May 11, 1948. C. F. STROMEYER 2,441,254

SYMMETRICAL SPACE CHARGE TUBE

Filed Aug. 4, 1945 3 Sheets-Sheet 1

Fig. 1

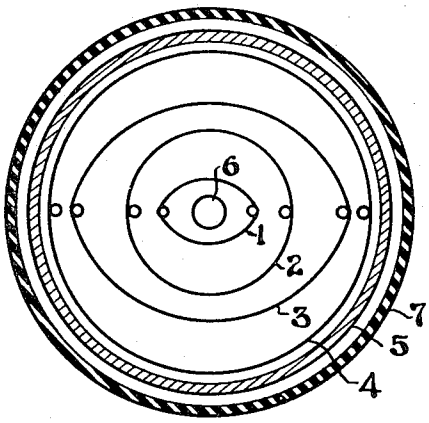


Fig. 2

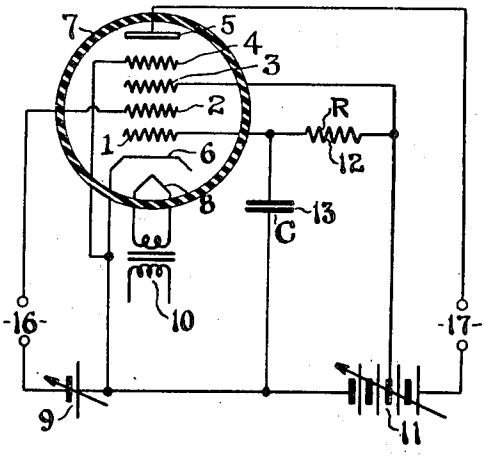


Fig. 3A

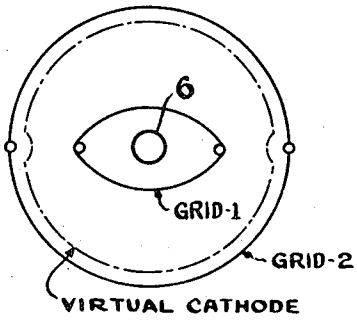


Fig. 3B

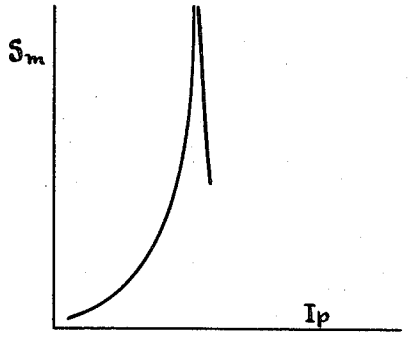
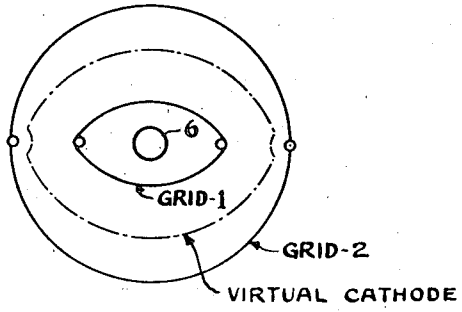


Fig. 4A



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SYMMETRICAL SPACE CHARGE TUBE

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Fig. 4B

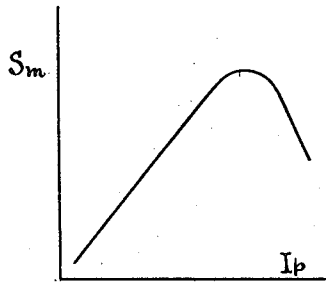


Fig. 4C

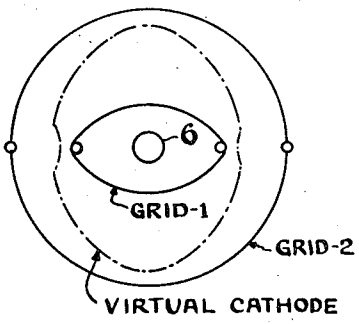


Fig. 5A

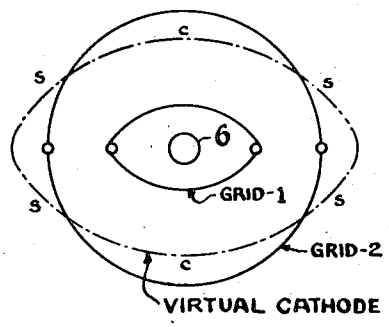
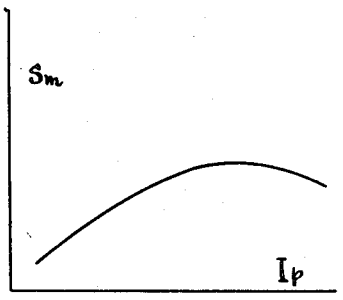


