Aug. 19, 1930. S. W. DEAN 1,773,097

STAGGERED WAVE ANTENNA SYSTEM

Filed March 3, 1927 2 Sheets-Sheet 1

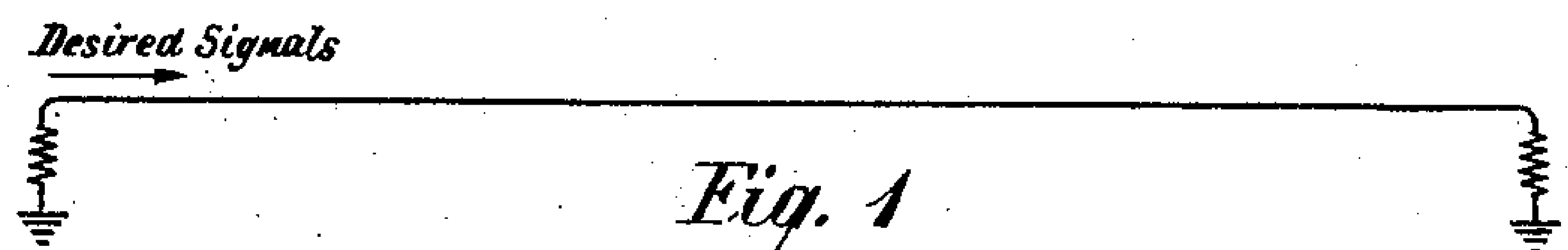

Fig. 1

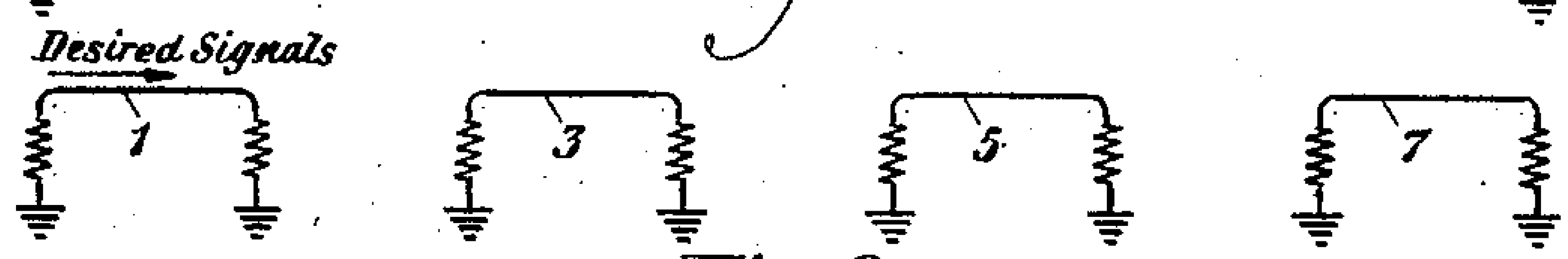

Fig. 2

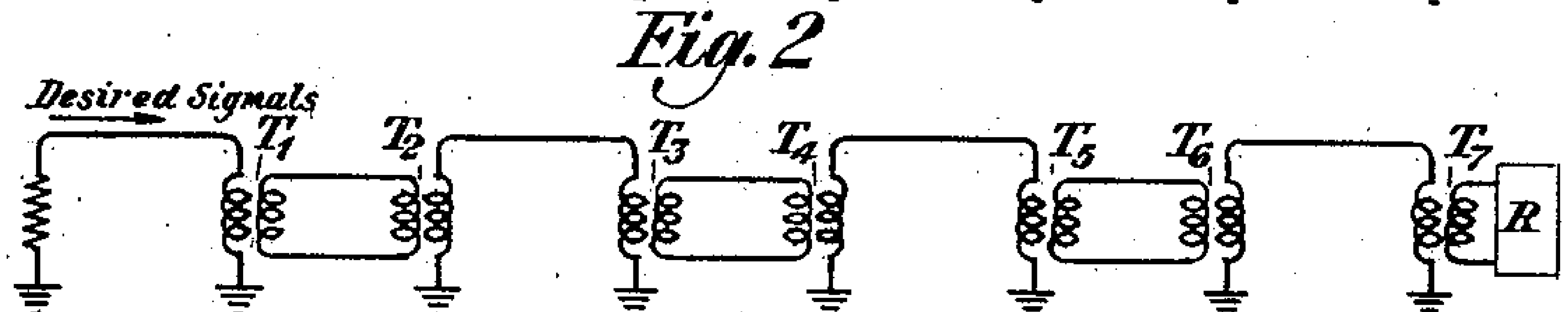

