Nov. 22, 1938. H. MOURADIAN 2,137,696

NEGATIVE IMPEDANCE REPEATER SYSTEM

Filed Dec. 18, 1934 2 Sheets-Sheet 1

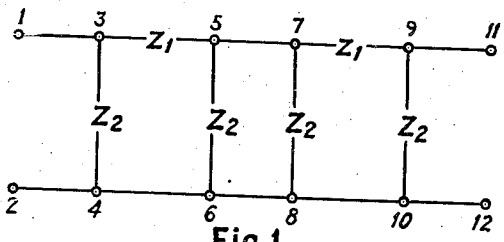


Fig. 1

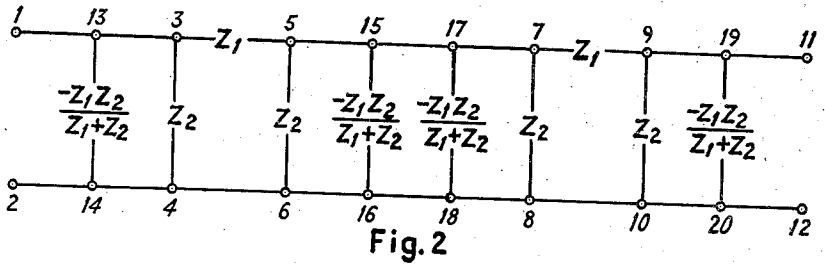


Fig. 2

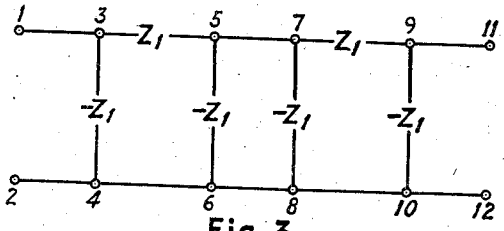


Fig. 3

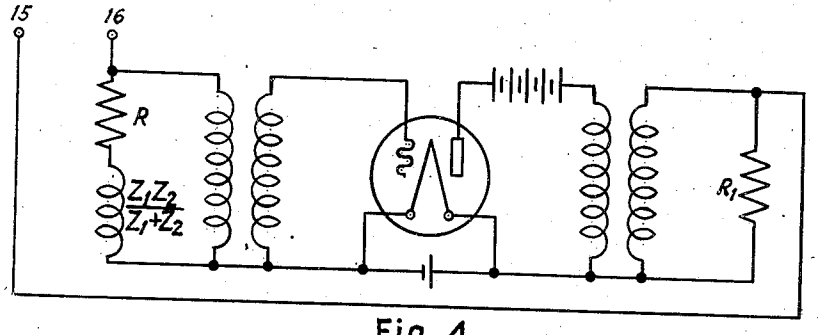


Fig. 4

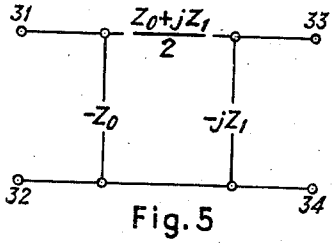


Fig. 5

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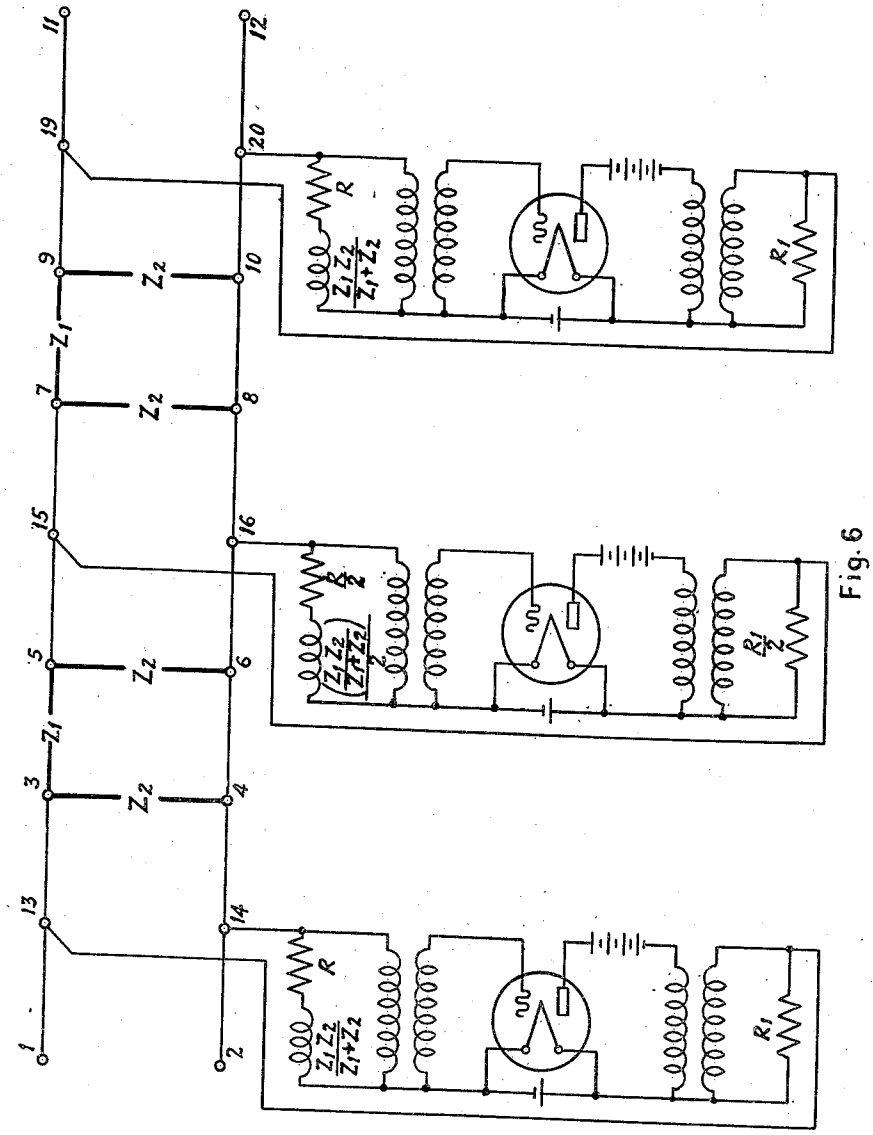


Fig. 6

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2,137,696

NEGATIVE IMPEDANCE REPEATER SYSTEM

Hughes Mouradian, Philadelphia, Pa.

Application December 18, 1934, Serial No. 758,056

7 Claims. (Cl. 178—44)

This invention relates to repeater systems and particularly to the use of negative impedances as the amplifying and phase correcting elements of such systems.

In an application originally filed on May 3rd, 1927, S. N. 188,497, I introduced into the art the conception of a transmission system in which negative impedance networks, in π or T formation, were introduced at intervals into a transmission line whereby the combination would act as a line of "zero" loss, viz:

1. The current at the beginning and at the end of the line would have the same amplitude, regardless of frequency.

2. The phase shift from end to end of the combined system would be zero, regardless of frequency.

This system is illustrated as Fig. 4 of the drawings of said earlier application and was reproduced as Fig. 5 of my later continuing application S. N. 379,017, which matured into U. S. A. Patent 1,955,681, and subsequently into U. S. A. Patent Re. 19,305, a re-issue of U. S. A. 1,955,681. This system made use at each amplifying station of three (3) negative impedances.

In application S. N. 379,017, filed July 17th, 1929, I have shown further how the above number of negative impedances required to realize a proper amplifying system could be reduced to two (2). In the case of a T structure it was sufficient to achieve the purpose cited, to provide negative impedances for the two series arms. In the case of a π structure, conversely, it was necessary and sufficient to provide negative impedances for the two pillar elements of the π structure.

