April 18, 1944.　　S. VAN MIERLO　　2,346,952

ELECTRON MULTIPLIER

Filed Nov. 18, 1936　　3 Sheets-Sheet 1

Fig. 1.

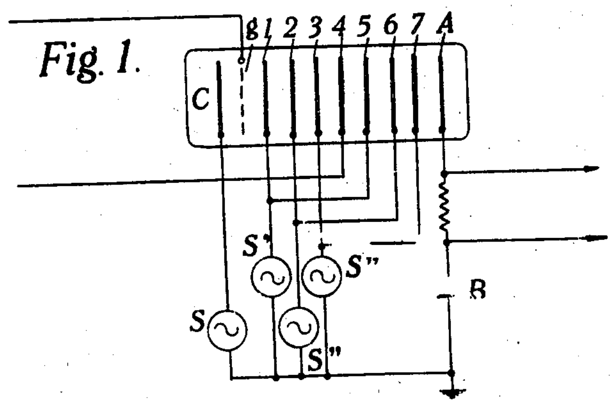


Fig. 2.

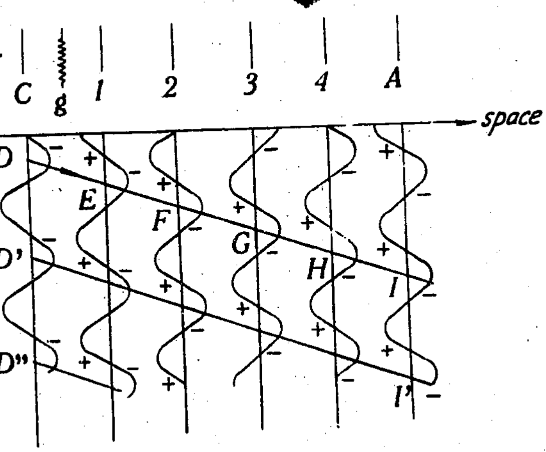
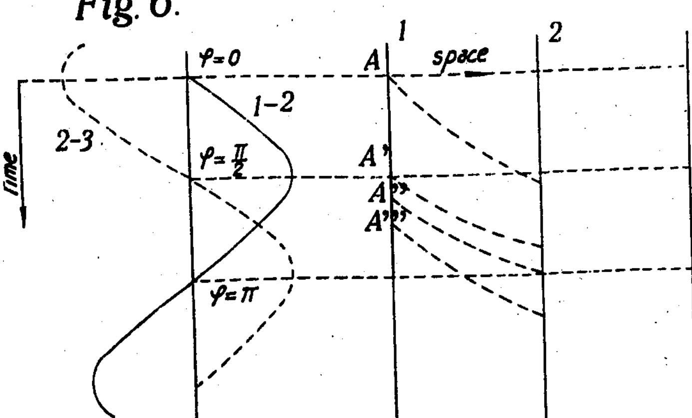


Fig. 6.



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April 18, 1944. S. VAN MIERLO 2,346,952

ELECTRON MULTIPLIER

Filed Nov. 18, 1936 3 Sheets-Sheet 2

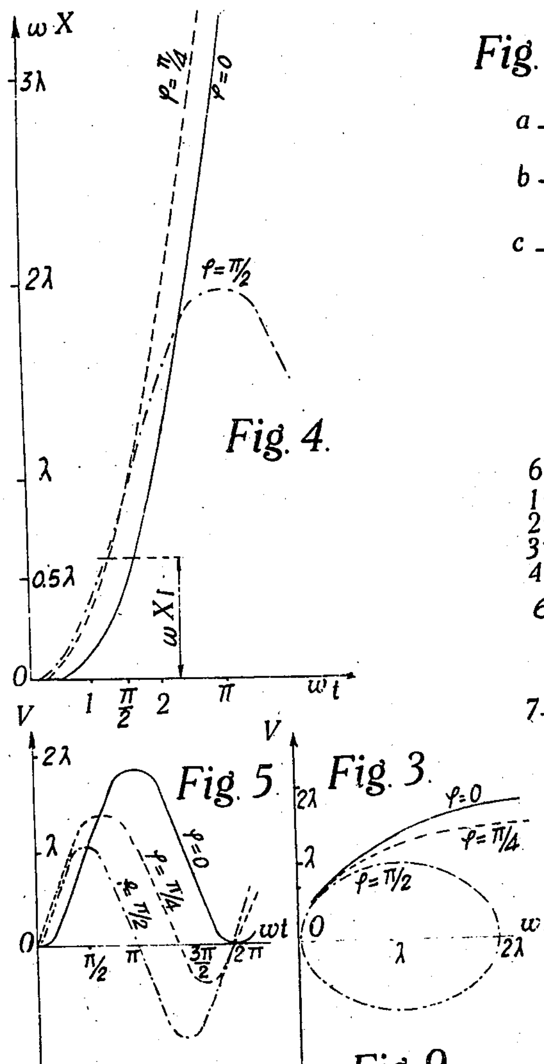


Fig. 4. Fig. 5 Fig. 3

Fig. 7

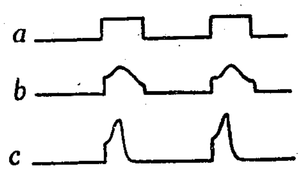
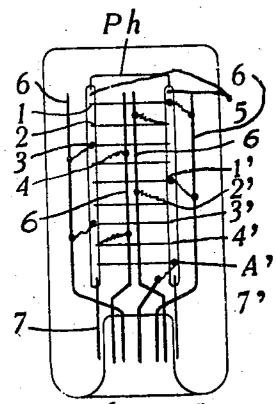


Fig. 8.



