April 24, 1962 G. WENNERBERG 3,031,663

MAGNETIC ANTENNA SYSTEMS

Filed Jan. 3, 1958 3 Sheets-Sheet 1

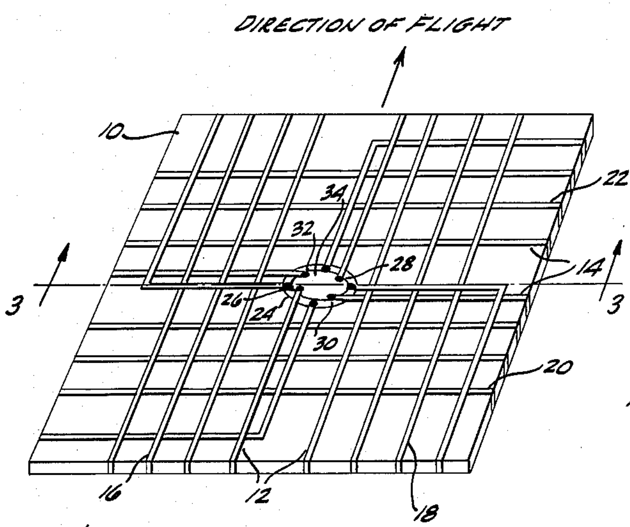


FIG. 1.

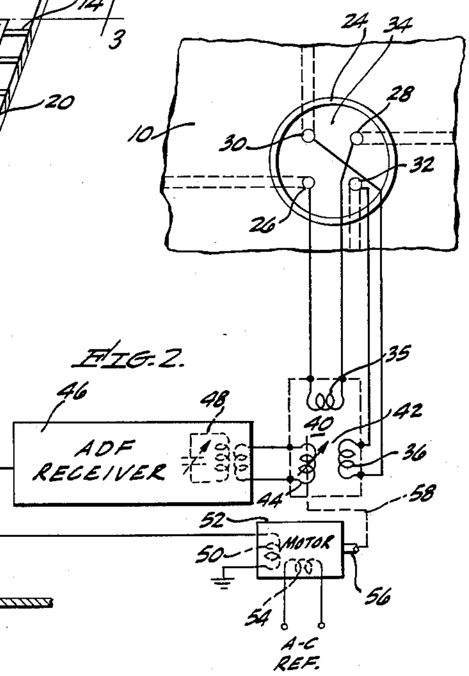
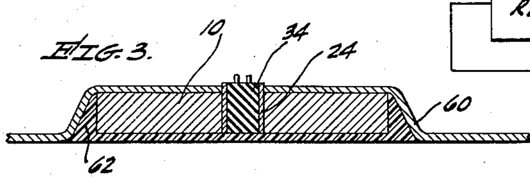


FIG. 2.

FIG. 3.



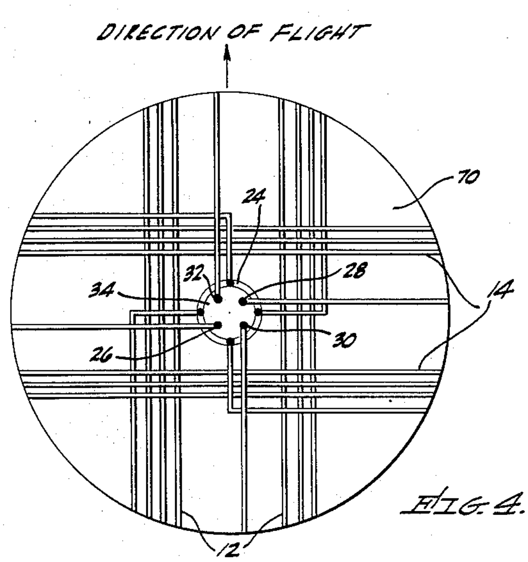


FIG. 4.

