

April 30, 1940.

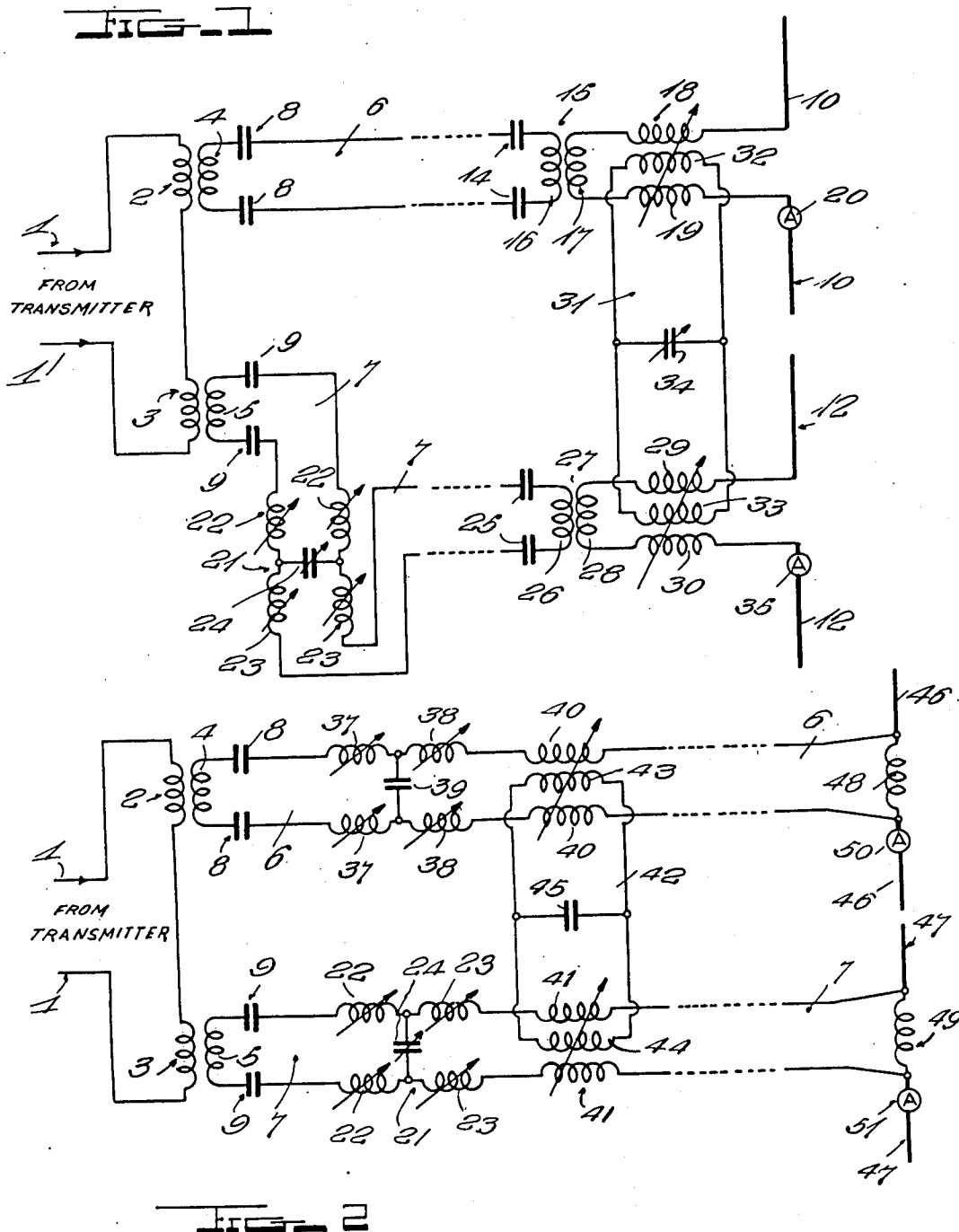
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2,198,604

