

Nov. 14, 1944.

S. G. HALE

2,362,549

WAVE TRANSMISSION NETWORK

Filed Sept. 23, 1942

FIG. 1

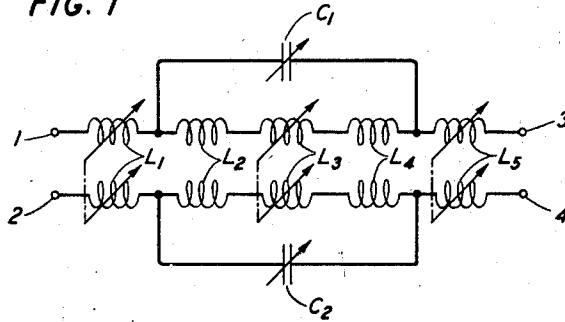


FIG. 2

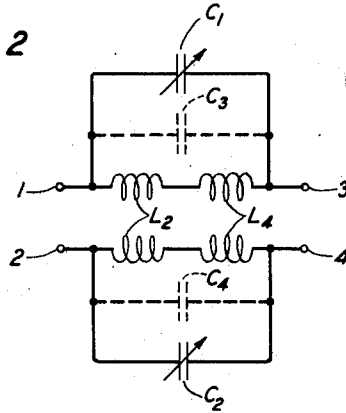
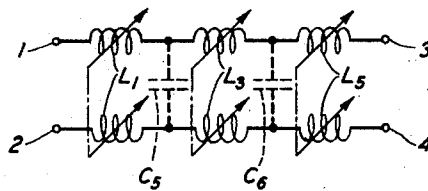


FIG. 3



INVENTOR
S. G. HALE

BY

Ralph T. Holcomb
ATTORNEY

UNITED STATES PATENT OFFICE

2,362,549

WAVE TRANSMISSION NETWORK

Stuart G. Hale, Chatham, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application September 23, 1942, Serial No. 459,401

31 Claims. (Cl. 178-44)

This invention relates to wave transmission networks and more particularly to a network for suppressing undesired longitudinal currents in a transmission line.

The principal object is to suppress undesired longitudinal currents over a range of frequencies without interfering with the transmission of signal currents in the same range in the loop circuit of a transmission line.

Another object is to improve the impedance match between a suppression network and the terminal loads between which it operates, and thereby reduce reflection effects at the junctions.

In order to suppress undesired longitudinal currents flowing in the same direction in both wires of a transmission line, a so-called suppression coil is inserted in the line. Such a coil has two equal, closely coupled windings connected one in each side of the line. A coil structure which will provide the extremely high balance to ground required and close inductive coupling will also have a comparatively large interwinding capacitance. This capacitance is, in effect, shunted across the line and, as a result, the suppression coil will have a poor impedance match with the line. This impedance mismatch causes undesirable reflection effects at the junctions of the coil and the line.

In accordance with the present invention the impedance match between the suppression coil and the line is greatly improved by the addition of auxiliary coils. There are preferably three of these and each one comprises two equal windings, one in each side of the line. One of the auxiliary coils is inserted in series at the midpoint of the suppression coil, which is split into two equal sections, and the other auxiliary coils are connected in series at the outer ends of the suppression coil sections. These auxiliary coils and the interwinding shunt capacitances associated with the two sections of the suppression coil thus form a two-section, low-pass wave filter effective in the loop circuit. The inductances of the auxiliary coils are so chosen that this filter has a nominal image impedance which matches the characteristic impedance of the line or other terminal load. The impedance match can be extended to a higher frequency if the end sections of the filter are given a fractional termination equal to K , where K in most cases falls between 0.3 and 0.4, and generally has an optimum value in the neighborhood of 0.36. To accomplish this, the inductance of each of the end auxiliary coils is made equal to K times the inductance of the central auxiliary coil. The inductances of the

auxiliary coils are preferably made variable so that the image impedance of the network may be precisely adjusted to the desired nominal value.