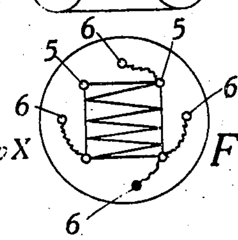


Fig. 8A

Fig. 9.

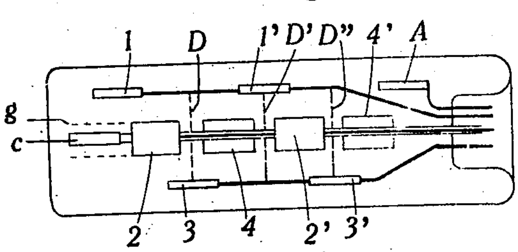
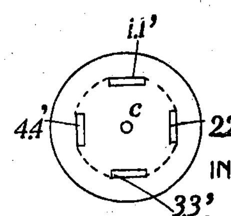


Fig. 9A



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ELECTRON MULTIPLIER

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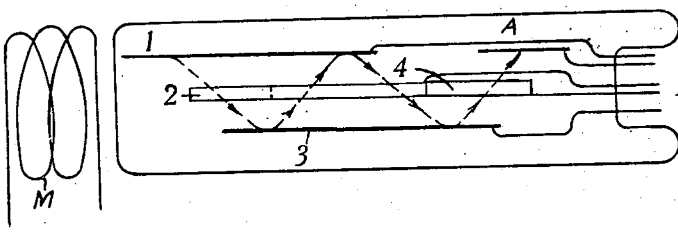


Fig. 10.

Fig. 11A.

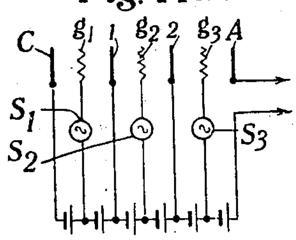


Fig. 11B.

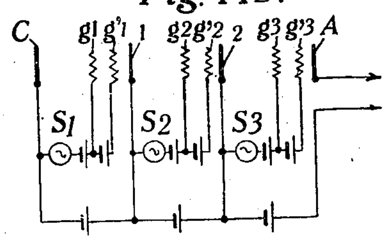


Fig. 12.

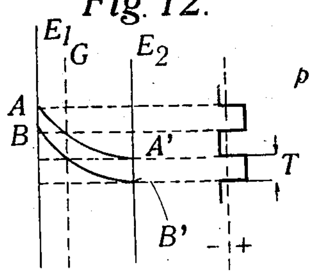


Fig. 13.

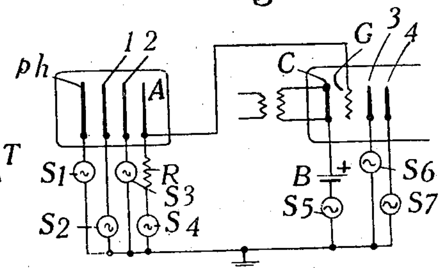


Fig. 14.

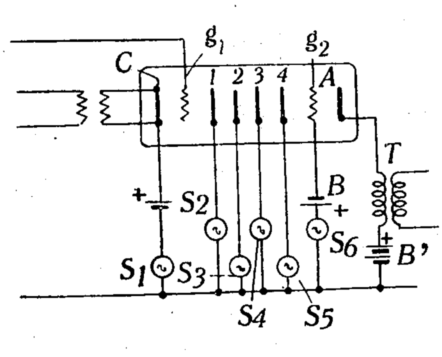
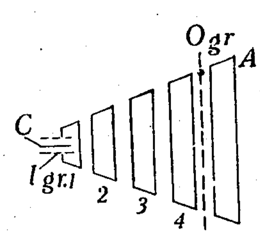


Fig. 15.



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Patented Apr. 18, 1944 2,346,952

UNITED STATES PATENT OFFICE

2,346,952

ELECTRON MULTIPLIER

Stanislas Van Mierlo, Paris, France, assignor to International Standard Electric Corporation, New York, N. Y.

Application November 18, 1936, Serial No. 111,429
In France December 28, 1935

21 Claims. (Cl. 250—27)

The present invention relates to electron discharge apparatus and particularly to such apparatus involving secondary electron emission.

