Jan. 24, 1939. E. BRUCE 2,145,024

DIRECTIVE ANTENNA

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FIG. 1

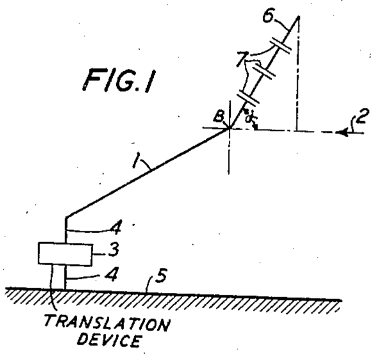
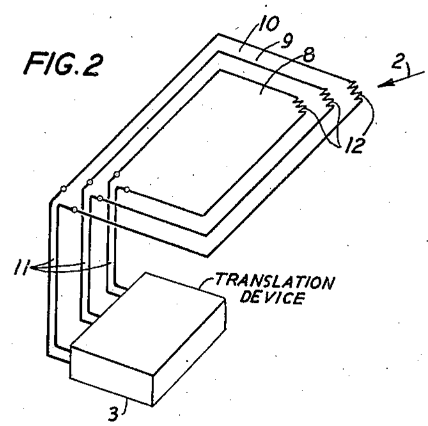


FIG. 2



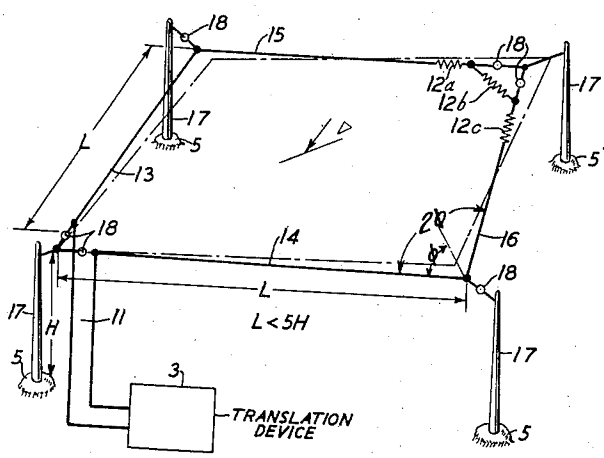


FIG. 3

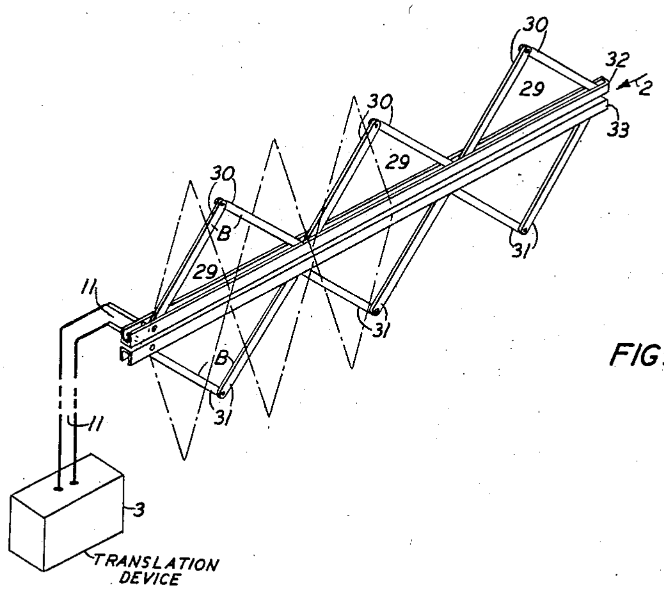


FIG. 5

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FIG. 6

