June 6, 1950 R. S. GRAHAM 2,510,283

VARIABLE EQUALIZER

Filed Jan. 18, 1949

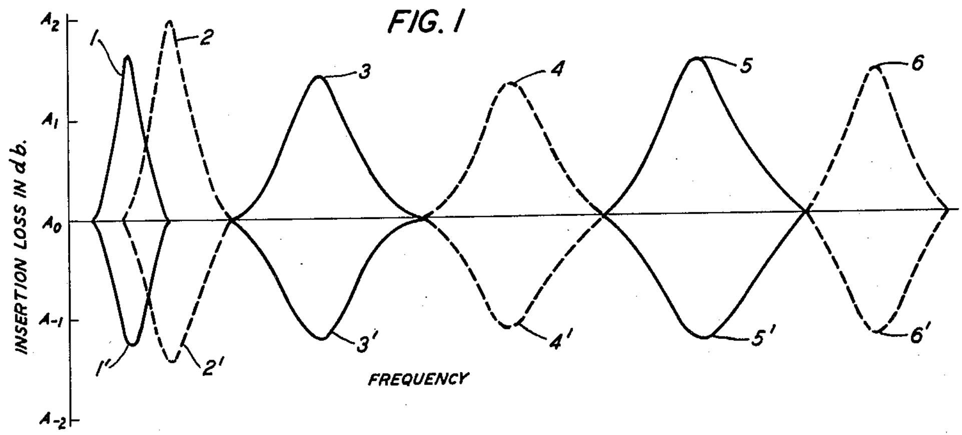

FIG. 1

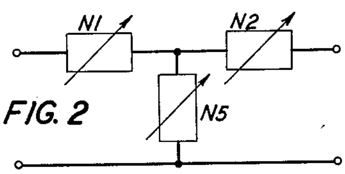

FIG. 2

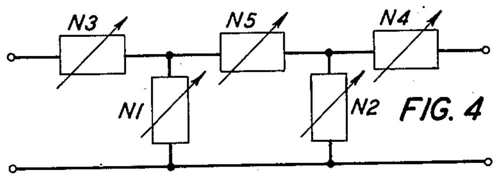

FIG. 4

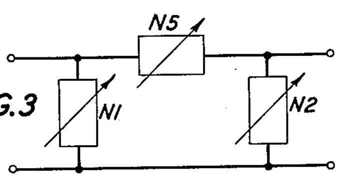

FIG. 3

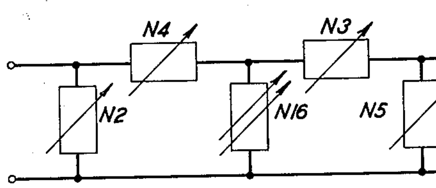

FIG. 5

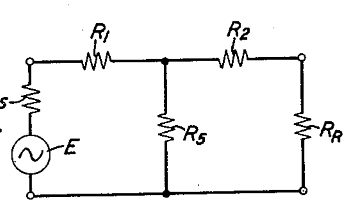

FIG. 6

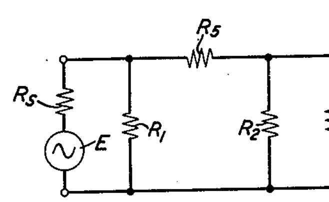

FIG. 7

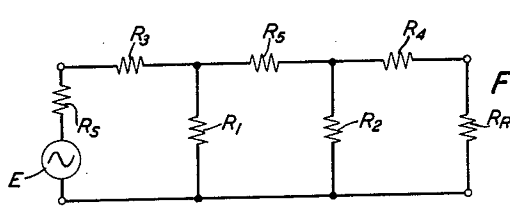

FIG. 8

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VARIABLE EQUALIZER

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Application January 18, 1949, Serial No. 71,413

12 Claims. (Cl. 178—44)

This invention relates to wave transmission networks and more particularly to variable equalizers.

The principal object of the invention is to improve the operation of a multirange variable equalizer of the type requiring only a single variable impedance for each operating range. More specific objects are to reduce the interaction between the different operating ranges and to decrease the flat loss of such an equalizer. A further object is to reduce the cost.

In order to compensate for the attenuation distortion in a transmission line, a variable equalizer of the two-terminal type requiring only a single variable impedance such, for example, as is disclosed in United States Patent 2,096,027 issued October 19, 1937, to H. W. Bode may be connected in series or in shunt with the line. Equalization over two non-adjacent frequency ranges may be provided by a variable two-terminal equalizer of the type disclosed in United States Patent 2,374,872, issued May 1, 1945, to W. R. Lundry. When more precise equalization than can be obtained by a single equalizer is required, it is necessary to employ two or more such equalizers, each of which has a fairly well defined operating range and which, between them, cover the entire range.

