Our invention relates to electron multipliers, and particularly to the use of electron multiplier repeaters in combination with telephone lines.

Among the objects of our invention are: To provide high gain multipliers for telephone transmission lines; to provide telephone repeaters which do not require frequent servicing; to provide repeaters that may be installed in cables without special requirements as to accessibility for frequent servicing; to provide repeaters which are operable upon currents which may be transmitted through the signal carrying line; to provide repeaters independent of periodically spaced local battery circuits; to provide repeaters operable with signals attenuated to a point far below that at which ordinary thermionic amplifiers become inoperable; to provide means for amplifying telephonic currents, of stable and long lived characteristics; to provide apparatus for the successive amplification of attenuated currents along long lines wherein the degree of amplification may be controlled within wide limits; to provide a telephone repeater system wherein the signal-to-noise ratio is higher than is possible with thermionic tube type repeaters.

Our invention possesses numerous other objects and features of advantage, some of which, together with the foregoing, will be set forth in the following description of specific apparatus embodying and utilizing our novel method. It is therefore to be understood that our method is applicable to other apparatus, and that we do not limit ourselves, in any way, to the apparatus of the present application, as we may adopt various other apparatus embodiments, utilizing the method, within the scope of the appended claims.

Briefly as to apparatus, our invention comprises a new type of electron multiplier wherein the initial signal impulse controls an electron stream having a narrow range of component electron velocities, constructed to require no servicing during its normal life, and so arranged as to fit within the cable sheath or housing of the line. It is peculiarly adapted to use with toll telephone lines, and is susceptible to the transmission of numbers of signals simultaneously by the use of principles well known in the art.

In the drawing:

Figure 1 is a schematic diagram partially in section, of our invention used as a one-way repeater on a two-wire line.

Figure 2 is a schematic, partial cross-sectional view of a preferred form of our repeater tube, taken along the line 2--2 of Figure 1.

Figure 3 is a circuit diagram showing our invention schematically applied to two-way communication on a two-wire circuit.

Long-line telephone communication has been handicapped since its inception by the rapid attenuation of voice currents therein, which is so rapid that for practical working conditions the limit of actual line length is approximately thirty miles, and beyond that point signal amplification must be provided. The earlier methods involve such apparatus as a series of mechanical amplifiers with the power supplied by local batteries connected to successive line sections.

The development of thermionic tube amplifiers provided the next big step forward, permitting high successive amplification with relatively slight distortion. Vacuum tube amplifiers, however, are expensive, and much auxiliary equipment is necessary to maintain stability.

Battery equipment must be maintained at frequent intervals along the lines, and frequent adjustment and replacement of tubes is necessary. It is not possible to distribute the repeating units at intervals much greater than thirty miles because of the low signal intensity, which prevents the tubes from functioning.

The present invention represents a radical step forward from the ordinary vacuum tube amplifier. The heart of the device is a modification of the electron multiplier which has been described in various forms in the prior Farnsworth Patent No. 1,969,399, issued August 7, 1934, entitled "Electron multiplier", and in the Farnsworth applications: Ser. Nos. 692,585, Electron multiplying device, now Patent No. 2,071,515, issued February 23, 1937; 706,865, Method of electron multiplication; 10,604, Means and method for interrupting electron multiplication.

The theory of electron multipliers, wherein repeated electron impacts generate secondary electrons, has been gone into in detail in these applications and issued patents, and need not be repeated. The tremendous gains possible with such electron multipliers, and the low noise-signal ratio, have greatly increased the length of line which may be utilized without intermediate repeaters, and at the same time decreased the necessity for frequent local battery stations.

