March 2, 1943. A. M. SKELLETT 2,312,498

SIGNAL TRANSLATING APPARATUS

Filed April 16, 1941

FIG. 1

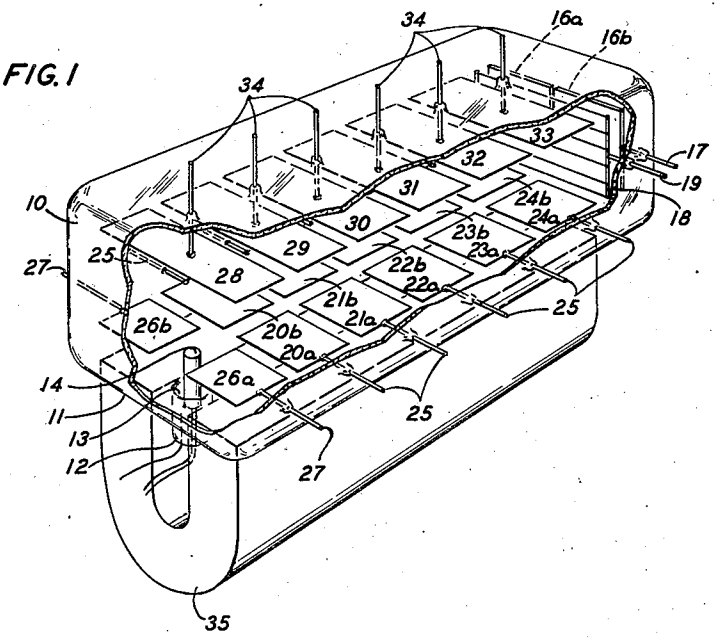


FIG. 2

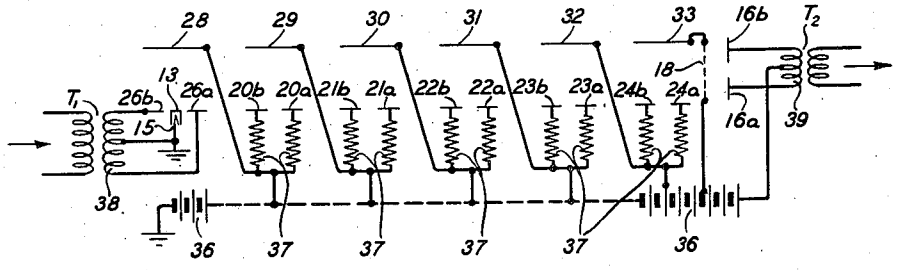


FIG. 3

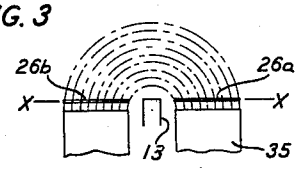
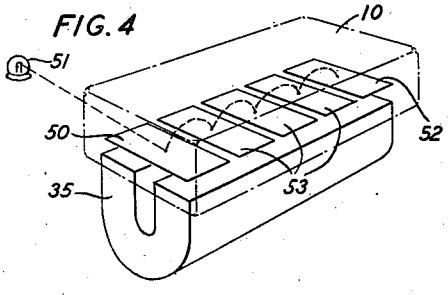


FIG. 4



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SIGNAL TRANSLATING APPARATUS

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7 Claims. (Cl. 250—175)

This invention relates to signal translating apparatus and more particularly to such apparatus including electron discharge devices having one or more secondary electron emissive electrodes and commonly known as electron multipliers.

Electron multipliers comprise, in general, a source of primary electrons, a collector electrode or anode, and one or more secondary electron emissive electrodes for amplifying the primary electron current by electron multiplication whereby the electron current to the collector electrode or anode is several times as great as the primary electron current. In such devices, one of the problems encountered is the dispersion of the electrons in flowing from one electrode to the next succeeding one. For example, in electron multipliers comprising substantially coplanar electron emitting surfaces, the electrons emanating from the primary cathode suffer a dispersion normal to their direction of flight to the secondary electron emissive electrode nearest thereto and also in the direction of their flight. In such multipliers, a similar dispersion effect occurs with the secondary electrons emanating from one secondary electron emissive surface and flowing to the next succeeding electrode of the device. Hence, some of the electrons flowing between successive electrodes may not impinge upon the electrode to which they are intended to flow or may impinge upon such electrode at a portion thereof at which the fields are not conducive to efficient electron multiplication.

