic the spacing l between the antenna units has to be only about 0.15 λ (exactly 0.1475 λ) instead of 0.5 λ required in conventional systems. If the individual antennae **30—30′**, and **31—31′** and the antenna **16**, Figure 4, are equal, the currents in **30—30′** and **16** should be in phase and of such amplitude relation that the directional characteristic corresponds to $a—a$ for the antennae **30—30′** and to b for the open antenna **16**, Figure 3. The current in the antennae **31—31′** should be in phase quadrature and preferably have twice the amplitude of the current in the antennae **30—30′**. Alternatively, the spacing between the wires **31—31′** may be greater than the spacing between the wires **30—30′**.

The arrangement according to Figure 6 is shown by way of example only and it is understood that many modifications are possible such as the employment of loop aerials in place of open wires. Furthermore, the masts **44** and **45** may be of non-radiating material and a special omni-directional or open antenna may be provided for each system and the units suspended between ground and a wire or other support connecting the two masts. The spacing l between the aerial systems or masts **44** and **45** may be further decreased. There is shown at i in Figure 8 a diagram for a spacing of .122 λ and for a radiation from the antennae **31—31′** two and a half times greater than the radiation from the antennae **30—30′**. By increasing the current in the open antenna, the diagram may be further improved as shown at j in Figure 8. An increased number of spaced antenna units may be provided to further improve the directional characteristics as is understood. Moreover, the system may be used with equal advantage for receiving, in which case preferably shielded loop aerials or Marconi-Adcock systems are employed to prevent distortion of the directional characteristic by the downcoming component of electromagnetic radiation known as night error.

Referring to Figure 9, there is shown a radio signal beacon embodying the principle of the invention. The system illustrated is substantially similar to that shown in the previous figures, such as Figure 1. The carrier potentials impressed upon the loops **10** and **11** and the open aerial **16** are simultaneously modulated in accordance with a first modulating signal such as a sinusoidal audible note sin p_1t while the carrier fed to the open aerial is additionally modulated in accordance with a different signal or modulating note sin p_2t. In the example illustrated, there is provided for this purpose a first modulating valve **70** having its grid excited by a potential varying according to the signal sin p_1t and being connected in shunt to the plate circuits of the amplifiers **22** and **23** in series with choke coils **71** and **72**, respectively, according to the well known plate modulation method. Item **73** is a further high frequency choke coil connected in the common lead between the modulating tube **70** and the anodes of amplifiers **22** and 23. In this manner the waves radiated by the loops 10 and 11 and the aerial 16 are modulated in accordance with a signal frequency in the example illustrated, a signal sin p_1t. Furthermore, the open aerial 16 is modulated additionally by means of a second modulating valve 74 having its grid excited by a different modulating signal in the example illustrated a sinusoidal potential varying according to sin p_2t, and having its anode connected to the anode of the amplifying tube 22 in series with a high frequency choke coil 75. As is understood, any other well known modulating system may be employed for the purpose of the invention. An arrangement of this type may be designed and adjusted in such a manner that the modulating signal sin p_2t applied by the valve 74 is transmitted only within a narrow angle α as shown in the diagram of Figure 10; whereas the modulating signal sin p_1t applied by the valve 70 is transmitted in all the remaining directions in accordance with the "phase cardioid" e.

This is further understood from the following: by assuming that the loop 10 in Figure 9 has a characteristic a—a, that the open aerial 16 has a characteristic b and that the loop 11 has a characteristic d—d as shown in Figure 3, and that furthermore the loop currents are in phase quadrature as described, the field strength at a point in space whose connecting line with the transmitter forms an angle ϑ with the axis x—x' in Figure 10 may be defined by the following theoretical expression:

$e=A_1 \sin \omega t+B_1 \sin p_1t \sin \omega t$ radiation from open antenna 16 modulated according sin p_1t
$-(A_1 \sin \omega t+B_1 \sin p_1t \sin \omega t)K_1 \cos \vartheta$ radiation from loop 10 modulated according sin p_1t
$+(A_2 \cos \omega t+B_1 \sin p_1t \cos \omega t)K_2 \sin \vartheta$ radiation from loop 11 modulated according sin p_1t
$+A_2 \sin \omega t+B_2 \sin p_2t \sin \omega t$ radiation from antenna 16 modulated according to sin p_2t

wherein A_1 and A_2 are the amplitudes of the carriers or unmodulated components, and B_1 and B_2 are the amplitudes of the modulated components of the carrier currents in the separate antennae.