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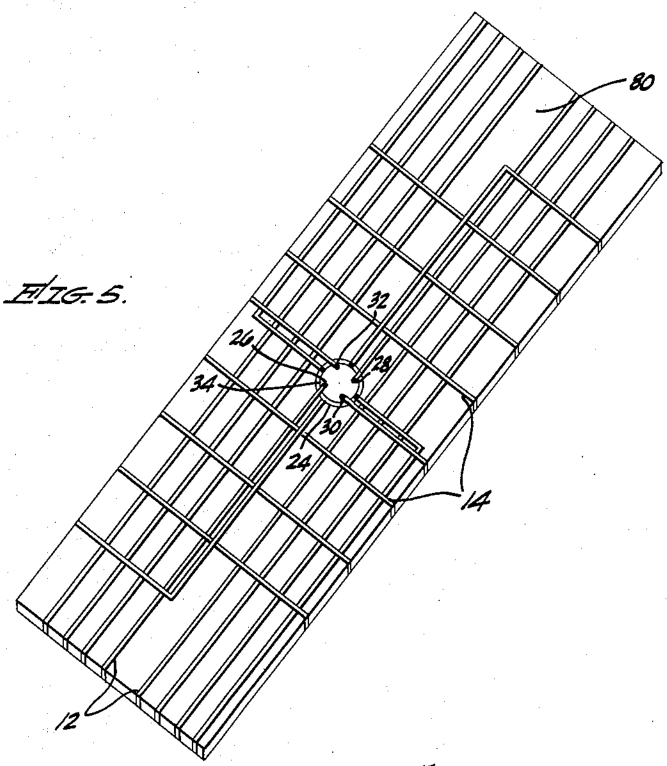

FIG. 5.

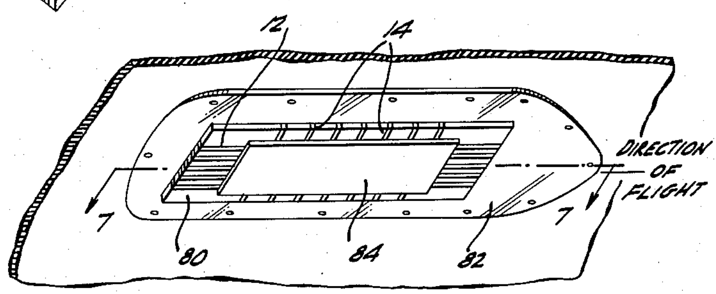

FIG. 6.

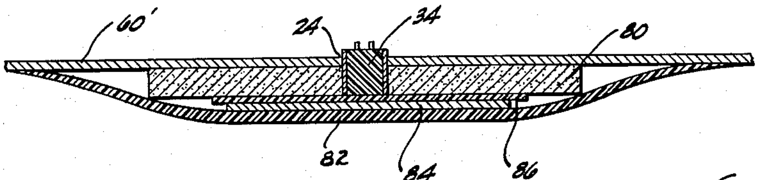

FIG. 7.

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April 24, 1962 G. WENNERBERG 3,031,663

MAGNETIC ANTENNA SYSTEMS

Filed Jan. 3, 1958 3 Sheets-Sheet 3

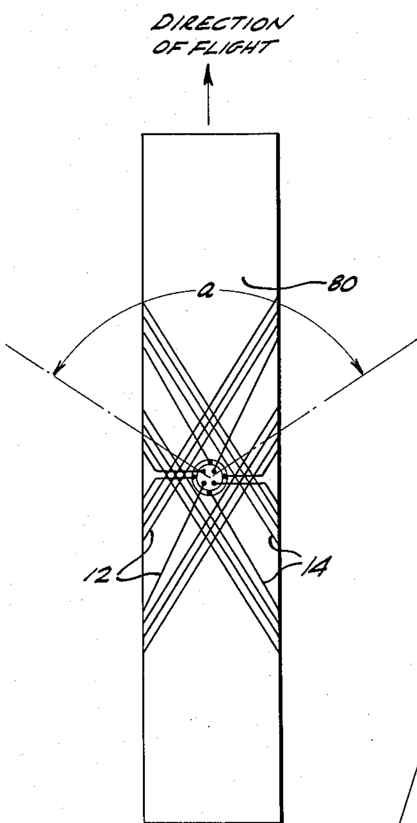

FIG. 8.

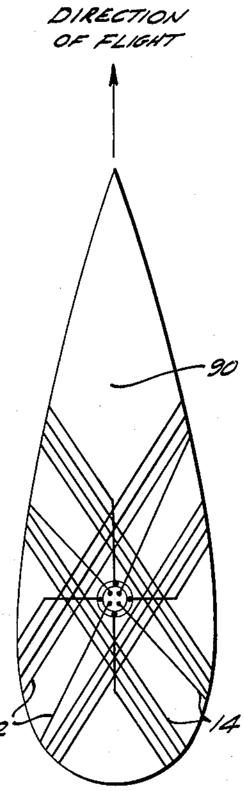

FIG. 9.