Furthermore, electron multipliers including one or more secondary electron emissive electrodes operated at a positive potential with respect to the next preceding electrode are effectively direct current amplifiers. Hence, when in such devices, the initial or primary electron current is varied in accordance with an alternating current signal both the direct current and alternating current components of the primary electron stream are amplified by the device so that the output current of the device includes a relatively large direct current component in relation to the alternating current component thereof.

One object of this invention is to effectively focus the electron stream emanating from each electron emissive surface in an electron multiplier upon a restricted area of the next succeeding electrode.

Another object of this invention is to improve the operating characteristics and efficiency of electron multipliers operable as alternating current amplifiers. More specifically, another object of this invention is to enable the attainment of a large amplification of the alternating current component of the primary electron current in an electron multiplier, in relation to the amplification of the direct current component thereof.

In one illustrative embodiment of this invention, an electron multiplier comprises a primary cathode, a collector electrode element, and a plurality of aligned coplanar secondary electron emissive electrodes or cathodes mounted between the primary cathode and the collector electrode element, the secondary electron emissive electrodes or cathodes being adapted to be maintained at successively higher positive potentials whereby the electrons emanating from each of the cathodes are subjected to an electric field accelerating them toward the next succeeding electrode.

In accordance with one feature of this invention, means are provided for producing adjacent each of the cathodes a curved or semicylindrical magnetic field symmetrical with respect to the axis of alignment of the several cathodes and concave downward with respect to the emissive surfaces thereof, whereby the electrons emanating from each cathode are focused upon the corresponding area of the next succeeding electrode.

In accordance with another feature of this invention, an electron multiplier is provided with two rows of coplanar secondary electron emissive electrodes arranged in pairs and mounted on opposite sides of an axis extending between the primary cathode and the collector electrode element, and means are provided for deflecting the primary electron stream in accordance with a signal to be amplified whereby the primary electron current is divided between the secondary electron emissive electrodes nearest the primary cathode, in accordance with the instantaneous magnitude of the signal whereby push-pull amplification is effected.

In accordance with a further feature of this invention, the secondary electron emissive electrodes in each pair are coupled to each other through impedances of such character that a potential difference is established therebetween when an electron stream impinges thereupon, whereby the deflection of the stream flowing away therefrom, with reference to the deflection of the impinging stream, is increased and the gain of the multiplier is increased.

The invention and the above-noted and other

features thereof will be understood more clearly and fully from the following detailed description with reference to the accompanying drawing, in which:

Fig. 1 is a perspective view of electron discharge apparatus illustrative of one embodiment of this invention, a portion of the enclosing vessel of the discharge device being broken away to show the electrodes therein more clearly;

Fig. 2 is a circuit diagram illustrating one manner of operating the electron discharge device shown in Fig. 1;

Fig. 3 is a diagrammatic view showing the form and direction of the magnetic field produced in the device illustrated in Fig. 1 and the relation thereof to the emissive electrodes in the device; and

Fig. 4 is a diagrammatic view illustrating another electron discharge device constructed in accordance with this invention, the enclosing vessel of the device being shown in phantom.

Referring now to the drawing, the electron discharge device shown in Fig. 1 comprises an elongated, evacuated enclosing vessel **10** having a plane base wall **11** and provided adjacent one end with a tubulature **12** in which a cathode **13** is supported. The cathode **13** may be of the equipotential type and comprises a metallic cup-shaped member the outer surface **14** of the base of which is coated with thermionic material which is heated to the desired emission temperature as by a heater filament **15**, shown in Fig. 2.

Mounted at the other end of the vessel **10** are a pair of coplanar collector electrodes or anodes **16***a* and **16***b* supported by lead-in conductors **17**, only one of which is shown in Fig. 1, sealed in the side walls of the enclosing vessel **10**. A screen grid **18** is mounted opposite and in parallel relation to the collector electrodes or anodes **16**, by a leading-in conductor **19** sealed in one side wall of the enclosing vessel **10**.

