

May 23, 1933.

E. BRUCE

1,910,147

ANTENNA SYSTEM

Filed March 9, 1927

3 Sheets-Sheet 1

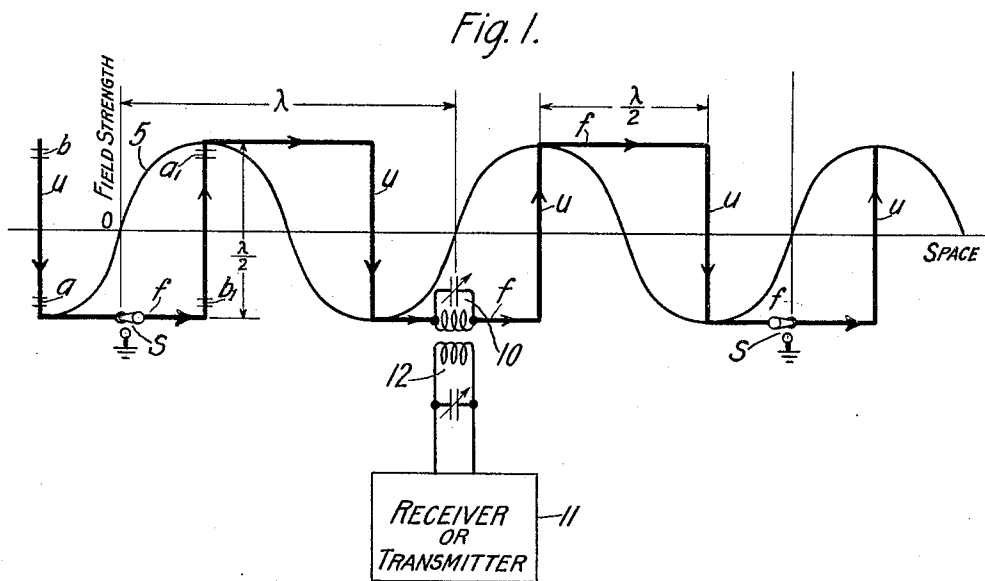


Fig. 2A.

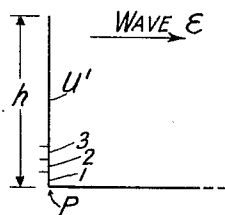
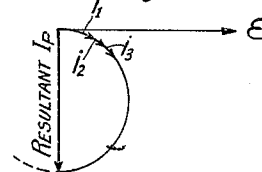


Fig. 2B.



