March 19, 1940. C. E. P. JONES 2,193,966

VOLUME RANGE CONTROLLING ARRANGEMENT EMPLOYING THERMIONIC AMPLIFIERS

Filed July 28, 1937 2 Sheets-Sheet 1

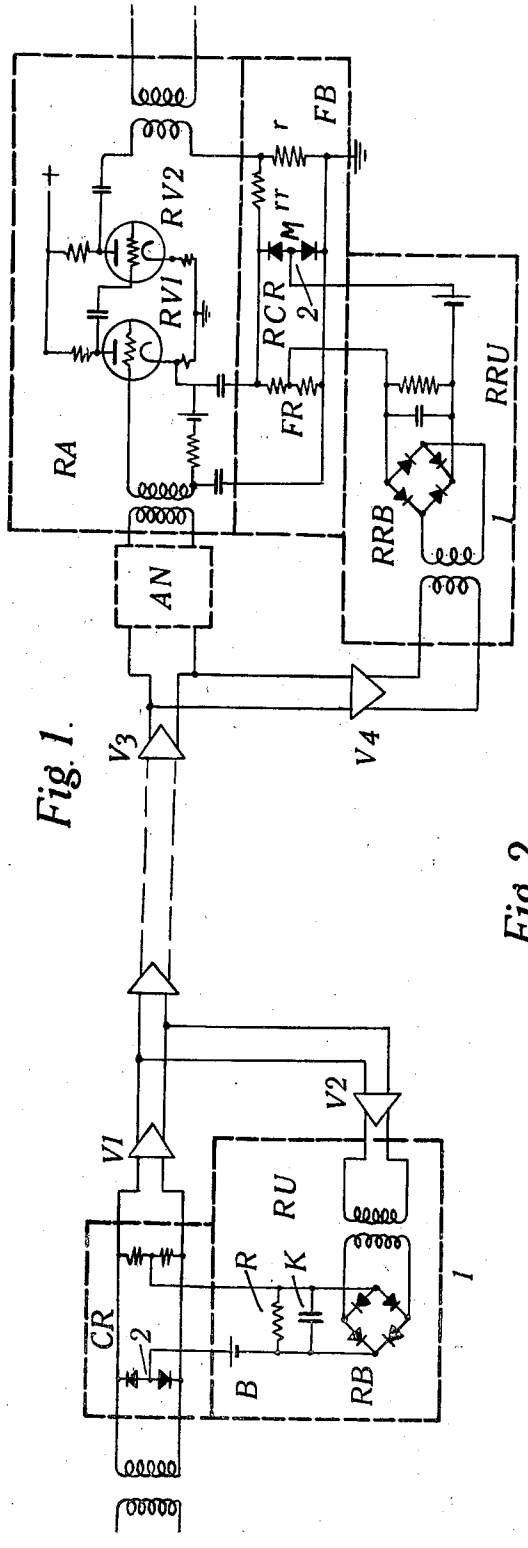



Fig. 1.