In the direction $\vartheta=0$ (axis x—x'), assuming $K_1=1$, the first six terms will disappear and the field strength found to be as follows:

$$e=A_2 \sin \omega t+B_2 \sin p_2t+\sin \omega t$$

From the above it is seen that in a system of this type, the modulating signal having a frequency $p_2/2\pi$ will be heard only within a narrow transmitting angle, in practice being only about 1 to 2 degrees. In all other directions, the second signal having a frequency $p_1/2\pi$ will be heard. This is further explained as follows. Since both loop aerials 10 and 11 and the open antenna 16 are energized by the carrier from oscillator 21 and modulated according to a modulating signal sin p_1t through valve 70 and choke coils 71 and 72, the directional characteristic obtained will be of the "phase cardioid" type as explained hereinbefore resulting in a narrow angle α of no emission. If therefore the currents in the open antenna are now additionally modulated according to a modulating signal sin p_2t through valve 74 and assuming the carrier in the open antenna to be greater than in the other antennae (e. g., A_1+A_2), then this open antenna modulation (according to sin p_2t) will be radiated in all directions including the angle α. In the direction other than covered by the angle α, however, the modulation signal according to sin p_2t will be drowned out or banketed by the stronger modulation, leaving only the angle α for effective radiation of the signal modulation according to sin p_2t. In Figure 10 the carrier and modulation according to sin p_1t for the different directions are represented by the curve e and the desired carrier and modulation by the circle K.

The transmitting angle α for the first signal will become extremely small if A_2 is made small in relation to A_1 in the above expressions. In Figure 10 there is shown by the circle k the carrier A_2 as compared with the "phase cardioid" e showing the amplitudes of the carrier for all other directions. If A_2 is made zero which can be easily accomplished by adjusting the carrier currents in the loop 10 and the open aerial 16 in the unmodulated condition in such a manner as to obtain a pure cardioid diagram, only the two modulated side bands will be transmitted in the direction x—x' within the angle α for the signal frequency $p_2/2\pi$ with the carrier being eliminated. As is understood, actually the signal $p_2/2\pi$ is transmitted in all directions, but is cancelled by the substantially stronger signal $p_1/2\pi$ except within a narrow sector or angle.

A system of the above described type is well suited as a radio range beacon for guiding ships, aircraft, or other vehicles along a fixed route by defining a sharp zone wherein a predetermined signal is received. As an example for this purpose, the valve 70 may be modulated by a message identifying the name of the transmitting beacon while the valve 74 may be modulated in accordance with a different characteristic signal such as a definite audible note of a thousand cycles or any other desired frequency. Thus, a pilot will hear the name of the beacon in substantially all directions of travel of his craft, but will receive the characteristic signal in a predetermined direction only corresponding to a predetermined course towards or away from the transmitting beacon.