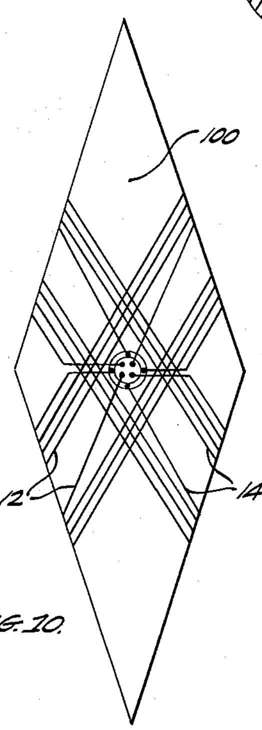

FIG. 10.

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Patented Apr. 24, 1962

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MAGNETIC ANTENNA SYSTEMS

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Filed Jan. 3, 1958, Ser. No. 706,912
11 Claims. (Cl. 343—117)

This invention relates to magnetic antenna systems, and more particularly to an improved flush type magnetic antenna, suitable for mounting on an aircraft, which employs no moving parts.

As heretofore employed, flush type magnetic antennas used as directional antennas for automatic direction finders on aircraft are formed either as a plurality of fixed magnetic elements arranged in spoke-like fashion about a rotatable core which carries a coil for connection to the receiver, or as a pair of crescent-shaped magnetic elements between which a rotatable coil is mounted. An antenna system comprising such numerous parts of course takes considerable time and pains to assemble, a factor which contributes considerably to its cost. In addition, the use of any rotating parts in the vicinity of the surface at which the antenna is mounted necessitates strengthening of the aircraft frame in the immediate vicinity, all of which contributes to the weight and bulk of the system. Furthermore, inherent in the movement of such coils is a variation in their inductance, which prevents receiver tuning to the same frequency in all positions of the coil.

Also in the prior art, quadrantal error compensation with ferrite antennas is achieved with undesirable structure configurations. Different schemes have been proposed for quadrantal error compensation in flush mounted antenna systems; in each, two or more ferrite elements are spaced from a rotatable coil, and means are employed to vary the shape and/or positions of such elements. Such means take the form either of ferrite stubs fixed across the outer or of means to vary the spacing between the elements. All such arrangements require painstaking care and machining to proper dimensions, and of course add to the weight, cost and bulk of the antenna structure. Furthermore, the inherent variations in inductance of the rotatable coil of previously known flush type antennas necessarily affect compensation; accordingly, all such means to effect quadrantal error compensation are at best only approximate.

It is an object of this invention to provide a flush mounted magnetic antenna which does not employ any moving parts, and which comprises a minimum number of component parts in a form simpler than any heretofore employed.

It is another object of this invention to provide an improved directional antenna of the flush mounted type for use in direction finding applications on aircraft, wherein a pair of windings form the antenna and are not subject to variations in inductance.

Another object of this invenion is to provide a fixed directional antenna system to replace rotatable loop antenna elements heretofore employed, wherein remote goniometer means are employed to effect translation of received signals to an ADF receiver, and wherein remote motor means are connected between the receiver and said goniometer means to reduce signals applied to the receiver to zero.

A further object of this invention is to provide an antenna arrangement using a flat magnetic element with windings thereon, wherein said element is configured to effect quadrantal error compensation.

The above and other objects and advantages of this invention will become apparent from the following description, taken in conjunction with the accompanying drawing, in which a preferred embodiment is illustrated by way of example. The scope of the invention is pointed out in the appended claims. In the drawing,

FIG. 1 is a perspective view of an antenna structure employing a square magnetic element, in accordance with this invention,

FIG. 2 is a schematic diagram illustrating an automatic direction finder system incorporating the antenna of FIG. 1, also in accordance with this invention,

FIG. 3 is a sectional view, taken along line 3—3 of FIG. 1 of the structure mounted on an aircraft,

FIG. 4 is a top plan view of an antenna structure employing a circular magnetic element, also in accordance with this invention,

FIG. 5 is a perspective view of an antenna illustrating a rectangular magnetic element for quadrantal error compensation, in accordance with this invention,

FIG. 6 is a perspective view of the structure of FIG. 5 mounted on an aircraft,

FIG. 7 is a sectional view taken along line 7—7 of FIG. 6,

FIG. 8 is a plan view of a rectangular magnetic element with a modified winding arrangement, further in accordance with this invention, and

FIGS. 9 and 10 are plan views of different shapes of magnetic elements employing a winding arrangement as in FIG. 8.

