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PEAK VOLTAGE LIMITER

Filed March 19, 1931

FIG. 1

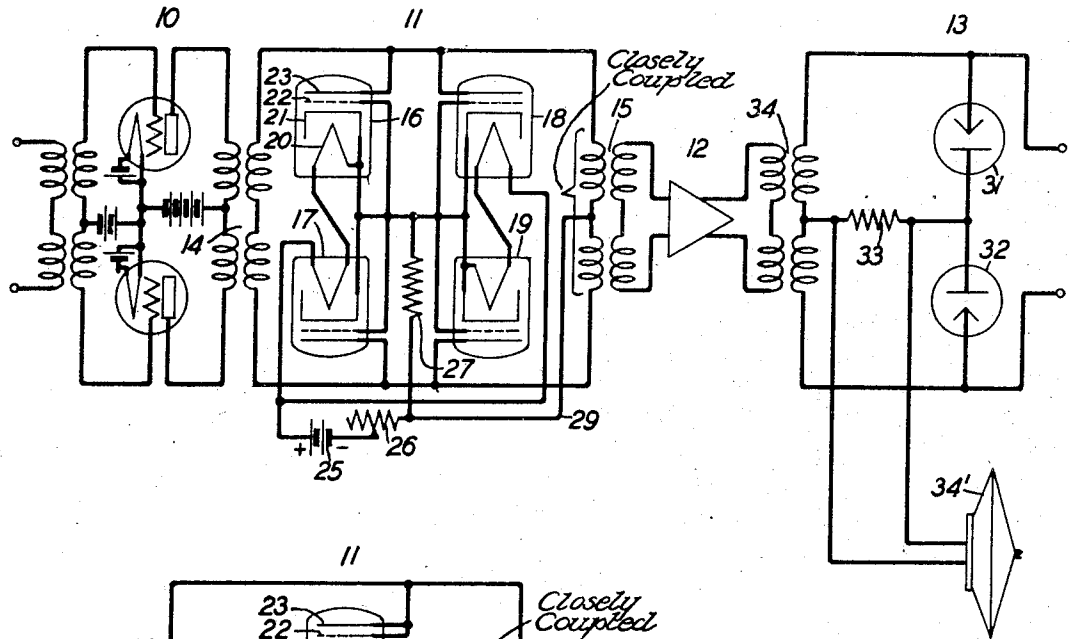


FIG. 3

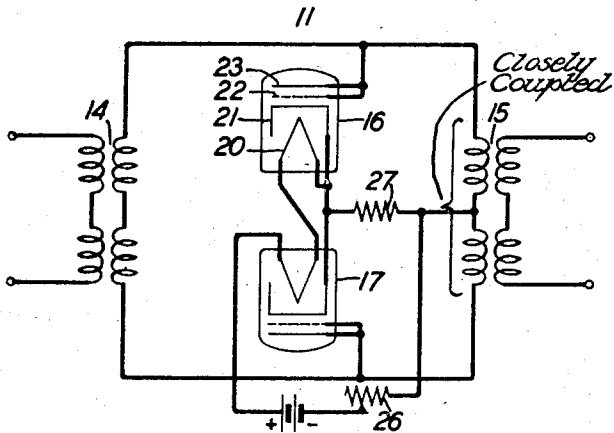


FIG. 2

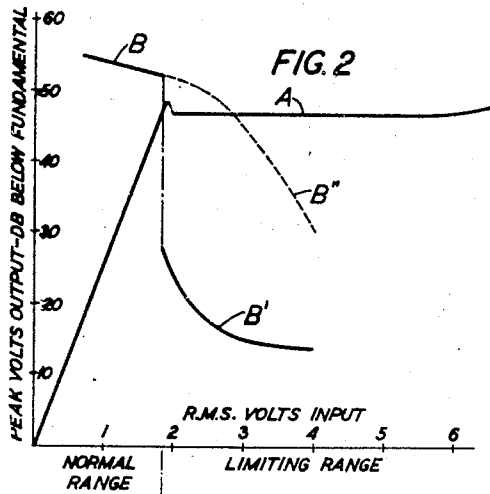
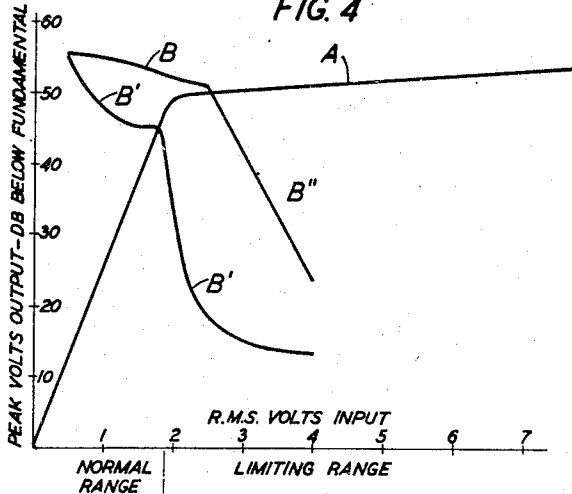


FIG. 4



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PEAK VOLTAGE LIMITER

Application filed March 19, 1931. Serial No. 523,682.

The present invention relates to peak voltage limiting circuits employing space discharge devices and has particular reference to voltage limiters for use in circuits carrying alternating current for signaling purposes such, for example, as speech currents.

Voltage limiters of the shunt type are known in the prior art as evidenced for example by Arnold reissue Patent No. 14,585, reissued January 14, 1919.

The present invention represents an improved type of voltage limiting circuit employing hot-cathode, gas-filled discharge tubes as shunting elements across the circuit on which the peak voltage is to be limited. The present invention was evolved in connection with development work on a speech transmitting circuit working at high energy level as, for example, in the input circuit to a system of very high attenuation such as a transoceanic telephone cable system. In systems of this character, not only is it very important that the voltages be limited within the prescribed voltage range, but it is almost equally important from the standpoint of quality of transmission that the voltage limiting device shall not introduce distortion. When the system is operating within the normal voltage range the low distortion in transformers, power amplifiers and other elements of the system is of very little avail if the voltage limiter of the circuit introduces large distortion. It was found when attempting to use prior art types of voltage limiters in a high quality telephone circuit that the relatively large distortion factor of the limiters rendered them unsuitable or else the limiting action after voltage limiting began to occur was not sufficiently constant.