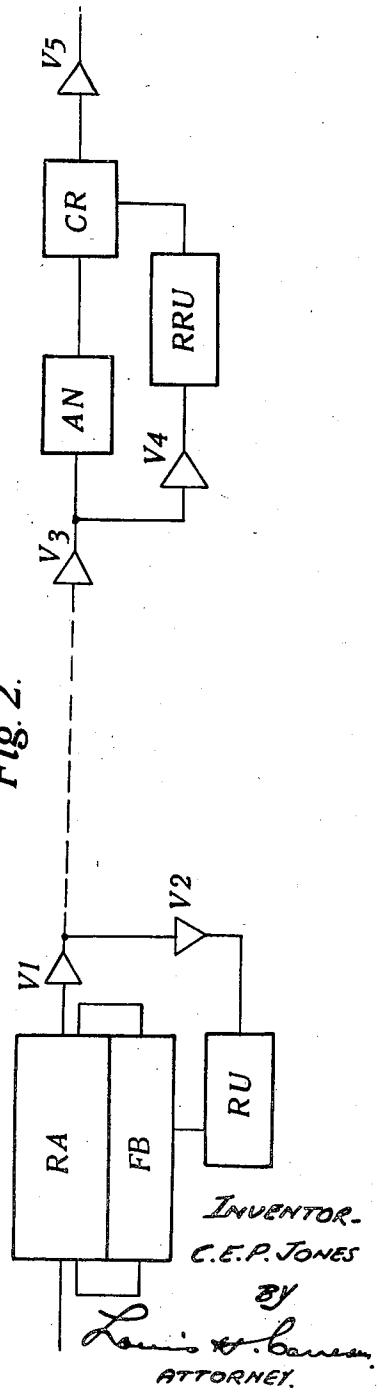



Fig. 2.

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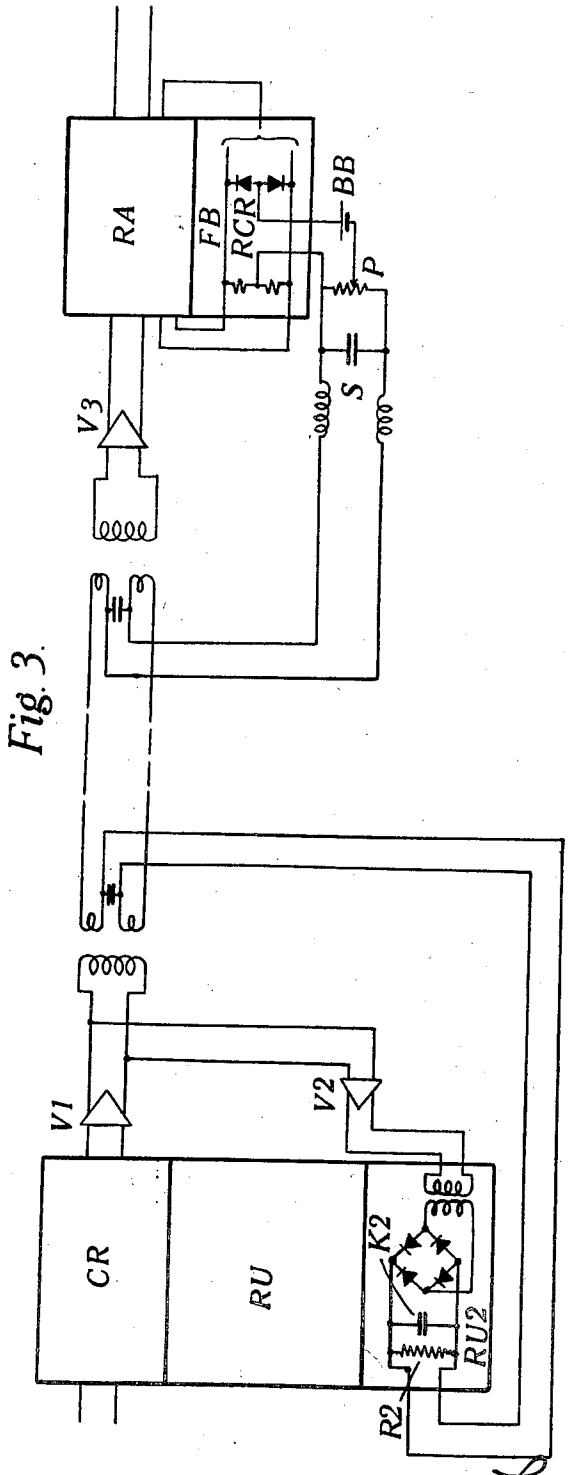



Fig. 3.

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## VOLUME RANGE CONTROLLING ARRANGEMENT EMPLOYING THERMIONIC AMPLIFIERS

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4 Claims. (Cl. 178—44)

This invention relates to volume range controlling arrangements employing thermionic amplifiers and their use in an electric signal transmission or recording system as hereinafter referred to.

According to one feature of the invention a circuit arrangement for giving a thermionic amplifying device a desired volume range distortion characteristic consists in the inclusion in a negative feedback path coupling the output of the amplifying device to the input thereof of a circuit or network providing an equal and converse distortion characteristic and controlling the attenuation of the circuit or network in the feedback path by a unidirectional current or by the passage through the circuit or network of the signals themselves.

