

April 29, 1947.

J. H. MOLE
MEANS FOR REDUCING IMPEDANCE EFFECTS IN
GROUNDED COMMUNICATION CIRCUITS
Filed Sept. 2, 1941

2,419,907

Fig. 1.

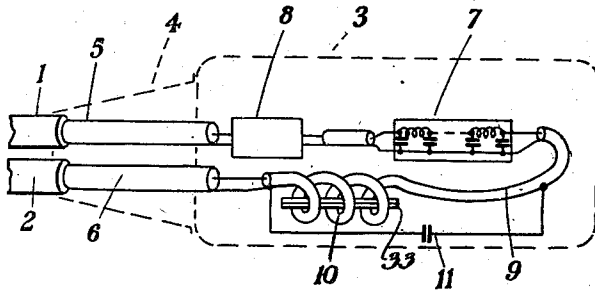


Fig. 2.

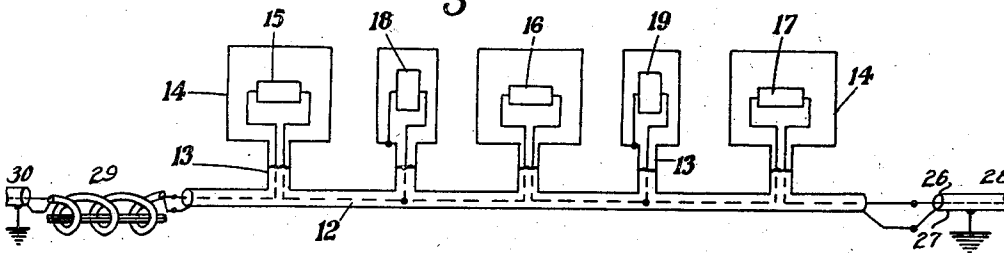
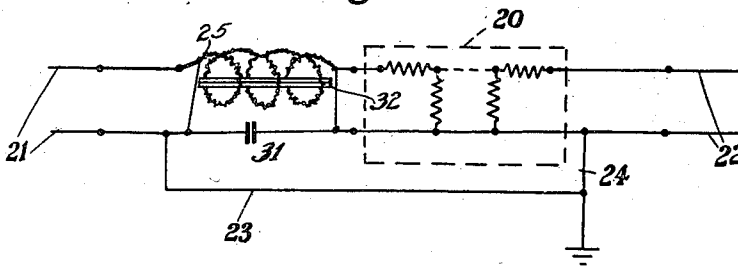


Fig. 3.



INVENTOR -
J. H. MOLE
BY *Louis S. Lencz*

ATTORNEY

UNITED STATES PATENT OFFICE

2,419,907

MEANS FOR REDUCING IMPEDANCE EFFECTS IN GROUNDED COMMUNICATION CIRCUITS

John Henry Mole, Eastcote, Ruislip, England, assignor to Siemens Brothers & Co. Limited, Westminster, London, England, a British company

Application September 2, 1941, Serial No. 409,262
In Great Britain September 27, 1940

6 Claims. (Cl. 178-44)

1

The present invention relates to arrangements adapted to minimise the effects of the impedance of the earth wire or earth bus-bar in alternating current electric circuits such as ladder networks or thermionic valve amplifiers. The effects of the impedance of the earth wire or earth bus-bar are especially likely to be serious in the case of filters or attenuators of the unbalanced ladder type where it is desired to obtain high attenuation of the order of 100 decibels or more. The effects may also in certain circumstances be serious in the case of so-called balanced circuits.

