

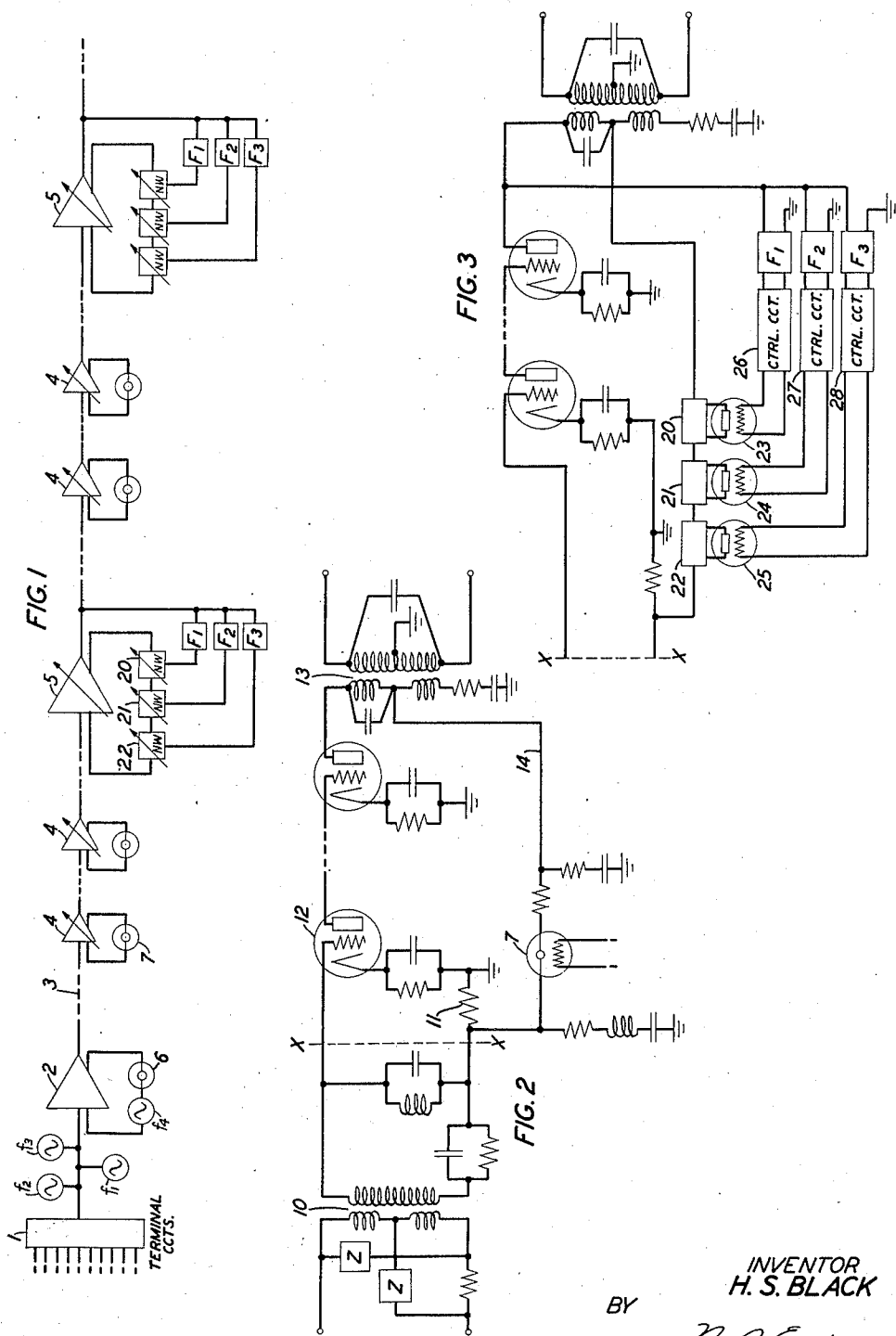
Oct. 31, 1944.

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2,361,593

TRANSMISSION REGULATION

Filed Dec. 5, 1942



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2,361,593

TRANSMISSION REGULATION

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Application December 5, 1942, Serial No. 467,947

6 Claims. (Cl. 178—44)

This invention relates to electric wave transmission systems and more particularly to automatic regulation of the transmission characteristics throughout a long distance signaling system comprising many repeaters.

