

March 17, 1942.

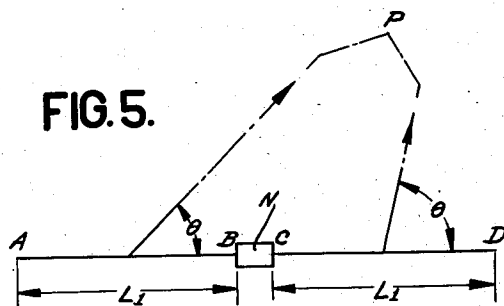
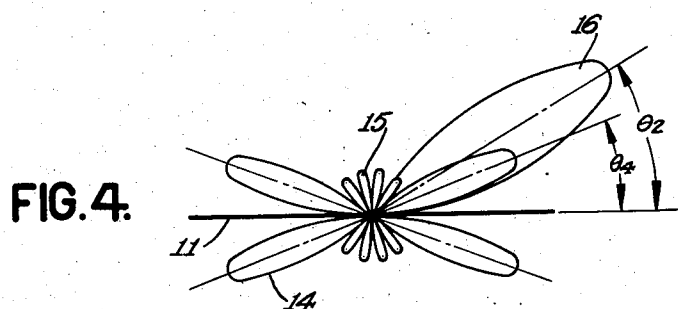
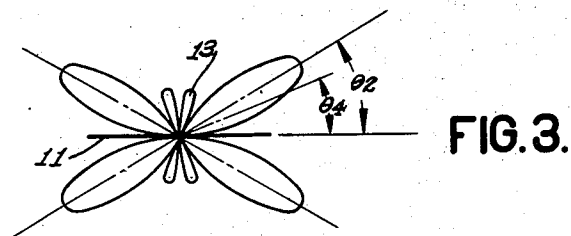
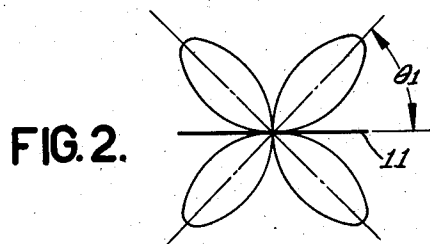
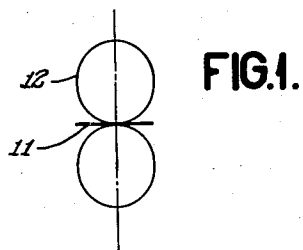
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2,276,910

PHASE SHIFTING NETWORK

Filed Aug. 3, 1939

3 Sheets-Sheet 1



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FIG. 6.

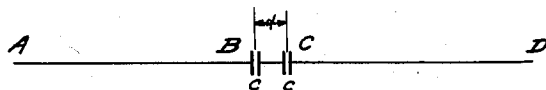


FIG. 7.

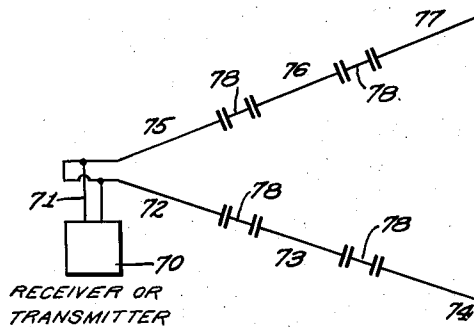


FIG. 9.

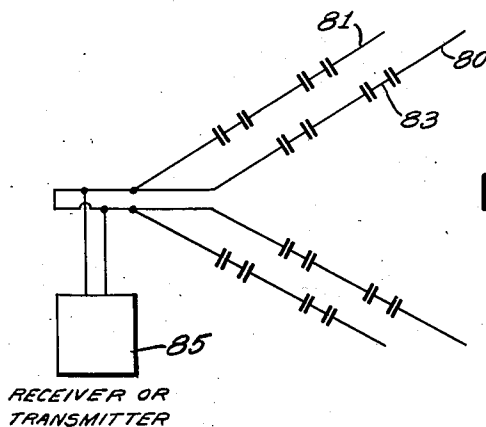
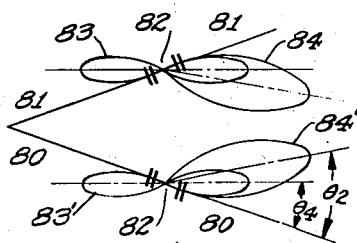


FIG. 8.