A plurality of pairs of coplanar secondary electron emissive electrodes or cathodes **20** to **24**, inclusive, are mounted in two parallel rows on opposite sides of an axis extending between the cathode **13** and the gap between the anodes **16***a* and **16***b*, the secondary cathodes in each pair being designated in the drawing by the same numeral followed by the letter *a* or *b*. These secondary cathodes are supported by individual leading-in conductors **25** sealed in the side walls of the vessel **10** and are arranged parallel to the base wall **11** of the vessel **10** and in immediate proximity thereto.

Mounted on opposite sides of the cathode **13**, equally spaced therefrom and coplanar with the surface **14** and the secondary cathodes **20** to **24** are a pair of deflector plates **26***a* and **26***b* which are supported by leading-in conductors **27** sealed in the side walls of the enclosing vessel **10**.

A plurality of field plates **28** to **33**, inclusive, are supported in coplanar relation parallel to the secondary cathodes by individual leading-in conductors **34**, each of the field plates **29** to **33** overlying and being aligned with one pair of the secondary cathodes and the field plate **28** overlying and being aligned with the deflector plates **26**.

An elongated U-shaped permanent magnet **35** is positioned with its poles in immediate proximity to the base wall **11** of the enclosing vessel, opposite the secondary cathodes and in alignment with the two rows thereof. The relation of the magnet poles and the secondary cathodes is illustrated in Fig. 3 from which it will be seen that the magnetic field lines are substantially semicircular, symmetrical with respect to the medial plane between the two rows of secondary cathodes and substantially coextensive laterally with the secondary cathodes.

As illustrated in Fig. 2, each pair of the secondary cathodes is biased at the same potential with respect to the preceding cathode of the device as by a battery **36**, the secondary cathodes in each pair being connected to each other through equal resistances **37**. For example, the secondary cathodes **20***a* and **20***b* may be biased at a potential of the order of 100 volts positive with respect to the primary cathode **13**, and each of the other pair of cathodes may be biased at a potential of the order of 100 volts positive with respect to the next preceding pair of secondary cathodes. Each of the field plates **28** to **32**, inclusive, is connected to and biased at the same potential as the pair of cathodes next succeeding the pair it overlies, and the field electrode **33** is connected directly to the screen grid **18** and maintained with it at a positive potential higher than that of the secondary cathodes **24***a* and **24***b*. The deflector plates **26***a* and **26***b* are connected across the secondary winding **38** of an input transformer T_1, the mid-point of which winding is connected to the cathode **13**. The collector electrodes or anodes **16***a* and **16***b* are connected across the primary winding **39** of an output transformer T_2, the mid-point of which winding is connected to the battery **36** so that the collector electrodes or anodes are maintained at a positive potential, for example of the order of 150 volts, with respect to the secondary cathodes **24***a* and **24***b*.

The electrons emanating from the emissive surface **14** of the cathode constitute an electron stream having, in the vicinity of this surface, a cross-section of substantially the same form and dimensions as the surface **14**. These electrons come under the influence of electric fields due to the potential difference between the cathode **14** and the field plate **28** and secondary cathodes **20***a* and **20***b*, and are caused to traverse arcuate paths which, in the absence of a potential difference between the deflector plates **26***a* and **26***b*, would pass through the plane of the cathodes **20***a* and **20***b* at points adjacent the medial plane between these cathodes, some of the electrons passing between these cathodes and others impinging thereon to cause the release of secondary electrons. These secondary electrons, in number greater than the impinging primary electrons, are similarly directed along arcuate paths toward the secondary cathodes **21***a* and **21***b* where a further electron multiplication occurs. This action is repeated at each of the succeeding secondary cathodes and the secondary electron current emanating from the cathodes **24***a* and **24***b*, which may be many times as great as the primary electron current, flows to and is collected by the anodes **16***a* and **16***b*.

In the absence of the magnetic field, between each pair of cathodes a dispersion of the electrons occurs and the dispersion increases at each successive multiplying stage in the device. Thus, for example, if the emissive surface **14** is circular in form, the primary electron stream would have at the plane of the secondary cathodes **20***a* and **20***b* an oval cross-section with axes greater than the diameter of the surface **14**. At each of the succeeding electrodes, the arriving electron stream would be in cross-section an oval with greater axes than those of the oval cross-section at the

preceding electrode. Consequently, at the later stages of the device some of the arriving electrons would fail to impinge upon the secondary cathode to which they were directed whereby a loss, a reduction in operating efficiency of the device and non-uniform operating characteristics would be occasioned.

