

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

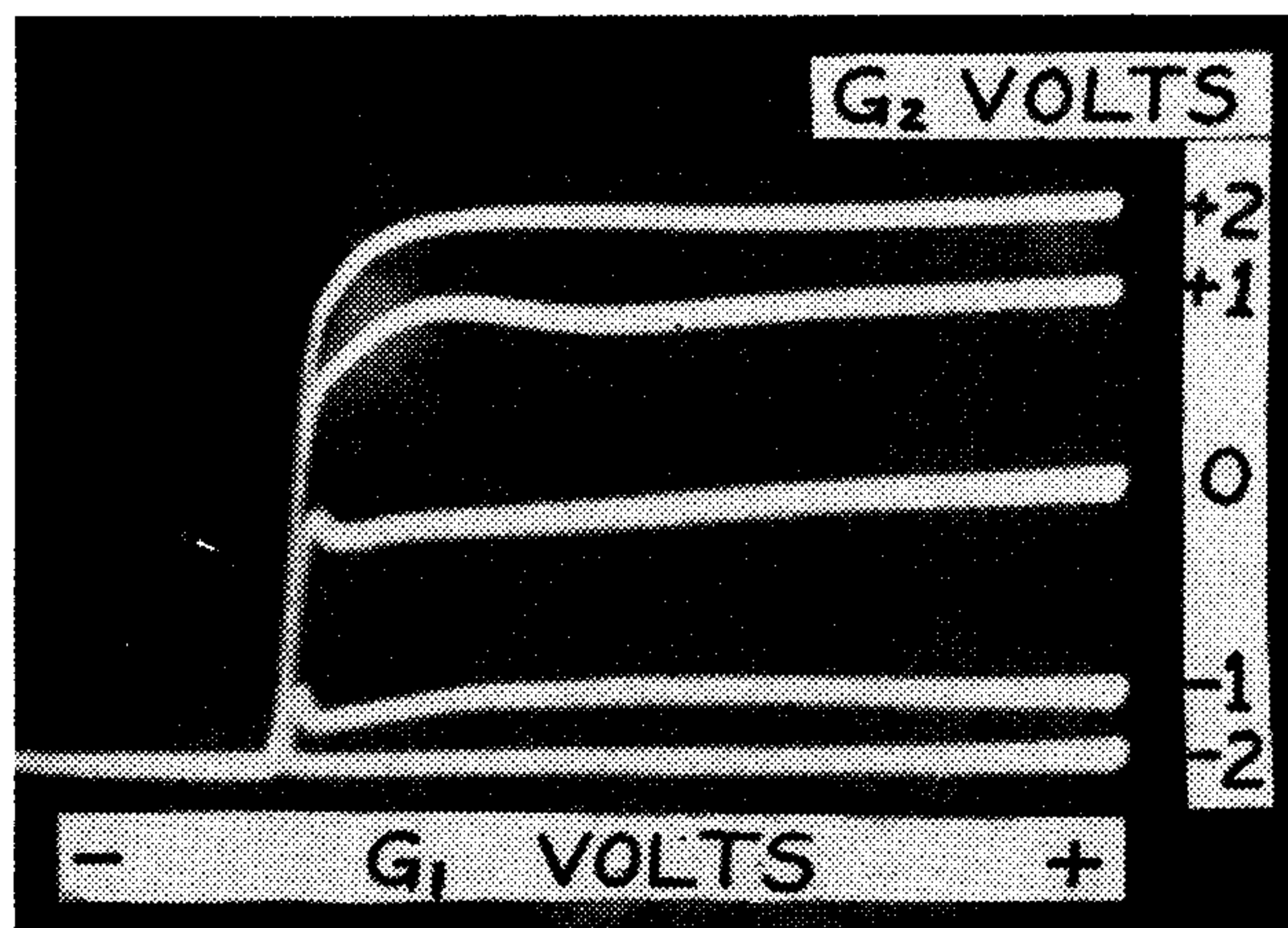


Fig. 1—Grid Voltage—Plate Current Curves of the 6BN6.

