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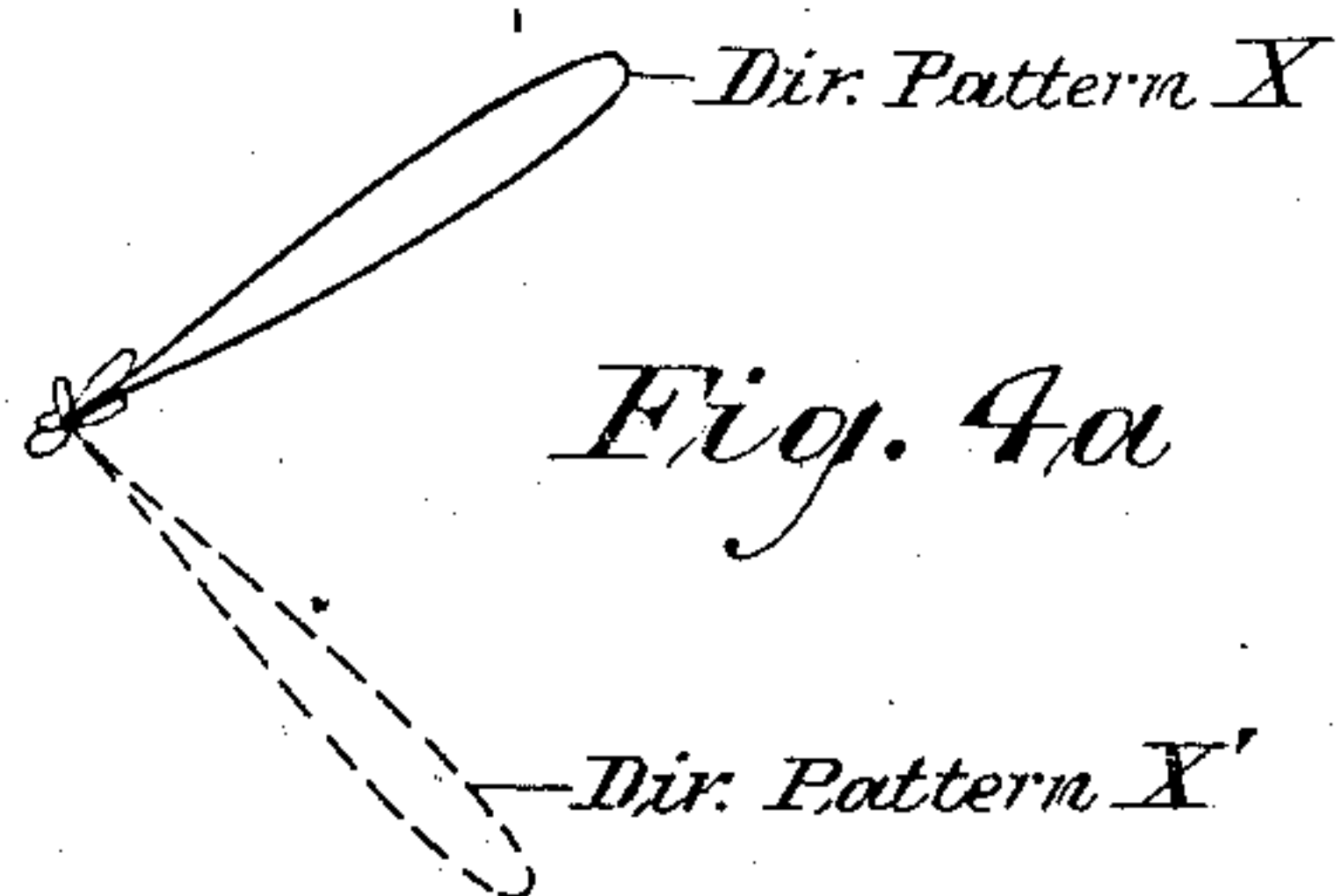
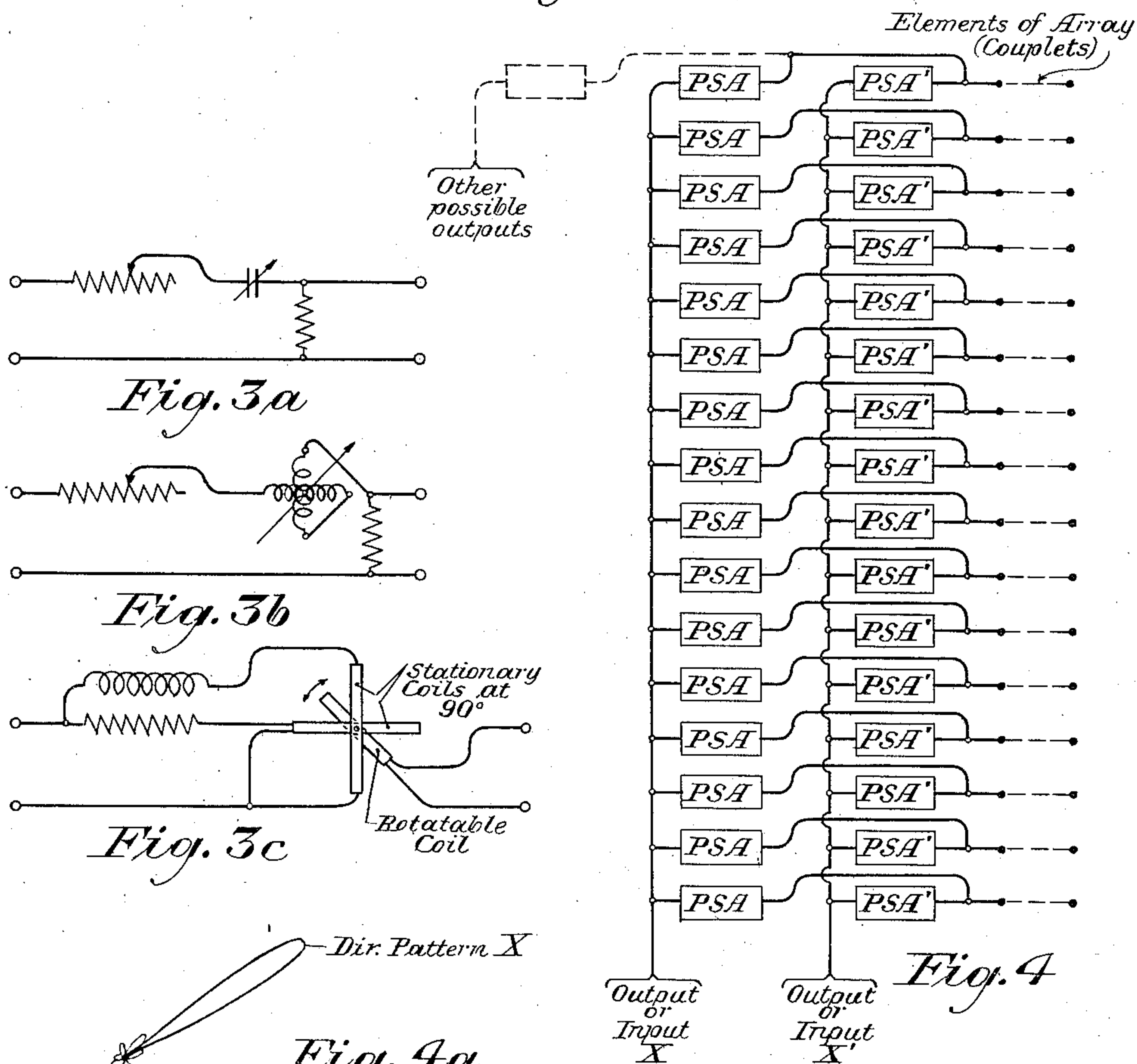
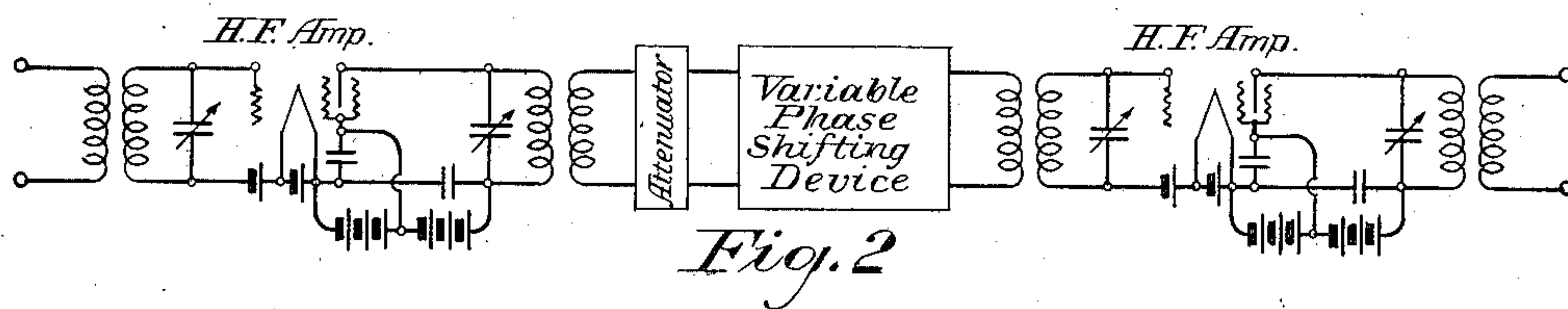