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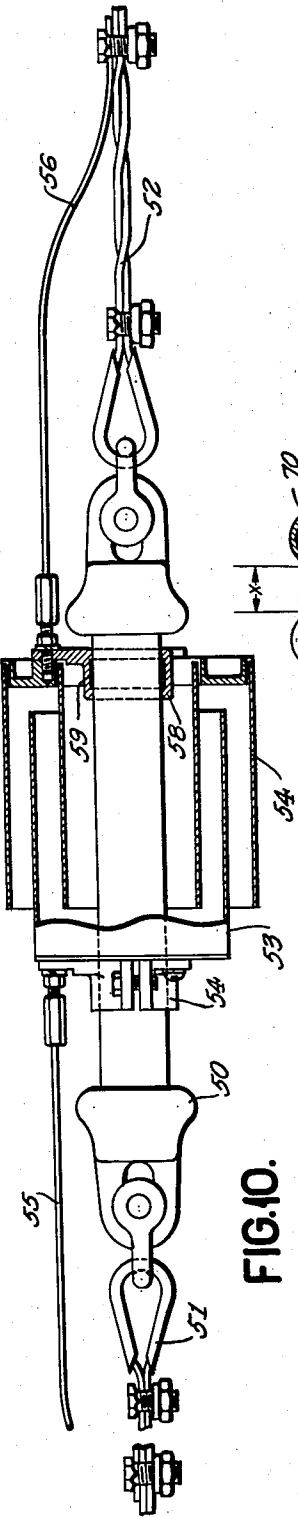


FIG. 10.