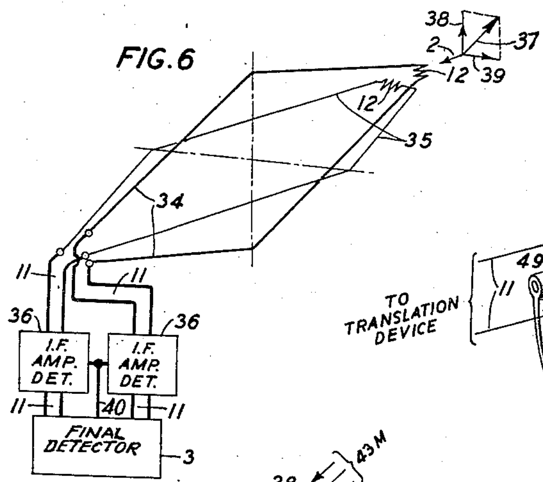

FIG. 7

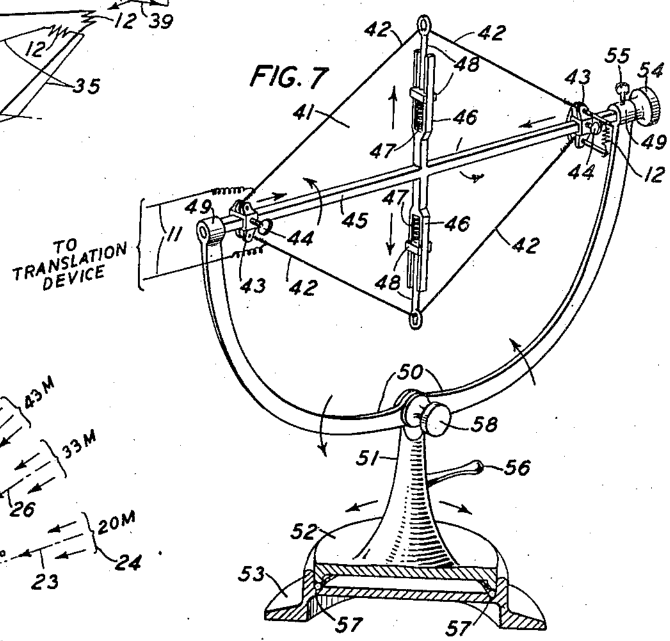

FIG. 4A

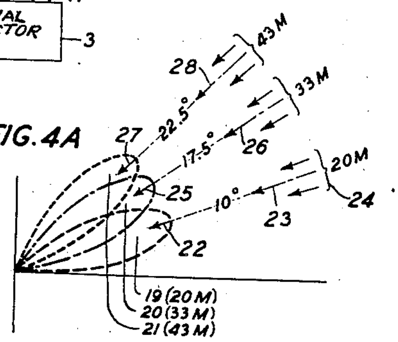

FIG. 4B

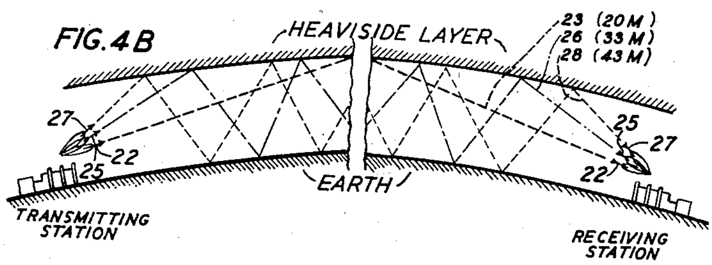

FIG. 8

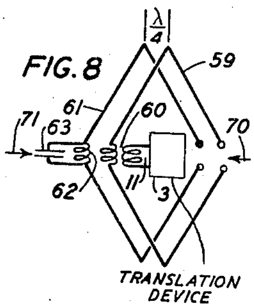

FIG. 9

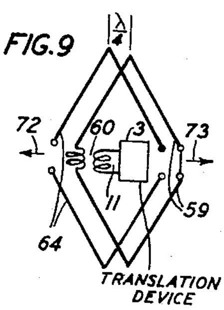

FIG. 10

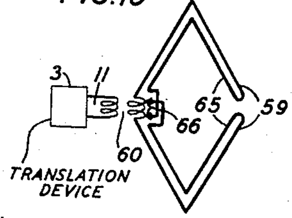

FIG. 11

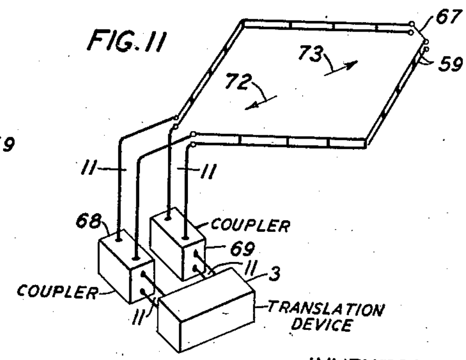