Fig. 3

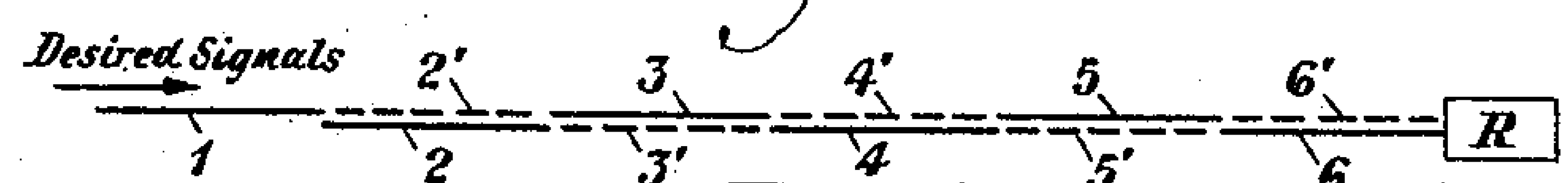

Fig. 4

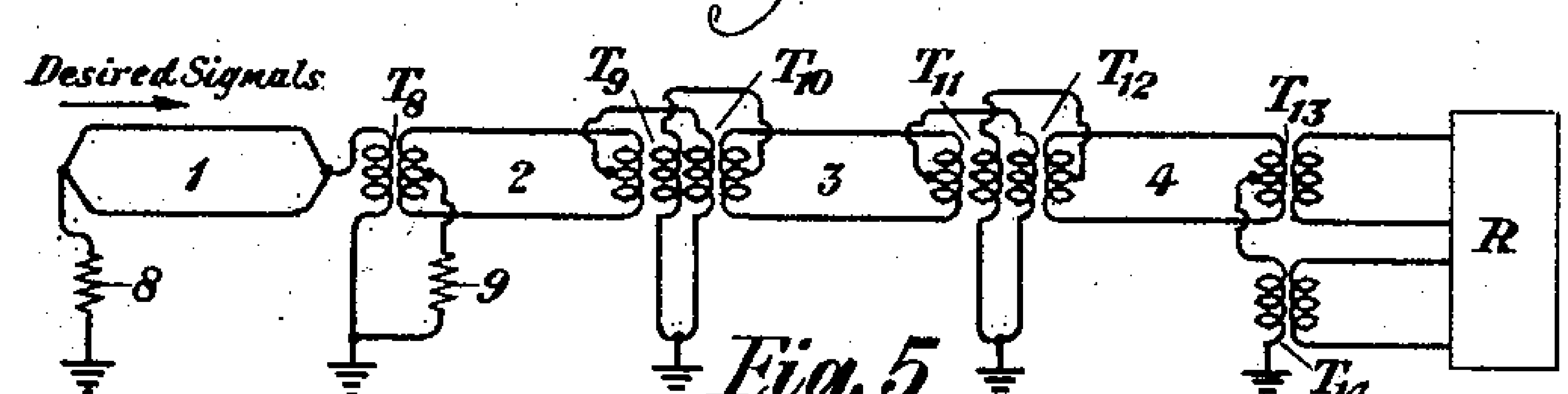

Fig. 5

Fig. 7

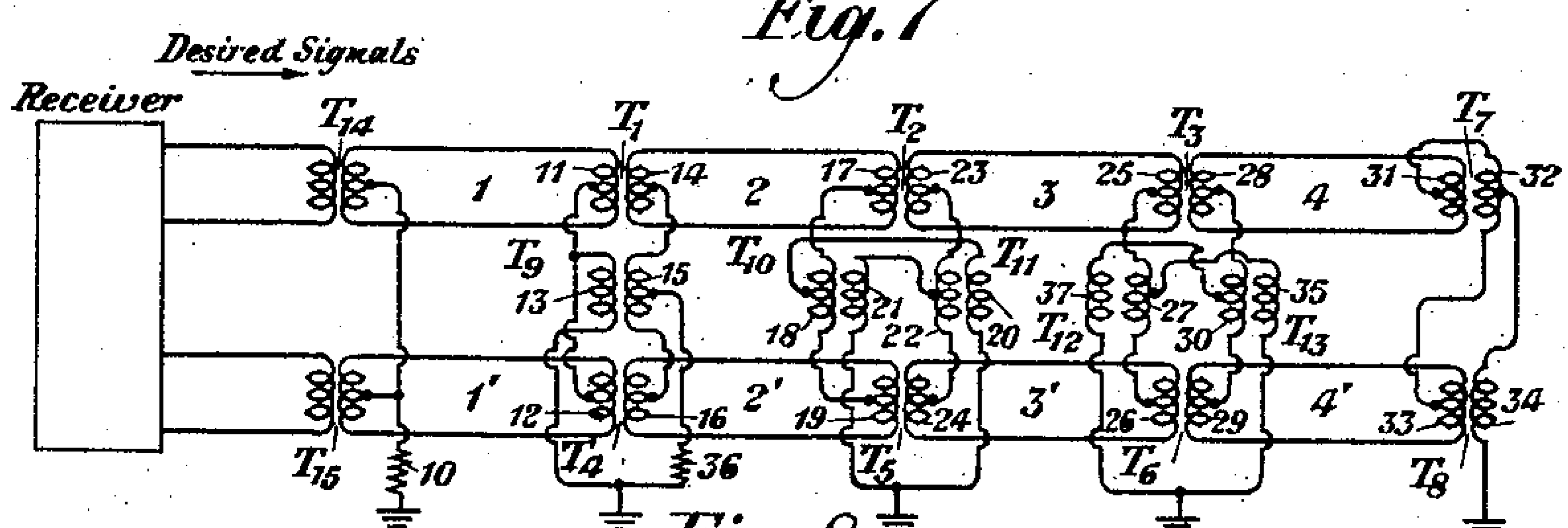

Fig. 8

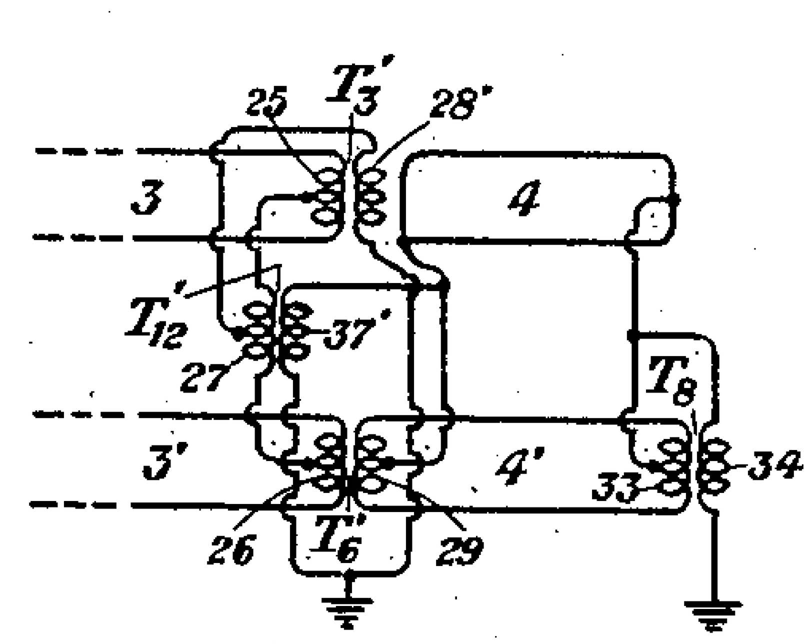

Fig. 9