In Figure 1 of the drawing, an electron multiplier is shown within an envelope connected to a pair of lines 2 and 4 through which an incoming signal is received. A load impedance comprising a capacitance 5 and an inductance 6 is connected across lines 2 and 4 through which an incoming signal is received. The midpoint 7 between capacitance and inductance is connected by a lead 41 to the housing 3, which acts as a shield and mechanical support for an electron gun within it, and in addition controls the gun output in accord with the strength of an incoming signal. Housing 3 is shown as rectangular, but might be of any other convenient shape, Insulating supports 10, positioned within the housing 3, support the gun assembly case 11. Within gun assembly case 11 and at one end thereof is supported a cathode 12, here shown as
a filament. This cathode may be of the heater type, if desired, or might be made of photosensitive or radioactive material, as the emission necessary is extremely low.

5 The gun assembly case 11 is transversely divided midway of its length by a diaphragm 14, having therein a small aperture 15 offset from the cathode 12. In the chamber formed by the diaphragm and the end of the gun not containing the cathode, a deflecting plate or control electrode 16 is positioned, having a lead 17 extending therefrom to the outside of envelope 1. An aperture 18 is disposed through the end of gun 11 opposite that adjacent the cathode 12.

10 This aperture 18 is axially aligned with aperture 15, both of them being equally displaced from said cathode. An aperture 20 in registry with aperture 19 and formed through case 8, and aperture 21 formed through an anode member 22, provide access to the multiplying chamber, comprising two parallel plate anodes 22 and 24, having their surfaces coated with discrete particles of secondarily emissive material, and having their body structure formed of material having a high electrical resistance. Between and parallel to said anodes is a herring-bone lattice or grid 25 of low resistance wire supported by two rods 26 and 27, the resistance material, having the spaces of the V-formed wires pointing toward the gun end of the envelope 1. At the opposite end of the envelope, a square rim 28 is formed integral with and normal to rods 26 and 27. Across this frame is stretched a lattice-work 30 of parallel conducting wires. A collecting plate 31 is supported parallel to grid 30, and in registry therewith, whereby electrons passing there through may be collected. Plate 31 is connected to line 32, and through a resistance 34 to the lattice 30.

20 Assumee a signal current to have been impressed upon line 2 at a considerable distance from multiplier 1. By the time it has traveled over line 2 and arrived at the multiplier, it will have become attenuated to a considerable degree. The return circuit through the grounded line 4 is reached through condenser 5 and impedance 8, and also through an impedance 36 connecting line 2 to ground through a condenser 38. The next segment of line 32, is connected through a corresponding impedance 37 and condenser 36 to ground.

The direct current flowing in line 2 is composed of a different component utilized to energize the multipliers and an audio-frequency voice component, plus additional signal frequencies if part of a phantom circuit or used for telegraph service. Impedance 35 prevents the audio-frequency current from passing, and any slight amount that does get through is grounded through condenser 38.

The direct current component, however, is permitted to pass through impedances 35 and 37, and to thereby feed current to successive operating units. The signal current impressed across lines 2 and 4 is passed by condenser 5 and impedance 8, and the potential drop across said impedance is utilized to bias the housing 3 and thereby control the number of electrons permitted to pass through aperture 20. The potential drop across a resistor 39 is utilized to heat cathode 12. It is not necessary to use a large current, since it is desired to have only a few electrons to start the multiplier operating.

In order, however, to secure a maximum response to the incoming signal, it is desirable to use an electron stream having a velocity band within the range of the potential of the impressed signal. This is obtained by proper construction of the gun. When electrons are emitted by the cathode 12, they have a wide range of velocities.