The importance of arranging the connections of an unbalanced ladder network such as a filter or attenuator so that the connections of the shunt elements to an earth bus-bar are made in the same order along the bus-bar as they appear on the ladder diagram of the network has previously been realised. The application of this system of connections to a high-frequency electric circuit such as a ladder network does not by itself in all cases provide the requisite minimisation of the effects of the finite impedance of the earth bus-bar. Thus, if there is an input terminal at one end of the earth bus-bar of the high-frequency circuit and an output terminal at the other end, and some other connection exists between the said two terminals, circulating currents of an alternating nature may be produced in the closed circuit formed by the bus-bar and the connection referred to and may, owing to the finite impedance of the bus-bar produce voltage drops along this bar which act to impair the performance of the high-frequency circuit. The other connection referred to between the terminals may exist for example owing to the fact that the circuits connected to the terminals are independently earthed. One method of obviating such flow of circulating currents is so to arrange the network or other circuit concerned by the inclusion of one or more transformers therein that the continuity of the earth bus-bar is broken. The use of such transformers has however disadvantages.

The present invention has in view the provision of arrangements by means of which the flow of undesirable circulating currents of an alternating nature in cases such as that which has been referred to may be greatly minimised without the use of a transformer or transformers.

Arrangements for attenuating currents flowing in the same direction in the two wires of a loop circuit without attenuating loop currents are known in which inductance coils are so connected as to introduce inductance in the path of leg

2

currents without introducing inductance in the path of loop currents. Such arrangements however have not been concerned with cases in which the currents flowing in the same direction in the two wires return through a third path joining two points on one of the loop conductors, the current flow being caused by the mutual impedance between the loop circuit and a circuit formed by one or other of the wires of the loop and the said third path.

According to a main feature of the present invention a two conductor input or output connection to an alternating current electric circuit such as a ladder network or a thermionic valve amplifier in which there is an earth bus-bar and there exists also another path between the two ends of the earth bus-bar is made in such a manner that each conductor of the input or output connection contains a coil which is tightly coupled to the coil in the other conductor the coil in the conductor connected to the earth bus-bar being connected in that part of the circuit that is shunted by the other path referred to, the two coils being so proportioned and connected in such sense that substantial inductance is introduced into the path of circulating currents flowing through a leg of the two conductor connection and the said other path while a comparatively low or negligible impedance is presented to the flow of loop currents over the connection. By the provision of this feature it can readily be arranged that two independently earthed systems can be connected together over apparatus such as a filter, attenuator, or amplifier without there being any risk of the production of serious circulating currents of an alternating nature in the circuit formed by the earth bus-bar and the said other path caused by the mutual impedance between the loop circuit and the circuit formed by one or other of the wires of the loop and the said other path.

One method of carrying out the feature is to arrange that the two-conductor input or output connection is made over the two conductors of a length of cable of the concentric type, a portion or the whole of the said length of cable being formed into a coil. This coil may be wound round a core of magnetic material.

Another method of carrying out the feature is to arrange that each conductor of the two-conductor connection contains one winding of a two-winding choke coil wound with "twin" wire the connection being such that the windings are in opposition in so far as loop currents are concerned. The two wires forming the "twin" wire

3

may simply be wires lying side by side, but I prefer to use a twisted pair. Each of the wires may be formed of a number of strands and the "twin" wire may be wound over a core of ferromagnetic material.

In carrying out the feature it is desirable (in order to achieve the desired object) to arrange that the conductor forming the coil included in the leg of the circuit in which the undesired circulating currents are liable to flow has a resistance which is as low as possible compared with the reactance values of this conductor at the frequencies concerned. The reason for this is that any voltage drop along the said conductor which is produced by the flow of loop currents through the resistance formed by the conductor will assist in the production of the circulating currents and militate against the improvement effected by the inclusion of the inductance of the conductor in the path of these currents.

According to a subordinate feature of the invention, one or each of the tightly-coupled coils of the input or output connection concerned is shunted by a tuning condenser so that the flow of circulating current of a critical frequency (or range of frequencies) is impeded by resonance effects.

In order that the provision of arrangements according to the invention may achieve the desired object, it is important that the impedance of the earth wire or earth bus-bar of the alternating current electric circuit concerned should be as low as possible, and that any possible circuit for the flow of undesired circulating currents which includes this bus-bar should have a minimum mutual inductance with each element and closed circuit of the alternating current electric circuit. In order to meet the last requirement, it is important to arrange that the various circuit elements are carefully screened and that all corresponding "go" and "return" wires are closely associated.