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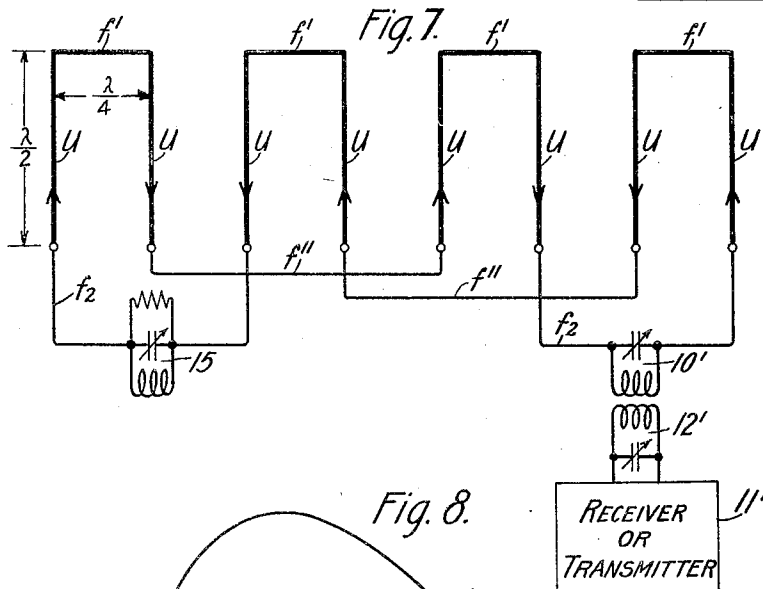
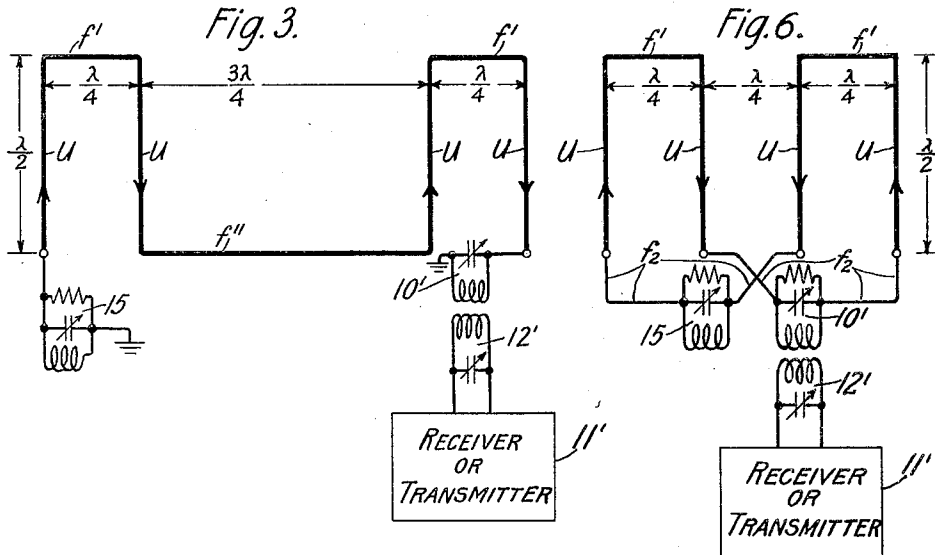
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3 Sheets-Sheet 2



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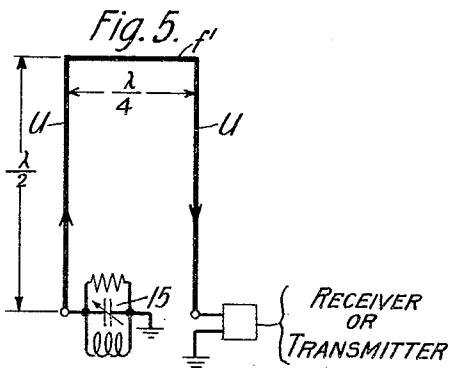
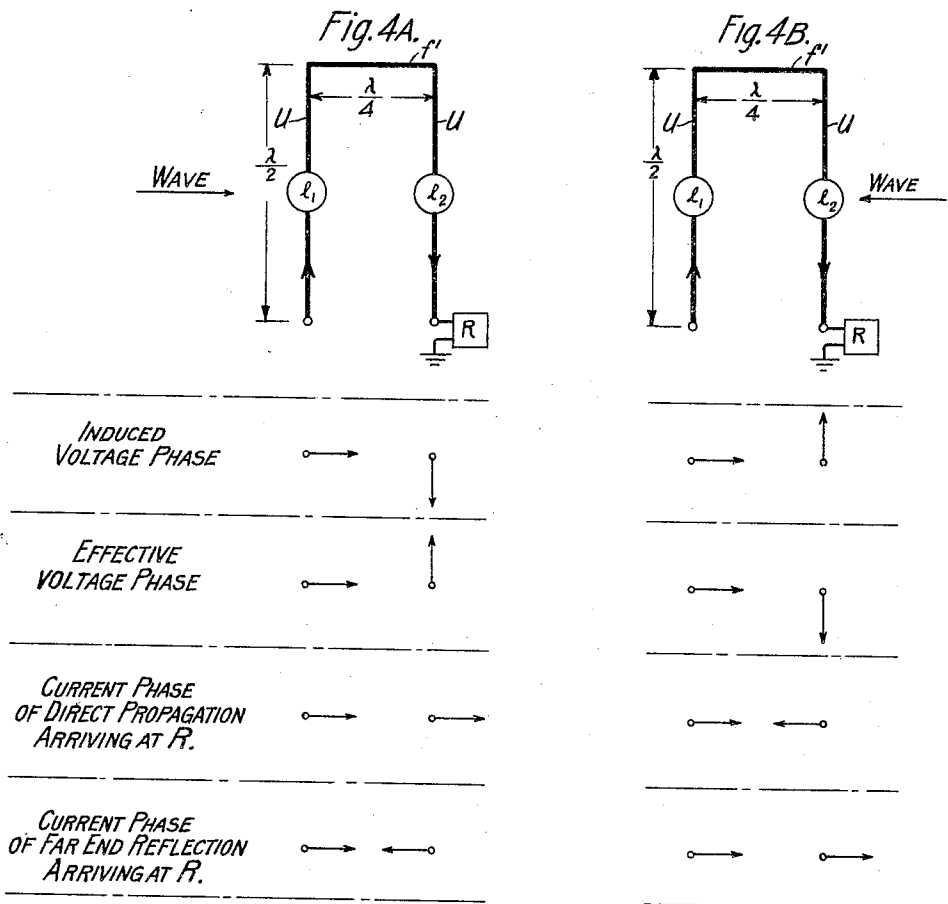
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3 Sheets-Sheet 3