The volume range distortion may consist in a condensing or expanding of the range or a part of the range of volumes of signals impressed on the amplifying device.

In an electric signal transmission or recording system, for example a telephone system, noises or crosstalk may be introduced into the system at some point between the transmitter and receiver. Such noise or crosstalk may be termed unwanted signals. It is desirable that wanted signals should always be at a greater level than unwanted signals and for this purpose the wanted signals may be amplified before transmission in such a manner that their range of volumes is condensed so that it does not extend below a predetermined level and an excessive upper limit is avoided. Amplification of this nature has the added advantage that it permits the operation of signal operated devices such as echo suppressors and crosstalk suppressors whilst allowing the devices to remain inoperative to unwanted signals.

In a system in which the volume range of signals is condensed before transmission or recording, a volume range restoring device, that is, a suitable expander, is provided at a subsequent point in the system for faithfulness of reproduction and in two-way systems for stability as well. According to another feature of the invention, one of these two volume range distortions (condensation or expansion) is brought about at one point in the system by the inclusion in the normal signal transmission path of a suitable variable attenuation network associated with an amplifying device, while the other volume range distortion (expansion or condensation) is brought about at another point by an amplifying device with a negative feedback circuit in which circuit is included a network which is a replica of that at the said "one" point, thus ensuring that the volume range of signals leaving the end of the system is similar to that of the signals entering the beginning of the system since the two distortions compensate each other substantially exactly. The variable attenuation network may include any suitable device providing a variable impedance or gain, and its control may be effected by a unidirectional current or by the passage through the network of the signals themselves. The network may, for example, include elements having a non-linear voltage-current characteristic. Unwanted signals arising within the system suffer expansion but not having suffered the condensation which the wanted signals have suffered it will be seen by those skilled in the art that it can be arranged that any unwanted signals are reduced to a level below the lowest level of the wanted signal, these levels being considered where the signals leave the end of the system.

It is obviously desirable in the proper execution of the invention that the networks (whether condensing or expanding) which are in use in two parts of the system shall be as nearly identical as possible, shall operate in circuits of like characteristic impedance and shall be provided with like biassing conditions and control voltage conditions for any signal level if either or both of these be necessary. In practice, however, the necessity for the exact fulfilment of these conditions is not stringent as the law connecting the input level and the output level of the condensing network can be made substantially linear.

For condensing the range of volumes of signals a condensing network may include an element having a non-linear voltage-current characteristic connected in the input circuit of a thermionic amplifier and in one form the network may consist of a pair of rectifiers connected back to back and shunting the signalling conductors and a resistance in shunt therewith, the impedance of the rectifiers being controlled by a unidirectional voltage obtained by rectifying a portion of the signals. The network is normally biassed if necessary to give a low attenuation. A time delay device is preferably included in the output of the rectifier which provides the control voltage. The polarity of the rectified voltage applied to the network is such that the shunting rectifiers offer to signals a shunting impedance which diminishes as these signals increase in amplitude. Thus, as the input volume rises the network attenuation will rise because the increase of recti-

fied current is applied to the shunting rectifiers in their conductive direction. Hence, the range of volumes is condensed. The rectifiers are conveniently dry plate metal rectifiers.

In the arrangements of the present invention a network substantially identical with that used for condensing the range of volumes is included in the negative feedback circuit of an amplifier at the point at which the received condensed volume range of signals is to be restored to its original range. The normal gain of the restoring amplifier is considerably reduced by feeding back negatively over an attenuation network to the input circuit all or a fraction of the output of signals which may appear as a voltage across a resistance in the output circuit. Increase in the attenuation of the network such as may be brought about by a loud signal in a manner similar to that described in the preceding paragraph produces a proportional rise of overall gain of the amplifier thus increasing the range of volumes of signals back to their correct relationship. The control of the attenuation of the network in the feedback circuit may be effected in a manner similar to that employed for the condensing network.