For a given nominal image impedance, the cut-off frequency of the filter is inversely proportional to the magnitude of the interwinding capacitances associated with the suppression coil. Since the cut-off must be above the upper limit of the range of the signal currents, and preferably several times this frequency, it is desirable to limit these capacitances to the lowest possible values.

The suppression coil is preferably so designed that the longitudinal distributed capacitance associated therewith causes the coil to antiresonate at some selected frequency at or near the upper end of the suppression range for longitudinal currents. In order to provide means for adjusting this frequency, and also for compensating for manufacturing variations in the distributed capacitance, variable capacitors may be connected in parallel with the windings of the suppression coil.

The nature of the invention will be more fully understood from the following detailed description and by reference to the accompanying drawing, of which:

Fig. 1 is a schematic circuit of a suppression network in accordance with the invention;

Fig. 2 is a schematic circuit of the network effective in the longitudinal circuit; and

Fig. 3 is a schematic circuit of the low-pass filter effective in the loop circuit.

Taking up the figures in more detail, the suppression network shown in Fig. 1 comprises a suppression coil, made up of two equal sections L_2 and L_4 , and three auxiliary coils L_1 , L_3 and L_5 . Each of the auxiliary coils, and also each section of the suppression coil, has two equal windings, connected one in each side of the line. The coils are all connected in tandem between two pairs of terminals 1, 2 and 3, 4, one pair of which serves as the input and the other as the output. The central auxiliary coil L_3 is connected between the sections L_2 and L_4 of the suppression coil and the other two auxiliary coils L_1 and L_5 are connected, respectively, at the outer ends of the suppression coil. The two variable capacitors C_1 and C_2 are bridged across the outer terminals of the suppression coil, one in each side of the line.

The function of the suppression coil is to suppress undesired longitudinal currents, that is, currents flowing in the same direction in both sides of the line, with ground as the return path.

However, this coil must not impede the flow of signal currents in the loop circuit, that is, the metallic circuit comprising the two sides of the line. To accomplish this, the two line windings of each of the sections L_2 and L_4 of the suppression coil are closely coupled inductively and connected in the series-opposing relationship for the loop circuit, which is parallel-aiding for the longitudinal circuit. This coil will, then, introduce a maximum impedance in the longitudinal circuit and a negligible impedance in the loop circuit.

The network effective in the longitudinal circuit is shown schematically in Fig. 2. The parallel-aiding inductance of the suppression coil provides a series impedance in this circuit. The auxiliary coils L_1 , L_3 and L_5 do not appear in this circuit since their inductance is negligibly small compared to that of the suppression coil and, furthermore, their line windings are usually coupled inductively and connected series-aiding for the loop circuit, which is parallel opposing for the longitudinal circuit. Bridged between the terminals 1 and 3 are the parallel-connected capacitances C_1 and C_3 , and between the terminals 2 and 4 are the parallel-connected capacitances C_2 and C_4 . The capacitances C_3 and C_4 represent the inherent longitudinal distributed capacitances associated with the suppression coil and are, therefore, shown in broken line. These capacitances cause the suppression coil to antiresonate at some frequency and the coil is so designed that this frequency is at or near the upper limit of the suppression range, thus providing maximum suppression of longitudinal currents at this frequency. The inductance of the suppression coil is, therefore, made as large as possible consistent with providing antiresonance at the desired frequency. However, since the longitudinal distributed capacitances C_3 and C_4 are subject to manufacturing variations from coil to coil the variable auxiliary capacitors C_1 and C_2 are added so that the frequency of antiresonance may be accurately adjusted. The capacitances of the capacitors C_1 and C_2 are kept equal so that a high degree of balance to ground may be maintained for the network. These capacitances may conveniently be furnished by short sections of a parallel pair of wires.

In order to get the required high degree of balance to ground, together with good magnetic coupling between line windings, the suppression coil may be wound from a twisted pair conductor in two sections on a toroidal core of powdered magnetic material. Such a construction, however, has a comparatively large shunt capacitance effective between the windings in the two sides of the line. This inherent shunt capacitance degrades the impedance match between the network and the line and gives rise to reflection effects in the loop circuit.