Hot-cathode, gas-filled discharge devices have been developed which possess a linear input-output voltage characteristic over a voltage range up to a certain critical voltage and a practically constant voltage characteristic for applied voltages in excess of this critical value.

The present invention combines hot-cathode, gas-filled tubes of this type with other circuit elements in a novel manner to provide an effective voltage limiting circuit possess-

ing high quality of transmission over the normal voltage range and substantially a flat characteristic over the limiting range.

An accessory feature of the invention comprises an alarm circuit for indicating failure of the voltage limiting portion of the circuit.

The various features and objects which characterize the present invention will be more clearly understood from the following detailed description of certain typical embodiments thereof as illustrated in the accompanying drawing.

Referring to the drawing,

Fig. 1 shows a speech amplifying and voltage limiting circuit embodying the invention;

Fig. 2 shows a characteristic obtained with the circuit of Fig. 1;

Fig. 3 shows a modified type of power limiting circuit; and

Fig. 4 shows characteristics obtained when using the type of limiter shown in Fig. 3.

The circuit of Fig. 1 is a speech amplifying and limiting circuit suitable for use for example in transmitting into a line of high attenuation such as transoceanic cable and may find application in terminal circuits for cables such as are shown in the U. S. application of A. M. Curtis, Serial No. 382,011, filed July 29, 1929 or in the transmitting circuit disclosed in an application of Charles N. Nebel, Serial No. 459,663, filed June 7, 1930.

The circuit of Fig. 1 shows an initial push-pull amplifier stage 10 supplied with speech waves from any desired or suitable source, a peak voltage limiting circuit 11, a power amplifying stage 12 and a protection circuit 13, the output of which is assumed to lead to the transmission path such as the deep sea telephone cable. Amplifiers 10 and 12 may be of the usual prior art construction.