The invention makes use of the secondary emission of electrons produced by the bombardment of a body by primary electrons or under the influence of radiations such as light radiations or in any other manner. All substances, even the insulating materials, can emit these electrons under certain conditions.

In order that the number of secondary electrons may be as high as possible it has been found desirable to fulfill the following conditions:

(1) To use as the emissive surface an unpolished surface preferably composed of electro-positive metal such as caesium or by a basic metal covered with a film of electro-positive metal.

(2) To employ speeds of primary electrons of the order of 400–600 volts.

Under these conditions one can obtain an emission of about 10 secondary electrons per primary electron.

It is further known that these secondary electrons have a rather low initial speed (corresponding to a tension of several volts) and that they are emitted in all directions. The temperature has very little influence upon the emission.

It is clear that the phenomenon of secondary emission can be utilised for the amplification of an electric current and several proposals have been made in this connection. In the case in which it is desired to obtain very high amplifications, tubes with several electrodes can be constructed and arranged in such manner as to produce several successive multiplications.

This may be done in two ways:

1. A number of electrodes are arranged in accordance with a "closed" arrangement (for example, a circle). In such arrangements the electrons are displaced from one electrode to the next and from the last electrode again towards the first.

The simplest case is that of two electrodes disposed opposite to each other, the electrons having a "to-and-fro" movement between the electrodes.

2. A number of electrodes are placed in accordance with an "open" arrangement (for example a straight line), the electrons being displaced from one electrode to the next and when the last is reached passing into an output circuit.

The first method has the advantage of employing fewer electrodes because certain or all of them are utilised several times. It has however the disadvantage that it is more difficult to cause the electrons to pass into the output circuit in such manner as to obtain a stable condition of functioning. In both cases it is necessary to arrange the circuits so that at certain moments a given electrode may be more positive than the preceding electrode which is emitting the electrons.

When the electrodes are placed in accordance with the closed arrangement, it is necessary continuously to change the potential of the electrodes in order that the electrons may find a higher potential when they begin anew. In the case of two electrodes, they can, for example, be connected with an oscillating circuit arranged so that each time the electrons are emitted by one of the electrodes they find the other electrode more positive. The frequency of this oscillating circuit will be chosen taking into consideration the potential and the distance between the electrodes.

When the electrodes are placed in accordance with an "open" arrangement, two cases may be considered:

1. The potentials of the electrodes have a fixed value: the potential is more positive for the second electrode than for the first, for the third than for the second, etc.

2. The potentials of the electrodes vary so that there is, so to speak, a wave of potential being displaced from the first to the last electrode, and attracting the electrons behind it.

Other cases may be considered when one utilises intermediate grids, as will be explained later.

The advantages of the second method is that it is possible to drive all the electrons emitted by one electrode towards the next, while this does not seem possible with the first method.

The invention will be better understood by means of the following description given in relation with the accompanying drawings in which:

Fig. 1 shows schematically an electron multiplier tube having several electrodes, certain of which are fed with alternating current;

Fig. 2 represents a diagram of the distribution of the potentials on the electrodes of the tube of Fig. 1;

Fig. 3 represents a diagram showing in various cases the variation of the speed of the electrons by function of ωX;

Fig. 4 shows the variation under different conditions of the quality of ωX by function of ωt;

Fig. 5 represents the variation under different conditions of the speed of the electrons by function of ωt;

Fig. 6 represents a diagram permitting the best operative conditions of the system to be obtained;

Fig. 7 represents curves showing the distortion due to the fact that the electrons are not all animated with the same speed;

Figs. 8 and 8A represent in elevation and in plane a construction of an electron multiplier tube;

Figs. 9 and 9A represent another arrangement of the electron multiplier tube;

Fig. 10 represents schematically another form of construction of an electron multiplier tube;

Figs. 11A and 11B represent different methods of connecting the electrodes of tubes employing the characteristics of the invention;

Fig. 12 shows a diagram of the distribution of the potentials for a given wave form on the electrodes of a tube employing features of the invention;

Fig. 13 represents a method of connection of two tubes employing features of the invention;

Fig. 14 represents a tube according to the features of the present invention, employed as radio-electric wave transmitter;

Fig. 15 shows a construction in which the dimensions of the various electrodes are different and in which a final grid is provided.

In Fig. 1 the cathode C emits electrons which are controlled by the grid *g*. The sources S, S', S'', S''' of alternating current are displaced by 90° from each other. The electrodes have thus successively a maximum potential with respect to earth. The electrons arriving on 1 produce secondary electrons, which, during one period of time are attracted towards 2, etc. Finally the electrons emitted by 7 arrive on the collecting electrode A, which communicates with the output circuit. In this case the latter electrode has been connected to a source of direct current B. It is to be understood that variable tension could also be employed.