In Figure 11 there is shown a system of the type according to Figure 9 for producing a radio signal beacon whose direction can be adjusted within 360° in a simple and easy manner by varying the phase of the carrier current fed to the open antenna 16. To accomplish this, in the example illustrated, there is shown a phase shifting arrangement connected between the source of carrier current 21 and the amplifier 22 energizing the open aerial 16. This phase shifting device comprises an induction coil 80 shunted by a condenser 79 to form a tuned circuit connected to the source 21. There are further shown a pair of crossed induction coils 81 and 82 having their planes arranged fixedly and mutually perpendicular to each other. The induction coil 81 has connected thereto a tuning condenser 83 in series with a coupling coil 86 and similarly the coil 82 has connected thereto a tuning condenser 84 in series with a coupling coil 85. The coils 85 and 86 are arranged in inductive coupling relation in such a manner that if the circuits of both coils are tuned to resonance with the impressed carrier signals, the phase of the carrier potential derived from one of the tuned circuits, in the example illustrated the circuit of coil 82 impressed upon the grid of the modulating tube 22 through coupling condenser 87 and grid leak resistance 88, may be varied between 0 and 360° by adjusting the relative position between the coil 80 on the one hand and the crossed coils 81 and 82 such as described in detail in my copending application Serial No. 133,793 filed March 30, 1937, entitled "Electrical systems." In this manner, the signal beam (angle α) may be rotated through an angle of 360° by rotating the crossed coils 81 and 82 in a most simple and easy manner. In an arrangement of this type, it is preferable to employ loops 10 and 11 of substantially equal radiating strength. As is understood, any other phase rotating device may be employed for the purpose of the invention, although the system shown has the advantage of general simplicity and efficiency. As is understood the valves 22 and 23 may be modulated in a manner described previously to obtain a signal beam radiation. To this effect, a first modulating valve 70 having its grid excited by a potential varying according to the signal sin p_1t is connected in shunt to the plate circuit of amplifier 23 in series with a low frequency choke coil 72 and a high frequency choke coil 73, and a second modulating valve 74 having its grid excited by a different modulating signal varying according to signal sin p_2t is connected in shunt to the plate circuit of amplifier 22 and in series with a high frequency choke coil 75; amplifier 22 is connected through a low frequency coil 71 with one end of the high frequency choke coil 26.

It will be appreciated that in this way the oscillatory energy of the principal character as to frequency and otherwise delivered by oscillator 21 is modulated with the signal sin p_1t and sin p_2t, respectively, according to the well known plate modulation method. The signals sin p_1t and sin p_2t can be substituted by any desired other form of signals.

A system of the type according to Figure 9 is also well suited for transmitting interlocking signals such as the letters *n* and *a* according to the well known Morse code. In the latter case, the valve 74 may be keyed according to the letter *a* (dot followed by a dash) and the valve 70 may be keyed in accordance with the letter *n* (dash followed by a dot), both letters interlocking so as to merge into a continuous dash if received with equal strength simultaneously. In this embodiment of the invention, the letter *n* will be heard in all directions such as indicated by *n* in Figure 10 except within the angle α wherein only the letter *a* is received. A deviation to the right or left will bring the aircraft or other vehicle into transition zones wherein a continuous dash signal is heard as indicated by *d* in Figure 10.

According to a further embodiment of the invention, two systems of the type shown in Figures 9 and 11 may be combined, one designed for defining a signal beam in a vertical plane, thereby enabling direction finding or guidance of moving craft in three dimensional space for blind landing and other uses. Thus, e. g., if one of the systems works with a note of say 400 cycles and the other with a note of 1000 cycles, it can be shown that predetermined zones are defined in a vertical plane at right angle to the transmission of the beams enabling a pilot to guide his craft in both azimuthal and elevational directions.

A system of this type is illustrated in Figure 12. In the latter the loops 10 and 11 and the open aerial 16 fed from the source 21 through valves 23 and 22 are provided to define a signal beacon in a horizontal or azimuthal plane in the manner described hereinbefore. To this end, both loops and the open aerial are modulated in accordance with a first signal note sin p_1t through a composite double section modulating valve 91 connected to the anodes of amplifiers 22 and 23 through choke coils 93, 95 and 92, 94, respectively. The open aerial is additionally modulated in accordance with a signal note sin p_2t by the aid of a modulating valve 90 connected to the anode of valve 22 in a manner similar as described hereinbefore. The tuning of and the coupling means between the loops 10 and 11 are not shown for purpose of simplicity, both having been previously described and illustrated.

