May 6, 1947. G. H. BROWN 2,419,985

REACTANCE COMPENSATION

Filed Aug. 25, 1944 2 Sheets-Sheet 1

Fig. 1.

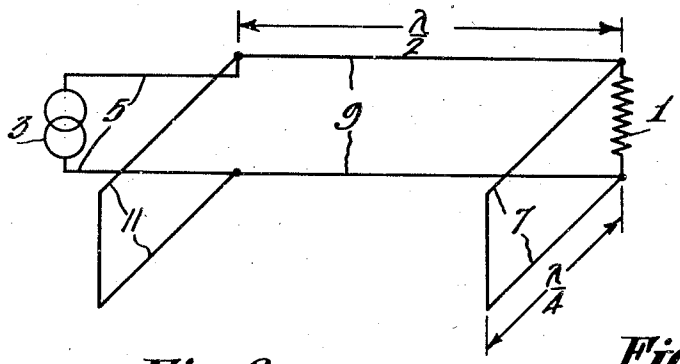


Fig. 2.

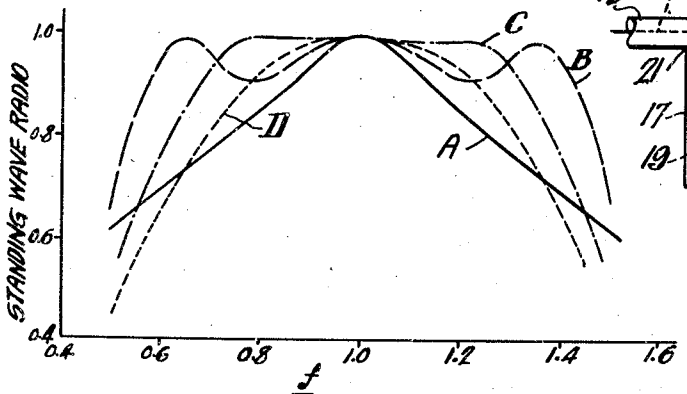


Fig. 4.

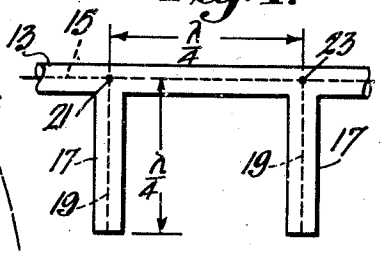


Fig. 5.

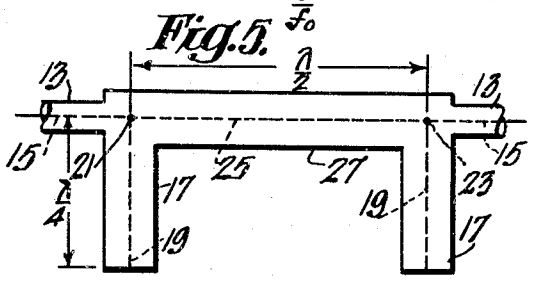
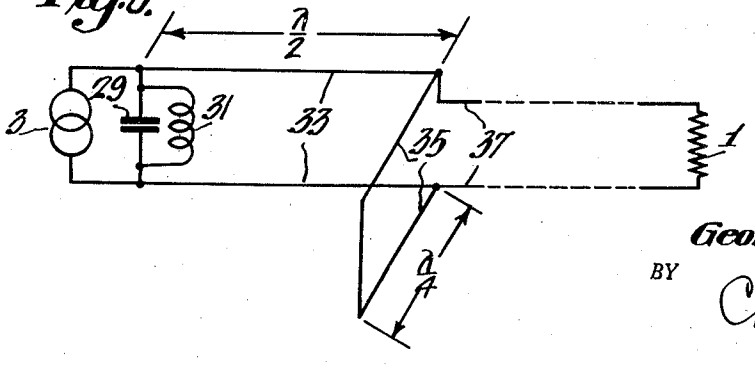


Fig. 8.



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May 6, 1947. G. H. BROWN 2,419,985

REACTANCE COMPENSATION

Filed Aug. 25, 1944 2 Sheets-Sheet 2

Fig. 6.

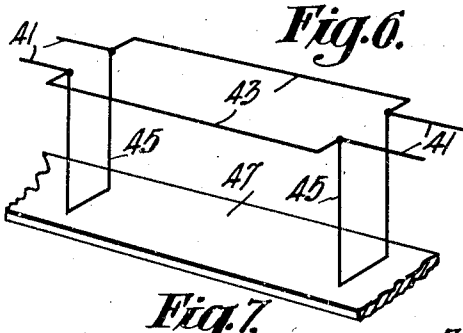


Fig. 7.