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FIG. 12B

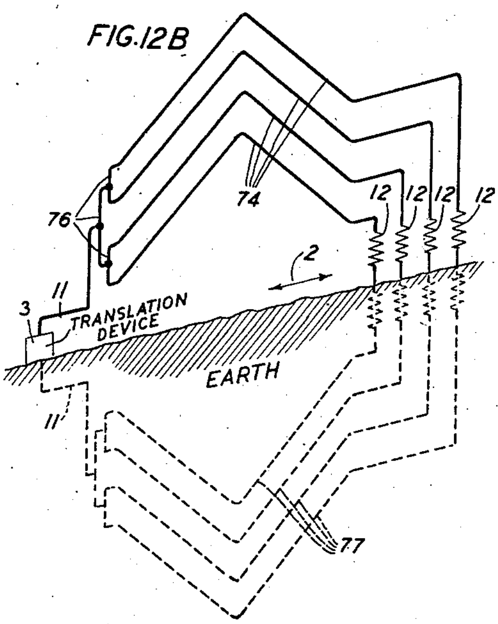

FIG. 12A

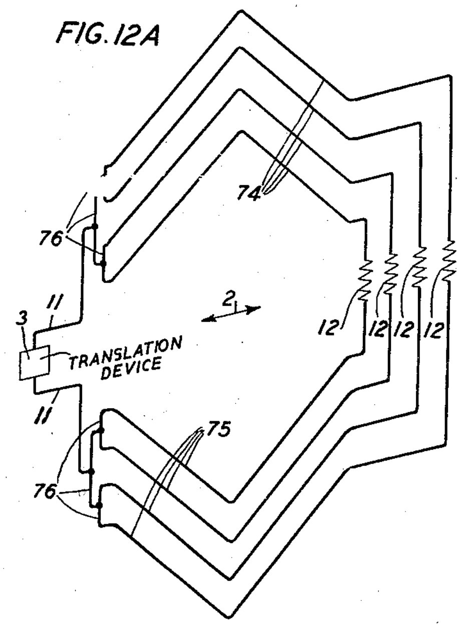

FIG. 13

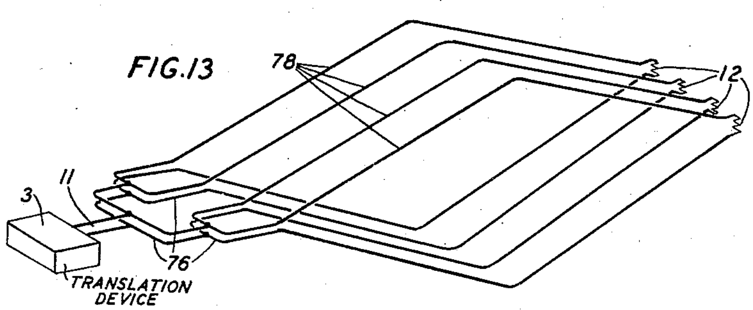

FIG. 14

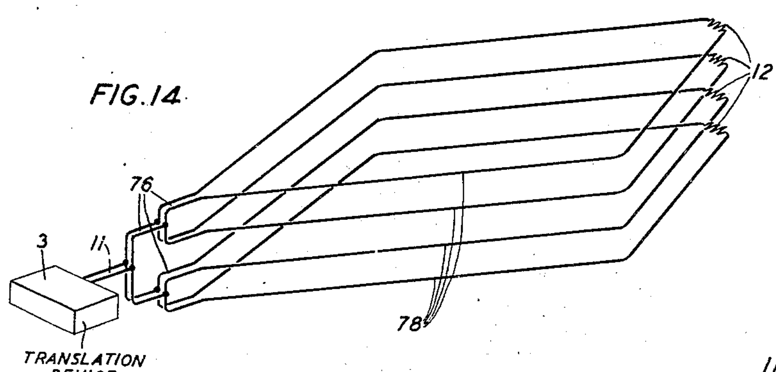

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FIG. 15

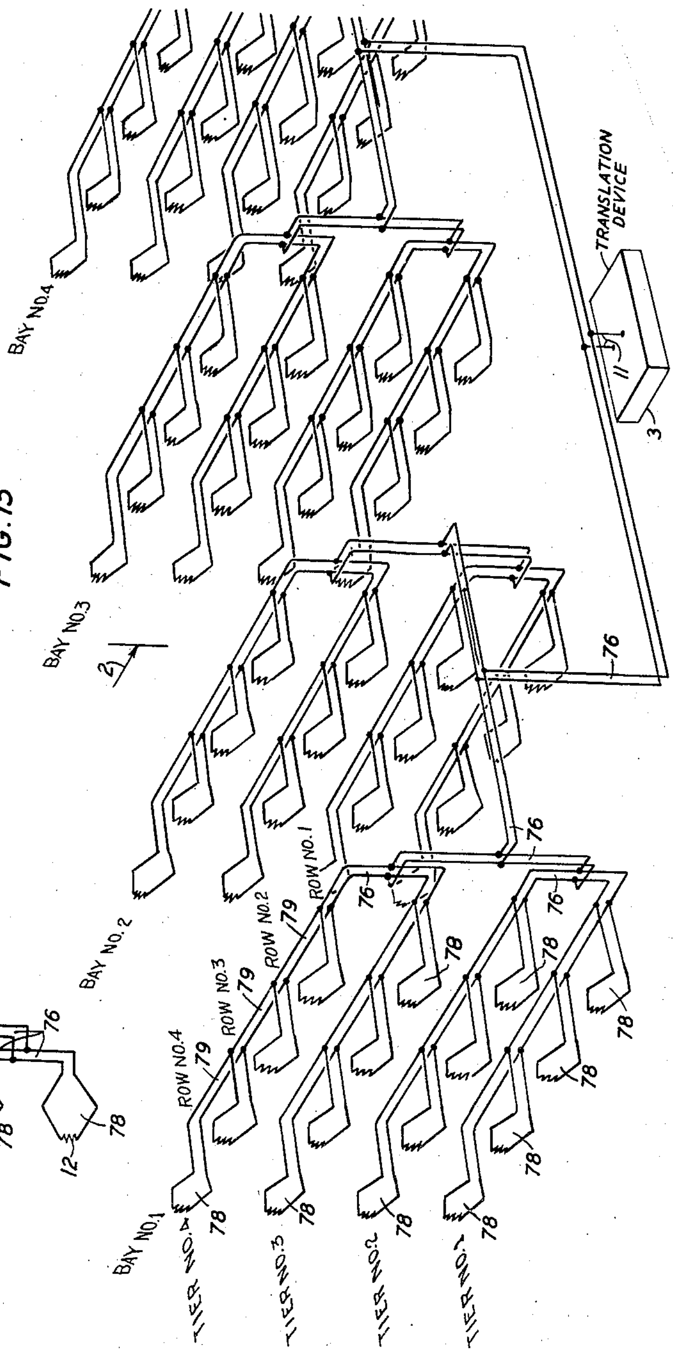
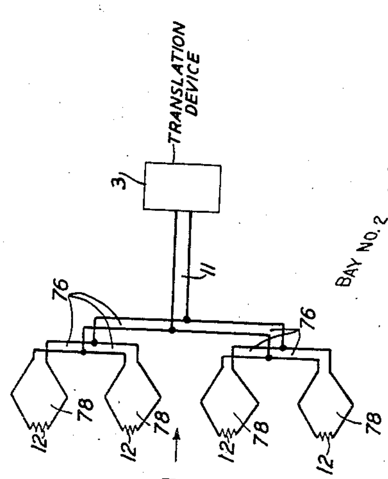