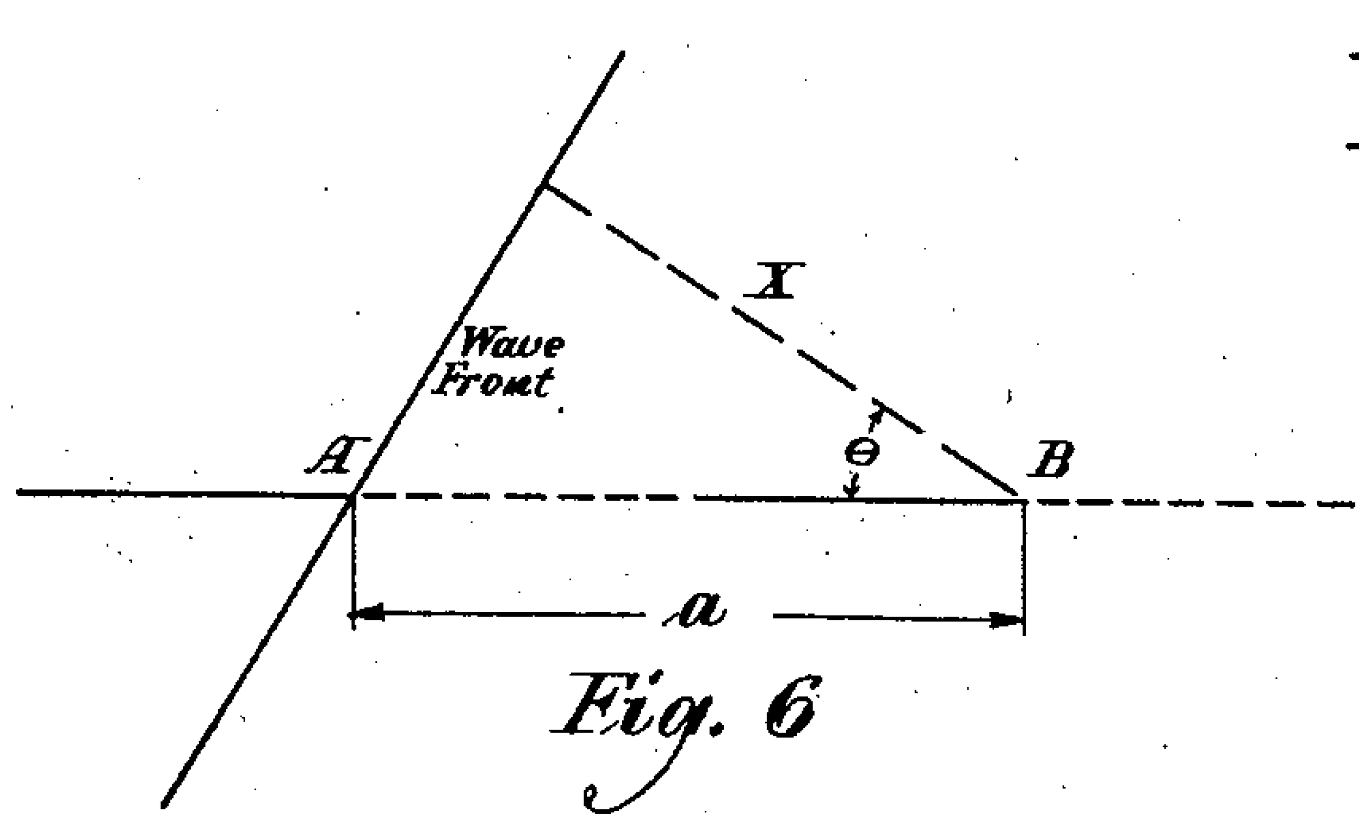

Fig. 6

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STAGGERED WAVE ANTENNA SYSTEM

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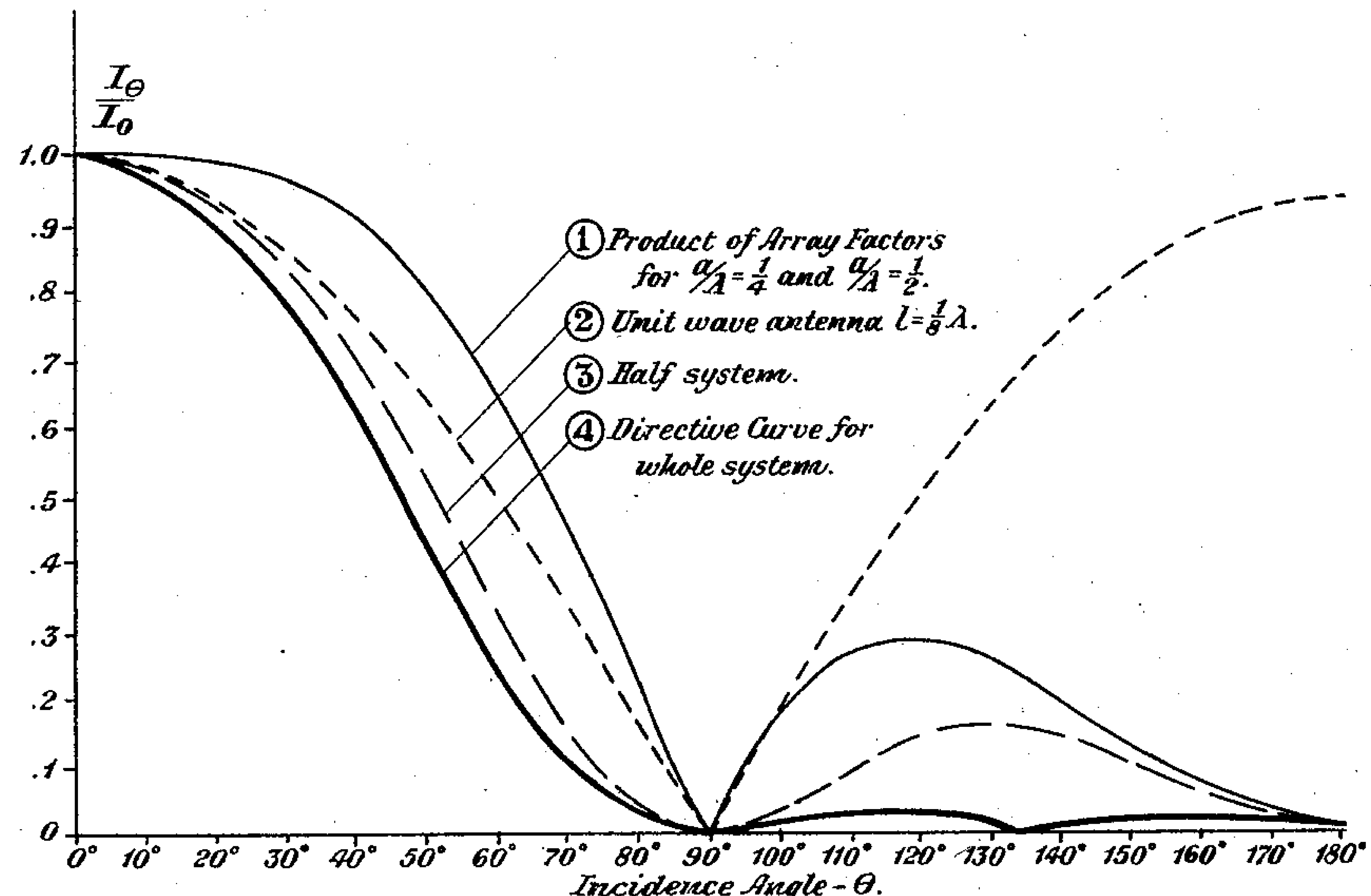

