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THE 6BN6 GATED BEAM TUBE

Part 1. The Laboratory Prototype And Its Circuit Applications

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Abstract—When an electron beam is focused upon a grid through a narrow slot in a positive accelerator, a grid control characteristic results which is useful for limiting purposes. Two such electrode systems in cascade can serve as limiter-discriminator. Prior work along related lines is reviewed and the development of the gated beam tube summarized. Typical circuits for intercarrier sound and for FM receivers are described, as well as the use of the tube as sync clipper.

I. INTRODUCTION

The gated beam tube, which has recently been introduced, represents a considerable departure from the construction and characteristics of conventional tubes.

The most important feature of this new species of receiver tube is the step-shaped control characteristic of its first grid (Fig. 1): in response to a grid potential which changes from negative to positive, the plate current rises abruptly from zero to a sharply defined maximum level. No further change occurs in the plate current no matter how strongly positive the grid may go.

The tube contains a second control grid which has similar properties: if it is made strongly negative, the plate current is cut off. Over a narrow range of potentials in the vicinity of zero, the second control grid acquires control over the height of the platform to which the plate current may rise; but if the second control grid is made strongly positive it also loses control over the plate current which can never rise beyond a predetermined maximum level.

The original purpose of the development of the gated beam tube was to provide a tube which would have inherent amplitude limiting characteristics and fit into an f-m detector circuit requiring a minimum number of components. But, as is so often the case, other applications have been found in which the unusual characteristics of the gated beam tube are put to work. Some of these circuits, like the sync clipper described in this article, are easily understood. The f-m detector circuit, on the other hand, involves the use of space-charge coupling, known to everyone as an unavoidable evil in converter tubes but not widely regarded as a useful tool.

To one unfamiliar with the long history of f-m detectors, this mode of operation of the gated beam tube may appear to be something as radically new as the tube itself. Actually, the principles of this f-m detector circuit are 13 years old; even the tube itself represents merely a further step in a direction in which a great deal of work has been published over a period of many years. A brief review of the highlights of this prior work appears in the last section of this paper.

II. PRINCIPLES OF OPERATION

When a sharply focused electron beam, emanating from a narrow opening in a solid positive electrode, is thrown against a control grid which is followed by an anode, unusual characteristics are sometimes observed. One would expect that with sufficiently high negative potential on the grid no anode current could flow, and that the entire beam current (except for a small portion caught on the grid wires) would pass to the anode if the grid were strongly positive. The experiment confirms these expectations, but the transition between the cut-off region and the full-current region is surprisingly steep. Transconductances of several thousand micromhos per milliampere of anode current are easily realized, and higher slopes up to the point of anode current instability can be obtained. While it would be difficult to reproduce these extreme conditions in production, a slope corresponding to virtually complete transition from zero to full anode current for about 2 volts change in grid potential can easily be duplicated.

Figure 2 shows schematically the operation of a gated beam system in one of its early experimental forms. On the left, the gate is open; the potential in the vicinity

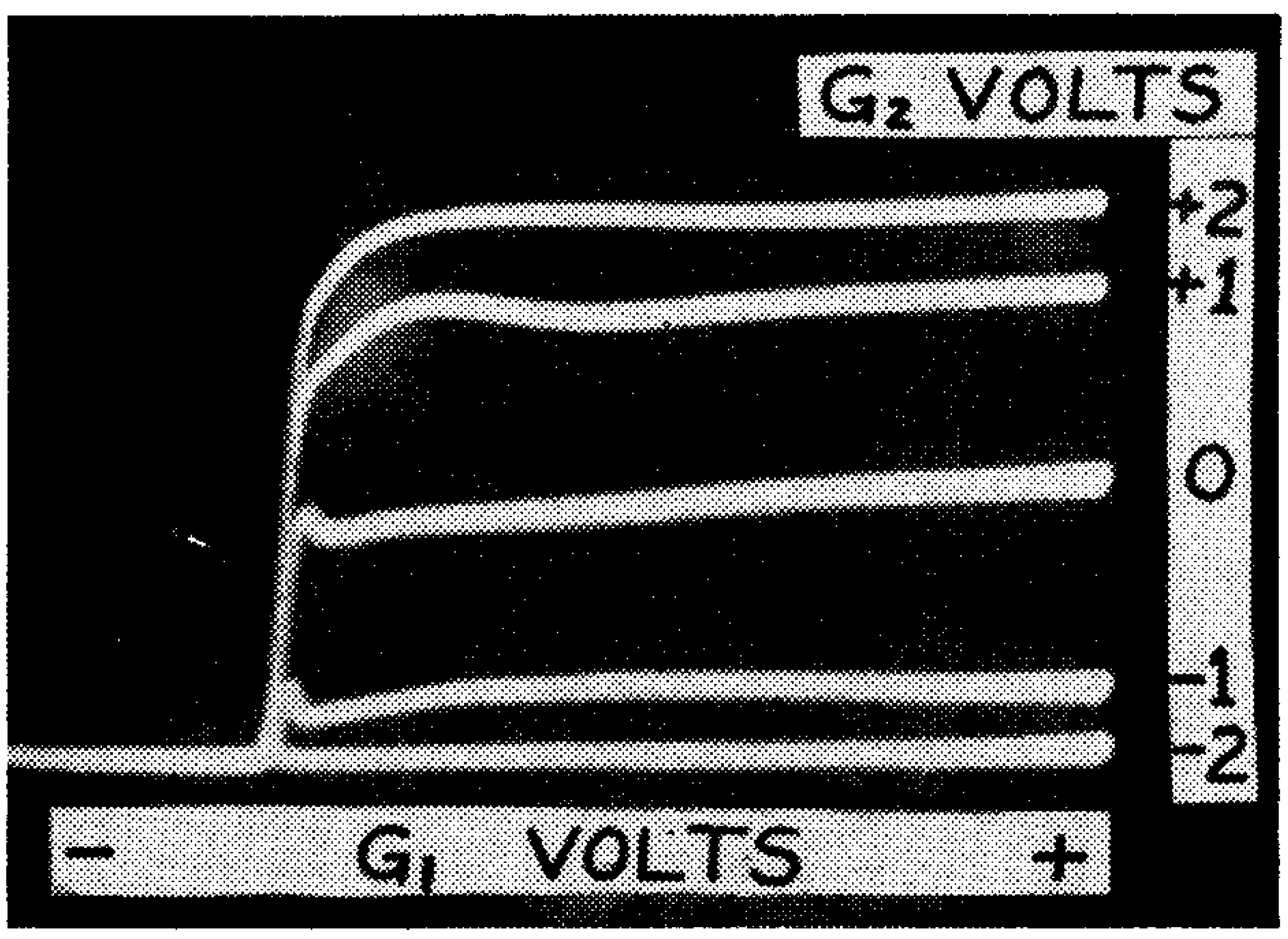

Fig. 1—Grid Voltage—Plate Current Curves of the 6BN6.

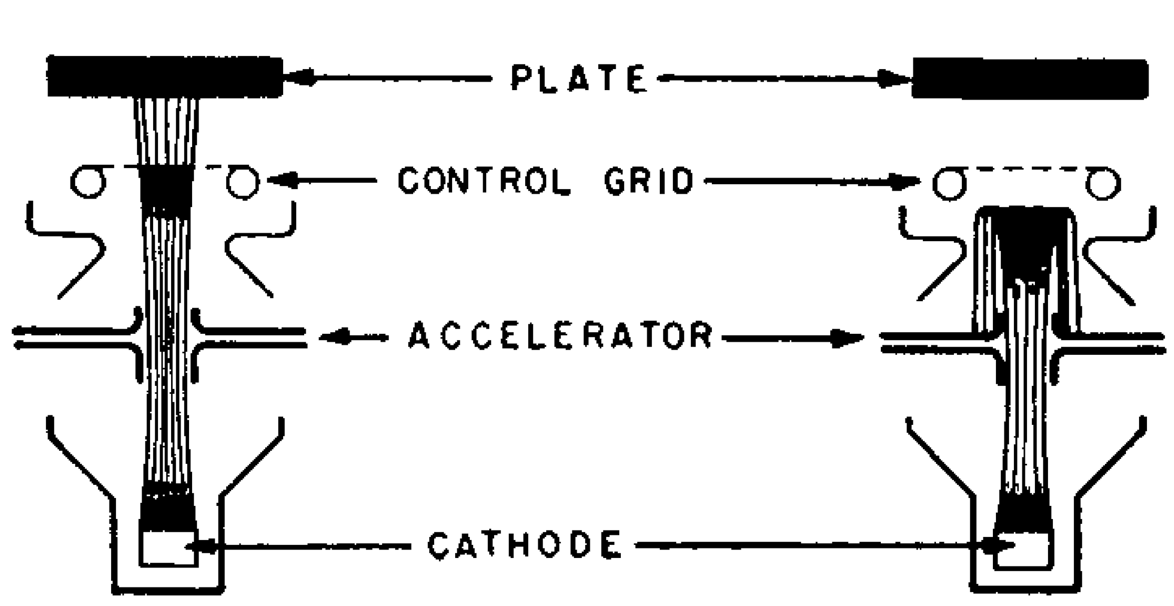

Fig. 2—Electron Paths in a Simple Gated-Beam System.

of the grid may be quite close to zero, forcing the electrons to move very slowly, but if the beam is accurately aimed and the balance between beam current and accelerator voltage is correctly chosen, most electrons will travel along substantially straight lines and succeed in passing through the grid.

On the right, the grid voltage has been made a little more negative, and a remarkable change has taken place: a few electrons may have started the trend by turning back in front of the grid; in doing so they increased the space charge and made others turn around, until an avalanche of desertions from the main stream blocked the path entirely. Because most of the space charge is concentrated in the center of the beam, most of the returning electrons diverge; like the spray from a fountain, they fall back but they miss the small opening from which they came.

We may now understand why it is possible to obtain unusually steep control characteristics in such a structure. To obtain high transconductance, electrons should approach a control grid head-on; no uncontrolled fraction of their kinetic energy must be squandered on lateral motion. But electrons approaching the grid head-on, if they are rejected, will return along the same line; in tubes of conventional construction they would come near the cathode, increasing the space charge there, reducing the outgoing current and flattening the control characteristic. In the gated beam tube, however, their chances of finding their way back through the narrow opening in the accelerator are small, especially because of the concentration of space charge in the thin beam.

The static characteristics of a simple gated beam tube are shown in Fig. 3. Such a tube may well serve as limiter or clipper. To make it perform the additional function

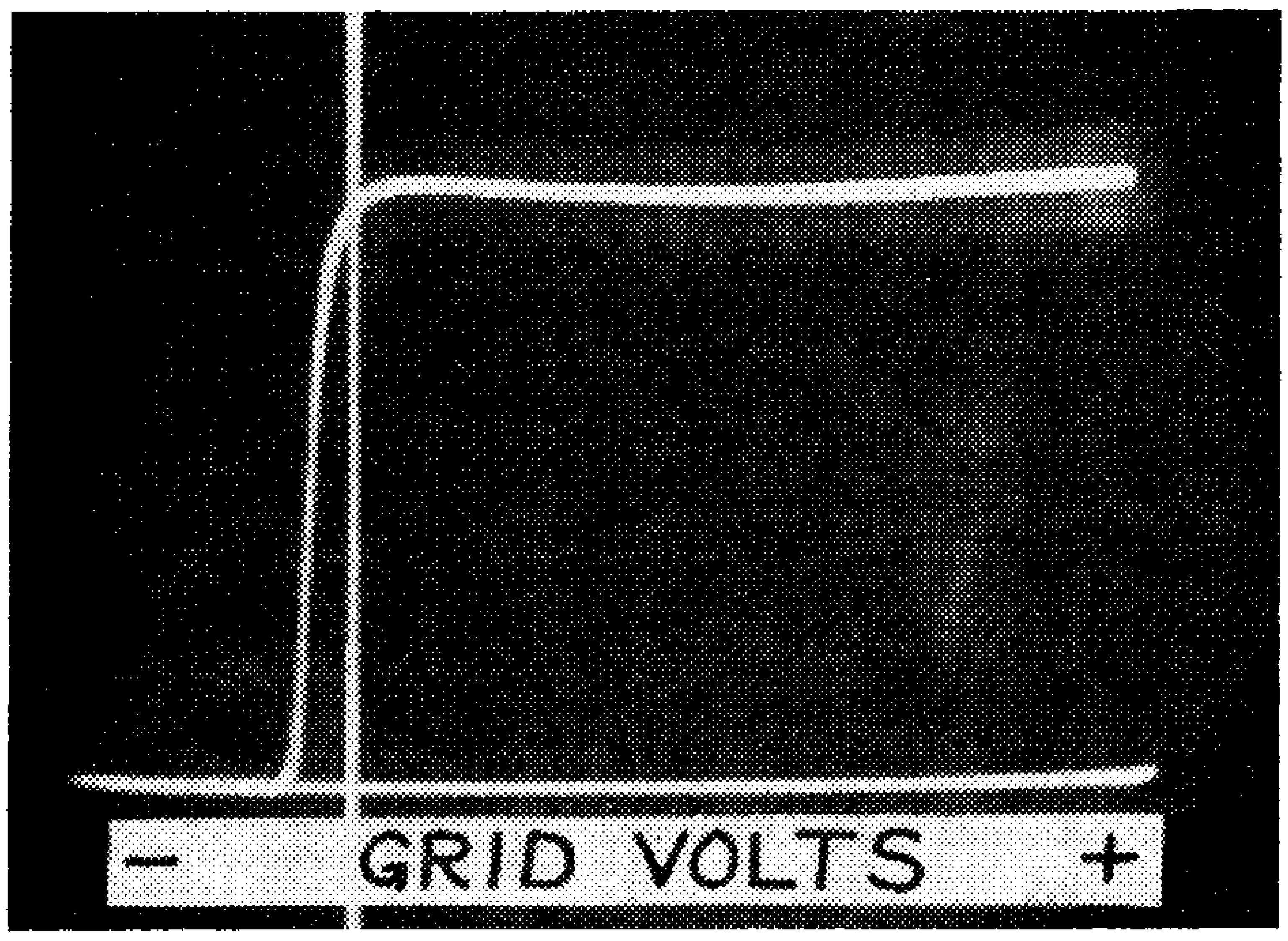

Fig. 3—Static Characteristics of Simple Gated-Beam System.

