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E. BRUCE

1,947,247

HIGH FREQUENCY TRANSMISSION SYSTEM

Filed Sept. 5, 1929

FIG. 1

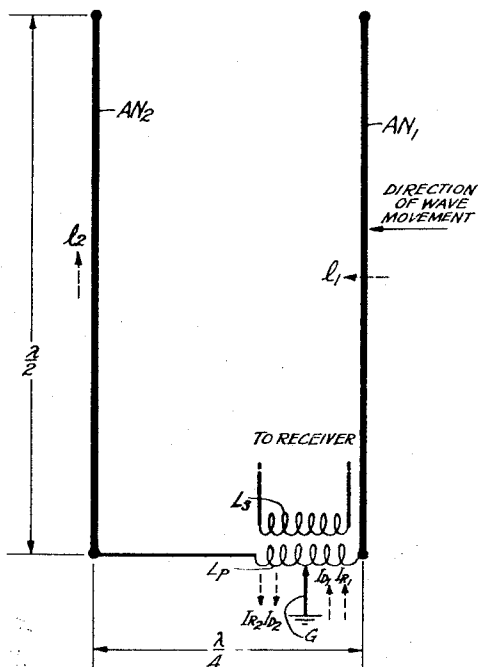


FIG. 2

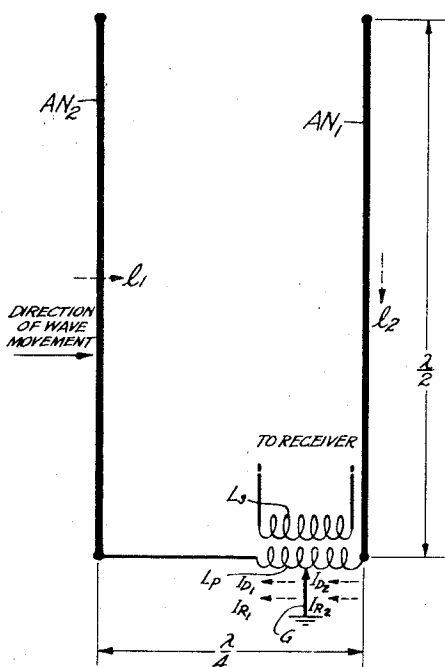


FIG. 3

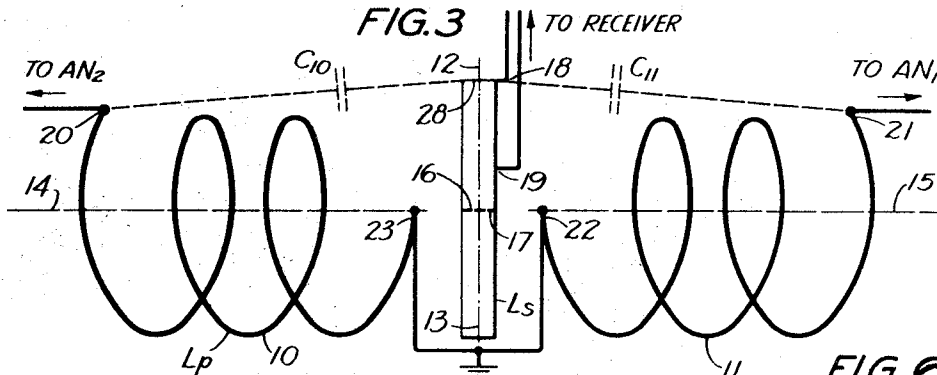


FIG. 6

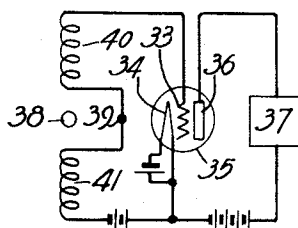


FIG. 4

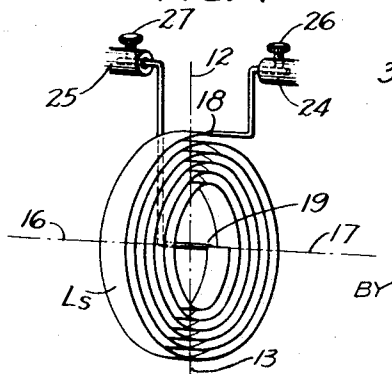
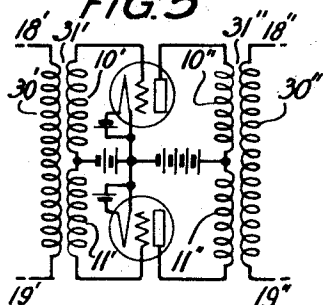


FIG. 5



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HIGH FREQUENCY TRANSMISSION
SYSTEM

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Application September 5, 1929. Serial No. 390,440

4 Claims. (Cl. 250—11)

This invention relates to systems for the transmission and reception of high frequency signals, and more especially to high frequency repeater circuits employed in connection with such transmission systems.

