A NEW MINIATURE BEAM-DEFLECTION TUBE*

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Summary—*A new method for beam-deflection control of plate current has been developed and applied to a tube design that uses beam-deflection control in addition to conventional grid control. The new tube, the 7360, is a nine-pin miniature type especially suitable for use in modulators, demodulators, and converters. It has an "electron gun" that comprises a cathode, a control grid, and a screen grid; a deflection structure that includes two grid-like deflecting electrodes; and two plates. Beam currents of several milliamperes can be deflected from one plate to the other by means of a potential difference of a few volts between deflecting electrodes.*

INTRODUCTION

BEAM deflection has been used in the past for sensitive control of current in high-frequency tubes. Although excellent per-performance has been obtained, it is very difficult to achieve sensitive control of beam currents higher than a fraction of a milliampere, and beam deflection has not been economically competitive with conventional grid control. It has been recognized, however, that beam deflection is more desirable than grid-No.3 control as the "outer control" means in product-modulator tubes.[1]

In pentodes and pentagrid tubes, the space current is determined by the voltages on grid No. 1 (control grid) and grid No. 2 (screen grid); the fraction of the space current passed on to the plate is controlled by the potential at grid No. 3. As a first approximation, therefore, the plate current is a function of the mathematical product of grid-No.1 and grid-No.3 voltages. Errors in the approximation arise from nonlinear characteristics of both grids, and from the fact that grid-No.3 voltage affects cathode current. This effect on cathode current is due, in a small degree, to the penetration of the field of grid No. 3 through the screen and control grids. The most serious cause, however, is that the electrons turned back from grid No. 3 reach the grid-No.1–cathode region and alter the space charge. Other effects

* Manuscript received February 8, 1960.

[1] R. Adler and C. Heuer, "Color Decoder Simplifications Based on a Beam-Deflection Tube," *Trans. I.R.E. PGBTR*, p. 64, January, 1954.

of the returned electrons are undesired coupling from grid No. 3 to grid No. 1 and variations of input loading of grid No. 1. The degree of influence of grid-No.3 voltage upon cathode current is a good indicator of the magnitude of these adverse effects. In conventional pentodes, such as the 6AS6, grid No. 3 has about one-third the control over cathode current that it has over plate current. The effect is reduced to about one-twentieth in pentagrid converters, which are designed to return electrons along different paths as much as practical.

In the beam-deflection tube, the electrons always move away from the cathode; thus, the major cause of interaction with the control grid is eliminated. Furthermore, balanced operation of the deflecting electrodes minimizes the influence of the deflecting-electrode signal voltage on the electric field near the cathode, and tends to neutralize capacitance coupling between deflecting electrodes and control grid. Another advantage is that both plates may be used for output signals in push-pull. Although output may be obtained from the screen grid of tubes having grid-No.3 control, the resultant feedback is usually not tolerable. The beam-deflection tube design described in this paper has further advantages of quite linear and almost exactly symmetrical deflection characteristics. It has transconductance about equal to that of good pentagrid converters, although its plate resistance is much lower. Its transconductance falls a little short of that of the best suppressor-grid-control pentodes.

DESIGN OF BEAM-DEFLECTION TUBES

The principle of beam deflection leads conventionally to a structure resembling that of a cathode-ray tube except that the electrodes are designed to produce a ribbon-like beam rather than a circular beam and to move the beam from one plate to the other. The tube cross section shown in Figure 1 illustrates this principle as applied to one experimental design.

Both the sharpness of beam focus and the distance the beam travels after deflection influence deflection transconductance. However, as the distance is increased to obtain higher deflection sensitivity, the beam tends to spread due to space charge; the net result is that the length of beam travel is of secondary importance. The velocity of electrons passing the deflecting electrodes also has a secondary effect on deflection transconductance in that low velocity increases deflection sensitivity, but beam focus suffers.

The most important factors in the design are the length of the deflecting electrodes and the spacing between them. For best deflection transconductance, the deflecting electrodes must be placed as close as possible to the beam throughout their length. However, the spacing must be sufficient to permit the beam to be deflected from one plate to the other without striking the deflecting electrodes. Design for minimum spacing leads to appreciable current collection by the deflecting electrodes because practical beams do not have sharp edges. Another fault of design for minimum spacing is that a part of the beam

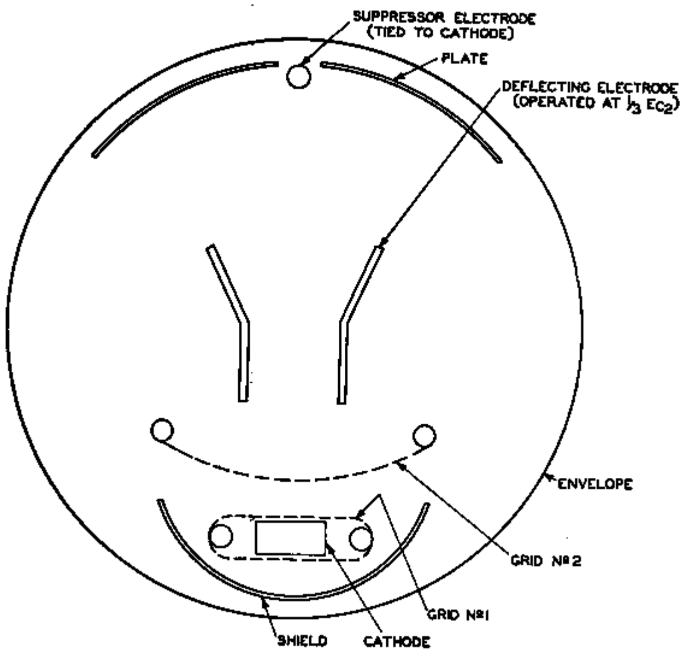

Fig. 1—Cross section of experimental tube using conventional beam-deflection principles.

current is collected by the deflecting electrodes as soon as the deflection exceeds the amount required to just switch the beam. With further increase in deflection, the amount of current collected by the deflecting electrodes increases until almost all of the current is collected by the deflecting electrodes. Even if the tube is designed so that the deflecting electrodes operate with negative bias, the instantaneous voltage is necessarily positive on the electrode that is approached by the beam. Any practical design is compromised by this factor of deflecting-electrode current.

