Oct. 29, 1940.

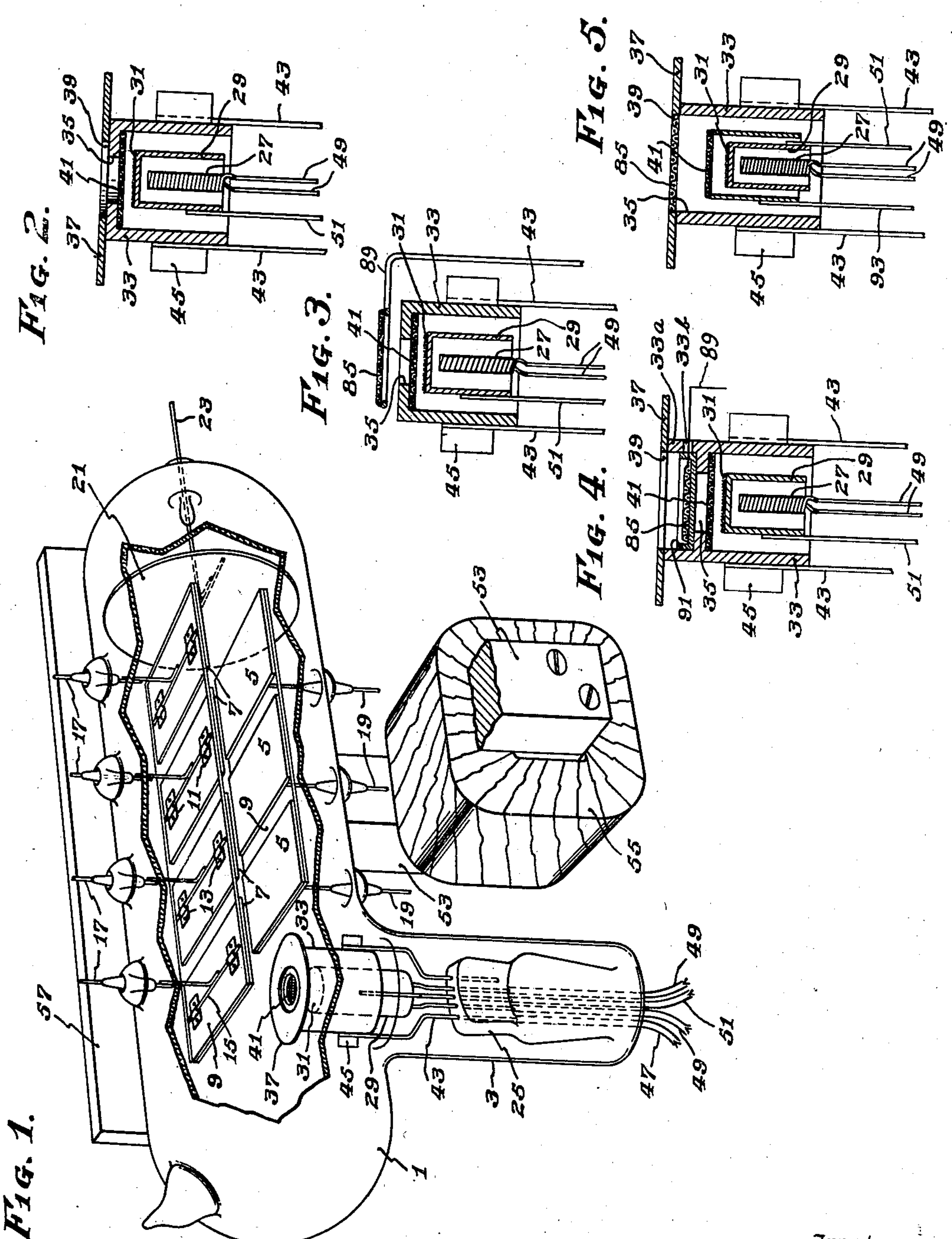
L. MALTER

2,219,871

ELECTRIC DISCHARGE DEVICE

Filed July 22, 1936

2 Sheets-Sheet 1



Inventor
Louis Malter

By

Attorney

Oct. 29, 1940. L. MALTER 2,219,871

ELECTRIC DISCHARGE DEVICE

Filed July 22, 1936 2 Sheets-Sheet 2

FIG. 6.