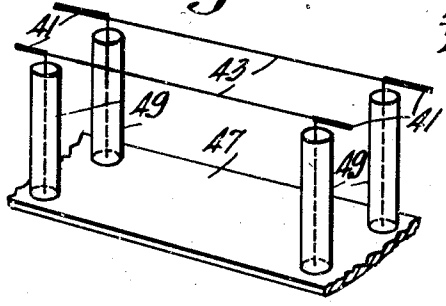


Fig. 5.

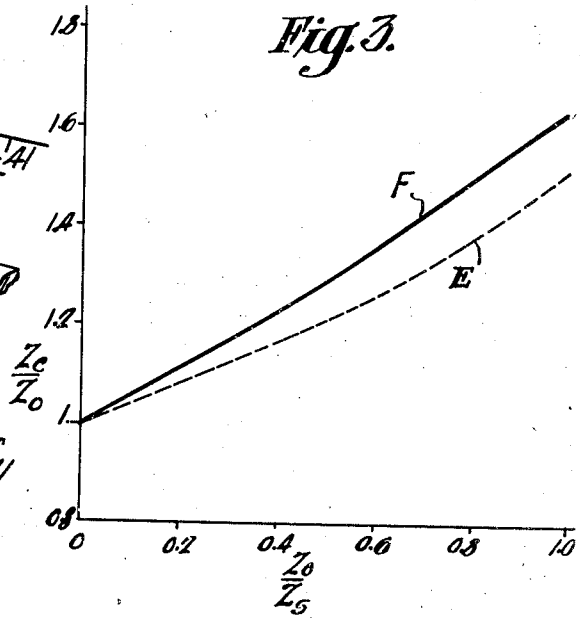


Fig. 9.

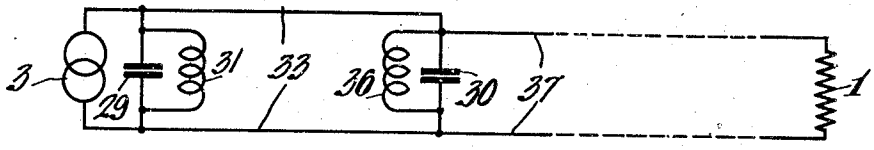
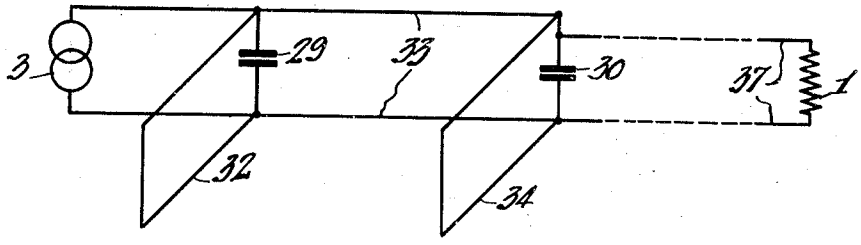


Fig. 10.



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Patented May 6, 1947 2,419,985

UNITED STATES PATENT OFFICE

2,419,985

REACTANCE COMPENSATION

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Application August 25, 1944, Serial No. 551,247

18 Claims. (Cl. 178—44)

1

This invention relates to reactance compensation and more particularly to improvements in the art of neutralizing the effects of the reactances which are unavoidably present in radio frequency power circuits. As is well known to those skilled in the art, the frequency band width throughout which a radio frequency transmission circuit operates efficiently to transfer power is a function of the shunt reactances present in the circuit. Thus a radio frequency source of internal resistance R shunted by a capacitance C will develop across a load of impedance R a voltage which is at least 70 percent of its maximum value at any frequency within a band of width

$$\Delta f=\frac{1}{\pi RC}$$

The center frequency f_0 of the band Δf depends upon the magnitude of inductance L connected across the source:

$$f_0=\frac{1}{2\pi\sqrt{LC}}$$

It is apparent that the greater the capacitance C, the narrower the band throughout which the system will transmit power efficiently.

The principal object of the present invention is to provide improved methods of and means for compensating the effects of reactance in radio frequency power circuits.

Another object is to provide improved methods of and means for obtaining broad-band operation of radio frequency power circuits.

A further object is to provide methods of and means for compensating the reactances of short-circuited quarter wave line sections such as are used in line balance convertor systems, quarter wave supporting stubs and the like.

A still further object is to provide an improved coaxial transmission line structure wherein the inner conductor is supported on quarter wave stub lines, including means for compensating the reactances of said stub lines.

These and other objects will become apparent to those skilled in the art upon consideration of the following description with reference to the accompanying drawings, of which Figure 1 is a schematic circuit diagram of a power transmission circuit embodying the invention; Figure 2 is a group of graphs illustrating the effects of varying the characteristic impedance of one of the transmission line elements in the circuit of Figure 1; Figure 3 is a further group of graphs illustrating the design of the circuit of Figure 1; Figure 4 is a schematic diagram of a stub supported coaxial transmission line constructed in accordance with prior art practice; Figure 5 is a schematic diagram of a stub supported coaxial line in accordance with the practice of the instant invention; and Figure 6 is a schematic diagram of a stub supported open-wire line analogous to the coaxial line of Figure 5; Figure 7 is a modification of Figure 6; Figure 8 is a schematic diagram of a further type of power transmission circuit embodying the invention; and Figures 9 and 10 are modifications of Figure 8.