Heretofore, when a plurality of two-terminal equalizers were used in association it has been customary to separate them one from another by means of interposed resistance pads, or the equivalent, in order to prevent interaction between the different equalizers. These pads not only increase the number of component elements required, and therefore the cost of the network, but also increase considerably the flat loss introduced, which is undesirable. In cases where it is possible to employ two variable impedances for one operating range, bearing the relation that the products of the impedances for all settings are constant, it is possible to eliminate the pads by constructing variable equalizers having constant impedance at all frequencies. However, this method substantially doubles the complexity of the equalizers, thus increasing the cost, and also requires somewhat greater flat loss than the method herein disclosed.

In accordance with the present invention isolating pads are entirely eliminated in a composite equalizing network made up of a number of two-terminal variable equalizers requiring only a single variable impedance for each operating range. The equalizers are connected in series-shunt relationship to form a ladder network with the branches so arranged that every pair of adjacent series and shunt equalizers has non-adjacent operating ranges. It is also preferable that adjacent series-connected equalizers, and adjacent shunt-connected equalizers as well, should have substantially mutually exclusive operating ranges.

In this way the interaction between the component equalizers is kept within permissible limits because, at frequencies sufficiently far away from the operating range, a two-terminal equalizer has an impedance which is substantially constant, regardless of the attenuation setting. Furthermore, since the isolating pads are eliminated, the flat loss is reduced, and also the cost. The proper impedance level for each equalizer in such a ladder network depends upon the required adjustment range of the equalizers, and may be found by trial or may be computed.

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

Fig. 1 is an insertion loss-frequency characteristic showing the limits of the equalization required over a number of operating ranges;

Fig. 2 is a diagrammatic circuit of a T-type ladder network in accordance with the invention for providing variable equalization over the operating ranges 1, 2 and 5 shown in Fig. 1;

Fig. 3 is a diagrammatic circuit of a π-type ladder network equivalent to the one shown in Fig. 2;

Fig. 4 shows a more extensive ladder network for equalizing the ranges 1, 2, 3, 4 and 5;

Fig. 5 shows a ladder network for equalizing all six of the ranges shown in Fig. 1, the equalizer N16 operating over the two separated ranges 1 and 6; and

Figs. 6, 7 and 8 are schematic circuits representing the networks shown, respectively, in Figs. 2, 3 and 4 at frequencies outside of the range of the individual equalizers, and are referred to in explaining how the impedance levels of the various branches are determined.

The successful operation of long broad-band carrier telephone circuits, or circuits for the transmission of television signals, requires the equalization of large amounts of attenuation distortion with a very small permissible tolerance. The daily and seasonal variations in this distortion may be many times the tolerances and must be corrected by automatic or manual adjustments.

The curves in Fig. 1, where insertion loss in decibels is plotted against frequency, show the limits of equalization of a typical variable equalizer, designed for such use, providing independent adjustment of six different characteristics. Each characteristic has a portion above, and a corresponding portion below, a reference loss A_0. The portions above A_0, designated 1 to 6, represent insertion loss, as indicated by the subscripts of the ordinates A_1 and A_2. The portions below, designated 1′ to 6′, represent negative insertion loss, or insertion gain, as indicated by the negative subscripts of the ordinates A_{-1} and A_{-2}. The oddnumbered characteristics are shown in full line and the even-numbered ones in broken line to make the different ranges stand out more clearly. In each range, by the adjustment of a single variable impedance, there is provided a family of characteristics which are limited by the curves shown. For example, in the third range the loss at one extreme setting is given by curve **3** and the gain at the opposite extreme is given by curve **3'**. The variable impedance may be adjusted manually or automatically, by means of a pilot channel regulator system, to maintain the circuit gain constant at arbitrarily chosen frequencies.

In Fig. 1, the normal settings of all controls are assumed to produce the "flat" or reference loss, A_0. If the circuit to be equalized requires a normal condition which is not flat, such equalization can be provided by equalizers in tandem with the variable equalizer, using well-known design methods. The magnitude of A_0 is the amount of gain that is required by additional amplification to compensate for the loss of the equalizer. Since the addition of any considerable amount of gain at all operating frequencies of a broad-band circuit increases the size or number of amplifiers, and hence the cost, possible means of minimizing the value of A_0 are desirable.

The usefulness of a variable equalizer having the characteristics shown in Fig. 1 depends on the property of independent adjustment of the various ranges. Changing the setting of any particular operating range should ideally have no effect on the loss at frequencies removed from that range. Practically, the small amounts of this "interaction" may be tolerated but it tends to complicate the adjustment procedure, or, in the case of automatic regulation, may reduce the stability of the circuit. Also, some of the adjustment range of the other equalizers is required to compensate for this interaction, thus reducing the amount of range available for compensating circuit distortion.