The invention has for one of its principal objects a reduction in the effect of the transient response that appears in repeated transmission systems having dynamic regulation of repeater gain.

Another and related object is to enable a substantial increase in the number of dynamically regulated repeaters that may be used in tandem in a transmission system, and therefore also to enable an increase in the length of the system, without incurring excessive transient effects in the operation of the regulators.

Another and more particular object is to provide an improved signal transmission system comprising repeater amplifiers of the self-regulating constant power output type.

For automatic regulation of the gain of the repeaters in a long distance signaling system it has been proposed heretofore to transmit concurrently with the signals a pilot wave that continuously varies in amplitude in such correlation with the normal variations in the intensity of the signals that the average power content of the signals and pilot waves combined is maintained substantially constant at the transmitting end of the system. Each of the repeaters in such a system is of a constant output type, that is, the gain of the repeater is continuously controlled by the signals and pilot wave jointly in such manner that the average power content of the two combined is maintained substantially constant at the output of the repeater. Each repeater is thus automatically adjusted in gain to offset the transmission loss that occurs in the preceding transmission section, irrespective of any fluctuations in loss, and each delivers the signals and pilot wave to the next transmission section in their original condition, i. e., the condition of constant average total power.

The transmitted effect that controls the gain adjustment at each repeater is, except at the first one, an effect that is simultaneously operated upon also by the gain regulator at each preceding repeater. Upon any change in the control effect, which in this case is the average power content of the signals and pilot wave combined, the repeater next following the origin of the change eventually completely compensates for it by proper adjustment of its gain, but inasmuch as any change in the control effect is communicated

instantly to all of the other following repeaters, the gain regulators associated with the latter immediately attempt to effect a compensating change in the gain of their respectively associated repeaters. The net result is that even in the normal operation of the system a change in the control effect at any point not only calls into proper action the repeater regulator next following that point but also gives rise to a transient operation of the regulators at all of the other following repeaters.

This transient response is a normal incident to dynamic regulation. Ordinarily the transient quickly subsides without perceptibly affecting the signals at the receiving end of the system. If the system is very long, however, or more particularly if there are a large number of repeaters in tandem, subject to the same dynamic regulation, a change in the control effect, and especially an abrupt change, may give rise to a transient that reaches excessively large proportions before it subsides. Since the attendant violent fluctuations in the intensity level of the signals at the receiving end of the system may be practically intolerable, special attention must be given to the transient response characteristic if a repeated system employing dynamic regulation is to be indefinitely extended. One object of the invention is to enable such systems to be substantially extended without incurring an excessive transient effect.

In accordance with the present invention, a plurality of different kinds of regulators are employed in a system for the dynamic control of the transmission characteristics of repeaters, the different kinds of regulators differing in respect of the rate at which they respond to a given change in the control effect that is supplied to them, and the relative number and spacing of each kind of regulator is systematically allocated in such manner as to substantially reduce the effect of transients or alternatively to permit substantial increase in the length of the system over which dynamic regulation can be successfully maintained. In one aspect the invention contemplates the division of a repeated transmission system into a plurality of sections with transmission regulators at the junctions thereof, and progressive subdivision of the sections with transmission regulators of progressively slower rates of response interposed at the junctions resulting from each subdivision. In another aspect the invention contemplates a repeated transmission system comprising a plurality of sections each embracing dynamically regulated repeaters in

such limited number, in relation to the rate of response of the regulators, as to preclude the development of an excessive transient wholly within the section, and dynamic repeater regulators at the junction of sections each having a rate of response fast enough to substantially suppress the transmission, from the preceding section to the next one, of such transient effects as may develop within the preceding section. The invention contemplates further the interposition of one or more additional dynamically regulated repeaters having a faster rate of response calculated to substantially suppress any transient which the succession of fast-acting regulators would of itself make possible in a long system.