Fig. 5B



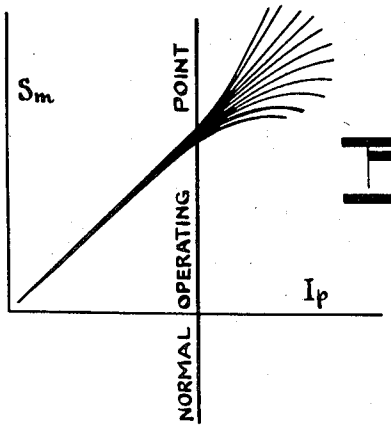


Fig. 8

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SYMMETRICAL SPACE CHARGE TUBE

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Fig. 6A

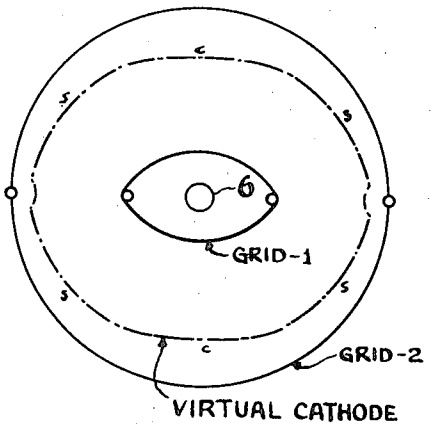


Fig. 6B

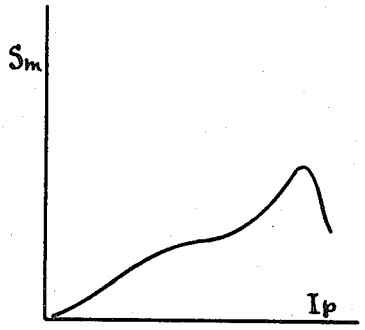


Fig. 7A

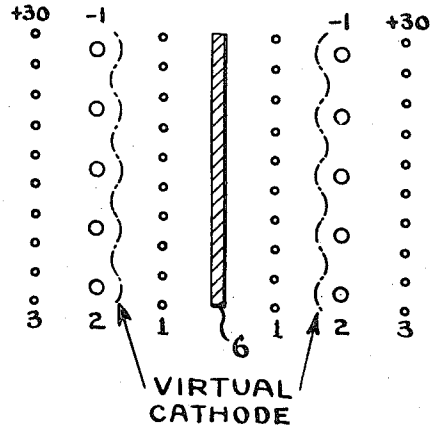
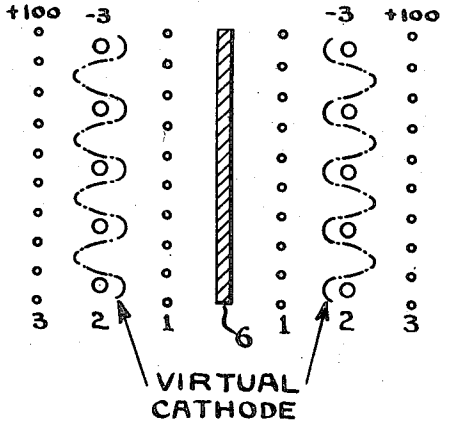


Fig. 7B



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Patented May 11, 1948 2,441,254

UNITED STATES PATENT OFFICE

2,441,254

SYMMETRICAL SPACE CHARGE TUBE

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Application August 4, 1945, Serial No. 608,890

5 Claims. (Cl. 250—27.5)

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This invention relates to thermionic tubes and especially to such tubes utilizing a space-charge electrode to provide a large virtual cathode.

This application is a continuation in part of my application Serial No. 443,585, now abandoned, filed May 19, 1942, for Symmetrical space charge tubes.

These particular tubes are often called space charge tubes. Their elements and operating potentials are arranged so that the positive space charge electrode attracts electrons from the cathode, the electrons that are not intercepted by the space charge electrode traveling on until their velocity momentarily reaches zero. If at this point at least some of the electrons return to the space charge electrode and others are drawn forward by any positive potential beyond, a virtual cathode can be considered formed at this point. The virtual cathode considered herein is therefore an imaginary surface exhibiting cathode characteristics, all points of which are at the minimum space potential. A control electrode may be situated between the virtual cathode and the anode. Since the virtual cathode may have many times the area of the real cathode, and since it may be located very close to the control electrode, a very high transconductance is possible.

The art relative to space charge tubes is not new. For instance United States Patent No. 1,756,893 filed in 1925 discloses some of their features. In spite of the fact that the idea has been known these many years, no substantial commercial adaptation of the principle has been possible. The chief obstacle is that it has not heretofore been possible to manufacture these tubes so that their characteristics are reasonably uniform. Methods employed in fabricating ordinary tubes fail to overcome the difficulties. In other words, modern manufacturing processes which produce excellent vacuum and apparently uniform cathode activation, as well as providing rigid control of the mechanical tolerances, still fail to make a practicable production of space charge tubes possible.