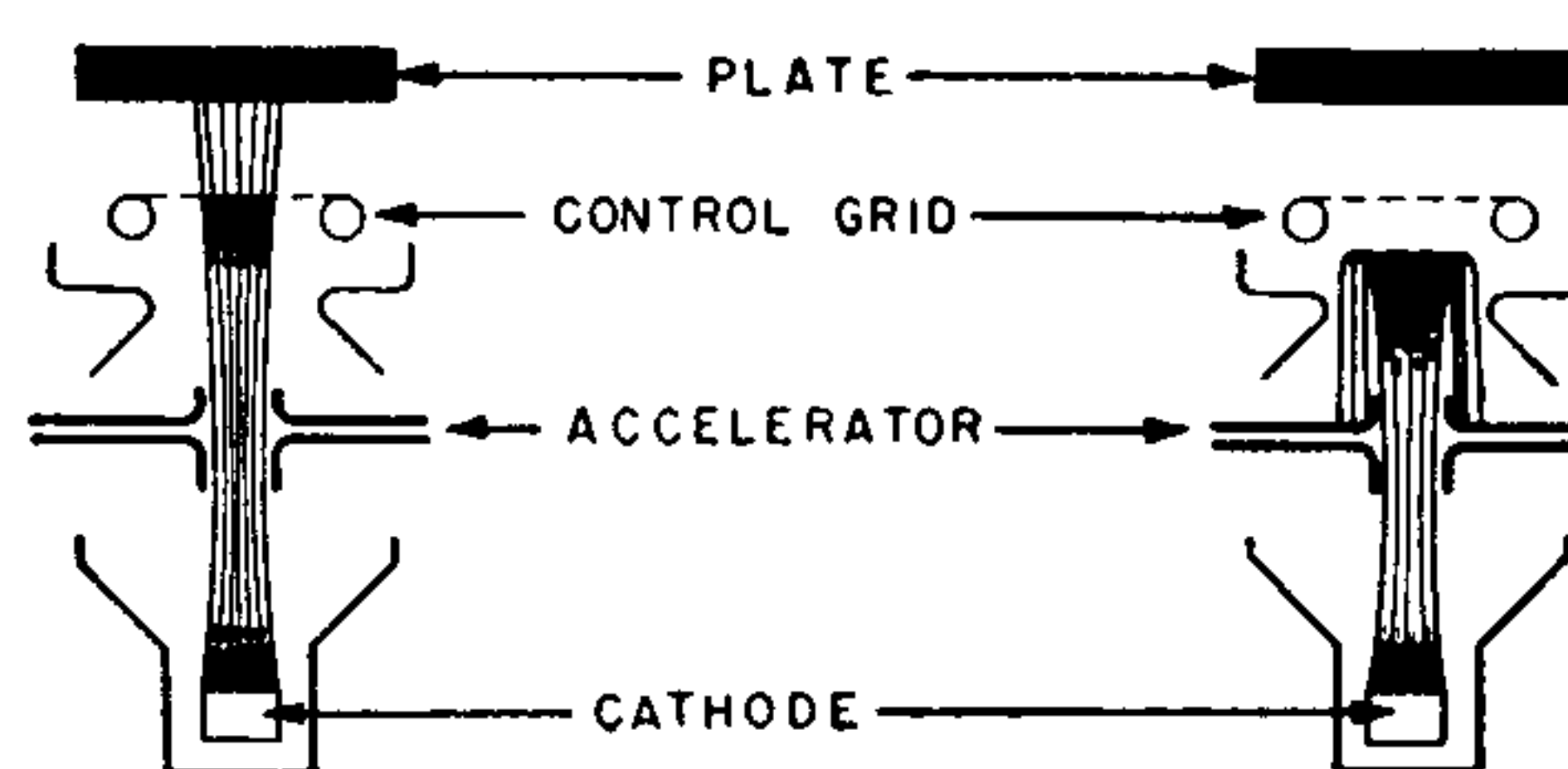


Fig. 2—Electron Paths in a Simple Gated-Beam System.