In accordance with the present invention, the detrimental effect of this shunt capacitance is effectively overcome by adding the three series-connected auxiliary coils L_1 , L_3 and L_5 so as to form, with the shunt capacitance, a low-pass filter structure. Fig. 3 shows the resulting network effective in the loop circuit. The capacitance C_5 is the total shunt capacitance effective between the two line windings of the suppression coil section L_2 , and C_6 is that associated with the coil section L_4 . Since these are inherent capacitances they are shown in broken line. The suppression coil furnishes only a negligible inductance in the loop circuit since its line windings are

closely coupled and connected series-opposing for this circuit. The capacitances C_1 , C_2 , C_3 and C_4 may also be disregarded in this circuit since they are comparatively small and their chief effect is to produce a peak of attenuation at some high frequency of the order of twice the cut-off frequency.

In the simplified form shown in Fig. 3 the filter is made up of the three balanced inductances L_1 , L_3 and L_5 connected in series, with the capacitances C_5 and C_6 connected in shunt at the junction points. There is thus provided a balanced filter comprising a full central section and two fractional end sections. The sections are of the low-pass type such as is shown, for example, in Fig. 7 of United States Patent No. 1,227,113, issued May 22, 1917, to G. A. Campbell. In accordance with filter theory the full central coil L_3 will have a series-aiding inductance given by the formula

$$L_3 = CR^2 \quad (1)$$

where C is the full shunt capacitance and R is the nominal image impedance of the filter. As is customary, R is made approximately equal to the impedance of the transmission line or other terminal load with which the filter is to operate. Each of the end coils L_1 and L_5 will have a series-aiding inductance equal to

$$L_1 = L_5 = KL_3 \quad (2)$$

where K is the value of the fractional end section. Each of the shunt capacitances C_5 and C_6 is made up of a half shunt capacitance $0.5C$, associated with the central section, plus a fractional shunt capacitance KC , associated with one of the fractional end sections. Therefore,

$$C_5 = C_6 = 0.5C + KC \quad (3)$$

For the best impedance match over a wide frequency range, K should, in general, have a value falling between 0.3 and 0.4, with approximately 0.36 as the optimum value. When K is equal to 0.36, from Equation 3

$$C_5 = C_6 = 0.5C + 0.36C = 0.86C \quad (4)$$

and therefore,

$$C = \frac{C_5}{0.86} = \frac{C_6}{0.86} \quad (5)$$

From Equation 1

$$L_3 = \frac{C_5 R^2}{0.86} = \frac{C_6 R^2}{0.86} \quad (6)$$

and from Equation 2

$$L_1 = L_5 = 0.36L_3 \quad (7)$$

The required values of the inductances L_1 , L_3 and L_5 are, therefore, given by Equations 6 and 7 in terms of the nominal image impedance R and the shunt capacitance C_5 or C_6 .

The cut-off frequency f_c of the filter is given by the formula

$$f_c = \frac{1}{\pi CR} = \frac{0.86}{\pi C_5 R} = \frac{0.86}{\pi C_6 R} \quad (8)$$

The cut-off must be above the upper limit of the signal range, and is preferably several times that frequency. The higher the cut-off frequency f_c the better the impedance match will be over the signal range. It is seen from Equation 8 that f_c is inversely proportional to the magnitude of the shunt capacitance C_5 or C_6 . It is, therefore, desirable to keep these capacitances as small as is consistent with a high balance to ground and close coupling between the line windings of the suppression coil.

The two line windings of each of the auxiliary coils L_1 , L_2 and L_3 may be constructed as two dual solenoids on a fiber tube. Stranded wire is preferably used, to reduce the attenuation introduced into the loop circuit. Furthermore, they may be inductively coupled, for the same reason, in which case they are connected in the series-aiding relationship for the loop circuit. These coils are preferably made variable in inductance so that the image impedance of the filter may be precisely adjusted to the desired nominal value. Ordinarily, an adjustment range of about eight or ten per cent in the series-aiding inductance will be sufficient. Plug-type cores of powdered magnetic material inserted in the tube may conveniently be used for this purpose, provided certain requirements are met. The two cores associated with the two line windings of each coil are preferably placed on a single push rod so that the self-inductance of each line winding will be changed by the same amount, thus maintaining the balance to ground. Since these windings may carry signal currents at high energy levels it is necessary to limit the flux density in the cores to such a value that harmonic generation is negligible.