In devices constructed in accordance with a feature of this invention, however, such dispersion of the electrons in the various streams flowing between successive electrodes is prevented so that at the plane of each of the secondary cathodes, the arriving electron stream has substantially the same cross-section as it had when leaving the preceding electrode. Stated in another way, in devices constructed in accordance with a feature of this invention, all of the electrons leaving any particular area of one electrode are focused upon the corresponding area of the next succeeding electrode. This result will be understood from the following considerations with particular reference to Fig. 3.

Each electron emanating from the emissive surface **14** of the cathode has a component of velocity normal to the medial plane between the deflector plates **26***a* and **26***b*, i. e. in the X direction indicated in Fig. 3 and travels along an arcuate path toward the secondary cathodes **20***a* and **20***b*. The magnetic field, however, because of its form changes the direction of the *x* component of electron velocity after the electron has passed the highest point in its arcuate path and, inasmuch as this field is symmetrical with respect to the medial plane between the deflector plates, each electron, under the influence of the magnetic field, will arrive in the plane of the secondary cathodes **20***a* and **20***b* at a point corresponding, in relation to the medial plane, to the point at which it left the surface **14**. Hence, all of the electrons emanating from the surface **14** will be focused upon a corresponding area in the plane of the secondary cathodes **20***a* and **20***b*. A similar focusing action is produced between each pair of succeeding secondary cathodes.

When the deflector plates **26***a* and **26***b* are at the same potential, that is when no signal is impressed upon the input transformer, equal portions of the primary electron current impinge upon the secondary cathodes **20***a* and **20***b* and equal multiplied currents are supplied to the collector electrodes or anodes **16***a* and **16***b*. However, when an alternating current signal, for example, is impressed upon the input transformer T_1, the primary electron stream will be deflected during one half cycle of the signal toward one of the secondary cathodes **20***a* and **20***b* to an extent proportional to the magnitude of the input signal so that the primary electron current to one of these cathodes is increased and that to the other of these cathodes is decreased. Hence, the multiplied current flowing to one anode will be increased and that to the other decreased. During the other half cycle of the signal, the conditions will be reversed. Honce, there will be produced in the winding **39** of the output transformer T_2 an alternating current corresponding to but of much greater magnitude than the signal impressed upon the input transformer T_1.

It will be noted that the number of secondary electrons leaving any one of the secondary cathodes is proportional to and greater than the number of primary electrons impinging thereon. Hence, when the beam is deflected in accordance with a signal so that, for example, more primary electrons flow to the secondary cathode **20***b* than to the secondary cathode **20***a*, the secondary cathode **20***b* will be more positive than the secondary cathode **20***a*. Consequently, the secondary electron stream leaving the secondary cathodes **20***a* and **20***b* will be further deflected in the same direction as the deflection due to the plates **26***a* and **26***b*, the magnitude of the increase in deflection being dependent upon the values of the resistances **37** connecting the secondary cathodes **20***a* and **20***b*. A further deflection in the same direction is produced in like manner at each succeeding pair of secondary cathodes. Hence, it will be seen that a high amplification of the alternating current component of the primary electron stream is achieved with relatively low amplification of the direct current component thereof.

It may be noted that each stage of the multiplier is regenerative to some extent inasmuch as the difference of potential between each pair of secondary cathodes is effective in both directions. The regenerative effect, however, may be made negligibly small without appreciably affecting the gain, by spacing the cathodes of each pair so that the electron stream thereto impinges upon only a very small portion of the plates adjacent the juxtaposed edges thereof. In such construction, electrodes at constant potentials may be provided between each pair of secondary cathodes to collect these electrons which do not impinge upon the cathodes, these electrodes functioning somewhat analogously to screen grids.

Although in the construction illustrated in Fig. 1 one field plate has been shown for each pair of cathodes, pairs of such field plates, one pair overlying a corresponding pair of cathodes or the deflector plates may be employed. In such case, each field plate is connected to the next succeeding secondary cathode in the row which it overlies. Thus, if the field plate **28** comprised two parts, each overlying a corresponding one of the deflector plates **26***a* and **26***b*, the field plate overlying the deflector plate **26***a* would be connected to the secondary cathode **20***a* and the other field plate would be connected to the secondary cathode **20***b*. Each field plate, then, would vary in potential with the secondary cathode to which it is connected so that the deflection, and, hence the amplification, would be increased.