FIG. 15A



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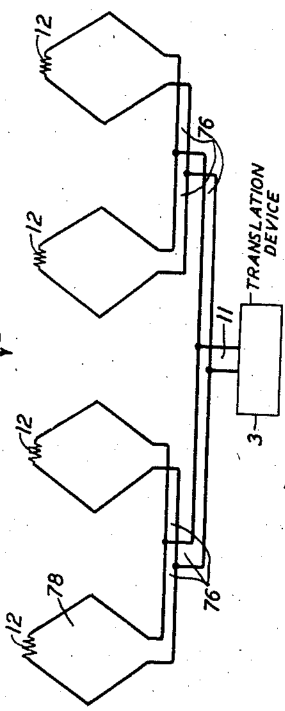

FIG.16A

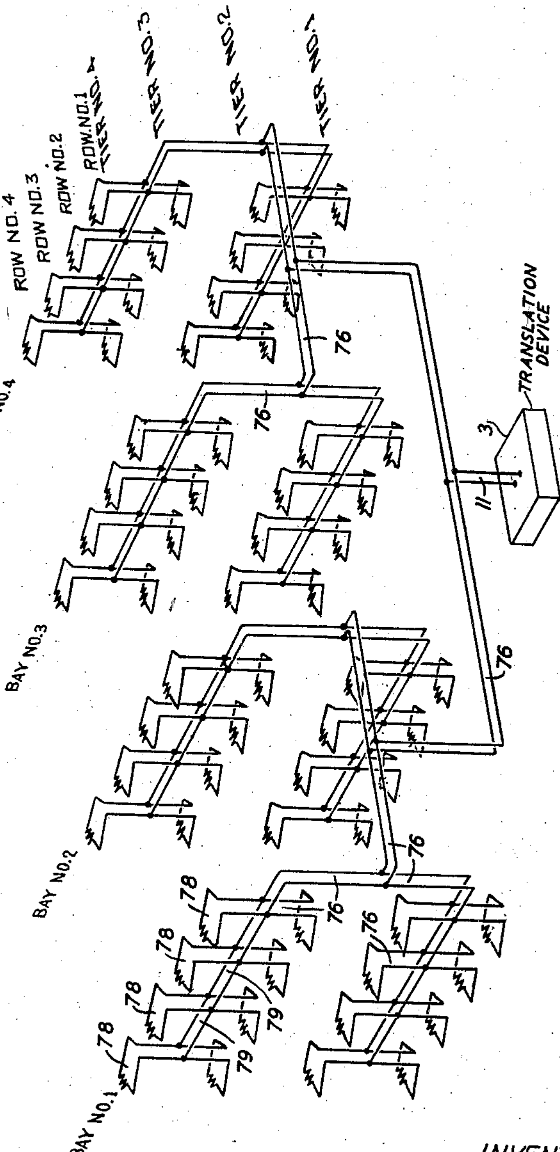

FIG.16

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Patented Jan. 24, 1939

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UNITED STATES PATENT OFFICE

2,145,024

DIRECTIVE ANTENNA

Edmond Bruce, Red Bank, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application January 11, 1936, Serial No. 58,642

9 Claims. (Cl. 250—11)

This invention relates to antenna systems and especially to improvements in multi-frequency directive antennas and arrays of directive antennas.

In the past antennas and antenna arrays employed in point-to-point communication systems have been for the most part designed for single frequency operation. Consequently, whenever conditions such as heavy communication traffic or frequent periods of frequency discrimination in the ethereal attenuation have warranted the use of several frequencies, it has been necessary to erect and maintain at considerable expense individual antenna systems including transmission systems for each channel or frequency utilized. Recently, however, multi-frequency antennas of the type disclosed in my Patent 1,899,410 granted February 28, 1933 and in my copending application, Serial No. 513,063 filed February 3, 1931 and comprising, respectively, V-shaped and rhombic antennas, have been employed with success over certain frequency ranges. It now appears desirable to extend the frequency range of such multi-frequency antennas and to receive with more and substantially equal efficiency waves having different frequencies and different incoming directions. It also appears desirable to arrange rhombic antennas of the type referred to above in diverse arrays for the purpose of securing improved reception or transmission, and to adjust such antennas, or arrays of such antennas, for maximum radiant action in any direction.

It is one object of this invention to improve radio communication.

It is another object of this invention to receive or transmit in any desired direction and with maximum effect, waves having any type or direction of polarization.

It is a further object of this invention to receive or transmit in a particular direction and with increased efficiency waves of a selected polarization.

It is still another object of this invention to receive with maximum effect, and simultaneously or non-simultaneously, radio waves having different frequencies and different directions of propagation utilizing a single energy absorbing structure.

According to one feature of the invention the dimensions of a rhombic antenna of the type disclosed in my copending application mentioned above, are chosen so that each of the different directions of maximum action of the antenna corresponding to the different wave-lengths, aligns with the ascertained and well-established mean incoming direction of the wave of corresponding wave-length. For operation on wave-lengths included in the 15 to 65 meter band the multi-directive characteristic of a multi-frequency rhombic antenna is properly aligned with the prevailing incoming wave direction when the side length of the antenna is greater than two wave-lengths of the longest operating wave-length and greater than five times the height of the antenna above ground.