What is claimed is:

1. A wave transmission network for suppressing undesired longitudinal currents over a range of frequencies while freely transmitting signal currents in the same range in the loop circuit of a transmission line comprising two suppression coil sections and three auxiliary coils all connected in series, each of said sections and each of said auxiliary coils comprising two equal line windings connected one in each side of the line, said two windings of each of said sections having close inductive coupling and being connected in the series-opposing relationship for said loop circuit, one of said auxiliary coils being connected between said sections, the other of said auxiliary coils being connected, respectively, at the outer ends of said sections and the inductance of said one auxiliary coil being approximately equal to the shunt capacitance effective between said line windings of one of said sections multiplied by the square of the impedance of a terminal load with which said network is to operate and divided by the factor $(0.5+K)$ when K has a value falling between 0.3 and 0.4.

2. A network in accordance with claim 1 in which the ratio of the inductance of one of said other auxiliary coils to the inductance of said one auxiliary coil is approximately equal to K .

3. A network in accordance with claim 1 in which K is approximately equal to 0.36 and the ratio of the inductance of one of said other auxiliary coils to the inductance of said one auxiliary coil is approximately equal to K .

4. A network in accordance with claim 1 in which said line windings of each of said auxiliary coils are inductively coupled and are connected in the series-aiding relationship for said loop circuit.

5. A network in accordance with claim 1 in which said suppression coil sections antiresonate at a frequency near the upper end of said range of frequencies.

6. A network in accordance with claim 1 which includes two capacitors, one of said capacitors being connected to bridge said line windings in one side of the line associated with said sections, the other of said capacitors being connected to bridge said line windings in the other side of the line associated with said sections and the

capacitances of said capacitors being proportioned to cause said sections to antiresonate at a frequency near the upper end of said range of frequencies.

7. A network in accordance with claim 1 in which the inductances of said auxiliary coils are variable.

8. A network in accordance with claim 1 in which K is approximately equal to 0.36.

9. A network in accordance with claim 1 in which K is approximately equal to 0.36 and the ratio of the inductance of one of said other auxiliary coils to the inductance of said one auxiliary coil falls between 0.3 and 0.4.

10. A wave transmission network for suppressing undesired longitudinal currents over a range of frequencies while freely transmitting signal currents in the same range in the loop circuit of a transmission line comprising two suppression coil sections and three auxiliary coils all connected in series, each of said sections and each of said auxiliary coils comprising two equal line windings connected one in each side of the line, said two windings of each of said sections having close inductive coupling and being connected in the series-opposing relationship for said loop circuit, one of said auxiliary coils being connected between said sections, the other of said auxiliary coils being connected, respectively, at the outer ends of said sections and the inductances of said auxiliary coils being proportioned with respect to the shunt capacitance effective between said line windings of said sections to provide a low-pass wave filter effective in said loop circuit.

11. A network in accordance with claim 11 in which said filter has its cut-off at a frequency which is several times that of the upper limit of said range of frequencies.

12. A network in accordance with claim 10 in which said filter has a nominal image impedance at one end substantially equal to the impedance of the load with which said filter is to operate at said one end.

13. A network in accordance with claim 10 in which the inductance of said one auxiliary coils is approximately equal to the shunt capacitance effective between said line windings of one of said sections multiplied by the square of the impedance of a terminal load with which said network is to operate and divided by 0.86.

14. A network in accordance with claim 10 in which the ratio of the inductance of one of said other auxiliary coils to the inductance of said one auxiliary coil falls between 0.3 and 0.4.

15. A network in accordance with claim 10 in which the inductance of one of said other auxiliary coils is approximately equal to 0.36 of the inductance of said one auxiliary coil.

16. A network in accordance with claim 10 in which said line windings of each of said auxiliary coils are inductively coupled and are connected in the series-aiding relationship for said loop circuit.