There is further shown in Figure 12 a system comprising a pair of crossed loop aerials 104 and 105 and a dipole antenna, all arranged with their axes horizontally, the dipole antenna comprising a central induction coil 106 and opposite horizontal radiating wires 106' and 106''. One of the loop aerials 104 or 105 is supplied with carrier energy through a valve amplifier 96 having its grid excited by the carrier source 21, coupling condenser 98 and a tuned circuit comprised of an induction coil 100 shunted by a condenser 99, the leads 100' from the tank circuit 99, 100 being connected to suitable tap points on the loop inductance. The loops 10, 11 and 104, 105 are tuned and mutually coupled with each other in exactly the same manner as previously described but not shown for the sake of simplicity of illustration. Similarly, the dipole antenna is supplied with carrier energy through an amplifier valve 97 also excited by the carrier source 21, a coupling condenser 107 and a tuned circuit comprising an inductance coil 109 shunted by condenser 108. The carrier currents impressed upon the loops 104 and 105 and the dipole antenna 106 are modulated in accordance with the signal note sin p_2t by the aid of a double section modulating valve 115 having its anodes connected to the anodes of the valves 96 and 97 through choke coils 116, 118 and 117, 119, respectively, while the dipole antenna is modulated additionally according to the signal note sin p_1t by means of a modulating valve 113 connected to the anode of valve 97. Further details, such as coupling between loops, etc., are substantially the same as shown and described in connection with the previous figures and are therefore not repeated for simplicity of illustration.

In a system of this type definite signal zones are created in a plane at right angles to the direction of the signal beacons as follows, assuming that the signal beacon in one plane such as the horizontal plane has a 400 cycle note keyed in interlocking relation according to the letters *a* and *n* in the manner as described hereinabove and that the signal beacon in the other (vertical) plane has a 1000 cycle note similarly keyed according to the letters *a* and *n*.

n–400 *n*–1000	*d*–400 *n*–1000	*n*–1000 *a*–400	*d*–400 *n*–1000	*n*–400 *n*–1000
n–400 *d*–1000	*d*–400 *d*–1000	*a*–400 *d*–1000	*d*–400 *d*–1000	*n*–400 *d*–1000
n–400 *a*–1000	*d*–400 *a*–1000	*a* (400 (1000	*d*–400 *a*–1000	*n*–400 *a*–1000
n–400 *d*–1000	*d*–400 *d*–1000	*a*–400 *d*–1000	*d*–400 *d*–1000	*n*–400 *d*–1000
n–400 *n*–1000	*d*–400 *n*–1000	*a*–400 *n*–1000	*d*–400 *n*–1000	*n*–400 *n*–1000

The signals are transmitted on the same wave length or carrier so that a simple receiver can be employed. There is thus defined a path or beam by the intersection of both signal beacons in three-dimensional space which may correspond to the gliding path of an aircraft for effecting a blind landing and which can be easily identified by the pilot when receiving the letter *a* on both notes simultaneously; that is, when hearing a pure double note interrupted according to the letter *a* without any background. The above table indicates a continuous dash by *d* at either 400 or 1000 cycles or with both notes received simultaneously.

Systems of the type according to Figures 9, 11 and 12 are subject to left-right ambiguity which can be eliminated by an improved arrangement shown in Figures 13 and 14. In Figure 13 the loop **10** and the open antenna **16** are energized by carrier currents in quadrature phase relation to the current fed to the loop **11** and similarly the modulating currents for the loop **10** and the antenna **16** are in phase quadrature to the modulating current for the loop **11**. To this end there is connected to the carrier source **21** a transformer **120** having its secondary shunted by a tuning condenser and a pair of series networks one of which comprises a non-reactive or ohmic impedance **121** and a condenser **122**. Similarly the other network comprises a condenser **123** in series with a resistance **124**. The potential developed at the junction between resistance **121** and condenser **122** is impressed upon the grids of a pair of amplifier valves **125** and **126**, the former serving to energize the antenna **16** and the latter energizing the loop aerial **10**. Similarly the potential at the junction between the condenser **123** and resistance **124** is impressed upon the grid of valve **127** serving to excite the other loop aerial **11**. Since the potentials at these junction points and ground are at a mutual 90° phase difference, it is seen that the antenna **16** and the loop aerial **10** are excited by carrier currents which are in quadrature phase relation to the currents exciting the loop **11**.