Referring to FIG. 1, one embodiment of a magnetic antenna structure in accordance with this invention employs a flat square element 10 of high-frequency, high-permeability material, which may be a dust iron or ferrite slab, upon which are mounted windings 12, 14. As shown, winding 12 is formed of a pair of coils 16, 18 made of conductive ribbons wound in one direction about element 10; similarly, winding 14 is formed of a pair of coils 20, 22 made of conductive ribbons wound at right angles to winding 12. Each coil has one end conductively connected, as by solder connections, to one end of the metallic cylinder 24 of a terminal socket centered in element 10; the remaining ends of coils 16, 18 are connected to respective terminal pins 26, 28 and the remaining ends of coils 20, 22 are connected to respective pins 30, 32 which are fixed in an insulating support 34 disposed within ring 24. In this manner, the pairs of coils 16—18 and 20—22 are connected in series to form the respective windings 12, 14.

Ring 24 will be recognized as used as a ground connection. Obviously each of the coil ends could be fixed to a separate ground pin (not shown) so that the ring need not be used for this purpose.

It will be noted that portions of the coils cross over portions of one or more of the other coils. To prevent direct contact, insulation is provided where necessary, as by coating the conductors with suitable material, or by inserting strips of insulation material between the portions involved, or between successive layers of conductors.

Referring to FIG. 2, connections are made from pins 26, 28 and from pins 30, 32 to the ends of respective stator windings 35, 36 of a conventional goniometer device 40; the goniometer is mounted within the aircraft, preferably on the instrument panel in the cockpit, in a position where movement of a pointer 42 carried by its rotor is visible to the pilot. The rotor winding 44 of the goniometer is connected to the input of an ADF receiver 46 in a conventional manner, the rotor winding 44 being inductively coupled to the tuner 48 of the receiver. The output of the receiver is connected to the control winding 50 of a two-phase motor 52 which has an A.-C. reference voltage applied to its reference winding 54. The output shaft 56 of motor 52 is connected to the rotor shaft of the goniometer, as indicated at 58.

It will be noted that in addition to or in lieu of pointer

42, a synchro device (not shown) may be operated by motor shaft 56, from which repeater synchro means may present indications elsewhere in the aircraft.

Preferably, windings 12, 14 each have the same inductance. This is effected by proper choice of number of turns and suitably spacing the turns of the windings. Thus, since the windings are fixed, no variations in inductance can occur; further, since they are wound at right angles to each other, there is no mutual inductance between them.

It should be noted that by placing the two windings on the same flat ferrite element as shown, one winding 14, being wound over the other winding 12, effectively supports such other winding in assembly. However, the procedure for winding can be varied as desired; for example, the windings may be assembled in a "basket-weave" pattern, i.e., with their turns interlaced, so they are mutually supporting in assembly. Electrically, basket-weaving achieves symmetry as to winding capacity.

After the windings are assembled as described, the structure is mounted on the surface of the aircraft, e.g., the belly of the aircraft, in a depression in the metallic skin 60. A suitable insulation material 62, which may be a thermoplastic resin, covers the outer surface of element 10 and, if desired, fills the crevices between the edges of the element and skin 60. The metallic ring 24 extends to the interior of the aircraft, where the electrical connections previously described are led to the goniometer in the cockpit.

By arranging the windings on the same flat element, i.e., with their axes in the same plane, maximum effectiveness of conversion of magnetic field variations in the ferrite material to electrical energy in the coils is realized. This may be better understood by considering that by so placing both windings, both are located in the vicinity of greatest concentration of magnetic lines of force. And by using element 10 as a common ferrite element to effect inducing of voltages in both windings, the irreducible minimum of magnetic elements is reached; as previously indicated, other magnetic antennas use two or more ferrite elements.