Instead of condensing the range of volumes of the signals in the manner before referred to the condensing may be brought about by the association of a thermionic amplifying device with a network adapted for volume range expansion in the negative feedback circuit, this in effect bringing about the opposite effect to that brought about by the above described restoring amplifier. The range of volumes may later be expanded by the connection in the line circuit of a replica of the expanding network.

An expanding network may consist of the condensing network already described but it should be operated by arranging that it is normally biased by means for example of a battery so as to have a high attenuation and that the control voltage has a polarity such that the shunt rectifiers have an increasing impedance as signals increase in amplitude. The condensing network described can thus be converted into an expanding network by providing a substantial bias voltage and connecting the control voltage obtained from rectifying signal voltages to oppose this bias, the rectifiers of the network remaining connected in the same manner and direction. It should be arranged that the control voltage due to the maximum signal voltage should not exceed the steady bias voltage. Alternately, an expander network may be formed in other ways. One such way which must be arranged to operate upon signals of considerable amplitude is to transmit from diagonal to diagonal of a Wheatstone bridge circuit whose arms taken in order are alternately resistors of low temperature coefficient and lamps or other resistors of high temperature coefficient, the signals themselves actually heating the resistors forming this bridge and causing the attenuation to fall as signals increase in amplitude. A condensing network may be similarly formed, the conditions for balance and attenuation being opposite in the two cases. The application of a steady biassing voltage to the bridge elements may be desirable in some cases.

The operation of the network in the feedback circuit of an amplifier may be interlocked with that of the network in the normal transmission path of the signals by the transmission from one to the other of a unidirectional current or an alternating current of suitable frequency the magnitude of which bears a relationship to the instantaneous attenuation of the said "one" network and which is subsequently rectified before application to the network in the feedback circuit. In the case of transmission via a record and reproducing apparatus such interlocking control current must also be recorded if the benefits of interlocking are required. At the said other network the interlocking control current replaces a locally derived control current and causes to flow in the said other network a current equal to that simultaneously flowing in the said one network the interlocking current if necessary being filtered and rectified and with or without amplification to provide the said equal current in the said other network.

The invention finds use in telephone and like signalling systems for the transmission of intelligence, music, pictures and the like including wireless telephone and broadcasting systems and to systems in which signals are recorded and stored and the stored record is later reproduced, where the system is subject to interference by crosstalk or noise or other disturbing currents.

For the purpose of the present invention it is to be understood that the above mentioned systems are embraced by the term electric signal transmission system.

Specific embodiments of the invention will now be described by way of example with reference to the accompanying drawings. The drawings are diagrammatic and thermionic amplifiers the circuits of which are not especially arranged for the purpose of the invention are shown in the conventional manner by triangles the apices of which point in the direction of transmission. Although the thermionic valves the circuits of which are shown are depicted as triodes they may be valves of other suitable types, e. g., pentodes.

Fig. 1 shows a transmission system in which at its input end, on the left of the drawing, the range of volumes of signals is condensed by means of the network CR associated with the amplifier V1 and at the output end, on the right hand of the drawing, the volume range is restored by means of the restoring amplifier RA provided with a negative feedback circuit FB which includes a volume range condensing network RCR substantially identical with that designated CR by which the range of volumes of the transmitted signals is condensed. The path between the input and output ends indicated by light broken lines may be a communication channel of any kind, wire or wireless, or it may be assumed to include a sound recording device in which the signals are stored. The apparatus on the right would in the latter case be connected to the sound reproducing device at a time when it is desired to reproduce the record. Fig. 2 shows in skeleton form a modification of Fig. 1 in which the amplifying device with negative feedback circuit is included at the input end of the line and in which the network in the feedback circuit is arranged for volume range expansion and an expanding network and amplifier is connected in the line circuit at a subsequent point. Fig. 3 shows another modification in which an interlock between the condensing and restoring amplifier is provided.