A certain number of electrons of random velocities will go through aperture 15. Since aperture 15 is aligned with aperture 15 but not with cathode 12, it is not likely that many of the electrons passing through the aperture 15 will pass through aperture 19. If, however, a positive charge is imposed on control electrode 16, by connecting it to the low potential end of anode plates, the slowest electrons may be deflected so much that they will be collected upon said control electrode, or upon the end of the gun chamber. The fastest electrons will be deflected only a small amount, and will be collected upon the gun sides and end. A certain number of electrons, having intermediate velocities, will be deflected just enough to cause them to pass through the aperture 19. After emerging from aperture 19 the stream must pass through a control aperture 20, the potential of which is controlled by the incoming signal through lead 41. Since the electrons passing through aperture 19 have been rigorously selected on the basis of velocity, the charge passing through the control aperture 20 can be fully controlled by the charge on the aperture 20, and the result is a perfectly modulated electron stream flowing through the anode aperture 21 into the multiplying chamber. At this point the stream of electrons comes under the accelerating influence of the potential existing on the herring-bone lattice 25. Due to the wide spacing of the lattice wires, while a few electrons will be collected, the majority will pass through and reach the opposite anode plate 24, where the impact will release secondary electrons which will, in turn, be attracted toward the lattice 25 and pass therethrough, striking anode 22, and repeating the process. Each time the process is repeated, however, the impacts occur nearer the collecting plate 31, due to the potential relations between anodes 22 and 24 and lattice 25.

The direct current potential on lines 2 and 32 is tapped and lead to the collecting plate 31, and then through a resistance 34 to the lattice 30 with its rim 28. A potential difference is thereby set up between the collecting plate 31 and the shield 30. Although little current flows, due to the high resistance of the rods 26 and 27, a large potential drop is produced along their length. At a point along the rods where a potential drop, of say one hundred volts from frame 28 has occurred, a connection 42 is made to the end of anode plate 24 and from said plate 24 to anode 22 through a lead 44 and similarly, a lead 45 is connected from the low potential end of rods 26 and 27 to a point on anodes 22 and 24, about one hundred volts from the low potential end of said anodes. The result is a constant potential difference of about one hundred volts between the lattice grid 25 and the anodes 22 and 24 at opposite points.

If the electrons passing through aperture 21 were to pass straight across the tube under the influence of the accelerating potential on lattice 25, they would not strike the opposite anode with sufficient force to cause the emission of secondary electrons, since the accelerating potential is equally effective in decelerating the electron has passed through the lattice, and by hypothesis the initial electron velocity was very small. Due, however, to the shape of the lattice, the potential distribution in the electrostatic field
within the space is such that the electrons are deflected slightly to the right in Figure 1 of the drawing, and consequently arrive at a point along anode 24 having a higher potential than that of the anode 22 which it had just left. This difference in potential supplies an additional accelerating force toward anode 24, and so overcomes the deceleration of the latter 22 and causes the electrons to strike with a velocity sufficient to knock out secondaries at a ratio greater than unity.

This process is repeated with a continuing drift toward the collecting plate, the number of electrons increasing by the next higher power of the emission ratio with each anode. The high potential end of the anode plates, the electron stream is attracted to the collecting plate through the screen 30. The concentration of electrons thus built up on the collecting plate 31 acts as a potential source to drive current through the next section of line 32.

In Figure 3 we have shown our invention applied to two-way service on a two-wire telephone line 2, 4, over which a signal is received. The impedance of lines 2 and 4 is matched by a balanced network 50 connected to lines 2 and 4 through the windings of a hybrid transformer 51.

The hybrid taps of transformer 51 are centered at points 52 and 54, from which leads are carried to the primary of an input transformer 55, the secondary of which is connected to one of our multiplier tubes 56. The output side of this tube 56 is fed through the primary windings of a hybrid coil 57, which feeds the output onto lines 58 and 59. The signal current traveling in the opposite direction is fed into the repeater on lines 59 and 60, which are terminated by a balancing network 58, and from center taps 61 and 62 on hybrid coils 57 is led to an input transformer 64, which inductively impresses the signal on the multiplier tube 65. The output of this tube, in turn, is fed into the primary of the hybrid coil 51, and so impressed on lines 2 and 4.

Potential supply is secured from the lines by connecting a low pass filter 66 between the balancing networks 50 and 51. By proper proportioning of the filter unit, the impedance matching network 50 and 51 against lines 2, 4 and 56, 60, respectively, is undisturbed in the audible range, while direct current is passed from one line section to the next. Lines 2 and 59 form the positive, and lines 4 and 60 the negative, sides of the supply.