According to a different feature of the invention, a rhombic antenna may be rotated about a diagonal and its direction of maximum action may be aligned with any direction. A further feature comprises a plurality of horizontal or vertical rhombic antennas arranged in an array of one, two or three dimensions. Another feature relates to the combination of the critically positioned antenna conductor disclosed in my patent mentioned above and another differently but also critically positioned antenna conductor. According to still another feature the backward energy heretofore dissipated by a terminating impedance in a transmitting rhombic antenna system is utilized for increasing the transmitting effectiveness of the system.

The above features and additional features will be more fully understood from the following detailed description taken in connection with the drawings on which similar reefrence characters designate elements of similar function and on which:

Fig. 1 illustrates a directive antenna system comprising two differently positioned antenna conductors;

Fig. 2 illustrates a multi-frequency multi-directive antenna array comprising individual antennas for the different frequencies;

Fig. 3 illustrates an adjustable multi-frequency multi-directive rhombic antenna;

Figs. 4A and 4B are diagrams useful in explaining the systems of Figs. 2 and 3;

Fig. 5 illustrates an array of steerable rhombic antennas especially adapted for ultra-short wave operation;

Fig. 6 illustrates a diversity array comprising a vertical and a horizontal rhombic antenna;

Fig. 7 illustrates a rhombic antenna, the maximum operating direction of which may be aligned with any direction;

Figs. 8, 9, 10 and 11 illustrate unidirectional non-dissipative rhombic antenna systems;

Figs. 12A and 12B each illustrate an antenna array comprising several V-shaped units;

Figs. 13 and 14 illustrate, respectively, a broad side array of vertical rhombic antennas and a stack array of horizontal rhombic antennas;

Figs. 15 and 16 each illustrate a two and a three-dimension array of, respectively, vertical and horizontal rhombic antennas; and Figs. 15A and 16A illustrate, respectively, a single-dimension stack array of vertical rhombic antennas and a single-dimension broad-side array of horizontal rhombic antennas.

Referring to Fig. 1 reference numeral **1** designates an antenna conductor having a length L equal to the projection of the conductor on the path **2** of the desired wave plus a half wave-length. Reference numeral **3** designates a translation device connected by means of conductors **4** to the ground **5** and to the antenna **1** and reference numeral **6** designates an antenna conductor connected to conductor **1** and positioned at an angle α with respect to the incoming direction or path **2**. The antenna conductor **6** is loaded with condensers **7** for the purpose of rendering the phase velocity of the wave along conductor **6** considerably greater than that of the wave in space. The conductor **6** may have any length and the angle α a value such that the ratio of the velocity of the wave in space to the velocity of the wave along conductor **6** is equal to the cosine of the angle.

In operation, the differently phased energies absorbed by the antenna conductor **6** from a wave following path **2** arrive in phase at the point B and are added to the differently phased energies absorbed by conductor **1** which produce, as explained in my patent mentioned above, a vector resultant at the translation device **3**. As a result, a greater amount of energy is absorbed from the incoming wave than is absorbed by either conductor taken alone.

Referring to Fig. 2 reference numerals **8**, **9** and **10** designate rhombic antennas of the type disclosed in my copending application mentioned above, the three antennas being positioned in the same horizontal or vertical plane and designed for operation on different frequencies. The side length of each antenna is approximately equal to the projection of the side on the desired direction or path of radiant action **2** plus a half of the wave-length for which the antenna is designed, whereby the directions of maximum action for the four elements constituting each antenna coincide with path **2**. Antennas **8**, **9** and **10** are connected by transmission lines **11** to a multi-frequency translation system **3** which, in this case may comprise a tunable translation device or a plurality of devices arranged for different frequency operation. A terminating impedance **12** is connected to each antenna for the purpose of rendering the antenna unidirective. For convenience and simplicity the supporting structure for the three antennas has been omitted from the drawings.

Referring to Fig. 3 reference numerals **13**, **14**, **15** and **16** designate side members or legs of a large horizontal steerable rhombic antenna of the type disclosed in my Patent 2,076,222, granted April 6, 1937. The antenna is supported by means of poles **17** and is rendered unidirective by means of the terminating resistances **12**a, **12**b and **12**c. Reference numerals **18** designate insulators connected between the antenna and the supporting structure. The antenna is connected by transmission line **11** to a translation system **3** similar to that employed in the system of Fig. 2. The broken lines illustrate an alternative position of the antenna elements obtained by adjusting the side interior angles, 2Φ. The letters L and H represent, respectively, the side or element length and the antenna height above ground.

Referring to Fig. 4A the multi-frequency multi-directive operation of the system of Fig. 2 will now be explained. Assuming that it is desired to receive horizontally polarized components of waves included in the 15–65 meter band as, for example, waves having an approximate wave-length of 20, 33 and 43 meters, the prevailing or well established incoming direction or directions in a vertical plane of sky waves having these different wave-lengths is first ascertained. These wave arrival angles may be easily determined by utilizing any of the well-known methods or systems employed for this purpose or by means of the system of Fig. 7 which will be described later. As indicated by Fig. 4A, the mean arrival angles of the 20, 33 and 43 meter waves are, respectively, in the neighborhood of 10, 17.5 and 22.5 degrees. In this figure the arrival angles have been shown greatly exaggerated in the interest of better illustration. Antennas **8**, **9** and **10** of the system of Fig. 2 receive, respectively, the 20, 33 and 43 meter waves, the side length and side apex angle of the antenna in each case being chosen such that the maximum receiving direction of the antenna aligns with the prevailing wave arrival angle of the wave received thereby. The vertical directive characteristics of antennas **8**, **9** and **10** are illustrated by lobes **19**, **20** and **21**, respectively, of Fig. 4A. In accordance with this invention, the principal or major axis **22** of lobe **19** aligns with the mean incoming direction **23** included in the 20 meter cluster designated by numerals **24** of incoming wave directions, axis **25** aligns with mean incoming direction **26** of the 33 meter cluster and axis **27** with mean incoming direction **28** of the 43 meter cluster.