2

Referring to Figure 1, it is assumed that a load 1, of impedance Z_0 is to be energized from a source 3, also of impedance Z_0 through a transmission line 5 having a characteristic impedance of Z_0. In the absence of any further circuit elements, the load 1 and line 5 will be matched to the source 3 at all frequencies, providing efficient transfer of power independently of frequency. It is assumed, however, that it is necessary to connect across the load 1 a transmission line section 7, short-circuited at its end remote from the load 1. It is well known that quarter wavelength short-circuited transmission lines exhibit characteristics similar to those of parallel resonant circuits. Thus at the frequency at which the line 7 is one-quarter wavelength long, a very high impedance, resistive in character, is presented across the load 1. At lower frequencies, the line 7 acts like an inductance connected to the load 1, while at higher frequencies the line 7 presents a capacitive reactance across the load 1. As long as the reactance of the line 7 is very much greater in magnitude than the impedance Z_0 of the load 1, there is substantially no impedance mismatch caused by the presence of the line 7. However, at all frequencies outside of a certain relatively narrow band, the reactance of the line 7 will be of the same order as the impedance Z_0, or lower. At any of these frequencies, a major portion of the current from the source 3 will flow through the line 7, causing serious impedance mismatch and preventing efficient transfer of energy from the source 3 to the load 1.

No great amount of energy is dissipated in the line 7 under the foregoing conditions. The current is reflected back down the line 5 to the source 3. Denoting the current transmitted by the source 3 as i_1, and the reflected current i_2, the absolute value of

$$\frac{i_2}{i_1}$$

is the reflection coefficient K. The degree of

impedance match is commonly expressed in terms of standing wave ratio R where

$$R=\frac{|i_1|-|i_2|}{|i_1|+|i_2|}$$

Referring to Figure 2, the standing wave ratio on the line 5 is a function of frequency, when supplying the load 1 shunted by the line 7 without compensation, as represented by the solid curve A. The ratio f/f_0 represents the departure from the resonant frequency of the line 7, that is f_0 is the resonant frequency of the line 7 and f is the actual frequency of the energy being transmitted. It is seen that at resonance the standing wave ratio is unity, indicating that no reflection occurs. At all other frequencies, R is less than 1, increasing with the departure from f_0. The curve of A, as well as the other curves of Figure 2, is based on the assumption that the characteristic impedance of the line 7 is twice the impedance of the load 1.

In accordance with the present invention, the line 5 terminates in a line section 9 of one-half wavelength at the resonant frequency of the line 7, and of impedance Z_c. A quarter wave line 11, electrically identical with the line 7, is connected across the junction between the lines 5 and 9. It is found that by adjusting the surge impedance Z_c of the line section 9 to the proper value, the standing wave ratio may be maintained substantially equal to 1 over a wide range of frequencies. The curves B, C and D of Figure 2 show how the ratio R varies with frequency with values of 1.1 Z_0, 1.2 Z_0, 1.3 Z_0 respectively for the surge impedance Z_c of the line section 9. It is seen that with $Z_c=1.1Z_0$, the standing wave ratio remains higher than .9 throughout the range .57 f_0 to 1.43 f_0. With $Z_c=1.2\ Z_0$, the ratio R remains substantially constant at unity from .75 f_0 to 1.25 f_0. The preferred value for Z_c probably lies somewhere between 1.1 and 1.2 Z_0, providing a standing wave characteristic intermediate those shown by curves B and C. Curve D shows clearly that 1.3 Z_0 is outside the preferred range of values for Z_c.

Families of curves similar to those of Figure 2 may be calculated and plotted for other ratios of

the impedance of the line 7 to the impedance of the load 1. From such families of curves the flattest curve, corresponding to the curve C of Figure 2, may be selected to determine the correct ratio Z_c/Z_0 for providing optimum reactance compensation. This has been done, and the results are illustrated by the curve E of Figure 3. The abscissa of the graph of Figure 3 is Z_0/Z_s, where Z_s is the surge impedance of the quarter wave line sections 7 and 11, and Z_0 of the impedance of the load 1. From the curve E the proper value of the impedance Z_c in terms of the load impedance Z_0 may be selected. Although the lines 5, 7, 11 and 9 are illustrated schematically in Figure 1 as parallel open-wire lines, it is to be understood that any or all of the above lines may be of coaxial construction.