The invention is especially useful in, although not limited to, short wave radio systems. It may also, for example be employed in connection with long wave radio systems and carrier telephone and telegraph systems.

It has been known for some time that unilateral directivity may be achieved by rectangular antenna arrays, comprising two or more antennae extending in a direction parallel to the direction of propagation, the energizing or receiving circuit being directly associated with one only of the antenna circuits of the array, the other units (there may be but one) therefore functioning as reflecting or reradiating antennae. If the inter-antennae spacing is a quarter wave length or an odd multiple thereof, and if further the receiving or energizing circuit is connected to an end antenna unit, there will be coincidence of phase at the receiver for waves propagated in one direction, and opposition of phase for waves propagated in the converse direction, between the direct and reradiated waves when account is taken of the phase reversal that occurs incidental to reflection or reradiation. Analogous conditions apply for transmission. Such systems are inherently directional and may be made strictly unilaterally directive if made to effect an amplitude as well as phase balance. As an example of such an arrangement, reference may be had to applicant's Patent 1,813,143, July 7, 1931.

An object of the invention is to provide a repeater or inductive coupling between two transmission circuits without introducing capacity coupling between the two circuits.

Another and more specific object of the invention is to secure unilateral directivity using a system of spacially related antenna units broadly as above, under conditions which would make the achievement of unilateral directivity difficult or impossible by such prior arrangements.

A qualification of perfection in the prior systems of that general type as applied in short wave operation, relates to the effect of elevating the antenna units above the earth and to the variation of effect depending on such elevation. In fact, where the elevation is comparable with the wave length, it has been found that substantial unilateral directivity may not be achieved

by the particular arrangement above explained or by other arrangements in the same category. By applicant's invention unilateral directivity may be achieved entirely independently of such condition or other conditions affecting the geometry of the system except only the inter-spacing of the antenna units.

As compared with prior systems of the above type or other directive antenna systems or apparatus, it is believed that applicant's system excels in simplicity, economy of construction and efficiency of operation, as well as in the quality of directivity and it is a further object of the invention to provide an aerial system for space propagated waves which will have such characteristics.

According to the present invention, the wave corresponding to the reflected or reradiated wave of the above described unilateral directive antenna system, instead of being reradiated to the receiving antenna proper is returned to such antenna by a conductive path interconnecting the antenna units at their lower terminals. This path constitutes a delay circuit for the wave propagated through it. The phase relation of the finally superposed waves depends on the electrical length of the connecting path in relation to the lengths of the antenna units through which also the currents corresponding to the elemental induced electromotive forces induced by the incident waves are propagated as a delay circuit. If the antenna units are each electrically half a wave length long and if they are spaced a quarter wave length or any odd multiple thereof, and if such interconnected circuit is electrically the same length as such spacing, the requisite conditions will be satisfied so that the resultant superposed waves will have the proper phase with respect to a properly related receiver. As a practical matter, these conditions may be satisfied, if with the antenna spacing as above, the antenna units are simple conductors so that waves are propagated therealong with the velocity of an ether wave and if the connection circuit is similarly constructed and is connected by the shortest path between the lower extremities of the antenna units. As an example of such arrangements, reference may be had to applicant's Patent 1,841,085, January 12, 1932. As to certain of the subject-matter disclosed in this patent, the present is a continuing application.

Another object of the invention is to provide a repeater circuit to properly transmit the reflected or reradiated wave of the above described unilateral directive antenna system as well as the

wave received from the antenna proper to the receiving circuit.

One of the features of the invention is the use of a three winding transformer, in the above mentioned repeater circuit, to provide variable coupling to the receiver, in which transformer the secondary winding is so constructed and disposed with respect to the two primary windings that the interwinding capacity between the secondary winding and the primary windings is neutralized. This provides symmetrical transmission for waves from the antenna proper and the reflected or reradiated waves of the above described antenna system to the receiver. The principle is equally applicable to transmitting systems.