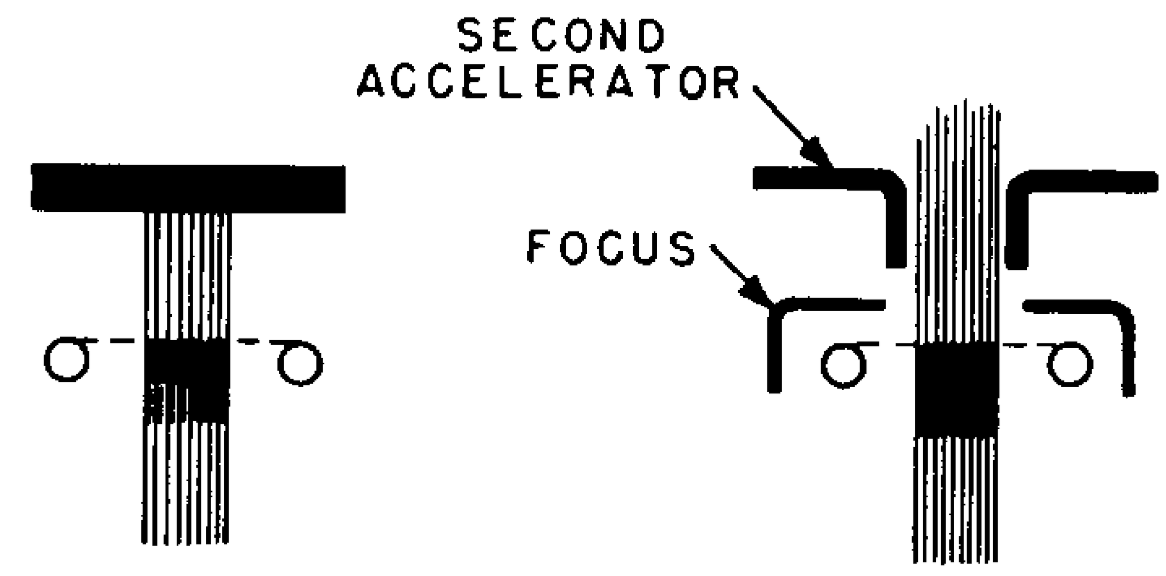

Fig. 4—Second Accelerator Substituted for Anode.

of a discriminator, a second control grid is needed. Because the electron beam arrives at the anode of Fig. 2 in the form of a thin sheet, a slot cut into this anode may serve as the starting point for another gated beam system (Fig. 4). Early experimental tubes were built in this manner, with various grounded focusing electrodes added on the sides to keep the beam from spreading (Fig. 5).

Later it was found that much more uniform tubes could be made by combining a separate electron lens with the second slot. Figure 6 shows a cross-section of the final laboratory model after which the production type 6BN6 was patterned. The focus electrode, together with the first accelerator slot, forms an electron gun which projects a thin sheet stream upon grid #1; the curved screen grid, together with the

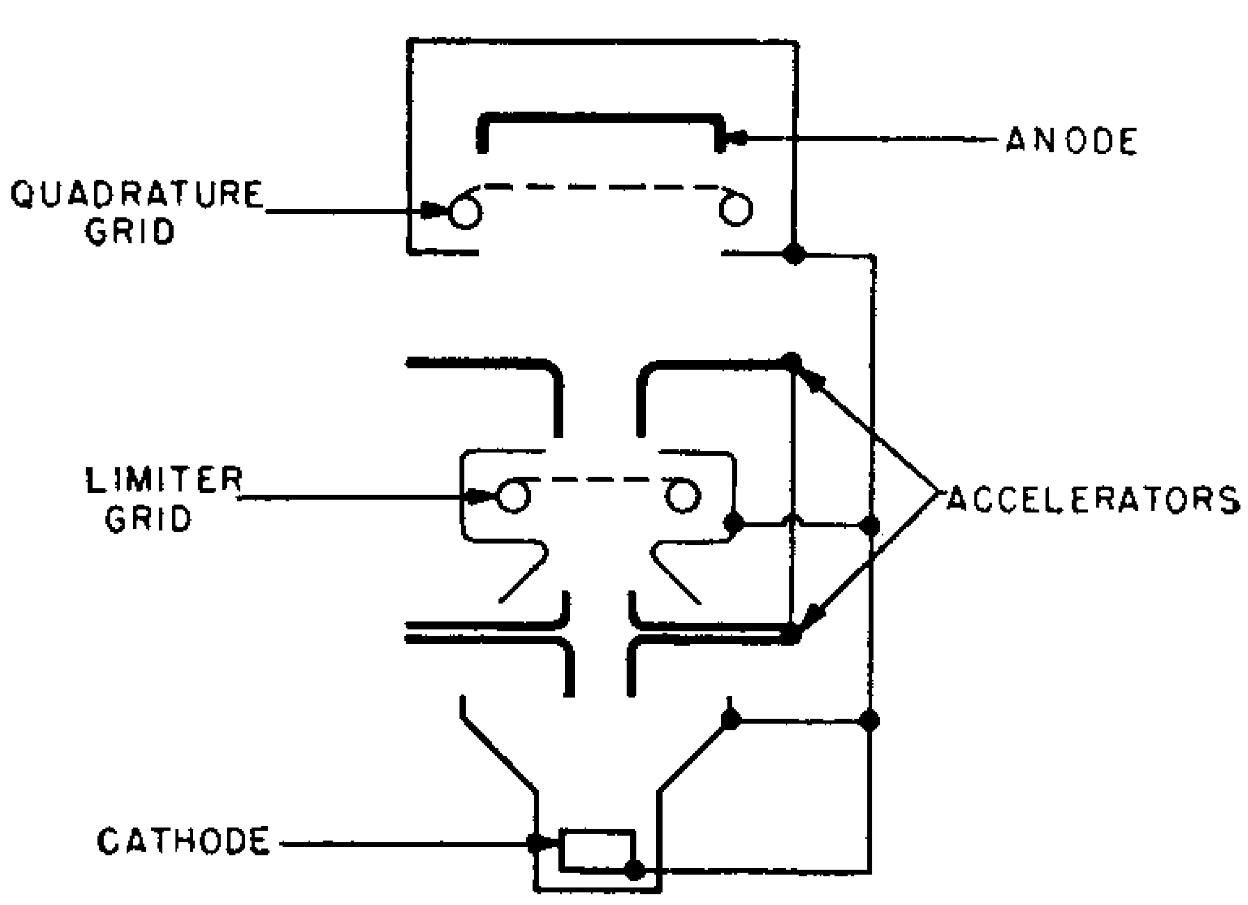

Fig. 5—Cross-Section of Early Experimental Model.

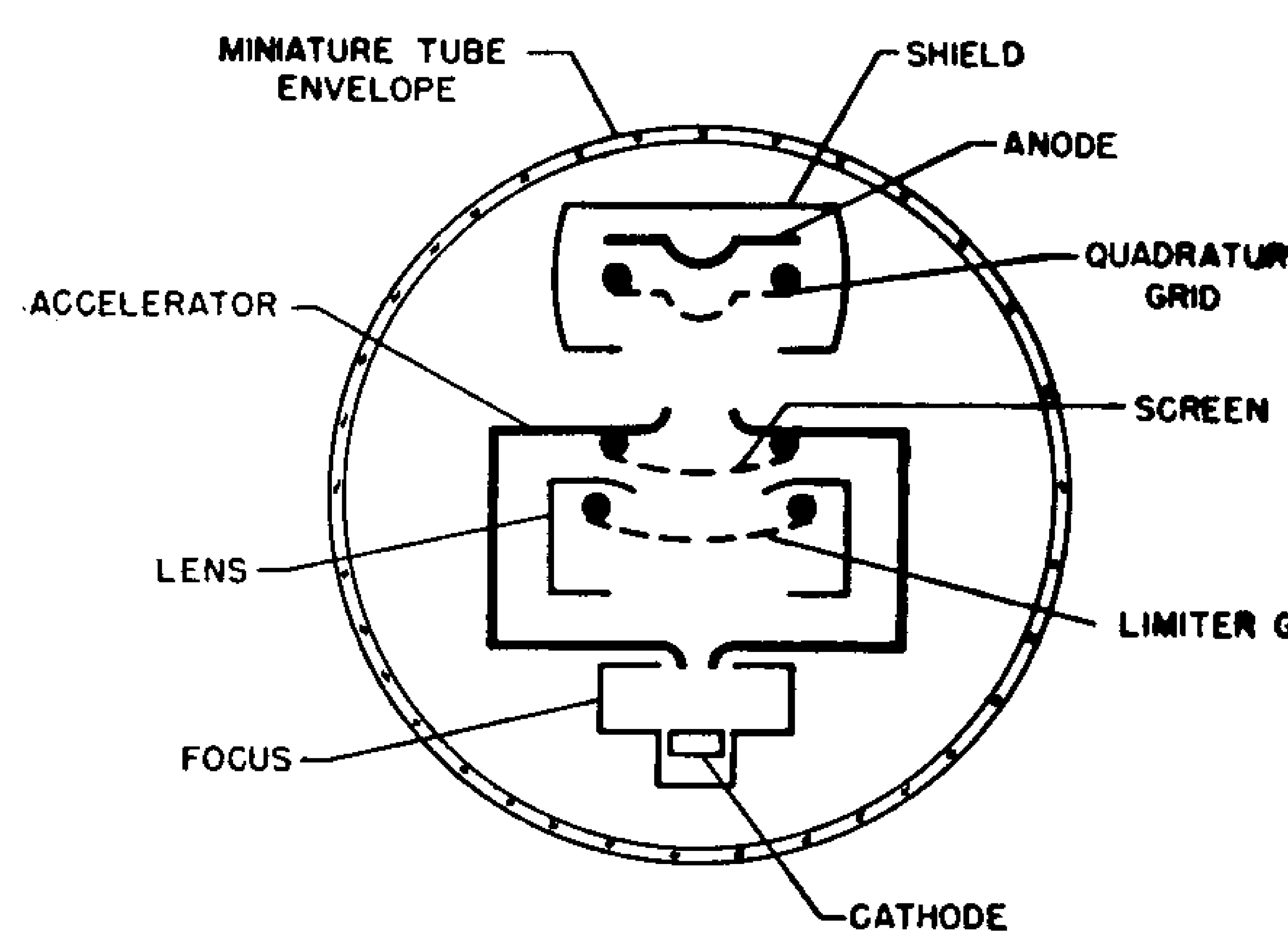

Fig. 6—Cross-Section of Final Model.

grounded lens slot and aided by the slight curvature of grid #1, re-focuses the beam and projects it through the second accelerator slot upon the second control grid. This grid and the anode which follows are enclosed in a shield box. Focus, lens, and shield electrodes are internally connected to cathode. The two accelerators are formed from a single stamping and the screen grid is connected to them internally. The entire assembly fits into a 7-pin miniature tube envelope.

With 60 volts on the accelerator, the cathode current is about 5 ma, of which slightly over 3 ma can be switched to the anode. Zero potential on grid #1 permits nearly full plate current flow; the positions of the lower and upper knee of the second control grid depend on the anode voltage, since these two electrodes have triode characteristics with respect to each other.

If the control grids are driven positive they will draw current, but they cannot draw more than their proportionate share of the total beam current. With 60 volts on the accelerator, the current to either control grid levels off at about 500 microamperes. It is therefore quite permissible to drive the grids positive, without incurring any danger of overloading the tube or damping the driving circuits too much. This feature is frequently useful.

III. LIMITER AND DISCRIMINATOR CIRCUITS

Perhaps the most straightforward of all applications is the use of the gated beam tube as limiter only. Figure 7 shows the circuit; the arrangement looks like a linear amplifier, and its limiting properties are entirely due to the plate current characteristic shown in Fig. 3. The optimum bias (about 1 to 2 volts) corresponds to the center of the steep part of this curve, and, in operation, this bias should remain fixed; the control grid should be returned to ground through a low d-c resistance, preferably a coil. Figure 8 shows oscillograms of the plate current for signals from 1 to 30 volts applied to the first grid. Limiting occurs instantaneously without the use of energy

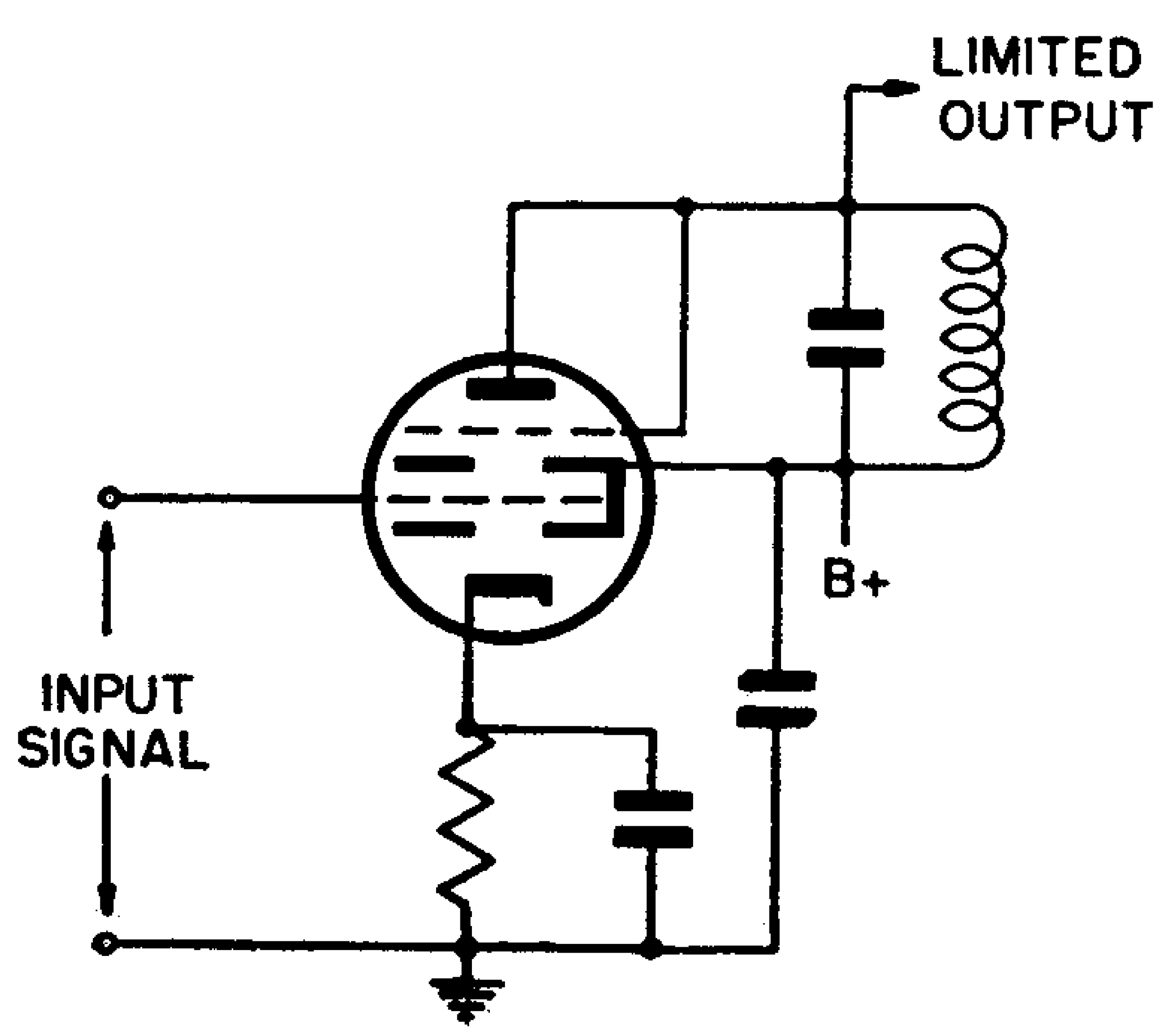

Fig. 7—Limiter Circuit.