Fig. 11

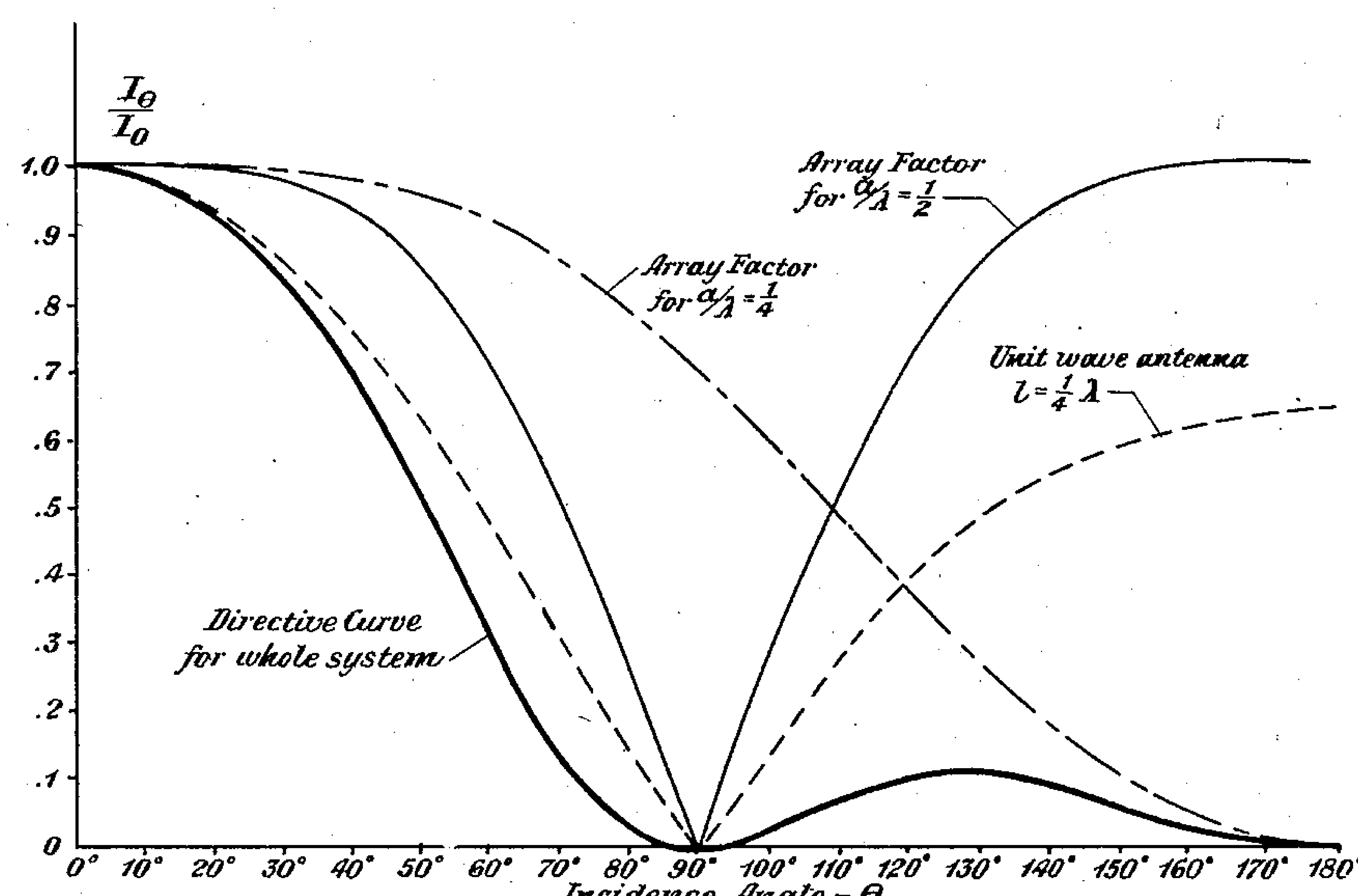

Fig. 10

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Patented Aug. 19, 1930 1,773,097

UNITED STATES PATENT OFFICE

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STAGGERED-WAVE ANTENNA SYSTEM

Application filed March 3, 1927. Serial No. 172,448.

This invention relates to a staggered wave antenna system and particularly to a system in which the conductors constituting the separate antennæ of the staggered system may be placed upon the same pole line without introducing crosstalk or other interference effects.

The wave antenna of the type described by Beverage et al. in the Journal of American Institute of Electrical Engineers, Vol. XLII, Nos. 3 to 6, inclusive, comprises a single conductor of considerable length relative to the length of the wave that the said antenna is intended to receive. While such an antenna has a good directional characteristic, it is not entirely devoid of receptional ability at 180 degrees from the desired direction of reception. This failure to entirely eliminate waves arriving from an undesired direction somewhat diminishes its value. It has been found that reception at 180 degrees may be substantially suppressed by combining the signals received by a plurality of wave antennæ, which are not only parallel but also are staggered. By staggering is meant that the initial ends of the wave antennæ are in a plane that is not parallel to the wave front of the waves desired to be received but makes an angle with the wave front. Such an antenna system has been characterized as a staggered wave antenna system and by properly proportioning the parallel antennæ and the extent of the staggering, the system has a directional characteristic in which reception at 180 degrees from the desired direction is practically eliminated. Similar results have been obtained by the system disclosed in the co-pending application of A. G. Chapman, Serial No. 130,637, filed August 21, 1926. One of the difficulties in the systems of the prior art set forth above is that the plurality of antennæ constituting the system cannot be placed upon the same pole line, because crosstalk and other interference effects will be created between the various antennæ of the system.