I have discovered that it is possible to further reduce the number of negative impedances required to just a single unit. This application discloses the arrangement which shows the possibility of realizing a repeating system, with full correction for both amplitude and phase holding true independently of frequency.

This invention will be clearly understood from the following description, which read in conjunction with the attached drawings, of which Fig. 1 shows a simple transmission line translated into a number of consecutive equivalent π structures; Fig. 2 indicates diagrammatically the transmission line of Fig. 1 in combination with the negative impedance

$$-\frac{(Z_1 \times Z_2)}{(Z_1+Z_2)}$$

wherein the characters Z_1 and Z_2 are the same as shown on Fig. 1 of the drawings. The impedance

$$\frac{(Z_1 Z_2)}{(Z_1+Z_2)}$$

as indicated in this figure, simulating as it does natural transmission line constants, will usually include a number of distributed elements. This is covered in some detail by Latour in U. S. A. 1,687,253 as well as by later inventors in this field. Both Z_1 and Z_2 are complex impedances. Actually $Z_1=Z_0 \sinh Pl$ and

$$Z_2=Z_0 \coth \frac{Pl}{2}$$

wherein

Z_0=characteristic impedance.

P=propagation constant;

Fig. 3 indicates the electrical effect of the bridging of the negative impedance

$$-\frac{(Z_1 \times Z_2)}{(Z_1+Z_2)}$$

across the transmission line, again as translated in equivalent π structures; Fig. 4 indicates one of many other arrangements already known to the art for obtaining a negative impedance, (that of Latour, U. S. A. 1,687,253 is shown) as it may be used in conjunction with the arrangement shown on Fig. 3 of the drawings. Fig. 5 indicates the "impedance changing device" required between the terminals of the transmission circuit and the composite transmission line. Fig. 6 shows the invention with the structural arrangement required at intervals along the transmission line in association with said line.

It will be noted that the negative impedances required to carry out my invention into practice must have negative resistance as well as negative reactance qualities. Electrical devices are already well known in the art which make it possible to neutralize any complex impedance, including resistance as well as reactance elements, and secure such neutralization independently of frequency. Examples of the types of negative impedance which may be used in conjunction with the present invention are shown by Latour, French Patent 501,472, issued in 1920, and U. S. A. Patent 1,687,253. There is already a long list of inventors who have been granted patents for realizing a negative impedance ($-Z_1$) which is the exact opposite of an impedance ($+Z_1$) such opposition of phase, holding true for the entire range of useful frequencies in the art of transmitting speech.

In order to clearly understand the operation of the invention herein disclosed from an electrical standpoint, reference will be made to Fig. 3 of the drawings. It will be clear that the arrangement shown on said figure of the drawings represents a series of π structures in succession, each π structure consisting of

(1) An architrave impedance ($+Z_1$).

(2) Two pillar impedances ($-Z_1$).

Now it is well known in the art that the propa-

gation constant (P) of any one π structure, shown on Fig. 3 of the drawings is defined by the relation:—

$$\cosh P=1+\frac{Z_1}{Z_2}$$

wherein (Z_1) is the architrave element and (Z_2) is the pillar element. Applying this well known formula to the case shown on Fig. 3 of the drawings, wherein the pillar element is a negative impedance ($-Z_1$) we note immediately that the hyperbolic cosine of the propagation constant (P) of any one π structure is given by

$$\cosh P=1-\frac{Z_1}{Z_1}=0 \quad (1)$$

It is thus clear that, independently of frequency, cosh P is zero. Now since cosh P is usually a complex quantity, each term thereof must, of necessity, be separately equal to zero—therefore,

$$\cosh a \cosh b=0 \quad (2)$$
$$\sinh a \sinh b=0 \quad (3)$$

where (a) and (b) are the component parts of $P=a+jb$, (a) representing the attenuation component, (b) the wave length component and (j) representing the usual imaginary factor. In order to satisfy relations (2) and (3), we must have

$$b=\frac{\pi}{2}$$

and $a=0$.