For the purpose of example it will be assumed that the system depicted in Fig. 1 is carrying speech and that the light broken lines in that figure represent a telephone line. It will be realised that speech may extend over a volume range from a maximum level to a minimum useful level. The maximum may be considered as

the greatest volume that is likely to be impressed on the input transformer at the left hand end of the drawing and this may be referred to as zero level. The volume of speech may fall at some instants to its minimum useful level of, say, 50 decibels below zero. Let it be assumed that a zero level signal is transmitted to the telephone line at zero level and that the line has its attenuation just compensated by the gain of the receiving apparatus on the right hand side when this level is transmitted. If unwanted signals which may be introduced into the line where it is shown broken have a level of, say 30 decibels below zero it will be necessary to amplify the speech so that the weakest components it is necessary to transmit will be above the level of the unwanted signals. Accordingly the range of speech may be condensed into a range of zero to —25 db. The maximum (or zero) line level which is limited by considerations of overloading and perhaps also of interference to other transmission channels has thus not been exceeded, although the weakest signals would be amplified by 25 db.

In the arrangement shown in Fig. 1 the condensing network CR comprises a pair of rectifiers connected back to back shunted across the line and a resistor in shunt therewith and the attenuation of the network is controlled by direct unidirectional) current obtained by rectifying the output of the thermionic amplifiers V1 and V2 by the rectifier bridge RB included in a rectifying unit RU and fed to midpoint connections of the rectifiers and shunting resistor. The network CR and the amplifier V1 may be considered as constituting a volume range condensing amplifier. The network CR has a low attenuation normally, that is in absence of any signals and might therefore remain unbiased but it is desirable to apply a small bias voltage, say 1½ volts, by means of battery B to ensure that signal rectification by the shunt rectifiers of CR does not take place to any appreciable extent on signals of low amplitude. The rectified output of the valve V2 is applied to a time delay device comprising a shunting condenser K and resistor R which relates the control voltage applied to CR to the average of the speech amplitudes during a short interval of time. The polarity of the rectified voltage applied to the network CR is such that the shunting rectifiers offer a diminishing shunting impedance to speech as its volume rises and so give rising attenuation because the increase of rectified current is applied to the shunting rectifiers in their conductive direction. The condenser range of signal volumes is amplified by VI and the amplified speech passes over the line to a subsequent point at which it is amplified by the thermionic amplifier V3. The gains of amplifiers V3 and V4 are preferably so adjusted that the voltage levels at the points 1, 1 are equal, but in practice exact equality is not always found essential for correct performance of the invention. After amplification by V3 the speech passes through the attenuator AN to the restoring amplifying device RA the attenuation of AN being such as to provide a suitable input level to RA. The device RA consists of the thermionic valves RV1 and RV2 and their connections and has a negative feedback path FB including a network RCR identical with the network CR. The connection of the feedback circuit to the input circuit of RV1 is made over isolating condensers for the purpose of excluding direct current from the feedback circuit. The output voltage of the valve RV2 developed across the resistance *r* is fed back over the network RCR whereby a considerable reduction in the gain of the device RA is effected. The network RCR comprises the resistor FR and rectifiers M. The resistance of FR is much greater than that of *r* and represents the characteristic impedance of the feedback circuit. The combined resistance of *r* and *rr* may be looked upon as the impedance of a generator and their impedance and the impedance of FR which represents a load on the generator are matched by adjustment of *rr*. This matched condition is disturbed by the shunt M across the load circuit to an extent depending on the rectified voltage applied to it, that is on the level of the speech actually passing. In a similar manner the impedance of the resistor in network CR and the impedance of transformer T are matched. The rectifier shunt in CR and that, M, in RCR are thus operating in circuits of like characteristic impedance; it is also desirable that they should operate on signals of like level and the attenuator AN is adjusted to provide an input level to RA such that the signal level across the rectifiers, that is at the points 2, 2 are equal for the best results. The bias batteries in RU and RRU should be passing equal small currents in the condition when no signal is passing and equal control currents should pass from RU to CR and from RRU to RCR when any signal traverses the system. The attenuation of the network RCR is controlled by a direct current voltage obtained by rectifying the output of valves V3 and V4 by means of the rectifier bridge RRB in the rectifying unit RRU in the manner described for the network CR. The increase in the attenuation of the network RCR such as may be brought about by a loud speech component produces a proportional rise of overall gain of the amplifier thus increasing the range of volumes back to their correct relationship. The rectifying unit RRU is substantially identical with the unit RU. It should be noted that even when the attenuation of FB is greatest there must be an appreciable amount of feedback, enough to reduce the gain of RA by about 15 to 20 db.