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

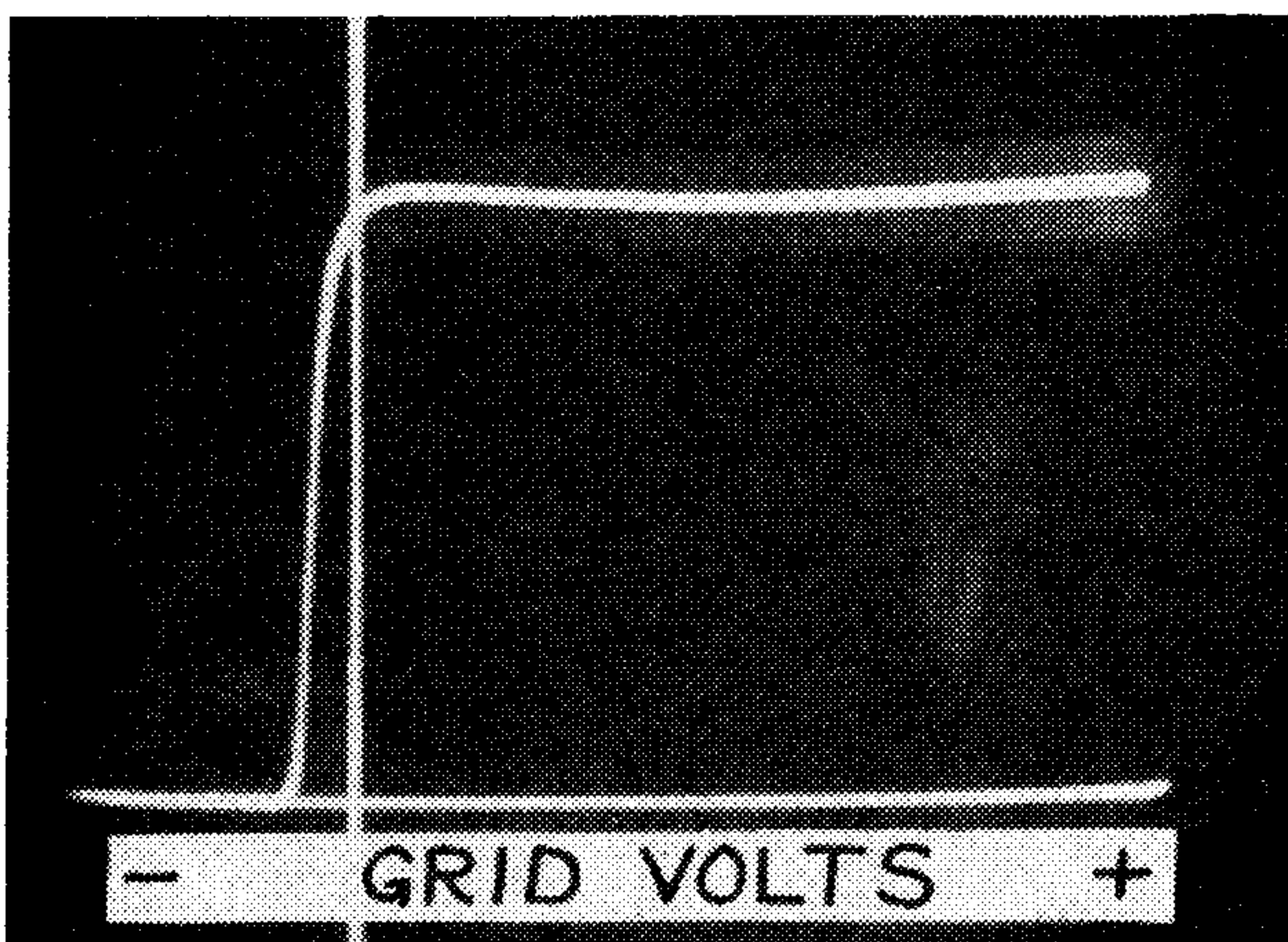


Fig. 3—Static Characteristics of Simple Gated-Beam System.

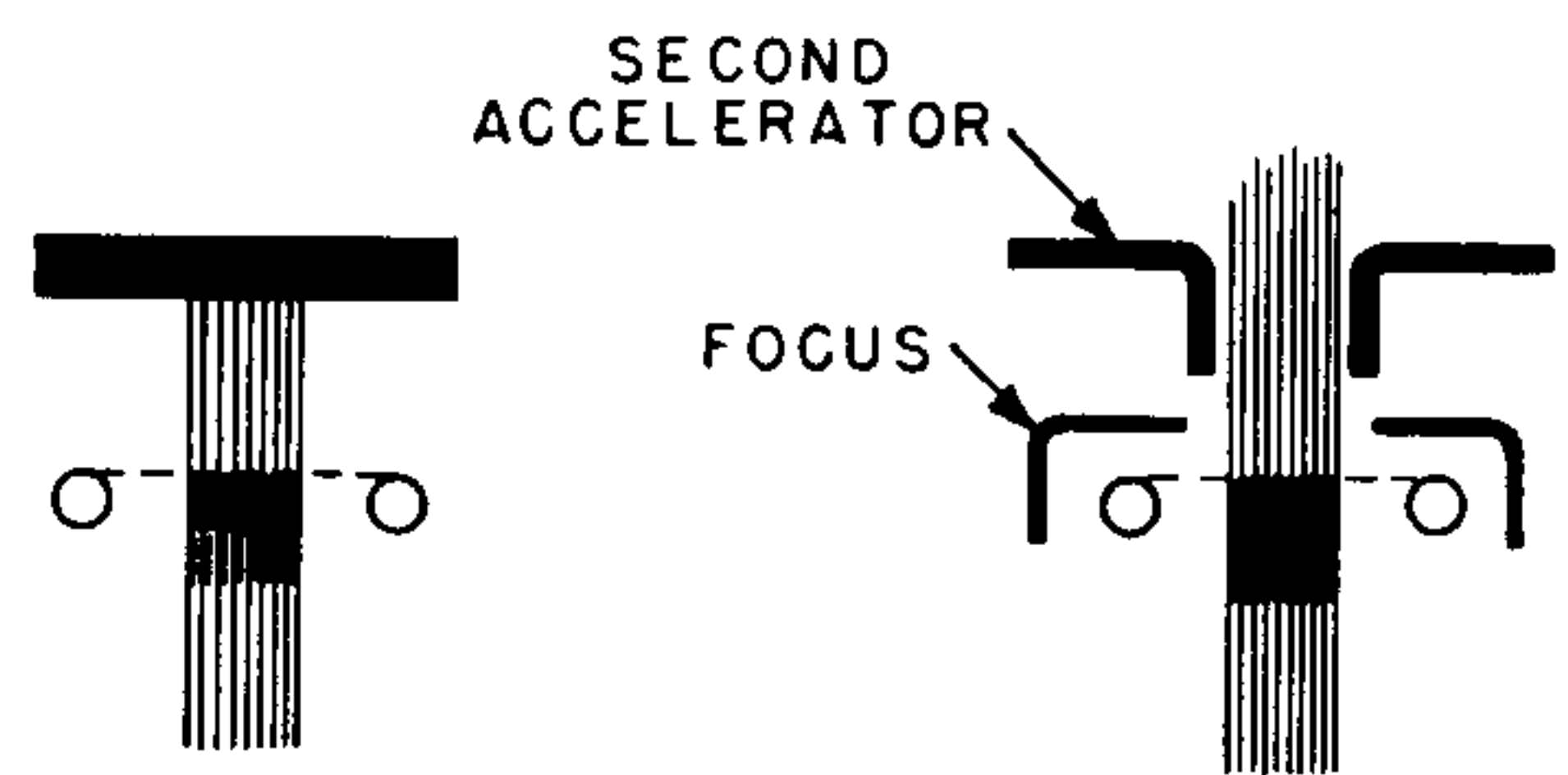


Fig. 4—Second Accelerator Substituted for Anode.