Where the above relations are satisfied and where they are satisfied independently of frequency, it means that the current in traversing any one π structure of Fig. 3 of the drawings suffers no attenuation since $a=0$, and regardless of frequency the current leaving the π structure is 90° lagging behind the current entering the same structure. We have also no phase distortion in that, the phase lag in degrees or radians is the same for all frequencies.

We now proceed to determine the impedance characteristics of the system shown on Fig. 3 of the drawings. This impedance is defined in general by:

$$Z_0=\frac{Z_1\times Z_2}{\sqrt{\frac{Z_1Z_2}{2}+\frac{Z_1^2}{4}}}\cdot\frac{1}{2} \quad (4)$$

where (Z_1) is the architrave element and (Z_2) is the pillar element. In the present instance, we have:—

$$(Z_1)=Z_1$$
$$(Z_2)=-Z_1$$

Therefore

$$Z_0=\frac{\frac{-Z_1^2}{2}}{\sqrt{\frac{-Z_1^2}{2}+\frac{Z_1^2}{4}}}=\frac{\frac{-Z_1^2}{2}}{\sqrt{\frac{-Z_1^2}{4}}}=\frac{-Z_1^2}{\pm jZ_1} \quad (5)$$

$$Z_0=\mp j(Z_1)$$

In what follows the negative (—) sign will be used in association with (jZ_1), as the use of this sign results in a positive resistance component for the characteristic impedance of the composite transmission line.

Now, it will be observed that Z_1 varies with frequency, since it is equal to

$$Z_1=Z_0 \sinh Pl$$

Unless, therefore, means are provided to compensate for this variation and secure constancy of the line impedance there will be serious reflection effects between the terminating impedances at each end of the transmission system indicated on Fig. 3 of the drawings. It is thus necessary to provide between the terminals of the transmission circuit which has an impedance varying in some complicated fashion with frequency and the terminating equipment itself which may be assumed to have (as it is usually done) a substantially constant impedance Z_0, some intermediate circuit which will have towards the transmission line a variable impedance ($-jZ_1$) and towards the terminating equipment a constant impedance Z_0. A circuit of this type, essentially an impedance changing circuit, is shown on Fig. 5 of the drawings. It may be noted that this circuit consists of a π structure which has towards the transmission line an impedance ($-jZ_1$) and towards the terminating equipment an impedance ($+Z_0$). It will be observed that a wave arriving from the distant end over the transmission line will find a terminal impedance equal to the characteristic impedance of the transmission line itself. Thus there will be no reflection effects. This result can be shown to be true, since the parallel impedance of the terminating equipment and the pillar of the π structure having ($-Z_0$) as impedance is infinity, hence all of the energy of the waves arriving over the transmission line is completely absorbed by the impedance ($-jZ_1$), the second pillar of the π structure. The transmission of energy to the terminating equipment from the line itself is thus furnished locally. To show more definitely the actual transmission situation under the conditions as just cited, assume an electromotive force E, acting through the line impedance ($-jZ_1$). The potential difference at terminals **33**, **34** of Fig. 5 of the drawings evidently will be

$$\frac{E}{2}$$

The current (i) actually transmitted to the terminating equipment ($+Z_0$) connected to terminals **31**, **32** is—

$$i=\frac{\frac{E}{2}(-Z_0)}{-Z_0\left(Z_0+\frac{Z_0+jZ_1}{2}\right)+Z_0\left(\frac{Z_0+jZ_1}{2}\right)}$$

Canceling the common term ($-Z_0$) and simplifying—

$$i=\frac{E}{2Z_0}$$

Everything thus happens as if the electromotive force E had been impressed directly upon the terminating equipment and the characteristic impedance of the line was $+Z_0$ instead of ($-jZ_1$).