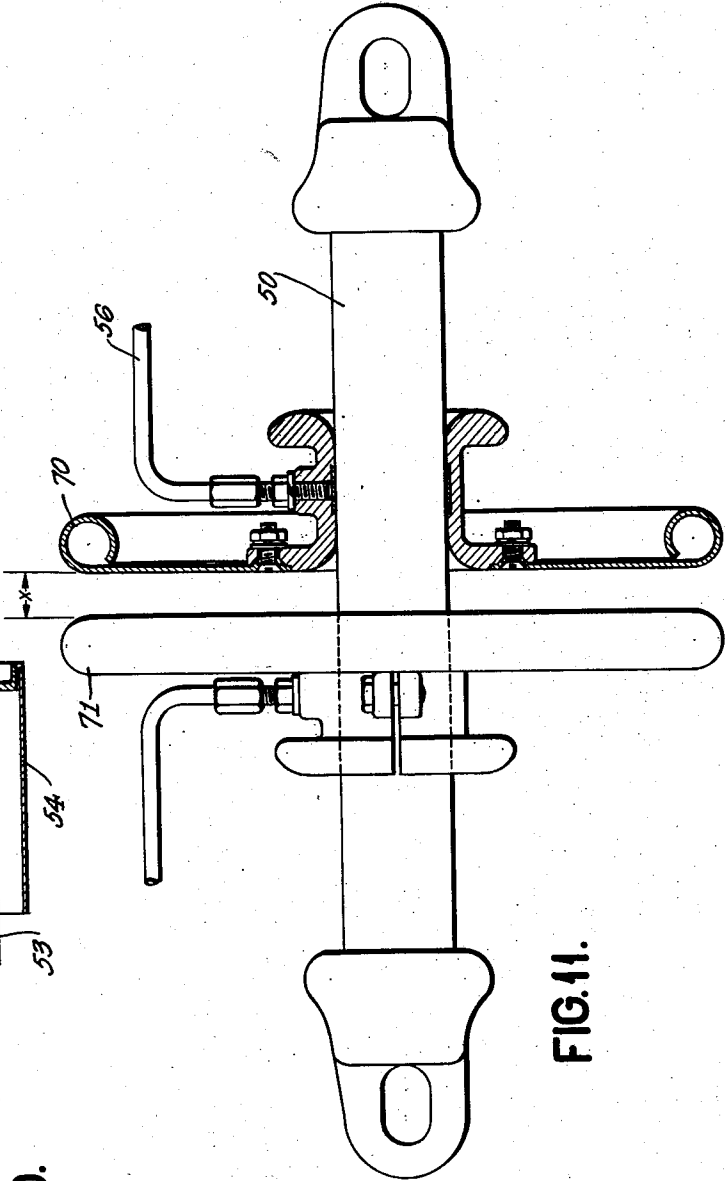


FIG. 11.

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UNITED STATES PATENT OFFICE

2,276,910

PHASE SHIFTING NETWORK

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Application August 3, 1939, Serial No. 288,132

8 Claims. (Cl. 250—33)

My invention relates to antenna systems and more particularly to antenna systems comprising a plurality of separate linear radiant acting portions coupled together by a phase advancing means.

In radiating and receiving antennae particularly of the directive type commonly known as V-antennae, operating with standing waves it has been recognized that improved radiant acting qualities may be obtained by dividing the radiant acting conductor into several sections interconnected with phase shifters so that the various sections of the antenna will produce a resultant radiation pattern in the desired direction, which is stronger than if only a conductor without such phase shifters were used. In these systems the phase shifting is generally accomplished by means of a length of folded transmission line coupled to the ends of the sections so as to cause the desired phasing at a particular frequency. Generally this type of phase shifter has been used since a loop of this nature will not produce a large discontinuity which will cause disturbing reflections in the line. Phase shifters of this type, however, must ordinarily be quite long since usually a small phase correction is required and consequently the phase delay must be equal to nearly a 360° phase retardation to obtain the equivalent phase displacement.

Furthermore, although these folded transmission lines are arranged to minimize the radiation therefrom, still there is an appreciable radiation from these phase shifters which will adversely effect the radiation pattern of the antenna as a whole.

A simple condenser, which produces a phase advance, is not suitable because it will produce a large discontinuity and a consequent large reflection resulting in greater distortion.

In accordance with my invention antennae of the same general nature as those discussed above may be constructed, but in place of a loop for retarding the phase of the energy to produce the desired phase shift, a phase advancing network is utilized. This network in general comprises two condensers arranged in the antenna and spaced such a distance apart as to produce a conjugate relationship, that is, so as to produce substantially no harmful reflection of energy in the line. The expression conjugate relationship as used herein refers to a network arrangement wherein two impedances if properly designed as to value are spaced a particular distance apart on a transmission line, they will produce no effect on the wave distribution in the line at a particu-

lar frequency. The particular dimensions for such networks may be more precisely determined by reference to my U. S. Patent 2,147,807 issued Feb. 21, 1939. This type of phase shifter may be utilized in an antenna arrangement wherein a phase shift between the radiant acting conductors connected together, if desired, regardless of the particular form of antenna to which it is applied. The invention is particularly useful in conjunction with the directive antennae of the type known as V-antennae.

According to another feature of my invention, any phase advancing units of the type utilizing conjugate condenser arrangements may be applied to existing antennae structure whereby an improvement of the radiation characteristics may be obtained without the necessity of other change in the existing structure.

In accordance with another feature of my invention, I provide antenna condenser arrangements on strain insulators, these condenser units being relatively light for use with suspended antenna structures.