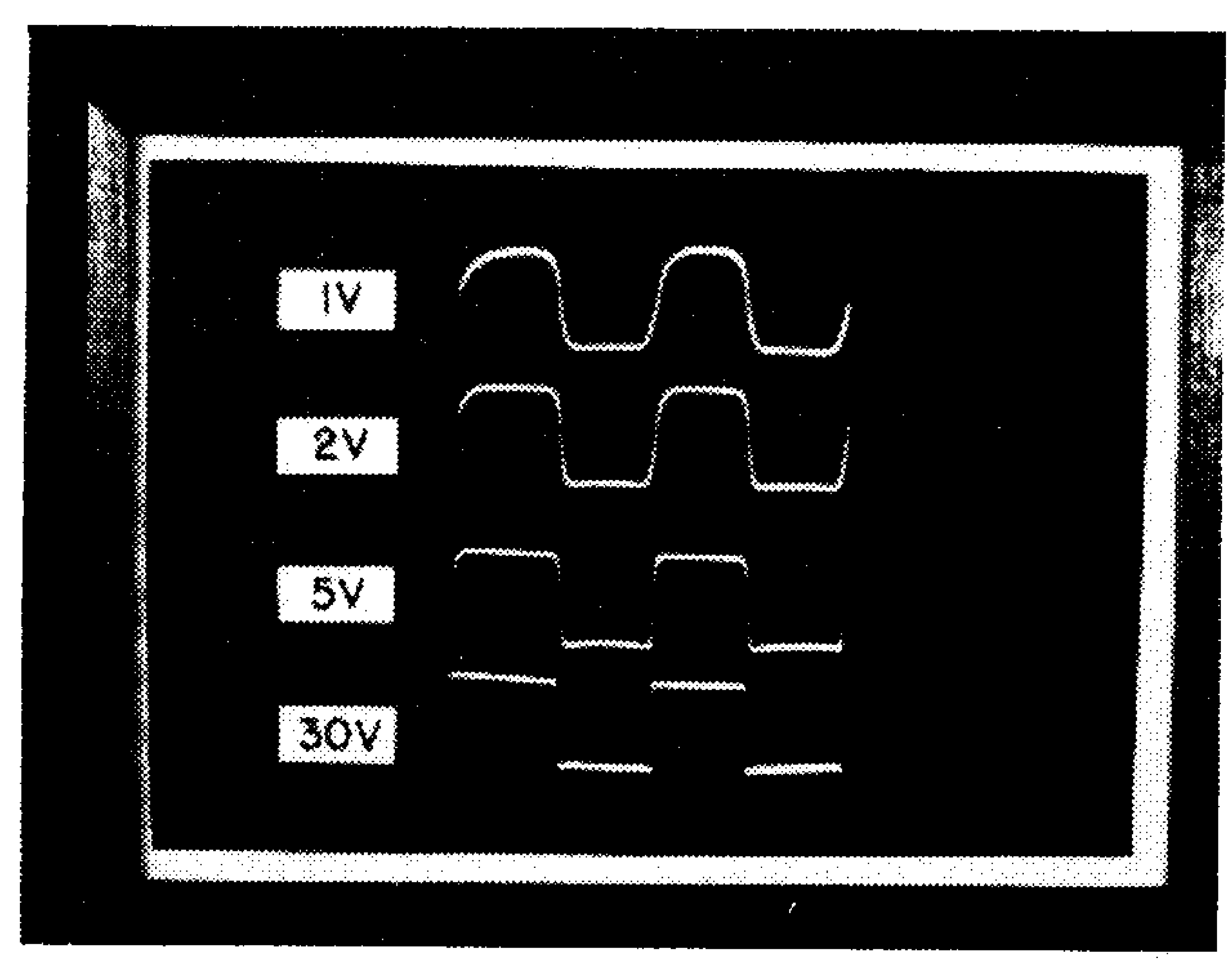

Fig. 8—Plate Current Waveforms for Four Input Levels.

storage; nothing is carried over from one cycle to the next. This type of limiting is helpful in the suppression of impulse noise and adjacent channel intereference.

The second control grid of the 6BN6 is not needed for straight limiting. To obtain the largest output amplitude, it should be connected to the plate. If limiting at the smallest possible input signal is more important, while some output amplitude can be sacrificed, the second control grid should be grounded.

Figure 9 shows the 6BN6 in its most interesting application—as limiter-discriminator for frequency-modulated signals. The function of grid #1—the limiter grid—is unchanged: biased near the mid-point of its control characteristic, it passes the beam during positive half-periods of the applied signal and rejects it during negative half-periods. The chopped electron beam then goes through the second accelerator and forms a periodically varying space charge in front of the second control grid. By electrostatic induction (space-charge coupling), a periodic charging current (about 15 microamperes per megacycle) is produced in the ground return of the second

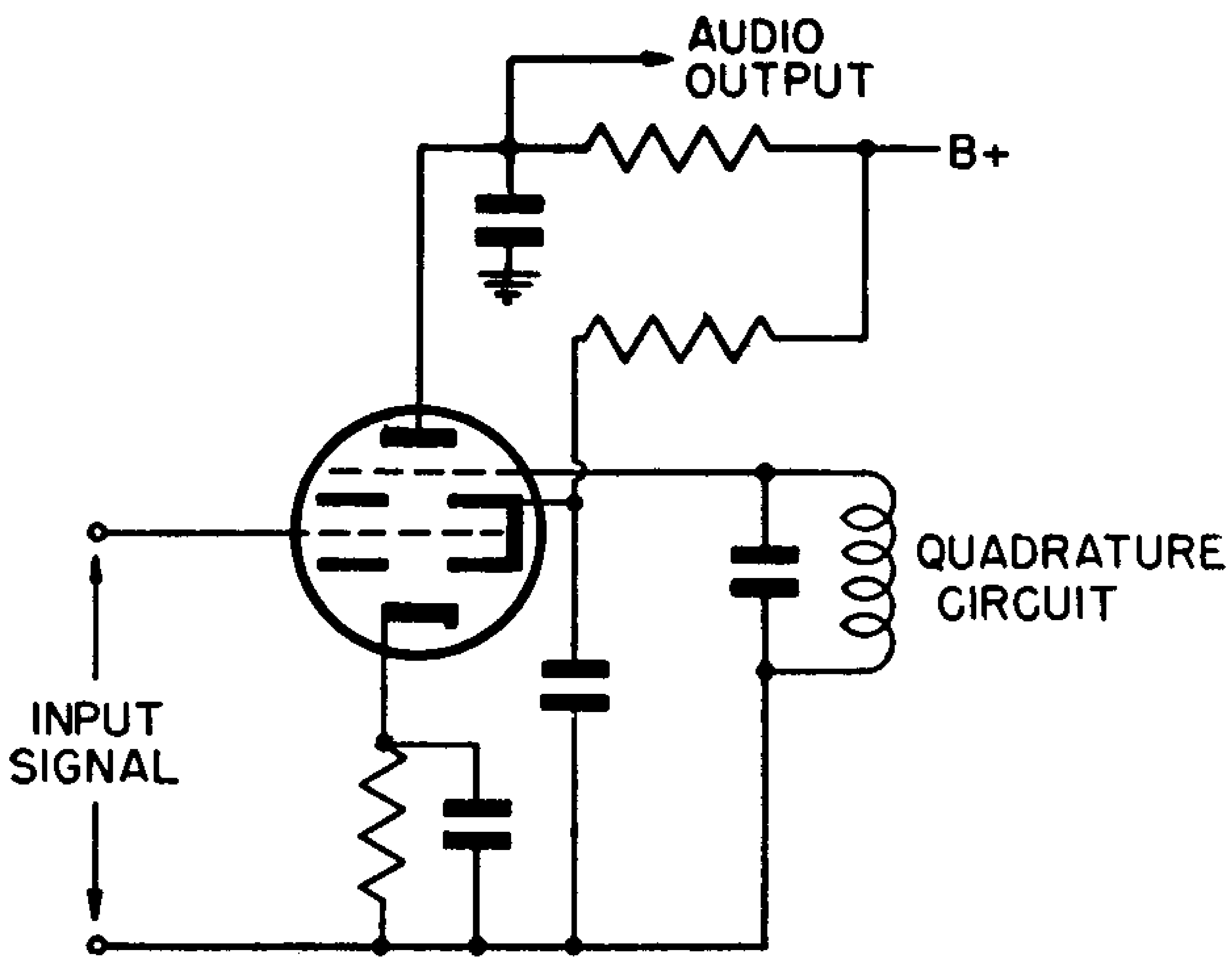

Fig. 9—Limiter-Discriminator Circuit.

control grid. Across the tuned circuit inserted between this grid and ground—the "quadrature circuit"—one so obtains approximately 5 volts of a signal which lags the input voltage on grid #1 by 90 degrees, assuming that the quadrature circuit is tuned to resonance.

We may now think of the two grids as gates which open and close periodically, the second gate lagging behind the first. The beam can reach the plate only when both gates are open; plate current flow starts with the delayed opening of the second gate and ends with the closing of the first.

Modulation of the frequency of the applied signal results in a corresponding variation of the phase shift between the two grids. This, in turn, varies the length of the period during which plate current can flow (Fig. 10). A de-modulated signal appears in the plate circuit, where it can be extracted across a dropping resistor.

Figure 11 shows a typical discriminator response for an f-m receiver with 10.7 mc center frequency. The most conspicuous difference between this curve and the one for

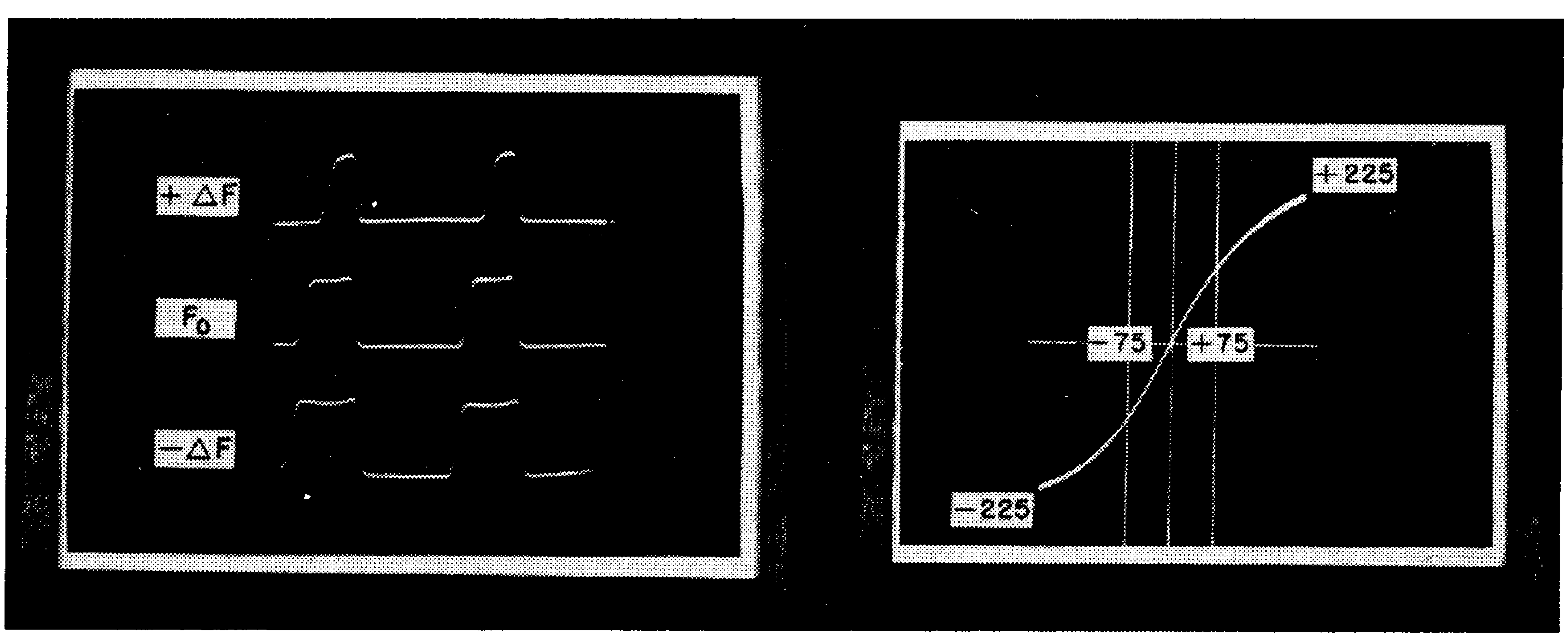

Fig. 10—Waveforms of Plate Current at High, Center, and Low Frequency.

Fig. 11—Typical Discriminator Response.

a conventional discriminator lies in the absence of any sharp curvature at frequencies beyond the range of normal signal deviations. This property aids in making the receiver easier to tune; it also provides improved adjacent-channel selectivity, as was first shown by I. Plusc[1] in 1947.

One of the important characteristics of an f-m detector is its ability to suppress amplitude modulation. The gated beam tube, when working as a limiter only, surpasses the Armstrong grid-bias limiter in this respect, even at low modulation frequencies where the grid-bias limiter is not yet hampered by its time constant. In the limiter-discriminator circuit, the gated beam detector cannot do quite as well because the audio output is taken directly from the anode, so that amplitude modulation may slip through as a result of spurious plate-bend detection. This tendency is minimized by careful adjustment of the limiter grid bias, normally determined by the cathode resistor. When this precaution is observed, the amplitude modulation suppression compares favorably with that of other f-m detectors in commercial use, and the gated beam detector appears to have the edge in the suppression of ignition interference where other circuits are burdened by time constants.

To obtain performance equivalent to that of a balanced discriminator, the plate current should not change when a center-tuned signal is suddenly applied or removed. In obtaining this balance, the bias on the second control grid is the determining factor; plate supply voltage and resistance values have some influence. The tube is so designed that the bias voltages required for both grids are equal so that only a single cathode resistor is needed.

The bandwidth of the useable portion of the discriminator curve is proportional to the bandwidth of the quadrature circuit. Higher L/C ratio in this circuit results in a broader curve. Further broadening can be obtained by damping the quadrature circuit but this results in somewhat impaired audio output and poorer amplitude modulation suppression. A better method for obtaining increased bandwidth will now be described.

Figure 9 shows the anode bypassed to ground for the intermediate frequency which is applied to the limiter grid. If a small resistance is inserted between anode and bypass condenser, i-f voltage appears on the anode, and through the interelectrode capacity between anode and quadrature grid it is also coupled into the quadrature circuit. The phase relations are fortunate so that this contribution aids in driving the quadrature circuit, already energized by space-charge coupling. At the same time, however, it must be remembered that the capacity from quadrature grid to anode is part of the total tuning capacity of the quadrature circuit; there is now a resistance in series with this capacity so that the circuit is damped.

Thus, insertion of a small series resistor (300 - 1000 ohms) into the anode lead has two effects: it damps the quadrature circuit but it also supplies more energy to it. As a consequence, the voltage across the quadrature circuit may stay constant or even rise while the bandwidth is increased. Good audio output and improved amplitude modulation suppression are the result.

The chopped electron beam which drives the quadrature grid carries already an amplitude-limited signal; the voltage induced on the quadrature grid is therefore substantially constant from about one volt signal input up to perhaps fifty or more. In practice, a small drop in the quadrature voltage at higher input signals is caused by narrowing of the beam in the 6BN6 at high positive limiter grid voltages. This is harmless as long as stray coupling between the two grids, or between the tuned circuits connected to them, is carefully avoided. Residual coupling will show up most at high input levels.

The internal capacity between the two grids of the 6BN6, or between first grid and anode, is less than .004 $\mu\mu$f.

The plate bypass condenser is normally made of such a size that it provides the correct amount of de-emphasis.

The audio output which can be obtained with low distortion is largely a function of the plate supply voltage. In f-m receivers where the highest available well-filtered voltage is about 80 volts, 4.5 volts rms are obtained for full deviation (75 KC at 10.7 mc). In intercarrier sound in television receivers, where at least twice as much plate supply voltage can be expected, 15 volts rms for full deviation (25 KC at 4.5 mc) is normal. This latter output is enough to omit the usual audio stage and go directly into the power tube. The input voltage for the 6BN6—a few volts at 4.5 mc—can be derived from the first video stage so that the entire sound channel is reduced to two tubes and two tuned circuits.