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UNITED STATES PATENT OFFICE

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ANTENNA SYSTEM

Application filed March 9, 1927, Serial No. 173,833, and in Great Britain January 10, 1927.

This invention relates to wave transmission, and especially to antennae adapted for short wave radio communication.

When an ordinary electromagnetic wave traveling along the surface of the earth and having its front in a vertical plane impinges upon a vertical receiving antenna, absorption of energy from the wave takes place in well known manner resulting in a current in the antenna. If several such independent antennae are spaced apart a distance of one-half wave length in the direction of propagation, upwardly directed currents are set up in the first, third, etc. of these antennae at the same time that downwardly directed currents are set up in the second, fourth, etc. By connecting these antennae electrically so that the effects of all these currents are added with respect to the receiving device, the response obtained is much greater than with a single antenna. Antenna arrays of this type have been suggested in the past. In accordance with this invention an improved antenna array of this general type suitable either for receiving or transmitting is provided.

One fundamental aspect of the invention lies in connecting the vertical antennae by means of conductors in such manner that phases are taken into account throughout the system with resulting increase in efficiency. This aspect of the invention may be better understood by considering a simple receiving antenna array comprising verticals connected in series by horizontally connected wires. The arrangement may be such, in accordance with this invention, that a current pulse set up by the space wave in the uppermost elemental section of the first vertical wire, for example, is just one wave length of the wire from the lowermost elemental section of the second vertical, so that there will be an adding of the current in the verticals in phase. In a simple case the verticals are one-half wave length high and one-half wave length apart. This additive effect may be obtained in other forms of antennae of this general type by having corresponding elemental sections somewhat differently spaced as will be hereinafter described.

In another aspect the invention pertains to

the choice of antenna height, the preferred form of antenna being one in which the height is one-half wave length.

Another aspect of the invention relates to the proper impedance termination of the antenna array to obtain a desired directional effect by preventing undesired reflections.

Again, the invention provides an antenna array of the type mentioned above, but folded back upon itself, so as in general to obtain compactness, and, in certain cases, the elimination of grounds.

Figs. 1, 3, 5, 6 and 7 of the drawings show five different systems of the type described above; Figs. 2A, 2B, 4A and 4B are diagrams for facilitating explanation of the invention; and Fig. 8 shows the polar directional characteristics of the system of Fig. 7.

In Fig. 1 the sinusoid 5 shows the space distribution of the electric or the magnetic field strength of an advancing electromagnetic wave at a given instant of time t . The heavy vertical and horizontal lines represent a series of vertical or upright inductor wires u a half wave-length high and spaced by a half wave-length and horizontal wires f of that length connecting the vertical wires. The wires are all in a plane perpendicular to the wave front, and the electric field of the oncoming wave is parallel to the vertical wires. Thus, the electromagnetic wave may be such as would be sent from a vertical transmitting antenna wire. The arrows on the conductors show the direction of current flow at the given time t . Interconnecting the inductors or verticals u by conductors f , as shown, secures the benefit of the cumulative effect of the verticals. This system satisfies each of two conditions which it is desirable to fulfill, namely that the height h be of proper value to produce the optimum effective induced voltage in each of the verticals, and that the height h and the spacing of the verticals in the direction of the wave motion, and the length of the horizontal wires f have values such that the resultant currents, one of which is produced by each vertical, are directly in phase at any point in the line so that the cumulative effect just mentioned is a maximum. (For the present it is assumed

that the current wave velocity in the wire is equal to the space wave velocity in the surrounding medium.)