While I have described above a few of the objects of my invention, a more complete understanding thereof, as well as other objects and advantages of my invention will be obtained from the specific description of preferred embodiments of my invention given in connection with the accompanying drawings, in which

Figs. 1 to 4, inclusive, are diagrams illustrating certain principles of my invention,

Figs. 5 and 6 are diagrammatic illustrations of radiant action conductors illustrating such principles of my invention,

Fig. 7 is a diagram of an antenna constructed in accordance with the principles of my invention,

Fig. 8 is a diagram illustrating another feature of my invention,

Fig. 9 illustrates another embodiment of my invention utilizing two antennae elements, and

Figs. 10 and 11 illustrate particular forms of condenser arrangements in accordance with my invention.

In Fig. 1 a short length of conductor 11 is shown having a radiation pattern 12. Such a short length of conductor 11 may be considered as a unit radiator and the maximum radiation is at right angles to the conductor. This condition obtains so long as the length L is maintained electrically very short, for example, less than a half-wavelength long. If we take any conductor of length L, each individual element of the conductor is energized in a fixed position,

that is, in certain relative phase with respect to the other element so that the resultant radiation is that of an array of such elements, each differently phased. For example, if conductor 11 is made equal to λ , where λ is the wavelength of the energy, then the radiation pattern will be in the form of lobes, as illustrated in Fig. 2, that is the radiation will be in the form of a hollow cone of revolution around the conductor 11 as an axis. The angle of maximum radiation will no longer be 90° as in the case of Fig. 1, but will be at different angle, θ_1 .

If, then, the conductor is further extended and is made two wavelengths long, a radiation pattern such as shown in Fig. 3 will occur. This radiation pattern has a maximum lobe at an angle of θ_2 to the conductor 11, and two minor lobes 13, as shown. However, if the conductor is made four wavelengths long, as shown in Fig. 4, then the radiation pattern has a still different shape, the maximum lobe 14 being at an angle θ_4 to conductor 11, which angle is considerably lower than the angle for the two wavelength conductors. Simultaneously, additional minor lobes are produced, as shown at 15. In each of these various patterns, the major lobe of radiation is larger for the longer length wire, but the increase variant is not proportional to the increase of length of wire because of the improper phasing of energy in the individual units. Thus, if the four wavelength sections were divided in the middle and a phase change sufficient to correct for the phase shift were supplied so that the individual 2λ unit would add together at the angle θ_2 , a larger radiation lobe 16 would be produced thereby.

Furthermore, it is clear that the two wavelength elements constituting the conductor 11 of Fig. 4 are not in phase in the direction θ_4 . In fact, if they were in phase at this angle, then for a larger value of θ , such as shown in Fig. 3, the elements would produce a stronger field, not only in the direction of θ_2 but in the direction of θ_4 . Accordingly, if the phasing were corrected so as to properly phase the elementary section, the radiation at angle θ_4 would be considerably increased because the phasing in that direction would be improved since the cosine of one-half of the phase difference varies slowly when this phase difference itself is near to zero. It is, therefore, clear that two elements may be used to produce more radiation not only in the angle θ_2 but even in the direction θ_4 by means of suitable phasing.

In the drawings, Figs. 2 to 4, the angles θ_1 , θ_2 , θ_4 , have not been shown in their actual relationship, but are shown with arbitrarily selected angles for the purpose of illustration. The correct angle of radiation with respect to the length of the conductor is different for every different conductor length. This is explained in "A discussion of methods employed in calculations of electromagnetic fields of radiating conductors," by Andrew Alford, pages 70 to 88 of "Electrical Communications" for July 1936, published by International Standard Electric Corporation.

The nature of the problem itself concerning the phasing of antenna units, may be better understood by reference to Fig. 5. In this figure are shown two co-linear wires AB and CD, arranged in a straight line. Wire AB is energized at A, and radiates primarily in a direction towards a point P at a great distance. If the length of the radiator AB is L_1 and the angle between the direction of radiation and of the

wire is θ , then the radiation starting from C has a shorter path to point P than the radiation starting from a corresponding point A on the other radiator. This difference in path is equal to $L_1 \cos \theta$.