For signal levels of one volt or more, the audio output remains substantially constant. In this respect, the gated beam detector acts very much like the conventional combination of grid-bias limiter and double-diode discriminator.

The gated beam f-m detector is adjusted by tuning the quadrature circuit for maximum audio output on an f-m signal of the correct intermediate frequency.

The loading which the 6BN6 presents to an input circuit varies with the signal level. With normal bias, loading is negligible for small signals up to limiting level (at about one volt). Then the load resistance drops, goes through a minimium of about 20,000 ohms at two to three volts signal, finally rises again toward infinity. This behavior is a consequence of the flat grid current characteristic mentioned previously.

IV. USE AS SYNC CLIPPER

The step-function-like characteristics of the 6BN6 make it an excellent tool for the task of separating the sync pulses from the picture content in a composite video signal. Figure 12 shows the simple circuit required for this purpose and illustrates the waveforms involved.

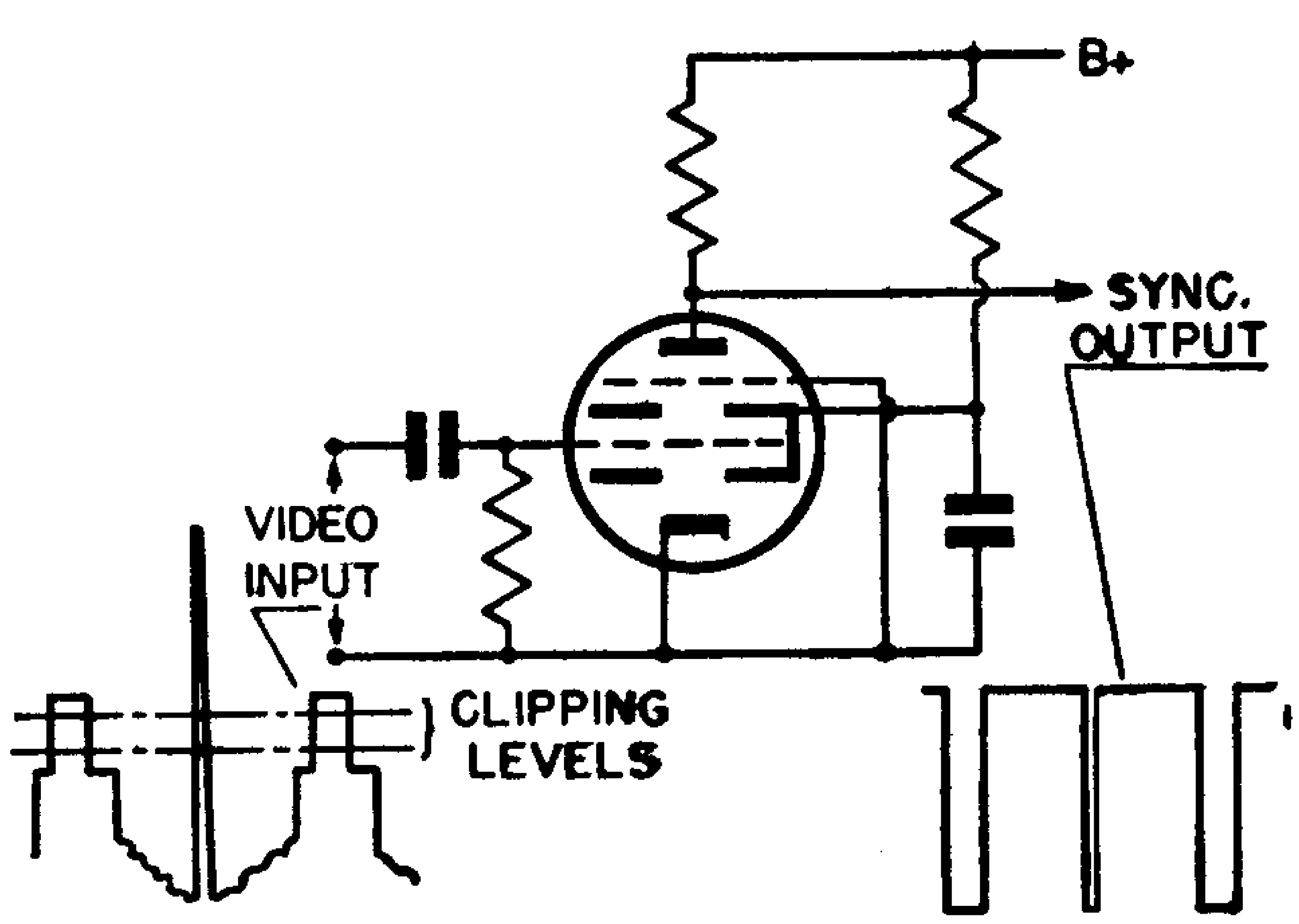

Fig. 12—The 6BN6 as Sync Clipper.

The composite video signal, with the sync pulses positive, is fed to the limiter grid through a large coupling condenser. Grid current flows during each sync pulse; across the grid leak resistor, negative bias builds up to the point where only the sync pulses are capable of driving the tube into plate current. This plate current itself is limited by the characteristics of the tube. Across the plate load resistor, therefore, there appear negative voltage pulses of constant amplitude with clean-out tops.

Figure 12 also shows a noise spike, much higher than the sync pulses, at the input to the sync clipper. In the plate circuit, this spike is clipped off at the same level as the sync pulses. In the grid circuit, each sync pulse draws the maximum available grid current of about 500 microamperes; noise pulses can draw no more, so that even very large noise pulses do not disturb the grid bias any more than moderate ones. The size of the grid leak resistance is determined by the required bias according to the following considerations: if the bias is allowed to rise too high, only the sync pulse tips remain effective in producing plate current flow, and with a noisy signal many pulses will get lost. As the bias is gradually reduced, cleaner pulses are produced in the output; eventually, however, picture content appears between the sync pulses. The optimum bias lies between these two extreme conditions; to obtain it, the grid leak resistance should be one megohm or slightly less.

The second control grid is not used in this circuit, and the rules previously given for limiters apply here: if maximum output is required, the second grid may be connected to the anode. Less output but cleaner clipping of the pulse tips is obtained by connecting it to ground or to a fixed d-c potential. It is also possible to apply a gating signal to the second control grid in order to suppress noise between sync pulses, or for the purpose of producing a control voltage for synchronizing the horizontal oscillator.

The input voltage to the sync clipper should be between 20 and 80 volts peak to peak of composite video. This makes it possible for the 6BN6, with its 2 volt cutoff-to-top range, to slice a small section out of the sync pulses which themselves represent only one-quarter of the total video signal.

In the circuit of Fig. 12 the sync pulses are extracted from the plate load, and they are of negative polarity. Because in the gated beam tube the total cathode current stays constant no matter what voltage is applied to the grids, the accelerator current drops whenever the plate current rises, and it is possible to derive positive sync pulses from the accelerator. Experience has shown that it is practical to obtain positive vertical pulses in this manner, with an integrating condenser connected from accelerator to ground. Horizontal pulses are best derived from the anode; fortunately, the balanced phase detectors used in most horizontal sync systems will work with either polarity.

V. CONCLUSION AND CREDITS

It is perhaps best to cover other applications of the gated beam tube merely in the form of a summary. The 6BN6 makes a good square-wave generator and frequency multiplier; it appears to have possibilities as a slicer in pulse time modulators and in some forms of phase modulators. Its two grids seem to invite uses in coincidence circuits for computers.

The f-m detector circuit used in connection with the 6BN6 goes back to a very similar circuit invented in 1936. At this early date, I. Zakarias[2] proposed the use of a pentagrid tube for f-m detection. The signal was applied to the first control grid and a resonant circuit was connected to the second one, driven by space-charge coupling. The circuit worked well but did not provide limiting. H. P. Kalmus[3] showed in 1939 that some limiting could be obtained if the input grid was operated with a coupling condenser and grid leak like an Armstrong limiter. Because the limiting problem was not satisfactorily solved, these circuits did not find commercial use and did not become generally known. This may account for the fact that, as late as 1948, Sargrove[4] in England re-discovered Zakarias' circuit, apparently independently.

In 1940, J. J. Okrent[5] found that in a converter tube the signal grid which follows a positive screen has a control characteristic suitable for limiting. Two years later he proposed[6] a special tube with two control grids, each preceded by a positive screen. The grids were driven from two coupled tuned circuits. This arrangement constituted a limiting discriminator. Quite recently, Mullard in England announced an experimental type (EQ40) which appears to be a practical embodiment of Okrent's idea.[8]

VI. ACKNOWLEDGEMENTS

The gated beam tube in which improved limiting characteristics are achieved by electron-optical means, was developed at Zenith's laboratory in Chicago. Preliminary information about it appeared in *Electronics*[7] in May 1948. The author wishes to express his thanks to Mr. E. C. Ewing, in charge of Zenith's receiver tube laboratory, for his valuable assistance during the period of development which led to the final experimental models.

The long journey from these models to the present commercial type 6BN6 is a story beyond the scope of this article. The credit for turning the unconventional tube structure into a production design and bringing it out in record time should go to Messrs. W. T. Millis, A. P. Haase and many others of the General Electric Company in Owensboro and Schenectady.

The author is indebted to Mr. J. S. Spracklen for much of the circuit work on the f-m detector. The sync clipper circuits were suggested and developed by Messrs. E. M. Roschke and W. S. Druz. All three are members of the Research Group of Zenith Radio Corporation.

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THE 6BN6 GATED BEAM TUBE

Part 2. The Commercial Realization Of The 6BN6

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Abstract.—The use of sharply focused beams in grid-controlled receiving tubes represents a new departure in tube design which entails many unusual problems. Mechanical and electrical considerations in the production design are reviewed. The transfer characteristics of the 6BN6 are given and experience to date with this type, as well as plans for future types, are briefly discussed.

I. DEVELOPMENT OBJECTIVE

The initial design of the 6BN6, features of which have already been discussed by Dr. Adler, demonstrated the practical nature of a beam type tube in which a quadrature voltage can be developed by space charge coupling to yield the discriminator circuit. The inclusion of a highly efficient limiter in the form of an electron beam whose current is defined by placing an apertured slot in the beam at a region of high current density, makes the 6BN6 limiter-discriminator circuit possible.

In developing this tube, it was our objective to design a tube which would have two control elements each having essentially a step function transfer characteristic in order to realize efficient circuit operation at low input levels. Operation at low levels necessitated a design which would yield a well-defined electron beam in order to insure high input transconductance and further required that the input admittance of the tube be low so that reasonably high gain could be realized in the last i-f amplifier of the receiver. Together, these features make possible switching of the plate current between cutoff and its limited value with low input signal to the receiver. A fourth design objective was that of making a tube which would have essentially constant cathode current regardless of the control electrode potentials. This characteristic would make possible the use of a cathode resistor for developing operating bias voltage.

II. UNCONVENTIONAL NATURE

The 6BN6 as illustrated in Fig. 1 is unique from many standpoints. The electron beam in this tube takes the form of a sheet beam of varying cross section and current density. In addition, there are no focusing or intensity controls as are found in most circuits in which electron beam tubes are used. This requires accurate initial beam forming and focusing and further requires tube processing stability to retain such forming when there is dependence upon cathode emission level and contact potential. Of particular interest is the fact that low voltage electron optics are utilized which necessitates holding unusually small manufacturing tolerances. The field strengths in the lens systems are not unusually high but they are obtained by using low supply voltages and small interelectrode spacings which further must be maintained symmetrically about a central plane. Since we are interested in gating the electron beam,

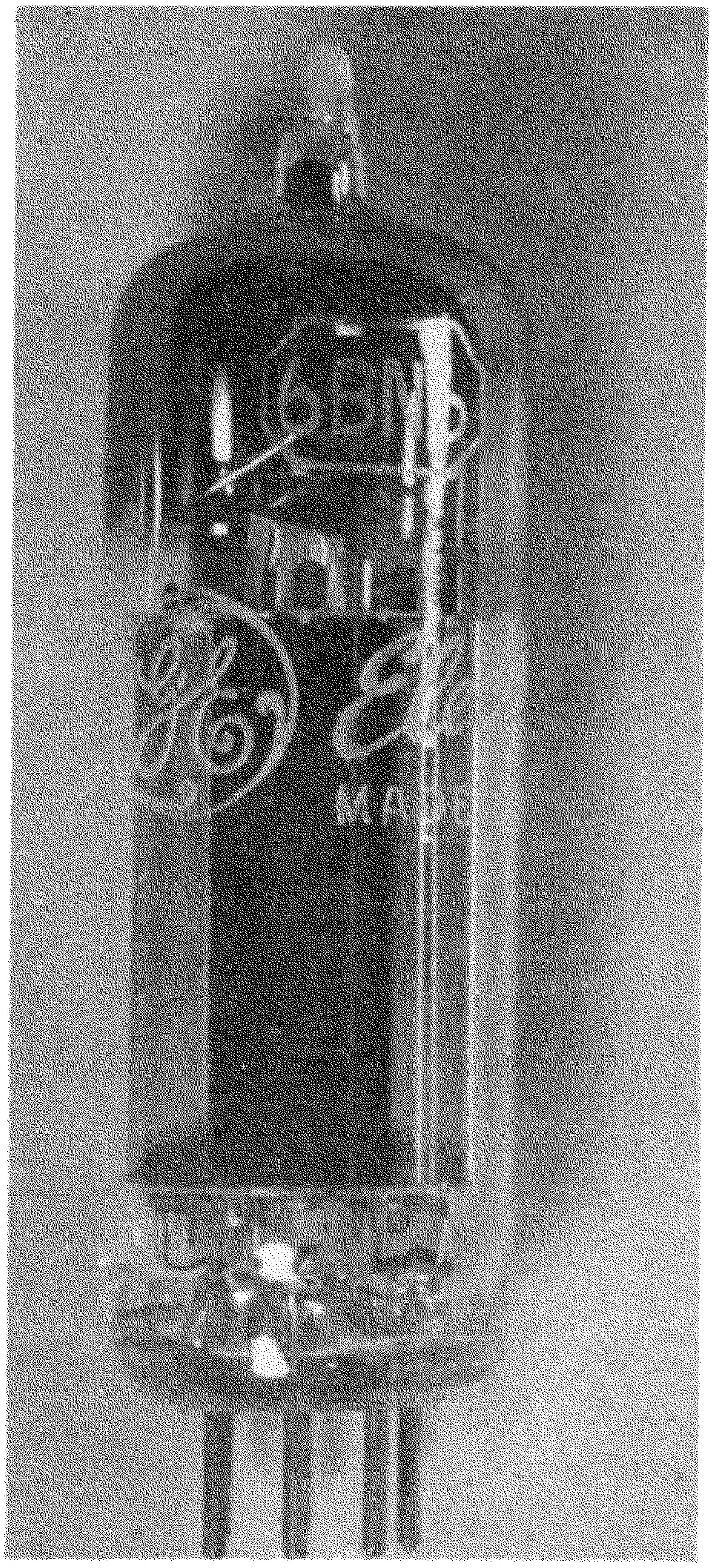


Fig. 1—The 6BN6 tube.

a third factor for consideration is that there are major changes of space charge distribution when the beam is stopped by one of the control grids. With either of the grids negative, conditions for Barkhausen-Kurtz oscillations are present and we must prevent such oscillations from occurring. Further, space charge coupling within the tube must be uni-directional if the input grid circuit is to remain unaffected by voltages appearing in the quadrature grid circuit.