As has already been remarked, it is necessary that the potential of the electrodes which emit the electrons be smaller than the potential of the next electrode and greater or equal to that of the preceding electrode at least during a portion of the time taken by the electron in passing from one electrode to the other. As, at the moment of the arrival of the electrons on an electrode, the same conditions are applicable for this latter electrode, which then becomes an emission electrode, it must be taken into consideration that the variations of potential may be the same for all the electrodes, but they must be dephased. As the potential cannot increase indefinitely, it is necessary to make use of periodical variations and I shall consider herein below in a more detailed manner sinusoidal variations, although other types of periodic variations may be more important (for example successive rectangular impulses or saw-teeth impulses).

In order that an electrode may during a portion of the time be more positive than the preceding electrode and less positive than the following electrode, I may consider dephasings of 90° or of 120°. For 180° the electrodes adjacent to those considered will be on the same potential, which is not generally desirable.

In order to examine the operation more closely we will suppose that the displacement is of 90°. Fig. 2 shows in space and time how the potentials of the electrodes vary.

Above the drawings are shown electrodes C, *g*, 1, 2, 3, 4 and A, imagining that they are spaced in a uniform manner. The vertical lines traced below the electrodes serve as time axis in order to represent the potential variations of the corresponding electrode. These variations are represented by sinusoidals displaced by 90°. An electron emitted by C at a moment D will find the electrode 1 more positive and will follow a curved path DE. This electron should find at 1 a potential equal to the potential which the electrode C had at the moment when the electron has quitted.

When this condition is approximately fulfilled the electrons will reach the other electrodes at the moments E. F. G. H. I. In the case in which the electrode C produces electrons all the time, they will only be attracted towards 1 during a certain period as will be seen later. The electron current will thus be modulated at a frequency corresponding to the frequency of the variations of potential. Fig. 2 represents three paths of electrons D I, D' I', D'' I'', at successive periods.

There is obviously a certain relation between the distance of the electrodes, the frequency and the potentials.

When an electron without initial speed is placed in an electric field, E, its speed after a journey S is implicitly given by the equation:

$$e\int_0^S E\,ds=\frac{1}{2}mv^2 \qquad (1)$$

in which e is the charge, m the mass and v the speed of the relatively slow electron.

In a uniform electrical field existing between two parallel electrodes having a difference of potential V, we have

$$Ve=\frac{1}{2}mv^2 \qquad (2)$$

The following table gives an idea of the speeds obtained:

Differences of potential in volts	Approximate speed
	Cm./Sec.
10	1.8×10^8
20	2.6×10^8
50	4.2×10^8
100	6.0×10^8
200	8.4×10^8
500	13.2×10^8
1,000	18.8×10^8

In order to obtain the maximum of secondary electrons, the difference of potential must be of the order of 400 to 600 volts, and the corresponding speed is then about 13×10^8 cm./sec.

It will be seen that the time taken by an electron in order to pass from one electrode to the next is very small and with a distance of some centimetres it is necessary to employ frequencies of several megacycles.

In the present case the conditions are more complicated because the electrodes are not large parallel plates (and the field is thus not uniform), because the difference of potential continually varies, and because electrons have an initial speed in any direction. It will, however, be sufficient for a first approximation to consider uniform fields and an initial speed of zero, the sole variant being the difference of potential.

As we are imagining that the potentials of all the electrodes with respect to earth vary in accordance with a sinusoidal law, the difference of potential between the adjacent electrodes will also be sinusoidal. In the case in which the initial speed of the electrons is zero, they will begin to be attracted towards the next electrode at the moment when the latter becomes more positive. In the case in which this electrode remains more positive during the whole time of their path, their speed will increase continuously. In the case in which this electrode remains negative at a given moment, their speed will diminish. In certain cases the electrode can undergo such a delay that the secondary electrons emitted when they strike the next electrode can no longer be effectively employed. In other cases the electrons may not reach the following electrode at all, but return to the electrode which has emitted them. For certain relations between the potential, the distance, and the frequency, the efficiency of the system will be the greatest. The following calculation may assist in determining these relations:

When:

$$E=E_0.\sin(\omega t+\phi)$$

$$m\frac{d^2x}{dt^2}=eE_0\sin(\omega t+\phi)$$

and

$$V=\lambda\cos\phi-\lambda\cos(\omega t+\phi)$$

$$X_0=\lambda t\cos\phi-\frac{\lambda}{\omega}\sin(\omega t+\phi)+\frac{\lambda}{\omega}\sin\phi$$

in which X is the distance through which the electron has traveled, V is the speed of the electron at the distance of X_0 and

$$\lambda=\frac{eE_0}{m\omega}$$

We here are considering two special cases:

(1) $\phi=0$

and

(2) $\phi=\frac{\pi}{2}$

We have:

$$\begin{cases}\phi=0\\ V=\lambda(1-\cos\omega t)\\ X_0=\lambda\left(t-\frac{1}{\omega}\sin\omega t\right)\\ \phi=\frac{\pi}{2}\\ V=\lambda\sin\omega t\\ X_0=\frac{\lambda}{\omega}(1-\cos\omega t)\\ V^2=\omega X_0(2\lambda-\omega X_0)\end{cases}$$

The curves in Figs. 3, 4 and 5 respectively represent the speed as a function of the distance, the distance as a function of the time and the speed as a function of the time for the values $\phi=0$,

$$\phi=\frac{\pi}{2}$$

and for the intermediate values of ϕ.