My invention resides in a staggered wave antenna system in which the several antennæ, upon which the system is based, may all be placed upon the same pole line without creating crosstalk or other interference effects.

Another object of the invention resides in the employment of the sections of the antenna system not only to pick up signals from the electromagnetic waves but also to serve as connecting circuits between adjacent sections of the antennæ, whereby the currents set up in the adjacent sections may be carried to and properly combined at the receiving apparatus connected with the antenna system.

Another object of this invention resides in the use of a four-wire phantom system in which the invention is embodied, having means whereby the receiving apparatus may be placed at the end of the system upon which the desired signal waves first impinge and means by which the signals may be returned from the distant end of the antenna system to the said receiving apparatus.

Other objects of this invention will be apparent from the following description when read in connection with the attached drawing of which Figure 1 shows schematically a wave antenna of the type disclosed by Beverage et al.; Figs. 2 and 3 show the sectionalizing of the wave antenna and means for transmitting the currents from the various section to the receiving apparatus at the remote end thereof; Figs. 4 and 5 show the combining of a plurality of sectionalized wave antennæ and means for propagating and combining in the correct way the currents from the various sections; Figs. 6 and 7 illustrate the description of the invention; Figs. 8 and 9 show the means for bringing back, from the remote end of the antenna system, the currents set up in the various sections of the antenna and combining them in the receiving apparatus at the initial end of the said system; and Figs. 10 and 11 are curves plotted to rectangular co-ordinates showing the directional characteristic of the antenna system.

The wave antenna of the type described by Beverage et al., which is shown in its simplest form in Fig. 1, has a directional characteristic, depending upon its length and other factors such as is disclosed in the paper published by Beverage et al. in the said Journal, Vol XLII, No. 4. As will be seen from those directional characteristics, such an antenna has a varying amount of receptional ability throughout the range extending from 90 degrees to 270 degrees from the desired direction of reception.

I have found that an antenna of the type shown in Fig. 1 may be broken up into a plurality of sections such as shown in Fig. 2 which sections are preferably of equal length, and by omitting the alternate sections and combining the currents set up in the respective sections, the directional characteristic will be substantially that of the antenna shown in Fig. 1. The currents from the various sections may be transmitted to the receiver in the manner shown in Fig. 3. As shown therein, sections 1, 3, 5 and 7 are connected by the transmission circuits 2, 4 and 6. The connection between the circuits and the unit antennæ is effected by means of the transformers such as T_1 to T_6, inclusive. The unit antenna 7 is connected with the receiving apparatus R by the transformer T_7. It will be apparent that the current set up in the antenna 1 by the wave advancing in the direction indicated by the arrow will be impressed by the transformer T_1, upon the metallic circuit 2, over which it will travel to the antenna 3, upon which it will be impressed by the transformer T_2. This current from antenna 1 will travel over antenna 3 as a grounded circuit. There will also be set up, in antenna 3, a current resulting from the impinging of the electromagnetic wave thereon. These two currents will be impressed by the transformer T_3 upon the metallic circuit 4 and in turn upon the unit antenna 5 which constitutes a grounded circuit for the transmission of the currents from the antennæ 1 and 3. The current set up in antenna 5, by the advancing wave, together with the currents from the other antennæ, will be transmitted over the circuit 6 to the antenna 7 and these currents, together with that created in antenna 7 by the advancing wave, will be impressed by the transformer T_7 upon the receiver R. The principle shown may be applied to any desired number of sections, the number shown in the drawing being chosen simply to illustrate the case and not constituting a limitation thereon. Since the currents generated in the various unit antennæ are propagated over the metallic circuits, such as 2, 4 and 6, to the initial ends of the succeeding unit antennæ with nearly the same velocity as they would if the antenna were continuous, such a system, therefore, should have a directional characteristic not greatly different from that which would be obtained from a continuous antenna such as shown in Fig. 1. That this is so is clear from the calculations hereinafter disclosed.