Among the unusual features of the 6BN6 is that its beam creating accelerator shields the cathode from the electrostatic fields of the control grids. This serves to make the cathode current independent of control electrode potentials. Considering this, we see that with plate current cutoff biases in the order of 2-volts, voltage developed across a cathode resistor by accelerator current alone is easily capable of biasing the tube past the cutoff voltage and therefore the tube is capable of cutting off its own plate current completely. Since the beam current is of constant amplitude, switching of that current away from the plate circuit by making either of the grids negative causes the current in the accelerator circuit to increase, yielding a negative transconductance characteristics to the accelerator electrode. The constant beam current provides limited grid 1 and grid 3 currents which reach saturation at about +2 volts. The magnitude of these limited currents is dependent upon the beam density and the screening area of these electrodes.

III. MECHANICAL CONSIDERATIONS

In order to satisfy our objectives, it is necessary to provide unusually complete shielding between the input and quadrature grids as well as to provide the necessary focusing, accelerating, and electron lens components. Whenever possible, several electrodes have been combined into single mechanical structures in order to provide the minimum number of parts in the 6BN6 assembly. By making these parts in such manner that mechanical symmetry is obtained about a plane formed by the center of the plate and the vertical axis of the cathode, a symmetrical beam is generated. As was mentioned, extremely close tolerances are required not only of the individual parts, but, as is apparent, of the whole assembly. Considering that a space between electrodes of forty thousandths of an inch is used to create an electric field intensity of 800 volts per centimeter, a change in position of plus or minus two thousandths of an inch represents a change of about plus or minus 40 volts per centimeter in field strength. In the critical area between focus electrode and accelerator, a field strength of approximately 1600 volts per centimeter exists with a spacing of only .015″. The current density along the beam varies downward from 25 milliamperes per square centimeter so that the relative importance of electronic space charge within the beam varies widely along its path. These two considerations require that high mechanical uniformity be maintained from tube to tube if a uniform product is to be realized. Those components which are of particular importance in this respect are shown in Fig. 2 and are the focusing electrode which surrounds the cathode, the accelerator

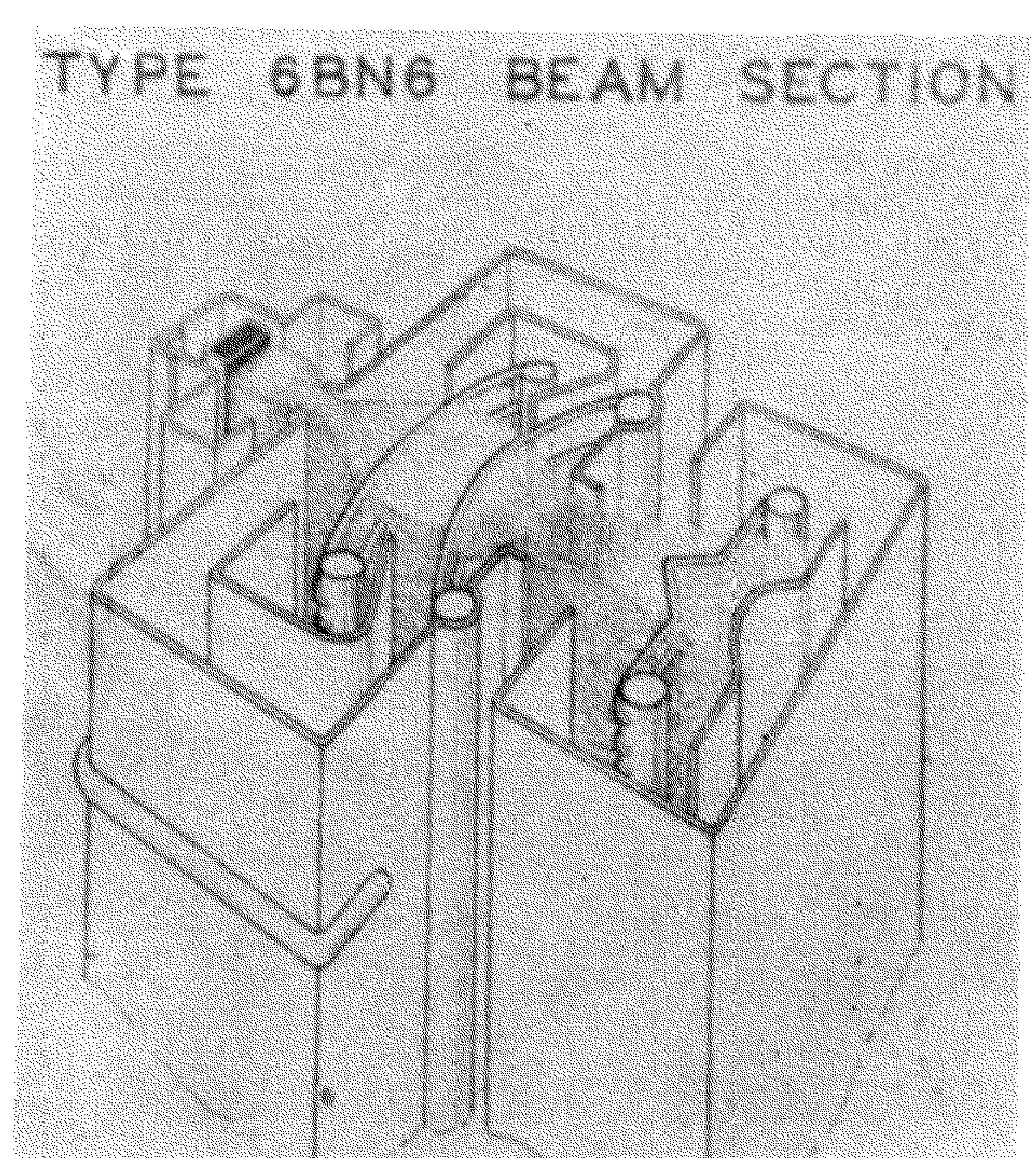


Fig. 2—Type 6BN6 beam section.

slot close to the cathode, the lens which surrounds the first grid, and the accelerator grid-accelerator region which is just behind the lens. As can be seen, half grids are used to gate the beam and act to shape the return paths of electrons reflected from these elements when they are negative. The lens structure not only forms the beam but also acts as a shield to reduce the inter-electrode capacitance from the input grid to the quadrature grid. The last shield structure which surrounds the quadrature grid and plate serves the same function with respect to inter-electrode capacitance and helps to define the effective cathode of this system and confine the paths of reflected electrons to a definite pattern. By preventing the electron beam from striking the side rods of these grid systems, it is possible to limit the grid currents to maximum values in the order of several hundred microamperes. A factor of some importance regarding the transfer of the beam from the cathode to the plate is that of maintaining low vertical dispersion of the beam. When the beam is passed through the input grid, the increased charge density between grid laterals is such as to cause the beam to disperse vertically after it has passed through them. While the effects of this dispersion cancel at the center of the grid, the end effects are not negligible and can result in some loss of plate current. Since this loss in general appears as additional accelerator current, and it is desired to keep the ratio of accelerator to plate current as low as possible, the 6BN6 has been designed to reduce the effect of such vertical dispersion. In addition, the concentration of space charge between the grid laterals can become high enough to reflect some electrons approaching the grid, resulting in a net loss of plate current when the grid voltage is low. This property is, of course, useful when cutting off plate current.

In the 6BN6 design, the convergent lens formed by the focus electrode and the accelerator lips, and the divergent lens between the apertured slot and the input grid when that electrode is at low or slightly negative potentials, cause the beam to spread as it approaches the input grid. This action increases the beam area and hence reduces the relative space charge density between grid laterals. The beam is reconverged by passing it through an electro-static field which is shaped between the lens and the accelerator grid to bring the electrons to a focus in the region in front of the quadrature grid. The quadrature grid is shaped to give an extended depth of grid control so that

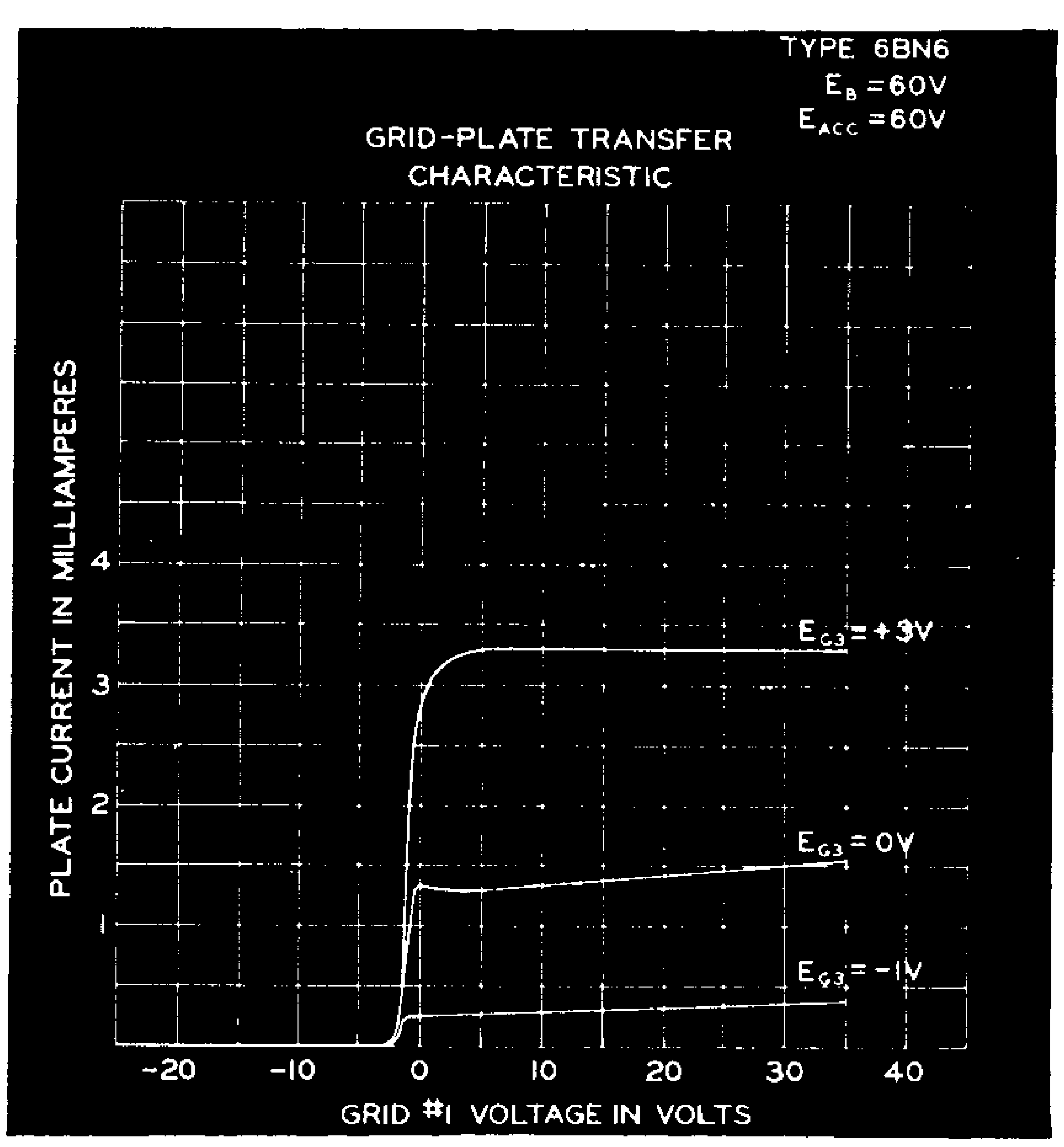


Fig. 3—Grid-Plate Transfer characteristic.