Design of Type 7360

The beam-deflection structure used in the 7360 circumvents several of the problems associated with conventional structures. The major innovation is the use of porous deflecting electrodes. The beam passes through these electrodes to plates situated alongside them. This structure is shown in cross section in Figure 2. The deflecting electrodes operate at an average voltage which is only slightly positive with

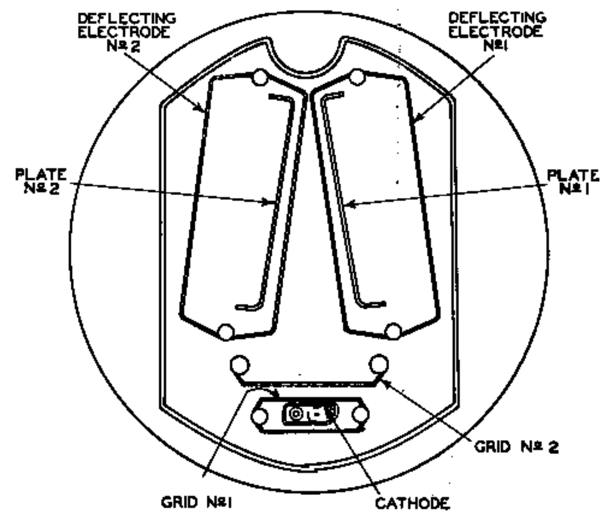

Fig. 2—Cross section of 7360 beam-deflection tube.

respect to cathode and, therefore, intercept only a small fraction of the beam current regardless of whether the beam is deflected not at all or far beyond the point at which all the current flows to one plate. Thus, the deflecting electrodes may be placed very close to the beam for most of the length of beam travel. This arrangement results in high deflection transconductance without abnormal deflecting-electrode current.

The porous deflecting-electrode construction also eliminates the need for the extremely sharp electron-beam focus that is required when solid deflecting-electrode construction is used. Although it is very important that the electrons be directed along the proper converging paths, sharp focus, a condition opposed by space charge, is not required.

The control grid and screen grid form an almost parallel electron beam and control its intensity. Because the beam emerging from the screen grid diverges somewhat in this simple "electron gun," more complex gun structures were tried in the early stages of design in an attempt to approximate a "Pierce gun"[2] and to mask the beam. The approximation was so poor in designs considered practical for manufacture, however, that these tubes had poorer performance than the 7360.

The electron beam is focused by the electron lens formed between the screen grid and the deflecting electrodes. The strength of the lens is a function of the spacing between the deflecting electrodes, the distance between the screen grid and the deflecting electrodes, and the potentials of the screen grid and the deflecting electrodes.

The spacing of the deflecting electrodes is made just large enough to accept the beam width. Wider spacing reduces deflection sensitivity; narrower spacing increases the amount of stray plate current (current not effectively controlled by the deflecting electrodes).

The potential of the screen grid must be at a level that will permit the desired beam current in the gun; the deflecting electrodes must be positive enough to permit passage of the current to the plates. As a result of the limitations on deflecting-electrode spacing and on the potentials of the screen grid and the deflecting electrodes, the distance from screen grid to deflecting electrodes is governed by the strength required of the electron lens.

It is interesting to note that, because of the effect of the deflecting-electrode potential on the electron lens, the axis of the electron lens will be skewed when there is a potential difference between the electrodes. This effect causes some deflection of the beam before it reaches the deflecting electrodes.

The space between deflecting electrodes is tapered away from the cathode to follow the contour of the converging beam so that deflection sensitivity and, hence, deflection transconductance are high. The gap at the far end of the deflecting electrodes is made as small as practical tube manufacture permits in order to achieve maximum deflection transconductance and to minimize the amount of beam current which passes through the gap. Although most of the electrons which do pass through the gap return to the plates, the percentage collected by the deflecting-electrode wires and side rods is higher than when the electrons pass through the deflecting electrodes in the normal fashion.

[2] J. R. Pierce, "Rectilinear Electron Flow in Beams," *Jour. App. Phys.*, Vol. 11, p. 548, August, 1940.

The spacing between the deflecting electrodes and between the plates is also tapered away from the cathode. This feature decreases the deflecting-electrode-to-plate amplification factor toward the far end and provides a slight accelerating field to inhibit the return of electrons toward the gun. The plates extend as close to the far end of the deflecting electrodes as practical to collect effectively the electrons which pass through the gap between deflecting electrodes. The plates do not extend close to the near end of the deflecting electrodes so that the deflecting-electrode potentials are more effective in focusing and deflecting the beam in the electron-lens region. The folded-over ends of the plates are used primarily for mechanical strength, although they do tend to collect some electrons which might otherwise graze the plate edge and follow long orbits before actually striking the plate. Experimental designs used half-grids for the control grid and the deflecting electrodes to eliminate the capacitance of the unused grid halves. Full grids, however, have been found to give a great advantage in the rigidity and reproducibility of the tubes.