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

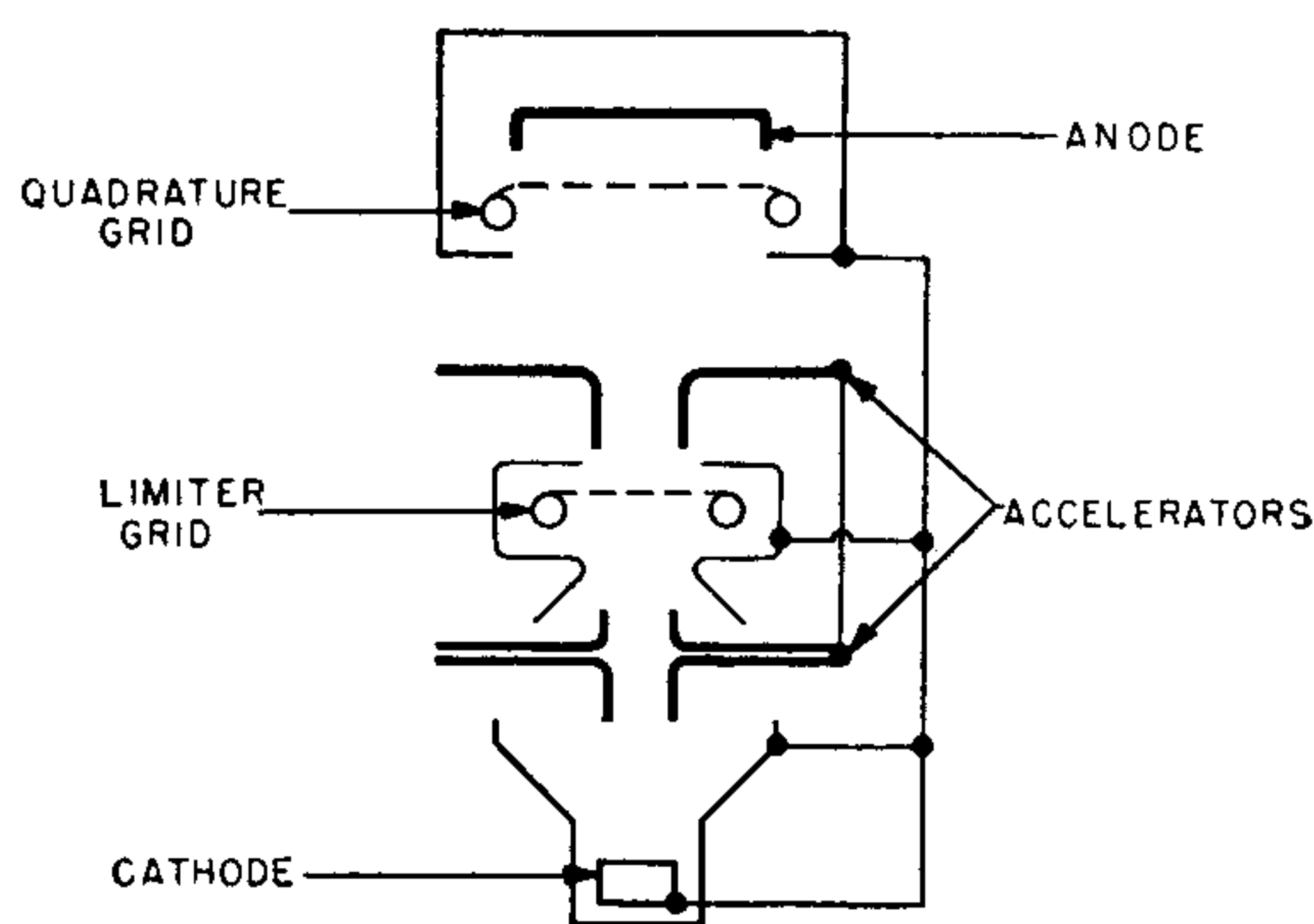


Fig. 5—Cross-Section of Early Experimental Model.