It will be observed from Fig. 4A that the wave angle of the incoming wave increases with wave-length. It is also true that the angle Ω between the maximum antenna receiving direction and the plane of the antenna, hereinafter designated the wave antenna angle, of a rhombic antenna of the type disclosed in my copending application increases with wave-length when employed for multi-frequency operation. Referring to Fig. 3 the dimensions of the antenna are so chosen that the change or increase with wave-length of the wave antenna angle is the same as the change or increase with wave-length of the angle between the direction of the incoming wave and the plane of the antenna, hereinafter designated the wave arrival angle Δ. For receiving with maximum efficiency wave-lengths included in the 15–65 meter band, the side length L is made greater than two wave-lengths of the longest wave received and at least five times the height H of the antenna above ground. In a specific embodiment for receiving in this range the dimension L equals 512 feet, H equals 90 feet and the side interior angle equals 150 degrees. By so dimensioning the antenna a multi-directive characteristic is obtained and the maximum directivities for the 20, 33 and 43 meter waves may be represented by lobes **19**, **20** and **21**, respectively, of Fig. 4A. The principal axis of each of directive lobes **19**, **20** and **21** of Fig. 4A accurately aligns with the mean incoming or outgoing direction of the wave of corresponding wave-length. For the general case of multi-frequency multi-directive operation over a large band of wave-lengths the values of H, L and Φ are given by the following equation:

$$\frac{H \text{ (in meters)}}{\lambda} = \frac{1}{4 \sin \Delta}$$

$$L = \frac{.371\,\lambda}{1 - \sin \Phi \cos \Delta}$$

where Φ=one-half the side interior angle
λ=the mean operating wave-length in meters
Δ=the elevation angle of the incoming or outgoing direction for the wave having the mean wave-length.

Fig. 4B illustrates the directive operation of a system in which a multi-frequency multi-directive antenna, of the type, illustrated by Fig. 3, is employed at both the transmitting and receiving station. In this system each of the directive lobes for the different wave-lengths, of both the transmitting and receiving antennas, is aligned with the prevailing ethereal path for the corresponding frequency, that is, the path of least attenuation normally. Paths other than those illustrated, of course, exist for each of the different frequencies.

Referring to Fig. 5 reference numeral **29** designates small steerable rhombic antennas arranged in an end-on array and each comprising two antenna elements **30** and two counterpoise elements **31**. The antenna elements are slidably mounted in a grooved insulated structure **32** and the counterpoise elements are similarly mounted or supported by the groove insulator structure **33**.

In operation of the system of Fig. 5 waves of a given frequency and having an incoming direction **2** are received with maximum effect by each of antenna **29** and supplied to the translation device **3**. For receiving waves of a different frequency the over-all length of the array may be decreased or increased as required so that the conductors **30** and **31** assume a position as, for example, that illustrated by the dotted lines. The adjustment is such that each of conductors **30** and **31** has a length equal to the projection of the conductor on the path **2** plus a half wave-length of the particular wave being received. When horizontally positioned so as to be subject to ground reflection slight adjustment of the interior angle of the three antennas effects a change in the antenna receiving angle included in the vertical plane. The system may be used for both receiving and transmitting and is unidirective to some extent in view of the fact that the serially connected antenna elements and serially connected counterpoise elements constitute long conductors.

In Fig. 6 reference numeral **34** and reference numeral **35** designate, respectively, a vertical and horizontal rhombic antenna each connected through a separate unit **36** comprising a detector and intermediate frequency amplifier to the final detector or translation device **3**. Neglecting ground reflection phenomena, the array of Fig. 6 is positioned so as to receive with maximum efficiency a wave traveling along path **2** as, for example, the wave represented by vector **37**. In the operation of the system illustrated by this figure the vertically polarized component **38** of wave **37** is received by antenna **34** and the horizontally polarized component **39** is received by antenna **35**. As indicated by connection **40** the amplifiers of the unit **36** include a gain control and are so associated that the amplifier receiving the weaker component is rendered inoperative and fading is greatly minimized, the arrangement being similar to that disclosed in my Patent 1,913,428 issued June 13, 1933.

Referring to Fig. 7, reference numeral **41** designates a rhombic antenna of the type previously referred to and comprising two V-shaped wires **42**. These wires are connected to movable members **43** equipped with set screws **44** and mounted on the rotatable bar **45**. The mid-points or apices of the V-shaped wires **42** are adjustably supported or separated by means of two colinear structures mounted on, and at right angles to bar **45**, each structure comprising a member **46** having a tuning fork shape, a spring **47** mounted therein, a movable slotted I-bolt plunger **48** in contact with spring **47** and arranged to move along member **46**, the I-bolt enclosing the antenna wire **42**. By manually positioning members **43** at equal distances from members **46**, and securing the members to bar **45** by means of set screws **44**, the side length of the rhombic antenna may be changed as desired. Of course, unicontrol means for simultaneously and similarly moving members **43** may be provided. A more rigid structure may be realized by utilizing in place of wires **42** tubular hinged rods.