On the other hand, if there were no phase advance between B and C, the energy arriving at C would be behind the energy at A in phase by the length of a path L_1 . Thus, the energy arriving from the second radiator C would be delayed in effect by L_1 and advanced by $L_1 \cos \theta$. Since $L_1 \cos \theta$ is always less than L_1 , the total natural effect is always a delay equal to

$$L_1 - L_1 \cos \theta = L_1(1 - \cos \theta) = \frac{360}{\lambda} L_1(1 - \cos \theta) \text{ degrees}$$

This difference will generally be considerably less than 180° and therefore a phase advance rather than a phase delay is desirable. The use of a phase delay arrangement has the objection that it causes a relatively large phase delay thus limiting the frequency range of the antenna. Furthermore, a loop radiates some energy which is difficult to neutralize because it travels in substantially all directions.

Furthermore, the loop phase changers cannot really be made reflectionless.

In accordance with my invention, difficulties arising from use of previously known arrangement is avoided. Referring to Fig. 6, two conductor sections AB, CD, are shown having between them a network comprising two condensers c, c, and a length of conductor α . Each of the condensers c, will produce a phase advance so that the total phase advance of the networks will be twice that caused by either condenser alone. By properly spacing these condensers a conjugate relationship may be established. A more complete description of conjugate arrangement of networks and the theory thereof, may be found in my United States patent "Transmission Lines" No. 2,147,807, issued February 21, 1939. It is also clear that each of the condensers produces an advance in phase.

The solution of the network and the dimensions thereof may be derived as follows:

If the reactance X of each condenser is

$$X = 1/c\omega$$

where c equals the capacity of the condenser ω is equal to 2π times frequency, then the phase advance due to the two conjugate condensers is 2ϕ where ϕ is such that

$$\tan \phi = X/2z_0$$

where z_0 is the surge impedance of the wire. From this is developed the the following table:

x/z_0	$x/2z_0$	ϕ	2 phase advance ϕ	Q	α
.1	.05	2.8	5.6	1.11	92.8
.2	.10	5.7	11.4	1.22	95.7
.3	.15	8.5	17.0	1.35	98.5
.4	.20	11.3	22.6	1.45	101.3
.5	.25	14.0	28.0	1.64	104.0
.6	.30	16.7	33.4	1.81	106.7
.7	.35	19.3	38.6	1.98	109.3
.8	.40	21.8	43.6	2.19	111.8
.9	.45	24.2	48.4	2.39	114.2
1.0	.50	26.5	53.0	2.63	116.5
1.1	.55				

In the next to the last column of the table Q is the standing wave ratio, that is the ratio of the maximum to the minimum standing waves

between the condensers. The spacings between the condensers is equal to $90^\circ + \phi$.

While with this relationship the conjugacy will be exact only at one frequency the phase changer, consisting of two series condensers will not cause much disturbance of frequencies near this conjugate frequency so long as the phase advance is not too large. This is because that for moderate values of phase advance the value Q between condensers is small, so that even if the second condenser is somewhat removed from the proper location, it will still produce a nearly reflectionless line. The only thing to be considered when the antenna is to be used for several frequencies is that the phase advance in one particular spot is not made too great.

In Fig. 7 is illustrated diagrammatically an embodiment of my invention utilizing phase advancing arrangements, such as illustrated in Fig. 6. In this figure, 70 represents a wave translating device such as a receiver or a transmitter. Transmitter or receiver 70 is coupled over lines 71 to a V-antenna comprising conductors 72, 73, 74, forming one leg of the antenna, and conductors 75, 76, 77, forming the other leg thereof. These conductor lengths 72 to 77, are preferably made equal and are preferably related to each other at the proper angle, so as to produce the desired radiation pattern in a direction toward the opening of the V and at an angle to the horizontal depending on the proximity of the ground or other reflecting structure. Between each of these conductor segments is provided a phase advancing network 78, which is preferably made in accordance with the teachings of my invention as shown in Fig. 6. Although in the antenna illustrated in Fig. 7, the antenna is divided into three sections, the number of sections into which the antenna is divided is not material to the invention; any number of two or more sections may be provided as desired.