ANTENNA SYSTEM

Filed Jan. 27, 1939

2 Sheets-Sheet 1



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FIG. 3

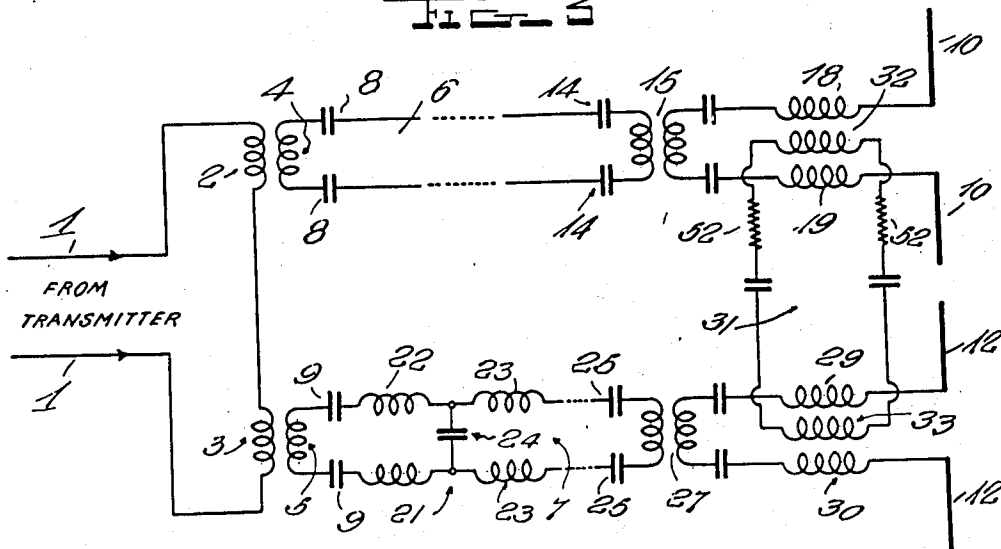


FIG. 4

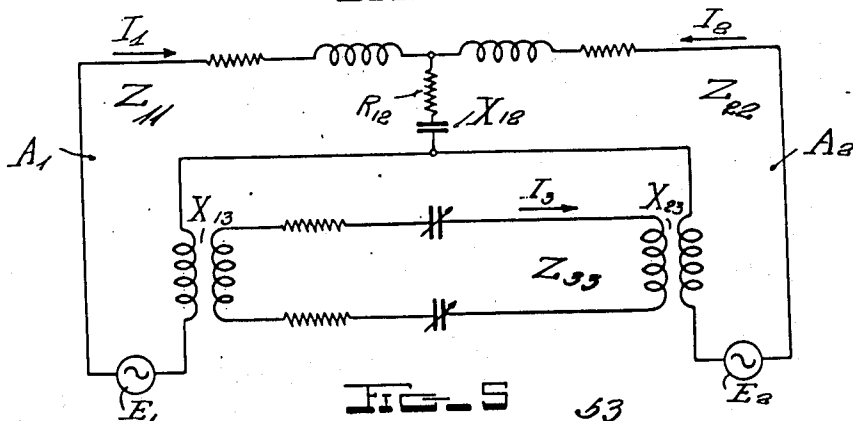


FIG. 5

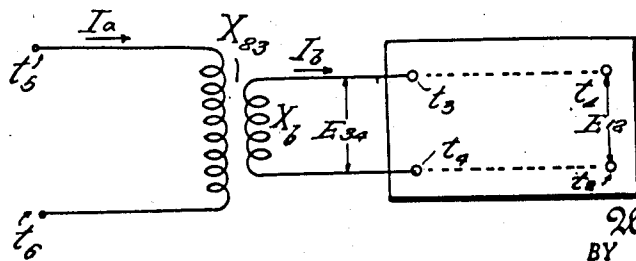
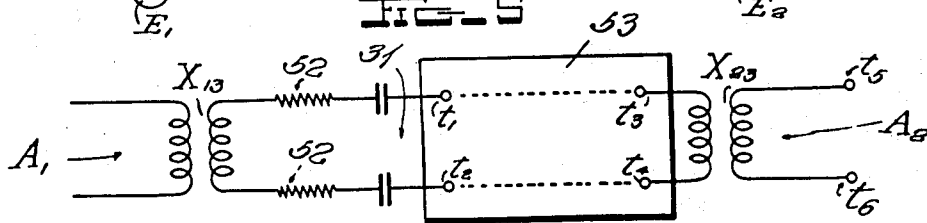


FIG. 6

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ANTENNA SYSTEM

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Application January 27, 1939, Serial No. 253,192

18 Claims. (Cl. 250—11)

My invention relates broadly to antennae systems and more particularly to a circuit arrangement for an antenna array.

This application is a continuation-in-part of my copending application Serial No. 43,764, originally filed October 5, 1935, for Antenna system.

One of the objects of my invention is to provide a circuit arrangement for an antenna array having means for independently adjusting the current in each antenna of the array.

Another object of my invention is to provide a circuit arrangement for an antenna array having coupling means between the separate antennae by which the individual currents in the separate antennae may be controlled.

Still another object of my invention is to provide a circuit arrangement for antennae array for balancing the separate antennas by control of the phase and magnitude of the current in the separate antennas.

A further object of my invention is to provide a circuit arrangement for antennae array having means interconnecting the transmitter with the separate antennas by which desired delay may be introduced in the phase of the current supplied to one antenna with respect to the phase of the current supplied to another antenna.

A still further object of my invention is to provide means for balancing out the coupling due to the proximity of two or more antennae and adjusting the magnitude and phase of the currents in the antennae of an antenna array.

Still another object of my invention is to provide a link circuit coupling transmission lines feeding different antennae of an antenna array, and including means for eliminating mutual resistance as well as mutual reactance between the different antennae.

A still further object of my invention is to provide reactive and resistive elements in a link circuit coupling transmission lines feeding separate antennae of an antenna array for eliminating the entire mutual impedance between the antennae.