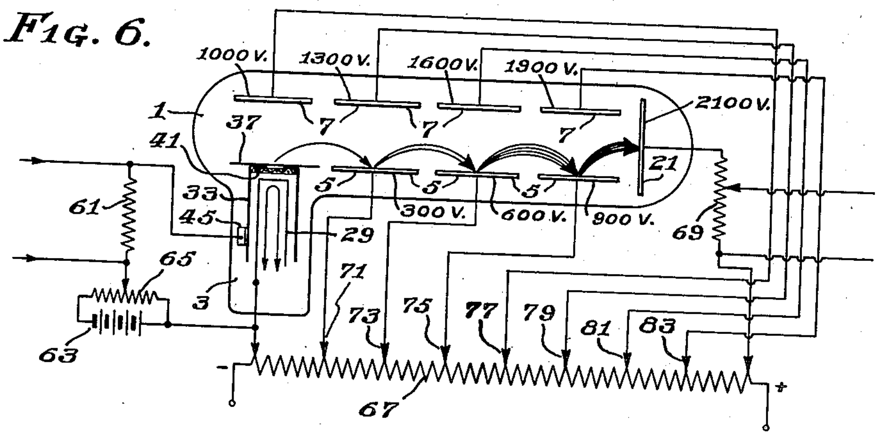
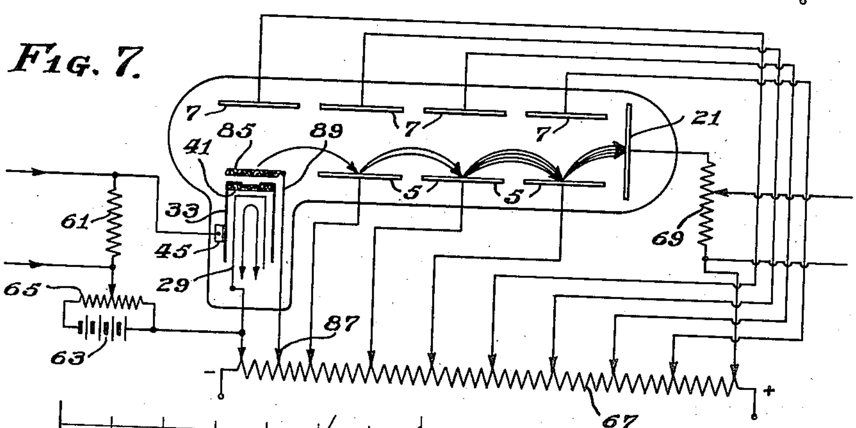


FIG. 7.



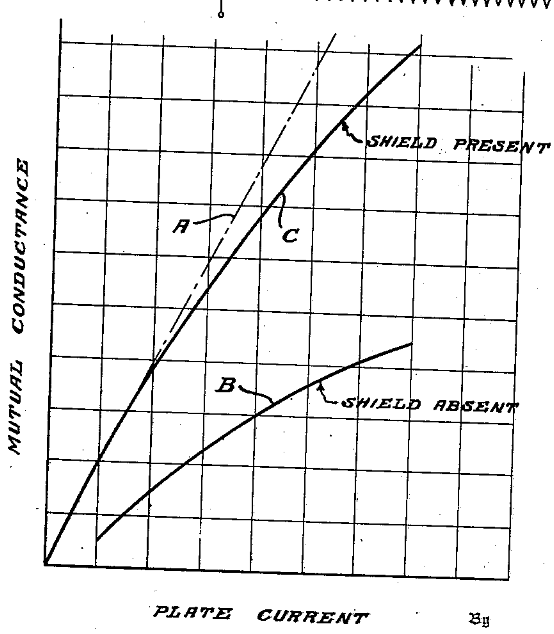


FIG. 8.

By

Inventor

Louis Malter

J. G. Huff

Attorney

Patented Oct. 29, 1940 2,219,871

UNITED STATES PATENT OFFICE

2,219,871

ELECTRIC DISCHARGE DEVICE

Louis Malter, Oaklyn, N. J., assignor to Radio Corporation of America, a corporation of Delaware

Application July 22, 1936, Serial No. 91,807

10 Claims. (Cl. 250—27)

This invention relates to electric discharge devices and methods of operating the same, particularly to grid controlled and magnetically influenced electron discharge tubes, and has special reference to the provision of improvements in the construction and operation of so-called "magnetic-type electron-multipliers."