Denoting the electrical length of the line section 9 as ρ, and that of the lines 7 and 11 as $\rho/2$, the impedance looking into the load 1 from the end of the line section 9 is

$$(1)\qquad Z_b=\frac{jZ_0Z_s\tan\rho/2}{Z_0+jZ_s\tan\rho/2}=\frac{jZ_0Z_s\sin(\rho/2)}{Z_0\cos(\rho/2)+jZ_s\sin\rho/2}$$

The impedance looking into the line section 9 from its junction with the line 5 is

$$(2)\qquad Z_d=\frac{\dfrac{jZ_0Z_s\sin(\rho/2)}{Z_0\cos\rho/2+jZ_s\sin\rho/2}+jZ_c\tan\rho}{Z_c-\dfrac{Z_0Z_s\sin\rho/2\tan\rho}{Z_0\cos\rho/2+jZ_s\sin\rho/2}}Z_c$$

$$=\frac{-Z_sZ_c\tan\rho\sin\rho/2+jZ_cZ_0\cos\rho/2\tan\rho+jZ_0Z_s\sin(\rho/2)}{Z_cZ_0\cos\rho/2-Z_0Z_s\sin\rho/2\tan\rho+jZ_cZ_s\sin\rho/2}Z_c$$

Denoting the impedance at the end of the line 5, looking into the line 9 and including the quarter wave line 11 as Z_i,

$$(3)\qquad \frac{1}{Z_i}=\frac{1}{Z_d}+\frac{1}{jZ_s\tan(\rho/2)}$$

$$(4)\qquad \frac{1}{Z_i}=\frac{Z_0Z_s\sin(\rho/2)\tan\rho-Z_cZ_0\cos\rho/2-jZ_cZ_s\sin\rho/2}{Z_sZ_c\tan\rho\sin\rho/2-jZ_cZ_0\cos\rho/2\tan\rho-jZ_0Z_s\sin\rho/2}\frac{1}{Z_c}-\frac{j}{Z_s\tan\rho/2}$$

Denoting the conductive component of the admittance

$$\frac{1}{Z_i}$$

as G_i:

$$(5)\qquad G_i=[(Z_0Z_s\sin\rho/2\tan\rho-Z_cZ_0\cos\rho/2)(Z_sZ_c\tan\rho\tan\rho/2)+(Z_cZ_0\cos\rho/2\tan\rho+Z_0Z_s\sin\rho/2)(Z_cZ_s)\sin\rho/2]$$
$$\div Z_c[(Z_sZ_c\tan\rho\sin\rho/2)^2+(Z_cZ_0\cos\rho/2\tan\rho+Z_0Z_s\sin\rho/2)^2]$$

Denoting the susceptive component of

$$\frac{1}{Z_i}$$

as B_i:

$$(6)\qquad B_i=[(Z_0Z_s\sin\rho/2\tan\rho-Z_cZ_0\cos\rho/2)(Z_cZ_0\cos\rho/2\tan\rho+Z_0Z_s\sin\rho/2)-Z_c^2Z_s^2\tan\rho\sin^2(\rho/2)]$$
$$\div Z_c[(Z_sZ_c\tan\rho\sin(\rho/2))^2+(Z_cZ_0\cos\rho/2\tan\rho+Z_0Z_s\sin\rho/2)^2]-\frac{1}{Z_s\tan\rho/2}$$
$$=[(Z_0^2-Z_c^2)Z_s^2\sin^2(\rho/2)\tan\rho-Z_c^2Z_0^2\cos^2(\rho/2)\tan\rho+Z_0^2Z_sZ_c\sin(\rho/2)\cos(\rho/2)\tan^2\rho-Z_0^2Z_sZ_c\sin\rho/2\cos\rho/2]$$
$$\div Z_c[(Z_sZ_c\tan\rho\sin(\rho/2))^2+(Z_cZ_0\cos\rho/2\tan\rho+Z_0Z_s\sin\rho/2)^2]-\frac{1}{Z_s\tan(\rho/2)}$$

Thus Z_i, R_i and X_i may be computed for any values Z_s, Z_0 and Z_c.

$$(7)\qquad Z_i=R_i+jX_i=\frac{1}{G_i+jB_i}$$

The standing wave ratio R may be computed as

mentioned above from the direct and reflected currents i_1 and i_2.

$$(8) \qquad i_1 = A\left[1+\frac{R_i}{Z_0}+j\frac{X_i}{Z_0}\right]$$

$$(9) \qquad i_2 = A\left[1-\frac{R_i}{Z_0}-j\frac{X_i}{Z_0}\right]$$

where A is a constant. The curves of Figure 2 are calculated by substituting the indicated values of Z_c, Z_0 and Z_s in the above Equations 4, 5, and 6 to determine R_i and X_i, which are substituted in Equations 8 and 9 to determine the currents i_1 and i_2 for calculating the standing wave ratio.