In carrying the invention into practice in a repeated transmission system of the kind described having a multiplicity of constant output repeaters, the latter are designed to be unusually sluggish in their response, with a view to limiting the rate of change of transmission level incident to transient operation, but fast enough to follow the variations in transmission equivalent that are due to fluctuations in line attenuation, for example. At infrequent intervals along the line there are interposed relatively fast-acting repeater gain regulators controlled by a pilot wave that is transmitted over the line concurrently with the signals. Additional pilot waves are also transmitted over the line for effecting at the fast-acting repeater regulators a compensation for such changes in transmission equivalent as are not uniform over the frequency range of interest.

The nature of the present invention and its various features, objects and advantages will appear more fully from a consideration of the embodiment illustrated in the drawing and now to be described.

In the drawing,

Fig. 1 shows schematically a multiplex carrier telephone system embodying the invention; and Figs. 2 and 3 illustrate schematically circuit details thereof.

Referring more particularly now to Fig. 1, there is represented schematically a repeated wire line transmission system which it may be assumed for specific example is adapted for multiplex carrier telephone transmission. Although a single one-way system is illustrated it will be understood that it would be paired with an oppositely-directed system for two-way telephone transmission. At the transmitting end of the system, shown at the left, terminal circuits 1 translate the telephone signals received over the several exchange circuits to respective positions in the carrier frequency range. For specific example, there may be twelve voice frequency circuits and twelve respectively corresponding carrier frequency channels ranging in frequency from somewhat more than twelve to somewhat less than sixty kilocycles. The translated signals from the terminal circuit are applied, together with pilot waves f_1 , f_2 and f_3 , to the input of an amplifier 2. The latter is arranged to supply pilot waves f_4 which are so automatically varied in intensity that the average total wave power delivered by amplifier 2 to the transmission line 3 is maintained substantially constant.

Interposed in the transmission line 3 are two different types of repeaters, 4 and 5. Repeaters 4 are of a constant output type, to be described further with reference to Fig. 2, and they may be spaced in the line 3 at the usual frequent intervals of fifteen miles, for example, in the case of a cable circuit. Repeaters 5 are of a type ar-

ranged to be regulated by pilot waves, and they will be described further with reference to Fig. 3. There are relatively few of this type of repeater and the spacing may be, for example, of the order of two hundred fifty miles in the case of an underground cable and one hundred miles in the case of an overhead cable. Each repeater is designed to compensate for the loss-frequency characteristic which the preceding section of transmission line has at some predetermined line temperature. Each also introduces a variable amount of gain, uniform over the frequency range of interest, to compensate approximately for changes in line attenuation induced by changes in temperature. Repeater 5 additionally compensates for such changes in transmission equivalent of the system as are non-uniform with respect to frequency.

Referring again to the terminal amplifier 2, this may be of the type disclosed in United States patent to C. O. Mallinckrodt, No. 2,231,542, dated February 11, 1942, or in the application of J. O. Edson, Serial No. 467,945, filed of even date herewith. In either case it may be described as a stabilized negative feedback amplifier having constant and uniform gain for waves applied to its input terminals, and as a generator of pilot oscillations of frequency f_4 . In either case too the intensity of the generated oscillations is varied by a current-dependent thermosensitive resistance 6 which is disposed in the oscillation generating path and which is heated in proportion to the total power output of the amplifier. In the course of normal operation the oscillation intensity may range from almost zero to a value comparable with the maximum anticipated signal intensity. Under certain conditions the power input to amplifier 2 may be so great that the oscillation intensity may reduce to zero and yet not prevent a substantial increase in the total power output of the amplifier. This fact is important inasmuch as the effect described may give rise to a transient operation of the regulator.

Each repeater 4 comprises an amplifier of a type such that the total wave power output thereof remains substantially constant despite variation of the wave power input to the amplifier over a wide range. The amplifier may take the form shown in my United States Patent No. 2,209,955, dated August 6, 1940, or in J. H. Bollman Patent No. 2,231,558, dated February 11, 1941, or it may take the specific form illustrated in Fig. 2. In each case the amplifier is essentially a stabilized negative feedback amplifier having in the negative feedback path a current-dependent thermosensitive resistance 7 which operates to vary the gain of the amplifier to compensate for any tendency of the wave power output to vary from a predetermined value.