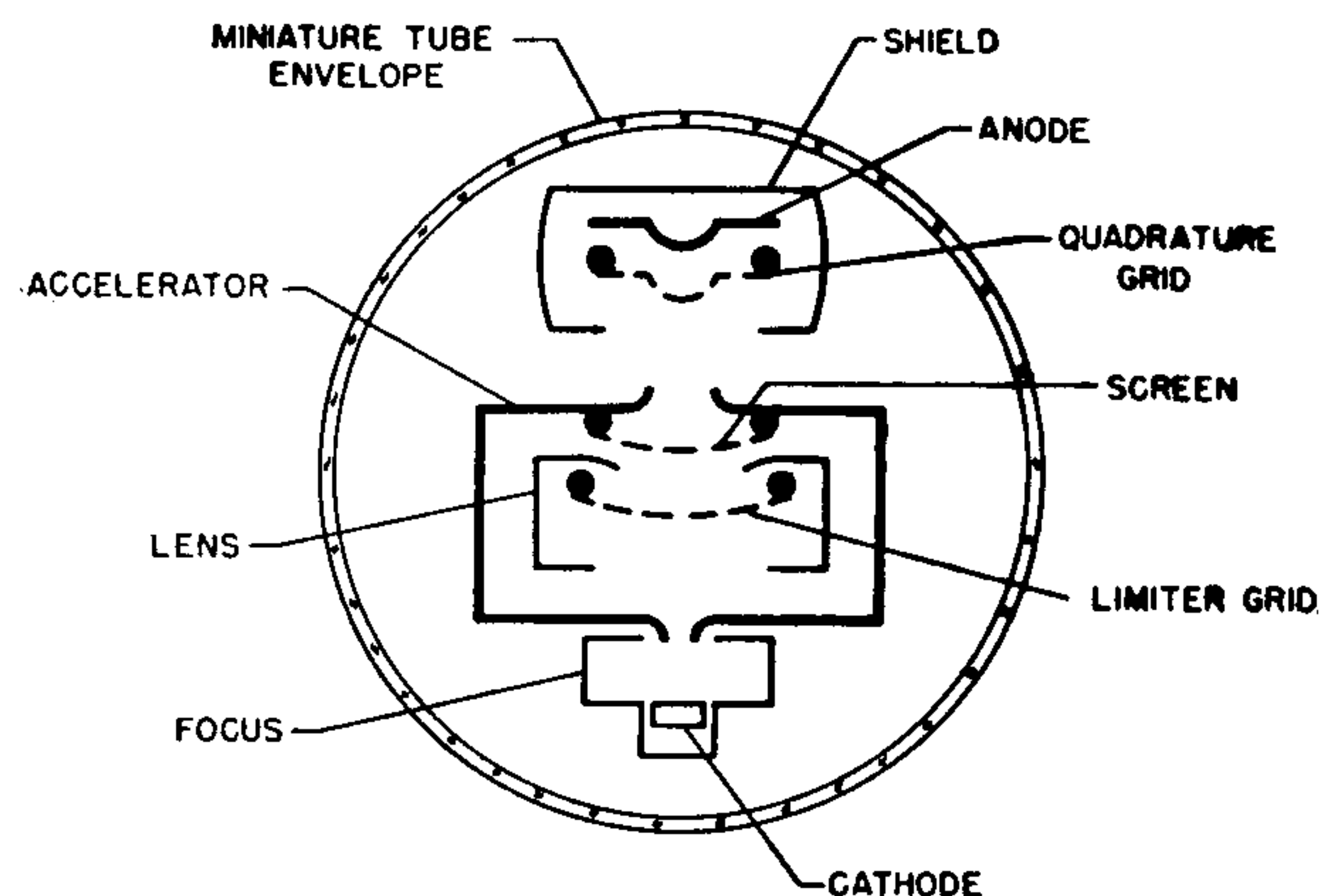


Fig. 6—Cross-Section of Final Model.

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

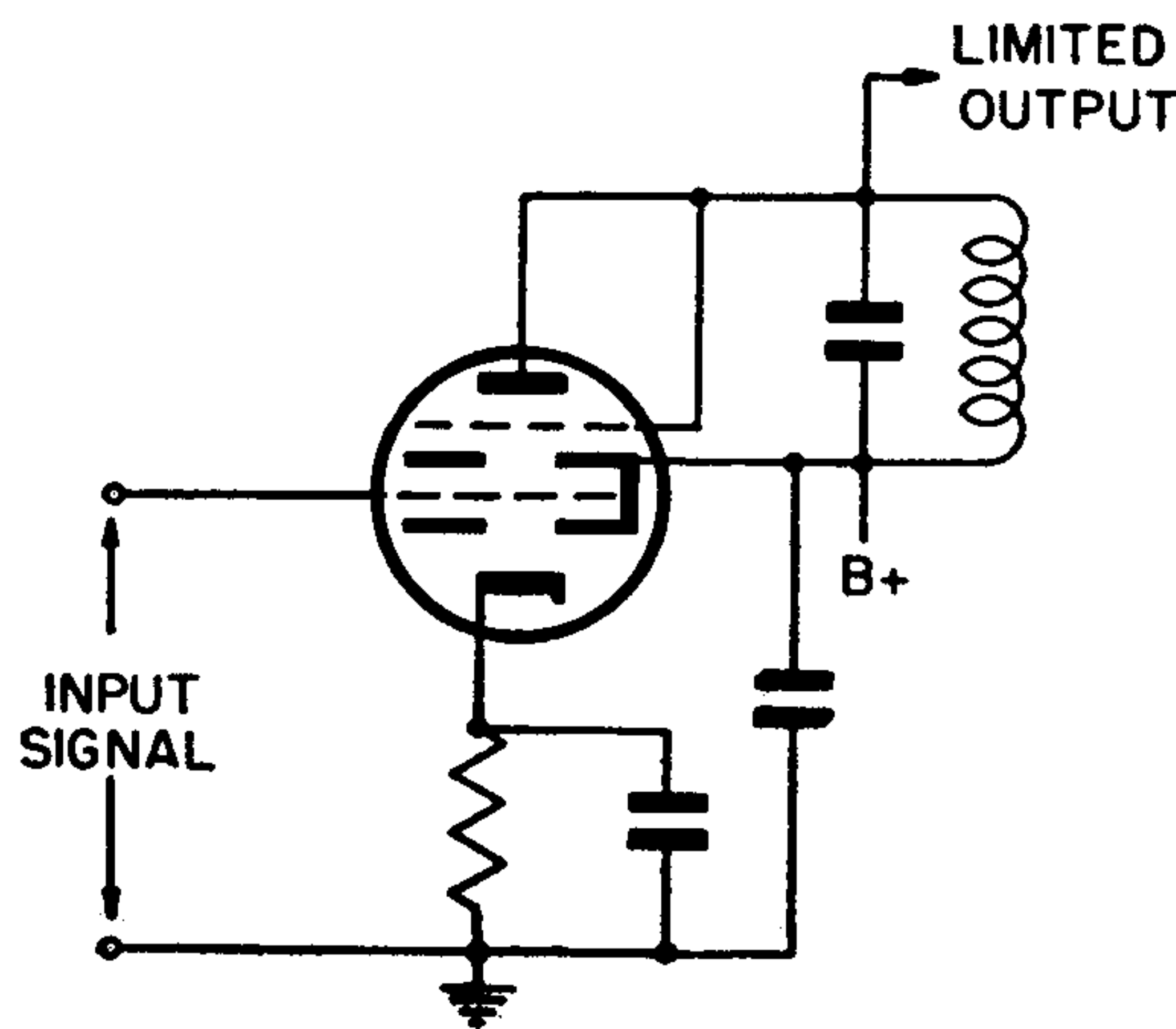


Fig. 7—Limiter Circuit.