By differentiating the expression for B_i (Equation 6) with respect to ρ, substituting $\rho=\pi$ radians, and setting

$$\frac{d(B_i)}{d\rho}=0$$

and solving for Z_c in terms of Z_0:

$$(10) \qquad \frac{Z_c}{Z_0}=\frac{1+\sqrt{1+4\left(\frac{Z_s}{Z_0}\right)^2}}{2\frac{Z_s}{Z_0}}$$

This represents the value of

$$\frac{Z_c}{Z_0}$$

which provides zero rate of change of B_i with frequency. Equation 10 is represented graphically by the line F of Figure 3. It is seen that the curve F deviates from the curve E by a varying amount, up to about 10 percent at

$$\frac{Z_0}{Z_s}=1$$

This is accounted for by the fact that the curve which is flattest at f_0 is not necessarily the flattest throughout an appreciable range. See Figure 2. Since the values of

$$\frac{Z_c}{Z_0}$$

represented by the curve E were determined by inspection of families of curves like that of Figure 2, it is probable that the optimum value, for a given set of conditions, for the ratio

$$\frac{Z_c}{Z_0}$$

lies somewhere between that indicated by the curves E and F of Figure 3.

The above described method of reactance compensation may be applied to the design of a stub supported transmission line. Referring to Figure 4, a coaxial stub supported line constructed in accordance with prior art practice comprises an outer conductor **13** and an inner conductor **15**. In order to avoid the use of insulating materials for supporting the inner conductor **15**, a plurality of quarter wave short-circuited stub lines are provided, with their outer conductors **17** connected to the outer conductor **13**, and their inner conductors **19** connected to and supporting the inner conductor **15**. At the frequency at which the stub supporting lines are exactly one-quarter wavelength, the impedances presented by the stubs are so great with respect to the characteristic impedance of the line **13, 15** that their shunting effect is negligible. At lower frequencies, the lines **17, 19** present inductive reactances

along the line **13, 15** and at higher frequencies, capacitive reactances. These reactances are neutralized to some extent by placing the stub lines at points **21** and **23**, one-quarter wavelength apart along the line **13, 15**. At frequencies somewhat lower than f_0, the inductive reactance presented by the stub at the point **21** is substantially inverted by the quarter wave section between the points **21** and **23** to provide capacitive reactance at the point **23**, which tends to cancel the inductive reactance presented by the other stub line at the point **23**. Thus the system of Figure 4 will operate efficiently throughout a band of frequencies, rather than only at the single frequency f_0. The same principle may be applied to a stub supported parallel open-wire line.

Referring to Figure 5, a stub supported coaxial line in accordance with the instant invention is shown. This line will operate over a wider band of frequencies than that shown in Figure 4. A line section comprising inner and outer conductors **25** and **27** respectively is inserted in series in the line **13, 15**. The section **25, 27** is one-half wavelength long at the frequency f_0, and the stubs **17, 19** are connected to the ends thereof. By proportioning the diameters of the conductors **25** and **27** to provide the proper surge impedance in accordance with the information illustrated graphically in Figure 3, the half wave line section and the supporting stubs are designed to introduce substantially no reflection throughout a relatively wide band of frequencies. It will be apparent that supporting sections such as that illustrated in Figure 5 may be placed at points along the line **13, 15** as far apart or as close together as dictated by mechanical consideration. A further possibility is to provide a stub at each half wavelength interval along the line **13, 15**. In this case the diameters of the inner and outer conductors will remain constant throughout the length of the transmission line. However, the input and output impedances of the line will be somewhat lower than the characteristic impedance of the line itself.

As is the case with the prior art stub supported line of Figure 4, analogous parallel open-wire lines may be constructed embodying the principles illustrated in Figure 5. Referring to Figure 6, an open-wire line comprising parallel conductors **41** includes a section **43** one-half wavelength long of characteristic impedance Z_c, shunted at each end by quarter wave open-wire stubs **45**, short-circuited at their lower ends, which rest on a supporting surface **47**. The correct value of the impedance Z_c of the section **43** may be obtained by adjustment of the spacing between the conductors **43**, as shown in Figure 6, or by using conductors in the section **43** which are of a different diameter from the conductors **41**.

Referring to Figure 7, a structure similar to that of Figure 6 is illustrated, in which the half wave conductors **43** are spaced the same as the conductors **41**, but are of smaller diameters to provide the correct value of Z_c. Coaxial quarter wave stubs **49** are substituted for the open-wire stubs **45** of Figure 6. Each of the stubs **49** comprises a conductor **50** surrounded by a conductive sleeve **52**. The sleeve **52** is one-quarter wavelength long at the mean operating frequency and is connected at its lower end to the conductor **50**. Four coaxial stubs **49** are required, one for each end of the conductors **43**. Each stub operates like the stubs **17, 19** of Figure 5. The operation of the system of Figure 7 is like that of Figure 6.