Any two-terminal series or shunt variable equalizer producing characteristics which are variable over a restricted frequency range such as those in Fig. 1 will have at other frequencies an impedance which approaches a value substantially independent of the setting of the variable control. The approximation is realized to a greater degree at frequencies further removed from the operating frequency range, and can be controlled to some extent by design. The present invention takes advantage of this property of two-terminal equalizers by connecting them in series-shunt relationship to form a ladder network arranged in a manner to reduce the interaction between equalizers having adjacent or partly overlapping operating ranges. This is accomplished by making sure that every pair of adjacent series and shunt equalizers has non-adjacent operating ranges.

Fig. 2 is a diagrammatic circuit of a three-range equalizing network in accordance with one embodiment of the invention. The network comprises two series equalizers **N1** and **N2** and an interposed shunt equalizer **N5** connected to form a **T**. The equalizers are of the two-terminal type requiring only a single variable impedance for each operating range and have insertion loss characteristics corresponding, respectively, to those designated **1**, **2** and **5** in Fig. 1. The loss may be varied between the limits shown, as indication by the arrows through the boxes. The component equalizers may, for example, be designed in accordance with the Bode patent mentioned above. The series equalizers **N1** and **N2** have operating ranges which overlap somewhat but the range of the interposed shunt equalizer **N5** is non-adjacent to the ranges of the other two and, in fact, is quite far removed from them in frequency. The degree to which interaction effects between equalizers **N1** and **N2** are reduced depends upon the amount of loss introduced by equalizer **N5**. This loss is, in general, somewhat greater than the gain range, shown by curve **5'** in Fig. 1. The greater the magnitude of this loss, the greater the reduction of the interaction effects will be. In the network of Fig. 2 interaction between the three different ranges of equalization is negligible, or at least tolerable.

Fig. 3 is a diagrammatic circuit of another embodiment of the invention equivalent in performance to the network of Fig. 2 but having relatively lower impedance levels, which may be more desirable for certain applications. In Fig. 3 the equalizers **N1** and **N2** are of the shunt type and equalizer **N5** is of the series type, interposed between the other two to form a π network. Here, again, it will be noted that each pair of adjacent series and shunt equalizers has non-adjacent operating ranges.

With a larger number of component equalizers involved, more choice is offered in ways of associating them in a ladder network to reduce the undesired interaction effects. For example, Fig. 4 is a diagrammatic circuit of a five-range equalizing network comprising the component two-terminal variable equalizers **N1** to **N5** arranged in an unbalanced structure. The insertion loss characteristics of equalizers **N1** to **N5** correspond, respectively, to those designated **1** to **5** in Fig. 1. Equalizers **N3**, **N5** and **N4** are arranged in series, in that order, **N1** is connected in shunt at the junction of **N3** and **N5**, and **N2** is connected in shunt at the junction of **N4** and **N5**. In this network, also, in each of the possible pairs of adjacent series and shunt equalizers, namely, **N1** and **N3**, **N1** and **N5**, **N2** and **N4**, and **N2** and **N5**, the operating ranges are non-adjacent. Furthermore, the series-connected equalizers **N3**, **N4** and **N5** have mutually exclusive operating ranges. Thus, the network of Fig. 4 gives a satisfactory performance with respect to interaction between the different ranges.

Fig. 5 is a diagrammatic circuit of a six-range, unbalanced, ladder network in accordance with the invention comprising the component two-terminal variable equalizers **N2** to **N5** and **N16**. Equalizers **N2**, **N16** and **N5** are connected in shunt, in that order, **N4** is interposed in series between **N2** and **N16**, and **N3** is connected in series between **N5** and **N16**. The insertion loss characteristics of equalizers **N2** to **N5** correspond, respectively to those designated **2** to **5** in Fig. 1. Equalizer **N16** covers the two separated ranges **1** and **6**, as indicated by the two arrows, and may, for example, be of the type disclosed in the above-mentioned Lundry patent. It will be noted that every pair of adjacent series and shunt equalizers has non-adjacent operating ranges. Also, the series-connected equalizers **N3** and **N4**, as well as the shunt-connected equalizers **N5** and **N16**, have operating ranges which are mutually exclusive. The interaction between the different ranges will, therefore, not be troublesome.

Figs. 6, 7 and 8 are schematic circuits representing the networks shown, respectively, in Figs. 2, 3 and 4 at frequencies outside of the range of the individual equalizers. The network is shown connected between a source of alternating electromotive force E of impedance R_S and a load of impedance R_R. The component two-terminal equalizers N1 to N5 appear as the resistances designated R_1 to R_5, respectively. The values of these resistances, that is, the required impedance levels of the equalizers, may be found by trial or may be computed by the method outlined below.