The stator windings 35, 36 of goniometer 40 are wound so as to be 90° apart electrically, as is conventional. When the transmitter station is straight ahead of the aircraft, a signal is picked up only in winding 12; the signal appearing in the output of receiver 46 causes motor 52 to position the rotor shaft so that winding 44 is at right angles to stator winding 35, at which point the induced signal disappears. Pointer 42 in this position indicates a null point aligned with the heading of the aircraft. If the station is directly to the rear of the aircraft, rotor winding 44 is positioned at right angles to stator winding 35, but reversed 180° from its position when the aircraft is flying directly toward the station. Pointer 42 in this situation would indicate that the station was 180° from null. Such ambiguity resolution will be recognized as conventional.

Similarly, for flight tangentially with respect to the transmitter, a signal would be induced in winding 14 only; the output of receiver 46 causes motor 52 to position winding 44 at right angles to stator winding 36. Pointer 42 would here indicate that the station was at 90° or 270° from null, depending upon the direction of tangential flight.

Where the station is to the right or left of the aircraft, the magnetic field threads both windings and induces a signal in each; the magnitude of one signal corresponds to the sine and the other to the cosine of the angle between the station and the aircraft. In this situation, motor 52 causes rotor winding 44 to assume a position between stator windings 35, 36 which corresponds to the vector addition of the signals. Pointer 42 here indicates the direction of the station relative to the line of flight.

Previously mentioned advantages of the system and structure above described will be readily apparent. Further, the elimination of any moving parts adjacent the surface of the aircraft removes such troublesome problems as oil, grease and dirt flowing along the surface and into the rotatable parts to disrupt their mechanical and electrical operation.

FIG. 4 illustrates windings 12, 14 are placed on a flat circular element 70 of ferrite. So long as the turns of the respective windings are symmetrically arranged on the element, and the windings are at right angles to each other, there is no mutual inductance. With the same inductance for each winding, the antenna functions in the same manner as that of FIG. 1.

The structures above described are useful where quadrantal errors are not a problem; however, they are not practical where large quadrantal errors exist. The problem of quadrantal error arises in ADF operation because of the effect of the shape of the structure (such as an aircraft) on which the antenna is mounted. For the antenna structures of FIGS. 1 and 4, this means that, measured from the same point in space, the strength of a signal induced in winding 12 during flight directly toward an ADF station is greater than that induced in winding 14 during flight tangential to the station. The effect of the different pickup sensitivities is that if, for example, the station is 45° from the major axis of the aircraft, pointer 42 would indicate that the station is less than 45° from the line of flight. The difference between the true and apparent directions to the station is the quadrantal error.

FIGS. 5–7 illustrate an antenna structure arranged in accordance with this invention to insure complete quadrantal error compensation. This is achieved by placing windings 12, 14 on an oblong ferrite bar 80 (in which case the turns of winding 12 are longer than those of winding 14) having a length-to-width ratio such that the previously indicated differences in field pickup are eliminated. As in the structures above described, windings 12, 14 have their axes in the same plane, they have the same inductance, and there is no mutual inductance. The placement of ferrite bar 80 with its greater dimension parallel to the line of flight has the effect of making the pickup sensitivities of the windings the same. Therefore, for flight in any direction relative to the station, pointer 42 indicates the true direction of the station from the heading of the aircraft.

FIGS. 6 and 7 illustrate an arrangement to affix the structure of FIG. 5 to an aircraft. The structure is placed within a thin plastic housing 82, here illustrated as transparent, which is secured to the skin 60' of the aircraft, e.g., by riveting. In this case, the skin does not have to be modified to provide a depression in which the structure is fitted; all that is necessary is to bore a hole in which the terminal socket is inserted, and from which connections to the goniometer are made as previously described.

Between the outer surface of bar 80 and housing 82 is a thin oblong element 84 of metal. Element 84 is sufficiently long to span all the turns of winding 14, and is sufficiently wide to span all the turns of winding 12. A sheet 86 of insulation material separates element 84 from the windings 12, 14. Element 84 may be the same metal as the skin of the aircraft, in which case the antenna elements are sandwiched between layers of aluminum. The effect of these layers is to minimize magnetic leakage in the vicinity of the windings and to improve shielding against capacitive pickup, thereby to enhance their pickup sensitivity.