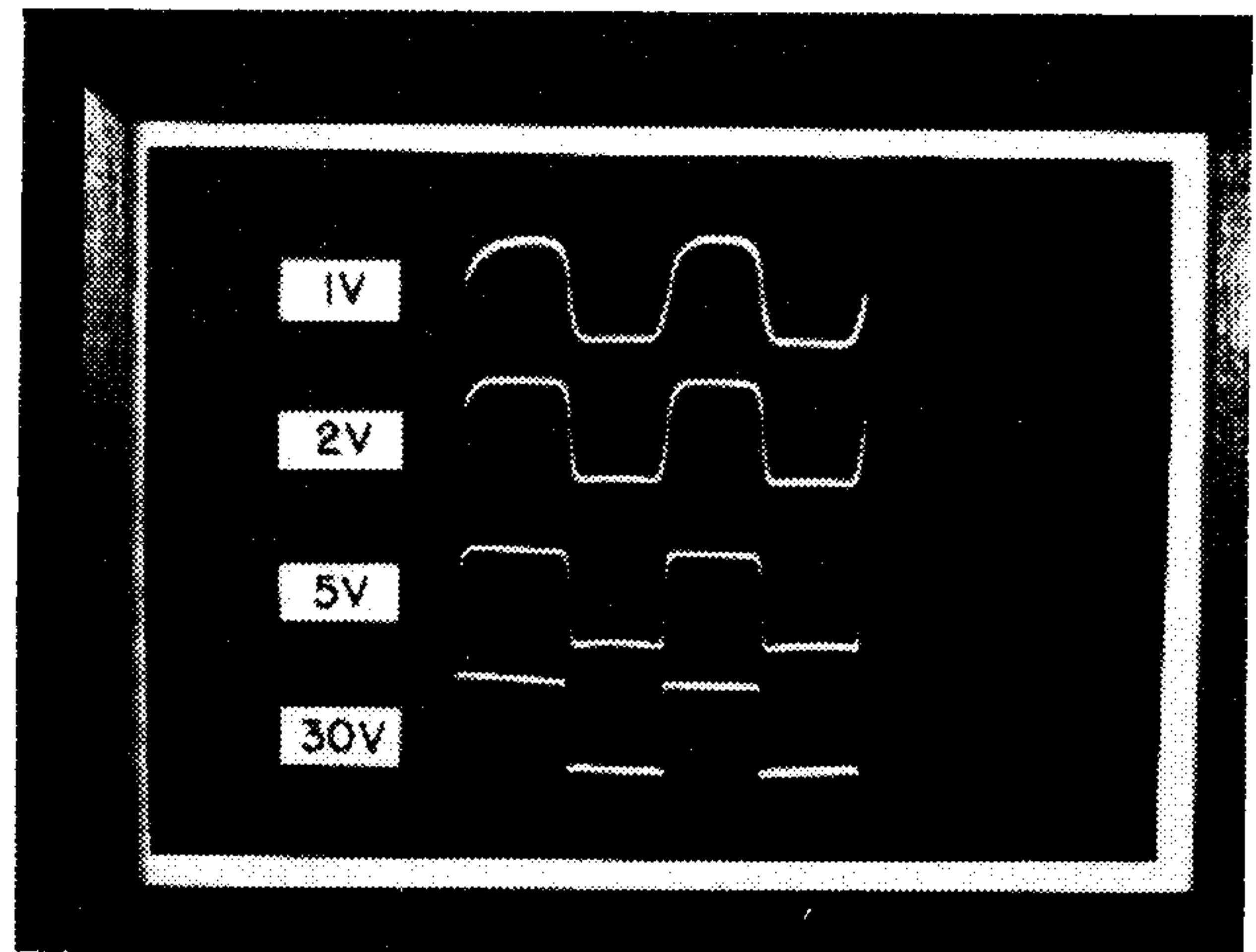


Fig. 8—Plate Current Waveforms for Four Input Levels.

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 interference.