In order to obtain the maximum efficiency the electrons emitted at the moment $\phi=0$ must not take a time less than

$$\frac{\pi}{2}$$

in order to reach the following electrode (otherwise the secondary electrons produced by the latter will not be useful) and the electrons emitted after

$$\phi=\frac{\pi}{2}$$

must not take more time than

$$\frac{\pi}{2}$$

to reach the next electrode (otherwise the secondary electrons will arrive too late).

In Fig. 6 the vertical lines 1, 2 and 3 represent the position of the electrodes 1, 2 and 3; the sinusoidals on the left represent the difference of potential between 1 and 2 and between 2 and 3.

The distance between 1 and 2 is chosen so that an electron A leaving 1 at the moment $\phi=0$ reaches 2 a little while after

$$\frac{\pi}{2}$$

It will thus be seen that when we consider the difference of potential between 2 and 3, the secondary electrons leave 2 a little while after $\phi=0$.

An electron A' leaving 1 at

$$\phi=\frac{\pi}{2}$$

reaches 2 before π. The electron A'' leaving 1 a little after

$$\frac{\pi}{2}$$

reaches A at the moment π. The last effective electron A''' leaves 1 a little later and reaches 2 at a corresponding moment when we consider the difference of potential between 2 and 3, the time of transit being

$$\frac{\pi}{2}$$

The distance necessary between the electrodes may be obtained by a graph of Fig. 4. One must take into consideration the distance ωX_1 corresponding to the case in which electrons leaving an electrode at $\phi=0$ reach the electrode 2 at the moment

$$\frac{\pi}{2}$$

is about equal to

$$\frac{5}{8}\lambda$$

Moreover, the speed of the electrons arriving on one of the electrodes must be of the order of 13×10^8 cm./sec. as explained herein above.

From Fig. 3 it is clear that at a distance

$$\omega X_1=\frac{5}{8}\lambda$$

the speed is on the average equal to λ.

We consequently get:

$$V=\lambda=\frac{e}{m}\quad\frac{E_0}{\omega}=13\times10^8$$

and

$$X_1=\frac{8\times10^8}{\omega}$$

$$E_0\text{ (in volts)}=74\times10^{-8}\omega$$

with $\omega=27\times10^7$ (corresponding approximately to 7 metres wave length).

These values lead us to take:

Distance X_1	About 3 cm.
Field intensity E_0	About 200 v.
Maximum difference of potential	$3\times200=600$ v.
Maximum of potential	$Vm.=600\times0.707=420$ v.
Effective value of potential	$V=420\times0.707=300$ v.

For a given distance between electrodes, the frequency will be less if we accept a greater speed on the arrival of the electron. In the case in which the distance is increased, the frequency may be decreased.

Fig. 6 shows that owing to the fact of their unequal speed the electrons are concentrated for a certain period, and when the multiplication is repeated at various times, the concentration will increase more and more.

In this simplified case (uniform field—zero initial speed) the current will be modulated in accordance with the curve *a* (Fig. 7) if all the electrons take the same time to reach the next electrode. This current is distorted according to the curve *b* when the speed is unequal. In the case in which the distance between the electrodes is increased, a certain number of electrons will not be employed and the current impulses will become shorter as indicated by the curve *c*. It is, of course, understood that for non-uniform fields and for initial speeds which are not zero, the conditions will be changed; thus for example certain electrons leaving **1** before $\phi=0$ may reach **2**, and the difference between the time which the different electrons take to make the journey will be greater than in the present case.

In the foregoing, space charges have not been taken into consideration which more or less modify the conditions of operation.

The multiplier tubes may be constructed in various ways. Three examples of relative arrangement of the electrodes are given in the following.

A series of parallel electrodes may be employed as shown in Fig. 8. Four glass rods **5** support a series of parallel electrodes **1**, **2**, **3**, **4**, **1'**, **2'**, **3'**, **4'**, A, which may be constructed like the grids in vacuum tubes. The conductors **6** bring the alternating current to the electrodes. The first electrode *Ph* may consist of a mica plate covered by a transparent layer of silver and caesium and treated so as to form a photo-sensitive surface.

The electrode unit is fixed by a ring **7** on the stem of the tube.

In this arrangement the majority of the secondary electrons are emitted by the upper surface of the electrode, while they must be displaced downwardly. In order to avoid this disadvantage the electrodes may be formed by circular wires or by tubes of any section and of short lengths arranged in parallel.

A series of plane electrodes or slightly concave or convex electrodes also could be employed arranged in a circle or a helix. An example of this latter arrangement is shown in Fig. 9. The electrons emitted by a cathode C and governed by the grid *g* are directed towards electrodes **1**, **2**, **3**, **4**, **1'**, **2'**, **3'**, **4'**, A. These various electrodes are supported by a series of mica discs D.