A further application of the invention is illustrated in Figure 8. A radio frequency source 3, which may be a vacuum tube oscillator or amplifier, is to be coupled to a load 1. It is assumed that the impedance of the source 1 is matched to that of the load 1. A capacitance, represented by a capacitor 29, is shunted across the source 3. As stated above, the smaller the value of the capacitor 29, the broader the band throughout which energy can be transmitted to the load 1. The capacitor 29 is shunted by an inductor 31 to resonate at the center frequency f_0 of the band throughout which transmission is desired. A half wavelength line section 33 is connected at one end to the source 3. The other end of the line 33 is shunted by a quarter wave stub 35. A line 37 is connected to the line 33 and across the stub 35, and extends to the load 1. The line 37 is designed to have a characteristic impedance Z_0 equal to the impedance R of the load 1. The characteristic impedance Z_s of the stub 35 is made equal to

$$\frac{1}{Sf_0C}$$

which is equal to

$$\frac{\pi}{4}\sqrt{\frac{L}{C}}$$

where L is the inductance of the inductor 31 and C is the capacitance of the capacitor 29. The proper characteristic impedance Z_c for the half wave section 33 may be determined from the curve E of Figure 3.

Referring to Figure 9, a capacitor 39 and an inductor 36, identical with the capacitor 29 and inductor 31, may be placed at the end of the half wave section 33 instead of the stub 35 of Figure 8. The impedance Z_c of the section 33 may be determined by using a value of

$$Z_s=\frac{1}{Sf_0C}$$

with the curve E of Figure 2.

Figure 10 illustrates a further modification, wherein stub lines 32, and 34, not necessarily one-quarter wavelength long, but identical with each other, are substituted for the inductors 31 and 36 of Figure 9. The system of Figure 10 is otherwise identical with that of Figure 9 and is designed in the same manner.

Thus the invention has been described as an improvement in the art of reactance compensation. A half wavelength transmission line is connected to the point at which the reactance to be compensated appears, and is shunted at its other end by a reactance element substantially identical with that to be compensated. By adjusting the characteristic impedance of the half wavelength line in accordance with that of the reactance elements and the impedance of the transmission circuit, compensation is effected throughout a relatively wide band of frequencies. Several applications of the invention have been described. It is to be understood, however, that the invention may be used in numerous other situations where undesirable reactance is present. One such application is illustrated in copending U. S. patent application Serial No. 550,566, filed by G. H. Brown and D. W. Peterson on August 22, 1944, and entitled Radio power division networks, wherein the reactance of a line balance convertor device is compensated.

The invention covered herein may be manufactured and used by or for the Government of the United States for any governmental purpose without payment to me or assigns of any royalty thereon.

I claim as my invention:

1. In a radio frequency network including a load and a reactance element shunting said load, means for compensating the effects of said reactance element comprising a transmission line one half wavelength long at the center of the band of frequencies throughout which the system is to operate, connected at one end to said load, and a second reactance element substantially identical with said first reactance element connected to the other end of said line.

2. In a radio frequency network including a source and a reactance element shunting said source, means for compensating the effects of said reactance element comprising a transmission line one half wavelength long at the center of the band of frequencies throughout which the system is to operate, connected at one end to said source, and a second reactance element substantially identical with said first reactance element connected to the other end of said line.

3. A radio frequency network including a source of radio frequency energy, a load, a resonant element shunting said load and resonant at the center of the band of frequencies throughout which the system is to operate, and means for compensating the reactance effects of said resonant element, comprising a transmission line substantially one half wavelength long at the center of the band of frequencies throughout which the system is to operate, with one of its ends connected to said load and the other of its ends connected to said source, and a second resonant element connected to said last mentioned end of said line and resonant at the center of the band of frequencies throughout which the system is to operate.

4. A radio frequency network including a source of radio frequency energy, a load, a resonant element shunting said source and resonant at the center of the band of frequencies throughout which the system is to operate, and means for compensating the reactance effects of said resonant element, comprising a transmission line substantially one half wavelength long at the center of the band of frequencies throughout which the system is to operate, with one of its ends connected to said source and the other of its ends connected to said load, and a second resonant element connected to said last mentioned end of said line and resonant at the center of the band of frequencies throughout which the system is to operate.