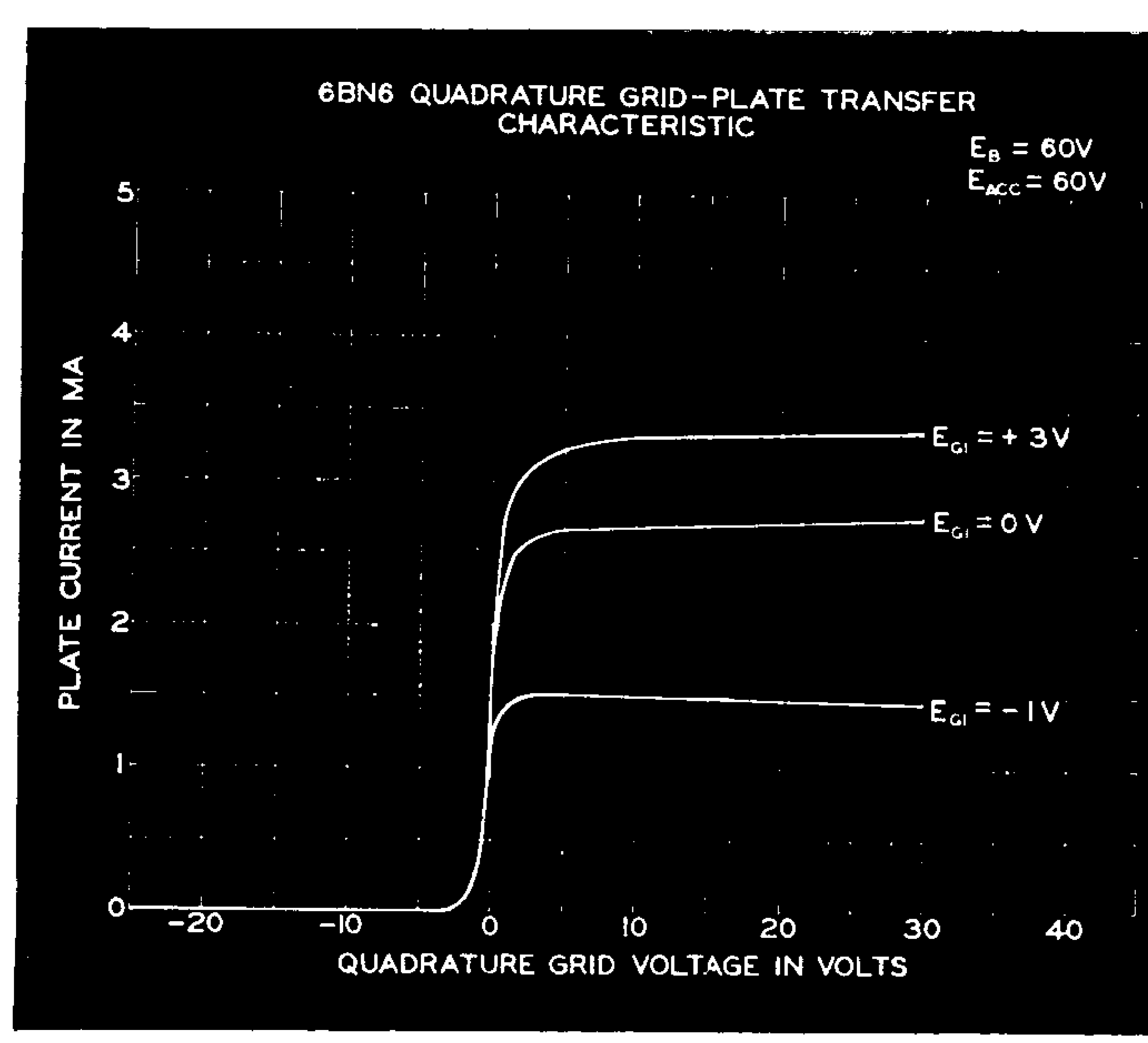


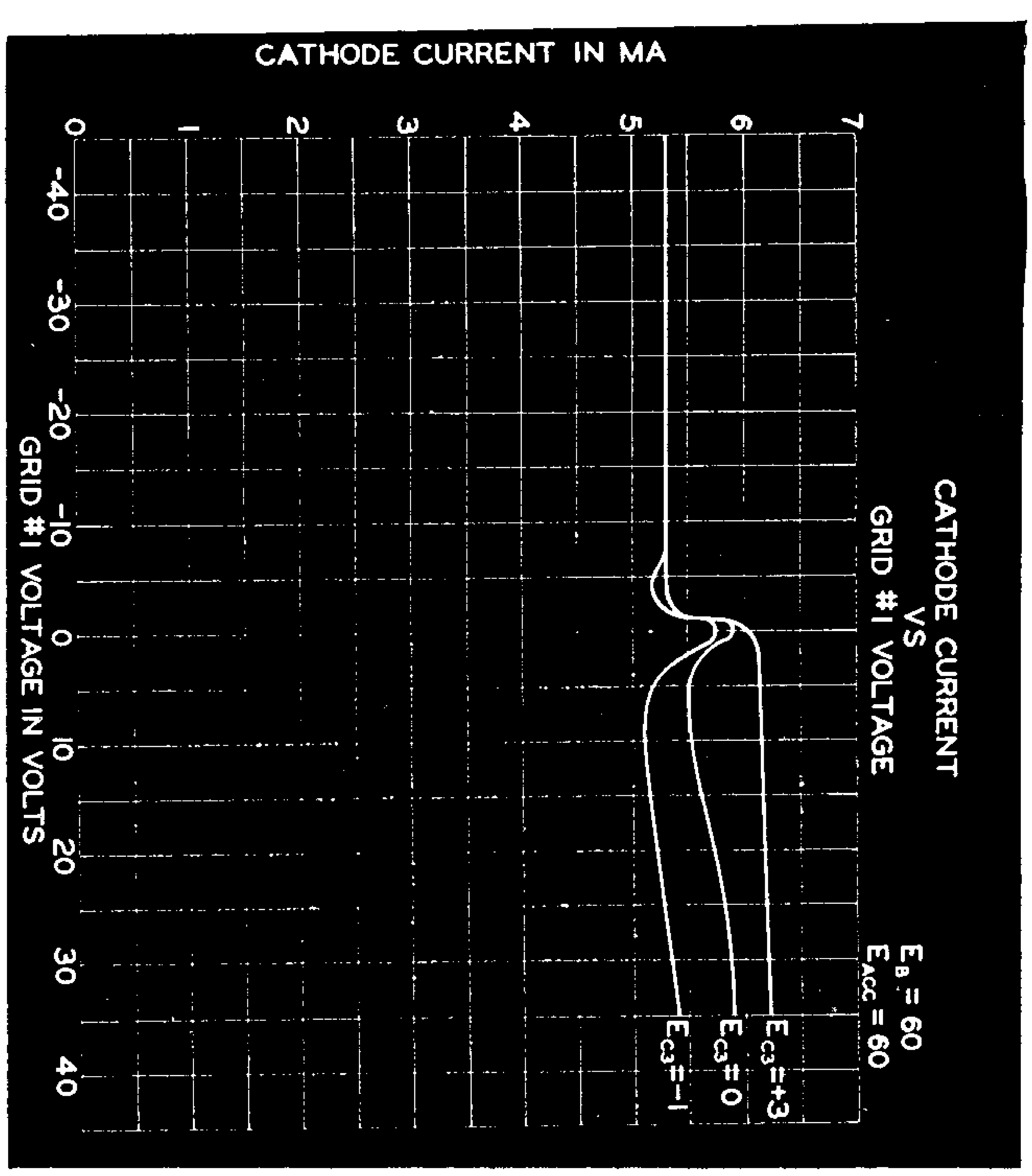
Fig. 4—Quadrature grid-plate transfer characteristic.

constant transconductance is obtained despite the movements of the effective cathode of this triode section as the potential of the input grid is changed. The plate structure is formed to obtain constant amplification factor for the triode section.

IV. TUBE CHARACTERISTICS

The extent to which the 6BN6 approaches the step function transfer characteristic can be seen in Fig. 3. For values of quadrature grid voltage in excess of +2 volts, the plate current is essentially constant. For lower grid voltages, the plate current is as indicated on the transfer characteristic curve. Note that this characteristic is essentially linear regardless of the potential of the No. 1 grid for any given value of quadrature grid potential. As has been indicated, two step function characteristics are required for discriminator operation. The quadrature grid-plate transfer characteristic is shown in Fig. 4, and approaches the step function reasonably well. The transconductance of the No. 1 grid is approximately 3,000 microhms at a plate current of .75 milliamperes. The transconductance of the quadrature grid under the same conditions of operation is approximately 1,500 microhms or a transconductance-to-plate current ratio of approximately 4,000 microhms per milliampere for the input grid and 2,000 microhms per milliampere for the quadrature grid. Considering this information, we see that the transfer functions satisfy our objectives reasonably well.

Figure 5 shows how cathode current varies with grid 1 and grid 2 potentials. It can be seen that the cathode current is, within reason, constant regardless of the grid signal levels and consequently a cathode resistor can be used to develop the necessary operating bias. Another transfer characteristic of particular interest is that shown in Fig. 6. Here we see that as the input grid is made more positive, switching the plate



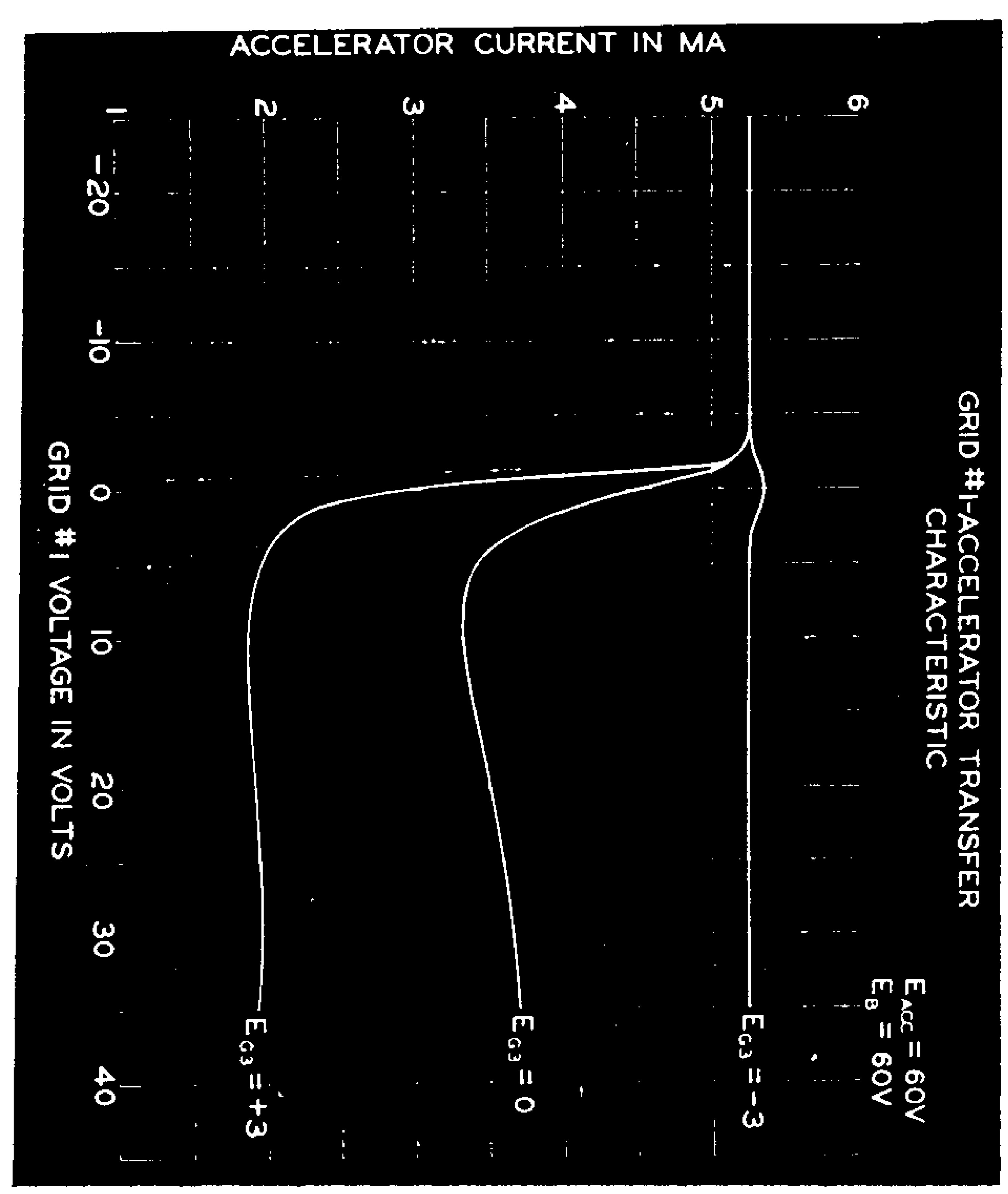


Fig. 5—Cathode Current vs. grid No. 1 voltage. *Fig. 6—Grid No. 1-Accelerator transfer characteristic.*

current from the cutoff to the limited value, the accelerator current varies from a maximum value downward to a relatively constant value yielding a negative transconductance to the accelerator electrode. This change in accelerator current represents a negative transconductance of 1,500 micromhos. Application of such a characteristic to oscillatory and "flip-flop" circuits is, of course, possible.

V. LIMITER-DISCRIMINATOR CIRCUIT

Figure 7 shows the limiter-discriminator circuit designed for operation in a-c, d-c receivers. At the standard f-m intermediate frequency of 10.7 megacycles, the output

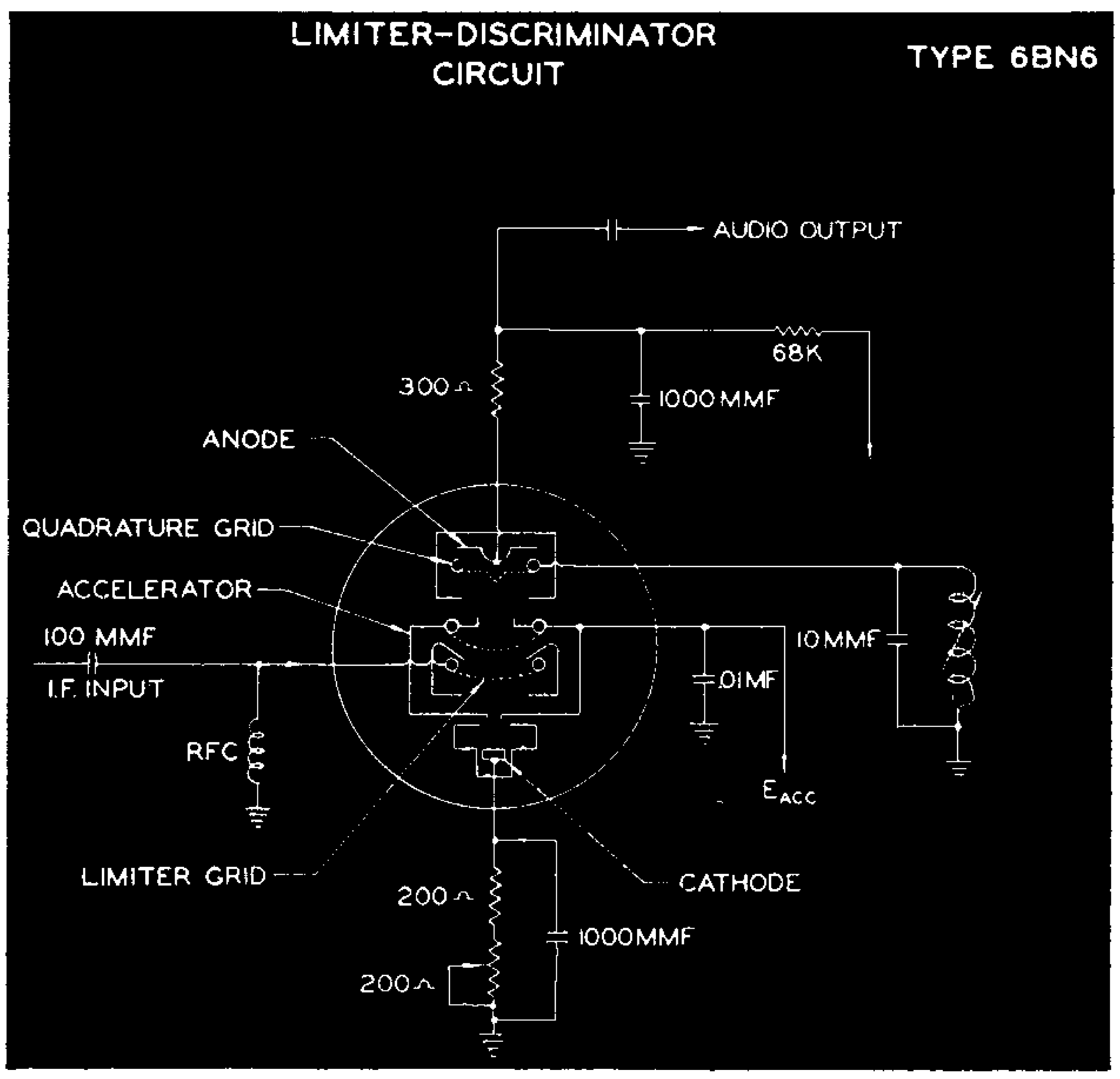


Fig. 7—Limiter-Discriminator circuit.

voltage for 75 kc deviation is approximately 4.5 volts rms. The a-m rejection, defined as the ratio of a-m output voltage to f-m output voltage taken with 30% a-m and 30% f-m simultaneously, can be optimized to approximately −35 db. The a-m rejection characteristic with respect to input signal level is irregular but is such that at least 20 db of a-m rejection is realized at input voltages of 1 volt, and 15 to 30 db of a-m