In addition, the carrier oscillation fed to the open antenna **16** and to the loop aerial **10** on the one hand and the loop antenna **11** on the other hand are modulated by quadrature modulating currents. For this purpose the source of modulating currents **128** has connected thereto a transformer **129** having its secondary shunted by tuning condenser and a pair of series networks, the network comprising a resistance **130** and a condenser **131** and the second network comprising a condenser **132** and a resistance **133**. The potential developed at the junction between the condenser **132** and resistance **133** is impressed upon the grids of a pair of modulating valves **134** and **135** serving to modulate the carrier currents supplied by the amplifier valves **125** and **126** and impressed upon the open antenna **16** and loop aerial **10**, respectively. Similarly the potential developed at the junction between the resistance **130** and condenser **131** is impressed upon the grid of modulating valve **136** serving to modulate the currents supplied by the amplifier valve **127** feeding the second loop aerial **11**.

It can be shown that in a system of the aforedescribed type wherein the radiation of the open antenna **16** is slightly higher than the radiation from the loop aerial **10**, a deviation of the vessel or aircraft to the right will cause elimination (within the zone *d* according to Figure 10) of one of the modulated signal side bands, such as the upper side band, while deviation to the left will result in elimination of the other or lower modulated side band according to the example chosen. By using on the vessel or aircraft a receiver including two resonant circuits one of which is detuned slightly above and the other is detuned slightly below the carrier frequency (or of the intermediate frequency in case of a superheterodyne receiver) with suitable rectifiers connected thereto in differential arrangement, the deviation can be indicated by means of a zero center indicating instrument.

A simple receiving circuit of this type is shown in Figure 14. In the latter, **140** represents a receiving antenna connected to ground through a coupling condenser **141** and the primary of a tuned input transformer **142**. The secondary of the latter is arranged to excite the grid of an amplifying valve **143** having a tuned circuit **144** connected in its output. The circuit **144** is coupled with two tuned circuits **145** and **146** each slightly detuned oppositely relative to the tuning of the circuit **144** (carrier frequency). The circuits **145**, **146** are connected in series with diode rectifiers **147**, **148**, load resistors **149** and **150**, the latter being shunted by smoothing capacities **151**, **152**. Numeral **153** represents a zero center type indicating instrument showing the deviation of a craft to the left or right from its true course as determined by a signal beam of the type shown in Figure 13.

For blind landing, two groups of detuned circuits will be required. One group for the horizontal bearing indication and another for indicating the vertical bearing. In this case one indicating instrument may serve to show the horizontal course and a further instrument to show the vertical course. Alternatively a combined instrument can be employed as is customary in systems of this type. Furthermore, the two groups of detuned circuits should differ only by the degree of detuning as one group should be sensitive only for one (such as the lower modulating frequency) and to the side bands produced by this frequency, while the other group should be sensitive for the other (such as a higher modulating frequency). Both beams that is, both for horizontal and vertical bearing indication may operate on the same wave length which may be of the order of 1000 meters or any other desired value.

Thus, supposing for instance that the two beacons, that is both the horizontal and vertical beacon to operate on 900 meters wave length and one (e. g., the vertical beacon) to be modulated by a 1000 cycle note and the other (i. e., the horizontal beacon in the example) to be modulated by a 5000 cycle note, two channels may be provided in the receiver for the intermediate frequency signals of say 130 kc.+1 kc. and 130 kc.+5 kc., respectively, with relatively detuned circuits in each as shown at **145**, **146**, Figure 14. The instrument in this case may be a double or twin instrument having their pointers arranged vertically and horizontally and each having its moving coil connected to one pair of detuned circuits.

Referring to Figure 15, there is illustrated a further application of the invention for point to point or secret communication. For this purpose there are provided at a first point (station *o*) two aerials one of which has a "phase cardioid" radiation pattern N while the other may be an omni-directional aerial or a directional aerial with a characteristic P whose axis coincides with the direction of zero radiation or receptivity of the first aerial. Similarly there are provided at a distant point (station *p*) two aerials, one with a "phase cardioid" pattern O and the other with a pattern Q and oriented in the direction of the station *o* as illustrated. Thus, as is seen, if the second aerials at both stations are of the omni-directional type in place of directional aerials (patterns P and Q as illustrated) and if different modulating signals are transmitted on the same wave length by the directional aerials ("phase cardioids" N and O) and by the omni-directional aerials by means of arrangements similar to Figure 9, communication for the desired signals may be carried out only in the direction *r* between the stations *o* and *p*; in all other directions the desired signal is drowned or blanketed by the signals according to the "phase cardioid" radiation in a manner similar to the operation described in connection with Figure 9. This effect, as will be evident from the above, is further improved by using directional aerials with patterns P and Q in place of omni-directional aerials oriented in the manner shown.