The nature of the invention will now be made clearer and the considerations which govern the design of the apparatus for carrying it into effect briefly indicated, by a description given with reference to the diagram shown in the three figures of the accompanying drawing.

Fig. 1 of the drawings shows the application of the invention to the circuits of a submerged repeater in a submarine cable system in which the inductance coils are formed by colling a length of concentric cable. Fig. 2 shows how the elements of an electric network may be connected to the input or output conductors for the purposes of the present invention and Fig. 3 shows the application of the invention to an unbalanced filter network, the inductance coils in this case being wound with twin wire.

Referring firstly to Fig. 1 of the drawing, this illustrates diagrammatically an application of the invention in which the alternating current circuit is a submerged repeater connected in a submarine cable of the concentric type. The two sections of the cable which are concerned are indicated at 1 and 2, and are arranged to enter the metal housing 3 of the repeater through a gland 4 at one end of the housing. The two sections have their outer conductors 5 and 6 bonded to this housing so that the conductors are joined through a circuit of very low resistance. The repeater apparatus is indicated diagrammatically as comprising a low-pass filter 7 and other apparatus 8. The invention finds an especially useful application in this instance, as

4

without special provision being made troublesome circulating currents are liable to be produced in a closed circuit including the earth bus-bar of the repeater apparatus and the circuit of low resistance just referred to.

As shown, the arrangements according to the invention whereby the flow of such circulating currents is greatly minimised take the form of a length 9 of cable of the concentric type, a portion of the length being formed into a coil 10. The coil 10 may be wound round a core 33 of magnetic material. The two conductors of the length 9 of cable are included in the connection between section 2 of the submarine cable and the filter 7, the outer conductor of the said length being included in the earth leg of the circuit. The effect of the inclusion of the coil 10 in the connection between the cable section and the filter is that substantial inductance is introduced into the path of circulating currents flowing through the earth leg only of the connection, while the coil only presents a comparatively low or negligible impedance to the flow of loop currents over the connection. An improved performance can often be obtained by shunting the outer conductor of the coil 10 by a tuning condenser 11.

As has previously been stated, it is important, in order that the provision of arrangements according to the invention may achieve the desired object, that the impedance of the earth wire or earth bus-bar of the alternating current electric circuit concerned should be as low as possible, and that any possible circuit for the flow of undesired circulating currents which includes this bus-bar should have a minimum mutual inductance with each element and closed circuit of the alternating current electric circuit. A method of connecting circuit elements which may be employed to meet the last requirement is shown diagrammatically in Fig. 2 of the drawing. The method consists in using a hollow metal tube 12 as the earth bus-bar, this tube having a number of branch tubes 13 jointed into it to which the screening cases 14 of the various circuit elements are connected by joints of good conductivity, and all wiring being carried out entirely within the tubes. The tubes are preferably of copper, and may of course be bent as is necessary to give the most compact or convenient layout of the circuit as a whole. In the figure, the circuit elements are for the sake of example shown as consisting of three series arms 15, 16 and 17 and two shunt arms 18 and 19. The metal tube 12 and the wiring therein connecting up the several circuit elements are connected at one end to the outer conductor 26 and inner conductor 27 of a concentric cable 28 and at the other end to similar conductors of a length of coiled concentric cable 29 which itself is connected to another concentric cable 30. In a modification which may be employed, it is arranged that the terminals of the various circuit elements are close to the main tube and the branch tubes are omitted. In a further modification, the tubes are replaced by suitably arranged lengths of concentric cable.