The present invention resides, in part, in the superposition upon a wave antenna comprising a plurality of unit antennæ such as is disclosed in Fig. 2; another similar wave antenna, likewise comprising a plurality of unit antennæ, in such manner that the active antenna sections of each system occupy upon the pole line the spaces or intervals between the sections of the other wave antenna. This idea is shown in Fig. 4, wherein the solid lines represent the unit antennæ and the dotted lines represent a transmission circuit, connecting adjacent unit antennæ of the system. As will be seen from Fig. 4, the unit antennæ 1, 3 and 5 are sections of one of the basic wave antennæ, the sections being connected by the transmission lines 2′, 4′ and 6′. Similarly, the unit antennæ 2, 4 and 6 are sections of another basic wave antenna displaced longitudinally by the distance 1 with respect to the basic antenna of which sections 1, 3 and 5 are units. These unit antennæ are connected by the lines 3′ and 5′. Since there is no parallelism between any two unit antennæ, there will be no crosstalk between the component wave antennæ, and, consequently, the interference, which heretofore has prevented the placing of the conductors of separate antennæ upon the same pole line, has been eliminated. The use of separate, parallel conductors such as 2 and 2′, one for picking up the wave and the other for the transmission of currents between sections is, of course, undesirable from the cost standpoint. Also, such conductors might have an undesirable effect on the characteristics of the antenna unless they are made an integral part thereof. This parallelism may be avoided by making the conductors that serve as active antenna units for one of the basic antennæ serve also as the transmission circuit between units of the other basic antenna. Such an arrangement is shown in Fig. 5. It involves a pair of conductors upon a pole line, which pair is sectionalized but rendered continuous electrically through a plurality of transformers spaced apart at such distance as to provide preferably equal lengths of conductors between them. As shown in the figure, the pair of wires is divided into four sections, designated 1 to 4, inclusive. The number of sections may be varied, of course, without departing from the scope of the invention. One end of section 1 is connected to ground through an impedance 8 and the other end to ground through the primary winding of the transformer T_8; the secondary of this transformer is connected across the conductors constituting section 2. The midpoint of the secondary is connected to ground through the impedance 9. The primary winding of transformer T_9 is connected across the other end of the pair constituting section 2, and the midpoint of this winding is connected with one side of the primary winding of transformer T_{10}, the other side of which is grounded. The secondary winding of transformer T_9 has one end grounded and the other end connected with the midpoint of the secondary of T_{10}, which is bridged across the conductors of section 3. Transformers T_{11} and T_{12} are connected with sections 3 and 4 in the same manner as transformers T_9 and T_{10} are with sections 2 and 3. The primary winding of transformer T_{13} is connected across the other end of section 4 and the secondary of this winding is connected with the receiver R. The midpoint of the primary of transformer T_{13} is connected with one side of the primary winding of transformer T_{14}, the other side being grounded. The secondary of T_{14} is connected with the receiver R. As the wave representing the desired signal strikes the section 1 of the antenna system, it will cause current to flow over the two conductors in parallel to ground, through the primary winding of the transformer T_8 and through the impedance 8. This will induce a voltage across the secondary winding of T_8 which will cause the circulation of current over these two conductors in series. This current flowing through the primary of the transformer T_9 will induce a voltage across the secondary winding thereof which will cause the flow of current over a circuit which includes the two conductors of section 3 in parallel, to ground through the primary winding of transformer T_{12}. The flow of current through the primary of transformer T_{12} will induce a voltage across its secondary, which will cause the flow of current over the conductors in series and the primary of transformer T_{13}. This will in turn cause current to flow through the circuit connected with the secondary of this transformer, which circuit is connected with the receiver R. It will be seen that the current, generated by the electromagnetic wave upon the unit antenna 1, is conveyed over sections 2 and 4 metallically and over section 3 as a grounded circuit. While this current is being transmitted, as described, the wave will also travel over sections 2, 3 and 4 and produce an electromotive force in each. It is evident that the currents in each basic antenna which constitutes one-half of the system traverse alternately grounded and metallic circuits and it is obvious that this principle can be extended to any desired number of sections. While traveling along the grounded circuits, the currents receive increments from the electromotive forces due to the signal waves in space, but, while traveling along metallic circuits, they do not receive such increments. Thus, the current created in section 1, by the wave in space, travels over section 2 metallically, over section 3 as a grounded circuit, receiving an increment from the wave in space; thence over section 4 as a metallic circuit and through transformer T_{13} to the receiver R. The electromotive force created in section 2 by the wave causes a current which flows over section 3 as a metallic circuit; thence over section 4 as a grounded circuit, receiving therein an increment from the electromagnetic wave in space. This grounded circuit is connected through the transformer T_{14} with the receiver R.

In the arrangement shown in Fig. 5, the receiving station is at the end of the antenna remote from the end upon which the desired signal strikes the antenna in the course of its travel from the transmitting station. It is sometimes desirable to have the receiving station at the same end of the antenna which the wave first strikes in the course of its travel. It therefore becomes necessary to bring back to the receiving station the currents from the end of the antenna remote from the receiving station. An arrangement for doing this is set forth in Fig. 8.

In the figure, the receiver R is connected by the transformers T_{14} and T_{15} with two pairs of conductors broken into sections by transformers which are so connected as to provide metallic or grounded phantom circuits for the picking up of the signal and the propagation to the receiver R of the currents resulting therefrom. The transformer T_{14} connects the receiver with section 1 of one pair of conductors and transformer T_{15} similarly connects the receiver with section 1′ of the other pair. The midpoints of the windings of these transformers connected with sections 1 and 1′, respectively, are connected to ground through a suitable resistance 10. Sections 1 and 1′ are connected with sections 2 and 2′, respectively, by the transformers T_1 and T_4, respectively. The midpoints of the windings 11 and 12 of T_1 and T_4, respectively, are both connected with one of the terminals of winding 13 of transformer T_9, the other terminal of which is connected to ground. The midpoint of winding 14 of transformer T_1 is connected with one terminal of winding 15 of transformer T_9. Winding 16 of transformer T_4 is connected with the other terminal of winding 15, the midpoint of which is connected to ground through a suitable resistance 36. Sections 2 and 2′ are connected with sections 3 and 3′, respectively, by the transformers T_2 and T_5, respectively. The midpoint of winding 17 of T_2 is connected with one terminal of winding 18 of transformer T_{10} and in like manner the midpoint of winding 19 of T_5 is connected with the other terminal of winding 18. The midpoint of winding 18 is connected with one terminal of winding 20 of transformer T_{11}, the other terminal of which is grounded. One terminal of winding 21 of T_{10} is connected with the midpoint of winding 22 of T_{11}, and the other terminal of 21 is grounded. One terminal of 22 is connected with the midpoint of winding 23 of T_2, and the other terminal of 22 with the midpoint of winding

24 of T_5. Sections 3 and 3′ are connected with sections 4 and 4′ by the terminals T_3 and T_6, respectively. The midpoints of windings 25 and 26 of T_3 and T_6, respectively, are connected with 27 of T_{12}. In like manner, windings 28 and 29 of T_3 and T_6 are connected with windings 30 of T_{13}. The connections of the windings 37 and 35 of transformers T_{12} and T_{13} are similar to those of T_{10} and T_{11}. The distant end of section 4 is connected across the winding 31 of the reflection transformer T_7, the other winding 32 of which has one terminal connected with the midpoint of winding 33 of T_8, the other being connected with the midpoint of winding 31 of T_7 and has its midpoint connected with winding 34 of T_8, the latter transformer being intended to reflect the signal over the circuit 1′—4′ to the receiver R. In the arrangement shown in Fig. 8, both pairs in each section together function as an antenna unit for the creation of a voltage from the signaling wave, and each pair also serves as a grounded or metallic circuit to transmit currents not only toward the reflection transformer but also in the reverse direction to the receiver R.

