Dec. 8, 1942.

A. W. CLEMENT

2,304,545

WAVE TRANSMISSION NETWORK

Filed Aug. 23, 1941

3 Sheets-Sheet 1

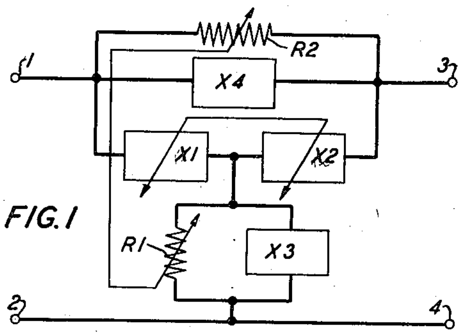

FIG. 1

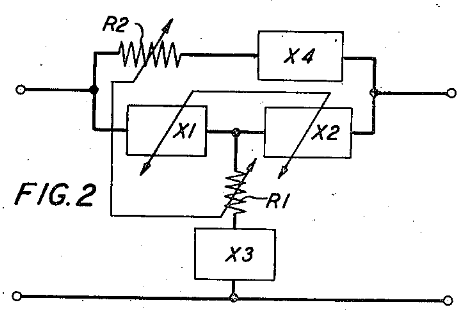

FIG. 2

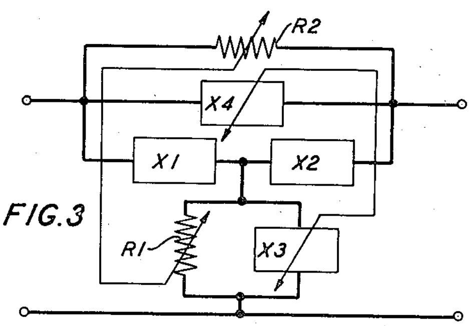

FIG. 3

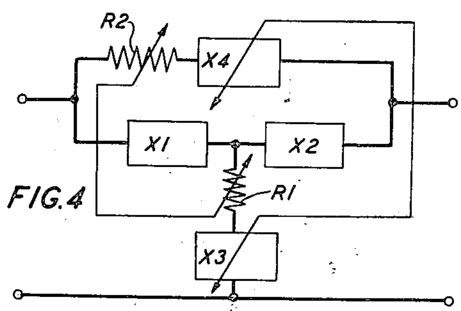

FIG. 4

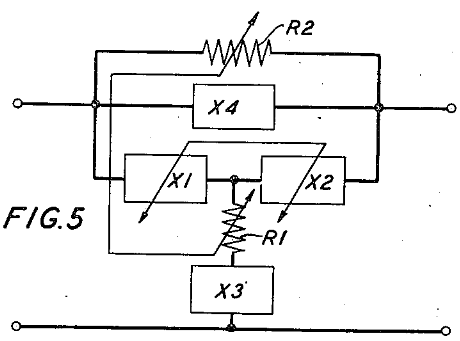

FIG. 5

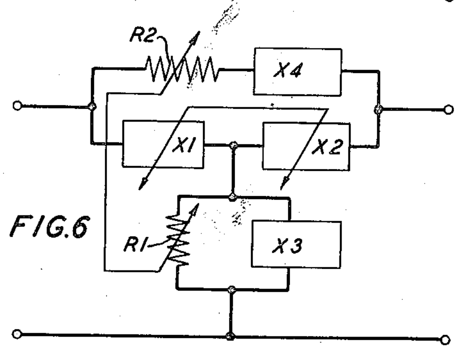

FIG. 6

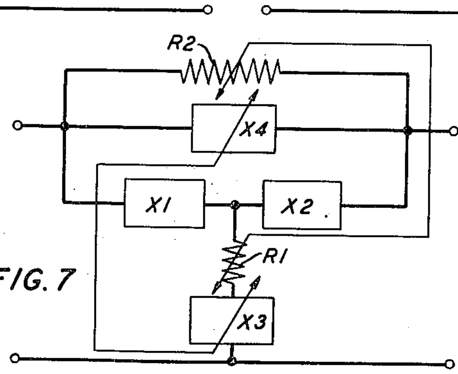

FIG. 7

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WAVE TRANSMISSION NETWORK

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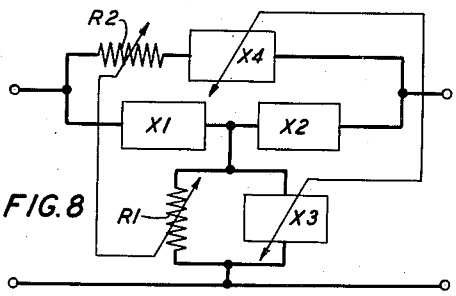