Referring now to Fig. 3 of the drawing, this illustrates diagrammatically an application of the invention in which the alternating current circuit is an unbalanced filter 20 connected between an input circuit 21 and an output circuit 22. The lower leg of the input circuit and the lower leg of the output circuit are both connected to earth independently of the earth bus-bar of

5

the filter, these earth connections being represented in the drawing by the leads 23 and 24. The invention finds a useful application in this instance, as without special provision being made troublesome circulating currents are liable to be produced in the closed circuit formed by the earth bus-bar of the filter and the earth connections just referred to. As shown, the arrangements according to the invention whereby the flow of such circulating currents is greatly minimised take the form of a two-winding choke coil 25. This choke coil is constructed by winding "twin" wire on an iron core 32, the "twin" wire preferably taking the form of a twisted pair. Each of the wires forming the "twin" wire may be formed of a number of strands. The two wires at one end of the "twin" are connected to leads 21 and the two wires at the other end of the "twin" are connected to the input terminals of the filter 20. One or each of the two windings formed by the "twin" wire may be shunted by a condenser 31 so that the flow of circulating current of a critical frequency (or range of frequencies) is impeded by resonance effects. The effect of the inclusion of the choke coil 25 in the connection between the input circuit 21 and the filter is that substantial inductance is introduced into the path of circulating currents flowing through the earth leg only of the connection, while the coil only presents a comparatively low or negligible impedance to the flow of loop currents over the connection.

The considerations which govern the design of such a choke coil will now be briefly indicated. With such a choke coil there is inevitably some leakage inductance between the two windings, and this shows itself as an inductance which operates to impede the flow of loop currents. Assuming by way of example that the choke coil is being used in the case just referred to where two independently earthed systems are connected together over an unbalanced filter, that only currents of a specific frequency need be considered, and that the two windings of the choke coil are connected in the input leads to the filter, one half of the impedance due to the said leakage inductance to currents of the specific frequency represents a mutual impedance between the input circuit of the filter and the circuit in which an undesired circulating current of the specific frequency is liable to be produced. It follows from this that the efficiency of the choke coil in limiting the flow of the undesired circulating current is limited by the ratio:

$$\frac{Z_c}{\frac{1}{2}Z_t}$$

where Z_c is the impedance presented by the choke to circulating current of the specific frequency and Z_t is the impedance presented by the choke to loop or transverse currents of the specific frequency, the limiting value being reached when the effective resistance R_e to circulating current of the earth wire of the filter and the other earth path is very small compared with $\frac{1}{2}Z_t$. However Z_t must not be too large or attenuation is introduced into the pass range of the filter by the resistance component of Z_t , and reflection loss is introduced by the reactance component of Z_t . An optimum design is obtained when the characteristic impedance of the twin wires when these are considered as a transmission line is equal to the characteristic impedance of the filter, so that only the resistance component of Z_t

6

introduces any loss. Unfortunately, in practice the characteristic impedance of the twin wires can only be varied by changing the separation of the wires or the dielectric constant of their insulation, so that it is not generally practicable to match the characteristic impedance of the wires to that of the filter. Consequently some reflection loss is inevitable, but it can of course be minimised by keeping small the length of the twin wires, i. e. by keeping Z_t small. The best compromise is probably reached when the modulus of Z_t is about three or four times R_e . A reasonable value for Z_t in many cases would be 2 ohms.

On working out detailed designs for specific cases on the basis of the considerations just set forth, we have found that at the lower end of a range of frequencies (e. g., at 6 kilocycles per second) the performance obtainable is limited by the resistance of the choke windings, and at the upper end of the range of frequencies (e. g., at 200 kilocycles per second) it is limited by the leakage inductance of these windings. The use of a coil of concentric cable reduces the undesired leakage inductance to zero, but increases the resistance owing to the poor space factor of concentric cable. At the lower frequencies, therefore, a choke coil should give better results than a coil of concentric cable, while at the higher frequencies the coiled concentric cable would be the more efficient of the two arrangements.

What is claimed is:

1. In combination, a four terminal telephone communication line filter comprising series and shunt impedance elements and an earth bus bar to which said shunt impedance elements have respectively one end connected; incoming and outgoing cables connected to the inlet and outlet pairs of terminals respectively; a connection between the respective earth wires of said cables forming a parallel path to said earth bus bar; and means to reduce the effect on the attenuation of the filter of currents induced by the four terminal network in the parallel path comprising reactive coils situated in one of said cables and in series with said parallel path so designed and arranged as to be in balancing magnetic opposition as regards line current in the cable circuit.