The invention will be better understood from the following description and accompanying drawing. Figs. 1 and 2 each schematically illustrate a receiving system of the invention, and the electrical relations therein for a particular direction of wave incidence, the two figures respectively illustrating the condition most favorable for reception and least favorable for reception; and

Figs. 3 and 4 illustrate schematically the construction of the preferred embodiment of the three-winding transformer to provide individual alternating current paths from the antennae AN_1 and AN_2 to the receiver. Figs. 5 and 6 illustrate schematically the use of the transformer or repeater in circuits other than those associated with radio antennae.

Each of Figs. 1 and 2 represents symbolically a certain receiving antenna system of the invention, which is unilaterally directive with respect to incident waves propagated in two opposite directions in the plane of the two antenna units AN_1 and AN_2 . In Fig. 1, as indicated, the incident wave is assumed to be propagated from right to left and therefore impinges on antenna AN_1 before it impinges on antenna AN_2 , the converse being true with respect to Fig. 2.

The waves impinging on each elemental portion of each of antennae AN_1 and AN_2 generate an electromotive force therein which progresses as a wave in each direction to eventually reach ground at G, the wave which is propagated downwardly being directly so transmitted and the wave which is correspondingly propagated upwardly being reflected at the upper free end of the antenna in question, with a phase reversal, and thence being propagated downwardly throughout the length of the antenna and to ground. The path to ground from the lower ends of the antenna proceeds through the connecting circuit including a portion of inductance L_F . The receiver is connected to the secondary L_s of the transformer whose primary is constituted by the two portions of inductance L_F . The dimensions of inductance L_F are assumed to be small as compared with the antenna interspacing, that is, as compared with the length of the connecting circuit and to be positioned at the end thereof adjacent to the antenna AN_1 .

Of course, a certain interval of time is required for the progression of an ether wave from a position in space corresponding to one antenna AN_1 to the corresponding position in space of the other antenna AN_2 . In the example illustrated the interspacing is one quarter wave length as indicated, so that the difference in time between the successive incidence of a given wave on the two antennae is one quarter period. However, in this description what will be particularly had in mind are the phenomena occurring in the

various parts of the system at a given instant of time. Therefore, if at a certain instant of time a certain electromotive force is being generated in antenna AN_2 , at the same instant of time the effective electromotive force in antenna AN_1 is advanced 90° in phase therefrom. The dashed arrows near the mid portions of the two antennae respectively indicate, as in accordance with the above, the vectors of the resultant electromotive forces e_1 and e_2 in antennae AN_1 and AN_2 , due to the composition of the corresponding electromotive forces for the various elemental portions of the respective antennae. It is proper and convenient to thus consider the effect as concentrated at the center. Of course, the vectors are continuously rotating so that little significance attaches to the indicated position of each vector, per se, although their relation is definitive and is adequately shown. Counter-clockwise rotation is assumed to be positive so that the phase of the wave e_2 is indicated as being 90° in advance of the phase of the wave e_1 , as has been shown above to be correct. The antennae are assumed to be each half a wave length long, as indicated. This dimension is that for which the resultant electromotive force is a maximum. This is true for either short waves or long waves although, of course, as a practical matter, this ideal is not attainable with long waves of the usual order. The fact is immediately apparent when account is taken of the time lag of the elemental waves from the various elemental portions progressing to the bottom of an antenna, that is, where the receiver is located, and there being superposed in the receiver. A graphical disclosure of the phenomenon is disclosed in Fig. 2B of applicant's copending application, Serial No. 173,833, filed March 9, 1927.

It is an object of the invention to insure by proper geometrical and electrical dimensions of the elements of the circuit that the waves corresponding to e_1 and e_2 after propagation from the midpoints of the antennae to the receiver will be in phase with respect to waves propagated in a certain direction and will be opposite in phase with respect to waves propagated in the opposite direction. This condition defines unilateral directivity. The antennae and connecting circuit function as transmission lines for the propagation of these waves. As would be the case with simple linear conductors illustrated it is assumed that the waves will be propagated over these conductors at the velocity of space waves so that a conductor of one quarter wave length will retard the wave as much as, or acquire the same time for propagation therealong as, in equal distance in etheric space.