To show that the first condition is satisfied, reference may be had to Figs. 2A and 2B. Fig. 2A represents a lossless wire w' divided into small elements 1, 2, 3, etc., each having the same induced voltage in time phase with each other. A current pulse from, say, element 3 travels toward point P with the speed of light. By the time it reaches P, it lags behind the instantaneous induced voltage in time phase an amount depending on the distance traveled. Fig. 2B shows the vector addition of these current pulses originating in elements 1, 2, 3, etc. which, for a lossless line, traces along the circumference of a circle. The resultant current I_P will be a maximum when it is the diameter of the circle. Since the diameter interconnects two elementary currents 180° out of phase, the optimum line length must necessarily be one-half wavelength. For any point other than P, the reasoning is similar. The only difference will be that the resultant current will have a different phase relation to the reference axis in the same manner as the ordinary space phase distribution of a wave. Thus it is seen that the arrangement in Fig. 1 satisfies the first condition stated above.

Fortunately, this arrangement also satisfies the second condition (with separation of verticals u equal to half of the wave-length λ) because any elemental length in one vertical has a corresponding elementary length, in the next vertical, just one wire wave-length away, as illustrated in Fig. 1 by a and a_1 , likewise b and b_1 . The elemental lengths a and a_1 are here referred to as "corresponding" elemental lengths because, or in the sense that, they are the same distance from the entrance ends of their respective verticals at any given instant, or in other words the same distance from those ends of their respective verticals which at each instant are given equal potentials relative to the other ends by the action of portions of the space wave one-half wavelength apart.

The far ends of the line or antenna may be free, as shown. However, if desired, an antenna with its ends grounded as about to be described may be employed. Preferably, when the ends are free the total length of the antenna is an integral odd multiple of half of a wire wave length and when the ends are grounded the total length of the antenna is an integral even multiple of half of a wire wave length. By fulfilling these conditions it is possible to obtain maximum reflection at the ends of the system and to cause the first or primary reflection of the resultant current due to the electromotive force induced in any vertical inductor u in Fig. 1, to be in phase with resultant current by the direct propagation, due to the electromotive force induced

in that vertical inductor u , at any point in the antenna, as for example at the load 10. The condition of free termination is the practical equivalent of a change of half a wave length, as compared with a condition of grounded termination, on account of the reversal of phase on reflection. Therefore, when an antenna with grounded ends is desired, switches S, which are located at the midpoints of horizontal conductors f , may be closed downward. Four of the verticals u are then effective.

If a line such as that in Fig. 1 were a lossless line, with no energy extracted from it (that is, with no load connected to it) it would develop a series of standing wave sections, each being one wire wave-length in length and each functioning irrespective of the adjoining sections. The instant a load is inserted in the line as at 10, the line current amplitudes decrease and all sections feed in energy toward this load in order to reestablish equilibrium.

In the system of Fig. 1, it is desirable to employ a character of load and to insert the load at a point in the line such that a maximum output voltage will be developed. The load is preferably connected at the midpoint of one of the half wave-length horizontal wires f , at the center of the wave collector, as shown in Fig. 1. The impedance which the load presents to the wave collector should be as high as possible and therefore may well be an anti-resonant circuit, as shown at 10, tuned to the wave length λ . The anti-resonant circuit is coupled to a radio receiver (or transmitter) 11 by a resonant circuit 12.

Regarding the directional characteristics of the system of Fig. 1, the system is bi-directional and the outputs due to signal field strengths in the broadside directions (directions perpendicular to the plane of the antennae), are negligible.