FIG. 8

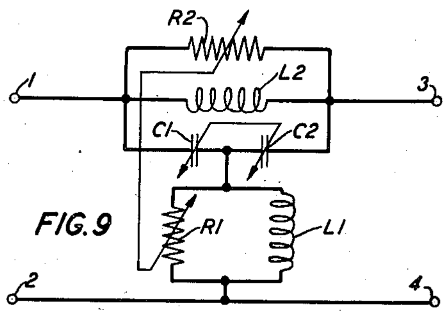

FIG. 9

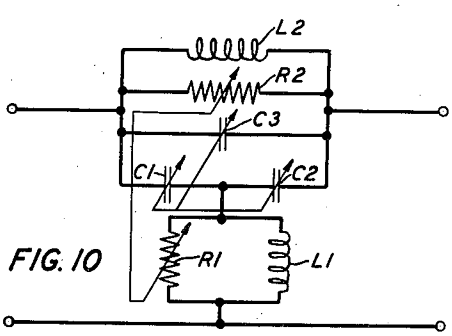

FIG. 10

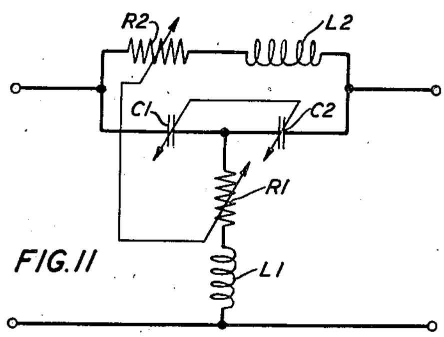

FIG. 11

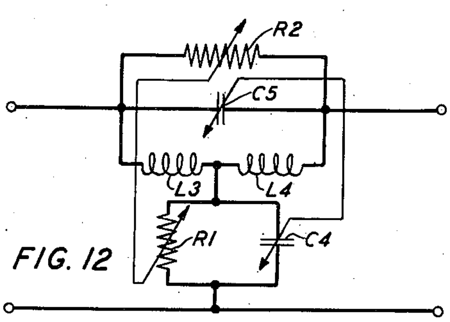

FIG. 12

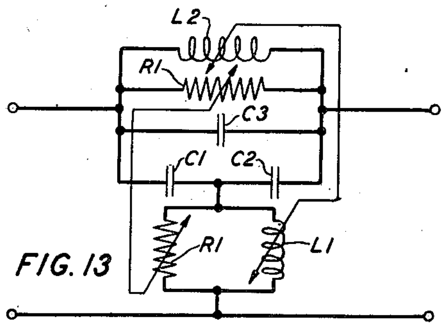

FIG. 13

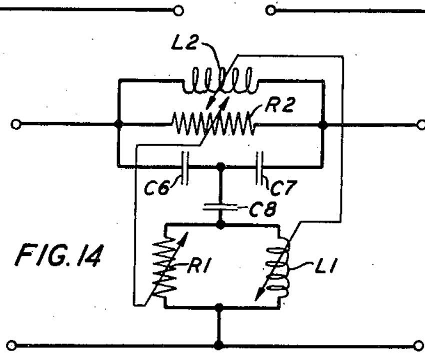

FIG. 14

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WAVE TRANSMISSION NETWORK

Filed Aug. 23, 1941 3 Sheets-Sheet 3

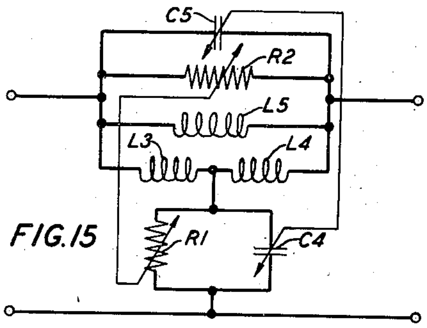

FIG. 15

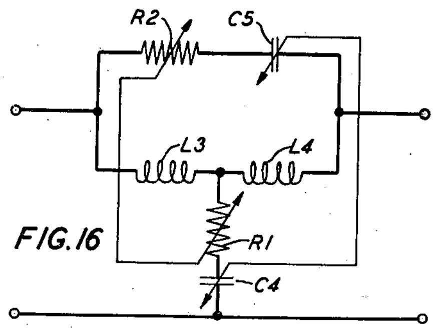

FIG. 16

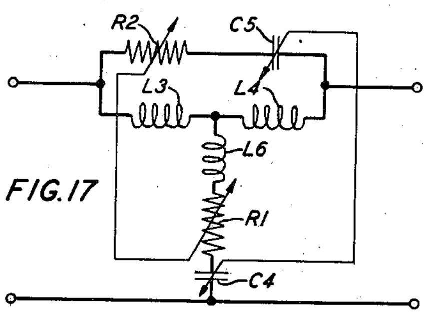

FIG. 17

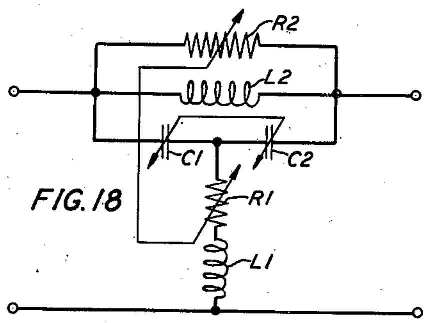

FIG. 18

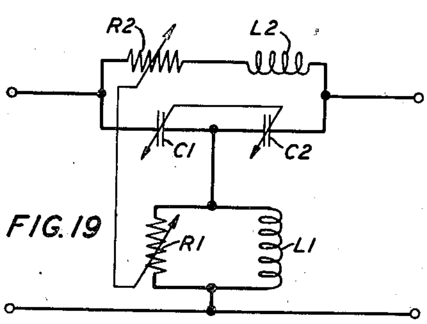

FIG. 19

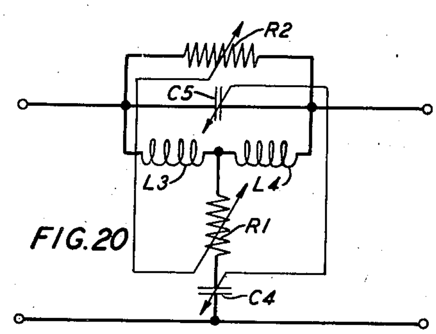

FIG. 20

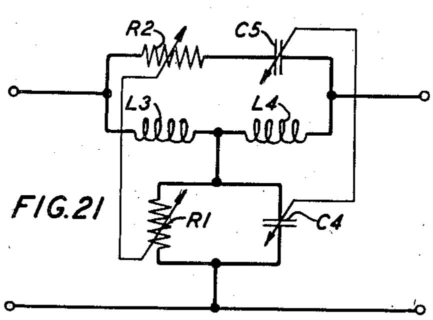

FIG. 21

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Patented Dec. 8, 1942 **2,304,545**

UNITED STATES PATENT OFFICE

2,304,545

WAVE TRANSMISSION NETWORK

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Application August 23, 1941, Serial No. 408,023

42 Claims. (Cl. 178—44)

This invention relates to wave transmission networks and more particularly to a combined variable phase shifter and attenuator.

An object of the invention is to combine the functions of a variable phase shifter and a variable attenuator in a single network.

Another object is to vary either the phase shift or the attenuation of a network without materially affecting the other characteristic.

Another object is to vary either the phase shift or the attenuation of a network without materially changing its image impedance.

A further object of the invention is to simplify the circuit of, and reduce the size and cost of, a network in which both the phase shift and the attenuation may be independently varied.

Heretofore, in wave transmission systems when it has been required to vary both the phase shift and the attenuation two independent networks have been used. In accordance with the present invention there is provided a single network in which both the phase shift and the attenuation may be varied, each substantially independently of the other, without materially affecting the image impedance. The network is of the bridged-T type, comprising two equal reactive series impedance branches, an interposed reactive shunt impedance branch and a reactive bridging impedance branch. A resistor is included in either the shunt branch or the bridging branch, or preferably, each of these branches includes a resistor. Each resistor may be connected either in series or in parallel with the impedance branch with which it is associated, or with a portion thereof.