The novel features characteristic of the invention are set forth in particularity in the appended claims. The invention itself, however, both as to its organization and method of operation, will be best understood by reference to the following description taken in connection with the accompanying drawings, wherein

Fig. 1 is a view in perspective of a thermionic magnetic type electron-multiplier embodying the invention, portions of the container wall and the associated magnet structure being broken away to more clearly illustrate the disposition of the electrodes,

Fig. 2 is a diagrammatic sectional view of the cathode, control grid, and magnetic shield of the device shown in Fig. 1,

Fig. 3 is a diagrammatic sectional view of a magnetic shield enclosing a cathode and a control grid, and shows a screen grid mounted exterior of the shield,

Fig. 4 is a diagrammatic sectional view of a magnetic shield enclosing a cathode, control grid, and a screen grid,

Fig. 5 is a diagrammatic sectional view of an assembly including the electrodes of Figs. 3 and 4, showing an alternative manner of supporting the screen grid,

Fig. 6 is a diagrammatic sectional view exemplifying the manner in which the device shown in Fig. 1 may be operated,

Fig. 7 is a diagrammatic view illustrating the circuit connections and manner of operating a multiplier having a screen grid similar to that shown in Figs. 3, 4, and 5, and

Fig. 8 is a graph exemplifying certain electrical characteristics of the improved device of the invention.

The mutual conductance of a tube is a good indication of the efficiency of the tube as an amplifier, in that it is dependent upon the effect of the applied grid voltage upon the plate current, the greater the change in plate current corresponding to any change of applied grid voltage, the greater the mutual conductance of the tube.

When it is recalled that electrons emitted from a thermionic cathode possess a Maxwellian velocity distribution, it can be shown theoretically that the mutual conductance cannot be greater than

$$\frac{e}{kT}I_p$$

where e is the electronic charge, k is Boltzmann's constant, and T is the absolute temperature of the cathode. I_p is the plate current measured in milliamperes. For a cathode operating at, say, 1000° K. the maximum value of this quantity is

$$g_{max}=11{,}600\ I_p \text{ micromhos}$$

Consequently, at a plate current of one milliampere and a cathode operating at 1000° K. the maximum possible value of mutual conductance is 11,600 micromhos. The mutual conductance of commercially available radio tubes operating at plate currents of one milliampere is usually no more than approximately 10% of this maximum value.

A principal object, therefore, of the present invention is to provide an electron discharge tube the mutual conductance of which approaches substantially the theoretical maximum value of mutual conductance.

While, theoretically, the mutual conductance of a thermionic discharge tube may be increased by forming the grid of very fine mesh spaced very close to the cathode, such construction carried to the extreme in practice, inhibits the passage of the electrons and thus prevents the desired increase in mutual conductance.

It would appear that if the relatively small number of electrons available on the anode side of a very fine mesh grid could be augmented, as by electron-multiplication, in the space between the grid and anode, then a high value of mutual conductance might be achieved. The present invention is predicated upon this principle.

The problems encountered in carrying the invention into effect differ in "electrostatic type" and "magnetic type" electron-multipliers. Thus, in electrostatic multipliers of the prior art, the field at each target drawing away the electrons is rather weak and the multiplier becomes space-charge limited at rather small current values. In prior art magnetic multipliers, the magnetic field interacts detrimentally with the low velocity electrons in the cathode-grid region.

The instant case has special reference to the solution of problems incident to carrying the invention into effect with electron-multipliers of the magnetic type, and contemplates a tube wherein the low velocity electrons in the cathode-grid region or area are shielded from the effects of the magnetic field, whereby they are constrained to approach and to leave the grid at an angle normal thereto instead of being deflected in return-paths to the cathode.

The invention further contemplates an electron multiplier of the type described wherein means are provided for maintaining the control characteristic of the grid substantially constant in spite of variations in the intensity of the electrostatic field required to operate the device.

Referring to Fig. 1, **1** designates an evacuated tube of glass or "Pyrex" having a depending neck portion **3**. The main body of the tube contains a plurality of secondarily-emissive lower electrodes **5** lying in the same plane and spaced apart along the long axis of the tube, and a plurality of upper or accelerating electrodes **7** disposed in a plane parallel to and spaced from the plane in which lie the first mentioned electrodes. The lower electrodes are preferably made of silver sensitized as by an application of caesium, and the upper electrodes of molybdenum, tantalum, nickel, or any other metal which is easily degassed and not readily oxidized.