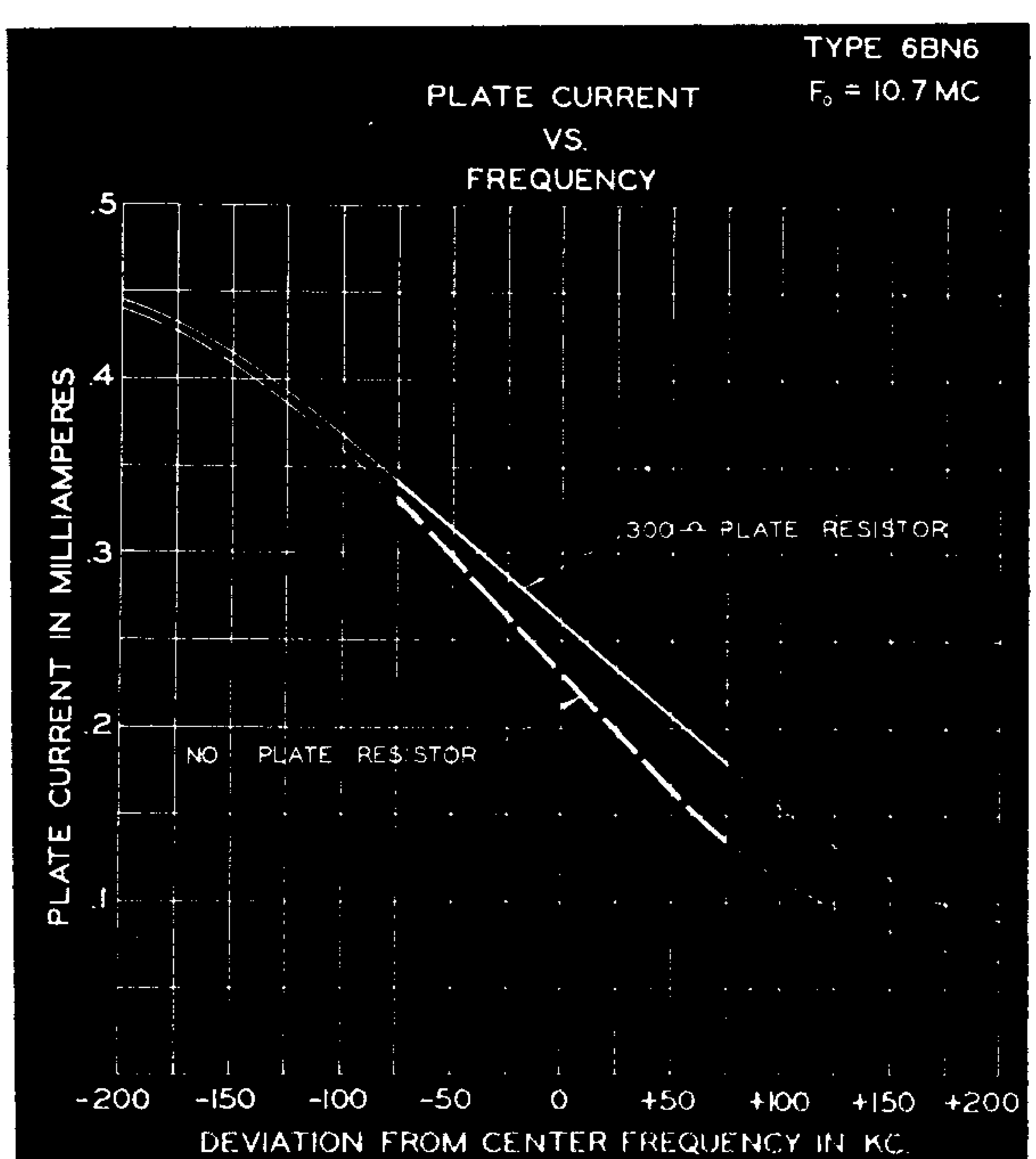


Fig. 8—Plate current vs. frequency.

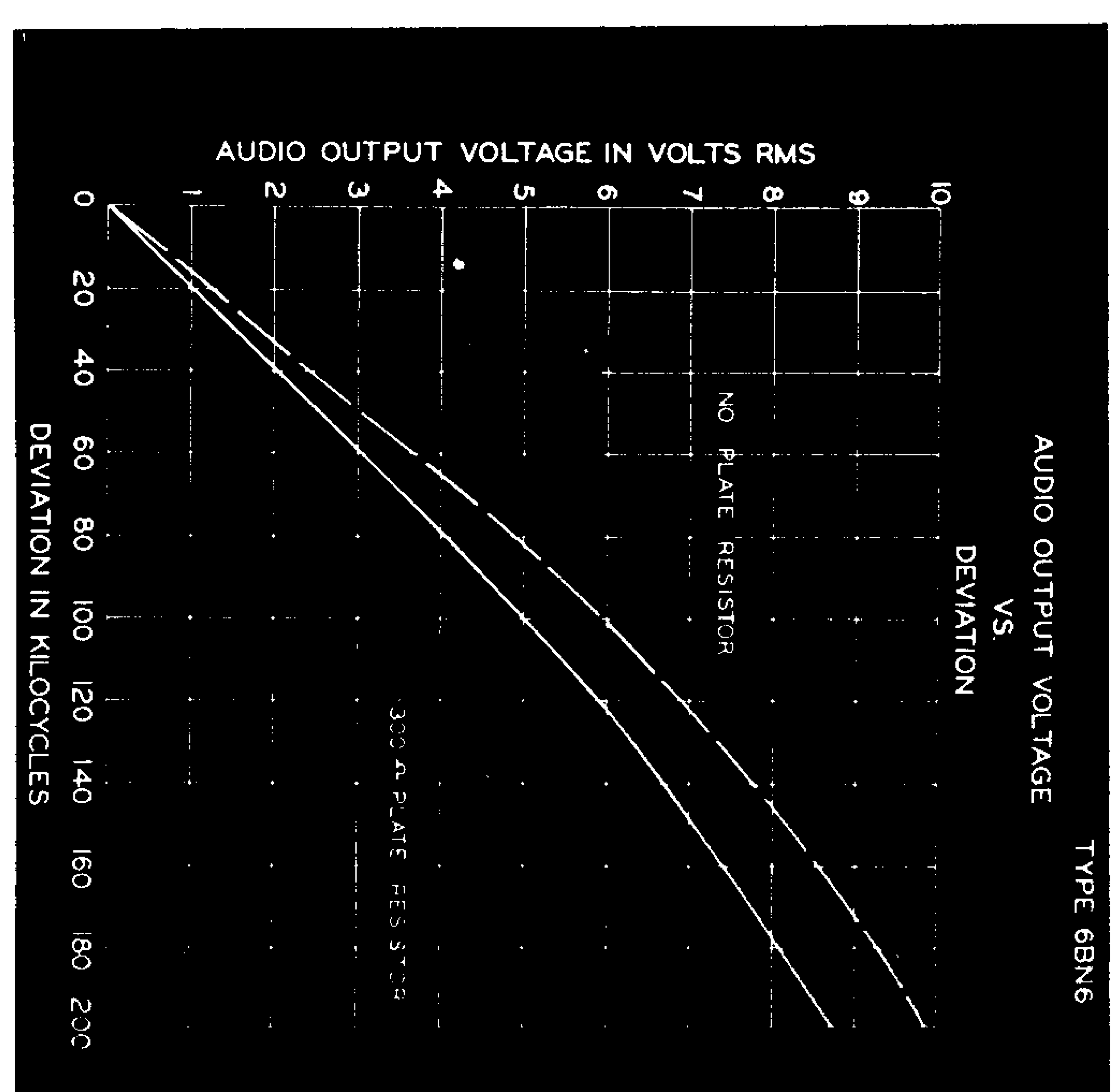


Fig. 9—Audio output voltage vs. deviation.

rejection is realized at signal voltages above the optimized level of 1.25 volts rms. Figure 8 shows the remarkably wide and linear variations of plate current with instantaneous frequency and indicates as well the effect of the 300 ohm series plate resistor upon this characteristic. Figure 9 shows the relationship between audio output voltage and deviation. This figure also indicates the effect that the series plate resistor has on both output and linearity. It should be noted that an increase in output voltage from 3.75 to 4.5 volts rms is realized by the omission of the series plate resistor. However, in receivers in which it is desired to keep harmonic distortion to a minimum, the use of the plate resistor will give output with less than 1% distortion whereas omitting the resistor will give somewhat greater output at approximately 3% distortion. The output voltages shown are obtained using accelerator voltage of 60 volts and plate supply voltage of 80 volts. Higher accelerator and plate voltages and a correspondingly higher plate load resistor yields audio output of 15 volts rms for 75 kc deviation.

The application of the 6BN6 limiter-discriminator to intercarrier television receivers is of particular interest. The intercarrier frequency of 4.5 megacycles allows operation of this circuit at a frequency at which a high impedance quadrature grid tank circuit can be obtained and utilized since the undesired external coupling reactance due to capacitance between the input grid and the quadrature grid is in the order of 3.5 megohms. The dependence of the output voltage upon the Q of the quadrature grid tank is indicated in Table 1 in which variations of parallel resonant impedance of

TABLE I

TYPE 6BN6 TABLE I

CENTER FREQUENCY	4.5 MC	E_{ACC} = 60 V
DEVIATION	22.5 KC	E_B = 80 V
		R_L = 68,000 Ω

COIL Q	RESONANT IMPEDANCE	E_{OUT} RMS
50	141,000 Ω	2.47 V
92	247,000 Ω	4.00 V
140	500,000 Ω	5.50 V

the quadrature grid tank from 141,000 ohms to 500,000 ohms yielded variations in output voltage from 2.47 to 5.5 volts rms at 22½ kc deviation. These output voltages were obtained with low supply voltages for the plate and accelerator electrodes. One application of the 6BN6 in an intercarrier television chassis where higher plate supply voltage and load resistance are used yields 15 volts rms at 25 kc deviation with an input signal of 1.25 volts. This output voltage is sufficient to drive the power amplifier tube directly and so eliminates one audio amplifier stage completely.

Operation of the 6BN6 at 21.5 megacycles has been realized but only when considerable care was taken to shield the input and quadrature grid circuits from each other. At this frequency, with 10 kc deviation and 30% a-m, output voltage of .55 volts rms and a-m rejection of about 20 db was obtained.

At all frequencies at which tests were made, the input voltage was varied from less than 1 volt to 40 volts rms so that the full range input signals which we could expect to find in receiver applications was covered.

A comparison between the performance of the 6BN6 limiter-discriminator and an Armstrong system, i. e., limiter and Foster-Seeley discriminator has been made using a now obsolete f-m receiver made by one of the well-known receiver manufacturers. Figure 10 shows the a-m rejection characteristic vs. input to the antenna terminals of the receiver. In this case, 30 microvolts represents an input signal to the limiter-discriminator of approximately 2 volts and the receiver gain is reasonably linear to the 1,000 microvolt value. It can be seen that the 6BN6 yields superior performance in the low input voltage regions, is very slightly inferior to the Armstrong system at intermediate inputs, and approaches the a-m rejection of the Armstrong system quite well at high input levels. The performance of the limiter-discriminator, comparing audio output voltage with the input voltage to the antenna terminals, is shown in Fig. 11. Here again the 6BN6 performance is considerably better than that of the

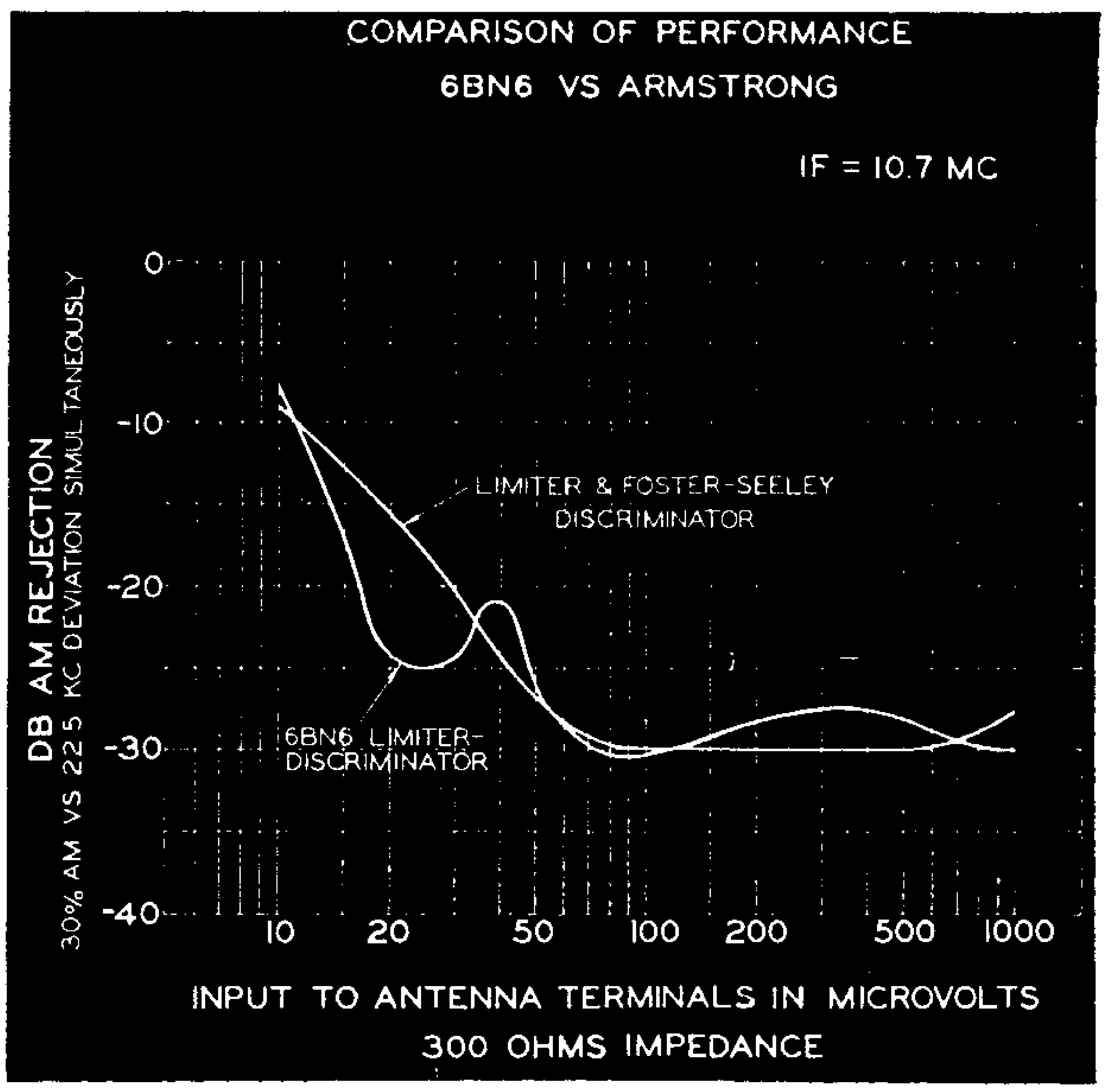


Fig. 10—AM rejection performance 6BN6 vs. Armstrong.