The object of this invention is to provide a space charge tube which is reproduceable in factory production.

In the drawings,

Figure 1 is a cross section of a tube constructed in accordance with the present invention;

Figure 2 is a circuit diagram illustrating the tube of Figure 1 in a simple amplifying circuit;

Figure 3A is a diagram illustrating the horizontal pattern of the virtual cathode for Ideal extreme class "A";

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Figure 3B is a curve illustrating the S_m/I_p characteristic for the pattern of Figure 3A;

Figure 4A is a diagram illustrating a virtual cathode pattern for Ideal class "AB";

Figure 4B is a curve illustrating the S_m/I_p characteristic for the pattern of Figure 4A;

Figure 4C is a diagram illustrating another virtual cathode pattern for Ideal class "AB";

Figure 5A is a diagram illustrating a virtual cathode pattern for Extreme class "B";

Figure 5B is a curve illustrating the S_m/I_p characteristic for the pattern of Figure 5A;

Figure 6A is a diagram illustrating the virtual cathode pattern for Class "C";

Figure 6B is a curve illustrating the S_m/I_p characteristic for the pattern of Figure 6A;

Figure 7A is a diagram illustrating a vertical virtual cathode pattern;

Figure 7B is a diagram illustrating another vertical virtual cathode pattern; and

Figure 8 is a series of curves illustrating the S_m/I_p characteristics of a group of tubes operating in class "AB".

An exacting analysis of the causes for the lack of reproduceability has been impossible. I am inclined to attribute the chief cause to the variation in the initial electron velocity distribution. With ordinary tubes, such variations have only a negligible effect if the cathode activation is apparently complete. With space charge tubes the position of the virtual cathode with relation to the control electrode is all important and this position is influenced by variations in the velocity distribution. The technique used in ascertaining the cathode activation of ordinary tubes is satisfactory but it is, indeed, inadequate when applied to space charge tubes.

For example, if a space charge tube (not designed according to the principles taught by this invention) which has a cathode whose activation is apparently complete, is subjected to a re-ageing process, its dynamic characteristics may be shifted considerably without any apparent change in emission. No doubt mechanical variations, although slight, are another factor responsible for the lack of reproduceability.

In my United States Patent No. 2,256,177, I have shown a method to alleviate this difficulty. This arrangement, however, is sometimes not appropriate for certain applications. For these cases I solve the problem by correctly dimensioning and spacing the electrode elements so as to selectively compromise certain tendencies. This

design work must be done empirically because the electron paths and current distribution are so complex that existing mathematical treatments, which are based on unattainable, idealized premises, fail completely in being of any practical value. The great number of variables involved in a single design makes the chances of evolving a suitable arrangement to overcome the lack of reproduceability very small unless a workable theory is followed so that the designer may have some intelligent means of knowing in what direction to proceed as the results of each test are observed. The results of my extensive investigations have proven that if certain characteristic tendencies are compromised, a practical production of space charge tubes is possible. The theory which I follow when designing such tubes is exceedingly useful.

It is, therefore, a feature of this invention to teach the principles required in the design of space charge tubes to make their characteristics reasonably reproduceable.

Before this work is expounded, the fundamental difference between a conventional type of tube and a tube with a virtual cathode should be appreciated. In the former, the cathode is fixed, and for a given geometrical structure the plate current depends upon the effective electrode potentials, so that its transconductance (*Sm*) is proportional to the 1/3 power of the plate current according to the familiar 3/2 power law. In the case of a space charge tube, on the other hand, the virtual cathode does not stay in one position but moves considerably, so that the effective control electrode voltage is no longer the only variable, and hence the characteristic does not obey the 3/2 power law. As more current is drawn from the space charge, i. e. as the plate current increases as a result of reducing the bias on the control grid, the virtual cathode moves outwardly from the cathode toward the anode, expanding more or less radially. Thus the contribution of any particular part of the virtual cathode to the over-all *Sm* depends upon its area and the distance from the control grid, the contribution increasing as it approaches the control grid and decreasing as it passes through. This will be referred to hereafter as the distance effect of the virtual cathode. The over-all characteristic is in the integrated distance effect over the entire virtual cathode surface.

My theory of the operation of a space charge tube is that the variation in integrated distance effect in previous tubes is responsible for their lack of reproduceability. Whether this theory is right or wrong, I have further discovered that if the theory is followed in designing a practical tube, that tube may be reproduced in factory production with sufficient similarity in characteristics for commercial purposes. If, therefore, the virtual cathode pattern is considered to exist in accordance with the theory, and if all the factors explained hereafter are considered to influence the integrated distance effect of that pattern in accordance with the theory, a design may be worked out in which the integrated distance effect is controllable, and therefore the tube characteristics reproduceable.