The internal shield around the cage provides electrostatic shielding to reduce undesired coupling capacitances as well as to provide a small amount of shielding from external magnetic fields. The shield also prevents electron bombardment of the glass bulb and resulting gas evolution and bulb charges. The indentation in the shield is very important in returning the electrons that pass through the gap between deflecting electrodes directly to the plates. Without such a shield near the gap, the deflecting-electrode current and input-impedance characteristics are impaired.

TUBE CHARACTERISTICS

The characteristics of the electron gun of the 7360 are best shown by plate-characteristics curves for the triode-connected tube, as shown in Figure 3. The curves of Figure 3 are useful in estimating cathode current with normal electrode connections because cathode current is normally almost independent of deflecting-electrode voltage or plate voltage. The screen grid normally intercepts about 20 per cent of the cathode current and the deflecting electrode intercepts about one per cent. Therefore, the beam current, or sum of both plate currents, is about 79 per cent of the current shown in Figure 3.

Although the mean* potential of the deflecting electrodes is chosen

* To avoid cumbersome descriptions later in the paper, the term "mean" will refer to the instantaneous mean of the two electrode quantities in question; "average" will refer to a time-average current or voltage; and "differential" will imply measurement of one electrode quantity with respect to the other, irrespective of another reference point.

primarily on the basis of best deflection characteristics, some limitations are imposed by other characteristics. If the mean deflecting-electrode voltage is less than about 10 volts, appreciable beam current may be turned back to the screen grid at low plate voltages; in effect, the tube will be "oversuppressed." Inasmuch as normal mean deflecting-electrode voltage is about 20 to 30 volts, the oversuppressed condition would be reached only if single-ended signals of large amplitude were applied to one deflecting electrode. If very large signals are to

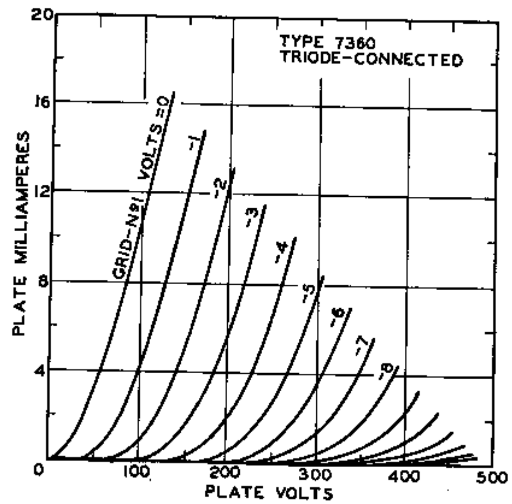

Fig. 3—Plate characteristics of triode-connected 7360 (deflecting electrodes and plates tied to Grid No. 2).

be encountered, therefore, push-pull operation of the deflecting electrodes is recommended so that the mean deflecting-electrode voltage will remain constant.

The effects of the mean plate voltage are apparent in the plate-characteristics curves of a "pentode-connected" tube shown in Figure 4. These curves are applicable for the values indicated for mean plate voltage and mean deflecting-electrode voltage even though a differential voltage may exist between plates or between deflecting electrodes. Plate voltage affects deflecting-electrode current appreciably; deflecting-electrode current is about one per cent of the beam current at plate voltages of 150 volts. It drops to about 0.5 per cent at 300 volts and rises to about 5 per cent at 50 volts.

Figure 5 shows the deflection characteristics obtained for one set

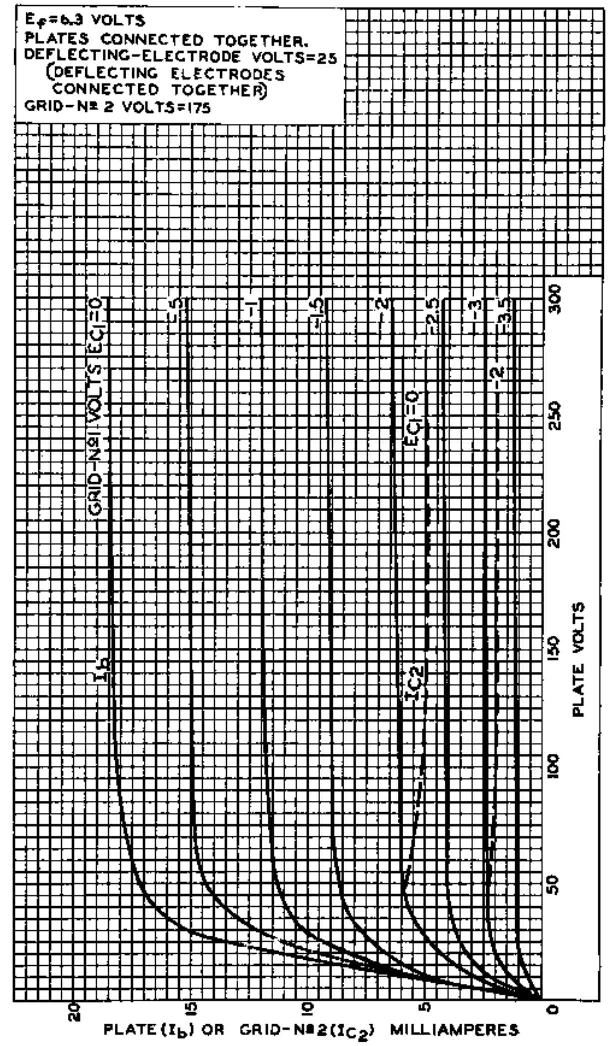

Fig. 4—Plate characteristics of 7360 used as pentode.