Although I have described in connection with Fig. 7, an embodiment of my invention wherein the angle between the radiating sections is adjusted with respect to their length, the principles of my invention may be utilized to improve the radiation characteristic of an existing antenna structure in spite of the fact that the angle thereof may not be adjusted for the maximum radiation.

The fact that such an improvement may be obtained can be gathered in part from Fig. 4 and is illustrated more clearly in Fig. 8. In Fig. 8 an antenna structure comprising two radiating sections 80, and two radiating sections 81, forms the arms of a V-type antenna. Between the arms 80 and 81, is provided a phase shifting network 82 made in accordance with the teachings of my invention. The radiation pattern of the conductors operating as a closed conductor without phase shift, is illustrated by the solid curves 83, 83'. These radiation patterns are illustrated omitting the lobes except in the direction of desired communication. It will be seen that these lobes form a particular angle θ_1 with the radiating arms of the antenna. By adding phase advancing networks in accordance with my invention the radiation lobes for each of the wires is enlarged and changed in direction, as illustrated at 84, 84'. By adding the phase shifters the maximum directive action of the radiators is changed from angle θ_1 to θ_2 so that maximum radiation would be obtained by widening the angle between these conductors. However, it can be seen that the radiation in the direction indi-

cated by angle θ_1 is also increased, so that the total radiation of the system is improved in the direction of existing communication.

As a particular example one may consider a plain V-antenna 6λ long which includes an angle of 40° . If a phase change is put in the center so as to give the best improvement at 40° , it should give a phase advance of approximately

$$360 \times 3 (1 - \cos 20^\circ) = 65^\circ$$

If the phase changer were not inserted, the radiations would add with 65° phase difference, whereas the phase changer would correct this so as to bring the phase difference to 0. This would mean an increase of from

$$2 \cos \frac{65}{2} = 1.68 \text{ to } 2$$

which represents the increase in radiation in the desired direction.

This shows that an improved radiation will be obtained from existing antennae by utilization of phase shifters in accordance with my invention, without necessitating the movement of poles and other supporting structures to make actual angular adjustment of the wires themselves.

Instead of correcting entirely for the complete 65° phase discrepancy in the example given above, the correction should be made for say 50° which will produce almost as much gain without requiring so great a phase advance in a single unit. At ten megacycles this would then require a condenser of about $26.5 \mu\text{F}$. Such a condenser is quite small and may be obtained from a pair of condenser plates of less than 20 cm. square spaced about a centimeter apart. Since the condenser is quite small and light, it may be readily supported in the antenna conductor by means of strain insulators.

Particular examples of condenser arrangements suitable for use in my invention are shown in Figs. 10 and 11. Fig. 10 shows a strain insulator 50 supported between loops 51, 52 made in the conductor of the antenna. On an intermediate portion of the insulator is supported the condenser structure comprising cylindrical plates 53, 54. Plates 53 are clamped to the insulator 50 by means of a clamp 58 and are connected by means of a conductor 55 with the portion of the antenna from which loop 51 is formed. The other plates of the condenser 54 are connected by means of conductor 56 with the portions of the antenna from which loop 52 are formed. The capacity of the condenser may be varied by adjusting the clamp 58 longitudinally of the insulator 50. Lead shims 59 are provided between the clamping portion of the clamp 58 and the insulator in order that the strain placed on the insulator by clamping may not cause the insulator to break.

An alternative insulator structure is shown in Fig. 11, wherein only a portion of the complete structure is shown, the remaining parts being preferably made substantially identical with that shown in Fig. 10. According to this embodiment instead of utilizing cylindrical conductor plates, disc shaped plates are formed as shown at 70, 71. These plates are preferably made of sheet metal and are rolled at the edges to increase the rigidity thereof and prevent vibration of the plates altering the tuning. The plates are adjustably clamped on the shank of insulator 50 in a manner similar to that disclosed in Fig. 10. In order to adjust the capacity of the antenna, the spacing between the plates may be adjusted

by loosening screws and shifting one or the other of the plates with respect to the other plate.