The positive line is connected through a lead 67 and the primaries of the hybrid coils 51 and 57 to the collecting anodes 31. A lower positive potential is placed on the screens 30 by connecting lead 67 to said screens through resistors 34. From screens 30 and the associated framework leads 62 make connection to the plates 22 and 24, as explained in connection with Figure 1, and the low-potential ends of the plates 23 and 24 are connected to supply the required positive potential on deflecting plate 18 of the gun.

Resistors 69 provide a potential drop between the deflecting plate 19 and cathode 12, and the return to the current supply lines is accomplished through current limiting resistors 70 and a lead 71.

This type of current multiplier has certain advantages arising from the use of a small velocity range of electrons in the electron gun which is the result of the impressed signal characteristic curve of electron emission. The number of electrons having a velocity within a particular narrow range is a very small percentage of the total emitted with random velocities.

The deflection of the electrons having velocities higher than that corresponding to the deflecting voltage is small. However, if the controlling or signal voltage is on the same order as the electron velocity, as for example, one microvolt signal controlling a segregated band of electrons having velocities corresponding to those imparted by an accelerating potential of one microvolt, full control will be secured.

The control of this segregated velocity band makes possible an amplifying operation entirely independent of the strength of the impressed signal. Since the degree of amplification is thus independent of the signal strength, by proper proportioning of the multiplier units, they may be adjusted to operate on varying potentials along the line, and to amplify signals of any desired strength. The location of the repeater-multiplier units is thus entirely independent of the various factors which require certain positions for the efficient operation of conventional types.

It should be pointed out that there are a large number of ways in which battery current may be supplied to the multiplier units. It may be carried by the lines themselves, or may be carried by auxiliary feeder cables. It is possible that with cable construction the metallic cable covering might be used as a feeder. Local battery supply at intervals could be used, or high potentials at infrequent stations. It is an advantage of our invention that the potential supply may be secured in so many different ways, without in the least decreasing the efficiency of operation.

It is also to be understood that our invention is equally applicable to four-wire circuits, and to the operation with phantom, band pass, or other circuit arrangements whereby a number of messages or signals may be sent simultaneously along wire lines, or for carrier frequencies with appropriate circuits.

The essential feature is the use of the electron multiplier with wired lines for transmitting signals or other messages, it being practically independent of the length of the lines with which it is used and the degree of attenuation of the signal which it is desired to amplify, since the velocity range of the emitted electrons in the multiplier need be no greater than that which may be controlled by a signal current of a few electrons.

Summarizing: our invention provides a means of utilizing electron multiplication with wired lines for the transmission of signals, which is so constructed that it may be built into cable lines with the cables, and is practically independent of servicing requirements. There is no critical length of lines over which the repeater will fail to function, and they are therefore independent of specific location.

Our multiplier, by its design, has an output current limited only by the heat dissipating ability of the tube, and not by the strength of the signal to be amplified. We have found that by this system a great economy of operation is obtained, and our amplifier will operate under conditions wherein the conventional type could not because the signal currents are below the threshold or minimum value.

We claim: 1. A method of operating electron multipliers which comprises producing electrons having ran-
dom velocities, segregating those electrons having velocities corresponding to the signal potentials to be amplified, modulating the number of said segregated electrons by said signal potentials, admitting said modulated number of electrons to a multiplying chamber having secondarily emissive surfaces and a perforate electrode therebetween, causing said admitted electrons to impact the walls of the said multiplying chamber, whereby an increased number of electrons may be produced by said impact attracting said electrons toward said perforate electrode, permitting the greater part of the attracted electrons to pass therethrough and produce further secondaries, causing such secondary electrons to drift along the multiplying chamber, collecting said electrons after a desired degree of multiplication has been obtained, and utilizing said collected electrons to produce an output current.