of conditions of control-grid, screen-grid, plate, and mean deflecting-electrode voltages. The transconductance and amplification-factor values are measured from deflecting electrode No. 1 to plate No. 1 or from deflecting electrode No. 2 to plate No. 2; the same values, though negative in sense, are obtained from deflecting electrode No. 1 to plate No. 2 or from deflecting electrode No. 2 to plate No. 1. The mean deflecting-electrode voltage may be reduced to about 11 volts or raised to 35 volts before the plate-current curves are noticeably affected. Similarly, the plate voltage is not critical over a range of 50 to 300 volts.

The value of the amplification factor (μ) is rather low, and, as a result, the values of *differential* plate resistance are rather low; *parallel* plate resistance is very high, as can be seen in the curves of Figure 4. This low-μ characteristic appears to be a result of the construction in which the plates lie alongside the deflecting electrodes.

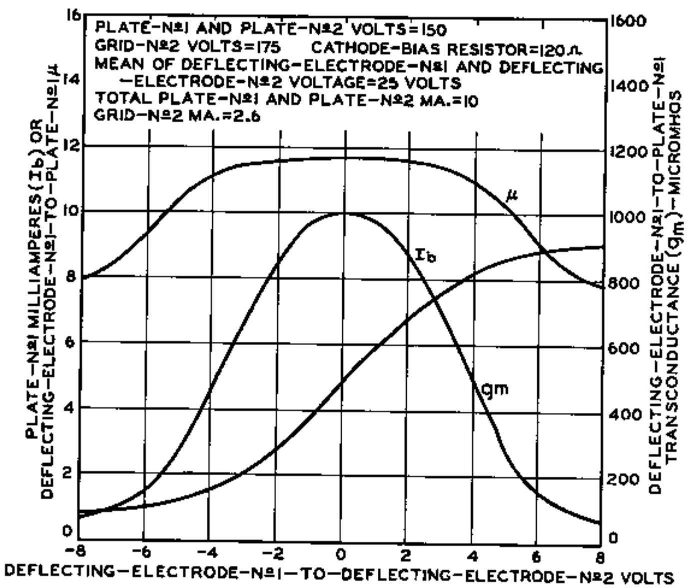

Fig. 5—Curves of 7360 showing plate current, transconductance, and μ as a function of differential deflecting-electrode voltage.

Differential plate voltage must also tend to deflect the beam, although the effectiveness is reduced by the deflecting-electrode-to-plate μ. It is less evident that the same effect occurs in the conventional structure shown in Figure 1; in fact, the μ of the design shown in that figure is almost the same as that indicated in Figure 5. The μ and plate resistance could be increased in either type of structure by the use of additional screen grids, but the grids would add considerable complexity.

The screen-grid voltage has a significant influence on deflection

characteristics. An optimum screen-grid voltage may be found for each value of beam current, although a range of plus or minus 25 volts from the optimum is not serious. This effect is illustrated by the two sets of curves shown in Figure 6. Both curves have the same

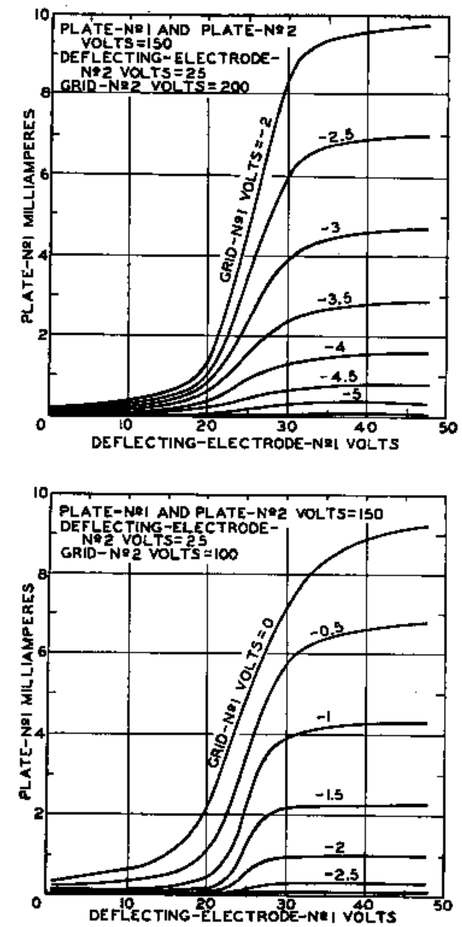

Fig. 6—Curves of 7360 showing influence of control-grid and screen-grid voltages on the linearity of deflection characteristics.

plate-current and differential deflecting-electrode voltage scales but represent different screen-grid voltages. Mean deflecting-electrode voltage was set at the optimum value for each screen-grid voltage. Deflection transconductance (slope of the plate-current curves) at low currents is best at the lower screen-grid voltage, while the higher screen-grid voltage is best at higher currents. The implication of these characteristics in obtaining linear deflection characteristics when the grid is operated under class-C conditions in some circuits will be discussed later.

The internal capacitances and average characteristics of the 7360 are given in Table I. One bit of additional information regarding capacitances may be useful in some circuits; although the internal cage shield is shown connected to the cathode, the mica and stem shields are connected to the screen grid for convenience and for heat radiation. It is usually preferable, therefore, to have both cathode and screen grid at r-f ground potential.