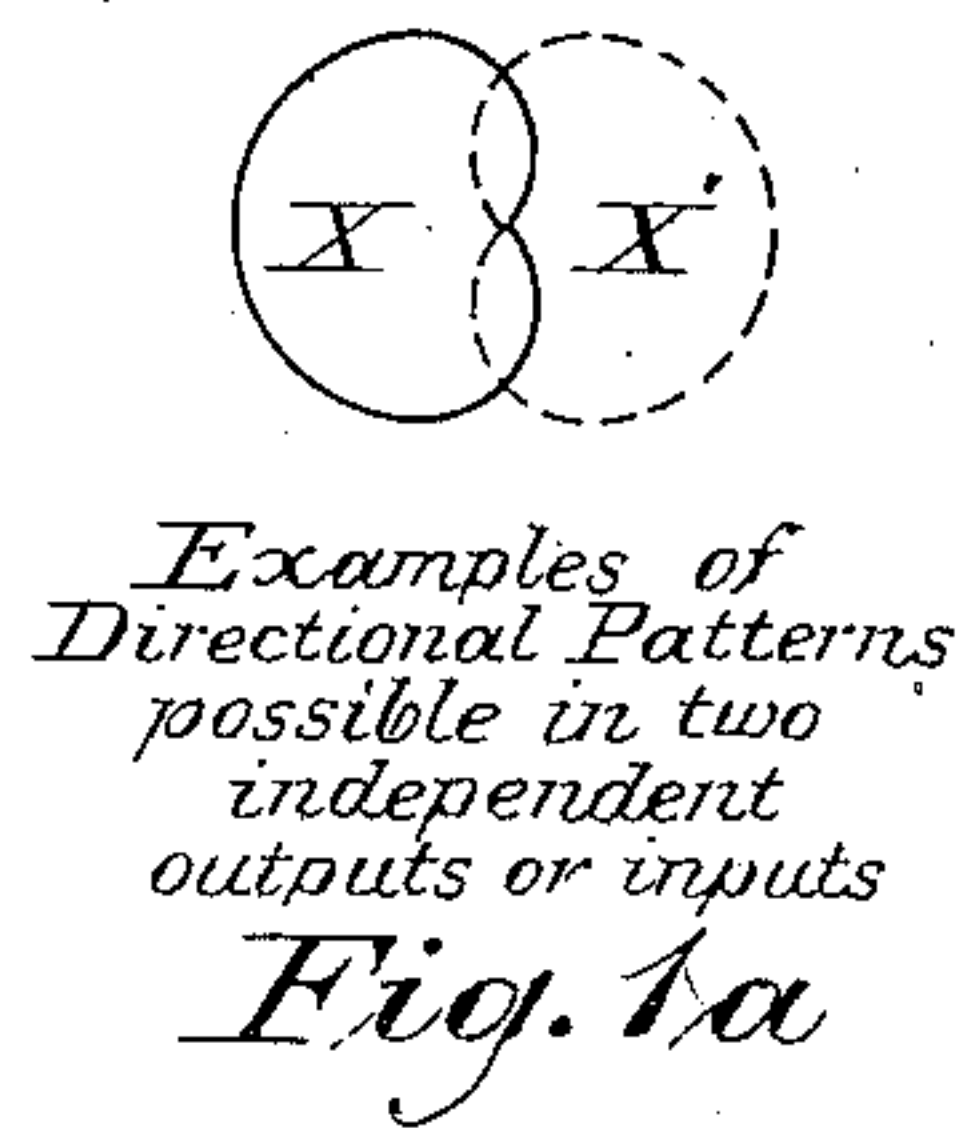
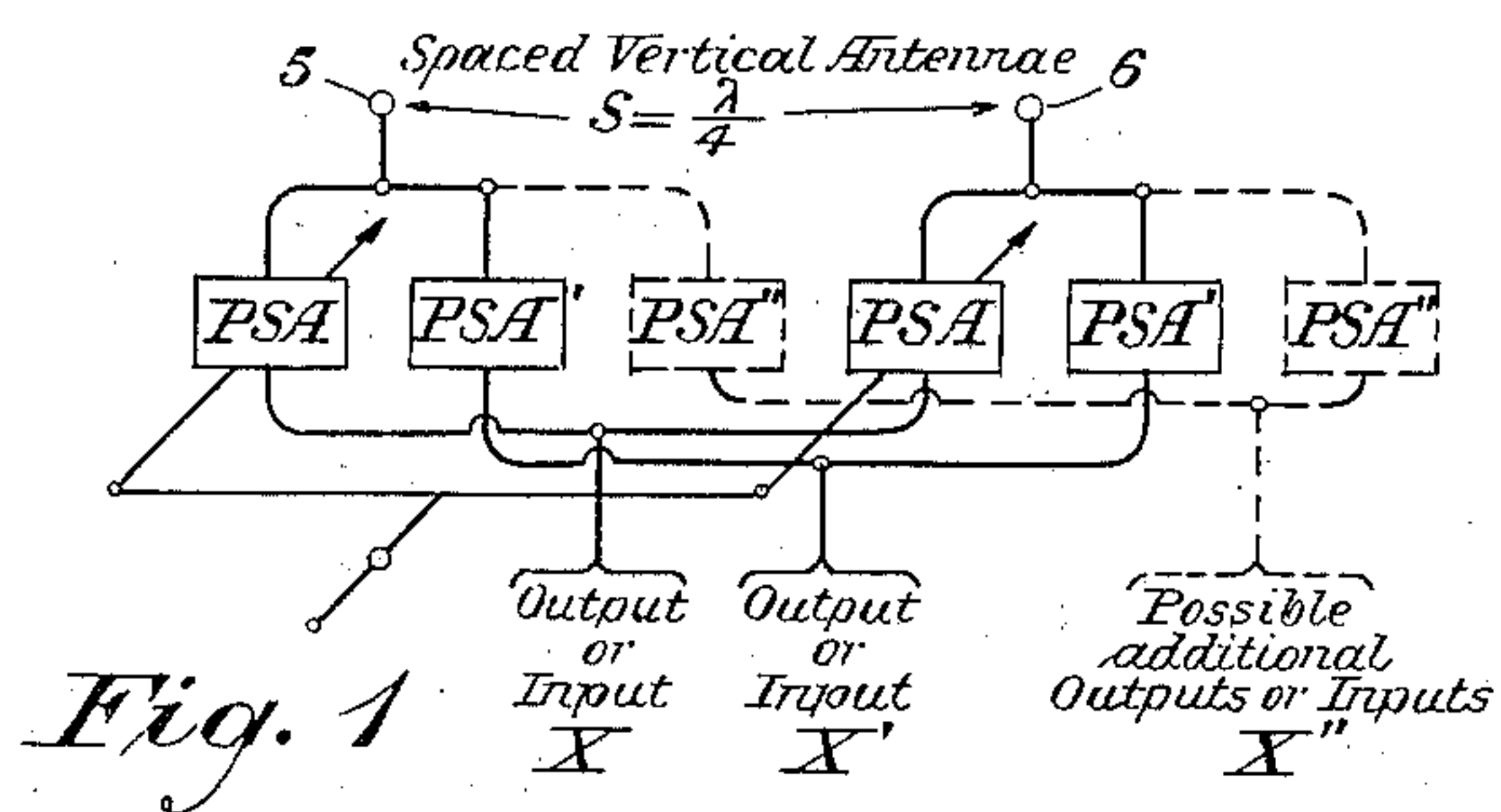
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2,030,181