The virtual cathode pattern of course does not remain constant as it moves out, but changes continually to some extent. For badly distorted fields and thin charge densities the change in pattern may be considerable. Thus a picture of the effects of a particular shape is valid only over the region where the change in shape is small. In order to simplify this discussion, a specific reference will be made to a particular design and arbitrary terms assigned. It is to be understood that this is done because it is more instructive to refer to a specific design rather than discuss generalities, and in so doing, it is to be understood that the scope of this invention is not limited thereby. The theory of course may be expanded to other structures.

A diagrammatical cross-section of the particular tube selected for the following discussion is shown in Fig. 1 in which the elements are arranged concentrically. Item 6 is the cathode, 1 the space charge grid, 2 the control grid, 3 the screen grid, 4 the suppressor grid, 5 the anode, and 7 the evacuated envelope encompassing the electrode elements.

Fig. 2 diagrammatically shows this particular tube arranged in a simple amplifying circuit.

Recurring reference numerals in all figures refer to like elements and will not be repeatedly described.

Heater 8 makes the cathode emit copiously. Items 9, 10 and 11 are potential sources for operation of the device. Resistor 12 limits the current taken by the space charge grid and condenser 13 makes the voltage on the grid substantialy constant to signal frequencies. Since there will be considerable reference to these last two items, they are also designated by R and C, respectively. The input signals are impressed across terminals 16 and the output taken off terminals 17.

I have previously mentioned the complexity of the virtual cathode. It is now necessary to show how the pattern of the virtual cathode is influenced when certain electrode alterations are made. For the purpose of classification, the surface of the virtual cathode may be considered to be divided into two independent parts, the horizontal pattern and the vertical pattern. Actually one is not entirely independent of the other, since both depend upon the entire space charge distribution, but in order to determine fundamental trends and behavior of virtual cathodes, each will be treated more or less separately.

Horizontal Pattern

The horizontal pattern of the virtual cathode is a cross-section of the surface of the virtual cathode intercepted by a plane perpendicular to the axis of the cathode. This horizontal pattern is determined by the combined effect of the horizontal shapes of the lateral wires of the various grids and potentials upon them. In general it is found that the shape of the number 1 or space charge grid is the chief factor, although the number 2 or control grid and number 3 or screen grid shapes do have considerable effect.

The horizontal patterns obtained may be divided into five main types, according to the characteristics that they produce.

I. *Ideal extreme class "A"*

This type has the following characteristics:

(*a*) The transconductance plate current (*Sm*—*Ip*) characteristic is an extreme power curve quite smooth and free from irregularities. The slope is extremely great on either side of the peak *Sm* and peak *Sm/Ip* is extremely high, sometimes as high as 10,000 micromhos per milliampere.

(*b*) If the curve covers a range of several mil-

liamperes of plate current before breaking, Sm is relatively low at low Ip.

(c) In the steep region Sm decreases considerably, if the condenser by-passing the resistor in series with the space charge grid is omitted.

The horizontal pattern of the virtual cathode for this type of characteristic always conforms to the shape of the control grid. This is diagrammatically represented by Fig. 3A. As the virtual cathode expands radially and approaches the control grid, the distance decreases and hence Sm/Ip increases continuously, thus producing a steep power curve. Such a characteristic is represented by Fig. 3B. Break up of the Sm occurs at the point where the entire virtual cathode enters the control grid surface at once. If the virtual cathode is initially far away from the control grid surface, the Sm is quite low at low plate current and the curve is extended over considerable range of plate current before breaking.

When the bypass condenser C is omitted Sm is changed by the effect of the number 1 grid on the Sm multiplied by the backward gain, i. e.

$$\text{Unbypassed } Sm_{2p} = \text{bypassed } Sm_{2p} - \frac{R}{R-r}\mu_{21}\, Sm_{1p}$$

where R is the resistance in series with grid #1, r is the internal resistance of grid #1, and μ is the amplification factor. The subscript numerals and letters refer to a particular element acting upon another particular element; for example Sm_{1p} means the transconductance in the plate circuit as a result of signal impressed on the number 1 grid. It should be understood that the "backward gain" is due to the negative transconductance in the grid number 1 circuit as a result of a signal impressed on the grid number 2. Of course, when R is by-passed, the backward gain is zero.

In the case of Ideal class "A" with C omitted, during the positive peak of the impressed signal the number 1 grid voltage increases, causing the virtual cathode to move backwards because the displacement caused by the increased charge density is greater than that produced by the increased electron velocity. The resulting decrease in Ip produces negative Sm_{1p}, and hence, for this class of operation, the Sm for the unbypassed condition is less than the Sm for the bypassed condition.