These condenser forms are particularly useful with the antenna arrangement according to my invention because they are light in weight and easily installed. Moreover, it is clear that many other forms of condensers suitable for use in my invention may be provided without departing from the spirit of the invention.

The principles of my invention are not confined to use with a single antenna structure such as those shown in Figs. 7 and 8. It is clear that the same principles may be applied to multiple antenna units forming either broadside or end-fire arrays or combinations of both. In Fig. 9 is disclosed an arrangement wherein a unidirectional effect is achieved by using two antennae 80, 81, suitably spaced. Each of these antennae conductors are divided into separate radiating sections by means of condenser phase shifters 83 constructed in accordance with the principles of my invention. Although only two units are illustrated in Fig. 9, it is clear, that if desired, more units may be provided in this arrangement. The antenna structures proper may be both energized from source 85, as shown in Fig. 9, or alternatively some of the antenna units, such as 81, may be parasitically energized.

While I have disclosed above some examples illustrating the preferred embodiment of my invention it should be distinctly understood that these showings are merely by way of examples and not as limitations on the scope thereof.

What I consider as my invention and desire to protect by Letters Patent is defined in the accompanying claims.

What I claim is:

1. An antenna comprising a first radiant acting conductor, a second radiant acting conductor and a phase advancing network comprising two phase advancing reactance elements connected in conjugate relation with respect to the operating frequency of said antenna interconnecting said radiant acting conductors.

2. An antenna according to claim 1 wherein said phase advancing network comprises condensers each producing a phase advance of ϕ and a conductive element effectively equal to $90+\phi$ electrical degrees in length connected between said condensers.

3. A directive antenna comprising a pair of radiant acting arms forming a V-shaped structure, each of said arms comprising a plurality of substantially equal length sections, and phase advancing means comprising a pair of condensers connected in conjugate relation with respect to the operating frequency of said antenna interconnecting said sections.

4. A directive antenna according to claim 1 wherein each of said condensers is of a size to produce the same phase advance and conjugate relation is established by a conductor interconnecting said condensers of an electrical length equal to a quarter wavelength plus said phase advance.

5. A directive antenna system comprising a plurality of pairs of radiant acting arms each pair forming a V-shaped structure, said pairs being arranged to form a directive array, each of said arms comprising a plurality of substantially equal length sections, and phase advancing means comprising a pair of condensers connected in conjugate relation with respect to the operating frequency of said antenna interconnecting each of said sections.

6. A phase advancing network for producing a predetermined phase advance at a particular frequency free from production of reflections in a line comprising a pair of condensers having a fixed capacity, each producing an advance of half said predetermined value, and means interconnecting said condensers equal electrically substantially to half said predetermined phase advance plus a quarter of a wavelength at said operating frequency.

7. A directive antenna comprising a pair of radiating arms arranged at a predetermined angle with respect to each other for radiating in a particular direction, and means for increasing the radiation in said direction comprising phase advancing means dividing each arm of said antenna into elements of substantially equal length, said phase advancing means comprising a pair of condensers connected in conjugate relation with respect to the operating frequency of said antenna.

8. An antenna comprising a first radiant acting conductor, a second radiant acting conductor, a phase advancing network interconnecting said conductors, said network comprising a pair of strain insulators fastened respectively to said conductors at one end and fastened together at their other ends by a network conductor, conductive means forming a condenser mounted on each of said strain insulators, and conductive connections between said first and second conductors and a respective one of said condensers, and between said condensers and said network conductor, said network conductor having a length substantially equal to the phase shift produced by one of said condensers, plus a quarter wavelength at the operating frequency of said antenna.

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