17. A network in accordance with claim 10 in which said suppression coil sections antiresonate at a frequency near the upper end of said range of frequencies.

18. A network in accordance with claim 10 which includes two capacitors, one of said capacitors being connected to bridge said line windings in one side of the line associated with said sections, the other of said capacitors being connected to bridge said line windings in the other side of the line associated with said

sections and the capacitances of said capacitors being proportioned to cause said sections to antiresonate at a frequency near the upper end of said range of frequencies.

19. A network in accordance with claim 10 in which the inductances of said auxiliary coils are variable.

20. A network in accordance with claim 10 in which said filter has its cut-off at a frequency which is several times that of the upper limit of said range of frequencies and a nominal image impedance at one end substantially equal to the impedance of the load with which said filter is to operate at said one end.

21. A network in accordance with claim 10 in which said filter has its cut-off at a frequency which is several times that of the upper limit of said range of frequencies and the ratio of the inductance of one of said other auxiliary coils to the inductance of said one auxiliary coil falls between 0.3 and 0.4.

22. A network in accordance with claim 10 in which said filter has its cut-off at a frequency which is several times that of the upper limit of said range of frequencies and said suppression coil sections antiresonate at a frequency near the upper end of said range of frequencies.

23. A network in accordance with claim 10 in which said filter has a nominal image impedance at one end substantially equal to the impedance of the load with which said filter is to operate at said one end and the ratio of the inductance of one of said other auxiliary coils to the inductance of said one auxiliary coil falls between 0.3 and 0.4.

24. A network in accordance with claim 10 in which said filter has a nominal image impedance at one end substantially equal to the impedance of the load with which said filter is to operate at said one end and said suppression coil sections antiresonate at a frequency near the upper end of said range of frequencies.

25. A network in accordance with claim 10 in which the ratio of the inductance of one of said other auxiliary coils to the inductance of said one auxiliary coil falls between 0.3 and 0.4 and said suppression coil sections antiresonate at a frequency near the upper end of said range of frequencies.

26. A network in accordance with claim 10 in which said filter has its cut-off at a frequency which is several times that of the upper limit of said range of frequencies, said filter has a nominal image impedance at one end substantially

equal to the impedance of the load with which said filter is to operate at said end and the ratio of the inductance of one of said other auxiliary coils to the inductance of said one auxiliary coil falls between 0.3 and 0.4.

27. A network in accordance with claim 10 in which said filter has its cut-off at a frequency which is several times that of the upper limit of said range of frequencies, said filter has a nominal image impedance at one end substantially equal to the impedance of the load with which said filter is to operate at said end and said suppression coil sections antiresonate at a frequency near the upper end of said range of frequencies.

28. A network in accordance with claim 10 in which said filter has its cut-off at a frequency which is several times that of the upper limit of said range of frequencies, the ratio of the inductance of one of said other auxiliary coils to the inductance of said one auxiliary coil falls between 0.3 and 0.4 and said suppression coil sections antiresonate at a frequency near the upper end of said range of frequencies.

29. A network in accordance with claim 10 in which said filter has a nominal image impedance at one end substantially equal to the impedance of the load with which said filter is to operate at said one end, the ratio of the inductance of one of said other auxiliary coils to the inductance of said one auxiliary coil falls between 0.3 and 0.4 and said suppression coil sections antiresonate at a frequency near the upper end of said range of frequencies.

30. A network in accordance with claim 10 in which the inductance of said one auxiliary coil is approximately equal to the shunt capacitance effective between said line windings of one of said sections multiplied by the square of the impedance of a terminal load with which said network is to operate and divided by 0.86, and the ratio of the inductance of one of said other auxiliary coils to the inductance of said one auxiliary coil falls between 0.3 and 0.4.

31. A network in accordance with claim 10 in which the inductance of said one auxiliary coil is approximately equal to the shunt capacitance effective between said line windings of one of said sections multiplied by the square of the impedance of a terminal load with which said network is to operate and divided by 0.86, and the inductance of one of said other auxiliary coils is approximately equal to 0.36 of the inductance of said one auxiliary coil.

STUART G. HALE.