DIRECTIONAL RADIO SIGNALING

Filed Oct. 6, 1933

2 Sheets-Sheet 1



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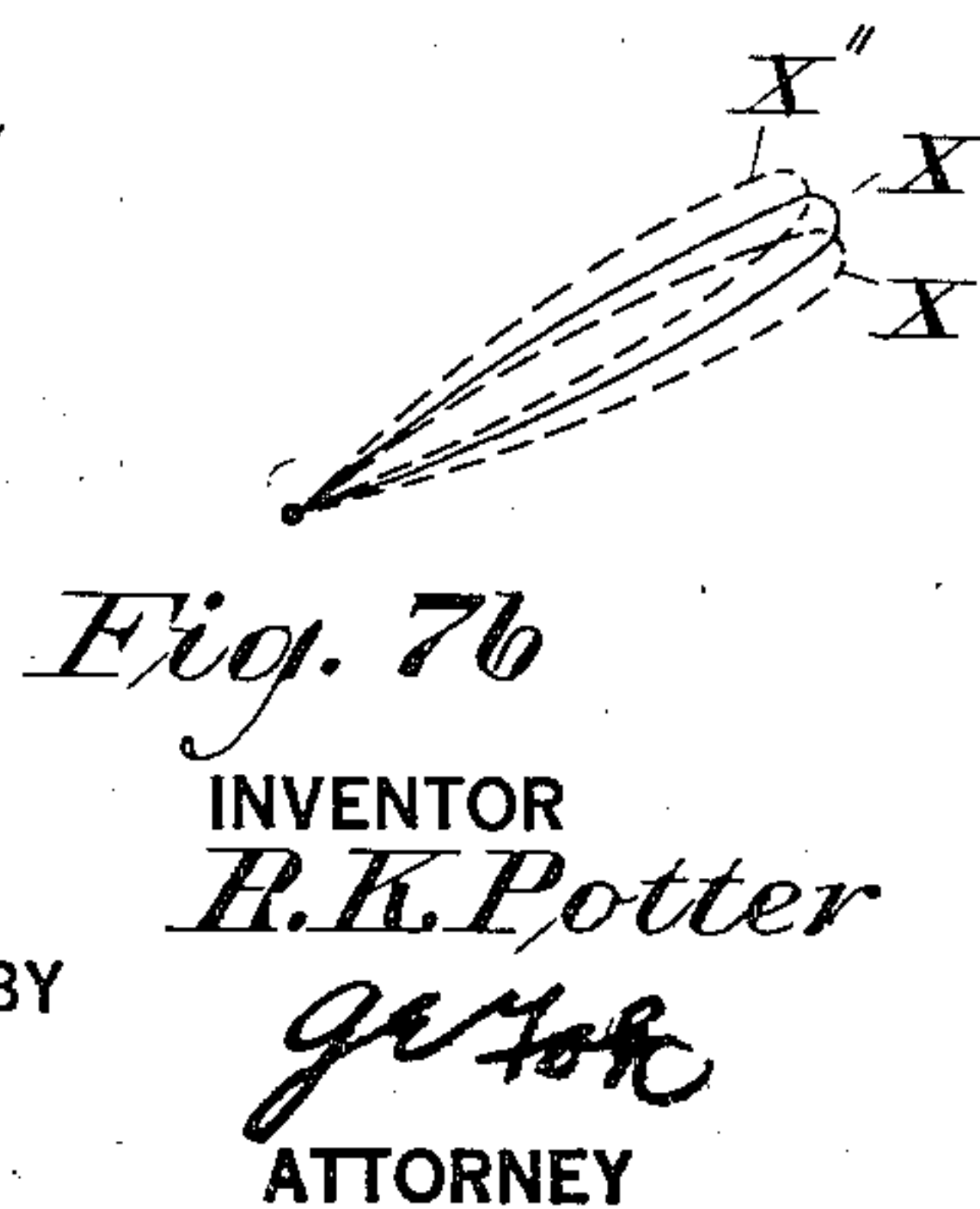
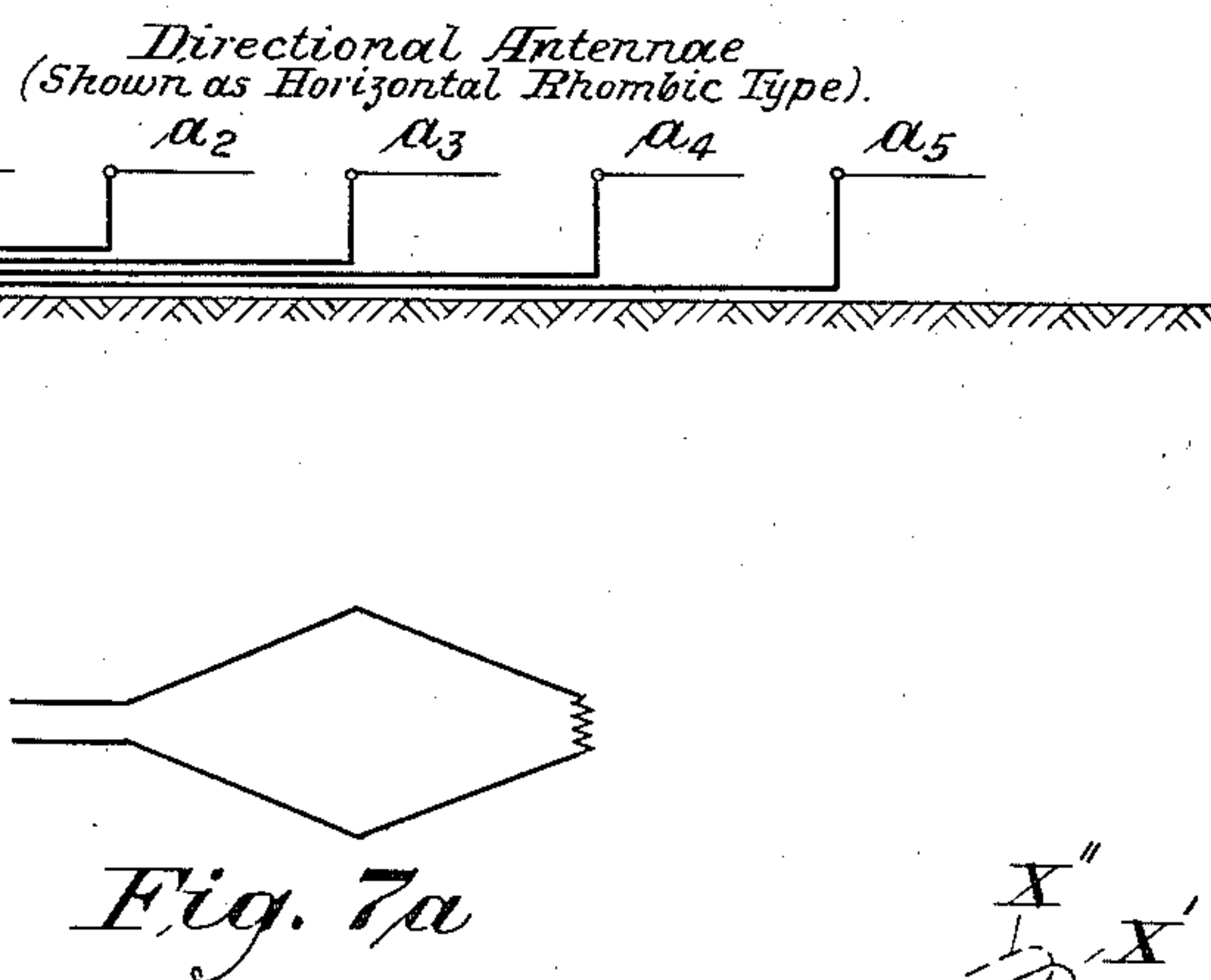
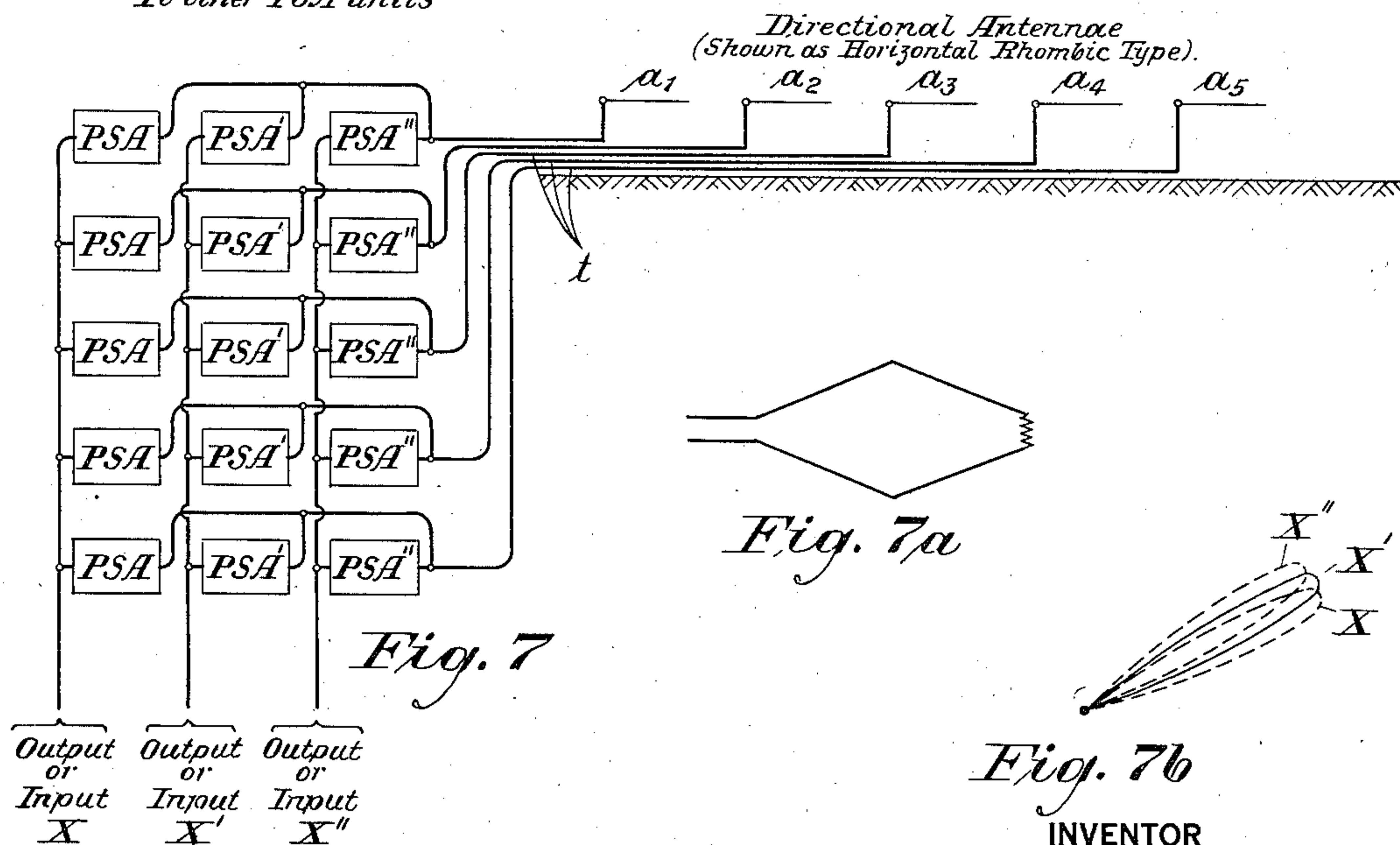
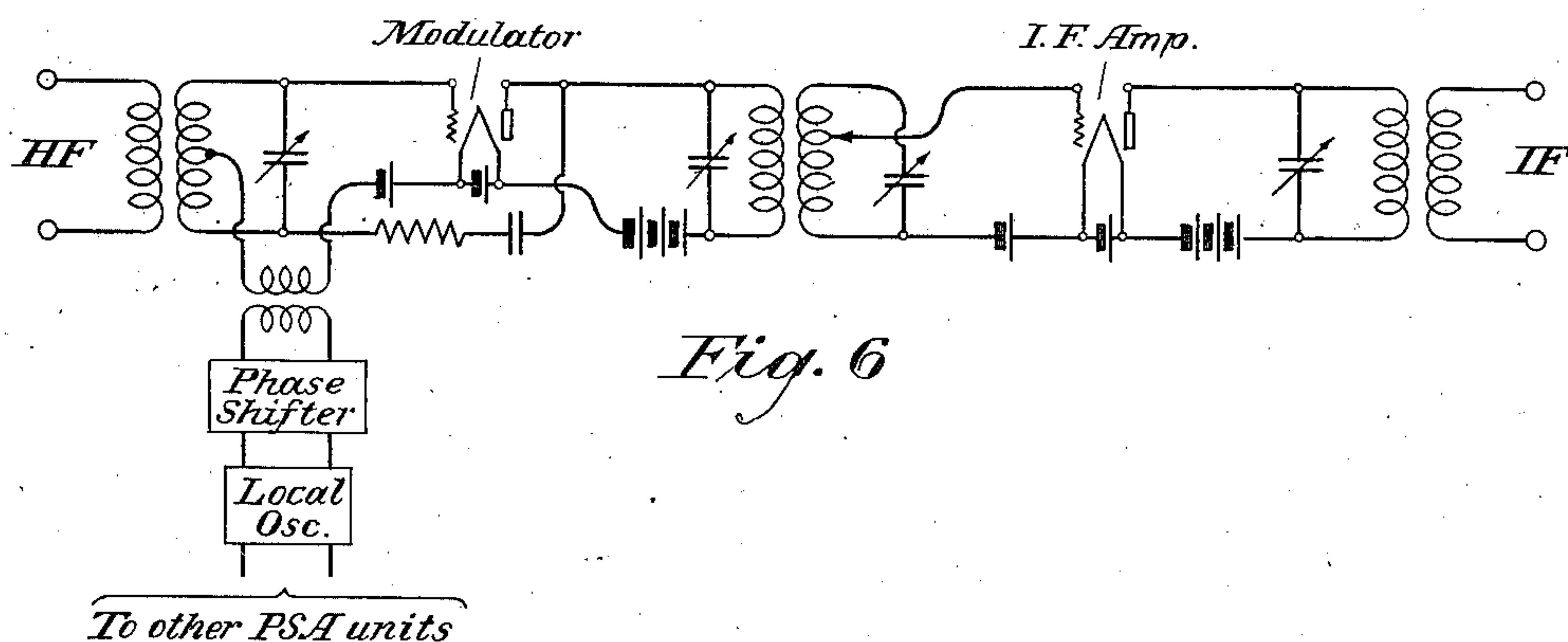