The dashed arrows Id_1 and Id_2 shown adjacent to ground indicate the resultant phase at ground G of the propagated wave initiated in the corresponding antennae AN_1 and AN_2 respectively, and propagated directly to ground. Considering the conditions with respect to antenna AN_1 there will be retardation of 90° on account of the one quarter wave length of antenna through which the resultant electromotive force wave e_1 must progress, so that, at the time of incidence of the wave in the antenna and therefore when the phase of the electromotive force wave e_1 is that indicated by the dashed arrow at the mid point of the antenna the phase of the wave at the foot of such antenna, and therefore at ground, would have a phase advanced 90° from the phase of the wave e_1 , as indicated. Correspondingly the wave e_2 propagated from the mid portion of antenna

AN₂ would be retarded 90° on account of such an antenna and another 90° on account of the connecting circuit. The phase vector I_{D2} for that antenna is accordingly indicated as advanced 180° over the vector for e₂. It is noteworthy that the two vectors I_{D1} and I_{D2} are in opposite phase at the ground, that is, in the ground lead. The corresponding currents would therefore flow in the same direction in the two portions of the inductance L_P on either side of the ground tap so that the waves propagated to ground add their effects in the receiver connected to the secondary L_S.

Following the same mode of reasoning with respect to Fig. 2, in which an opposite direction of incidence of the ether wave is assumed, it will be found that at ground the phases of the waves corresponding to those discussed in the above paragraph is the same for the two antennae and therefore opposite in the two portions of the primary L_P, so that their effects are opposed in the receiver connected to conductance L_S.

It has thus been demonstrated with respect to waves directly propagated from the antennae to the ground the system is unilaterally directive. It remains, however, to consider the effect of the waves propagated upwardly in the antennae and reflected at the free ends. These waves as measured at the ground are illustrated by the dashed arrows I_{R1} and I_{R2}. Considering the conditions with respect to antenna AN₁ of Fig. 1 the wave e₁ as thus propagated is retarded 90° in progressing to the free end of the antenna, is then effectively retarded 180° by reflection, and is then retarded 180° by propagation along the entire length of the antenna, so that the phase of the propagated current at ground is 450°, that is, effectively 90°, in advance of the phase of wave e₁ as indicated. By a similar course of reasoning it is apparent that the corresponding phase of the current propagated from the middle of antenna AN₂ is 180° in advance of the phase of the wave e₂. This means that the two reflected waves, similarly as the two direct waves, are in opposite phase in the ground lead or in the same phase with respect to the receiver. It is also true that the reflected and direct waves are in the same phase. An analogous relation may easily be found with respect to the conditions illustrated by Fig. 2, that is, the reflected waves affect the receiver in opposite directions and have the same phase as the direct wave at the receiver. Accordingly it has been demonstrated that the system of Fig. 1 or Fig. 2 is unilaterally directive with respect to the reflected, as well as the direct waves and to such waves jointly and therefore with respect to all waves which may affect the receiver.

It is obvious that the principle applied above to a specific instance, is much more generally applicable. For example, the principle is equally operative if the spacing of the antennae is any other odd multiple of a one quarter wave length than the multiple one. Further it is possible to design the transmission line, comprising the connecting circuit and antenna proper, so that waves will be propagated therealong at a velocity either greater or less than that of waves in space. Therefore it is possible to use antennae which are other than half a wave length long and a connecting circuit which is longer or shorter than the inter-antenna spacing. It is also obvious that the principle is equally applicable to a transmission system, the receiver in Figs. 1 and 2 being replaced by a transmitting source.

It has been assumed that the waves directly

transmitted or reflected at the receiver will have the same amplitude, as they would tend to have with the conditions as illustrated. Of course, unilateral directivity in a strict sense requires that these amplitudes should be the same.

The antenna systems as shown in Figs. 1 and 2 have been disclosed and described in applicant's Patent 1,841,085 mentioned above.

Reference will now be made to Figs. 3 and 4. In order to secure proper reception at the receiver it is necessary that the path from the antenna AN₁ have the same frequency amplitude characteristics as the path from the antenna AN₂ for every adjustment of the inductive coupling between L_S and L_P.

Preferably, therefore, the two windings 10 and 11 which comprise the inductance L_P are coaxially mounted and are made identical as regards the number of turns and relative dimensions. The inductance L_S which is connected to the receiver is preferably a disc-shaped coil as shown in Fig. 4. It may have as few turns as one or two or may even comprise a single straight conductor. If a large number of turns are to be employed, it may be a "pancake" coil in which the outside diameter is greater than the thickness of the coil.