The voltage limiting circuit 11 is connected between the output transformer 14 of preliminary amplifier 10 and the input transformer 15 of power amplifier 12. This voltage limiting circuit comprises two pairs of hot-cathode gas-filled discharge tubes, each pair being connected back-to-back in shunt across the two sides of the line. One pair of tubes is shown as comprising tubes 16 and

17 while the other pair comprises tubes 18 and 19. These tubes may all be similar to each other in construction, and each comprises a heater element 20, a cathode 21, a control element 22 and an anode 23. The cathodes 21 of all of the tubes are heated by means of the heaters 20 which in turn are supplied with heating current from battery 25 through regulating resistance 26 and a polarizing resistance 27. A lead 29 extends from the negative end of the polarizing resistance 27 to the middle of the primary winding of the output transformer 15. This transformer is designed in a manner known in the art so as to have very close coupling between the two halves of its primary winding for a purpose which will appear presently.

In the operation of the voltage limiting portion of the circuit the four tubes shown are all maintained with heated cathodes ready to transmit current instantly when the applied voltages between the cathode and anode are of proper magnitude and sign. The heating of the cathode is accomplished as stated by passing current from battery 25 through the heater element 20. This current in passing through polarizing resistance 27 develops a voltage between the terminals of this resistance such as to make the cathodes of all of the devices positive with respect to the center point of the primary winding of the output transformer 15. This voltage may be made any desired value within practical limits and together with the characteristics of the tubes themselves determines the peak value at which the voltage in the circuit 11 will be limited. Let it be supposed that a wave is transmitted to circuit 11 which makes the anode 23 of tube 16 positive with respect to its cathode 21, that is, the voltage is in excess of the voltage drop in the polarizing resistance 27. If this voltage rises to a value equal to the anode-cathode voltage of tube 16 at which current begins to flow, current will flow across between anode 23 and cathode 21 through polarizing resistance 27, lead 29, the lower half of the primary winding of transformer 15, the lower side of line 11 and through the secondary of output transformer 14 (which is taken as the source of the applied voltage) which is connected at its other end of the anode 23 through the upper side of the circuit 11. It is a characteristic of the tube 16 that as soon as this current begins to flow the voltage between the anode 23 and cathode 21 and therefore the voltage across the upper half of the primary winding of output transformer 15 assumes a definite maximum value which is substantially constant notwithstanding that the applied voltage through transformer 14 may tend to increase. Any tendency of this voltage to increase results in a further lowering of the impedance of the space path of tube 16 and an increase in discharge current, but the terminal voltage remains substantially

constant. The voltage across the lower half of the primary winding of transformer 15 likewise remains constant on account of the close coupling between the two halves of this transformer winding mentioned above.

The relation between the applied voltage and the peak voltage in the output circuit of the voltage limiting circuit 11 is shown by the curve A of Fig. 2. As is seen from this curve there is a linear relation between the applied voltage and the output voltage over the normal operating range while for all voltages in excess of the normal range, the output peak voltage is maintained substantially constant. Curve B of this figure shows that the distortion introduced by the voltage limiting circuit is no greater than the distortion present in the amplifiers 10 and 12, the curve for amplifier 10 alone being B''. The distortion is indicated by the level of the third harmonic with respect to the fundamental. If the third harmonic is of lower intensity than the fundamental and if the difference in level is large, the distortion is correspondingly low. It is seen from curve B that the level difference between the third harmonic and fundamental is large and that the peak voltage limiting circuit does not introduce more distortion than is already present in the amplifier circuits. In fact, curve B practically coincides with the curve B'' for the amplifier 10 by itself. The amount of distortion in the limiting range is of no moment but as a matter of interest curve B' for the combined amplifier 10 and limiter circuit has been indicated. The discontinuity in the curve B—B' is probably due to the small peak in the curve A at the point where limiting action begins to take place.

It will be understood that on the opposite half cycle of the voltage waves impressed from the amplifier 10 onto the voltage limiting circuit 11, a tube, say tube 17, which is poled oppositely to the tube 16 will operate in the same manner as has been described of tube 16 so that both half cycles of the alternating voltage waves are limited in the same manner.