The discussion so far has been under the assumption that the line phase velocity is equal to the velocity of light. In long line experience, this has been found decidedly not to be the case. In fact, the line wave velocity is less than the space wave velocity to such an extent that should the dimensions given above be maintained, additional sections would not add materially to the output. In order to avoid this limitation, should the wire velocity be retarded, the spacing of the verticals should still be maintained at one-half a space wave-length but the verticals should be shortened in length sufficiently to reestablish the proper space relation between the wire and the space waves. The system of Fig. 1 can be extended indefinitely, to include any desired number of verticals, and will give continuously increased output voltages as its dimensions are enlarged. Its most desirable size will be determined largely by the economics of the problem. However, such an

antenna is preferably built for a definite frequency and a definite direction of reception, for use in point to point communication, for example. The output voltage maximum of one or more verticals of an antenna of this type, if the antenna were lossless, would be directly proportional to the wave length for which it was designed.

It has been stated above that the antenna system of Fig. 1 is bi-directional, meaning that it responds readily to waves from either horizontal direction in the plane of the antenna. The system of Fig. 1 is equally responsive for these two opposite directions. One way in which asymmetry, or lack of equality, of responsiveness for the two directions may be obtained is by rearranging the spacing of the wires of half wave-length height, while maintaining the alternate ones of those wires at a wave length apart and maintaining the lengths of the horizontal connecting wires equal to the distances between the verticals which they connect. When the spacing of the wires of half wave-length height is, by way of example, alternately a quarter and three quarters of the wave-length, as shown in Fig. 3, the antenna is responsive to waves from only one of the two opposite horizontal directions in its plane, provided the reflections from the far end are absorbed by properly terminating that end as shown at 15 in Fig. 3. An antenna having this directional property will be referred to in this specification as a unidirectional antenna. The action of the proper termination can be explained by reference to Figs. 4A and 4B, each of which represents a single section. In Figs. 3, 4A and 4B, horizontal quarter wave-length conductors f' or three-quarter wave-length conductors f'' connect adjacent verticals.

It can be shown that, in Figs. 4A and 4B, the resultant effective voltage induced in a vertical u , can be represented by a lumped voltage centrally located in that vertical, as at e_1 and e_2 . A vector picture of the currents and voltages for each vertical is drawn below the vertical. It is seen that the voltages' phase difference between verticals is a quarter period. Assuming the velocity of the current pulses as the speed of light, one complete period elapses for a current pulse to travel directly from e_1 to receiver R, likewise a quarter period is necessary between e_2 and R. For the current pulses arriving at R via the far end reflection, e_1 to R requires effectively two complete periods while e_2 to R requires two and three-quarter periods. Figs. 4A and 4B represent receiving conditions for waves in opposite directions. Examination of the current vectors, drawn below these figures, shows receiver directional discrimination for the direct and reflected propagations separately, but if both are allowed to exist simultaneously, the directional discrimina-

tion is destroyed. Therefore, for complete suppression of reception from one horizontal direction in the plane of the antenna, far end damping should be employed, as shown at 15 in Figs. 5 and 3.

Thus, Fig. 5 represents the preferred form for a single section, unidirectional antenna while Fig. 3 is desirable for a multi-section layout. In Fig. 3, a spacing of three-quarter wave length between sections makes corresponding elements, of adjacent sections, one space wave length and two wire wave lengths apart which is a proper relation to satisfy the phase requirements for arithmetical current addition. Those requirements will also be satisfied if corresponding elements of adjacent sections are any integral multiple of one space wave length and any integral multiple of one wire wave length apart.