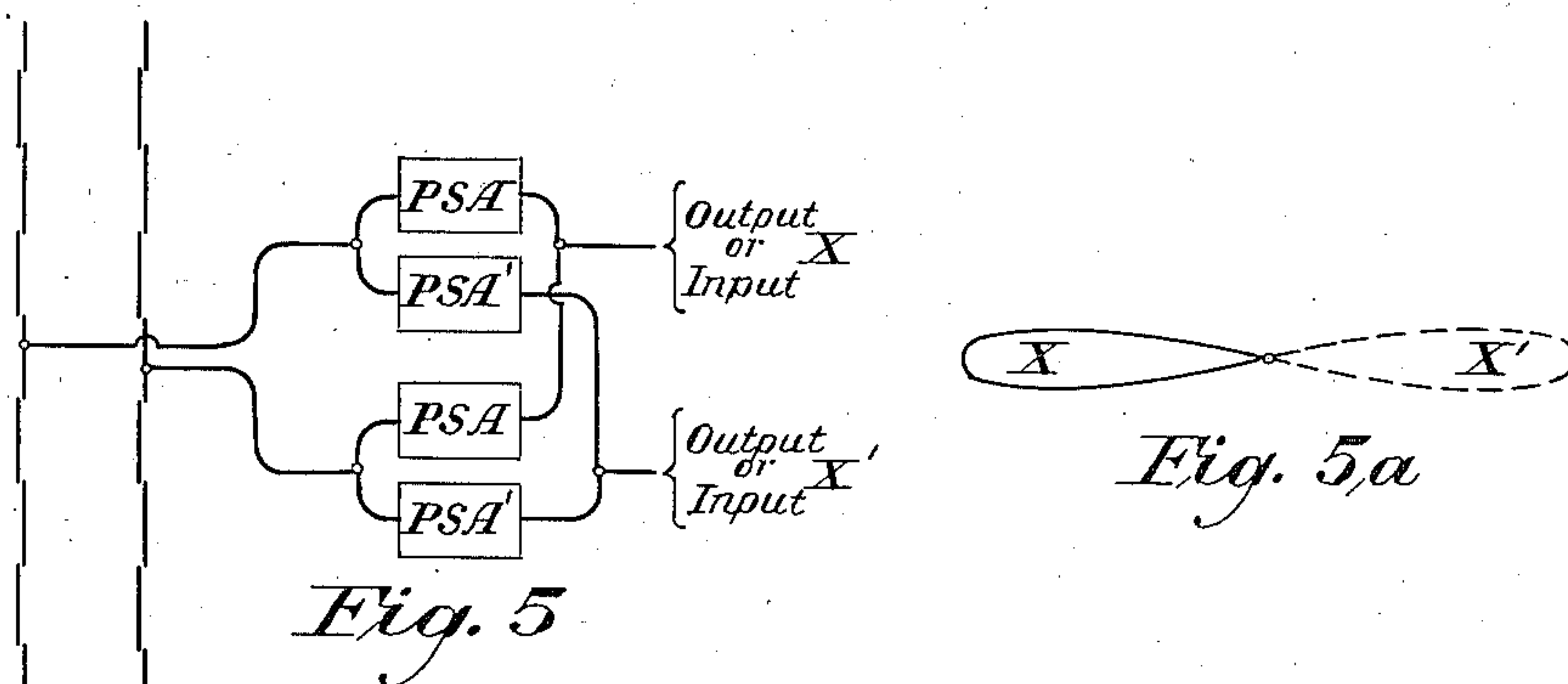
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DIRECTIONAL RADIO SIGNALING