2. A method of operating electron multipliers which comprises producing electrons having random velocities, segregating those electrons having velocities corresponding to the signal potentials to be amplified, modulating the number of said segregated electrons by said signal potentials, admitting said modulated number of electrons to a multiplying chamber having secondarily emissive opposed surfaces and a perforate electrode therebetween, setting up a potential gradient along said multiplying chamber, setting up a potential gradient upon said perforate electrode whereby electrons may be attracted toward said electrode, permitting the majority of said electrons to pass therethrough and impinge upon the opposite walls of the said multiplying chamber, whereby successive electron multiplications may occur, accelerating said electrons along the potential gradient, wherein said successive electron multiplications may occur at points of successively higher potential, collecting said multiplied number of electrons, and utilizing said collected electrons to produce an output current.

3. A method of operating electron multipliers which comprises producing electrons having random velocities, segregating those electrons having velocities corresponding to the signal potentials to be amplified, modulating the number of said segregated electrons by said signal potentials, admitting said modulated number of electrons to a multiplying chamber having secondarily emissive opposed surfaces and a perforate member therebetween, setting up a potential gradient along said multiplying chamber, setting up a potential gradient upon said perforate member, accelerating the admitted electrons across and along the multiplying chamber, whereby successive impacts occur at points of successively higher potential, collecting said multiplied number of electrons to produce an output current.

4. A method of operating electron multipliers which comprises producing electrons having random velocities, segregating those electrons having velocities corresponding to the signal potentials to be amplified, modulating the number of said segregated electrons by said signal potentials, admitting said modulated number of electrons to a multiplying chamber having secondarily emissive opposed surfaces and a perforate electrode therebetween, setting up a potential gradient along said multiplying chamber, setting up a potential gradient along said perforate electrode, attracting said admitted electrons toward said perforate electrode, permitting the greater portion of said electrons to pass therethrough, attracting said electrons onto the opposed secondarily emissive surface, whereby an increased number of electrons is released, deflecting said electrons by said potential gradient, whereby successive impacts will occur at points having successively higher potential, collecting said multiplied number of electrons, and utilizing said collected electrons to produce an output current.

5. A method of operating electron multipliers which comprises producing electrons having random velocities, separating out those of said electrons having velocities within a desired range definitely related to the order of magnitude of a signal current to be amplified, introducing a number, modulated by the signal to be amplified, of said electrons to a multiplying chamber, multiplying said admitted electrons to a desired value, collecting said multiplied quantity of electrons, utilizing said collected electrons to produce an output current, and a perforated element central thereof, setting up a potential gradient along said chamber increasing away from the point of admission of said segregated electrons, setting up a potential gradient centrally, whereby said admitted electrons will be attracted toward said perforate element, permitting the major portion of such attracted electrons to pass therethrough, to produce secondaries by impacting said multiplying chamber; collecting said electrons toward the points of higher potential within said multiplying chamber, whereby successive impacts will occur at points of successively higher potential, collecting said electrons after a desired degree of amplification has been obtained, and utilizing said collected electrons to produce an output current.

6. A method of operating electron multipliers which comprises generating electrons, segregating those of said generated electrons having velocities, within a desired range, introducing a number, modulated in proportion to the amplitude of a signal to be amplified, into a multiplying chamber having opposed secondarily emissive walls and a centrally located apertured element, setting up a potential gradient on said multiplying chamber, setting up a potential gradient centrally of said chamber having a higher potential at each point that is to be on the inner points of said multiplying chamber, attracting said admitted electrons toward said centrally located apertured member, permitting the major portion of said electrons to pass therethrough and impact upon said secondarily emissive surface, whereby secondary electrons will be produced.

7. A method of operating electron multipliers which comprises generating a group of electrons of random velocities, separating those electrons having velocities within a desired range, admitting a number, proportioned to the amplitude of the signal to be amplified, of the electrons of said desired velocity range to a multiplying chamber having opposed secondarily emissive walls, creating a potential gradient longitudinally of said multiplying chamber, setting up a higher potential gradient intermediate of said multiplying chamber, whereby said admitted electrons are deflected toward the high potential regions of said multiplying chamber, simultaneously utilizing said electrons to produce secondary electrons, and collecting said electrons, and utilizing said collected electrons to produce an output current.

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