General Product-Modulator Considerations

The beam-deflection tube is intended to be used as a product modulator. To the extent that the output of the tube is the mathematical product of the two input signals, two sine-wave inputs will give an output proportional to the product of the amplitudes of the input signals. The frequencies of the output will be the sum and difference frequencies of the input signals. If the input signals are of the same frequency, the output will comprise a second-harmonic component and a direct-current component. The direct-current component will be proportional to the cosine of the phase difference between the two input signals. If the input signals have a direct-current component, the output will include components at the input frequencies. This type of output is usual because most product devices must be biased in a manner such that the input signals have, in effect, a direct-current component. In applications of this type, one of the input frequencies may be eliminated from the output by balanced operation of the beam-deflection tube. In addition to the output components mentioned above, other components will be produced by distortion in the product device.

The basic product modulator may be used to perform many circuit functions, including modulation in transmitters; frequency conversion in superheterodyne receivers; and product detection for single-sideband reception, synchronous detection, and frequency-modulation detection.

Efficiency and Gain Considerations

In most circuits utilizing a product modulator, one of the input signals, the CW signal, has constant amplitude, while the other signal contains the communicated information. The CW signal input is often

Table I — General Data

Electrical:		
Heater, for Unipotential Cathode:		
Voltage (AC or DC)	6.3 ± 10%	volts
Current	0.35	amp
Direct Interelectrode Capacitances (With no external shield):		
Grid No.1 to all other electrodes except plates	7.5	μμf
Grid No.1 to deflecting-electrode No.1	0.015	μμf
Grid No.1 to deflecting-electrode No.2	0.015	μμf
Grid No.1 to plate No.1	0.003	μμf
Grid No.1 to plate No.2	0.003	μμf
Plate No.1 to all other electrodes except deflecting-electrode No.1	0.8	μμf
Plate No.2 to all other electrodes except deflecting-electrode No.2	0.8	μμf
Plate No.1 to plate No.2	0.3	μμf
Deflecting-electrode No.1 to all other electrodes except plate No.1	4.6	μμf
Deflecting-electrode No.2 to all other electrodes except plate No.2	4.6	μμf
Deflecting-electrode No.1 to plate No.1	4.0	μμf
Deflecting-electrode No.2 to plate No.2	4.0	μμf
Deflecting-electrode No.1 to deflecting-electrode No.2	1.4	μμf
Characteristics, Class A1 Amplifier:		
Plate-No.1 Voltage	150	volts
Plate-No.2 Voltage	150	volts
Deflecting-Electrode-No.1 Voltage	25	volts
Deflecting-Electrode-No.2 Voltage	25	volts
Grid-No.2 Voltage	175	volts
Cathode Bias Resistor	150	ohms
Total Beam Current (Plate-No.1 Current plus Plate-No.2 Current)	8.5	ma
Grid-No.2 Current	2.1	ma
Transconductance, between grid No.1 and plates connected together	5400	μmhos
Deflecting-Electrode No.1 Transconductance to Plate No.1.	800	μmhos
Deflecting-Electrode No.2 Transconductance to Plate No.2.	800	μmhos
Maximum Ratings, Absolute-Maximum Values:		
Plate-No.1 Voltage	300 max.	volts
Plate-No.2 Voltage	300 max.	volts
Deflecting-Electrode-No.1 Voltage	±100 max.	volts
Deflecting-Electrode-No.2 Voltage	±100 max.	volts
Grid-No.2 (Screen-Grid) Voltage	250 max.	volts
Plate-No.1 Dissipation	1.5 max.	watts
Plate-No.2 Dissipation	1.5 max.	watts
Grid-No.2 Input	0.5 max.	watt

overdriven to minimize the effects of variations in its amplitude so that the output will be proportional only to the information-bearing signal. The efficiency and gain are improved when sufficient amplitude to saturate one input is used. The ultimate theoretical efficiency is 25 per cent with linear operation, but rises to 31.8 per cent when one input is overdriven. In circuits in which outputs insensitive to either input amplitude and responsive only to phase difference are desired (as in phase detectors and FM detectors), both inputs may be overdriven. Maximum efficiency with both inputs overdriven is 50 per cent. Furthermore, the output is more nearly a linear function of phase difference with this type of operation than it is when linear, or class A, operation is used. Use of only one output current, as required with conventional grid-No.3 control, reduces the efficiencies to one half the above values.

CW Signal Input

The CW signal may be applied to either the control grid or the deflecting electrodes depending upon the operating characteristics desired. In general, it is preferable to apply the CW signal to the deflecting electrodes in small-signal circuits, such as frequency converters in receivers, where maximum gain is desired. In detectors, modulators, and transmitter frequency converters, lack of distortion may be more important than gain, and operation with the CW signal on the grid is preferable.

Either type of input may be used to convert on a harmonic of the CW signal. Although gain and noise performance are sacrificed by harmonic operation, the result may be more economical in some applications than the use of frequency multipliers preceding the converters.

CW Signal Applied to Grid

When the CW signal is applied to the grid and the information-bearing signal is applied to the deflecting electrodes, the information-bearing signal and the modulation products are in push-pull at the two plates, while the CW signal components are in the same phase. Because they are in the same phase, the CW signal components may be cancelled out in a balanced load circuit. The information-bearing signal may be applied to the deflecting electrodes in either a single-ended or a push-pull arrangement; it is the voltage difference between deflecting electrodes that produces deflection. At very high frequencies, however, push-pull operation has the advantage of lower effective input capacitance.