The repeater amplifier 4 that is illustrated schematically in Fig. 2 comprises an input transformer 10 and four associated impedance branches designed in accordance with the teachings of H. W. Bode application, Serial No. 435,171, filed March 18, 1942, and issued as Patent No. 2,337,965, dated December 28, 1943, to provide a fixed amount of equalization calculated to compensate for the attenuation-frequency characteristic of the preceding transmission line section at an assumed normal line temperature. Connection of the input network to the input terminals of the first stage of the amplifier is made through an impedance element 11 which serves as a feedback coupling impedance. The wave output of the last stage of the amplifier is de-

livered to the outgoing line through an output transformer 13 which is arranged in the manner described in E. H. Perkins Patent No. 2,210,001, dated August 6, 1940, to afford a negative feedback connection 14.

Interposed in series in the feedback connection 14 is the current-dependent thermosensitive resistance 7 and associated impedance elements which together control the amount of loss in the negative feedback path. Thermistor 7 has a negative temperature coefficient of resistance and it is so proportioned that its temperature and resistance are controlled by the feedback currents traversing it in accordance with the average power content thereof. The circuit elements can be and are so proportioned that the resistance of thermistor 7 and the over-all gain of the amplifier may vary over a wide range while the total wave power output varies over a minute range. Thus if the wave power input to the amplifier should increase, for example, because of some change in line condition, the output of the amplifier would tend to increase in proportion. Any increase in the power output, however, increases the flow of current through thermistor 7, reduces the resistance of the thermistor and increases the amount of negative feedback, thus reducing the gain of the amplifier and allowing only a slight net increase in the total wave power output.

It is important to note that upon a change in the wave power input to the amplifier, thermistor 7 cannot instantly assume the proper temperature and resistance called for by the changed condition, for a finite time is required to heat the thermistor to a higher temperature and a finite time is likewise required for it to cool to a lower temperature. Within limits, a thermistor such as 7 can be designed in manner well known in the art to have any predetermined rates of response to an increase or decrease, respectively, in the intensity of the current traversing it. The thermal time constants of thermistor 7 then control the rate of response of the gain regulators at repeaters 4. Thermistor 6 in terminal amplifier 2 likewise has finite thermal time constants, hence the total wave power delivered to the line 3 is constant only as averaged over some small but finite time interval. The development of transients in the operation of the regulators and the suppression of such transients both involve the electrothermal properties of the thermistors 6 and 7.

What may tend to become a severe transient can originate at the terminal amplifier 2. Infrequently, for example, the signals received from the terminal circuits 1 may all be fairly strong and in such phase relation that the total wave power is, for a short time at least, of such intensity that even though the pilot oscillations f_1 are reduced to zero, the total power delivered to the line 3 exceeds the predetermined constant value. Again, and incidental to normal operation of a telephone exchange system, powerful pulses of ringing or "ring-back" current may appear in one or more of the voice frequency circuits and their corresponding carrier channels with the same temporary effect on the power output of the amplifier 2. Although such pulses of excess power are of short duration, and usually less than one second, their energy content may be sufficient to call the regulators at the repeaters 4 into action. Furthermore, after the termination of the pulse of ringing current or the like, there is a finite time interval in which the power delivered to the line is less than the predeter-

mined value, for thermistor 6 must first cool sufficiently to allow oscillations to resume and cool further to allow the oscillation intensity to build up to the required value. The circumstances described are not the only ones which can give rise to undesirable transient effects, for lightning strokes on the line, for example, can have the same effect on repeater regulators of the kind described.

In accordance with a feature of the invention, the thermistors 7 in the regulated repeaters 4 are designed to be extremely sluggish; they may have, for specific example, a thermal time constant of the order of forty-five seconds for heating and one hundred thirty seconds for cooling. The thermal time constant, it will be understood, indicates the time elapsing after a change in heating power delivered to the thermistor before the resulting correction in thermistor resistance and repeater gain is approximately two-thirds completed. By virtue of their sluggishness, they are substantially unresponsive to momentary changes in the received power, hence they are not liable to cause an excessive transient to develop from such a change. They are not so sluggish, however, as to ignore the relatively slow changes in line attenuation that are due, for example, to temperature variations. By virtue of their sluggishness too, the transient response of the series of repeaters, upon a change in line power of short duration, is limited in rate of change if not in amplitude.