The magnetic focusing described hereinabove may be utilized also in multistage multipliers including a single row of secondary cathodes, as illustrated in Fig. 4. The multiplier shown in this figure comprises a photoelectric primary cathode **50**, which may be energized by a beam of light emanating from the lamp **51**, a collector electrode or anode **52**, and a plurality of secondary electron emissive electrodes **53**, the several electrodes being substantially coplanar as shown. A magnet **35** is provided for producing a field symmetrical with respect to the axis of alignment of the electrodes and concave downward with respect to the emissive surfaces of the cathodes, whereby all of the electrons emanating from each of the cathodes are focused upon the corresponding area of the succeeding electrode in each case.

Although specific embodiments of this invention have been shown and described, it will be understood, of course, that they are but illustrative and that various modifications may be made therein without departing from the scope

and spirit of this invention as defined in the appended claims.

What is claimed is:

1. Electron discharge apparatus comprising an electrode having an electron emissive surface, a second electrode having an electron receiving surface substantially parallel to and in edge-to-edge relation with said first surface, and means adjacent said surfaces for producing a curved magnetic field adjacent said surfaces having its lines of force transverse with respect to the electron path between said electrodes and concave downward with respect to said surfaces.

2. An electron multiplier comprising means including an electron emissive surface for producing an electron stream, secondary electron emissive means substantially coplanar with said emissive surface and in alignment therewith, electron receiving means adjacent said electron emissive means, and means for focusing electrons emanating from said surface upon a corresponding area in the plane of said electron emissive means comprising means adjacent said surface and said electron emissive means for producing a substantially semicylindrical magnetic field adjacent said surface and said electron emissive means, concave downward with respect to said surface, and symmetrical with respect to the axis of alignment of said surface and said emissive means.

3. Electron discharge apparatus comprising an elongated substantially plane electrode having an electron emissive surface, electrode means adjacent thereto for energizing said surface to produce electron emission therefrom, an electron receiving means having opposite surfaces one of which is substantially coplanar with said emissive surface and opposite one of the longer sides thereof, said electron receiving means having end portions on opposite sides of a median line extending through said emissive surface and said electron receiving means, and a U-shaped magnet having its poles opposite said end portions and in face-to-face relation with the other of said opposite surfaces of said electron receiving means.

4. Electron discharge apparatus comprising a series of substantially plane electron emissive means mounted in alignment in coplanar edge-to-edge relation, electrode means adjacent thereto for energizing the first means in said series, a collector electrode in electron receiving relation with the last means in said series, and means adjacent said emissive means for producing a semicylindrical magnetic field adjacent said emissive means, said field being symmetrical with respect to the axis of alignment of said emissive means.

5. An electron multiplier comprising a plurality of pairs of substantially coplanar discrete electron emissive surfaces mounted side by side in two parallel rows, a pair of collector electrodes at one end of said rows, cathode means at the other end of said rows for producing an electron stream to energize the pair of emissive surfaces at said other end, resistance means connecting the surfaces in each pair together, and electrode means adjacent said cathode means for deflecting said stream to vary its division between the surfaces energized thereby.

6. An electron multiplier comprising a plurality of pairs of electrodes having secondary electron emissive surfaces, mounted side by side in two parallel rows, a plurality of field electrodes one opposite each of said pairs of surfaces, a U-shaped magnet having one pole opposite one row of said electrodes and its other pole opposite the other row of said electrodes, means adjacent one end of said rows for producing an electron stream, collector electrodes at the other end of said rows, and means in cooperative relation with said first means for deflecting said stream transversely to the longitudinal axis of said rows, whereby the division of said stream between the pair of electrodes nearest said first means is varied.

7. An electron multiplier comprising a primary cathode, a plurality of substantially coplanar secondary electron emissive surfaces mounted in pairs in two rows on opposite sides of an axis passing through said primary cathode, a pair of collector electrodes in cooperative relation with the pair of said surfaces furthest removed from said cathode, field plates opposite said emissive surfaces, a pair of deflector plates on opposite sides of said axis, adjacent said cathode and substantially coplanar with said surfaces, means adjacent said cathode and said surfaces for producing a substantially semicylindrical magnetic field symmetrical with respect to said axis and concave downward with respect to said surfaces, and impedance means connecting the surfaces of each of said pairs.

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