Small-signal performance may be conveniently analyzed by the use

of frequency-converter theory.[3] For determination of conversion transconductance, deflecting-electrode-to-plate transconductance is plotted as a function of control-grid voltage, as shown in Figure 7. Then, with assumed conditions of control-grid bias and CW-signal amplitude, the deflecting-electrode-to-plate transconductance (g_m) curve as a function of time is analyzed by Fourier methods for the fundamental frequency component. This component gives the conversion transconductance (g_c). After a few calculations from trial grid-voltage conditions, inspection of the curves reveals that the average grid voltage

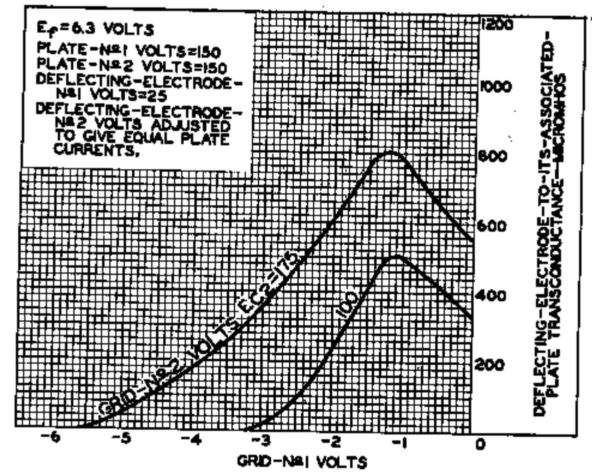

Fig. 7—Curves of deflecting-electrode-to-plate transconductance.

should be placed near cutoff on the g_m curve, and that the CW signal should swing slightly past the peak of the g_m curve for maximum conversion transconductance. Operation under these conditions of grid voltage and signal input results in a conversion transconductance of 25 to 30 per cent of the peak g_m; 300 to 350 micromhos is the maximum obtainable within tube ratings.

The effective plate resistance, r_p, at the output frequency may be determined from the same data used to find conversion transconductance. The average g_m is calculated; average r_p is the quotient of the deflecting-electrode-to-plate μ (about 13) and the average g_m. The average of the g_m curve is slightly higher than the fundamental com-

[3] E. W. Herold, "The Operation of Frequency Converters and Mixers for Superheterodyne Reception," *Proc. I.R.E.*, Vol. 30, No. 2, February, 1942.

ponent (g_c). Therefore, the product of g_c and r_p, the maximum possible conversion voltage gain, is slightly less than the deflecting-electrode-to-plate μ, or about 10. This maximum gain is not critically dependent upon control-grid operating conditions; small changes in grid conditions, in the direction that will reduce g_c, usually raise r_p. This characteristic is sometimes useful in that it is possible to increase grid drive to raise r_p, and thereby to accommodate a convenient circuit impedance more easily.

The conditions for maximum conversion gain require that the peak positive excursion of the grid voltage be about -2 volts. The conditions for minimum distortion are similar, as may be seen qualitatively by examination of the curves of Figure 6. Although the transfer curve for each grid voltage has a long straight portion, the grid swings through a range of voltages, and the conversion transfer curve is a composite of the curves shown. It is clear that the upper set of curves provides a more linear composite. When the CW signal is supplied from an external source, the bias and signal amplitude can be set so that the instantaneous grid voltage will be at least two volts negative at all times. Self-bias obtained from grid current may be desired, however, because it is relatively noncritical to CW signal amplitude and is the most convenient way to limit the amplitude of oscillation in a self-excited circuit. The advantage of grid-resistor bias may be obtained by use of a diode suitably biased so that it conducts while the grid is still negative. It is best to obtain the bias voltage from a cathode resistor, as shown in the circuits of Figures 9, 10, 11. Additional circuit stability may be obtained in this manner.

The "electron-gun" section of the beam-deflection tube can serve as a good oscillator for self-excited circuits. Feedback can be obtained from cathode current, screen-grid current, or total plate current. The use of cathode current in the Hartley circuit commonly used with frequency converters is usually preferable. In this circuit, the r-f cathode voltage is in the proper phase to place the cathode above ground potential during the cathode current pulse. The resulting reduction in effective deflecting-electrode bias should be considered in choosing the average deflecting-electrode-to-ground voltage.

CW Signal Applied to Deflecting Electrodes

When the CW signal is applied to the deflecting electrodes, the conversion transconductance may be determined by the same type of analysis used when the CW signal was applied to the grid. A plot of grid-to-plate g_m as a function of differential deflecting-electrode voltage is used as the starting point. This curve will follow the pattern

of the plate-current versus differential-deflecting-electrode-voltage curves shown in Figures 5 and 6. The g_c to each plate may be as high as about 30 per cent of the peak g_m to each plate. A g_c of 1500 micromhos is readily obtained under the operating conditions given in Table I, which shows a g_m of 5500 micromhos at 10 milliamperes of beam current. The differential r_p is approximately 14,000 ohms at the instant that the beam current is equally divided between the plates, but is very high when the current is fully switched to one plate. The average differential r_p is, therefore, a function of the amplitude of the deflecting-electrode signal; the amplitude of the signal determines the fraction of the cycle during which the r_p is low. The average differential r_p may be as high as several hundred thousand ohms under practical operating conditions. The conversion gain, therefore, may be higher than that of the best pentagrid tubes, and about equal to that of a good pentode mixer in which both signals are applied to the control grid. It is difficult to apply automatic gain control to the beam-deflection tube. In this respect, it is no better than the pentode. The oscillator-to-signal coupling and the oscillator radiation are, however, lower in the beam-deflection tube than they are in the pentode.