These separate sets of electrodes **5** and **7** may be mounted within the tube in any convenient manner. In the embodiment illustrated, each set of electrodes is supported by a sheet of mica **9** which serves to keep them accurately aligned in a common plane. Each electrode is provided with two straps **11** which lie in corresponding openings **13** in the mica sheet, straddling a small cross-rod or wire **15** disposed against the upper surface thereof. During the application of welding the straps to an electrode, the rod **15** is forcibly biased against the mica sheet, thus locking the electrode firmly in position. Each cross-rod has a lead **17** welded thereto, which lead extends through the wall of the tube to the exterior thereof. Each lower cross-rod is also provided with an output lead **19**.

An output electrode **21** is mounted in one end of the tube, preferably fairly close to the sets of electrodes and in a plane transverse to the tube axis. The output electrode is provided with a terminal connection **23** which extends through the wall of the container to the outside thereof.

The depending neck portion **3** of the tube has a press **25** of the usual type sealed therein. The press supports a virtual source of electrons constituted by a filamentary heater element **27** contained in a metal thimble **29** having a layer of electron-emissive oxides **31** (see Fig. 2) on its upper end. The thimble is surrounded and shielded by a cylindrical structure **33** having an orifice **35** therein and constituted of iron or other metal of high magnetic permeability which terminates in a perforated cap **37**. The upper face of the cap lies in the plane of the multiplying electrodes and, preferably, the perforation **39** therein is coaxial with the emitting portion **31** of the cathode and the orifice **35** in the magnetic shield **33**.

A grid **41** of very fine mesh (say 60 mesh, .003″ wire) is supported by the shield about 1/64″ from the primary-electron emitting surface and spanning the coaxial perforations **35** and **39** in the shield and cap. The grid is preferably spaced about 1/64 of an inch from the cathode. By reason of its fine mesh and its close proximity to the primary-electron source **31**, grid **41**, when supplied with proper potentials, will exert a very high degree of control over the electrons, provided they reach the grid without numerical diminution such as might be caused, in the absence of the magnetic shield **33**, by a deflection from their normal paths due to the influence of the magnetic field.

The magnetic shield about the cathode-grid space is mounted above the press on supports **43** which contact the shield adjacent its outer surface and are fixed thereto by a metal band **45**. During assembly these supports are slidable in the band so that the top surface of the cap may be accurately aligned in the plane of the lower or multiplying electrodes. One of these supports **43** terminates in the press and the other one terminates in an external connection **47** to which the grid potentials are applied. The cathode heater leads are designated **49**, and the single lead to the thimble-shaped cathode **51**.

Any convenient means may be utilized for establishing a magnetic field parallel to the surfaces of the electrodes **5** and **7**. The device shown in perspective in Fig. 1 is constituted by a U-shaped element **53** of magnetically permeable material on which is mounted an energizing coil **55** and to each upstanding portion of which is affixed a plate **57** also of permeable material. The tube is disposed between these plates in such position that a substantially uniform magnetic field is set up parallel to the opposed surfaces of the multiplying and the accelerating electrodes.

Referring now to Fig. 6, which shows one manner of utilizing the device of Fig. 1; the input circuit elements connected between the control-grid **41** and the cathode **29** of the tube **1** are exemplified by an input resistor **61**, a grid biasing potential source **63**, and a potential divider **65**.

It is necessary to maintain each of the lower multiplying electrodes positive with respect to the cathode and with respect to any electrode between it and the cathode. For this purpose the cathode may be connected to the negative terminal of a source of unidirectional potential, exemplified in the drawing by a resistor **67**; the output electrode **21** may be connected to the positive terminal of the source through an output device such as a resistor **69**; and, starting from the cathode, the next adjacent electrode **5**, or first multiplying electrode, may be connected to a point **71** on the resistor somewhat more positive, and each of the remaining electrodes **5** connected to successively more positive points **73** and **75** on the resistor.

The first upper accelerating electrode **7**, immediately above the disc **37** surrounding the primary electron source **31**, may be connected to a point **77** on the resistor more positive than the point **75** to which the last multiplying electrode is connected, and the successive accelerating electrodes connected, respectively, to points **79**, **81** and **83** on the resistor still more positive, as clearly shown in the drawing.

It is not to be inferred from the foregoing description of Fig. 6 that the invention is limited to the exact potential distribution disclosed. In general, it might be stated that it is best to have each accelerating (upper) electrode positive with respect to the electrode directly beneath it. Excellent results are achieved by maintaining each multiplying electrode at the same potential as the next preceding accelerating electrode. With such potential distribution, the number of wire to glass seals may be reduced by the provision of jumpers (not shown) connecting the several mentioned "pairs" of electrodes within the tube.