Assuming that the desired signals come in the direction shown by the arrow, a voltage will be set up in the section 1—1′ in which the four conductors of the two pairs are connected in parallel to ground through the midpoints of the windings of transformer T_{14}, T_{15}, T_1 and T_4. This current in the course of its flow over the grounded circuit passes through winding 13 of transformer T_9. It thereby establishes a voltage across winding 15 which causes current to flow over a phantom circuit made up of the conductors of pairs 2 and 2′ and the windings 14, 16, 17 and 19. It will be seen that by the manner in which the voltage is applied to this phantom circuit, the current flows thereover metallically. The current flows in opposite directions through each half of each of the windings 14, 16, 17 and 19, so that no voltage will be established across the pairs of conductors of the adjacent sections. This current flows through winding 18 of transformer T_{10} and creates a voltage across winding 21, which winding has one of its terminals grounded, and the other connected to the midpoint of winding 22. This voltage causes current to flow over a grounded phantom circuit which includes windings 21, 22, 23, 24, 25, 26, 27 and 35. The flow of current through all windings except 35 is in such directions as to produce no effect upon the other windings of the transformers of which the said windings form a part. The flow of current through the winding 35 establishes a voltage across winding 30, which causes current to flow over a metallic phantom circuit which includes windings 28, 29, 31, 32 and 33. Windings 28, 29, 31 and 33 are differential under the condition just stated to windings 25, 26, 32 and 34. The flow of current through winding 32 establishes a voltage across winding 31, which is across the pair of conductors constituting section 4. This voltage will cause current to flow through winding 28 of T_3, which in turn will create a voltage across winding 25. This current, which is the reflected signaling current set up by the electromagnetic wave in the antenna-section 1—1′ and augmented by the effect of the electromagnetic wave upon the section 3—3′, will continue to travel through sections 3, 2, 1 of one of the pairs and will be impressed by the transformer T_{14} upon the receiver R. The electromagnetic wave will likewise create a voltage to ground across antenna-section 2—2′, the four wires of which are connected to ground through the windings 14, 16, 15 and the resistance 36, at one end of said section, and through windings 17, 19, 18 and 20 at the other end thereof. The flow of current through winding 20 will establish a voltage across winding 22 of transformer T_{11}, which will cause current to flow over conductors of section 3—3′ as a metallic phantom circuit. This current will flow through windings 23, 24, 25 and 26 differentially and also through winding 27. The flow through the latter creates a voltage to ground across winding 37, which causes a flow of current over the conductors of section 4—4′ as a grounded phantom circuit. This current will be augmented by the current set up therein by electromagnetic wave in space. These currents in section 4—4′ will flow through windings 30, 28, 29, 31, 32, 33 and 34. Since the flow of currents through windings 30, 28, 29, 31, 32 and 33 is in a differential manner that is, in opposite directions through halves of each winding there will be no effect upon the other windings of the same transformers with which the said windings are associated, and furthermore there will be no reflection of current from 32 upon the circuit with which 31 is connected. On the other hand, since the current flows through the coils of winding 34 in series, a voltage will be created across winding 33 which will cause current to flow over section 4′, which current will create a voltage across winding 26 of section 3′ and, in this manner, the signaling current created by the electromagnetic waves in section 2—2′ and 4—4′ will be reflected by transformer T_8 over the pair comprising sections 4′ to 1′ to the receiver R. These currents will be combined therein in the manner disclosed, for example, in the co-pending application of H. T. Friis, Serial No. 746,753, filed October 30, 1924. A modification is shown in Fig. 9 which is intended to simplify the transformer arrangement at the remote end of the system shown in Fig. 8. In Fig. 9, the currents resulting from the effect of the waves in sections 1—1′ and 3—3′ flow through the windings 25 and 26 differentially, through winding 27, also differentially, and then through winding 28′ to ground. Winding 28′, which serves the same purpose as winding 32 in Fig. 8, impresses across winding 25 the voltage which is created by the effect of the waves on sections 1—1′ and 3—3′, which voltage causes the transfer of the signal over sections 3, 2, 1 to the receiver R. The signaling currents resulting from the effect of the wave on section 2 flow over the conductors of section 3—3′, as a metallic phantom circuit; that is to say, they flow over the conductors of pair 3 in parallel to the midpoint of winding 25, thence through winding 27 to the midpoint of 26, thence over the conductors of pair 3′ in parallel. The flow of this current through winding 27 creates a voltage across winding 37′ of transformer T'_{12}. This causes the flow of current over section 4—4′ as a grounded phantom, which current is augmented by current created therein by the signal wave. The combined currents of sections 2—2′ and 4—4′ flow through winding 34 of transformer T_8, which creates a voltage across winding 33 which voltage starts the transfer of the signal over the sections 4′, 3′, etc. to the receiver R.

The directional characteristics of the antenna system, which has just been described from the physical standpoint, are clearly shown in Figs. 10 and 11 by curves having heavy solid lines. These directional curves show the reception ability of the antenna system over a range extending from zero to 180 degrees but it is to be understood that the curve is symmetrical throughout the remainder of the range to 360 degrees. In order to simplify the calculations upon which these curves have been based, the attenuation has been neglected and the velocity of propagation has been assumed to be that light on both metallic and grounded circuits. To make the calculations, consider an antenna system such, for example, as that illustrated in Fig. 4 which may be considered as comprising two basic antennæ, each made up of a plurality of sections. To obtain the characteristic curve for the antenna system, made up of two basic antennæ, the diagram of each half of the system, that is, of each basic antenna, may be calculated from the diagram of a simple wave antenna whose length is that one of the sections of the basic antenna and an array factor corresponding to the directional diagram of an array of vertical antennæ located, for example, at the ends of the sections constituting the unit antennæ of each basic antenna. The directional characteristic for the complete system may then be obtained from the directional characteristic of each half and from an array factor corresponding to the staggering and phasing of the two halves. This method of procedure will be clear by considering a specific instance such as that represented by Fig. 10, which shows the characteristic for an antenna system comprising two basic antennæ each having two unit antennæ, each unit or section-antenna being one-quarter wave length long, and the longitudinal spacing between any point upon one unit antenna and the corresponding point upon the succeeding antenna being one-half of a wave length.