In the case of outgoing transmission with an electromotive force E impressed upon the terminating equipment with impedance ($+Z_0$) connected to terminals **31**, **32**, we have a current i' into the transmission line connected to terminals **33**, **34** (Fig. 5 of the drawings).

$$i'=\frac{\frac{E}{2}(-jZ_1)}{-jZ_1\left(\frac{Z_0+jZ_1}{2}-jZ_1\right)-jZ_1\frac{(Z_0+jZ_1)}{2}}$$

Eliminating the common term ($-jZ_1$) and simplifying—

$$i'=\frac{E}{2Z_0}$$

Thus, in final analysis, everything happens from end to end of the entire combination, from transmitting station to receiving station at the other

end, as if the transmission line had been completely removed between the two extreme terminating points. It may be further noted that the outgoing impedance as seen through the special π structure, is $(+Z_0)$ ohms, of constant value, even though the impedance of the composite transmission line is variable with frequency. To prove this point, consider first the impedance of the pillar $(-jZ_1)$ of the special π structure in parallel with the similar impedance $(-jZ_1)$ of the transmission line. It is obviously equal to

$$\frac{(-jZ_1)}{2}$$

This parallel impedance is in series with the architrave impedance

$$\frac{(Z_0+jZ_1)}{2}$$

of the special π structure. The series impedance of the two is therefore:—

$$\frac{Z_0+jZ_1}{2}-\frac{jZ_1}{2}=\frac{Z_0}{2}$$

If now this last mentioned impedance is considered in conjunction with the pillar $(-Z_0)$ of the special π structure, it can be readily seen that the combined parallel impedance of the two, viz.

$$\frac{(+Z_0)}{2}$$

and $(-Z_0)$ is exactly $(+Z_0)$. Thus the condition is obtained wherein there is no impedance irregularity between the terminating equipment and the transmission system, including under this designation the special impedance changing device and the composite transmission line.

Many other impedance changing arrangements can be conceived which would satisfy the requirements of the problem. But this application is only indirectly concerned with these and it is sufficient to show that at least one circuit is available which it is possible to use to avoid the extremely undesirable impedance irregularities between line and terminals. The presence of such irregularities might conceivably render the line transmission system impractical.

As a conventional proposition, the negative impedance shown on Fig. 4 and Fig. 6 of the drawings is that of Latour. As the negative impedances required in the present invention are used in shunt with the transmission line, it is preferable to use shunt type negative impedances from the standpoint of increased stability of operation. For an understanding of this subject, one of the latest references may be consulted,—Crisson, U. S. A. 1,776,310, pages 2 and 3, also drawings 3—*a* and 4—*a*.

It may be pointed out that while the negative impedance conceived by Latour is illustrated on the drawings, any other of the many negative impedances now known to the art may be used provided their design is properly correlated with the requirements of the present invention.

Attention is also called to the fact that the impedances

$$\frac{Z_1Z_2}{Z_1+Z_2}$$

and R associated with Fig. 4 and with Fig. 6 of the drawings are not indicated on these drawings in absolute magnitude but are directly proportional thereto. It will be noted that Mathes has covered this subject in U. S. A. Patent 1,779,382 granted to him. (Page 2, line 86—page 3, line 19.)

I have thus shown that it is possible to construct a composite transmission line system which transmits with equal effectiveness all frequencies with no amplitude distortion and in addition has the additional invaluable property of transmitting all frequencies with the same relative phase displacement. Thus all frequencies are transmitted with exactly the same phase velocity and with no attenuation distortion.

It will be noted that, for purposes of convenience in exposition of the underlying physical transmission relationships involved, two negative impedances are shown on Figure 2 (connected to terminals **15**, **16** also **17**, **18**) and correspondingly two negative impedances $(-Z_1)$ are shown on Figure 3 (connected to terminals **5**, **6** also **7**, **8**). Since, however, the two negative impedances referred to above are always bridged between the same electrical points, nothing prevents us from providing a single negative impedance device which will be equal to the parallel impedance of the two negative impedances diagrammatically represented on Figure 2 and Figure 3 of the drawings. When the successive sections of transmission lines provided with negative impedance networks are of equal length, then clearly the two negative impedances are also of equal magnitude and hence in that case the single negative impedance required is one-half the parallel impedance of $(-Z_2)$ and $(-Z_1)$, which is specifically covered in claim 1 hereunder. It is clearly obvious, however, that the spacing between negative impedance bridges need not, and in practice probably will not, be the same. Under the last mentioned conditions the magnitude of the single negative impedance bridge will be that obtained through the application of the well known relationship of parallel impedances.