In order to vary the phase shift, means are provided for varying the reactances of two of the reactive impedance branches, either the two series branches or the shunt branch and the bridging branch, and these means may be arranged for unitary control. In some cases it is necessary to vary three reactances, for example the two series branches and the bridging branch. In order to vary the attenuation, the resistor or resistors are made variable, and when two resistors are used, the means employed may also be under unitary control. An adjustment of the phase shift through a considerable range will have but slight effect upon the attenuation and on the other hand, when two resistors are used, an adjustment of the attenuation through a considerable range will change the phase shift only slightly. Furthermore, the network may be designed to have an image impedance which is a constant, pure resistance over a wide frequency range and adjusting either the phase shift or the attenuation will not materially change this impedance. This feature is of importance when the network is connected between matching resistive load impedances.

The nature of the invention will be more fully understood from the following detailed description and by reference to the accompanying drawings, in which like reference characters represent like or similar parts and in which:

Fig. 1 is a diagrammatic circuit showing one embodiment of the invention wherein two resistors are connected in parallel with their respective branches and the series reactive impedance branches are made variable;

Fig. 2 shows another embodiment of the invention similar to Fig. 1 except that the resistors are connected in series with their respective branches;

Fig. 3 is a circuit similar to that of Fig. 1 except that the reactances of the bridging branch and the shunt branch instead of the series branches, are made variable;

Fig. 4 shows a circuit similar to that of Fig. 3 except that the resistors are in series with their respective branches;

Fig. 5 is similar to Fig. 1 except that the resistor in the shunt branch is in series instead of in shunt therewith;

Fig. 6 is similar to Fig. 1 except that the resistor in the bridging branch is connected in series instead of in shunt;

Fig. 7 is similar to Fig. 3 except that the resistor in the shunt branch is in series therewith;

Fig. 8 is similar to Fig. 3 except that the resistor in the bridging branch is in series;

Fig. 9 is a specific circuit in accordance with Fig. 1, the series reactances being capacitors, the reactance in the bridging branch being an inductor and the reactance in the shunt branch being a second inductor;

Fig. 10 is similar to Fig. 9 except a variable capacitor has been added in parallel with the bridging branch;

Fig. 11 is similar to Fig. 9 except the resistors are in series with their associated reactances;

Fig. 12 follows the circuit of Fig. 3, the series reactances being inductors, the reactance in the bridging branch being a capacitor and the reactance in the shunt branch being a second capacitor;

Fig. 13 is the same as Fig. 10 except the inductors are variable instead of the capacitors;

Fig 14 is similar to Fig. 13 except that the Δ of capacitors has been replaced by its equivalent T;

Fig. 15 is similar to the circuit of Fig. 12 except that an inductor has been added in parallel with the bridging branch;

Fig. 16 is similar to Fig. 12 except the resistors are in series with their associated reactances instead of in parallel;

Fig. 17 is similar to Fig. 16 except an inductor has been added in series with the shunt branch;

Fig. 18 is similar to Fig. 9 except the resistor and the inductor in the shunt branch are connected in series instead of in parallel;

Fig. 19 is similar to Fig. 9 except the resistor and the inductor in the bridging branch are in series instead of in parallel;

Fig. 20 is similar to Fig. 16 except the resistor and the capacitor in the bridging branch are connected in parallel instead of in series; and

Fig. 21 is similar to Fig. 16 except the resistor and the capacitor in the shunt branch are in parallel instead of in series.

Returning to Fig. 1, there is shown schematically a symmetrical bridged-T structure embodying the invention. The network has a pair of input terminals 1, 2 and a pair of output terminals 3, 4 to which terminal loads of suitable impedance may be connected. The T comprises two equal reactive impedance branches X1 and X2 connected in series between the input terminal 1 and the corresponding output terminal 3 and an interposed shunt impedance branch, consisting of a reactive impedance X3 and a resistor R1 in parallel, connected on one side to the common terminal of the reactances X1, X2 and on the other side to the remaining input terminal 2 and output terminal 4. The bridging branch, which includes a resistor R2 and a reactive impedance X4 in parallel, is also connected between the terminals 1 and 3. The network is shown in its unbalanced form, so that the path connecting terminals 2 and 4 may be grounded or otherwise fixed in potential, but it may, of course, be built in the balanced form if desired.