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2 Sheets-Sheet 2



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## UNITED STATES PATENT OFFICE

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## DIRECTIONAL RADIO SIGNALING

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21 Claims. (Cl. 250—11)

This invention relates to directional radio signaling and, more particularly, to a system in which the direction of the reception or transmission of radio signals can be controlled by controlling the spacing of the elements of the antenna array and the phase and amplitude relationships of the currents in these elements.

The object of the invention is to arrange for reception or transmission of radio signals in several directions on the same antenna array. Another object is to permit simultaneous reception or transmission of radio signals under such circumstances. Still another object is to make changes in any one or more of the directions of signaling with ease and without altering the antenna array itself.

It is well known in the art that two or more antenna elements, such as vertical antennas, may be so spaced and so related in phase excitation as to give directivity to the combination either in reception or transmission and that the directional pattern can be shifted by varying the phase of one or more of the outputs. This feature of radio signaling is well set forth in an article by G. C. Southworth on Certain factors affecting the gain of directional arrays, in the Proceedings of the Institute of Radio Engineers, vol. 18, page 1503, September, 1930. With suitable spacing and relative phase adjustment, the combined antennas can be made to suppress signal reception from one direction and augment that from another. For example, with two vertical antennas properly spaced the horizontal wave pattern is in the form of a cardioid and if the phase of the signal from one of the pair is shifted 180 degrees before combination, the directive response of the combination is reversed.

My invention can be briefly explained by taking the case of two spaced non-directional antennas. The outputs from each antenna are led or branched through amplifiers and if the output of the branch or circuit from one antenna is combined through a phase shifter with the output of branch or circuit from the other antenna, the directional response of the combination can be varied. Simultaneously, the outputs of other branches or circuits from the same antennas brought together through a phase shifter may be combined in any desired phase to vary the directional response of the combination. Thus, a plurality of systems are provided each capable of independent reception or transmission and in each of which the directional response can be varied independently. As many other independent systems may be had from these same antennas

as there are branches from each element of the antennas or array of antennas. In accordance with the above, it is my purpose to obtain different directional response characteristics at the same frequency or at different frequencies. The method disclosed for bringing this about, while practical for signals of all wave lengths, is particularly suitable for comparatively short wave signaling for the reason that it is easier to construct relatively extensive antenna combinations that are especially directive both in the horizontal and in the vertical plane.

The invention will be better understood by reference to the following specification and the accompanying drawings in which Figure 1 shows a system of two or more vertical antennas equipped to carry out my invention, and Fig. 1a shows a typical directional pattern of two antennas such as is used in Fig. 1. Fig. 2 shows a phase shifting device and amplifier unit which is particularly useful and important in this invention. Figs. 3a, 3b, and 3c show types of phase shifting circuits. Fig. 4 shows the system of Fig. 1 extended to a more extensive array and Fig. 4a shows a possible corresponding directional pattern. Fig. 5 shows the invention as applied to a different type of antenna array and Fig. 5a is a possible corresponding directional pattern. Fig. 6 is a modified form of the phase shifter and amplifier unit of Fig. 2. Fig. 7 shows the application of my invention to directivity in the vertical plane with provision for a certain amount of "diversity"; Fig. 7a is a type of antenna element suitable therefor, and Fig. 7b is a possible corresponding directional pattern.

Referring more particularly to Fig. 1, there is shown an antenna element 5 and an antenna element 6, these being of any suitable type, such, for example, as the simple vertical antenna and these antennas are spaced preferably by a distance equal to one-quarter of the wave length in use. Each of these antennas has a branch going to an output or input circuit indicated by X, these branches including variable phase shifting and controllable amplifying units, as shown. Similar branches from each antenna pass through phase shifting and amplifying units to a second output or input circuit indicated by X'. It is evident that, by proper adjustment of the phase and amplitude relationship between the two components coming to the circuit X, a wide change may be made in the direction from or to which this pair of antenna elements, with their branch circuits going to X, are especially sensitive.

The phase shifting and amplifier units referred



to above may take on a large variety of forms and one which I have found is particularly useful is illustrated in Fig. 2 as consisting of a high frequency amplifier, a variable attenuator, a variable phase shifting device and a second high frequency amplifier. One purpose of the amplifiers is to isolate electrically the attenuator and the phase shifter from external circuits to which they may be connected, thus making the reactions from any changes in one of the phase shifting devices negligible so far as any or all other parts of the circuit are concerned. Reliance for this is placed chiefly on the unilateral or substantially unilateral characteristics of vacuum tube amplifiers. The attenuator of Fig. 2 permits an adjustment of the output amplitudes and the phase shifter permits an adjustment of the output phase. The attenuator may be of any of the familiar resistive devices and/or it may be simply a variable voltage applied to any of the elements of the amplifiers to change their gain. The phase shifting devices may also be of the familiar types of which some are shown under Figs. 3a, 3b, and 3c. Any other suitable form might be used. For purposes of brevity, units of the kind just described (or any of the many similar circuits that would accomplish a similar result) will be referred to hereinafter as a "phase shifter-amplifier" unit or simply as a "PSA" unit.