Other and further objects of my invention reside in the circuit arrangement for antennae array as set forth in the specification hereinafter following by reference to the accompanying drawings, in which:

Figure 1 diagrammatically illustrates one proposed circuit arrangement for the antennae array of my invention; Fig. 2 illustrates a modified form of circuit arrangement for antennae array embodying my invention; Fig. 3 is a schematic diagram of a modified form of the circuit ar-

range ment illustrated in Fig. 1; Fig. 4 is a schematic diagram of the equivalent circuit of Fig. 3, indicating lumped elements as considered in the analysis of the circuit hereinafter set forth; Fig. 5 is a diagram of a portion of Fig. 4 with the inclusion of a line component; and Fig. 6 is a diagram of a detail in Fig. 5 with the elements in rearranged positions.

In a system of transmission employing antennae array, difficulty has been encountered by reason of the fact that the current in one antenna induces a voltage in each of the other antennae of the array. This induced voltage modifies the apparent impedance in each of the coupled antennas. As a result, it becomes difficult to make adjustments of current ratio involving both magnitude and phase. The coupling due to the proximity of two or more antennae is balanced out by a link circuit by adjustments of the magnitude and phase of the mutual impedance of the circuits interconnecting the antennae. I employ two or more antennae in the antennae array and connect each antenna with the high frequency transmission system through suitable transmission lines. I introduce a construction of delay circuit in one of the transmission lines and I introduce means for mutually coupling the transmission lines with adjustable circuit elements in both the delay means and in the coupling means for controlling the magnitude and phase of the current in each antenna. When adjustments are made for proper phase and magnitude of currents in each antenna, the mutual interaction of one antenna with respect to another is eliminated.

The mutual impedance between two antennas makes it difficult to properly adjust the coupling networks connecting the antennas to the lines which deliver the power. A change in the magnitude or phase of the current in one antenna modifies the voltage induced in the other antenna and so changes the apparent impedance which the latter antenna presents to its coupling network. The effect of this mutual impedance between the two antennas can be eliminated by circuits of the following general form.

Referring to the drawings in more detail, reference character 1 designates circuit connections from the output of a high frequency transmitter which includes an electrical circuit connection through output inductances 2 and 3 in series. Secondary inductances 4 and 5 are coupled respectively to the output inductances 2 and 3. Connections through transmission lines 6 and 7 are made to secondary inductances 4 and 5

through sets of coupling condensers indicated at 8 and 9 respectively. The transmission lines 6 and 7 may extend any practicable distance to the antennae array. For purposes of explaining my invention, I have shown two separate antennas in the antennae array but it is to be understood that the principles of my invention are applicable to antennae array of any desired number. I have represented one antenna system at 10 as comprising a doublet, but any type of antenna system may be employed. I have shown another antenna system at 12 consisting of another doublet. The doublet 10 is excited from transmission line 6 through electrostatic coupling means 14 and transformer system 15 constituted by primary winding 16 and secondary winding 17. Coupling coils 18 and 19 are inserted in series between the ends of secondary winding 17 and the doublet 10. A suitable ammeter 20 is disposed in series with doublet 10 to determine the magnitude of the current flow therein.

The connection of doublet 12 to transmission line 7 is completed through a delay network which I have indicated generally by 21 as being constituted by sets of adjustable inductance elements 22 and 23 with a variable condenser connected therebetween indicated at 24. The transmission line 7 connects through electrostatic coupling elements 25 with primary winding 26 of transformer 27, the secondary winding 28 of which connects to doublet 12 through inductance elements 29 and 30, as shown.

The adjustable link circuit for interconnecting the transmission lines is represented at 31, including coupling coil 32 adapted to be variably coupled with windings 18 and 19 and coupling coil 33 adapted to be variably coupled with windings 29 and 30. A tuning device 34 is disposed in the link circuit 31 in connection with the other elements in the link circuit. A suitable indicating meter 35 is provided in circuit with doublet 12 for indicating the magnitude of the current in the doublet.

Adjustment in current ratio with respect to both magnitude and phase in doublets 10 and 12 may be made by adjustment of coupling coils 2-4 and 3-5. The adjustable elements of the delay network 21 and the variable elements in the link circuit 31 interconnecting the doublets are adjusted to effect the desired phase relationship of the currents. The link circuit 31 is adjusted so that the coupling due to the antennae is balanced out by the link circuit.

The circuits of my invention in which the antennae are conjugate permit tests to be made of the field strength of the transmitter at a distance by first exciting one antenna then the other antenna and then both simultaneously for observing whether the currents are in proper phase.

In the modified form of my invention shown in Fig. 2, the transmission line 6 is also provided with a delay network which I have indicated at 36 as including adjustable inductance elements 37 and 38 interconnected by variable condenser 39. In this form of my invention, the transmission line 6 includes inductance coils 40 while transmission line 7 includes inductance coils 41 and to these sets of inductance coils, I couple the link circuit shown at 42 including coupling coil 43 and coupling coil 44 connected through a variable condenser 45. Adjustment may be made of the link circuit and of the elements in the delay networks 21 and 36 for determining the magnitude and phase relation of the currents in the antennae which I have indicated at 46 and 47.