5. In a radio frequency network including a load of impedance Z_0, shunted by an element which exhibits parallel resonant characteristics to energy of wavelength λ, and has a surge impedance Z_s, a system for compensating the reactance of said element throughout a band of frequencies, comprising a transmission line of length $\lambda/2$ and surge impedance Z_c, connected at one of its ends to said load, and a second element exhibiting parallel resonant characteristics identical with those of said first mentioned element, connected to the other end of said line, the surge impedance Z_c of said line being such as to satisfy the relation:

$$\frac{Z_c}{Z_0}=\frac{1+\sqrt{1+4\left(\frac{Z_s}{Z_0}\right)^2}}{2\frac{Z_s}{Z_0}}$$

6. In a radio frequency network including a source of impedance Z_0, shunted by an element which exhibits parallel resonant characteristics to energy of wavelength λ, and has a surge impedance Z_s, a system for compensating the reactance of said element throughout a band of frequencies, comprising a transmission line of length $\lambda/2$ and surge impedance Z_c, connected at one of its ends to said source, and a second element exhibiting parallel resonant characteristics identical with those of said first mentioned element, connected to the other end of said line, the surge impedance Z_c of said line being such as to satisfy the relation:

$$\frac{Z_c}{Z_0}=\frac{1+\sqrt{1+4\left(\frac{Z_s}{Z_0}\right)^2}}{2\frac{Z_s}{Z_0}}$$

7. In a radio frequency network including a load of impedance Z_0, shunted by an element which exhibits parallel resonant characteristics to energy of wavelength λ, and has a surge impedance Z_s, a system for compensating the reactance of said element throughout a band of frequencies, comprising a transmission line of length $\lambda/2$ and surge impedance Z_c, connected at one of its ends to said load, and a second element exhibiting parallel resonant characteristics identical with those of said first mentioned element, connected to the other end of said line, the surge impedance Z_c of said line being such that the quantity

$$\frac{Z_c}{Z_0}$$

has a value lying within the range of 90 percent to 100 percent of that of the quantity

$$\frac{1+\sqrt{1+4\left(\frac{Z_s}{Z_0}\right)^2}}{2\frac{Z_s}{Z_0}}$$

8. In a radio frequency network including a source of impedance Z_0, shunted by an element which exhibits parallel resonant characteristics to energy of wavelength λ, and has a surge impedance Z_s, a system for compensating the reactance of said element throughout a band of frequencies, comprising a transmission line of length $\lambda/2$ and surge impedance Z_c, connected at one of its ends to said source, and a second element exhibiting parallel resonant characteristics identical with those of said first mentioned element, connected to the other end of said line, the surge impedance Z_c of said line being such that the quantity

$$\frac{Z_c}{Z_0}$$

has a value lying within the range of 90 percent to 100 percent of that of the quantity

$$\frac{1+\sqrt{1+4\left(\frac{Z_s}{Z_0}\right)^2}}{2\frac{Z_s}{Z_0}}$$

9. In a radio frequency network including a source of radio frequency energy, a load of impedance Z_0, a transmission line section connected to said load device, and having a length of an integral number of quarter wavelengths at the center of the band of frequencies throughout which the system is to operate and a surge impedance Z_s, a system for compensating the reactance of said transmission line section, including a second transmission line section of one half wavelength and a surge impedance Z_c connected at one of its ends to said load and at the other of its ends to said source, and a third transmission line section substantially identical electrically with said first transmission line section, connected to the source end of said half wave line, the impedances Z_0, Z_s and Z_c being related as follows:

$$\frac{Z_c}{Z_0}=\frac{1+\sqrt{1+4\left(\frac{Z_s}{Z_0}\right)^2}}{2\frac{Z_s}{Z_0}}$$

10. In a radio frequency network including a load, a source of impedance Z_0, a transmission line section connected to said source, and having a length of an integral number of quarter wavelengths at the center of the band of frequencies throughout which the system is to operate and a surge impedance Z_s, a system for compensating the reactance of said transmission line section, including a second transmission line section of one half wavelength and a surge impedance Z_c connected at one of its ends to said load and at the other of its ends to said source, and a third transmission line section substantially identical electrically with said first transmission line section, connected to the load end of said half wave line, the impedances Z_0, Z_s and Z_c being related as follows:

$$\frac{Z_c}{Z_0}=\frac{1+\sqrt{1+4\left(\frac{Z_s}{Z_0}\right)^2}}{2\frac{Z_s}{Z_0}}$$

11. In a radio frequency network including a source of radio frequency energy, a load of impedance Z_0, a transmission line section connected to said load device, and having a length of an integral number of quarter wavelengths at the center of the band of frequencies throughout which the system is to operate and a surge impedance Z_s, a system for compensating the reactance of said transmission line section, including a second transmission line section of one half wavelength and a surge impedance Z_c connected at one of its ends to said load and at the other of its ends to said source, and a third transmission line section substantially identical electrically with said first transmission line section, connected to the source end of said half wave line, the impedances Z_0, Z_s and Z_c being related so that the quantity

$$\frac{Z_c}{Z_0}$$

has a value within the range of 90 percent to 100 percent of that of the quantity

$$\frac{1+\sqrt{1+4\left(\frac{Z_s}{Z_0}\right)^2}}{2\frac{Z_s}{Z_0}}$$

12. In a radio frequency network including a source of radio frequency energy, a load of impedance Z_0, a transmission line section connected to said source, and having a length of an integral number of quarter wavelengths at the center of the band of frequencies throughout which the system is to operate and a surge impedance Z_s, a system for compensating the reactance of said