As the electrodes **1** and **1'**, **2** and **2'**, **3** and **3'**, **4** and **4'** are connected together two by two, one may also employ fairly long plates as shown in Fig. 10; the electrons will follow a helicoidal path under the influence of a central magnet M, and each electrode will be employed twice by the electrons before reaching the collecting electrode A. It will be taken into consideration that this method of proceeding more or less resembles a closed arrangement, except that a definite output has been provided for the electrons. This arrangement may be considered as a combination of a closed and open arrangement.

In these tubes plates may be employed which reflect the electrons, or screens and electrodes which modify the electrical field so as better to direct the electrons towards the next electrode. Magnetic fields may also be employed for this purpose.

For the polarisation of the electrodes ordinary alternating current or rectified alternating current may be employed or a periodic current of special form and a superposed direct tension. The difference of potential must not be the same between the successive electrodes. In the same way the distances may vary. For a given tube the tension will be regulated so as to obtain the maximum output.

At certain places the electrons may be divided into two or more channels in phase agreement or otherwise and used to feed separate circuits or otherwise.

Two or more tubes may also be connected in parallel and in this case again the phases may or may not coincide.

In the case of a dephasing of 180° an arrangement is obtained which will recall the well-known "push-pull" connection.

The amplification of these tubes may be varied during operation by changing the number of multiplier electrodes, by changing the potential of the grids, or by changing the tension of the electrodes.

In the case of an "open" arrangement a much greater stability of operation may be obtained by means of variable potentials than with fixed potentials. That is, with fixed potentials a portion of the secondary electrons emitted by a given electrode cannot be attracted towards the next electrode owing to the existence of an electrostatic field between the electrode which is emitting and the preceding one. Certain electrons may thus be forced to return towards the electrode which has emitted them. Slight variations of potential, of magnetic fields, etc., have an action on the number of useful electrons and as this action may be exercised simultaneously on all stages, the total amplification may greatly vary.

In the case of variable potentials, these conditions may be improved by increasing at least for a part of the time, the proportion of the useful electrons. This can be done by reducing the intensity of the electrostatic field in which the electron is situated at the moment when it touches an electrode. In the extreme case this field can be cancelled completely. In order to obtain this condition a single positive impulse is successively given to the various electrodes until the moment when the electrons arrive on the collecting electrode. Only at this moment is the cycle of operations begun again. The electrons emitted by the first electrode would only be employed for a fraction of the time, but one would have the advantage of employing at each multiplication all the secondary electrons, and the consequent advantage that the gain per stage and the stability will be very great. In order to give a clear picture we will consider here 7 multiplications of 10 and we will suppose that only a tenth of the electrons emitted by the first electrode are employed. The total amplification will thus be 10^6 or 120 db. In order to obtain the same amplification with a tube in which there are only 5 useful electrons out of 10, at each multiplication 9 multiplications will be necessary. If the number of electrons varies from 5 to 4, the amplification will vary by about 20 db. It will thus be seen that more stability is obtained with fewer stages in the first case.

The spaced impulses may be produced in various known ways, for example, by means of a tube whose grid has a negative high tension so as only to pass the peaks of the alternating current.

The method of variable potential can also be combined with that of constant potential. For example, by using multiplication electrodes of fixed potential and intercalary electrodes or grids intended to cause the field to vary in the direction indicated above.

Thus during the period in which the electrons touch one of the multiplication electrodes, the preceding grid may be of the same potential (or approximately), while normally this grid is more negative.

Figs. 11A and 11B give two examples of a tube with grids of variable potentials and multiplication electrodes of fixed potential. Grids G1, G2, G3, are provided as well as sources of alternating current, S1, S2, S3.

The grids may be adapted to act as doors which close the passage behind as soon as the electrons have passed through them.

It will be taken into consideration that in accordance with this method one may consider the tube as consisting of a series of elementary tubes which operate in turn and are all connected in cascade without external coupling elements. The electrodes operate sometimes as cathodes, sometimes as anodes. The separations between the elementary tubes are effected by means of grids.

If electrons are continuously emitted by the first electrode they will be stopped in part by the grid or grids during certain periods.

This device may be improved by inserting several grids. In the case of two grids, the first may have as main function to give an initial speed to the electrons and the second may have as its function to prevent a field reaching the next electrode, at least during the period when this electrode emits secondary electrons.

The grids may be given variable potentials periodically, either in accordance with a sinusoidal law (with or without constant polarisation) or in accordance with another more complicated law.

The distance between a grid and the next multiplying electrode could be such that the time taken by an electron to pass through this space is of the order of a half-period of the variations of potential of the grid. The latter will (in the case of rectangular variations) assume the potential of the multiplication electrode at the moment when the electrons arrive on this electrode and will return to the negative potential at the moment when the last electrons will have reached the multiplication electrode, as is shown in Fig. 12, where E_1 and E_2 are two successive multiplication electrodes, G is a grid, A A′ the path of the first electron from a given group and B B′ the path of the last electron of this group. The grid is at the potential of E_2 during the period T. In the case of several grids we can see still better the analogy with a series of elementary tubes connected in series. The whole of the present art of multiple electrode tubes may be applied in the present case.