Transmission line 6 connects to opposite terminals of inductance element 48 in circuit with the antenna 46. Transmission line 7 connects to opposite terminals of inductance element 49 in circuit with antenna 47. A suitable meter 50 is connected in circuit with antenna 46 and a suitable meter 51 connected with antenna 47 for indicating the magnitude of the current in each antenna.

A link circuit of the type shown in Fig. 1 by 31, and Fig. 2 by 42, which has no dissipative elements can only be used to eliminate the mutual reactance between the antennae and cannot affect the mutual resistance. A useful object is accomplished by eliminating this mutual reactance as in many cases it is the predominant form of coupling. If the link circuits also contain resistive elements, it is possible to eliminate the entire mutual impedance but at the expense of the power which is dissipated in the resistive elements of the link circuit. This principle must be realized in order to make any adjustments on any antenna system containing a decoupling network.

In Fig. 3 I have shown the circuit of Fig. 1 in somewhat modified form; the principal distinction, however, is the provision of resistive elements 52 in the link circuit 31 the purpose and function of which will be understood from the following analysis of the principles involved. To facilitate the explanation, the equivalent circuit of Fig. 3 wherein all elements are lumped and represented in theoretical entities, will be considered. Fig. 4 shows the equivalent circuit of Fig. 3 and represents the voltage supplied to the antenna coupling circuit 15 at E_1 , and that to antenna coupling circuit 27 at E_2 , in accordance with Thevenin's Theorem. Currents I_1 and I_2 are represented as flowing in the respective coupling circuits and antennae which have resistances R_{11} and R_{22} and reactances X_{11} and X_{22} , both respectively. Impedance Z_{12} , comprising reactance X_{12} and resistance R_{12} , constitutes the mutual impedance between the antenna systems. The characteristics of the link circuit are similarly represented, X_{13} and X_{23} representing the coupling reactances to the respective antenna systems fed from E_1 and E_2 , and Z_{33} the impedance of the link circuit comprising resistance R_{33} and reactance X_{33} ; the current in the link circuit is represented as I_3 .

The separate systems related through the mutual impedance Z_{12} will be termed antenna mesh A_1 and antenna mesh A_2 , indicating the systems supplied from sources E_1 and E_2 , respectively. The link circuit will be termed antenna decoupling mesh A_3 , with current I_3 flowing therein, the function of this decoupling mesh A_3 being to counteract the detrimental coupling effected by the mutual impedance Z_{12} between antenna meshes A_1 and A_2 .

If the decoupling mesh is to serve its purpose, then the voltage induced by I_1 in mesh A_2 due to the mutual impedance Z_{12} must be equal and opposite to that induced in mesh A_2 due to the link circuit. In this case a current I_1 will not tend to set up any current in mesh A_2 . By the reciprocity theorem, if this condition is achieved, a current I_2 will not tend to set up any current in mesh A_1 . The voltages induced in mesh A_2 may be computed most conveniently by considering mesh A_2 as open circuited.

The voltage induced in mesh A_2 due to the mutual impedance Z_{12} will be

$$e_{12}=I_1Z_{12}$$

If mesh A₂ is open and mesh A₃ is closed

$$I_1 = \frac{E_1 Z_{33}}{Z_{11} Z_{33} - Z_{13}^2}$$

$$\therefore e_{12} = \frac{E_1 Z_{12} Z_{33}}{Z_{11} Z_{33} - Z_{13}^2} \quad (1)$$

The current induced in mesh A₃ by mesh A₁ with mesh A₂ open will be

$$I_3 = \frac{-E_1 Z_{13}}{Z_{11} Z_{33} - Z_{13}^2}$$

The voltage induced in mesh A₂ by current in mesh A₃ will be

$$e_{23} = I_3 Z_{23}$$

$$\therefore e_{23} = \frac{-E_1 Z_{13} Z_{23}}{Z_{11} Z_{33} - Z_{13}^2} \quad (2)$$

As explained, the condition for decoupling will be

$$e_{12} = -e_{23}$$

$$\therefore \frac{E_1 Z_{12} Z_{33}}{Z_{11} Z_{33} - Z_{13}^2} = \frac{E_1 Z_{13} Z_{23}}{Z_{11} Z_{33} - Z_{13}^2}$$

This gives as the necessary and sufficient condition for decoupling,

$$Z_{12} Z_{33} = Z_{13} Z_{23} \quad (3)$$

Now Z₁₃ and Z₂₃ are pure reactances and may be either of positive or negative sign. Hence

$$Z_{12} Z_{33} = (\pm j X_{12})(\pm j X_{23}) = \pm X_{12} X_{23} \quad (4)$$

The mutual impedance Z₁₂ between two antennas may lie in any of the four quadrants, i. e., its resistive component may be either positive or negative. On the other hand, Z₃₃ must have a positive resistance. If Z₁₂ has a positive resistance Eq. 4 can be satisfied by using the positive sign on its right hand side and making Z₃₃ have an angle which is the negative of the angle of Z₁₂. If Z₁₂ has a negative resistance Eq. 4 is satisfied by using the negative sign on the right hand side and making the angle of Z₃₃ equal to 180° minus the angle of Z₁₂.