A further important advantage of the compensated antenna is that, since there is no problem of variation in inductances of the windings, and there is no mutual inductance, the windings and their associated structure resonate at the same frequency in all positions of the rotor winding of the goniometer.

FIG. 8 illustrates an arrangement for achieving quadrantal error compensation wherein windings 10, 12 of equal dimensions are wound across bar **80** so that the angle α between their axes which intercepts the major axis of bar **80** is bisected by such major axis. The angle α preferably is chosen so that for the dimensions of the ferrite element, the mutual inductance is zero. For zero mutual inductance, angle α is greater than 90°, due to the effect of the ferrite.

To further explain the arrangement in FIG. 8, it should be noted that if the windings are centrally located on bar **80**, and are placed parallel to each other and at right angles to the major axis of the bar, a maximum mutual inductance of one sign would exist. Similarly, a parallel arrangement of the windings parallel to the major axis of the bar would result in a maximum mutual inductance of opposite sign. By orienting both windings so that they cross the major axis of the ferrite element, an angle as described is reached wherein the mutual inductance is zero; as previously indicated, it has been found that this angle is greater than 90°. However, if some mutual inductance can be tolerated, as is possible in some situations, it is sufficient if the angle α is chosen so that the mutual inductance does not exceed the tolerable limits; such angle may be greater or smaller than 90°, depending upon the configuration of the ferrite element.

The proper orientation of the windings for zero or tolerable mutual inductance may be determined by connecting a Q-meter to one winding and orienting the windings until the Q-meter shows no change when the other winding is alternately open-circuited and short-circuited.

FIGS. 9 and 10 illustrate an arrangement wherein windings **12**, **14** are positioned on respective tear-drop and rhombic ferrite elements **90** and **100** in the manner shown in FIG. 8. As in that arrangement, elements **90** and **100** each have an axis of symmetry and the windings crisscross such axis so that their axes form equal angles with it. In each, the windings are arranged for zero or minimum mutual inductance; and in each the orientation of the ferrite element with its major axis parallel to the longitudinal centerline of the aircraft insures that the windings have the same pickup characteristics.

Where the ferrite element is located on the aircraft in a position where it is not centered with respect to the longitudinal centerline, the angles between the axes of the respective windings and the longitudinal axis of the ferrite element differ slightly in the position of the windings to effect zero mutual inductance.

From the foregoing, it will be apparent that this invention embraces a variety of shapes of ferrite elements for supporting the windings, and that the portion of its periphery engaged by the conductors may be straight and/or curved. And as will also be apparent, the particular winding arrangement illustrated is presented as an example only. For example, instead of using coils connected in series to form a winding, a single coil could be used wherein its ends are connected to respective terminal pins; alternatively, additional coils could be wound on the bar and connected to form windings having parallel coils.

Nor is this invention limited to any particular type of conductor. Instead of flat ribbon, the conductors could be conventional round wire, flat braided wire, Litz wire, printed strips, or any of numerous types. The choice of wire and winding arrangement would be dictated by design factors, e.g., shielding desired, and pickup sensitivity.

What is essential is that the ferrite element be flat, and shaped to permit turns to be wound thereon to form two windings having axes in the same plane, and positioned so there is substantially no mutual inductance. In the case of antenna structures adapted for quadrantal error compensation, an additional requirement is that the ferrite element be elongated in one dimension along an axis of symmetry, and that the windings be disposed about such axis.

A further advantage to the arrangements of FIGS. 8–10 is that the windings are disposed to equalize or balance temperature and capacitance effects between them. It will be noted that the open-circuit magnetic paths for the two windings contain equal lengths of ferrite and equal air-gaps. With windings of the same dimensions, their stray capacitances are the same, in which case the capacitance effects between them are balanced. Also, since the temperature coefficients of equal lengths of the ferrite are equal, then with windings of equal dimensions disposed as in FIGS. 8–10, temperature effects in one path are matched in the other, whereby pickup characteristics for both windings remain equal.