II. *Ideal class "AB"*

This type has characteristics as follows:

(a) Sm—Ip characteristic is a straight line over a considerable range of Ip.

(b) Peak Sm is moderately high.

(c) At low Ip, Sm is relatively high compared to class "A."

(d) Sm changes but little when the bypass condenser is removed. The reason for this will be clarified when discussing the "Extreme class B" type.

There are two types of horizontal pattern which will produce this characteristic namely.

1. Oval horizontal pattern with major axis coinciding with grid post line. This is diagrammatically represented by Fig. 4A. As the virtual cathode expands radially, the amount of effective area close to the control grid surface increases in such a way that a straight line Sm—Ip characteristic is obtained. This characteristic is represented by Fig. 4B. Relatively high Sm at low Ip is due to the sides being near the control grid surface.

2. Oval horizontal pattern with major axis perpendicular to the post line. This is diagrammatically represented by Fig. 4C. The effective area increases in the same manner as above, except that here the center enters first and produces the relatively high Sm at low Ip.

In both types of this class, the useful Ip range is limited, and in order to keep it as high as possible, the amount of area "lost," due to intercepting the control grid surface at or near the start of the curve, should be kept as low as possible.

III. *Extreme class "B"*

This class has characteristics as follows:

(a) Slope of Sm—Ip curve decreases with increasing Ip. Maximum Sm is low, and peak is well rounded.

(b) Sm is moderately high at low Ip.

(c) If bypass condenser is removed, Sm increases (this is opposite to class "A").

This type of characteristic is the result of an "AB" pattern which starts with too much of its area already intercepted by the control grid surface, so that the effective area decreases continuously with increasing Ip, thus producing a low decreasing slope and rounded peak. This is diagrammatically represented in Fig. 5A and its associated characteristic by Fig. 5B.

Removal of the bypass condenser C increases Sm, because in this case Sm_{1p} is positive (opposite to class "A"), and therefore adds to Sm_{2p}. The reason for this positive Sm_{1p} is as follows:

The virtual cathode displacement of the center portions (C) Fig. 5A, as a result of a positive increase in the grid number 1 voltage, is the same as class A and tends to decrease Ip. However, the side portions (S), which are into or beyond the control grid, move forward instead of backward because the displacement caused by the increased electron velocity is greater in this region than that caused by the increased current density. Since the increase in current due to the sides moving out is greater than the decrease due to the inward motion of the center, the overall Sm_{1p} is positive.

When Sm_{1p} is zero, the Sm for both the bypassed and unbypassed condition are identical. This is what occurs in class "AB" tubes.

IV. *Class "C"*

This class has the following characteristics:

(a) Sm—Ip characteristic is a straight line at the start. At some mid-point of Ip the slope decreases, but further on increases again into a power curve of class "A."

(b) Maximum Sm may be high, but not as high as extreme class "A."

(c) Sm is relatively high at low Ip.

The horizontal pattern for this class is similar to an "AB," but much flatter at the start. This is diagrammatically represented by Fig. 6A. Sm is high and the curve is straight because the regions move in as in an "AB" tube. At the point where most of the side portions (a) have intercepted the control grid surface, and the center regions (c) are still relatively far away, Sm levels off since insufficient effective area close to the grid remains to maintain Sm. Finally as (c) approaches the control grid, the slope increases and may even result in a power curve. This characteristic is represented by Fig. 6B.

Removal of the bypass condenser C increases Sm over the initial part of the curve and decreases it over the second part where the power curve exists.

V. *Class "D"*

This class has a wavering Sm—Ip characteristic curve with more than one point of maximum Sm.

The horizontal pattern may be similar to a class "C" but with the center region flattened to such an extent that the ends pass through the control grid surface and cause Sm to actually decrease before the center portion gets close enough to start a power characteristic.

Erratic curves come under this classification and are usually the result of irregularly shaped horizontal patterns; for example, a saddleback pattern with the center region depressed.

Vertical Pattern

The vertical pattern of the virtual cathode is corrugated due to the distortion in the equipotential surfaces caused by the finite grid lateral wires. The corrugations are such that the pattern extends out toward the screen at points in between the number 2 grid laterals and is pushed back at points opposite the laterals. The depth of corrugation depends upon the variation in electric field which in turn depends upon the fineness of the grid structure and potentials upon grid and screen. The coarser the pitch the greater is the depth. Also for a given geometry, the higher the screen potential and consequently the more negative the control grid potential, the greater the depth. This is diagrammatically shown in Figs. 7A and 7B.