Eq. 4 may be used to solve for the values of R₃₃ and X₃₃ required. Two cases must be considered.

Case I: R₁₂ positive

Let Z₁₂ = R₁₂ + jX₁₂

and Z₃₃ = R₃₃ + jX₃₃.

Then by Eq. 4

$$Z_{12} Z_{33} = R_{12} R_{33} - X_{12} X_{33} + j(R_{33} X_{12} + R_{12} X_{33}) = X_{12} X_{23} \quad (5)$$

Equate the reals and imaginaries:

$$R_{12} R_{33} - X_{12} X_{33} - X_{12} X_{23} = 0 \quad (5a)$$

$$R_{33} X_{12} + R_{12} X_{33} = 0 \quad (5b)$$

Solve Eq. 5a for R₃₃:

$$R_{33} = \frac{X_{12} X_{33} + X_{12} X_{23}}{R_{12}} \quad (6a)$$

Solve Eq. 5b for R₃₃:

$$R_{33} = -\frac{R_{12} X_{33}}{X_{12}} \quad (6b)$$

Equate Eqs. 6a and 6b and solve for X₃₃:

$$X_{33} = \frac{-X_{12} X_{23} X_{13}}{R_{12}^2 + X_{12}^2} = \frac{-X_{12} X_{23} X_{13}}{|Z_{12}|^2} \quad (7a)$$

Substitute Eq. 7a in Eq. 6b:

$$R_{33} = \frac{R_{12} X_{23} X_{13}}{|Z_{12}|^2} \quad (7b)$$

From Eqs. 7a and 7b:

$$\frac{R_{33}}{X_{33}} = -\frac{R_{12}}{X_{12}} \quad (8)$$

Hence, for this case, X₃₃ must be the opposite type of reactance to X₁₂.

As it is desirable to make the power dissipated in the link circuit a minimum, let the apparent impedance presented to the generator E₁ be designated by the symbol Z₁₁', and the apparent impedance presented to the generator E₂ be given the symbol Z₂₂', where

$$Z_{11}' = R_{11}' + jX_{11}'$$

$$Z_{22}' = R_{22}' + jX_{22}' \quad (15)$$

Now, due to the fact that there is no effective coupling between meshes 1 and 2,

$$Z_{11}' = Z_{11} + \frac{X_{12}^2}{Z_{33}} \quad (20)$$

and

$$Z_{22}' = Z_{22} + \frac{X_{23}^2}{Z_{33}} \quad (25)$$

or

$$R_{11}' = R_{11} + \frac{X_{12}^2 R_{33}}{|Z_{33}|^2} \quad (9a)$$

and

$$R_{22}' = R_{22} + \frac{X_{23}^2 R_{33}}{|Z_{33}|^2} \quad (9b)$$

By Eqs. 7a and 7b,

$$|Z_{33}|^2 = R_{33}^2 + X_{33}^2 = \frac{(R_{12}^2 + X_{12}^2) X_{23}^2 X_{13}^2}{|Z_{12}|^4} = \frac{X_{23}^2 X_{13}^2}{|Z_{12}|^2} \quad (35)$$

and by making further use of Eq. 7b

$$\frac{R_{33}}{|Z_{33}|^2} = -\frac{R_{12}}{X_{23} X_{13}} \quad (10)$$

Insert Eq. 10 in Eqs. 9a and 9b:

$$\therefore R_{11}' = R_{11} + \frac{X_{12} R_{12}}{X_{23}} \quad (11a)$$

and

$$R_{22}' = R_{22} + \frac{X_{23} R_{12}}{X_{13}} \quad (11b)$$

The power delivered to the system by the two generators will be

$$P_{gen.} = |I_1|^2 R_{11}' + |I_2|^2 R_{22}' = |I_1|^2 R_{11} + |I_2|^2 R_{22} + \left[|I_1|^2 \frac{X_{12}}{X_{23}} + |I_2|^2 \frac{X_{23}}{X_{13}} \right] R_{12} \quad (12)$$

The ratio

$$\frac{X_{12}}{X_{23}}$$

may be picked to make this power delivered a minimum.