The four reactive impedance branches X1, X2, X3 and X4 are designed as an all-pass bridged-T structure having an image impedance which is a constant, pure resistance at all frequencies and the desired phase shift over the operating frequency band for certain settings of the variable reactances X1 and X2. The mid-frequency of the operating range is usually placed at or near the point where the phase shift-frequency characteristic has the maximum slope. The phase shift is varied by increasing or decreasing each of the reactances X1 and X2 by the same amount. These reactances are made variable for this purpose and they may be arranged for unitary control, as indicated. Varying the phase shift over a considerable range does not materially affect the attenuation of the network and if this range is not great the image impedance is not much affected.

The attenuation of the network is largely dependent upon the values of the resistors R1 and R2 and these resistances are ordinarily large compared to the image impedance. To increase the attenuation R1 and R2 are decreased by proportional amounts, and to decrease the attenuation the resistances are increased by proportional amounts. In order to adjust the attenuation the resistors R1 and R2 are made variable and they may be arranged for unitary control as shown. Varying the attenuation over a considerable range does not materially affect either the phase shift or the image impedance of the network. If larger deviations in the image impedance are permissible either one of the resistors may be omitted in Fig. 1, or in any of the other figures.

The network of Fig. 2 is similar to the one shown in Fig. 1 except that the resistors R1 and R2 are connected in series with their associated reactive impedance branches instead of in parallel with them. In this case the resistors ordinarily have values which are small compared to the image impedance and they are increased by proportional amounts to increase the attenuation and decreased by proportional amounts to decrease the attenuation.

The circuits shown in Figs. 3 and 4 are similar to those shown in Figs. 1 and 2, respectively, except that the reactances X3 and X4 are varied instead of X1 and X2. In these networks the reactances are varied together in the same direction and by proportional amounts to adjust the phase shift.

The network of Fig. 5 is similar to the one of Fig. 1 except the resistor R1 is connected in series with the reactance X3 instead of in parallel. To increase the attenuation R1 is increased and R2 is decreased but the product of R1 and R2 is kept substantially constant.

The circuit shown in Fig. 6 is also similar to Fig. 1 but the resistor R2 is in series with X4 instead of being in parallel. In this case R1 is decreased and R2 is increased to increase the attenuation.

The network of Fig. 7 is similar to the one shown in Fig. 3 except that R1 is in series with X3. To increase the attenuation R1 is increased and R2 is decreased.

The circuit shown in Fig. 8 is also similar to Fig. 3 except that R2 is connected in series with X4. To increase the attenuation R1 is decreased and R2 is increased.

From the above, it is seen that the following general rules may be deduced as to the direction in which the resistors R1 and R2 are to be varied in order to vary the attenuation of the network:

1. If connected in series with its associated reactive impedance branch the resistor is increased in value to increase the attenuation and decreased in value to decrease the attenuation.

2. If connected in parallel with its associated reactive impedance branch the resistor is decreased in value to increase the attenuation and increased in value to decrease the attenuation.

An advantage of the networks in which both of the resistors R1 and R2 are connected in series with their associated reactances, or both are connected in parallel therewith, is that both resistors are varied proportionally and in the same direction in making attenuation adjustments. In the other circuits, in which one resistor is in series and the other one is in parallel, the resistors must be varied oppositely and the product of the two resistances is kept substantially constant for all settings. For the best image impedance this product is kept approximately equal to the square of the image impedance. Generally, it is easier to design two variable resistors, with unitary control, which are to be varied in the same direction and proportionally than resistors which are to be varied in opposite directions and inversely with respect to a constant.

The remaining figures show, by way of example only, a number of specific embodiments of the invention, and these will now be described briefly.