While a single pair of limiting tubes 16, 17 might be used, it is preferable to employ a reserve pair of tubes 18, 19 which may act similarly to tubes 16, 17 but which preferably have slightly different characteristics so that they do not operate except by failure of tubes 16 and 17. Even where two practically identical tubes such as 16 and 18 are connected in parallel in a circuit, it has been observed that only one of the tubes will as a rule become conductive. This is for the reason that the impedance of the tube drops to a very low value immediately upon the establishment of current flow through the tube. This fall of the internal impedance to a lower value prevents the anode voltage from rising to a higher value so that unless the second tube

(such as 18) has already begun to conduct current it will not begin to conduct after the first tube (such as 16) has started to pass current. For this reason two substantially identical tubes 16 and 18 could be used and also tubes 17 and 19 could be substantially identical since only one pair of tubes 16, 17 or 18, 19 would be operative at the same time. However, by choosing for tubes 18 and 19 tubes which have slightly different characteristics the normal limiting will be accomplished by tubes 16, 17 and the tubes 18, 19 will serve as reserve tubes.

The power amplifier 12 is shown connected through outgoing transformer 34 to circuit 13 which is provided with two cold-electrode gas-filled protection devices of the discharge gap type 31 and 32 shunted across the circuit 13. These are in the nature of emergency protectors to safeguard the cable against accidental application of excessive voltages thereto due to some irregularity or failure in the transmitting circuit. If for example all four of the tubes 16, 17, 18 and 19 should fail and an excessive voltage be applied to the input of transformer 34, one or both of the discharge gap protectors 31, 32 would break down causing a current to flow through resistance 33. An alarm device which may conveniently be in the form of a loud speaker is shown connected across the terminals of resistance 33 so that the discharge current through the resistance will produce a howling effect in the loud speaker indicating that the circuit should be cut out of service.

It was mentioned above that the tubes 16, 17, 18 and 19 are of the hot-cathode gas-filled type. These tubes are preferably of the type disclosed in an article entitled "Gas Filled Thermionic Tubes" by Albert W. Hull, published in the Transactions of the American Institute of Electrical Engineers, Vol. 47, July, 1928, pages 753 to 763. The specific type of tube used by applicant with successful results is disclosed in a patent application in the name of A. L. Samuel, Serial No. 465,083, filed July 1, 1930. Instead of the "Thyratron" or the three electrode type of tube disclosed in the Samuel application, a tube having no controlling element, but only a cathode and an anode such as disclosed in the Hull article referred to, for example, may be used. As explained in the Hull article cathode disintegration can be reduced and long tube life can be obtained by observing the fundamental principle in the operation of the tube that the cathode potential drop must not exceed the critical value, sometimes called the disintegration voltage, above which cathode disintegration first begins to take place. This critical value lies between 20 and 25 volts for the common inert gases and is considerably above the ionizing potential. By proper design and use of the tubes as explained by Hull and Samuel re-

spectively, tubes of this type can be made to have very large current carrying capacity and an active life of the order of 1,000 hours or greater.

In accordance with the tube construction disclosed in the Samuel application referred to, the cathode 21 is in the form of a pencil or rod which is coated with thermionically active material. The control element 22 is in the form of a cylinder with a hole in one side thereof through which the electrons may pass and the anode 23 is in the form of a wire which is placed opposite the hole in the cylinder. In the circuit arrangement of Fig. 1 having the characteristics disclosed in Fig. 2, it will be observed that the cylinder (shown dotted) is connected to the cathode in each case while the wire (anode) is connected to the respective side of the circuit 11. With this type of connection actual practice has shown the limit voltage to be of the order of 24 to 25 volts. This of course is the limit voltage due to the tube alone. The actual limit voltage across the two sides of the circuit 11 is equal to twice this value plus twice the value of the voltage drop in resistance 27. As explained above the voltage drop in resistance 27 may be made of any value within wide limits and may be given either polarity by proper connection in the circuit, so that the actual limiting voltage across the circuit 11 may be readily controlled to suit various conditions of use.