This minimum is obtained by differentiating P_{del.} with respect to the ratio

$$\frac{X_{12}}{X_{23}}$$

and equating to zero which gives

$$\frac{X_{12}}{X_{23}} = \frac{|I_2|}{|I_1|} \quad (13)$$

If this ratio of

$$\frac{X_{12}}{X_{23}}$$

is selected, Eq. 12 becomes

$$P_{gen.} = |I_1|^2 R_{11} + |I_2|^2 R_{22} + 2|I_1||I_2| R_{12} \quad (14)$$

In the network it is assumed that all resistances in mesh A_1 and mesh A_2 are negligible, except those due to the antennas. Then the power delivered to the antennas is given by the relation which is well known for coupled circuits with mutual resistance:

$$P_{ant.} = |I_1|^2 R_{11} + |I_2|^2 R_{22} + 2|I_1 I_2| R_{12} \quad (15)$$

The power dissipated in the link circuit will be the difference between the values given by Eqs. 14 and 15:

$$P_{dis.} = P_{gen.} - P_{ant.} = 2R_{12}[|I_1||I_2| - |I_1 I_2|] \quad (16)$$

If the angle between the two currents I_1 and I_2 is designated by θ ,

$$|I_1 I_2| = |I_1||I_2| \cos \theta$$

Eq. 16 then becomes.

$$P_{dis.} = 2R_{12}|I_1||I_2|(1 - \cos \theta) \quad (17)$$

Eq. 17 shows that if the currents I_1 and I_2 are in phase with each other, there will be no power dissipated in the link circuit when the two antennas are being fed. During the process of adjustment the resistances presented to each generator will not be changed by changes in the opposite mesh, and their values are given by Eqs. 11a and 11b.

Case II: R_{12} negative

The analysis for Case II where R_{12} is negative follows a similar reasoning. However Eq. 5a becomes

$$+R_{12}R_{33} - X_{12}X_{33} + X_{13}X_{23} = 0$$

This gives the following relations for this case:

$$R_{33} = -\frac{R_{12}X_{23}X_{13}}{X_{12}^2} \quad (7c)$$

$$X_{33} = +\frac{X_{12}X_{23}X_{13}}{X_{12}^2} \quad (7d)$$

$$R_{11}' = R_{11} - \frac{X_{12}^2}{X_{23}} R_{12} \quad (11c)$$

$$R_{22}' = R_{22} - \frac{X_{23}^2}{X_{13}} R_{12} \quad (11d)$$

$$P_{gen.} = |I_1|^2 R_{11} + |I_2|^2 R_{22} - 2|I_1||I_2|R_{12} \quad (14a)$$

(for the case where Eq. 14 applies)

$$P_{dis.} = -2R_{12}|I_1||I_2|(1 + \cos \theta)$$

(Note that in the above equation R_{12} itself is a negative number).

Eqs. 8 and 13 also apply to this case without modification.

In this case there will be no power dissipated in the link circuit when I_1 and I_2 are in phase opposition.

Continuing with the general considerations, in operation the antennas will be separated in space and so the decoupling link will require a line with distributed constants to connect the mutual inductances adjacent to each antenna. When the decoupling adjustment is made and antenna mesh A_1 is excited, the link circuit is effectively terminated in an open circuit at the end coupled with antenna mesh A_2 since the voltage set up there does not produce any current. On a dissipationless line terminated in an open circuit the voltage does not shift phase along the line except at a voltage node where it reverses phase.

The decoupling link 31 of Fig. 3 is represented in Fig. 5. This is essentially the same as the decoupling circuit of Fig. 4 except that the line 53 has been added. However, the line 53 and the

mutual reactance X_{23} can be considered as a four-terminal coupling network in itself, the mutual impedance of which will be shown to be a pure reactance and will be termed the effective mutual reactance between the link circuit 31 and antenna mesh A_2 . Its value for Fig. 3 may be determined by the same equations as determine X_{23} in the analysis of Fig. 4. The mutual impedance would be the vector voltage which appears between terminals t_3-t_4 when one ampere is sent into terminals t_1-t_2 . It is easier to compute this if the network is reversed as shown in Fig. 6, and the mutual impedance is computed as equal to the ratio E_{12}/I_a where I_a is the current supplied at terminals t_3-t_4 . This is true because of the reciprocity theorem.

Assume that the line has the characteristic impedance and propagation constant of a dissipationless line with the following designations:

$$Z_0 = R_0 + j0$$

$$\gamma = 0 + j\beta$$

Then the input impedance at the terminals t_3-t_4 will be

$$Z_{in.} = Z_0 \coth \gamma l \\ = -jR_0 \cot \beta l$$

Let X_b be the reactance of the secondary circuit exclusive of the line, and I_b the current therein. Then

$$I_b = \frac{jI_a X_{23}}{jX_b + Z_{in.}} = \frac{I_a X_{23}}{X_b - R_0 \cot \beta l}$$

The voltage E_{34} will be

$$E_{34} = I_b Z_{in.} = -j \frac{I_a X_{23} R_0 \cot \beta l}{X_b - R_0 \cot \beta l}$$

On an open circuited line the following relation applies:

$$\frac{E_{34}}{E_{12}} = \cosh \gamma l = \cos \beta l$$

Therefore the effective mutual impedance of the four-terminal coupling network including Z_0 and X_{23} will be

$$Z_m = \frac{E_{12}}{I_a} = \frac{-jX_{23}R_0}{X_b \sin \beta l - R_0 \cos \beta l} \quad (18)$$

Frequently, tuning reactances are inserted to reduce X_b to zero. In this case Eq. 18 reduces to

$$Z_m = \frac{jX_{23}}{\cos \beta l} \quad (18a)$$

In either case, therefore, the effective mutual impedance is a pure reactance. This reactance should be of such a value as to fit the equations derived in the discussion of Fig. 4. Its magnitude can be controlled by any of the factors in Eq. 18 or 18a.