When the cathode heater 27 is energized, thermionic electrons will be given off by the emissive coating 31. Many of these primary electrons will be lost by reason of the barrier presented to their passage by the relatively large effective area of the wires constituting the fine mesh grid 41. Those electrons which do pass through the interstices in the grid are subject in passing to its controlling action. Once past the grid they will be accelerated toward the upper electrode 7 directly above the emitter, because of the electrostatic field between it and the surface of 37, and, if no magnetic field were present, they would impinge thereon. However, the magnetic field (not exemplified in Figs. 6 or 7), which is parallel to the planes of the electrodes, subjects the electrons, moving toward the accelerating electrode, to a force component at a right angle to their instantaneous direction of travel. The direction of the component depends upon the polarity of the field. If the electric and magnetic fields are adjusted to proper values, the electrons will describe trochoidal paths and will strike the first multiplying electrode, which is the second from the left end of the device, as illustrated in the drawing.

If this first multiplying electrode is maintained at a potential positive with respect to the emitting electrode, the primary-electrons striking it will cause the emission of secondary electrons, the number of which is dependent, in part, upon the magnitude of the potential difference. The secondary electrons, as shown in the drawing, will in turn be accelerated toward the second upper electrode but, by reason of the magnetic field, they will be diverted and be focused upon the third lower electrode. Here again, a multiplication, by reason of the secondary emission, is secured and this process is repeated in any number of stages until the amplified stream of secondary electrons is collected by the output electrode and caused to flow in a utilization circuit exemplified in the drawing by the resistor 69 included between the output electrode 21 and the positive terminal of the potential source 67.

It will be apparent that if the primary electrons in the cathode-grid space were permitted to be influenced by the magnetic field, they would be given trajectories similar to the trochoidal trajectories exhibited by the electrons in their travel from one multiplying electrode to another. This in itself would be most undesirable, since it would direct the electrons which might ordinarily pass through the grid, by reason of their velocity of emission, away from this electrode, back to the cathode. As the number of electrons which pass through the very closely spaced grid wires will in any event be a relatively small per cent of those originally emitted, a further reduction might render the device inoperative, or at least require that this additional loss be made up by increasing the gain in the multiplying stages.

Of greater importance is the effect of the magnetic field upon the mutual conductance of "shielded" and "unshielded" devices. It has been found experimentally that the relative change in current transmitted through the grid for a given change in grid voltage is less when the magnetic field is present than when it is not present. By way of example, without the magnetic field, let the current transmitted through the grid at a fixed value of grid voltage (E_g) be, say, 10 microamperes. Let the grid voltage now be changed to E_g—0.1 volt, then the current transmitted through the grid may be 5 microamperes. Here this change in grid voltage has caused a two to one change in the current transmitted through the grid. With the cathode-grid space unshielded and the magnetic field applied in the manner illustrated, it was found that the available currents corresponding to each of the above values of grid voltage were 5 microamperes and 4 microamperes, respectively. Thus with the magnetic field present, the relative change of plate current caused by a change of —.1 volt is only in the ratio of 5 to 4 instead of 2 to 1. Now, the current transmitted through the grid in each case may be stepped up to the same final value by electron-multiplication, but in the former case the change in the output current caused by a certain change in grid voltage will be greater than in the latter case, where the magnetic field is present. Thus it is clear that with the cathode-grid space shielded against the magnetic field, the mutual conductance of the device is materially increased.

This increase in mutual conductance is graphically shown in Fig. 8, which shows a plot, A, of the mutual conductance theoretically attainable; a plot C of the mutual conductance obtained with a tube having a magnetically unshielded cathode-grid region; and a plot B of the mutual conductance obtained with the same tube when the cathode-grid region is magnetically shielded in accordance with the principle of the invention. An inspection of these plots shows clearly that the mutual conductance achieved in a tube having a magnetically shielded cathode-grid space more nearly approaches the theoretically attainable value than that obtained in the absence of a magnetic shield.

The final output current from an electron-multiplier of the type described, in addition to being proportional to the number of electrons available adjacent the side of the grid remote from the cathode, is also dependent upon the potential of any one of the electrodes with respect to the next adjacent electrode which is normally maintained at a lower potential. When the gain of the multiplier is changed by changing the voltage per stage, alteration of the potential on the first upper or accelerating electrode affects the control characteristic of the grid due to the fact that the potential distribution in the cathode-grid region is affected.