Whereas an indefinitely long chain of repeaters of the type 4 would therefore be not immune to the development of an excessive transient under certain conditions, I divide the repeated line into a plurality of sections and substantially isolate the sections from each other in so far as transmission of the said transient is concerned, and I further restrict the number of repeaters of type 4 in each section to a number such as to preclude the development of an excessive transient within any one section. Pilot-controlled repeaters of the type 5 effect the aforesaid division of the system.

The input power at any of the repeaters 5 will vary as the attenuation of the preceding section of line varies, and it will vary also in accordance with any transients developed within the preceding string of repeaters 4 and any other fluctuations in transmission equivalent too rapid to be compensated by the preceding repeater regulators. The repeaters 5 are designed to substantially compensate for these variations under the control of the pilots f_1 , f_2 and f_3 .

Each of the repeaters 5 in the Fig. 1 system may comprise, as illustrated in detail in Fig. 3, a negative feedback amplifier the transmission characteristics of which are substantially determined by the transmission loss introduced in the feed-back circuit by networks 20, 21 and 22. The loss-frequency characteristic of each network is controlled in a manner known in the art by a respective thermistor 23, 24, 25, which is indirectly heated under the control of a respective pilot wave, f_1 , f_2 , f_3 . Network 20 determines the amount of flat gain. It introduces a loss that is uniform over the twelve to sixty-kilocycle frequency range, and the amount of loss is controlled by pilot f_1 . The pilot f_1 , which may have a frequency of fifty-six kilocycles for specific example, is partially diverted at the output of each repeater 5 through a filter F_1 and applied to a control circuit 26. The latter supplies heating current to the heater associated with thermistor 23 and the

intensity of the heating current is continually varied in correlation with the variations in the intensity of the pilot wave f_1 appearing at the output of the repeater. The circuit elements are so proportioned and arranged that any departure in the output intensity of the pilot f_1 from a predetermined normal value gives rise to a compensating change in the gain of the repeater amplifier such as to maintain the pilot intensity at substantially its normal value.

In accordance with an important feature of the invention, thermistor 23 and control circuit 26 are designed to respond to a given change in pilot intensity at a rate much faster than the rate at which repeater 4 would respond to the same change in total power output. If the control circuit 26 is made fast enough in its operation, the speed of the flat gain regulator comprising thermistor 23 will be substantially dependent on the thermal time constants of the latter. In such case suitable time constants for thermistor 23 are 0.2 second. I will be noted that this is at least two hundred times that of thermistor 7 and represents a different order of magnitude.

The corrective change in flat gain introduced by any repeater 5, therefore, takes place rapidly enough to substantially suppress the transmission of such variations as the repeaters 4 fail to compensate, and more especially the rate of response is fast enough to compensate for, and substantially prevent the transmission of, any transient effects developing within the preceding string of repeaters 4. Hence the repeated transmission system is in a sense divided into substantially isolated sections in so far as the transient operation of the regulators 4 is concerned, and at the same time dynamic regulation is maintained over the entire system.

Networks 21 and 22 and their respectively associated thermistors 24 and 25 operate under the control of the transmitted pilot f_2 and f_3 , respectively, to compensate for changes in transmission equivalent that are not uniform with respect to frequency. These changes may be regarded as comprising a change in the slope of the transmission-frequency characteristic and a change in the curvature of the characteristic. Assuming that network 21 and pilot wave f_2 are to be used for controlling changes in the slope of the gain-frequency characteristic of the amplifier, the pilot frequency may be twelve kilocycles, for example. Curvature of the characteristic is controlled by network 22 and pilot wave f_3 , the latter having a frequency of twenty-eight kilocycles, for example. In view of the possibility that the operation of the networks 21 and 22 may effect also the transmission at pilot frequency f_1 , which would lead to interaction between the thermistors 24 and 25 on the one hand and thermistor 23 on the other, the former are made comparatively sluggish in their operation. Their thermal time constants may be, for example, sixty seconds average for heating and cooling cycle.