It is of importance to note that the length of the line does not affect the phase shift, with the possible exception of a phase reversal if the denominators of Eqs. 18 and 18a are negative. A phase reversal can be eliminated in this case by interchanging terminals t_1 and t_2 .

In Figs. 1-3 the elements shown are arranged to provide a balance to ground. It is customary to analyze circuits in which the balance is not given consideration, as was the case in the discussion of Fig. 4, and subsequently to rearrange the elements when a balance condition is necessary. The principles of accomplishing this are well known and need not be discussed here. In a similar way the circuits of my invention shown in

Figs. 1-3 can be modified to take care of lines or antennas which are not balanced to ground.

Thus, if a resistive element is inserted in series in the decoupling system, as shown in Fig. 3, the antenna systems can be completely decoupled. The formula for the energy lost in the two systems under optimum conditions of coupling when the mutual resistance of the two antennas is positive is:

$$\text{Power lost} = 2R_{12}|I_1||I_2|(1 - \cos \theta) \quad (17)$$

where

R_{12} is the mutual resistance of the two antennas

$|I_1|$ is the absolute value of the current in antenna 1

$|I_2|$ is the absolute value of the current in antenna 2

θ is the phase angle between the two currents.

Hence if the mutual resistance is positive there will be no power dissipated in the decoupling link if either

(a) I_1 and I_2 are in phase with each other, or

(b) The mutual resistance between the two antennas is zero.

If the mutual resistance is negative the power dissipated in the decoupling link is

$$\text{Power lost} = -2R_{12}|I_1||I_2|(1 + \cos \theta) \quad (17a)$$

In this case there will be no power dissipated if I_1 and I_2 are in phase opposition.

The conditions for decoupling are that the effective resistance and reactance in the decoupling network shall be

$$R_{23} = \pm \frac{R_{12}X_{23}X_{13}}{|Z_{12}|^2}$$

$$X_{23} = \mp \frac{X_{12}X_{23}X_{13}}{|Z_{12}|^2}$$

The upper signs are used when R_{12} is positive and the lower signs are used when R_{12} is negative. From the above:

$$\frac{R_{23}}{X_{23}} = -\frac{R_{12}}{X_{12}}$$

where

R_{12} is the mutual resistance of the antennas,

X_{12} is the mutual reactance of the antennas,

X_{13} is the effective mutual reactance between antenna mesh A_1 and the link circuit, and

X_{23} is the effective mutual reactance between antenna mesh A_2 and the link circuit.

For minimum dissipation,

make:

$$\frac{X_{13}}{X_{23}} = \frac{|I_2|}{|I_1|}$$

Therefore, the magnitude and phase of the individual currents in each antenna may be precisely controlled in accordance with the principles of my invention so that one antenna does not tend to react upon another antenna of an array, and the mutual resistance as well as the mutual reactance between the antennae is effectively eliminated.

In the drawings I have illustrated my invention as applied to doublets, but it is to be understood that my invention is equally applicable to radiating systems of various types and arrangements.

While I have described my invention in certain of its preferred embodiments, I am aware that various modifications of the circuit of my invention may be made and that I intend no limita-

tions upon my invention other than are imposed by the scope of the appended claims.

What I claim as new and desire to secure by Letters Patent of the United States is as follows:

1. A transmission system comprising a source of high frequency energy, a pair of doublet radiating systems, a pair of transmission systems connected with said source of high frequency energy, circuits interconnecting said transmission systems with each branch of said doublet radiating systems, a delay network disposed in one of said transmission systems, and a separate delay network interconnecting said circuits.

2. In a balanced antenna array employing a plurality of doublet antennae, in combination, means individual to each antenna for adjusting the phase and magnitude of the current in the respective antenna with respect to the currents in the other antennae, and means common to all antennae in said antenna array for compensating each antenna for the effects of the other antenna thereon, the last said means being coupled with both branches of each of said doublet antennae.

3. In a balanced antenna array employing a plurality of doublet antennae, in combination, means individual to selected antennae in said antenna array for adjusting the phase and magnitude of the current in the respective antenna with respect to the currents in the other antennae, and means common to all antennae in said antenna array for compensating each antenna for the effects of the antennae thereon, the last said means being coupled with both branches of each of said doublet antennae.

4. In a balanced antenna array including a pair of doublet antennae, in combination, means individual to one antenna for adjusting the phase and magnitude of the current in said antenna with respect to the current in the other antenna, and means common to both branches of each of said doublet antennae for compensating each antenna for the effects of the other antenna of said pair thereon.

5. In a balanced antenna array, a plurality of doublet antennae, means for compensating each antenna for the effects of currents in the other antennae which comprise an inductance element in circuit with each branch of each doublet antenna, and a coupling link circuit including separate inductance elements coupled with those of the said inductance elements in circuit with the branches of individual doublet antennae, and a variable capacitance element connected with said separate inductance elements for adjusting the phase of the energy transferred through said coupling link.