The inductance L_S is preferably mounted between the two coaxial windings 10 and 11 of the inductance L_P, the distance between the inductance L_S and the coils 10 and 11 being made identical and the center line 12, 13 of the inductance L_S being made perpendicular to the axis 14, 15 of the inductance L_P.

Preferably the inductance L_S is arranged to move so that its axis 16, 17 can be made to coincide with the axis 14, 15 of the inductance L_P or so that the axis 16, 17 does not coincide with the axis 14, 15 but at all times remains parallel to the axis 14, 15. This is preferably accomplished as shown in Fig. 4 by providing terminals 18 and 19 for the inductance, which terminals are heavy enough to rigidly support the inductance L_S in any desired position, and by further providing binding posts 24 and 25, arranged so that the inductance L_S can be rotated about them, and having screws 26 and 27 associated therewith, which may be loosened when it is desired to change the coupling and tightened to retain the adjustment. This method of providing variable inductive coupling eliminates the necessity for flexible leads and maintains the leads at the same distance from each other for all adjustments, and at the same time provides positive contact between the inductances and the terminals or binding posts. It also enables the inductance L_S to be readily replaced by another having different wave length characteristics. Obviously, when desired the inductance L_S can be made fixed and the inductance L_P movable, or both L_S and L_P can be made movable.

If the outer terminal 18 of the inductance L_S is connected to the high potential side of the receiver and the inner terminal 19 is connected to the low potential or ground side of the receiver there will be a capacity C₁₀ between the point 28 on inductance L_S and the terminal 20 on coil 10, and a capacity C₁₁ between the same point 28 on the inductance L_S and the terminal 21 on coil 11. Since at any given instant the potential at terminal 20 of coil 10 will be the same as the potential at terminal 21 of coil 11, but of opposite sign, and since the distance from the point 28 on inductance L_S to terminal 20 is the same as the distance from this point 28 to terminal 21, it follows that the capacities C₁₀ and C₁₁ will be

equal but that the potentials thereacross will be of opposite sign and will, therefore, neutralize each other.

As any given point on the inductance L_s will, for any given adjustment of the inductive coupling between L_s and L_p , be equi-distant from any given point on coil 10 and the corresponding point of same potential but opposite sign on coil 11, it follows that the capacity between coils 10 and 11 will be neutralized and that there remains only the inductive coupling between these inductances.

It will be readily seen that the capacities between the coils will be neutralized and the capacity coupling therefore eliminated even though the outer terminal 18 of inductance L_s is connected to ground potential and the inner terminal 19 connected to the high potential at the receiver, or if the antennae AN_1 and AN_2 are connected to the terminals 22 and 23 of coils 11 and 10 respectively and the terminals 21 and 20 connected together and to ground.

If the transformer comprising the inductances L_s and L_p are mounted in a shielded box which is connected to ground, it would be preferable to have the terminals 22 and 23 connected to the antennae AN_1 and AN_2 respectively and the other terminals 20 and 21 of L_p connected to ground in order to reduce the capacity between the grounded shield and the inductance L_p .

It is not essential to capacity balance that the coils 10 and 11 be solenoidal coils as shown. Other types of coils will be satisfactory provided the two coils are identical as regards the number of turns and relative dimensions and are so wound and connected to the antennae and ground and that the distance from any given point on inductance L_s is equi-distant from all points of equal potential but opposite sign on the two coils of inductance L_p .

It will be observed that one distinct and important result obtained by neutralizing or balancing the capacity currents in transformers associated with directive antenna systems, such as shown in Figs. 1 and 2, is that maximum unilateral directivity is secured. For example, substantially none of the energy absorbed from the "back-end" or undesired wave represented by the arrow designated "Direction of wave movement" in Fig. 2 will be effective in the secondary coil L_s , inasmuch as the resultant equal and opposing magnetic fields in the transformer will prevent voltages from being induced in the secondary winding and the capacity balance will prevent the flow of capacity currents in winding L_s . Consequently, the ratio of the received front-to-back signal strength will be larger and the directivity greater than would otherwise be the case.