The provision of a "screen grid" on the anode side of the control grid has been found to prevent variations in the control characteristic when the potential distribution among the accelerating and multiplying electrodes is altered. As shown in Fig. 7 (which is otherwise similar to Fig. 6), the screen-grid, designated 85, is maintained at a fixed potential, positive with respect to cathode 29 by a connection to a suitable point 87 on the potential divider 67. Due to the shielding action of this screen-grid, alteration of the accelerating potential on the electrode immediately thereabove does not react upon the control grid-cathode region.

Referring now to Fig. 3. The auxiliary or "screen" grid 85 need not necessarily be shielded from the effects of the magnetic field, but may be mounted upon a separate support 89 with the surface of the screen above the magnetic shield and covering the orifice 35 in the shield 33, which is spanned by the control grid 41.

In Fig. 4 the screen grid, 85, rests upon an annulus of mica 91 or other insulating material which is supported on the rim about the orifice 35 covered by the control grid 41. The walls of the shield **33** are extended as at **33**[a], to protect the space about the screen-grid from the influence of the magnetic field and to provide a spaced support for the electrostatic disc **37**. The conductive lead **89** for the screen grid **85** enters the magnetic shield **33** through an insulated bushing **33**[b] in the extended position **33**[a] of the shield. As in Figs. 2 and 3, the shield itself forms part of the conductive lead to the control grid.

An alternative construction is shown in Fig. 5. Here the magnetic shield **33** forms part of the conductive connection to the screen grid **85**, which is mounted directly thereon and encloses the end of the electron-conduit through which the electrons must pass. The control grid **41** which, as in the other embodiments of the invention, is of very fine mesh, is here supported on a hollow cylinder **93** surrounding the thimble **29** containing the heater element **27**.

As a number of possible embodiments may be made of the above invention, and as changes may be made in the embodiments set forth without departing from the spirit and scope of the invention, it is to be understood that the foregoing is to be interpreted as illustrative and not in a limiting sense, except as required by the spirit of the appended claims and by the prior art.

I claim as my invention:

1. Method of operating an electron multiplier which comprises generating a stream of primary-electrons, subjecting said electrons to a controlling potential adjacent their point of origin and causing said controlled primary-electrons to produce a stream of secondary-electrons under the influence of a magnetic field while shielding the region of origin and control of said primary-electrons from the influence of said magnetic field.

2. Method of operating an electron multiplier which comprises generating a stream of primary-electrons, subjecting said electrons to a controlling potential adjacent their point of origin, subjecting said controlled electrons to the accelerating influence of an electrostatic field, and causing said controlled accelerated primary-electrons to produce a stream of secondary-electrons under the influence of a magnetic field while shielding the region of origin and control of said primary-electrons from the influence of said magnetic field and from variations in the intensity of said electrostatic field.

3. An electric discharge device comprising a cathode, a grid and an anode mounted in spaced relation in an evacuated container, means for producing a magnetic field through said container, and means for shielding said cathode-grid space from the influence of said magnetic field.

4. An electric discharge device comprising an electron emissive cathode, a control electrode mounted in the path of electrons from said cathode, a shield composed of a magnetically permeable material immediately surrounding said path and a third electrode mounted remote from said shield and accessible to said electrons.

5. An electron-multiplier comprising a cathode for generating a stream of primary electrons, a grid mounted adjacent said cathode, an electrode surface adapted to liberate electrons by secondary emission, an anode, a magnet for directing said primary electrons to said emissive surface, whereby secondary-electrons are released from said surface and for directing said secondary electrons from said surface to said anode, and a conduit of magnetically permeable material about the space intermediate said cathode and said grid through which said primary electrons pass.

6. An electron tube comprising a primary-electron emitter, an electrode surface adapted to liberate electrons by secondary emission, a conduit of magnetically permeable material extending part way between said emissive electrodes, a control electrode within said conduit, an accelerating electrode for directing primary electrons from the terminal of said conduit to said secondary-electron emitting surface, and an auxiliary grid for shielding said control grid from said accelerating electrode.

7. The invention as set forth in claim 6, wherein said auxiliary electrode is mounted within said conduit.

8. The invention as set forth in claim 6, wherein said auxiliary electrode is supported by said conduit and is electrically connected thereto.

9. The invention as set forth in claim 5 wherein said grid is electrically connected to said conduit.

10. The invention as set forth in claim 5 wherein said grid is of fine mesh and is mounted in close proximity to said cathode.

LOUIS MALTER.