In the above disclosure, the transmission line was considered as translated into a series of equivalent π networks. We might just as well have translated the successive transmission line sections into their equivalent T structures. In such a case, proceeding in the manner already described, we could just as readily construct a transmission system equivalent to that shown on Figure 3 of the drawings by providing series negative impedances without disturbing the shunt characteristics of the transmission line. In such a case the diagram corresponding to Figure 3 would consist of a series of T structures each with a series arm of $(-Z_2:2)$ and shunt arm of $(-Z_2:2)$. The magnitude of the series negative impedance required would be, in such a case, for each series arm an impedance equal to $-(Z_1+Z_2):2$. The negative impedances

$$-(Z_1+Z_2):2$$

of the series branches of two succeeding T structures can naturally be combined into a single series negative impedance. It is important to note that under both of the above two cases, the resulting electrical structure always consists of networks having successive series and shunt branches of opposite signs with the shunt branches having exactly one-half the magnitude of the series branches.

I claim:

1. In combination, a transmission line between two terminals with negative impedances bridged at intervals, the negative impedances at each bridge being chosen equal to one half the parallel impedance of $(-Z_2)$ and $(-Z_1)$, wherein

$(+Z_1)$ represents the architrave impedance and $(+Z_2)$ the pillar impedance of a π structure equivalent to the section of transmission line between the consecutive bridges of negative impedance.

2. Means for obtaining a composite transmission line system, free from distortion so far as amplitude of voltage and current of the waves transmitted over said circuit are concerned and also free from distortion from the standpoint of speed of propagation of the various frequencies included in the band of frequencies transmitted, which consists in negative impedances bridged at substantially regular intervals across the transmission line, said negative impedances having an absolute value proportional to

$$\frac{Z_1 Z_2}{Z_1 + Z_2}$$

wherein Z_1 is the architrave impedance and Z_2 the pillar impedance of each section of natural line between successive negative impedance bridges.

3. A system of transmission over a composite system, consisting of the combination of sections of transmission line with bridged negative impedance interposed between such sections, the combined systems being equivalent to a series of π structures in consecutive succession, each said π structure consisting of an architrave impedance $(+Z_1)$ and two pillar impedances each equal to $(-Z_1)$.

4. A system of transmission over a composite system consisting of successive sections of transmission line and negative impedances bridged between said successive line sections, the combined system being equivalent to a succession of impedance networks with series and parallel branches, in which the parallel branches are of opposite sign to the series branches and have one-half the impedance of the series branches in absolute magnitude, substantially as described.

5. A system of transmission over a composite system consisting of successive sections of transmission line and negative impedances inserted in series between said successive line sections, the combined system being equivalent to a succession of impedance networks with series and parallel branches, in which the parallel branches are of opposite sign to the series branches and have one-half the impedance of the series branches in absolute magnitude, substantially as described.

6. In combination with a transmission line for transmitting electrical waves of different frequencies, means for effectively compensating for all distortion produced by said line in the transmitted waves of all frequencies, including distortion in phase and amplitude, said means comprising an electrical structure inserted in shunt with said line—said structure in combination with said line having an attenuation constant equal to zero and a wave length constant equal to 90° between successive structures.

7. In combination with a transmission line for transmitting electrical waves of different frequencies and means bridged at intervals to effectively compensate for all distortion produced by said line, both as regards phase and amplitude, of means located at the terminals of said transmission line for preventing the reflection of waves between said composite line and the terminating equipment, said last means being equally effective at all frequencies.

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