Referring again to Fig. 1, it is evident that when, according to this diagram, signals arrive from either the right or left it is possible by adjustment of one or another of the first set of PSA units to bring about phase equality between the two components for that particular direction and from the relationships set forth in the article by Southworth, referred to above, it will be equally evident that signals coming from the opposite direction will produce substantially no effect on the circuit X. Looked at from another point of view, it is evident that by suitable adjustment of the two PSA units, it is possible to make the two antenna elements combine for reception additively for any one direction desired or to combine additively for transmission for any one direction, the directional pattern in either case being of the form given by X of Fig. 1a.

At the same time, it will be evident that an additional branch from each antenna might be combined in a circuit X', the component elements having first passed through units PSA' and these PSA units may be adjusted to combine additively for any other desired direction independently of the adjustments for the circuit X. Thus, for this circuit X', the units might be adjusted so that the directional pattern would be that given by the dotted curve X' of Fig. 1a. Still additional branches might be taken off from each antenna element to a third independent circuit X'', through the units PSA'' in the manner described above.

Furthermore, it is evident that by changing the PSA units going to any of the circuits, it would be possible to change the preferred direction of that circuit at will. This may be accomplished by changing one of the PSA units or by changing both of those associated with one circuit. At times, it would be desirable to alter the two phase shifters together in such manner as indicated in Fig. 1.

While a single pair of antenna elements arranged as in Fig. 1 has a certain amount of directivity, this is very much increased if one uses a much larger array of elements or couplets as disclosed in Fig. 4. From each couplet in this array, there is a branch circuit going through a

unit indicated as PSA and all combining, after suitable adjustment of each individual unit, in the circuit X. Similarly, other branches passing through a group of units indicated as PSA' combine after appropriate setting of each phase shifter in the circuit X'. In both groups of units, such as those going to the circuit X and X', the settings of the units may be progressively larger as one moves in one direction until a total phase shift of 360 degrees is introduced, whereupon the settings of the units commence to repeat. By making the rate of this progressive phase shift different in the two cases the outputs will be caused to vary differently as the direction of reception is varied. Such an array as this of Fig. 4 has a very high order of directivity as is indicated by Fig. 4a which shows a possible directional pattern for the circuits X and X', respectively, and while these are shown as being in what may be called, approximately, the northeast and southeast directions, it is to be understood that each one of these directional patterns may be swung around to any direction within the limits of directivity of the couplets alone, the two outputs being entirely independent of each other. Also, as explained in connection with Fig. 1, other possible outputs may be obtained by an additional set of branches from the elements of the antenna array.

It will be seen from the description above for the system of Fig. 4 as well as other figures in the drawings that one may separate signals of the same wave-length coming from different directions. This separation involves a suitable distribution of the antenna elements and proper adjustment of the phase and amplitude relationships so that in one receiver set the components for the one signal are additive whereas the components for the other signal of the same wave-length will not, in general, be additive. Conversely, in the transmitting case with reversal of the PSA units signals of a certain frequency from one input may be transmitted in a different direction than signals of the same frequency from another input.

The methods herein described also apply to the directional effectiveness of the same unit antenna combinations for signals of different frequencies. When the wave-length difference is small the circuits will function as already described. When the wave-length difference is large the unit antennas should be aperiodic or thin conductors so arranged in space as to provide a suitable directional response for the different frequencies to be received or transmitted. Also the different PSA units combining to provide a particular output or input would be tuned to pass the signal associated with that output or input.

Fig. 5 shows the invention as applied to a different type of antenna, this being of a form sometimes spoken of as a curtain array one form of which is shown and described by Oswald in Bell System Technical Journal, April, 1930, page 270. Such an array may have a directional pattern as given in Fig. 5a, in which the output or input X' may receive or transmit east while that of X may be used to receive or transmit west. Within the resonant limits of the array, different frequencies may be used in connection with X or X' or the same frequencies may be employed in the two cases, if desired. Also, for the same reasons as pointed out above, there may be several other independent outputs than those shown.

There are several ways in which units that would accomplish the purpose of the circuit of



Fig. 2 can be constructed. Thus, instead of amplifying and shifting the phase at the high frequency as shown in Fig. 2, it may be preferable to use substantially the arrangement of Fig. 6 to modulate a high frequency incoming wave down to a constant intermediate value through the means of a local oscillator and then change the phase of this latter frequency. Also, as illustrated specifically in Fig. 6, the phase shift may be accomplished by varying the phase of the local oscillator input to the modulator rather than the phase of the high frequency or the phase of the intermediate frequency. One local oscillator would be associated with each group of PSA units combining to form a particular output circuit. The relative phase of the local oscillator inputs to the PSA units can be varied by any of the familiar schemes, such as those shown in 3a, 3b, and 3c.

Fig. 7 shows an application of the principle thus far described to vertical directivity. The elements of the array  $a_1, a_2, a_3$ , etc. may be of any type capable of providing, through their combination, different response in the vertical plane. In this figure we may for illustration, assume horizontal antennas of the rhombic type as shown in Fig. 7a. Thus  $a_1, a_2$ , etc. are intended to represent separate rhombic antennas of a form now well known in the art. In the receiving case, the separate antenna outputs are led over transmission lines,  $t$ , through three sets of PSA units shown in the figure as PSA, PSA' and PSA''. The outputs of these separate units may be adjusted in relative amplitudes and phase to provide such vertical directive diagrams as shown in Fig. 7b. The separate outputs of the array shown as X, X', and X'' may be treated as if they were from separate antennas and in this receiving case may be used to provide "directional diversity" by hand or automatical switching or by blending from one output to the other as the direction of the sky wave alters with changes in the conditions of the upper atmosphere.

In the above description, mention has been made of the fact that this method of control of directivity applies to both transmission and reception. It will be understood, however, that there is one difference, namely, that the PSA units must be differently arranged in the two cases. In certain situations, the same array of antenna elements might be used for both transmitting and receiving. In this event, it would, of course, be desirable to have a sufficient separation of the frequencies used in transmission and reception, although such wide separation is not necessary if the antenna is alternately used for the one and the other. Such alternative use could, of course, be arranged for by suitable switching mechanism as voice-operated relays, all in a manner which will now be understood in the art.

It is to be understood that this invention applies to any type of directive antenna array, either of the one, the two or the three dimensional type. Thus combinations of vertical and horizontal directivity may be obtained by the use of suitably spaced elements comprising the array, each element or group of elements being associated with a PSA unit, and these PSA units may be connected mechanically or otherwise, as pointed out for Fig. 1 so that they may be readily shifted in groups or as a whole by appropriately related amounts to give a desired change in directivity.

Having now described this invention, what is claimed is:

1. A radio signal receiving system consisting of

an array of more than two antenna elements and a plurality of receiving devices responsive to radio signals, separate means for unilaterally connecting each of said antenna elements to each of said receiving devices.