The decrease in depth of corrugation with lower voltage, as illustrated in Fig. 7A, probably accounts for the fact that almost all tests show much better grouping of the characteristics of a batch of tubes at low screen voltages (30 to 50 volts) than at high screen voltages (100 volts). Evidently any differences that may exist from tube to tube such as extremely small variations in mechanical dimensions or cathode activity are more liable to show up as appreciable changes in horizontal pattern, when the vertical pattern is badly corrugated, than when it is uniform and free from corrugations. In the latter case the charge density is more uniform over a vertical plane and hence able to iron out small variations in charge distribution to some extent, whereas in the former the density may be quite thin in between turns and thus unable to resist small changes in charge distributions. This effect of vertical corrugation on horizontal pattern explains why the characteristic curves at high and low screen voltages differ very little for some patterns. In the case of a strictly class "A" type, a decrease in the screen voltage merely makes the curve a trifle steeper due to the fact that the vertical pattern becomes more uniform and hence the entire virtual cathode surface conforms slightly better to the control grid surface. On the other hand, in the case of an extreme "B" or "C" type, the depth of corrugation at the sides may be much less at low screen voltage than at high screen voltage, whereas the center region may not change much, thus producing quite a change in horizontal pattern, and hence in characteristic.

In the case of class "D" types where the virtual cathode patterns are badly distorted, the characteristic curves may change tremendously between high and low screen voltages, since the accompanying changes in pattern may be violent.

Maximum Plate Current

Maximum Ip is defined here as the value of plate current at which peak Sm occurs. Beyond this point Sm decreases, either because all or a major part of the virtual cathode has passed by the control grid surface, or else because the virtual cathode disappears due to the space charge density being insufficient to maintain it. If the space charge is dense enough so that break up does not occur, then maximum Ip is determined entirely by the over-all effect of the horizontal and vertical pattern entering into the plane of the control grid surface. This last is assumed to be valid for most of my tests for two reasons: First, in order to obtain high Sm/Ip very close spacing between virtual cathode and control grid is used, while at the same time relatively high space charge current is maintained; second, a true break up or disappearance of a virtual cathode is accompanied by a discontinuity in plate current, which has never been observed with any of my tubes, providing they were properly activated.

In the case of a theoretically ideal class "A" tube with uniform vertical control grid and virtual cathode surfaces free from corrugations, the Ip range would depend upon the starting distance between the virtual cathode and control grid, and maximum Ip would be extremely critical, since the entire virtual cathode surface would pass through the control surface at the same point. In an actual tube, of course, vertical corrugations must occur due to the finite structure, and hence the point of maximum Ip is not quite so sharp. Nevertheless, for a reasonable range of pitch and wire sizes of the laterals of the various grids, the same conclusions hold over most of the Ip range, which, therefore, can be made short or extended as desired by varying the distance between the virtual cathode and control grid.

In the case of a class "AB" tube, on the other hand, the Ip range is limited, since the virtual cathode must be close enough to the control grid so that part of it is nearly or already intercepted at the start. Accordingly little can be done to alter considerably the Ip range without changing the shape of the characteristic at the same time.

The Compromised Class

For general applications, the steep rising characteristic of class "A" is highly undesirable from the standpoint of excessive variations in circuit performances as a result of slight shift in plate current. For example, I have made tubes which produced an Sm equal to 10,000 micromhos at an Ip of 4 milliamperes and if the Ip was increased to 5 milliamperes the Sm rose to 40,000 micromhos. Moreover, extremely small variations in mechanical dimensions or cathode activity that may exist from tube to tube will cause tremendous variations in Sm when working on the steep part of the characteristic. This holds true even under the condition of comparing the tubes at like plate current. If the normal point of plate current operation is below the rising knee of the characteristics, the tubes can be made reasonably alike, but then their amplifying performance is poor since the Sm is relatively low in this region.

The class "B" operation is rejected because of its inherently low Sm. Obviously class "C" and class "D" operations are rejected because the erratic shape of their characteristics are undesirable and because of the lack of reproducibility.

The compromised operation is class "AB." If the normal operating plate current is set somewhat below the average peak value, variations of a given design are not severe. Furthermore, normal variations in plate current caused by practicable tolerances for operating potentials and circuit components do not greatly shift the circuit performance.

Fig. 8 shows individual characteristics of a group of tubes of this class. The advisability of operating somewhat below an average peak value is clearly indicated. Removal of bypass condenser C would seem desirable since it has little effect on the *Sm*, but this is not possible in most circuit applications because the negative *Sm* of the number 1 causes parasitic oscillations. If it were not for this, there is an additional advantage of eliminating C in that the results of small dimensional variations and variations in cathode activity tend to be further nullified.

To take advantage of the compromised operation it is not necessary to have a strictly "AB" characteristic but one that reasonably approaches it.