In the case of power tubes, the latter may be connected to a first multiplier tube. One of the first problems which arises is thus that of the connection of these two tubes with each other. The two tubes need variations of potential of the same frequency and the phases must thus have a certain relation. Fig. 13 shows a method of connecting these tubes together.

The collecting electrode A is connected to the source of current by means of a resistance R. A can be directly connected to the grid g of the power tube. The cathode C of this tube is polarised by means of alternating current having a suitable phase with respect to the phases employed for the first tube. Further, a polarising battery B can be provided. The phase and the tension of polarisation will, for example, be chosen so that the grid has a small negative potential compared with C during the period when the electrode A is receiving electrons.

The two tubes may also be connected by means of a transformer, a condenser etc., in short all the methods employed at the present time for coupling vacuum tubes together may be employed in the present case.

Another problem consists in supplying the necessary A. C. biasing power to the output electrode. In the case in which biasing was effected throughout with alternating current, the very high power necessary for biasing the collecting electrode would be difficult to obtain, since the biasing power in question must be supplied as a current of very high frequency. It is desirable to use direct current for the last electrode. As moreover there must be no secondary emission from this electrode, it may be composed of the usual substances and very high tensions may be employed.

These high tensions cannot be applied without special precautions, because a portion of the electrons might then be attracted directly towards this electrode without passing through the intermediate electrodes. It is thus necessary to arrange the electrodes so that this cannot occur. One can thus make use of grids or supplementary electrodes acting as screens. Fig. 14 gives an example of the connections which can be employed in the latter case.

The relative phases of the alternating currents and the voltages of the batteries which polarise these grids are chosen so that the electrons coming from 4 pass freely, but the electric field produced by C cannot reach the electrodes 1, 2 and 3. The field on the electrode 4 will be sufficiently weak to avoid a primary emission.

As the voltage of the source B′ may be very high, a rather high voltage amplification can be obtained so as to necessitate only a rather low power in alternating current.

A third problem is that of obtaining the alternating current for polarising the electrodes, particularly for the last.

It might be produced by a common oscillator, the necessary phase angles being obtained by means of combinations of resistances, condensers and transformers. In the case of power multiplier tubes a rather high energy would be required. A small auxiliary multiplier tube can also be employed which in turn receives alternating current from a crystal controlled tube oscillator.

Moreover, one might also employ a kind of auto-energisation. A portion of the current emitted by the multiplier is passed through a filter which isolates the carrier current, but this solution can only be considered in the case in which the lowest modulating frequency is relatively high compared to the carrier or A. C. biasing frequency, otherwise the problem of filtering would be very difficult. This method more or less resembles a feedback circuit, but as the number of secondary electrons does not vary very much with the potential of the modulating electrodes, there is no critical adjustment. One could further, if necessary, stabilise the potential obtained after filtering.

For very high power it is necessary to employ very large collecting electrodes, cooled for example by water circulation. Fig. 15 shows a method of arranging the electrodes.

The electrons emitted by the cathode C and controlled by the grid Igr, arrive successively on the electrodes 1, 2, 3, 4, A of increasing surfaces; a grid Ogr separates the electrode A from the others.

These tubes may be arranged as shown in Figs. 11A and 11B with constant tensions on the multiplication electrodes and variable tensions on the intermediate grids.

In the case of a radio amplifier, one can often choose the dimensions and tensions in such a way that the alternating current feeding the multiplier tubes has the frequency which it is desired to employ for the carrier of the radio emission. A transmitter for the radio-broadcasting of television can thus be composed of a first multiplier tube with photo-electric cell supplying several watts modulated at a frequency corresponding for example to a wave-length of 7 metres. This first tube is connected to a power multiplier tube directly connected to the antenna.

In other cases it may be necessary to multiply or demultiply the frequency. In the case in which carrier is not desired, the signals can first of all be detected.

It is understood that the multiplier tubes can serve as amplifiers, oscillators and modulators. The amplifiers may be connected so as to obtain a reaction of the output on the input. If the reaction is negative the stability of the whole can still be increased. These reaction circuits may also be connected to grids or to intermediate electrodes. The whole art of negative reaction amplifiers may be applied here.

What is claimed is:

1. An electron multiplier comprising a source of primary electrons, a plurality of secondary electron emissive electrodes spaced a predetermined distance from one another, and means for establishing progressively phased variable electric fields between successive secondary emissive electrodes.

2. An electron multiplier comprising a source of primary electrons, a plurality of secondary electron emissive electrodes spaced a predetermined distance from one another, and means for producing progressively phased variable potentials and applying said potentials to said secondary emissive electrodes.