An alternative scheme of connection in which the cylinder is connected to the wire and both elements are connected to the respective side of the circuit 11 is shown in Fig. 3. For simplicity of disclosure only one pair of tubes 16 and 17 is shown in this figure, the reserve pair being omitted. In all other respects the circuit may be identical with that shown in Fig. 1. Actual experience with this type of circuit has shown that the limit voltage across each tube is of the order of 18 volts. As explained in connection with Fig. 1, however, the actual limit voltage for the circuit 11 may be made any convenient or suitable value by a proper choice of resistance 27.

The characteristics of the circuit of Fig. 3 are given in Fig. 4 and are in general similar to those already described in Fig. 2. The principal differences are two; first, it will be observed that the curve A does not possess the slight hump which is shown in Fig. 2 at the point where the limiting action begins; secondly, slightly more distortion is introduced by the circuit of Fig. 3 than by the circuit of Fig. 1. The curve B of Fig. 4 indicates as before the difference in level between the third harmonic and the fundamental of the amplifier alone without the limiting circuit 11 connected in. Curve B' at the left of the curve A shows the combined characteristic of the amplifier and the volt-

age limiting circuit. This is seen to be somewhat lower than curve B indicating a correspondingly higher amount of distortion component. However, by actual trial the

- 5 lowest point of the curve B' at the left of the point where it crosses the curve A corresponded to 35 d. b. difference in power level between the third harmonic and the fundamental which is an ample margin for
10 most purposes. Curve B'' and curve B' at the right of the point where it crosses the characteristic A are the corresponding relations within the limiting range. As explained above these portions of the characteristics are unimportant since in general the
15 amount of distortion which may be present over the limiting range is of no interest.

What is claimed is:

1. The combination with a transmission
20 line comprising a pair of conductors, of a voltage limiting circuit comprising a pair of hot-cathode gas-filled discharge devices having anodes connected to opposite line conductors and cathodes connected to a neutral
25 point of said line, said devices having a resultant zero discharge voltage range as great as the maximum normal voltage on said line, and a substantially constant voltage discharge characteristic over a limiting range
30 in excess of said normal maximum voltage.

2. The combination with a transmission line having a pair of conductors of an inductance in shunt of said line having a mid-connection, the two halves of said inductance
35 being closely coupled, a pair of hot-cathode gas-filled discharge tubes having anodes connected to respective line conductors and cathodes connected to the mid-connection of said inductance coil, and an output circuit
40 coupled to said inductance.

3. A voltage limiting circuit for a line, comprising a transformer with a mid-connection, and a pair of hot-cathode gas-filled
45 discharge tubes connected across the line, one shunting each half of said transformer and oppositely poled, said tubes transmitting current only in case of excess applied voltage and maintaining the voltage substantially constant throughout the limiting range.

4. A voltage limiting circuit for a line, comprising a transformer shunting said line and provided with a mid-tap, a plurality of
50 hot-cathode gas-filled discharge tubes similarly connected between said mid-tap and one side of the line, and a plurality of hot-cathode gas-filled discharge tubes similarly
55 connected between said mid-tap and the other side of the line, whereby certain of said tubes act as reserves for others and take up the limiting action upon failure of the
60 latter.

5. In a voltage limiting circuit for a transmission line, a transformer having a winding in shunt to said line, a pair of hot-cathode
65 gas-filled discharge devices having their

cathodes connected to a point in said winding and their anodes connected respectively to opposite sides of said line, a source of direct current connected to impose a positive voltage on said cathodes with respect to said point, and connections for deriving voltage of limited range from said transformer. 70

6. A voltage limiting circuit for a transmission line, comprising a transformer having a winding in shunt to said line, a pair of gas-filled discharge tubes having anodes and cathodes, the anodes being respectively
75 connected to opposite sides of said line, a circuit supplying heating current for said cathodes including a resistance connecting said cathodes to a point in said winding, the voltage developed in said resistance making
80 said cathodes of positive potential with respect to said point in said winding, and a load circuit connected to said transformer. 85

7. A circuit according to claim 6 in which said load circuit is equipped with a shunt protection device having a zero current characteristic throughout the voltage range to which said limiting circuit is designed to
90 limit the voltage, and an alarm device connected in series with said protective device for indicating failure of said limiting circuit. 95

In witness whereof, I hereunto subscribe my name this 12th day of March, 1931.

WILLIAM A. KNOOP.