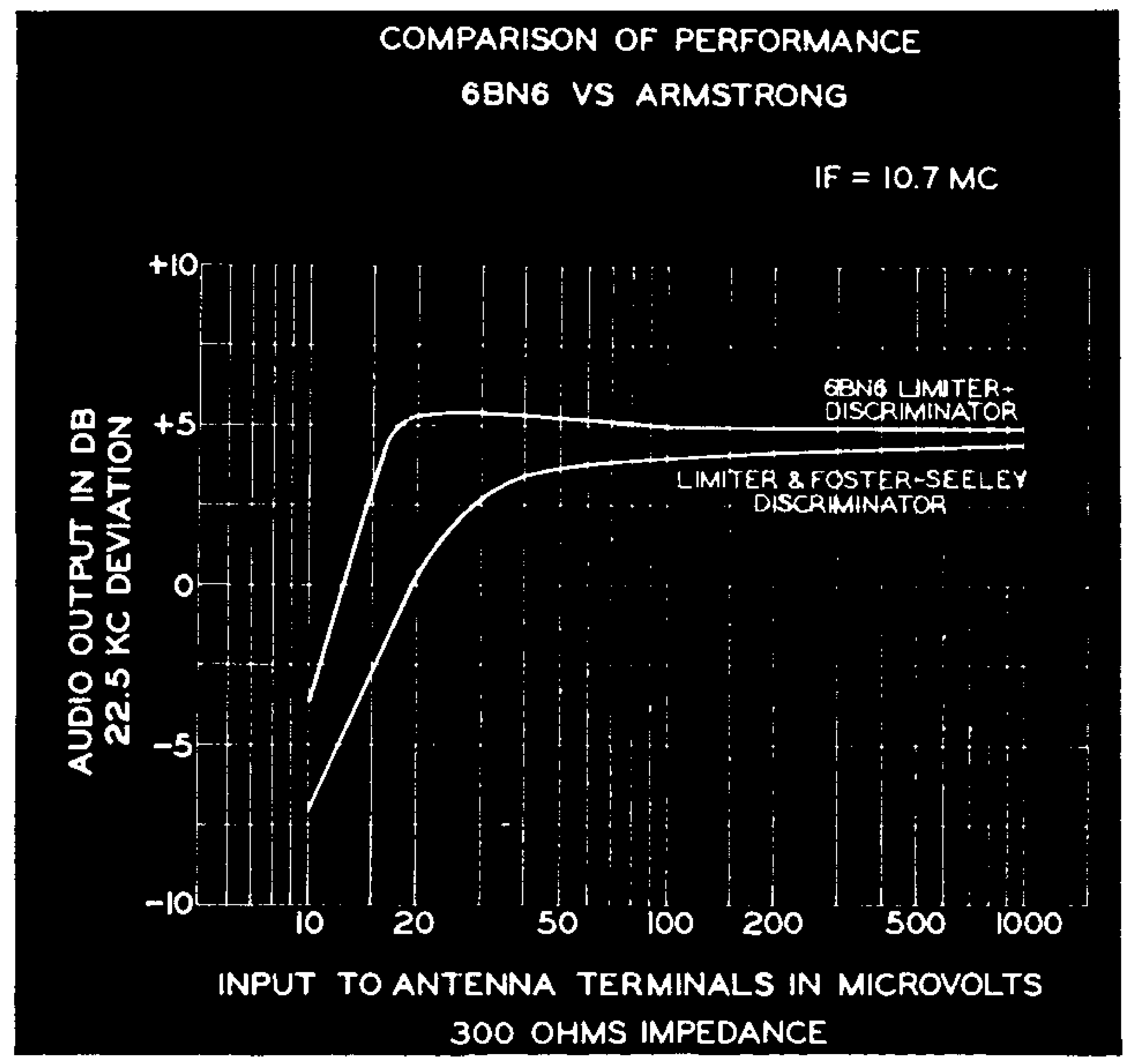


Fig. 11—Audio output performance 6BN6 vs. Armstrong.

limiter and Foster-Seeley discriminator. The audio voltage reaches a maximum with about 1 volt rms signal at the input of the 6BN6 and remains essentially constant over the range of input voltages normally covered. In addition to these desirable characteristics, the limiter has associated with it no RC time constants of importance at the operating frequency and hence can respond at a rate limited only by the inertia of the electron beam. This means that ignition noise and other similar pulse noise is rejected to a degree previously unobtainable even when cascade limiter stages are used. Such response of the limiter circuit makes possible the effective reduction of common channel interference of both the beat note and cross-modulation type. The discriminator does not utilize separate cathodes as is the case in most of the other popular discriminator circuits, and hence unbalance due to variations in the aging characteristics of cathodes as the receiver is operated do not appear as a factor in discriminator performance. As has been indicated, the band-pass characteristic of this discriminator is not dependent upon transformer coupling and tuning and is linear over an unusually wide frequency range. Consequently, the discriminator accepts the full band over which modulation energy is distributed and yields low output distortion.

The plate current vs. plate voltage family with the voltage of the No. 1 signal grid as parameter has a characteristic similar to that of a pentode and is quite usual in every respect. This curve is shown in Fig. 12, while Fig. 13 shows the same plate current—plate voltage family where the quadrature grid voltage is used as parameter.

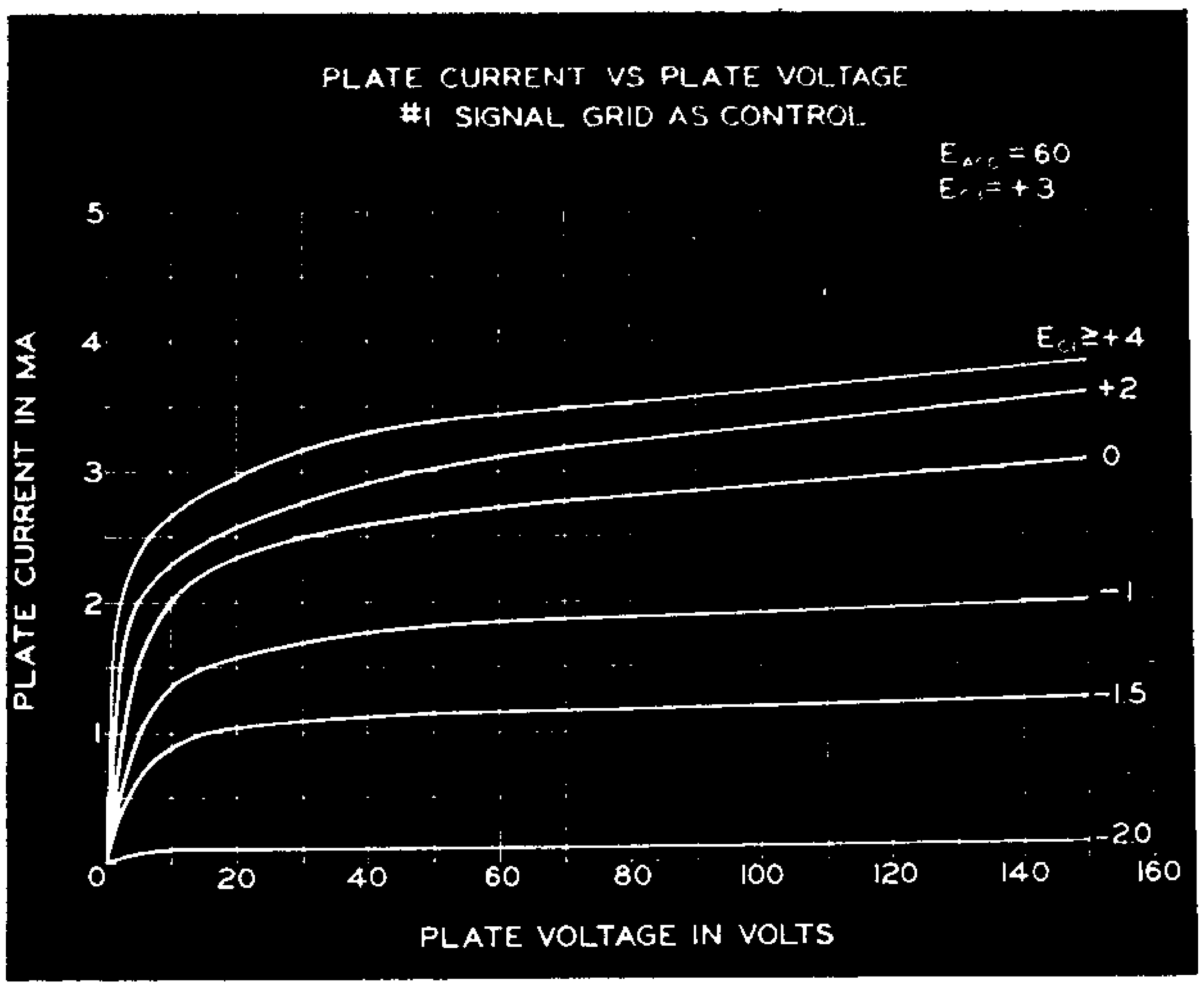


Fig. 12—Plate current vs. plate voltage No. 1 grid parameter.

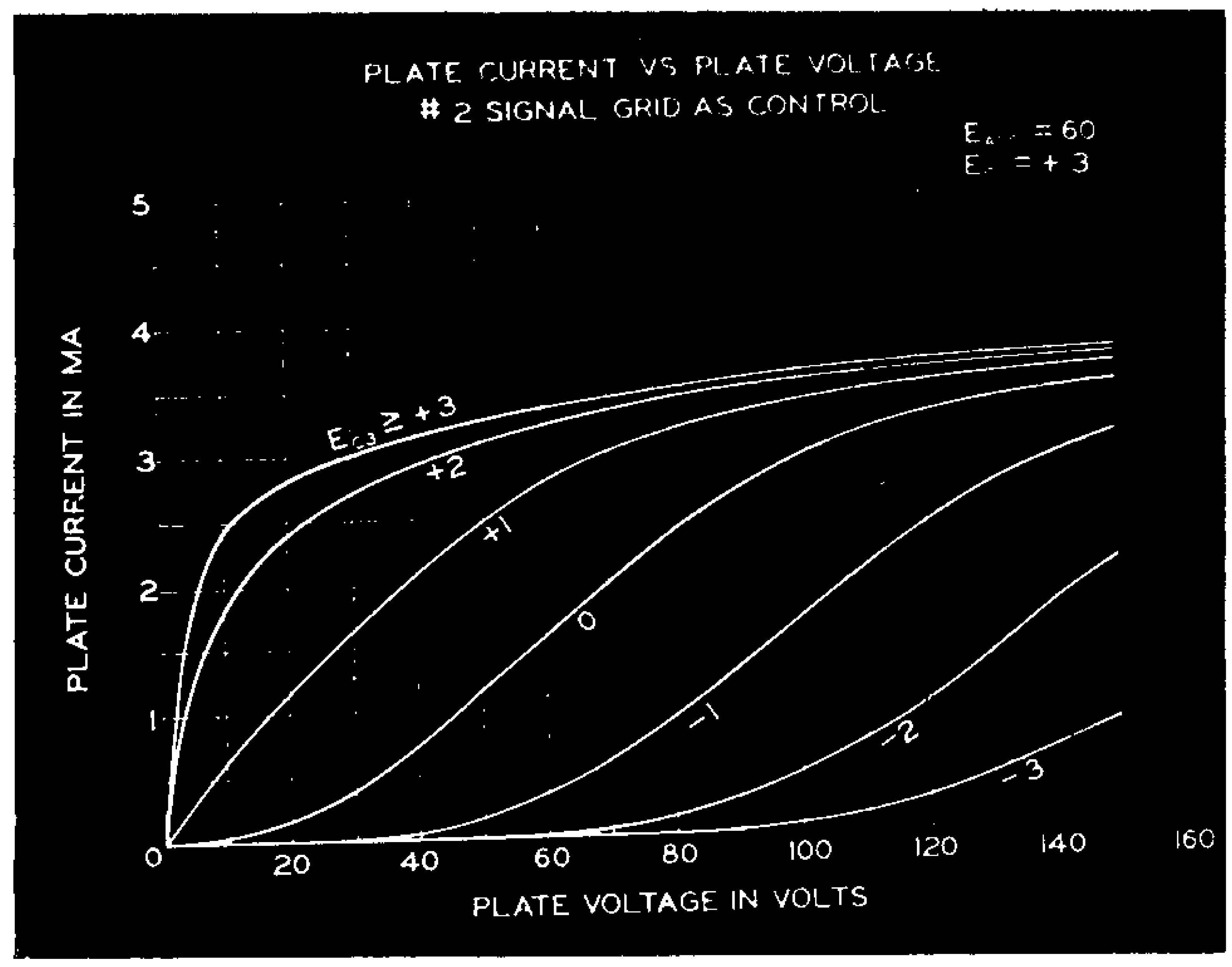


Fig. 13—Plate current vs. plate voltage No. 2 grid parameter.

In this instance, we have a very unique characteristic since the plate current is limited by the beam and the system utilizes an effective cathode whose density is determined to a large extent by the potential of the quadrature grid. When the quadrature grid is negative, the characteristic triode plate family is seen with a plate current limit due to beam limits. As the voltage on this grid is made positive, the characteristic shifts to become similar to that of a pentode. Considering these factors, we see that plate current is essentially independent of plate voltage in the case of the input grid and for the quadrature grid varies from a dependence upon plate voltage similar to a triode, to that of a pentode. By applying proper biases to the two signal grids in the limiter-discriminator circuit, it is possible to optimize a-m rejection and to obtain a ratio of plate current with signal to plate current with no signal to the input grid, which is very close to unity. This means that the over-all tuning characteristic of the f-m receiver using the 6BN6 limiter-discriminator would be characterized by a broad region of smooth tuning with noisy regions on either side due to slope detection in the i-f stages. This is a distinct advantage by comparison with the ratio detector and other systems in which the band-pass characteristic yields multiple tuning points for a single station. In this respect, the input signal level is not of great importance to the tuning characteristic since the discriminator output is very low in regions where slope detection in the i-f system occurs.

The objective of obtaining low input conductance with the input grid positive has been achieved quite well in the 6BN6 design. The limited input grid current is approximately 500 microamperes and the limited quadrature grid current is about 200 microamperes with both grids positive under static operating conditions.

VI. OTHER APPLICATIONS

The 6BN6 can, of course, be used as a plain limiter where it is desired to remove ignition or pulse-type noises from a-m signals or amplitude variations of any sort from f-m signals.

Since two step, function control characteristics are available, the tube would also find application wherever coincidence counting is desired and where such coincidence can be indicated in terms of several volts of signal.

A third application is that of a square wave generator where the input voltage may be of any frequency up to approximately 30 megacycles.

By using the two control grids, pulse-time modulation may be obtained directly from the output circuit of the 6BN6 stage.

A sync clipper circuit has been designed which, due to the limiting of grid current, yields a uniform sync pulse despite noise modulation of the incoming signal.

The 6BN6 has been used as an efficient speech amplifier-clipper for communications type audio equipment in which it is desired to maintain high modulation levels.

Considering power circuits, the 6BN6 finds application as a phase measuring device in such manner that power-factor can be metered directly or as a synchroscope type of instrument in which the relative phase angle and frequencies of alternators or alternator and line is indicated directly.

It has been found that the unique characteristic of the 6BN6 which allows generation of cathode bias sufficient to cut off plate current completely can be utilized to form a highly efficient frequency multiplier which requires little driving power and so makes possible high multiplication in cascade stages without generation of sidebands due to amplitude variation associated with conventional multipliers.

The 6BN6 has also been used in "flip-flop" circuits and as one-kick and free-running multivibrators.

Use of the tube as a self-contained oscillator to which load can be coupled either directly or through the electron stream where isolation is desired, should be possible due to its accelerator's negative transconductance. Since the output of such an oscillator can be controlled in both phase and amplitude by the quadrature grid and plate circuits, another variation of its limiter-discriminator application is that of obtaining phase modulated output from the plate circuit or obtaining four voltage vectors displaced 90° in phase from each other.

VII. CONCLUSIONS

The original objective of developing an improved limiter discriminator for f-m and television applications has been realized in the completion of the 6BN6 development. Many circuit components are eliminated completely and several are simplified to an extent. The alignment problem is simplified by the elimination of the discriminator transformer and, in the case of 4.5 mc operation, audio output voltage is sufficient to drive the power amplifier stage directly. All of these factors combine to make a very desirable performance to price balance for the manufacturer of electronic equipment. The research and development work which preceded the announcement of this type covered several years' time and has resulted in a tube which places a new tool in the hands of circuit designers. Vacuum tube characteristics which have never before been available to the industry are now a reality and should find widespread application not only in radio receiving and transmitting equipment but in industrial control circuits and laboratory instruments as well. Some of the applications mentioned have already been reduced to practice and many others should be possible.

ACKNOWLEDGMENTS

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