Bar **45** is supported on bearings **49** of the U-shaped member **50** which in turn is supported by upright member **51** mounted on the rotatable base plate **52** and the stationary base plate **53**. The bar **45** may be rotated by means of knob **54** and set in position by means of set screw **55**. Reference numeral **56** designates a handle for rotating base plate **52** on ball bearings **57** in a horizontal plane and reference numeral **58** designates a knob for securing the U-shaped member **50** at any desired angle or position in a vertical plane. The antenna is connected by means of line **11** to a translation device, not illustrated.

It is believed to be obvious from the above description that the maximum direction of radiant action of antenna **41** which direction coincides with bar **45** and a diagonal of the antenna may be aligned with any desired direction of action by proper manipulation of the apparatus associated with the antenna, and that the antenna may be positioned for receiving horizontally, vertically or other linearly polarized waves by means of knob **54** and set screw **55**. Different wave-lengths may be transmitted or received by properly positioning members **43** on bar **45**. The system of Fig. 7 is especially useful for point to point communication and direction finding operation in the short, ultra-short and millimeter wave fields and may be used for ascertaining the elevation angle of an incoming wave in a given vertical plane. It may also be used with great advantage in airport landing communication systems.

Figs. 8, 9, 10 and 11 each disclose a rhombic antenna system in which unidirectivity is achieved without the use of the terminating impedance heretofore used for dissipating energy producing the backward radiation. While these systems may be used for transmitting or receiving energy, the system of Fig. 8 is especially adapted for receiving and the systems of Figs. 9, 10 and 11 for transmitting energy. In these figures, reference numerals **59** designate a rhombic antenna exciter, and numerals **60** designate transformers connecting the rhombic exciters to the translation devices. In Fig. 8 reference numeral 61 designates an active or energized rhombic antenna reflector positioned a quarter wave-length from the exciter 59 and energized through coil 62 coupled to transformer 60. Reference numeral 63 designates a tuning condenser. In Fig. 9 reference numeral 64 designates a passive or unenergized rhombic antenna reflector energized by the radiation from exciter 59. The reflector 64 is positioned a quarter wave-length distance from the exciter 59. In Fig. 10 reference numeral 65 designates a transmission line the conductors of which are adjustably connected by movable contacts 66 to the secondary winding of transformer 60, and are positioned adjacent the sides of antenna 59 to form in effect a rhombic antenna. In Fig. 11 the two rhombic antennas 59 are arranged in a vertical broadside or stack array and are preferably closely positioned so as to be in effect superimposed although insulated from and independent of each other. They may, if desired, be spaced and also may be arranged in an horizontal broadside array. Reference number 67 designates a conductive bar or short circuit connected across the far-end terminals of the upper antenna 59, reference numbers 68 and 69 designate couplers or coupling circuits for properly connecting from an impedance matching standpoint, respectively, the upper shorted antenna 59 and the lower open antenna 59 to transmitting device 3. By reversing the connections between device 3 and one of the antennas 59, the unilateral radiation direction may be reversed.

In the operation of the receiving system illustrated by Fig. 8 the currents from exciter 59 and reflector 61 combine at device 3 in the same phase for waves having direction 70 and in opposite phase for waves having direction 71. In the transmitting system of Fig. 9 the reflector 64 functions to cancel waves propagated in direction 72 by exciter 59 and to assist waves propagated in direction 73. In the transmitting system of Fig. 10 the energy supplied to the antennas 59 by translation device 3 and unradiated before reaching the antenna terminals remote from the translation device is returned, respectively, by transmission line 65 to the input terminals of the antenna. The contacts 66 are so adjusted as to insure phase agreement between the energy returned and that originally supplied to the input terminals of the antenna whereby a unidirective effect is obtained. The corresponding or parallel portions of antenna 59 and the line or antenna 65 radiate in phase energy. Of course the conductors of line 65 may be positioned parallel in which case waves radiated by these conductors mutually cancel and the energy returned to the input terminals of antenna 59 is radiated.

In operation of the system of Fig. 11 in-phase energy is supplied by device 3 to both antennas and in the case of each antenna the energy radiated before reaching the far-end terminals is propagated in direction 73. Energy reflected at the far-end terminals of each antenna is propagated in direction 72. The energy reflected by the substantially infinite impedance or open circuit at the far-end terminals of the lower antenna is, however, oppositely phased with respect to the energy reflected by the substantially zero impedance or short circuit at the far-end terminals of the upper antenna, whereby a complete cancellation occurs in the ether in direction 72. This arrangement therefore provides a simple, safe and efficient means for eliminating undesired reflection and back-fire or backward radiation.

Referring to Fig. 12A reference numbers 74 designate V-shaped antenna units of the type disclosed in my patent mentioned above and reference numerals 75 designate V-shaped counterpoise units similar in construction and design to the units 74. The units 74 and 75 are positioned in the same plane which may be horizontal, vertical or otherwise. They are each connected to the translation device 3 by means of transmission line 11 and branch transmission lines 76 which are dimensioned, so as to render the conductive paths connecting the translation device 3 and the units 74, 75 equal in electrical length whereby in-phase currents are received from or supplied to the units. The far end terminals of units 74 and 75 are connected to separate terminating impedances 12. In operation the directions of maximum action for the units 74 and 75 coincide with the direction or path 2 and an extremely narrow diagram results in the plane of the units. When it is desired to receive vertically polarized wave components at a point near the ground, the virtual or metallic counterpoise comprising units 75 may be omitted and a ground image counterpoise comprising image units 77 may be used, as shown in Fig. 12B. Each of the antennas in the arrays of Figs. 12 and 12B is unidirectional, the double headed arrow 2 being used to indicate that the direction of maximum transmitting action is opposite to the direction of maximum receiving action.