What is claimed is:

1. In combination with an automatic direction finder receiver, a flat oblong element of magnetic material, a pair of superimposed windings having equal inductances supported on said element with their axes in a common plane and extending perpendicular to each other and parallel to edges of said oblong element, said windings being positioned on said element so that there is no mutual inductance therebetween, said element being positioned so that said plane is aligned with the magnetic field set up by a transmitter station, a remote rotary transformer device having an output member, said rotary transformer responding to signals induced in said windings due to said magnetic field to apply a resultant signal to the receiver, and means responsive to the output of the receiver to orient said output member to a position wherein the error signal is reduced to zero and means for indicating the direction to the station being coupled to said output member.

2. In combination with an automatic direction finder having a turner to which input signals are to be applied, an antenna system comprising a thin solid magnetic element of uniform thickness between flat surfaces thereof, first and second antenna windings wound one over the other and about said element and on said flat surfaces, said windings having equal inductances, portions of said windings being located on either side of a predetermined axis, said windings being positioned so there is no mutual inductance when a magnetic field set up by a transmitter station threads said element, a goniometer device having first and second stator windings respectively connected to said first and second antenna windings, said stator windings being displaced 90 electrical degrees from each other, a rotor for said goniometer device having a winding supported thereon, said rotor winding being inductively coupled to the tuner, said rotor winding having induced a signal representing the vector addition of signals induced in said antenna windings due to said magnetic field, means responsive to signals from the receiver to rotate said rotor to a position wherein the signal in said rotor winding is reduced to zero, and indicating means operable in said position of said rotor to indicate the direction to the station.

3. A combination in accordance with claim 2, wherein equal portions of said windings are located on either side of an axis of symmetry parallel to said flat surfaces.

4. A combination in accordance with claim 3, wherein the axes of said antenna windings form equal angles with said axis of symmetry.

5. An antenna structure comprising a flat magnetic element, said element having at least one axis of symmetry and being elongated in the direction of said one axis, a pair of windings supported one over the other on said element, said windings each having the same inductance, said windings having their axes in the same plane, said element being adapted to be positioned so that a magnetic field established by a transmitter station passes through said element in the direction of said plane, and said windings being disposed on said element so that mutual inductance between them is zero.

6. In combination with an automatic direction finder receiver for use on an aircraft, an antenna system including a flat element of magnetic material, said element be-

ing elongated in the direction of flight of the aircraft, a pair of windings having equal inductances supported one over the other on said element with their axes in a common plane, a goniometer device having first and second stator windings disposed at right angles to each other, a rotor having a winding thereon coupled to the input of the receiver, a motor connected between the output of the receiver and said rotor, said element being positioned so that a magnetic field established by an automatic direction finder transmitter station threads said element and induces signals in said windings, said stator windings causing a signal to be induced in said rotor winding which represents the position of said rotor relative to the station, and said receiver applying a signal to the motor to effect positioning of said rotor so that the signal in said rotor winding is reduced to zero, whereby the position of said rotor corresponds to the direction to the station.

7. The combination of claim 6 wherein said flat element of magnetic material is of oblong shape.

8. An antenna structure for use on a movable vehicle including in combination, a thin magnetic element having flat parallel surfaces and adapted to be mounted on the vehicle, said element being elongated in the direction of movement of the vehicle and being symmetrical about an axis extending in such direction, and a pair of windings having turns on said flat surfaces and having axes in the same plane, said windings being disposed with the axis thereof at an angle with respect to each other and with one winding being wound over the other, said windings having the same inductance and being disposed about said axis of symmetry so that the mutual inductance therebetween is substantially zero.

9. An antenna structure in accordance with claim 8 wherein said magnetic element is oblong, and one of said windings has turns extending parallel to the greater dimension of the element and the other of said windings has turns extending perpendicular to the turns of said one winding and parallel to the shorter dimension of said element.

10. An antenna structure in accordance with claim 8 wherein said magnetic element is pointed in the direction of movement of the vehicle and the axis of symmetry thereof bisects the angle between the axes of said windings.

11. A directional antenna structure for use on a movable vehicle including in combination, a thin solid magnetic element adapted to be mounted in fixed position on the vehicle, said element having flat rectangular surfaces each having one pair of parallel sides which are parallel to the direction of movement of the vehicle, and a pair of windings about said element having turns extending across said flat surfaces, said windings having axes in the same plane and one winding being wound over the other, one of said windings having turns extending parallel to the direction of movement and the other of said windings having turns extending perpendicular to the direction of movement, said windings having the same inductance and being disposed so that the mutual inductance therebetween is substantially zero.

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