Fig. 2 shows in skeleton form a modification of the arrangements shown in Fig. 1. In Fig. 2 the range of volumes of speech is condensed by means of an amplifier RA having a volume range expanding network in its feedback circuit FB. The apparatus in the two figures bearing like designations are similar except for the differences mentioned in the following sentences. For the control of the attenuation of the network in the feedback circuit a rectifying unit RU connected to the circuit in a similar manner to the similarly designated unit in Fig. 1 is employed but the voltage of the bias battery is increased to a value greater than the maximum rectified signal voltage to be expected. Since, however, the network in the feedback circuit is for volume range expanding and not condensing the rectifiers in the rectifier bridge similar to RB will be reversed so that increase in the output of the amplifier in the unit consequent on receipt of loud speech components will bring about decreasing attenuation of the network and consequent reduction in gain of the amplifier RA. At the subsequent point CR is a similar network to that of Fig. 1 but again the bias voltage applied to it is correspondingly increased and again the rectifiers in the rectifier bridge corresponding to RB are reversed so that the effect of increasing applied rectified voltage to the network is to decrease the attenuation of

the network for loud signals and so to expand the volume range of the signals which are afterwards amplified by the amplifier V5. The voltage levels at the points corresponding to I, I in Fig. 1 and at the points of connection of the expander network in FB and CR respectively are made equal by suitable adjustment of the gains of the amplifiers.

Fig. 3 shows in diagrammatic form another modification of the arrangements shown in Fig. 1. In Fig. 3 the amplifier V4 and the rectifying unit RRU are not required the control current being provided by RU at the transmitting end via the line conductors. The same current as circulates in CR due to the bias battery and control voltage could be made to flow over the line conductors and through the network RCR but leakage due to defective line insulation would be detrimental to this arrangement. It is therefore preferred that a second rectifying unit RU2, similar to RU, be also connected to amplifier V2, the direct current output of RU2 being greater than but proportional to that of RU. The output of RU2 is connected to the line conductors by the well-known arrangement using a transformer with a split secondary winding, the circuit being terminated at the receiving end by a potentiometer P. A sufficient voltage is tapped off this potentiometer to provide for RCR a control voltage equal to that provided for CR by RU. The bias battery is omitted in RU2 and a bias battery BB is included in series between P and RCR. The capacity of the condenser K2 in RU2 corresponding to K in RU is less than that of K by an amount necessary to allow for the line capacity and for that of the smoothing circuit S if this latter is found to be necessary. Similarly the resistance of the resistor R2 differs from that of a R by an amount to take account of the line leakage and of the shunt circuit including the line and the potentiometer P. Thus modified, K2 and R2 with the line-and-P circuit will have the same time constant as K and R. Obviously in a recording system a suitable allowance in the values accorded to the components K2, R2 can be made in similar manner but will not include conditions beyond the record.

The smoothing circuit S should not be required under perfect balance conditions but may be found necessary in practice in spite of the application of the control voltage to the network RCR by a midpoint connection.

In an alternative arrangement that may be employed the rectified output of RU, Fig. 3, may, besides effecting control of the attenuation of the network CR also take effect on an amplifier fed with alternating current to release the alternating current for transmission over the line to the distant end where it is rectified to provide the control voltage for the network thereat. The amplifier may be so biased that no alternating current flows over the line while the circuit is in a quiescent condition. Variations in the output level of the rectifier unit RU which are dependent on signal level effect variations in the bias of the amplifier for the control of the amplitude of the alternating current to be transmitted over the line. The alternating control current is of a frequency outside the range of frequencies of the signals to be transmitted to prevent interference with the signals. To prevent any undesired effect at the distant end filters may be inserted in the line circuit between the tapping to the rectifier unit and the volume restoring amplifier, the filter being designed to block the transmission of currents of the control frequency.