The impedance level, or the impedance the two-terminal equalizer assumes for the reference control setting, required for each equalizer in any of these ladder networks shown in Figs. 2 to 5 can be determined from the arrangement selected for the network, the maximum excursion each characteristic is required to have in the gain direction as shown by the curves 1' to 6' in Fig. 1, and the impedances R_S and R_R between which the network must operate. The relation is that the change in impedance of each two-terminal equalizer from the reference condition to the maximum gain condition at the frequency of maximum gain must cause a reduction in the insertion loss of the whole network equal to the maximum gain excursion required. This assumes that, in the condition of maximum gain, the equalizer, if of the series type, presents an impedance of zero value at the frequency of maximum gain; and, if of the shunt type, presents an infinite impedance. If this condition is not satisfied, the reduction in the insertion loss must be made correspondingly greater. One such relation holds for each equalizer in the network, and, taken together, they form a set of simultaneous equations from which the impedance levels can be computed.

Let A_n be the ratio of the current flowing in the receiving termination R_R for the maximum gain condition of an equalizer, N, of the series type, to the current for the reference condition, assuming the controls of all the other equalizers remain fixed at their reference conditions, and that the generator voltage, E, remains constant and has the frequency of maximum gain for equalizer N.

Then, in general, the relation for determining the impedance lever of N, R_n, is

$$R_n=(A_n-1)\ (R_{n1}+R_{n2}) \qquad (1)$$

where R_{n1} and R_{n2} are the two equivalent impedances facing R_n, toward the generator E and the load R_R, respectively.

Likewise if A_m be the corresponding ratio for an equalizer, M, of the shunt type, the relation for determining the impedance level of M, R_m, is

$$R_m=\frac{1}{(A_m-1)}\cdot\frac{(R_{m1}\cdot R_{m2})}{(R_{m1}+R_{m2})} \qquad (2)$$

where R_{m1} and R_{m2} are the two equivalent impedances facing R_m.

For example, the three relations required to determine the values of the resistances R_1, R_2, and R_5 in Fig. 6 are given implicitly by the folowing equations, which can be solved directly or by the method of successive approximations:

$$R_1=(A_1-1)\left(R_S+\frac{R_2R_5+R_RR_5}{R_R+R_2+R_5}\right) \qquad (3)$$

$$R_2=(A_2-1)\left(R_R+\frac{R_1R_5+R_SR_5}{R_S+R_1+R_5}\right) \qquad (4)$$

$$R_5=\frac{(R_1+R_S)}{(A_5-1)}\,\frac{(R_2+R_R)}{(R_1+R_2+R_S+R_R)} \qquad (5)$$

In a similar manner a set of equations may be written for determining the values of the resistances R_1, R_2 and R_5 in the π network of Fig. 7 and another set for determining the values of the resistances R_1 to R_5 in the more elaborate ladder network shown in Fig. 8. The required empedance levels of all of the component two-terminal equalizers may thus be determined, since they correspond to the values found for the resistances in the equivalent circuits.

The insertion loss of the ladder network in the reference condition will in all cases be less than the sum of the maximum gain excursions of each component equalizer. A reduction in the reference loss A_0, as compared to other known methods of associating variable equalizers in a composite network, is thus effected in the networks of the invention.

What is claimed is:

1. In combination, a plurality of two-terminal variable equalizers connected in series-shunt relationship to form a ladder network, every pair of adjacent series and shunt equalizers having non-adjacent operating ranges.

2. The combination in accordance with claim 1 in which adjacent series-connected equalizers have substantially mutually exclusive operating ranges.

3. The combination in accordance with claim 1 in which adjacent shunt-connected equalizers have substantially mutually exclusive operating ranges.

4. The combination in accordance with claim 1 in which said equalizers comprise only a single variable impedance for each operating range.

5. A multirange equalizing network comprising two two-terminal variable equalizers connected in series-shunt relationship, said equalizers having non-adjacent operating ranges.

6. A network in accordance with claim 5 in which said equalizers comprise only a single variable impedance for each operating range.

7. In combination, three two-terminal variable equalizers, two of said equalizers being connected in series, the third being connected in shunt at the junction of said two, and said third equalizer having an operating range which is non-adjacent to the operating ranges of said two equalizers.

8. The combination in accordance with claim 7 in which said two equalizers have mutually exclusive operating ranges.

9. The combination in accordance with claim 7 in which said equalizers comprise only a single variable impedance for each operating range.

10. In combination, three two-terminal variable equalizers, two of said equalizers being connected in shunt at the respective ends of the third and said third equalizer having an operating range which is non-adjacent to the operating ranges of said two equalizers.

11. The combination in accordance with claim 10 in which said two equalizers have mutually exclusive operating ranges.

12. The combination in accordance with claim 10 in which said equalizers comprise only a single variable impedance for each operating range.

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REFERENCES CITED

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

UNITED STATES PATENTS

Number	Name	Date
2,096,027	Bode	Oct. 19, 1937
2,374,872	Lundry	May 1, 1945