3. An electron multiplier comprising a source of primary electrons, a plurality of secondary electron emissive electrodes spaced a predetermined distance from one another along a substantially straight line and arranged in the path of said primary electrons, a collector electrode, sources of variable potentials connected to said electrodes, the phase of the potential applied to each electrode being progressively delayed as viewed from the source of primary electrons, and an output circuit connected to said collector electrode.

4. An electron multiplier comprising a source of primary electrons, a plurality of secondary electron emissive electrodes spaced a predetermined distance from one another along a substantially straight line and arranged in the path of said primary electrons, sources of variable potentials of the same frequency connected to said electrodes, the phase of the potential applied to each electrode being progressively delayed as viewed from the source of primary electrons, and the phase, magnitude, and frequency of said potentials and the spacing of said secondary electron emissive electrodes being so related that a plurality of groups of electrons are in transit through said multiplier at the same time.

5. An electron multiplier comprising a source of primary electrons, a plurality of secondary electron emissive electrodes spaced a predetermined distance from one another along a substantially straight line and arranged in the path of said primary electrons, and sources of sinusoidally varying potentials of the same frequency connected to said electrons, the phase of the potential applied to each electrode being progressively delayed as viewed from the source of primary electrons.

6. An electron multiplier according to claim 2 further comprising sources of direct current connected to said electrodes.

7. An electron multiplier according to claim 2 wherein said means comprise sources of alternating current potentials connected to said electrodes, the phase of said potentials applied to each successive electrode as viewed from the source of primary electrons being progressively delayed 90°.

8. An electron multiplier according to claim 2 further comprising means for producing a magnetic field along the path of said electrons.

9. An amplifier comprising two coupled electron multipliers according to claim 2, grid and cathode electrodes in each, a connection from the output electrode of the first to the grid of the second, and means for producing and applying alternating potentials to the electrodes, the phase of the potentials being such that the grid of the second has a small negative potential with respect to its cathode during the period that the output electrode of the first is receiving electrons.

10. In an electron multiplier according to claim 2, further comprising a last electrode, fixed potential means connected to the last electrode, a screening grid electrode inserted between said last electrode and the next preceding electrode and means for applying a variable potential to said grid electrode such that said grid electrode is normally very negative but is only slightly negative during the periods when secondary electrons are being emitted by the preceding electrode.

11. An electron multiplier according to claim 1 comprising an electron emitting cathode, a plurality of secondary electron emissive electrodes spaced a predetermined distance from one another, a control grid located between said cathode and the first secondary electron emissive electrode, and means for producing cyclically varying progressively phased potentials and applying said potentials to said secondary electron emissive electrodes.

12. An electron multiplier according to claim 1, in which said electrodes comprise grid-like structures which are supported in parallel planes within an evacuated bulb by a plurality of rods of insulating material.

13. An electron multiplier according to claim 1 comprising a succession of secondary electron emitting electrodes and an auxiliary grid electrode positioned between successive secondary electron emitting electrodes for the purpose of controlling the secondary electrons traversing the interelectrode spaces.

14. An electron multiplier according to claim 1, wherein said secondary emissive electrodes are grid-like structures and further comprising an evacuated vessel surrounding said electrodes and means for mounting said grid-like structures in parallel planes comprising a plurality of rods of

insulating material attached to said vessel and said structures.

15. An electron multiplier comprising a source of primary electrons, a plurality of secondary electron emissive electrodes spaced a predetermined distance from one another, a plurality of auxiliary grid electrodes, each of said grid electrodes being positioned between successive secondary electron emissive electrodes, and means for establishing and periodically varying the potentials of said grid electrodes.

16. An electron multiplier according to claim 15 further comprising fixed potential means connected to said secondary emissive electrodes.

17. An electron multiplier according to claim 15, wherein the potentials on said grid electrodes have a wave-form and phase such that after a group of electrons in transit from a first secondary electron emissive electrode to a successive electron emissive electrode has passed through said grid electrodes, said grid electrodes have negative potentials with respect to said successive secondary emissive electrodes.

18. An electron multiplier according to claim 15, further comprising a second plurality of grid electrodes, each of said second grid electrodes being positioned between one of said auxiliary grid electrodes and its adjacent successive secondary electron emissive electrode, and fixed potential means connected to said second plurality of grid electrodes.

19. An electron multiplier according to claim 15, in which the distance between an auxiliary grid electrode and the next secondary electron emitting electrode is so chosen that the time taken by an electron in traversing this space is of the order of a half-period of the potential variation on said grid electrode.

20. An electron multiplier comprising a succession of secondary electron emitting electrodes each having a progressively increasing surface area.

21. In a signal modulated carrier wave signalling system an amplifier comprising a source of primary electrons an electron multiplier comprising a plurality of secondary electron emissive electrodes spaced a predetermined distance from one another, and means for producing and applying progressively phased alternating potentials to said electrodes, the frequency of said potentials bearing a predetermined multiple relation to the frequency of the signal-modulated carrier wave to be amplified.

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