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

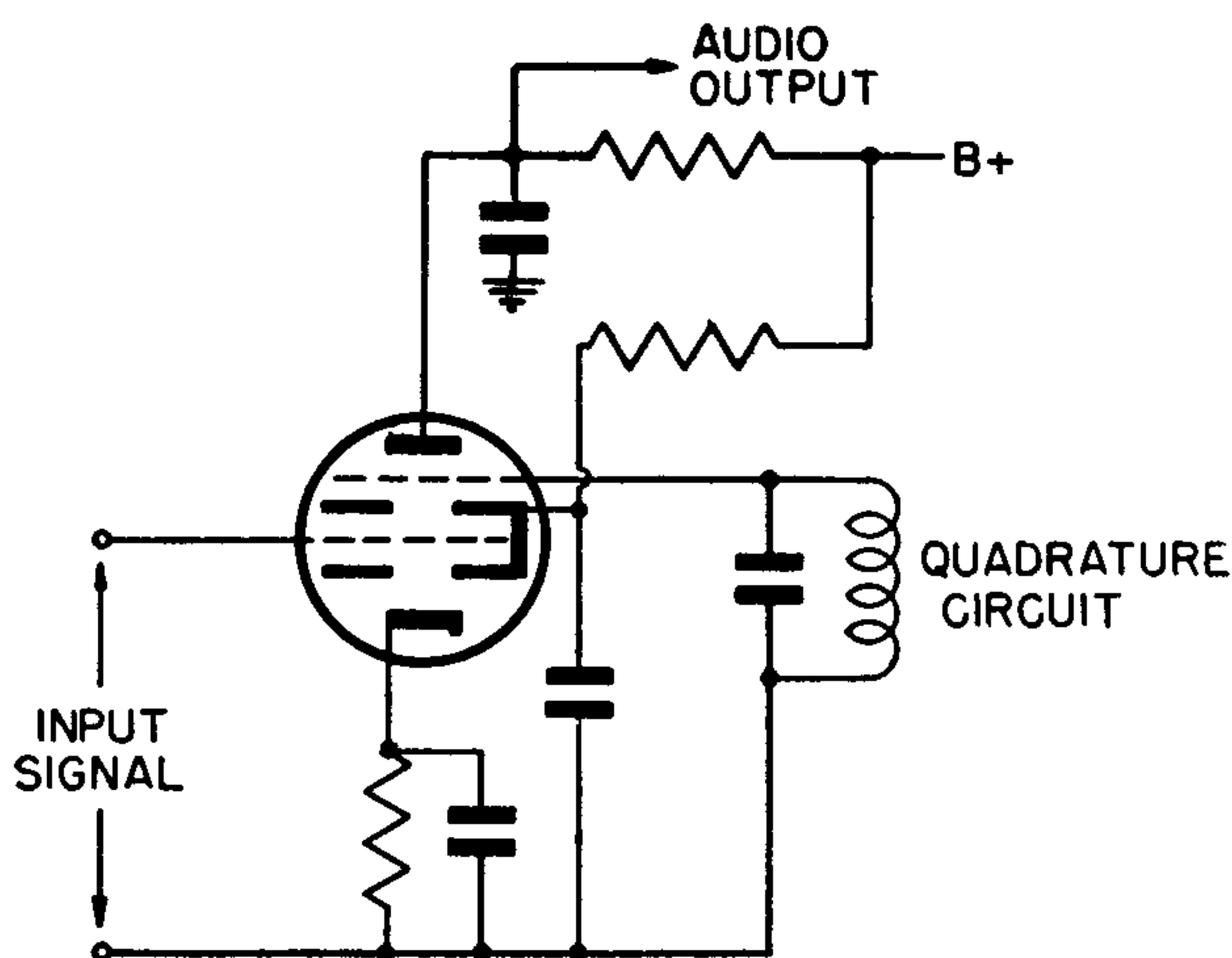


Fig. 9—Limiter-Discriminator Circuit.

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

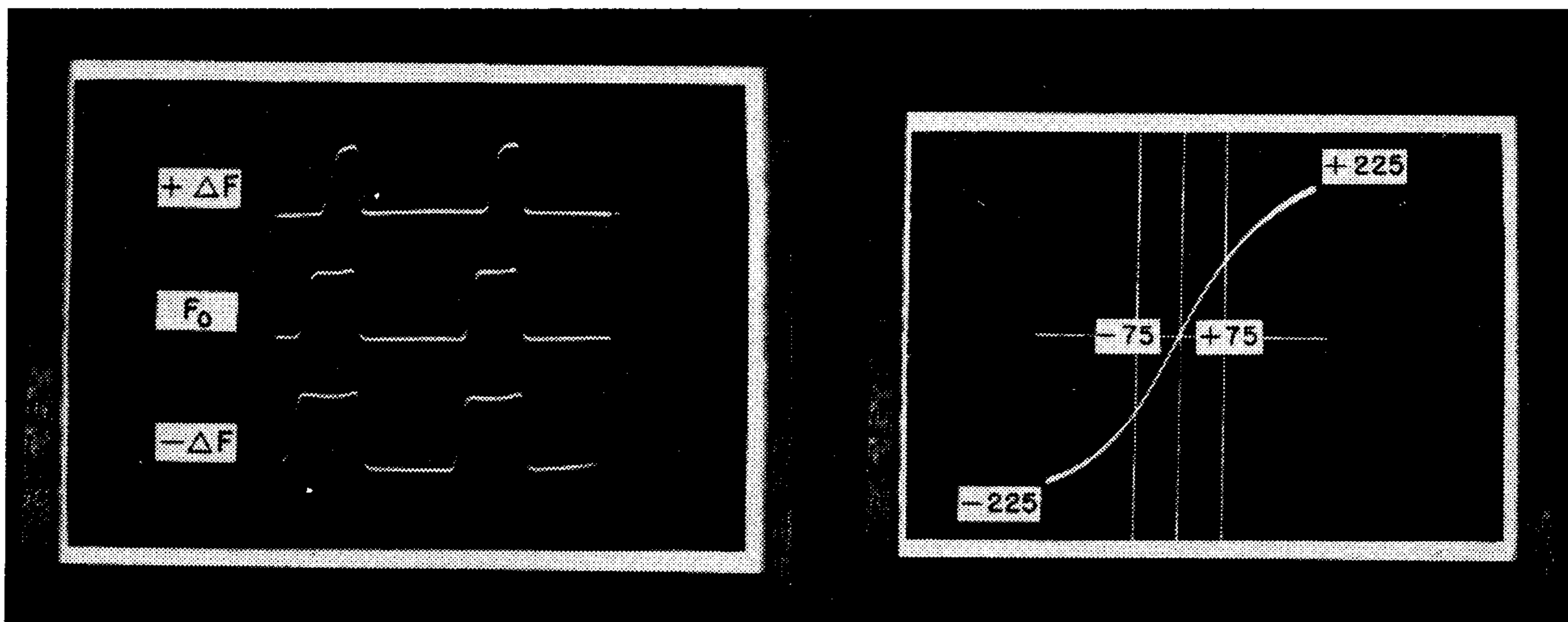


Fig. 10—Waveforms of Plate Current at High, Center, and Low Frequency.