From the foregoing it would seem that the design problem becomes quite simple but this is not so because, obviously, the pattern is not really "seen."

Becoming familiar with it for evolving a particular design is only possible by deductive reasoning from results of many tests. One of my designs, which has proven to be outstandingly successful, has the following approximate specifications:

Grid No.	Minimum Diameter	C—C Major Diameter	Lateral Wire Diameter	Grid Post Diameter	TPI (Turns per inch)
	Inches	*Inches*	*Inches*	*Inches*	
1	.150	.220	.003	.025	50
2	.325	.320	.003	.025	50
3	.390	.530	.004	.030	56
4	.600	.640	.006	.030	15

Cathode, .030" outside diameter x 24 mm.-15 mm. coating band.
Plate, .910" outside diameter.
The effective operating length of these elements is .800".
The entire structure is shielded to minimize extraneous coupling.

This tube is intended for general R. F. amplifier purposes and this mechanical arrangement of elements is now used in conjunction with a "dynamic-coupled" driver as shown in Fig. 6 of my previously mentioned United States Patent No. 2,256,177.

In order to have an appreciation of magnitude, the following are approximate characteristics of a tube having its elements arranged as specified above.

Heater power	watts	1.25
Anode voltage (*Ep*)	volts	250
Screen voltage (Ec1)	do	50
Resistor R	ohms	3500
Control grid bias (Ec2)	volts	−1.75
Plate current (*Ip*)	mils	5.0
Screen current (Ic3)	do	1.2
Space charge grid current (Ic1)	do	6.2
Transconductance	umhos	10,000
Plate resistance	megohm	0.4

On the basis of the classification of the virtual cathode as previously expounded, one may explain the trends in characteristic changes that occur as the grid dimensions are varied somewhat. Reference is now made to the particular cited arrangement. The effect of changing the horizontal shape of the grids is considered first. With the oval number 1 grid the virtual cathode pattern tends to be flatter than the number 1 grid shape due to the increased density at the center region where the number 1 grid is closer to the cathode than it is at the ends. However, this is somewhat offset by the round number 2 grid and oval screen grid which tend to make the pattern round. Thus, for the given center to center of the number 1 grid, a decrease in the minor diameter tends to make the pattern flatter, and hence increases the possibility of a wavering or saddleback characteristic of class "C" or "D." For example, with a tube dimensioned as previously described, a change in the #1 minor O. D. (outside diameter) to .143" definitely produces a saddleback, .150" is just on the verge, and .156" is smooth.

Since the number 2 or control grid is negative, it tends to repel the space charge of the virtual cathode and, hence, causes the virtual cathode pattern to conform to its shape to some extent. The effect of the number 2 grid on the virtual cathode pattern is much less than that of the number 1 grid. Small changes in the diameter of the number 2 grid do not affect the characteristic curve nearly as much, since the space charge tends to follow changes in the number 2 grid due to its repelling action and, hence, cause the distance between the virtual cathode and number 2 grid to remain more or less constant. Large changes in number 2 grid shape may change the density distribution and alteration of the virtual cathode pattern. A small change in the diameter of the number 2 grid will alter the peak *Sm* appreciably; for example, with a tube dimensioned as previously described, if the minor O. D. is increased by .010" the peak *Sm* will be increased and the *Sm*—*Ip* characteristic will tend to be more of the class "A" type. On the other hand, if it is decreased by the same amount, the peak *Sm* will be low and the characteristic will tend to be more of the class "B" type.

The number 3 or screen grid has the opposite effect on the virtual cathode pattern to that of the number 2 grid, since it attracts electrons from the space charge, thereby decreasing the charge density. Thus a round number 3 grid tends to flatten an oval virtual cathode pattern because more current is taken from the end of the oval which is closer to the screen, and, hence, moves out further than the middle region. On the other hand, an oval number 3 grid tends to make the virtual cathode pattern round. Thus with a tube dimensioned as previously described, an oval number 3 grid and round number 2 tend to make the oval virtual cathode pattern round.

With regard to limits on TPI (turns per inch) and wire sizes, it would seem advisable offhand to make the TPI of the number 1 grid as high and the wire size as low as possible in order to approach an ideal, uniform, vertical pattern. This is not true. I have never been able to make tubes which were reasonably reproduceable when using number 1 grids of 2 mil wire and 80 TPI. Possibly this can be explained on the basis that uniformity of characteristics cannot be obtained by means of correct horizontal pattern alone, but must involve a certain amount of corrugation in the vertical pattern to also aid in nullifying the effect of small dimensional tolerances and variations in cathode activity. When using 2 mil wire, 70 TPI seems to be an upper limit. If the TPI is made too low, the depth of corrugation becomes so great that the available *Sm* for a given *Ip* suffers too greatly. For 2 mil wire, 50 TPI seems to be a limit in this direction. When using 3 mil wire, 50 TPI is an optimum value.