Fig. 9 is a combined variable phase shifter and attenuator following the generalized circuit shown in Fig. 1. The series reactances X1 and X2 are constituted, respectively, by the equal capacitors C1 and C2, the shunt reactance X3 is the inductor L1 and the bridging reactance X4 is a second inductor L2. The reactors just mentioned are formed into a phase shifter of the bridged-T type such as is shown, for example, in Fig. 13*a* of United States Patent 1,735,052 to Nyquist, issued November 12, 1929, the detailed design of which is given therein. The capacitors C1 and C2 are made variable, under a unitary control, to provide an adjustment of the phase shift. The resistor R1, connected in parallel with L1, and the resistor R2, in parallel with L2, are made variable, under a unitary control, to provide an adjustment of the attenuation.

The network shown in Fig. 10 is the same as Fig. 9 except that a parallel-connected capacitor C3 has been added to the bridging branch. This type of phase shifter is shown, for example, in Fig. 13*c* of the above-mentioned patent. In this case all three of the capacitors are made variable under a unitary control.

The circuit of Fig. 11 is similar to Fig. 9 except the resistors R1 and R2 are connected in series with their associated reactances.

The network of Fig. 12 follows the generalized circuit of Fig. 3. The series reactances are the equal inductors L3 and L4, the shunt reactance is the capacitor C4 and the bridging reactance is a second capacitor C5. This type of circuit is shown, for example, in Fig. 13 of the Nyquist patent.

The circuit of Fig. 13 is the same as Fig. 10 except that the inductors L1 and L2, instead of the three capacitors, are made variable.

The network shown in Fig. 14 is similar to Fig. 13 except that the Δ made up of the capacitors C1, C2 and C3 has been replaced by its equivalent T constituted by the capacitors C6, C7 and C8. This circuit is shown, for example, in Fig. 13*b* of the above-mentioned patent.

The circuit of Fig. 15 is similar to Fig. 12 except that a parallel-connected inductor L5 has been added to the bridging branch, as shown for example, in Fig. 11 of the Nyquist patent.

The network of Fig. 16 is similar to the one shown in Fig. 12 except that the resistors R1 and R2 are connected in series, instead of in parallel, with their associated reactances.

The network shown in Fig. 17 is similar to Fig. 16 except that an inductor L6 has been added in series with the shunt branch. This circuit is shown, for example, in Fig. 10 of the above-mentioned patent.

The circuit of Fig. 18 is similar to Fig. 9 except that the resistor R1 and the inductor L1 in the shunt branch are connected in series instead of in parallel.

The network shown in Fig. 19 is also similar to Fig. 9 except that the resistor R2 and the inductor L2 in the bridging branch are connected in series instead of in parallel.

The circuit of Fig. 20 is similar to Fig. 16 except that the resistor R2 and the capacitor C5 in the bridging branch are connected in parallel instead of in series.

The network shown in Fig. 21 is also similar to the circuit of Fig. 16 except that the resistor R1 and the capacitor C4 in the shunt branch are connected in parallel instead of in series.

As already mentioned, if a somewhat wider variation of the image impedance of the network is permissible for a given variation of the attenuation, one of the resistors, either R1 or R2, may be omitted. If this is done, about twice the former variation in the resistance value of the remaining resistor is required, for a given change in the attenuation. Furthermore, if only one variable resistor is used a somewhat larger change in the phase shift will occur for a given variation of the attenuation.

What is claimed is:

1. A combined variable phase shifter and attenuator of the bridged-T type comprising two reactive series impedance branches, an interposed reactive shunt impedance branch, a reactive bridging impedance branch, a variable resistor associated with one of the two last-mentioned branches and means for varying the reactances of two of said branches.

2. A network in accordance with claim 1 in which said resistor is associated with said shunt branch.

3. A network in accordance with claim 1 in which said resistor is associated with said bridging branch.

4. A network in accordance with claim 1 in which said resistor is connected in series with its associated branch.

5. A network in accordance with claim 1 in which said resistor is connected in parallel with its associated branch.

6. A network in accordance with claim 1 in which the reactances of said series branches are variable.

7. A network in accordance with claim 1 in which the reactances of said shunt branch and said bridging branch are variable.

8. A combined variable phase shifter and attenuator of the bridged-T type comprising two reactive series impedance branches, an interposed reactive shunt impedance branch, a reactive bridging impedance branch, two variable resistors included, respectively, in said shunt branch and in said bridging branch and means for varying the reactances of two of said branches.

9. A network in accordance with claim 8 in which each of said resistors is connected in series with its associated impedance branch.