transmission line section, including a second transmission line section of one half wavelength and a surge impedance Z_c connected at one of its ends to said load and at the other of its ends to said source, and a third transmission line section substantially identical electrically with said first transmission line section, connected to the load end of said half wave line, the impedances Z_0, Z_s, and Z_c being related so that the quantity

$$\frac{Z_c}{Z_0}$$

has a value within the range of 90 percent to 100 percent of that of the quantity

$$\frac{1+\sqrt{1+4\left(\frac{Z_s}{Z_0}\right)^2}}{2\frac{Z_s}{Z_0}}$$

13. In a radio frequency network including a source of radio frequency energy, a load of impedance Z_0, a transmission line section one-quarter wavelength long connected at one end to said load device, and short-circuited at its other end and having a surge impedance Z_s, and a system for compensating the reactance of said transmission line section, including a second transmission line section of one half wavelength and a surge impedance Z_c connected at one of its ends to said load and at the other of its ends to said source, and a third transmission line section substantially identical electrically with said first transmission line section, with one end connected to the source end of said half wave line and its other end short-circuited, the impedances Z_0, Z_s and Z_c being related so that the quantity

$$\frac{Z_c}{Z_0}$$

has a value within the range of 90 percent to 100 percent of that of the quantity:

$$\frac{1+\sqrt{1+4\left(\frac{Z_s}{Z_0}\right)^2}}{2\frac{Z_s}{Z_0}}$$

14. In a radio frequency network including a source of radio frequency energy, a load of impedance Z_0, a transmission line section one-quarter wavelength long connected at one end to said source and short-circuited at its other end, and having a surge impedance Z_s, and a system for compensating the reactance of said transmission line section, including a second transmission line section of one half wavelength and a surge impedance Z_c connected at one of its ends to said load and at the other of its ends to said source, and a third transmission line section substantially identical electrically with said first transmission line section, with one end connected to the load end of said half wave line and its other end short-circuited, the impedance Z_0, Z_s and Z_c being related so that the quantity

$$\frac{Z_c}{Z_0}$$

has a value within the range of 90 percent to 100 percent of that of the quantity:

$$\frac{1+\sqrt{1+4\left(\frac{Z_s}{Z_0}\right)^2}}{2\frac{Z_s}{Z_0}}$$

15. A radio frequency power transmission system including a load of impedance Z_0, a radio frequency source of impedance Z_0, a transmission line having a surge impedance Z_c connecting said load to said source, and a plurality of short-circuited stub line sections of lengths $\lambda/4$ and surge impedance Z_s connected to said transmission line at intervals along its length of $\lambda/2$, wherein λ is the wavelength at the center of the band of frequencies throughout which the system is to operate, and the impedances Z_0, Z_s, and Z_c are related so that the quantity

$$\frac{Z_c}{Z_0}$$

has a value within the range of 90 percent to 100 percent of that of the quantity:

$$\frac{1+\sqrt{1+4\left(\frac{Z_s}{Z_0}\right)^2}}{2\frac{Z_s}{Z_0}}$$

16. A stub supported coaxial transmission line of characteristic impedance Z_0, including at least one supporting member comprising a half wavelength coaxial line section of characteristic impedance Z_c provided with short-circuited quarter wave supporting stub lines of characteristic impedance Z_s connected to each end thereof, wherein

$$\frac{Z_c}{Z_0}$$

is within the range of 90 per cent to 100 percent of

$$\frac{1+\sqrt{1+4\left(\frac{Z_s}{Z_0}\right)^2}}{2\frac{Z_s}{Z_0}}$$

17. In a radio frequency power system including a source of internal resistance R and a capacitance C, tuned to resonance at a frequency f by a shunt inductance L, a load of resistance R, broad band transmission means for coupling said source to said load including a transmission line of one half wavelength at the frequency f and of characteristic impedance Z_c connected between said load and said source, and a short-circuited transmission line of one-quarter wavelength at the frequency f and of characteristic impedance Z_s connected across said load, wherein Z_s and Z_c are related to R in such manner that

$$\frac{Z_c}{R}$$

is within the range of 90 percent to 100 percent of

$$\frac{1+\sqrt{1+4\left(\frac{Z_s}{R}\right)^2}}{2\frac{Z_s}{R}}$$

18. A stub supported transmission line of characteristic impedance Z_0, including at least one supporting member comprising a half wavelength line section of characteristic impedance Z_c provided with short-circuited quarter wave supporting stub lines of characteristic impedance Z_s connected to each end thereof, wherein

$$\frac{Z_c}{Z_s}$$

is within the range of 90 percent to 100 percent of

$$\frac{1+\sqrt{1+4\left(\frac{Z_s}{Z_c}\right)^2}}{2\frac{Z_s}{Z_0}}$$

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