It will be apparent from the above that the invention is not limited to the specific arrangement of parts and elements shown and disclosed herein for illustration but that the underlying idea and principle of the invention are susceptible of numerous modifications and variations differing from the embodiments described and illustrated and coming within the broader scope and spirit of the invention as defined in the appended claims. The specification and drawings are therefore to be regarded in an illustrative rather than in a limited sense.

I claim:

1. A directional radio system comprising a plurality of spaced antenna units, each unit comprising an open antenna and a pair of directional antennae having "figure of eight" characteristics arranged at an angle of 90° relative to each other, the phases of the "figure of eight" characteristics of corresponding directional antennae in successive units being reversed by 180°, means for causing oscillatory energy in the open antenna and one of the directional antennae in each unit to be in phase quadrature with the energy in the remaining directional antenna of each unit, and a common operating circuit connected to all of said antennae.

2. A radio transmitter comprising an open antenna, a pair of directional antennae having "figure of eight" characteristics oriented at a substantially right angle relative to each other, a source of oscillatory energy, means for feeding energies of substantially equal phase relation from said source to said open antenna and to one of said directional antennae and for feeding to said other directional antenna energy in quadrature phase relation to said first energy, means for modulating the energies fed to said open antenna and said directional antennae in accordance with a first modulating signal, and further means for additionally modulating the energy fed to said open antenna in accordance with a second different modulating signal.

3. In a radio system as claimed in claim 2, means for variably adjusting the phase of the energy fed to said open antenna.

4. A radio transmitter comprising an open antenna, a pair of loop antennae arranged with their planes forming substantially a right angle, a source of carrier current, resonant circuits connected to said loop antennae, inductive coupling means connecting said resonant circuits, means for feeding energies from said source to said open antenna and to one of said loop antennae, means for modulating said energies in accordance with a first modulating signal and further means for modulating the energy fed to said open antenna in accordance with a second different modulating signal.

5. In a radio transmitter as claimed in claim 4, including means for adjusting the phase of the carrier current fed to said open antenna.

6. A directional radio transmitter comprising an open antenna, a pair of directional antennae having "figure of eight" characteristics oriented at substantially a right angle relative to each other, a source of carrier energy, means for feeding energies in like phase from said source to said open antenna and one of said directional antennae, further means for feeding energy from said source to said other directional antenna in phase quadrature relative to said first energies, a source of modulating signals, means for modulating the energy fed to said open antenna and to said first directional antenna in accordance with said modulating signals, and further means for modulating the energy fed to said other directional antenna in accordance with modulating signals in phase quadrature to said first modulating signals.

7. A directional radio transmitter comprising an open antenna, a pair of loop antennae arranged with their planes forming substantially a right angle, a source of oscillatory energy, means for feeding energies in phase quadrature relation from said source to said open antenna and one of said loop antenna and to said other loop antenna, respectively, a source of modulating signals, and further means for modulating each of said energies in accordance with signal components in quadrature phase relation derived from said modulating source.

8. A directional radio system comprising two spaced antenna units, each unit comprised of an open antenna and a pair of directional antennae having "figure of eight" characteristics oriented at a substantially right angle relative to each other, means for feeding oscillatory energies of like principal characteristic and substantially in phase to the open antenna and one of the directional antennae and shifted in phase by about 90° to the other directional antenna of each of said units, means for modulating said oscillatory energies fed to all antennae of one and to the open antenna of the other of said units in accordance with a first signal, and said oscillatory energies fed to all antennae of said other unit and to the open antenna of said first mentioned unit in accordance with a second signal.

9. In a system as described in claim 8 in which each of said units comprises directional antennae with their directions of maximum receptivity in a common plane, said planes of said units being arranged substantially perpendicular to each other.

10. In a system as described in claim 8, said first and second signals being of interlocking character.

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