A multiple section antenna such as that in Fig. 3 may be folded back upon itself and the terminating impedances connected between wires, as shown in Fig. 6, thus eliminating the necessity of ground connections. In the system of Fig. 6 the two sections per se are similar to the section disclosed in Fig. 5 and, singly, would each have the unidirectional characteristics of the section of that figure since they are similarly associated with the corresponding surge impedance and receiver. These sections are so related to each other that their currents act cumulatively since, although the corresponding elements of adjacent sections are differently spaced than in Fig. 3, which illustrates an alternative unidirectional arrangement, the wire wave length spacing is correspondingly less and such as to provide adequate compensation. Fig. 7 illustrates how this scheme may be enlarged. The theoretical polar directional characteristics for the antenna system of Fig. 7 are given in Fig. 8. The symbol ϵ in Fig. 8 represents field strength. The origin of polar coordinates is at the tip of the right-hand arrow in Fig. 8. In Figs. 6 and 7, as in the case of Figs. 3 and 5, the antenna lies in a plane containing the direction of the electric force in the wave front of the wave to be received (or transmitted) and points from the receiver toward the oncoming wave.

The surge impedance of a lossless line, and therefore the proper terminating impedance for such a line, is a pure resistance. At the high frequencies for which these antennae are especially well adapted, it is difficult to construct resistances without reactive effects. An arrangement which proved most satisfactory for the far end line termination consisted of an anti-resonant circuit in parallel with a limiting resistance element or resistance element for limiting the resistance of the termination as a whole. Even though reactance is present in the resistance element, there exists an adjustment of the anti-reso-

nant circuit, which will make the combination effectively a pure resistance. In practical antennæ, where losses are present, the theoretical surge impedance contains a small reactive term in addition to the resistance. This condition can also be realized with this terminal combination.

The impedance presented to the antenna by the receiver (or transmitter) and its antenna coupling in Figs. 3, 5, 6 and 7 is preferably equal to the surge impedance of the antenna, and may comprise elements 10', 11' and 12' similar to elements 10, 11 and 12, respectively, of Fig. 1 but adjusted to simulate the impedance 15.

The electrical lengths or wire wave lengths of the elements 10, 10' and 15 are substantially zero or negligibly small. In Figs. 3 and 5 the electrical lengths of the conductors connecting elements 10' and 15 between a one-half wave length vertical conductor u and earth are substantially zero or negligibly small. In Figs. 6 and 7 the elements 15 and 10' are connected at the center of one-half wave length horizontal conductors f_2 which connect the lower ends of two of the one-half wave length vertical wires u . In Figs. 5, 6 and 7, as in Figs. 3, 4A and 4B, conductors f' and f'' are horizontal one-quarter wave length and three-quarter wave length conductors respectively, each connecting two vertical wires u .

Although it was mentioned above, it may be again pointed out that, should the wire velocity be retarded by losses, the proper phase relation with the space wave may be reestablished by slightly shortening the length of the verticals.

Fig. 8 is the calculated polar directional characteristic for the antenna system of Fig. 7, the system being unidirectional, with maximum effectiveness for one horizontal direction in the plane of the antenna and zero effectiveness for the opposite direction.

Although, in the specific systems described above, the wires u are vertical and the wires f , f' and f'' horizontal, the principle of the invention is independent of the absolute direction of the wires u and f , f' and f'' . In the several specific embodiments of the invention shown in the drawings the wires u , it will be noted, are parallel to the direction of the electric force in the wave front, or in other words, are parallel to the axis of polarization of the waves to be received by, or radiated from, the antenna, and the wires f , f' and f'' are perpendicular to the axis of polarization. The term "height" as used in this specification and in the claims is not restricted to vertical dimensions.

The expression "integral multiple" of a quantity, as used in this specification and in the claims, includes unity as the multiplier involved. Thus the quantity may be an integral multiple of itself.

The dimensions mentioned above for the length, spacing, height, etc. of the component parts of the antenna may be increased by any integral multiple of one wave length, since the phase relations of the voltages and currents in the system will not be thereby altered.

In referring herein to directions in which portions of the antenna extend, difference of sign or sense is not regarded as a difference of direction, although in referring to the directional characteristics of the antenna opposite signs or senses of direction are regarded as opposite directions.

What is claimed is:

1. An antenna for space wave communication, comprising inductors spaced in a direction of propagation of the space waves past said antenna, and current conducting means connecting said inductors, the electrical length of said antenna between corresponding elementary lengths of any two of said inductors differing an odd integral multiple of a half wave length from the spacing, measured in space wave lengths, of the two inductors in said direction, at the frequency of said waves.