Noise in beam-deflection-tube converters that have the CW signal on the deflecting electrodes is comparable to that in good pentode mixers. The main contribution to noise is made by partition noise from the screen-grid current. In the 7360, the screen grid collects about the same fraction of the space current as it does in pentodes, and much less than it does in pentagrid converters. At high frequencies, the noise factor of the 7360 is degraded by fairly high input loading. This loading results from the cathode-lead inductance which is higher than normally found in pentodes. Tubes made with a special basing arrangement to reduce cathode-lead length provided noise figures of about 11 decibels at 100 megacycles and conversion power gain of about 16 decibels. This basing arrangement has not been adopted, however, because it is inferior for other applications.

The converter may be made self-exciting by use of the deflecting electrodes and plates for the oscillator. Although the deflection transconductance is rather low compared to the transconductance of triodes, oscillation up to about 200 megacycles has been obtained with a balanced oscillator having a tuned circuit between plates, and capacitance coupling from each plate to the opposite deflecting electrode. Inductive coupling may also be used with a single tuned circuit or with tuned circuits between plates and between deflecting electrodes. The oscillator circuit for a converter is complicated by the presence of the inter-

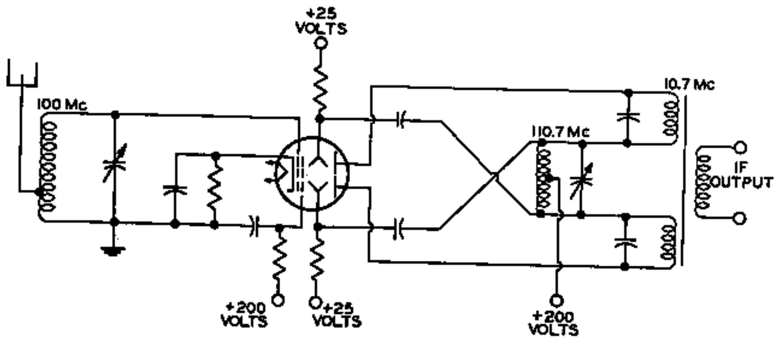

Fig. 8—Diagram illustrating use of 7360 as a self-excited frequency converter for FM receivers.

mediate-frequency transformer, but a circuit like that shown in Figure 8 has been made to work in the FM band.

Balanced-Modulator Application

The balanced modulator used to generate single-sideband signals makes especially good use of the beam-deflection-tube characteristics. The main technical requirements in this application are stability of carrier balance and low distortion. Low distortion implies carrier

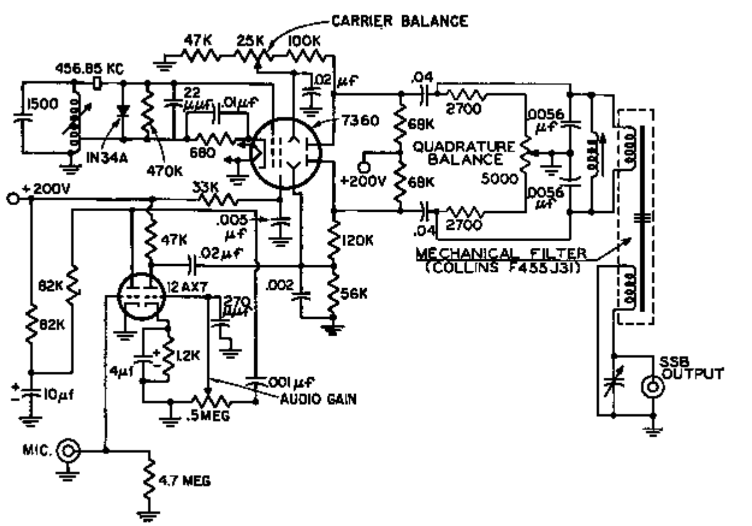

Fig. 9—Schematic of experimental single-sideband modulator using 7360.

suppression at various signal levels, and minimum spurious outputs. For economic reasons, it is desirable to have input signals at convenient voltage and impedance levels and to have some gain to reduce requirements for subsequent amplification.

The structure of the 7360 is particularly well suited to achieving stable balance of plate currents, because both plate currents originate from the same cathode face, grid, and screen grid. It also lends itself to simple and effective feedback stabilizing circuits. The deflection characteristics have very good linearity, and substantial power gain can be obtained.

The features of the tube in this application may be conveniently described by examination of a laboratory single-sideband generator that was built to investigate circuit design and tube performance. The schematic diagram of Figure 9 shows the carrier oscillator, audio amplifier, balanced modulator, and mechanical filter. The mechanical-filter system, which eliminates one sideband, was chosen as the most straightforward way to study balanced-modulator performance. The tube, however, should work well in phasing systems also.

The beam-deflection tube, used in a crystal-oscillator circuit with cathode-current feedback, provides the carrier at approximately 455 kilocycles. The proper grid-to-cathode signal amplitude of 5 to 10 volts peak-to-peak is easily provided by this type of crystal-oscillator circuit, as well as by several other types. The diode is used in conjunction with cathode bias to clamp the grid signal so that the grid swings no more positive than —2 volts.

The audio signal from a crystal microphone is amplified by a two-stage amplifier. The 270-micromicrofarad capacitor at the grid of the second stage was needed to reduce coupling of the carrier into the audio channel even though there is a carrier-frequency bypass capacitor (0.002 microfarad) from deflecting electrode to ground.