2. In combination, a four terminal telephone communication line filter comprising series and shunt impedance elements and an earth bus bar to which said shunt impedance elements have respectively one end connected; incoming and outgoing concentric cables connected to the inlet and outlet pairs of terminals respectively; a connection between the outer conductors of said concentric cables forming a parallel path to said earth bus bar; and means to reduce the effect on the attenuation of the filter of currents induced by the four terminal network in the parallel path comprising reactive coils situated in one of said cables and in series with said parallel path so designed and arranged as to be in balancing magnetic opposition as regards line current in the cable circuit.

3. In combination, a four terminal telephone communication line filter comprising series and shunt impedance elements and an earth bus bar to which said shunt impedance elements have respectively one end connected; a metallic container in which said filter is situated; incoming and outgoing concentric cables connected to the inlet and outlet pairs of terminals respectively; an electrical connection between the outer conductors

7

of said concentric cables and said container forming a parallel path to said earth bus bar; and means to reduce the effect on the attenuation of the filter of currents induced by the four terminal network in the parallel path comprising reactive coils situated in one of said cables and in series with said parallel path so designed and arranged as to be in balancing magnetic opposition as regards line current in the cable circuit.

4. In combination, a four terminal communication line filter comprising series and shunt impedance elements, screens surrounding respectively each of said elements, a metal tube, branch tubes jointed into said metal tube and connected respectively to said screens and connections between one end of the said shunt impedance elements and the respective surrounding metal; incoming and outgoing cables, the earth wires of said cables being connected respectively to the ends of said metal tube; a connection to the other wire of each cable passing through said metal tube and branch tubes and connected to said impedance elements; an earth connection between the earth wires of said cables forming a shunt path to said metal tube; and means to reduce the effect on the attenuation of the filter of currents induced by the four terminal network in the parallel path comprising reactive coils situated in one of said cables and in series with said parallel path so designed and arranged as to be in balancing magnetic opposition as regards line current in the cable circuit.

5. In combination, a four terminal communication line filter comprising series and shunt impedance elements, screens surrounding respectively each of said elements, a metal tube, branch tubes jointed into said metal tube and connected respectively to said screens and connections between one end of the said shunt impedance elements and the respective surrounding metal; incoming and outgoing concentric cables the outer conductors of which are connected respectively to the ends of said metal tube; a connection to the inner wire of each cable passing through said metal tube and branch tubes and connected to said impedance elements; an earth connection between the outer conductors of said concentric cables forming a shunt path to said metal tube; and means to reduce the effect on the atten-

8

uation of the filter of currents induced by the four-terminal network in the parallel path comprising reactive coils situated in one of said cables and in series with said parallel path so designed and arranged as to be in balancing magnetic opposition as regards line current in the cable circuit.

6. In combination, a four terminal telephone communication line filter comprising series and shunt impedance elements and an earth bus bar to which said shunt impedance elements have respectively one end connected; incoming and outgoing cables connected to the inlet and outlet pairs of terminals respectively; a connection between the respective earth wires of said cables forming a parallel path to said earth bus bar; and means to reduce the effect on the attenuation of the filter of currents induced by the four terminal network in the parallel path comprising reactive coils situated in one of said cables and in series with said parallel path so designed and arranged as to be in balancing magnetic opposition as regards line current in the cable circuit, the modulus of the impedance presented by the reactive coils to transverse currents being about three times the effective resistance to circulating current of the earth bus bar and said parallel path.

JOHN HENRY MOLE.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,204,721	Blumlein	June 18, 1940
2,176,211	Cork et al.	Oct. 17, 1939
1,985,042	Lane	Dec. 18, 1934
2,158,875	Leeds	May 16, 1939
2,097,491	Lair et al.	Nov. 2, 1937
1,994,905	Bowles	Mar. 19, 1935
1,964,048	Gerth	June 26, 1934
2,280,950	Harder	Apr. 28, 1942

FOREIGN PATENTS

Number	Country	Date
603,627	German	Oct. 4, 1934