Referring to Fig. 6, the linear phase difference between the ends A and B of the two active sections, for waves of incidence-angle θ, will be $x=a\cos\theta$; the angular phase difference will be $\phi'=2\pi\frac{a}{\lambda}\cos\theta$, where λ is the wave length of the signals. In addition we have a phase lag in the current from A when propagated to B which is $\phi''=2\pi\frac{a}{\lambda}$. So the angle at which the outputs combine is

$$\phi''-\phi'=\phi=2\pi\frac{a}{\lambda}(1-\cos\theta)\quad(1)$$

The resultant of two equal vectors I_1 combining at such an angle is

$$I_\theta=2I_1\cos\left[\frac{\pi a}{\lambda}(1-\cos\theta)\right]\quad(2)$$

Since for $\theta=0$, $I_\theta=2I_1$,

$$\frac{I_\theta}{I_0}=\cos\left[\frac{\pi a}{\lambda}(1-\cos\theta)\right]\quad(3)$$

and this is the equation of the desired array factor.

Upon applying this equation, first to the one-half wave-length staggering between active sections of each half of the system, and then to the one-quarter wave-length staggering between the two halves, we get the curves of Fig. 10. The resultant diagram for the whole system is obtained by multiplying together the directive curve for a single one-quarter wave-length antenna and the two array factors above mentioned. It is almost identical with the diagram of an ideal one wave-length antenna. This might be expected, as the currents from the individual sections are in this case combined in exactly the same relations as they would be in a continuous wave antenna of the conventional type.

An eight-section system would seem to be better than the four-section arrangement, since it would utilize a one-quarter wave-length staggering in each half of the system, thus giving a point of zero reception at 180 degrees; the phasing of the two halves could then be utilized to either reinforce this null point or to produce others, as desired.

One-half of such a system is shown in Fig. 7. To utilize existing information the directive diagram for each half can be obtained by multiplying together the following: Directive curve of one-eighth wave-length wave antenna, one-quarter wave-length staggered array factor, and one-half wave-length staggered array factor. Then a suitable one-eighth wave-length staggered array factor (due to the staggering between the two halves) may be applied to get the curve for the whole system.

The formulæ for the one-quarter and one-half wave-length staggered array factors have already been worked out (Equation 3). The formula for the one-eighth wave-length staggering with arbitrary null points may be derived as follows:

In the general case we have

$$\frac{I_\theta}{I}=2\cos\left[\frac{1}{2}\left(\phi-\frac{2\pi a\cos\theta}{\lambda}\right)\right] \quad (4)$$

where ϕ is the phase shift which may be introduced in combining signals from the two halves of the system in receiver R.

A null point will be produced at an angle θ' when

$$\phi=\frac{2\pi a\cos\theta'}{\lambda}+\pi \quad (5)$$

as can be seen by setting $I_\theta=0$ in Equation (4) and solving for ϕ. Substituting (5) in (4):

$$\frac{I_\theta}{I}=2\cos\left\{\frac{1}{2}\left[\pi+\frac{2\pi a}{\lambda}(\cos\theta'-\cos\theta)\right]\right\} \quad (6)$$

or

$$\frac{I_\theta}{I}=2\cos\left\{\frac{\pi}{2}\left[1-\frac{2a}{\lambda}(\cos\theta-\cos\theta')\right]\right\} \quad (7)$$

For $\theta=0$,

$$\frac{I_0}{I}=2\cos\left\{\frac{\pi}{2}\left[1-\frac{2a}{\lambda}(1-\cos\theta')\right]\right\} \quad (8)$$

Here I refers to the current from each antenna. We desire $\frac{I_\theta}{I_0}$, which is given by:

$$\frac{I_\theta}{I_0}=\frac{\cos\frac{\pi}{2}\left(1-\frac{2a}{\lambda}[\cos\theta-\cos\theta']\right)}{\cos\frac{\pi}{2}\left(1-\frac{2a}{\lambda}[1-\cos\theta']\right)} \quad (9)$$

This is the equation of the array factor of a staggered antenna system so adjusted as to be non-receptive to signals arriving from an angle θ'.

In Fig. 11, curve (1) shows the result of multiplying together the one-quarter and one-half wave-length staggered array factors. Curve (2) is that of the one-eighth wave-length unit wave antenna. The resultant directional curve for each half of the antenna system is plotted as curve (3). It is seen to have an "ear" in the neighborhood of 135 degrees which can well be suppressed by by the one-eighth wave-length staggering array factor utilizing phasing between the two halves of the system to give a null point at $\theta'=135$ degrees. We have calculated such an array factor using formula (9) above, in which we have set

$$a/\lambda=\frac{1}{8}, \theta'=135 \text{ degrees.}$$

The directive curve for the whole system is obtained by multiplying this array factor by the curve (3) for the half system, and is shown as curve (4). It is seen that the half-system curve is nearly as good as that of an ideal one wave-length wave antenna, and the curve for the whole system is quite good and compares favorably with curves for ordinary staggered systems.

Of course, it must be realized that the actual system, in which attenuation has to be taken into account, will not have a null point at 180 degrees. It may therefore be necessary to utilize the one-eighth wave-length staggering to produce a null at 180 degrees. This would leave the ear at 135 degrees to be taken care of by other means (such as broadsiding or further staggering).

It will be apparent that from the foregoing equations, it is possible to design a staggered antenna system having a directional characteristic which will give good reception from a desired direction and substantially no reception from the diametrically opposite direction and which will also have no reception at any predetermined angle θ' as may be desired to fit in with the conditions existing in specific cases.

While the staggered antenna systems shown in the drawing and described herein comprise only two basic antennæ, each of which may be made up of a plurality of sections, it is to be understood that the invention may comprise any number of such basic antennæ, all having the same number of sections, which number may vary through a wide range.

It will furthermore be apparent that while the invention has been described as embodied in certain specific forms, it is capable of embodiment in other and different forms without departing from the spirit and scope of the appended claims.

What is claimed is:

1. An antenna system comprising a plurality of antenna sections, and means to couple the adjacent sections, the said coupling means being arranged and connected with the said sections and to ground in such manner that each section interposed between other sections acts not only as a conducting circuit between the said other sections but also to intercept the electromagnetic waves in space.

2. An antenna system comprising a plurality of antenna sections each consisting of a pair of horizontal conductors, and means to couple the adjacent sections together, the said coupling means being so arranged and connected with said sections and to ground