It should be noted in connection with the figures that the earth connection shown is the negative connection to the plate battery and it is not necessarily connected to earth, although this is often the case. Where the line circuit arrangement of Fig. 3 is employed it may be of advantage to insulate the negative end of the plate battery from earth.

What I claim is:

1. In an electric signal transmission system a transmission circuit and at one end thereof means for condensing the range of volumes of signals to be transmitted over the circuit including a variable attenuation network, an amplifier and control means for deriving a control current the amplitude of which is dependent on the volumes of signals received at said end and for applying said control current to said network and to the transmission circuit for transmission thereover and at the other end of the transmission circuit further means for restoring the volumes of signals to their original ranges comprising a thermionic amplifier, an input circuit thereto, an output circuit therefrom, a feedback circuit connecting said output circuit to said input circuit and connected in the feedback circuit a variable attenuation network which is a replica of that at said first mentioned end of the transmission circuit and means for varying the attenuation of the network in the feedback circuit in accordance with the amplitude of the control current transmitted over the transmission circuit.

2. In an electric signal transmission system a transmission circuit and at one end thereof means for condensing the range of volumes of signals to be transmitted over the circuit said means including a variable attenuation network and a thermionic amplifier an isolating device impervious to direct current between said means and the transmission circuit, a first control means for deriving a direct current the amplitude of which is dependent on the volumes of signals received at said end and applying it to said network to vary the attenuation thereof, a second control means for deriving a corresponding direct current and applying it to the transmission circuit for transmission thereover and at the other end of the transmission circuit, further means for restoring the volumes of signals to their original range, an isolating device impervious to direct current connected between the transmission circuit and said further means, said further means comprising a thermionic amplifier, an input circuit thereto, an output circuit therefrom, a feedback circuit connecting said output circuit to said input circuit and connected in said feedback circuit a variable attenuation network which is a replica of that at said first mentioned end of the transmission circuit and a direct current path connecting the transmission circuit to the attenuation network in the feedback circuit over which direct current transmitted over the transmission circuit is applied to the network in the feedback circuit for varying the attenuation thereof.

3. In an electric signal transmission system a transmission circuit and at one end thereof means for condensing the range of volumes of signals to be transmitted over the circuit including a variable attenuation network, an amplifier and control means for deriving a control current the amplitude of which is dependent on the

volumes of signals received at said end and for applying said control current to said network and to the transmission circuit for transmission thereover and at the other end of the transmission circuit further means for restoring the volumes of signals to their original ranges comprising a thermionic amplifier, an input circuit thereto, an output circuit therefrom, a negative feedback circuit connecting said output circuit to said input circuit and connected in the feedback circuit a variable attenuation network which is a replica of that at said first mentioned end of the transmission circuit and means for varying the attenuation of the network in the feedback circuit in accordance with the amplitude of the control current transmitted over the transmission circuit.

4. In an electric signal transmission system a transmission circuit and at one end thereof means for condensing the range of volumes of signals to be transmitted over the circuit said means including a variable attenuation network and a thermionic amplifier an isolating device impervious to direct current between said means and the transmission circuit, a first control means for deriving a unidirectional current the amplitude of which is dependent on the volumes of signals received at said end and applying it to said network to vary the attenuation thereof, a second control means for deriving a corresponding unidirectional current and applying it to the transmission circuit for transmission thereover and at the other end of the transmission circuit, further means for restoring the volumes of signals to their original range, an isolating device impervious to direct current connected between the transmission circuit and said further means, said further means comprising a thermionic amplifier, an input circuit thereto, an output circuit therefrom, a negative feedback circuit connecting in said feedback circuit a variable attenuation network which is a replica of that at said first mentioned end of the transmission circuit and a direct current path connecting the transmission circuit to the attenuation network in the feedback circuit over which unidirectional current transmitted over the transmission circuit is applied to the network in the feedback circuit for varying the attenuation thereof.

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