2. In combination, an antenna for space wave communication, and terminal apparatus for said antenna, said antenna comprising portions spaced in a direction of propagation of the space waves past said antenna, and current paths connecting said portions in series with each other and said terminal apparatus, the difference between the electrical lengths of said antenna between corresponding elementary lengths of adjacent ones of said portions on the one hand and said terminal apparatus on the other hand, differing by an integral odd multiple of half a wave length from the spacing, measured in space wave lengths, of the adjacent portions, at the frequency of the waves.

3. An antenna comprising a plurality of elements extending in two right-angularly related directions, occupying a common plane, and series connected in zig-zag form and therefore comprising in part a series of parallel non-colinear elements, the spacing of said parallel elements being so related to the electrical length of a cyclically repeated unit of the antenna as a whole that, with respect to any two points separated by such a unit length, the phase difference between currents induced from a space wave whose front is parallel with said parallel element will be the same as the corresponding phase difference between currents at the same point resulting from propagation of a wave along the antenna between such points.

4. In combination, an antenna for radio wave communication, comprising a conductor having a height approximately an odd integral multiple of half of the wave length, in said conductor, of current of the frequen-

cy of the communication wave, signaling apparatus, and means coupling said apparatus to said antenna and presenting a high impedance to current flowing in said antenna.

5 5. An antenna comprising a plurality of sections, each section comprising two conductors and a third conductor positioned at right angles to said two conductors and connecting said two conductors in series, said
10 two conductors being spaced a quarter space wave length apart, and another conductor connecting two of said sections in series, the electrical lengths of said two conductors of
15 each section and said last mentioned conductor being such that the time required for current to flow from the electrical center of one of said two conductors of one of said two sections to the electrical center of the
20 corresponding one of said two conductors of the other section is such that at said center points said current is in the same phase relation to the space wave identified with the current.

25 6. An antenna system for radio wave communication, comprising conductors each having a height approximately half of the wave length of the communication wave, and connecting conductors, at right angles to said first conductors, joining said first
30 conductors in series, the spacing of said first conductors being alternately a quarter wave length and three quarters of a wave length.

35 7. An antenna comprising conductors extending in a given direction, and means in a plane at right angles to said conductors connecting said conductors in series, said conductors being so spaced apart, and the length of said antenna between corresponding elementary lengths of said conductors being
40 such that direct propagations in said conductors identified with a space wave moving in a given direction are cumulative at a given point in said antenna, and direct propagations in said conductors identified with a
45 space wave moving in another direction are differential at said point.

50 8. An antenna system having an asymmetrical directional characteristic, comprising a plurality of antenna members connected by conductors having substantially no antenna characteristics, and means terminating the antenna system in an impedance equal to the surge impedance of such system.

55 9. In combination, an antenna system, comprising a plurality of antenna members connected by conductors having substantially no antenna characteristics, in which direct and reflected propagations identified with a
60 space wave moving in a given direction are cumulative and differential, respectively, at a point in said antenna, and direct and reflected propagations identified with a space wave moving in another direction are differential and cumulative, respectively, at said
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point, and means rendering said reflected propagations substantially zero.

10. An antenna comprising a plurality of main conductors, each approximately one-half wave length in height, and auxiliary
70 conductors positioned at right angles to and connecting said main conductors in series, said main conductors being so spaced that the successive spacings are unequal and that at the center points of alternate main conductors the current is in the same space relation to the space wave identified with the current.
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11. An antenna according to the next preceding claim and an electrical network of impedance substantially equal to the surge
80 impedance of the antenna connected between one end thereof and ground.

12. An antenna for radio wave communication comprising a plurality of main conductors, each approximately one half a wave
85 length in height, and auxiliary conductors positioned at right angles to and connecting said main conductors in series, said main conductors being so spaced that the successive spacings are unequal and alternate conductors are separated by a distance of approximately one wave length in the direction of propagation of the communication wave.
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In witness whereof, I hereunto subscribe my name this 7th day of March A. D. 1927.
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EDMOND BRUCE.

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