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. Plusc¹ 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 $\mu\mu\text{f}$.

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 minimum 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.

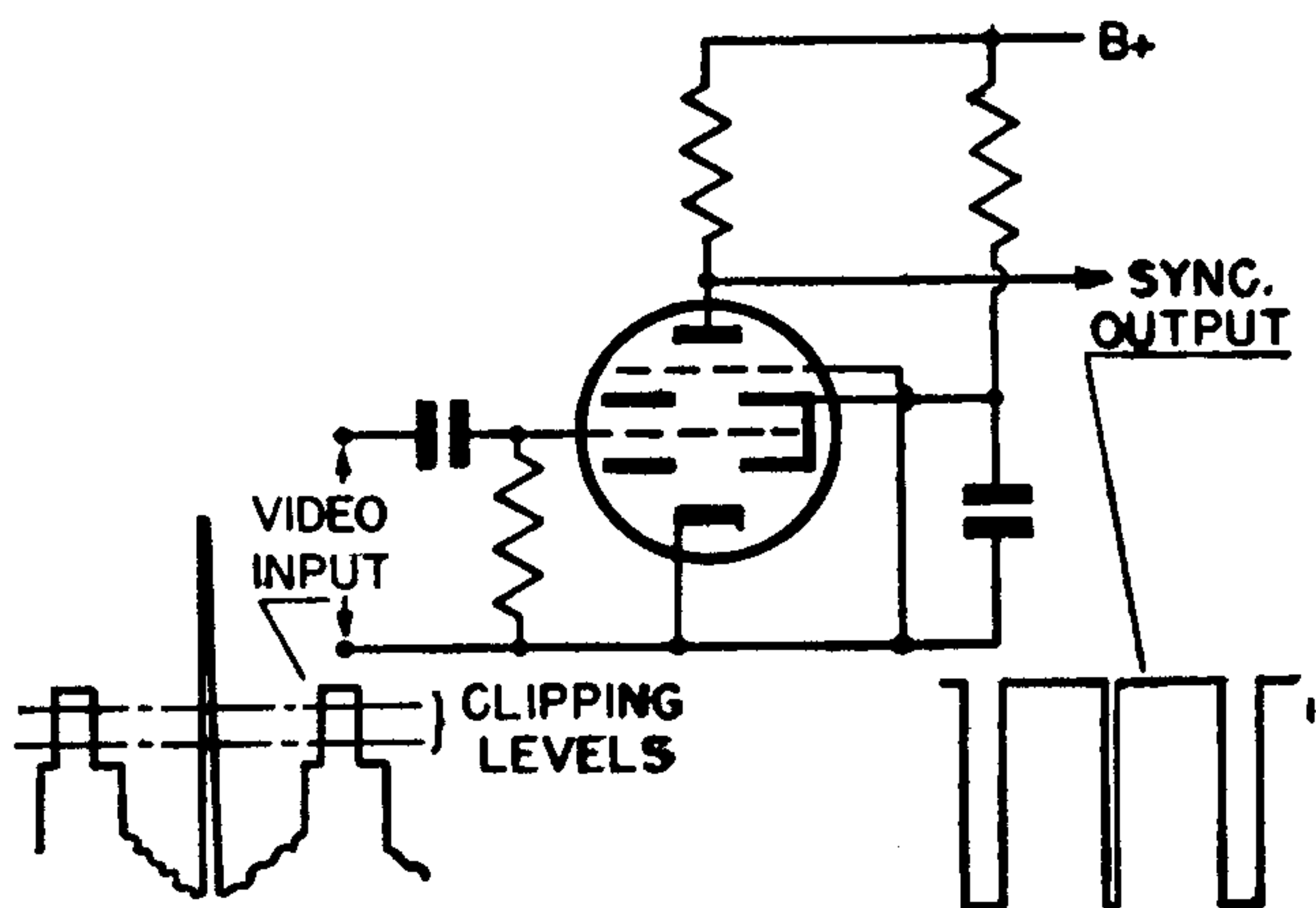


Fig. 12—The 6BN6 as Sync Clipper.

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. Zakarias² 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. Kalmus³ 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, Sargrove⁴ in England re-discovered Zakarias' circuit, apparently independently.

In 1940, J. J. Okrent⁵ 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 proposed⁶ 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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8. Note added in October, 1949: Information regarding this tube has now appeared in the *Philips Technical Review*, Vol. 11, No. 1, p. 1, July 1949. (J. L. H. Jonker and A. J. W. M. van Overbeek: The "Φ-Detector", A Detector Valve for Frequency Modulation.) According to this article, this tube employs seven conventional grids; constructed and used in accordance with Okrent's patent, it requires 8 volts RMS for limiting, compared to 1 volt RMS for the 6BN6.