6. In a balanced antenna array, a plurality of doublet antennae, means for compensating each antenna for the effects of currents in the other antennae which comprise an inductance element in circuit with each branch of each doublet antenna; and a coupling link circuit including separate inductance elements variably coupled with pairs of said inductance elements in circuit with individual doublet antennae for adjusting the magnitude of energy transferred through said coupling link circuit, and a variable capacitance element connected in said coupling link circuit for adjusting the phase of the energy transferred through said coupling link circuit.

7. In a balanced antenna array including a pair of doublet antennae, means for compensating each antenna for the effects of currents in

the other antenna which comprise an inductance element in circuit with each branch of each doublet antenna; and a coupling link circuit including separate inductance elements variably coupled with pairs of said inductance elements in circuit with individual doublet antennae, and a variable capacitance element connected in parallel with said separate inductance elements in said link circuit.

8. In a balanced antenna array, a doublet antenna, a pair of transmission lines connected with said doublet, an inductance element connected in each transmission line, a separate inductance element coupled with said inductance elements in common; a duplicate arrangement of antenna, transmission lines, and inductance elements; means including a condenser for interconnecting said separate inductance elements for forming a link coupling between said antennae; and other inductance elements connected with the transmission lines of at least one of said pairs, and a condenser connected across the transmission lines in cooperative relation with the last said inductance elements, for forming a delay network for adjusting the phase and magnitude of current in the respective doublet antenna.

9. A transmission system comprising a source of high frequency energy, a pair of radiating systems, a pair of transmission systems connected with said source of high frequency energy, circuits interconnecting said transmission systems with said radiating systems, a delay network disposed in one of said transmission systems, and a separate network interconnecting said circuits.

10. In a balanced antenna array, a radiating system, a pair of transmission lines connected with said radiating system, an inductance element connected in each transmission line, a separate inductance element coupled with said inductance elements in common; a duplicate arrangement of radiating system, transmission lines, and inductance elements; means including a condenser for interconnecting said separate inductance elements for forming a link coupling between said radiating systems and other inductance elements connected with the transmission lines of at least one of said pairs, and a condenser connected across the transmission lines in cooperative relation with the last said inductive elements, for forming a delay network for adjusting the phase and magnitude of current in the respective radiating systems.

11. In a balanced antenna array including a pair of radiating systems, means for compensating each radiating system for the effects of currents in the other radiating system, which comprise an inductance element in circuit with each radiating system; and a coupling link circuit including separate inductance elements variably coupled with pairs of said inductance elements in circuit with the respective radiating systems, and a variable capacitance element connected in parallel with said separate inductance elements in said link circuit.

12. An antenna system comprising a multiplicity of individual antennae, separate antenna coupling means connected with each antenna,

and means interconnected with said coupling means and having a reactive characteristic for counteracting mutual reaction in said individual antennae and a resistive characteristic for counteracting mutual resistance in said individual antennae, in operation.

13. An antenna system comprising a multiplicity of individual antennae having separate coupling means for supplying energy thereto, and a decoupling link circuit interconnected with said coupling means and including means for counteracting mutual resistance and mutual reactance in said individual antennae in operation.

14. An antenna system comprising a multiplicity of individual antennae having separate coupling means for supplying energy thereto, said individual antennae being simultaneously energized and having mutual reactive and resistive characteristics, and means interconnected with said coupling means and operative for counteracting the mutual reactance and resistance in said individual antennae.

15. An antenna system comprising a multiplicity of individual antennae having separate coupling means for supplying energy thereto, a single source of energy common to all said coupling means, means individually connected with selected ones of said coupling means for adjusting the phase and magnitude of the current in the respective antenna with respect to the currents in the other antennae, and means common to all said coupling means for counteracting the mutual impedance in said individual antennae, the mutual impedance including mutual reactance and mutual resistance.

16. An antenna system comprising a multiplicity of individual antennae having separate coupling means for supplying energy thereto, said individual antennae being simultaneously energized and having mutual reactive and resistive characteristics, and a link circuit reactively coupled with selected ones of said coupling means and including an energy dissipative element, said link circuit being operative to counteract the mutual reactance and resistance in said individual antennae.

17. An antenna system comprising a multiplicity of individual antennae having separate feeding means for supplying energy thereto, said individual antennae being simultaneously energized and having mutual reactive and resistive characteristics, a resistance element, and means having a substantially pure reactance characteristic connected between said resistance elements and selected ones of said feeding means for coupling said resistance element and the selected feeding means, said resistance element being effective to counteract the mutual resistance in the respective antennae and said reactive coupling means being cooperative through said resistance element to counteract the mutual reactance in the respective antennae.

18. An antenna system as set forth in claim 17 and including a transmission line in the said reactive coupling means, said line having a substantially pure reactance characteristic as a portion of said reactive coupling means.

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