Further details of a repeater amplifier 5 in accordance with Fig. 3 will be found in the copending application of J. G. Kreer and C. O. Mallinckrodt, Serial No. 467,946, filed of even date herewith and now issued as Patent No. 2,340,813, dated February 1, 1944.

Although the three pilot frequencies f_1 , f_2 and f_3 have been assumed to be constant, it should be understood that a rapid cyclical change in their respective frequencies is permissible. Such change allows for manufacturing variations in the selective properties of the filters F_1 , F_2 and F_3

and also for slight changes in the respective pass frequencies due, for example, to change in temperature.

Strong power pulses applied to the input of a repeater 4 of the form shown in Fig. 2 may reduce the feedback loss to such an extent that oscillations are generated within the amplifier at a frequency or frequencies above or below the twelve to sixty-kilocycle band. This condition may be prevented from persisting after the power pulse has ceased, by designing the feedback circuit, and more especially the output transformer 13 to attenuate transmission between the output of the amplifier and the thermistor 7 at the critical frequency or frequencies.

Although the invention has been described with reference to a specific embodiment, it will be appreciated that it is susceptible of application in various forms within the spirit and scope of the appended claims.

What is claimed is:

1. A repeated signal transmission system of the type in which the average total power transmitted is maintained substantially constant irrespective of variations in signal power content, comprising a plurality of self-regulating constant output repeaters in each of a plurality of sections, and pilot-controlled transmission regulators between the pairs of successive sections, said pilot-controlled regulators being many times faster in their regulating action than said constant output repeaters.

2. In a long distance repeated signal transmission system of the type in which there are transmitted, concurrently with the signals, auxiliary currents the intensity of which is continually varied in such manner that the average total power is maintained initially substantially constant, a multiplicity of repeaters in each of a plurality of tandem sections, each of said repeaters having the characteristic that the total power output thereof is substantially constant independent of wide variations in the total power input thereto, and a plurality of repeaters respective to the junctions of said sections, means for transmitting a pilot wave through said system concurrently with said signals and auxiliary currents, and means for automatically regulating the gain of said last-mentioned repeaters in accordance with variations in the said pilot wave, the number of repeaters in each of said sections and the rate at which each of said repeaters responds to a change in total power input being so restricted as to substantially preclude the development of an excessive transient variation within any section, and said regulating means at the said junctions having a rate of response to changes in said pilot wave that is great enough to substantially preclude the transmission from one of said sections to another of transmission variations arising within any one of said sections.

3. A long distance repeated signaling system comprising a transmission line subject to variations in attenuation, means at a multiplicity of repeater points automatically regulating repeater gain under the control of currents transmitted through said line, the speed of response of said regulating means to a change in the said control currents being great enough to follow variations in the attenuation of said line, means at a plurality of less frequent repeater points automatically regulating repeater gain under the control of currents transmitted through the line, the speed of response of said last-mentioned

means to a change in the said currents controlling it being many times as great as the said speed of response of said first-mentioned regulating means.

4. A long distance repeatered transmission system having a multiplicity of repeaters geographically spaced apart therein, means for automatically regulating a transmission characteristic of all of said repeaters under the control of an effect transmitted through all of said repeaters in tandem, and means for automatically regulating the same transmission characteristic, at a plurality of points along said system separated from each other by a plurality of said repeaters, under the control of an effect transmitted through all of said points in tandem, the two said regulating means differing from each other in respect of the rate at which they respond to a change in the respectively corresponding control effect.

5. In a long distance transmission system, the method of automatic transmission regulation which comprises effecting relatively low speed dynamic regulation at a multiplicity of points in

each of a plurality of successive sections of said system, and effecting relatively high speed dynamic regulation at each of the junctions of said sections, whereby transients tending to develop as a result of the operation of the said low speed regulation in any one section are substantially prevented from affecting the low speed regulation in following sections.

6. A long distance transmission system subject to variations in attenuation, a multiplicity of repeaters spaced apart in said system, means at certain of said repeaters for automatically regulating the gain thereof under the control of an effect transmitted through the system, said regulating means operating relatively slowly, means at less frequent repeaters for automatically regulating the gain thereof under the control of another effect transmitted through the system, said second-mentioned regulating means operating relatively quickly, and each of said regulating means substantially compensating for said variations in attenuation.

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