10. A network in accordance with claim 8 in which each of said resistors is connected in parallel with its associated impedance branch.

11. A network in accordance with claim 8 in which one of said resistors is connected in series with its associated impedance branch and the other of said resistors is connected in parallel with its associated impedance branch.

12. A network in accordance wtih claim 8 in which the reactances of said series branches are variable.

13. A network in accordance with claim 8 in which the reactances of said shunt branch and said bridging branch are variable.

14. A network in accordance with claim 8 in which each of said series branches includes a capacitor.

15. A network in accordance with claim 8 in which each of said series branches includes a capacitor, said shunt branch include an inductor and said bridging branch includes a second inductor.

16. A network in accordance with claim 8 in which each of said series branches includes a capacitor, said shunt branch includes an inductor and said bridging branch includes a second inductor and another capacitor.

17. A network in accordance with claim 8 in which each of said series branches includes a capacitor, said shunt branch includes an inductor, said bridging branch includes a second inductor and one of said resistors is connected in parallel with its associated impedance branch.

18. A network in accordance with claim 8 in which each of said series branches includes a capacitor, said shunt branch includes an inductor, said bridging branch includes a second inductor and one of said resistors is connected in series with its associated impedance branch.

19. A network in accordance with claim 8 in which each of said series branches includes a variable capacitor.

20. A network in accordance with claim 8 in which each of said series branches includes a variable capacitor and said capacitors are arranged for unitary control.

21. A network in accordance with claim 8 in which each of said series branches includes an inductor.

22. A network in accordance with claim 8 in which each of said series branches includes an inductor, said shunt branch includes a capacitor and said bridging branch includes a second capacitor.

23. A network in accordance with claim 8 in which each of said series branches includes an inductor, said shunt branch includes a capacitor and another inductor and said bridging branch includes a second capacitor.

24. A network in accordance with claim 8 in which each of said series branches includes an inductor, said shunt branch includes a capacitor, said bridging branch includes a second capacitor and one of said resistors is connected in series with its associated impedance branch.

25. A network in accordance with claim 8 in which said shunt branch includes a variable capacitor and said bridging branch includes a second variable capacitor.

26. A network in accordance with claim 8 in which said shunt branch includes a variable capacitor, said bridging branch includes a second variable capacitor and said capacitors are arranged for unitary control.

27. A network in accordance with claim 8 in which said variable resistors are arranged for unitary control.

28. A network in accordance with claim 8 in which said means for varying the reactances are under unitary control.

29. A network in accordance with claim 8 in which said variable resistors are arranged for unitary control and said means for varying the reactances are under unitary control.

30. A combined variable phase shifter and attenuator of the bridged-T type comprising two variable series capacitors, an interposed shunt impedance branch including an inductor and a variable resistor and a bridging impedance branch including a second inductor and a second variable resistor.

31. A network in accordance with claim 30 in which said bridging branch includes a third capacitor.

32. A network in accordance with claim 30 in which said inductor and said resistor in said shunt branch are connected in parallel and said second inductor and said second resistor in said bridging branch are also connected in parallel.

33. A network in accordance with claim 30 in which said inductor and said resistor in said shunt branch are connected in series and said second inductor and said second resistor in said bridging branch are connected in parallel.

34. A network in accordance with claim 30 in which said variable capacitors are arranged for unitary control.

35. A network in accordance with claim 30 in which said variable resistors are arranged for unitary control.

36. A network in accordance with claim 30 in which said variable capacitors are arranged for unitary control and said variable resistors are also arranged for unitary control.

37. A combined variable phase shifter and attenuator of the bridged-T type comprising two series inductors, an interposed shunt impedance branch including a variable capacitor and a variable resistor and a bridging impedance branch including a second variable capacitor and a second variable resistor.

38. A network in accordance with claim 37 in which said shunt branch includes a third inductor.

39. A network in accordance with claim 37 in which said capacitor and said resistor in said shunt branch are connected in series and said second capacitor and said second resistor in said bridging branch are also connected in series.

40. A network in accordance with claim 37 in which said variable capacitors are arranged for unitary control.

41. A network in accordance with claim 37 in which said variable resistors are arranged for unitary control.

42. A network in accordance with claim 37 in which said variable capacitors are arranged for unitary control and said variable resistors are also arranged for unitary control.

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