The invention may also be used in connection with push-pull amplifier circuits of the type disclosed, for example, in United States Patent No. 1,128,292 to E. H. Colpitts, February 16, 1915. Referring to Fig. 5, the incoming conductors to the repeating apparatus are represented by the wires 18' and 19' terminating in the primary winding 30' of an input repeating coil 31'. The coil 30' corresponds to the inductance L_s shown in Figs. 3 and 4. The secondary winding of the repeating coil 31' is divided into two coils 10' and 11', which coils correspond to the coils 10 and 11 respectively of the inductance L_p shown in Fig. 3. The outgoing conductors from the repeating apparatus are represented by the wires 18'' and 19'' terminating in the secondary wind-

ing 30'' of an output repeating coil 31''. The coil 30'' corresponds to the inductance L_s shown in Figs. 3 and 4. The primary winding of the repeating coil 31' is divided into two coils 10' and 11', which coils correspond to the coils 10 and 11 respectively of the inductance L_p shown in Fig. 3.

The invention may also be used in repeating circuits other than those having their input circuits differentially connected. Referring to Fig. 6, coils 40 and 41, which correspond to coils 10 and 11 in Fig. 3, are connected together and to the grid 33 and the filament 34 of a three-electrode vacuum tube 35. The plate 36 of vacuum tube 35 is connected through a load circuit 37 to the filament 34 of vacuum tube 35. A conductor 38 through which a varying current is flowing is located equi-distant from the coils 40 and 41. This conductor 38 corresponds to coil L_s shown in Figs. 3 and 4. Coils 40 and 41 preferably have the same number of turns and relative dimensions as have the coils 10 and 11 shown in Fig. 3.

When a single conductor comprises the primary winding, as at 38 in Fig. 6, the coils 40 and 41 do not necessarily have to be coaxially located as shown in Fig. 6, but the distance from the conductor 38 to any given point on coil 40 must be equal to the distance from the conductor 38 and the point on coil 41 at which the voltage drop between the connection 39 of coils 40 and 41 is equal to the voltage drop from this point 39 to the above mentioned point on coil 40.

By elaboration of detail the principle of the invention may be made applicable to a similar relation of more than two antennae although, of course, the quantitative effects will tend to be different so that there will be required quantitatively different values of the physical dimensions to give the requisite amplitude phase unbalance.

Although for the sake of clearness, specific embodiments of the invention have been shown and described, it is to be understood that the invention is generic in character and is to be limited only by the scope of the appended claims.

What is claimed is:

1. In a radio frequency system, a directive receiving antenna comprising a principal antenna and an auxiliary antenna each a half wave length long, said auxiliary antenna being a quarter wave length farther away than the principal antenna from a cooperating station, a three-winding transformer having substantially any given point in the turns of one winding positioned equidistant from and symmetrically with respect to the other two windings, said other two windings being similar in design and electrically connected to a common ground terminal and to the principal and auxiliary antennae, and a receiver associated with the first mentioned winding.

2. In a radio frequency system, a unilateral antenna comprising a plurality of half wave length elements positioned parallel to each other and spaced a quarter wave length apart in the plane of wave propagation, a quarter wave length conductor connecting corresponding terminals of said elements, a transformer having its primary winding included in said conductor immediately adjacent one of the elements, said primary winding being grounded at its midpoint, said transformer having substantially any given point in its secondary winding positioned symmetrically with respect to and equi-distant from both halves

of said primary winding, and a translation device associated with said secondary winding.

3. In a radio frequency system, a directive receiving antenna comprising two antenna elements each a half wave length, or an odd multiple thereof long and spaced a quarter wave length apart in the vertical plane of desired wave propagation, a transformer positioned between the antenna elements immediately adjacent to one of the said elements and comprising a primary winding grounded at its midpoint and a secondary winding, the secondary winding being so positioned that substantially any given point thereof is equi-distant from corresponding portions of both halves of the primary winding, said elements being conductively connected to each other through the primary winding, and a translation device associated with the secondary winding.

4. In combination, a directive receiving antenna system comprising a front and a rear unit each comprising at least one vertical half wave length element, the rear unit being a quarter wave length farther away from a cooperating station than the front unit, a quarter wave length conductor connecting said units, a transformer having a primary winding comprising two co-linear helical coils and a secondary winding comprising a spiral coil positioned perpendicularly to and symmetrically with respect to said helical coils so that corresponding points in the said helical coils are equidistant from said spiral coil substantially, said primary winding included in said conductor immediately adjacent said front unit, and a receiver associated with the secondary winding.

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20	95
25	100
30	105
35	110
40	115
45	120
50	125
55	130
60	135
65	140
70	145
75	150