The remaining figures on the drawings, Figs. 13, 14, 15, 15A, 16 and 16A illustrate single-dimension, two-dimension and three-dimension arrays comprising rhombic antenna systems. Referring to these figures reference numerals 78 designate rhombic antennas which, in the system of Fig. 13, are positioned in different parallel vertical planes and in the system of Fig. 14 are horizontally positioned in different parallel planes. The antennas of Fig. 13 constitute one type of broad-side array and the antennas of Fig. 14 one type of stack array. In-phase currents are supplied to or received from the device 3 over lines 11 and 76.

In the array of Fig. 15 the rhombic antenna systems are positioned in vertical planes and in the array of Fig. 16 in horizontal planes. In each of these three-dimensional arrays the antennas are arranged in four vertical bays and four horizontal tiers, each tier including four parallel rows of rhombic antennas. As represented on the drawings in both of the systems of Figs. 15 and 16 the antennas included in the first vertical array row are connected over paths of equal length to the translation device 3. The adjacent antennas in the same bay and in the same tier, and therefore in different rows are connected by means of transmission line 79 equal in length to the spacing between the adjacent antennas, whereby the four antennas included in the same bay and in the same tier radiate or receive energy in phase with the space wave having the direction 2. Any bay, any row or any tier of the systems of Fig. 15 or 16 may be used alone as a complete antenna system, and when so employed constitutes a two-dimensional array. In addition, any row of any bay of the system of Fig. 15 may be employed as a single dimensional array as illustrated by Fig. 15A and any row of any tier of the system of Fig. 16

may be similarly employed as illustrated by Fig. 16A.

The various arrays described above function to produce improved directive transmission or reception as compared with that produced by a single antenna unit. Thus the single dimension arrays of Figs. 14 and 15 each possess an extremely narrow lobe in a plane perpendicularly related to the planes of the antennas and the single dimension arrays of Figs. 15A and 16A are each relatively thin in the plane of the units. The directive lobes for the two-dimensional arrays are very sharp and for the three-dimensional arrays even sharper.

Although the invention has been described in connection with certain specific embodiments thereof it is to be understood that it is not to be limited to these embodiments and that embodiments differing from the above may be successfully used without exceeding the scope of the invention.

What is claimed is:

1. A horizontal rhombic antenna for receiving or radiating waves of different wave-lengths with substantially the same efficiency comprising side conductors each having a length greater than twice the longest operating wave-length, equal to the conductor projection on the path of propagation plus one-half the mean operating wave-length and at least five times greater than the height of the antenna above the ground, and the side interior angles of said antenna having a value between 140 and 160 degrees and being critically chosen so that each of the antenna maximum directions of action for the different operating frequencies is aligned with the path or direction normally followed by the wave of corresponding frequency.

2. A horizontal rhombic antenna for waves of different wave-lengths comprising four conductors positioned at a height in wave-lengths above ground equal to

$$\frac{1}{4\sin\Delta}$$

and each having a length equal to

$$\frac{.371\,\lambda}{1-\sin\Phi\cos\Delta}$$

where λ is the mean operating wave-length, Δ the angle between a horizontal plane and the direction of maximum action of the antenna for the mean wave-length and Φ is the angle included between an antenna conductor and a vertical plane perpendicular to the vertical plane of propagation.

3. A unidirective antenna system comprising two rhombic antennas connected to a translation device and arranged in broadside, and means connected to one of the antennas for rendering the energies radiated from said antennas in one direction in phase and the energies radiated in the opposite direction oppositely phased.

4. A unidirective antenna system comprising two rhombic antennas arranged for broadside operation connected to a translation device, the impedance of the path between the remote terminals of one antenna being greatly different from that across the remote terminals of the other antenna, whereby the reflected currents are oppositely phased.

5. A unidirective antenna system comprising two similar rhombic antennas connected to a translation device and having their corresponding elements positioned immediately adjacent, the remote terminals of one antenna being short-circuited and the remote terminals of the other antenna being open-circuited.

6. A single dimension array comprising a plurality of horizontal rhombic antennas spaced in a given direction, each in accordance with claim 1, said antennas having their directions of maximum action for each operating frequency in effect superimposed.

7. In combination, a plurality of antennas each comprising a plurality of angularly related wires positioned in a horizontal plane, each wire having a length equal to a half wave-length plus its projection on the desired path of radiant action and greater than twice the longest operating wave-length, a translation device connected between one set of terminals of each antenna, and means for rendering the system unidirective comprising a path of zero impedance connecting the remaining set of terminals of at least one antenna, and a path of large impedance connecting the remaining terminals of a different antenna.

8. In combination, an antenna system comprising a plurality of rhombic antennas, each in accordance with claim 1, said antennas being positioned in parallel horizontal planes, and a translation device connected to each of the antennas.

9. In combination, an antenna system comprising a plurality of rhombic antennas, each in accordance with claim 1, said antennas being included in the same horizontal plane and having their longest diagonals included in parallel vertical planes, and a translation device connected to each of said antennas.

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