The selection of TPI and wire sizes for both the number 2 and number 3 grids is governed by similar considerations given to ordinary tubes. If the TPI of the control grid, number 2, is too low, say 40, the loss of SM is severe due to "island effects." If the TPI is too great, sufficient bias cannot be obtained. The wire size of number 2 should be made as small as practicable. The screen grid, number 3, must have sufficient concentration to adequately shield the plate field from having any appreciable influence upon the virtual cathode.

When all of the factors mentioned are taken into consideration, it becomes possible to design reproduceable space charge tubes. It will, of course, be obvious that the various influences of each factor on all of the others must be considered in order to secure an integrated distance effect, as I have defined that term above, which has a high value, and which varies at a uniform rate over the operating range of the tube.

It is characteristic of tubes made in accordance with my invention that the second grid from the cathode shall have the same shape as the cathode and that the third grid from the cathode shall have the same shape as the first grid, as shown in the drawing. It is further characteristic of my invention that the first grid shall have a different shape from the cathode as will, of course, also the third grid, as also shown in the drawings.

By the same shape, I do not mean that the shapes must be exact with high precision, but include elements of substantially the same shape. I mean, for example, that if the cathode is rectangular in cross section having a certain ratio of length to breadth, the second grid shall also be rectangular in cross section and have the same ratio within, say, 20%. Similarly, as to the third grid and first grid the long and short diameters should match but the departure in the ratio of long and short diameter may be as much as, say, 30%. Of course, it will be understood that while a rectangular cathode may have right angle corners the second grid may be considered to be rectangular in accordance with my invention even though the corners are somewhat rounded.

In saying that the first and third grids have a different shape than the cathode and second grid, I mean that in a plane through the tube the shortest distance between the elements of different shape will differ at different points along the two surfaces. This is illustrated in Figures 1, 3*a*, 4*a*, 4*c*, 5*a* and 6*a* as to the cathode, first, and second grid, and in Fig. 1 as to the third grid as well.

What is claimed is:

1. A space charge tube comprising a cathode, a first, a second, and a third grid spaced in that order from the cathode, the second grid having the same cross-sectional shape as that of the cathode, the third grid having the same cross-sectional shape as that of the first grid, and the first and third grids having a cross-sectional shape different from that of the cathode and second grid.

2. A space charge tube comprising a cathode, a space charge grid, a control grid, and a screen grid, the control grid and the cathode having the same cross-sectional shape, and the space charge grid and screen grid having the same cross-sectional shape, the cross-sectional shape of the space charge grid and screen grid being different from that of the cathode and control grid.

3. A space charge tube comprising a cathode, a space charge grid adjacent the cathode, a control grid beyond the space charge grid from the cathode, and a screen grid beyond the control grid from the cathode, the control grid and the cathode having the same cross-sectional shape, and the space charge grid and screen grid having the same cross-sectional shape, the shape of the space charge grid and screen grid beng different from that of the cathode and control grid.

4. A space charge tube comprising a cathode, a space charge grid nearest to the cathode, a control grid beyond the space charge grid from the cathode, and an additional grid beyond the control grid from the cathode, the control grid and cathode having the same cross-sectional shape, and the additional grid and space charge grid having the same cross-sectional shape, the cross-sectional shape of the space charge grid and additional grid being different from that of the cathode and control grid.

5. A space charge tube having the following dimensions:

Grid No.	Minimum Diameter	C—C Major Diameter	Lateral Wire Diameter	Grid Post Diameter	TPI (Turns per inch)
	Inches	*Inches*	*Inches*	*Inches*	
1	.150	.220	.003	.025	50
2	.325	.320	.003	.025	50
3	.390	.530	.004	.030	56
4	.600	.640	.006	.030	15

Cathode, .030" outside diameter x 24 mm.–15 mm. coating band. Plate, .910."O. D., the effective operating length of these elements being .800", and the entire structure being shielded to minimize extraneous coupling.

CHARLES F. STROMEYER.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
2,031,137	Steimel	Feb. 18, 1936

Certificate of Correction

Patent No. 2,441,254. May 11, 1948.

CHARLES F. STROMEYER

It is hereby certified that error appears in the printed specification of the above numbered patent requiring correction as follows: Column 12, line 22, claim 3, before the word "shape", second occurrence, insert *cross-sectional;* and that the said Letters Patent should be read with this correction therein that the same may conform to the record of the case in the Patent Office.

Signed and sealed this 7th day of September, A. D. 1948.

[SEAL]

THOMAS F. MURPHY,
Assistant Commissioner of Patents.