2. A radio signal transmitting system consisting of an array of more than two antenna elements and a plurality of signal generating devices, separate means for unilaterally connecting each of said antenna elements to each of said generating devices whereby each generator transmits directly in a specified direction.

3. A radio signal receiving system consisting of an array of more than two antenna elements and a plurality of receiving devices responsive to radio signals, independent and adjustable means for combining a portion of the output power from each array element at the input to each receiving device, said independent and adjustable means consisting of a transmission line, signal amplifier, an adjustable phase shifting device, and an adjustable attenuator.

4. In a radio signal receiving system consisting of an array of antenna elements and a plurality of receiving devices responsive to radio signals, branch paths for diverting a part of the output of the plurality of array elements to the input of each receiving device, means for combining the outputs of branch paths from the array elements at the input to each receiving device, and means for independently adjusting the phase and amplitude of each branch path before combination at the input to the receiving device.

5. In a directional radio signaling system, an antenna array, a plurality of terminal sets, a branch from each element of the array to each terminal set, and a phase controlling element in each branch whereby the selected direction of each terminal set is controlled independently.

6. In a directional radio signaling system, an antenna array, a plurality of terminal sets, a branch from each element of the array to each terminal set, and a unilateral phase shifting and amplitude control device in each branch whereby the selected direction of each terminal set is controlled independently.

7. In a signaling system with two output circuits, means for adjusting the currents in these circuits independently of each other, said means comprising a separate unilateral device in series with each output circuit, each such device being connected in multiple with at least one other such device both on its input side and on its output side, each device consisting of two unilateral conductors connected in tandem and an adjustable phase shifting device and an attenuating device connected between the two tandem conductors.

8. In a signaling system with two output circuits connected in parallel at their inputs and likewise at their outputs, means for adjusting the currents in these circuits independently of each other, said means comprising a separate unilateral device in series with each output circuit, the device consisting of two unilateral conductors connected in tandem and an adjustable phase shifting device and an attenuating device connected between the two tandem conductors.

9. In a signaling system with a plurality of output circuits and a plurality of input circuits, connections from each output circuit to each input circuit of such nature that there is no reaction from one output circuit upon the others, said connections being in parallel on their input ends and also on their output ends, and each such connection comprising two unilateral amplifiers



connected in tandem and an adjustable phase shifting device and an attenuating device connected between the two tandem amplifiers.

10. In a signaling system with a plurality of  
5 output circuits and a plurality of input circuits, connections from each output circuit to each input circuit of such nature that there is no re-  
10 action from one input circuit upon another or from one output circuit upon another, said connections being in parallel on their input ends and also on their output ends, and each such connection comprising two unilateral amplifiers connected in tandem and an adjustable phase shifting device and an attenuating device connected  
15 between the two tandem amplifiers.

11. In a directive radio signaling system comprising an array of antenna elements and a plurality of terminal sets and connections there-  
20 between, the method of directive signaling along a plurality of directions which consists in transmitting one way between each terminal set and each antenna unit and introducing independent phase and amplitude adjustment in each connection between an antenna unit and a terminal set  
25 whereby the system is effective for independent directive signaling.

12. In a directive radio signaling system comprising an array of antenna elements and a plurality of terminal sets and connections there-  
30 between, the method of simultaneously and directionally signaling along a plurality of directions which consists in unilaterally transmitting signals one way between each terminal set and each antenna unit and introducing phase and ampli-  
35 tude adjustment in each connection with the terminal sets whereby the system is effective for independent directive signaling.

13. In a directive radio signaling system comprising an array of antenna elements and a plurality of receiving sets, the method of simultaneous and directive reception along a plurality of directions which consists in unilaterally receiving signals on each receiving set from each antenna element and introducing phase and amplitude adjustment in each connection to the  
45 receiving sets whereby each such set is effective for independent and adjustable reception from a desired direction.

14. In a directive radio signaling system comprising an array of antenna elements and a plurality of transmitting sets and connections there-  
50 between, the method of simultaneous and directive transmission along a plurality of directions which consists in unilaterally transmitting signals to each antenna element from a plurality of transmitting sets and introducing phase and amplitude adjustment in each connection from the transmitting sets whereby each transmitting set is effective for independent directive transmission in a specified direction.  
60

15. In a directive radio signaling system comprising an array of antenna elements and two receiving sets and connections therebetween, the method of simultaneous and directive reception  
65 of two signals of different wave length and from the same direction which consists in unilaterally receiving signals on each receiving set from each antenna element and introducing a phase shift and amplitude change in each connection to the receiving sets of such magnitude that the component signals of one wave add in one receiver and the components of the other wave neutralize each other in that receiver.  
70

16. In a directive radio signaling system comprising an array of antenna elements and two receiving sets and connections therebetween, the method of simultaneous and directive reception of two signals of different wave lengths which  
5 consists in unilaterally receiving signals on each receiving set from each antenna element and introducing phase and amplitude adjustment in each connection to the receiving sets of such magnitude that the component signals of one wave  
10 length add in one receiver and the components of the other wave length neutralize each other.

17. In a directive radio signaling system comprising an array of antenna elements and two receiving sets and connections therebetween, the  
15 method of simultaneous and directive reception of signals of the same wave length and from different directions which consists in unilaterally receiving signals on each receiving set from each element and introducing phase and amplitude  
20 adjustment in each connection to the receiving sets of such magnitude that the component signals from one direction add in one receiver and the components from the other direction neutralize each other.  
25

18. A radio signal receiving system comprising an antenna array, a plurality of distinct receiving circuits, energy transmitting connections from each antenna of the array to each receiving circuit and an adjustable phase shifter in each  
30 such connection so that there are as many such phase shifters as the number of antenna elements multiplied by the number of distinct receiving circuits whereby the phase shifters for the connections to one receiving circuit can be adjusted  
35 to make the array directionally selective in one direction and the phase shifters in the connections for another such circuit can be adjusted to make the array selective in another direction.

19. A radio signaling system comprising an  
40 array of antenna elements, a plurality of energy translating devices, energy transmitting connections between each antenna element and each such device, and respective phase shifters in these connections so that the number of phase shifters  
45 is equal to the number of antenna elements multiplied by the number of such devices, said phase shifters being adjustable, whereby the antenna array in relation to one such device can be made selective in one direction and the same antenna  
50 array in relation to another such device can be made selective in another direction.

20. The method of operating simultaneously in different directions in different translating devices associated with one and the same antenna  
55 array which consists in introducing the appropriate phase relations for one direction between each antenna element and a particular device, and likewise introducing the appropriate phase relations for respective directions for each other  
60 device.

21. The method of operating an antenna array selectively in several different directions at the same time which consists in introducing appropriate phase adjustments for one direction between all the antenna elements and a respective translating device, and similarly introducing different but appropriate phase adjustments for other directions in relation to other translating  
70 devices.

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