The d-c resistance in the deflecting-electrode circuit is preferably limited to about 50,000 ohms because of the flow of current to the deflecting electrodes. Furthermore, the nonlinearity of the current as a function of deflecting-electrode voltage has been considered even though the current is small. Equal d-c resistance is used in each deflecting-electrode circuit to minimize shift in carrier balance with audio-signal level. The coupling capacitor to the driven deflecting electrode is made large for minimum source impedance to minimize distortion of the audio signal from the nonlinear load. The undriven deflecting electrode is bypassed for audio frequencies to ensure that the current flow in that deflecting electrode does not set up a distorted audio voltage.

The 12AX7 provides an audio signal of 5 to 10 volts peak-to-peak. The plate load resistance is rather low for a high-μ tube, and it would be somewhat easier to drive the deflecting-electrode from a medium-μ triode. If a medium-μ tube were used, however, it might be best to use a pentode in the preamplifier stage to make up for the lower gain.

The transducer coil of the mechanical filter could be used as the push-pull load circuit except for the fact that the output of the beam-deflection tube is so large that there is severe distortion in the mechanical filter. (Double-sideband output of 40 volts peak-to-peak is readily obtained in high-impedance loads.) It is desirable to use the full output capabilities of the tube to realize the best relative carrier suppression. Consequently, the load impedance was reduced to about 2500 ohms by means of a tuned circuit in parallel with the filter input. The net Q of the output circuit was also increased in this way; the filter input coil has a Q of about 10. The tube output could have been reduced by decreasing screen-grid voltage, but the oscillator performance would have been impaired.

Each plate of the 7360 is shunt-fed through a 68,000-ohm resistor to achieve stable balance. Any unbalance in plate currents produces a voltage difference between plates which opposes the unbalance. The d-c feedback obtained in this manner amounts to 9 decibels in the circuit shown. For reduced distortion, the negative feedback can be extended through the audio range by coupling the output to the load with about 0.002-microfarad capacitors in place of the 0.04-microfarad capacitors shown. This audio feedback was not used in the experimental circuit because the audio amplifier had excessive distortion at the high output level required. However, the 0.04-microfarad capacitors used provide some hum reduction by feedback at 60 cycles.

Additional d-c feedback is provided by obtaining deflecting-electrode voltage with bleeders from the plates. In this way, part of the plate voltage change, caused by shifts in plate-current balance, is applied to the deflecting electrodes to oppose the change. The total d-c feedback is 17 decibels. This feedback is a substantial aid to stability of carrier balance. It should be noted, however, that feedback to the deflecting electrodes shifts some of the burden of stability from the tube to the resistors in the two bleeders. If this type of feedback is not used, a common bleeder should be used for deflecting-electrode voltage so that resistor changes primarily affect mean deflecting-electrode voltage rather than the differential deflecting-electrode voltage.

Adjustment of plate-current balance is provided by making one deflecting-electrode voltage variable. The adjustment is the main carrier balance control, but, for excellent carrier balance, the phases of

the currents being balanced must be equal within very small tolerance. An adjustment of quadrature balance, therefore, is usually required. In the circuit of Figure 9, the tuned load circuit has a high C/L ratio; unbalance of resistances across each half of the balanced circuit provides adjustment of quadrature balance almost independent of in-phase balance. The resistance in the quadrature-balance circuit must be fairly high compared to the resonant impedance of the tuned circuit to preserve the independence of the balance adjustments.

Another method of obtaining quadrature balance has been tested successfully. In this method, some carrier signal is applied to the appropriate side of the balanced load circuit through a small adjustable capacitor to provide 90 degrees phase shift. The use of a differential capacitor connected to both plates provides a practical means to adjust the amplitude of the inserted carrier at either plus or minus 90 degrees. Alternatively, a variable capacitor can be connected from the grid to one plate, and a fixed capacitor with a value at about the center of the range of the variable capacitor can be connected from the grid to the other plate. The necessary phase corrections are so small that capacitance values less than one micromicrofarad are needed when the carrier signal is obtained from the grid. More commonplace values of capacitance can be used if the carrier is fed from a lower voltage point, such as the cathode in the circuit of Figure 9.

The mechanical filter attenuates the carrier frequency about 20 decibels, and carrier balance of 90 decibels below peak signal output is readily obtained. The significant feature of performance, however, is that carrier suppression remains better than 60 decibels with 10 per cent variations of heater voltage, B voltage, or both.

BALANCED-MIXER APPLICATION

Tube operation in the balanced-mixer circuit is much like that in the balanced modulator. The balanced mixer is frequently used in single-sideband transmitters. When modulation is performed at a low frequency, the signal is translated to the carrier frequency by mixing, or heterodyning, with appropriate frequencies. The modulation must not be distorted as it would be in a frequency multiplier. There is a restriction on the frequency of the CW signal relative to the frequency of the information-bearing signal, because the CW signal and the unwanted "beat" signal must be far enough from the desired "beat" signal to be conveniently eliminated by the selectivity of the tuned circuits. This restriction is eased by the use of a balanced mixer which substantially attenuates the CW signal. The balance requirements are not as severe as they are for the balanced modulator, however, because simple selective circuits capable of adequately attenuating the undesired beat also considerably attenuate the CW signal frequency. Balance is consistent enough among 7360 tubes that a balance adjustment is unnecessary if oscillator signal level up to about 20 decibels below the desired signal (excluding circuit selectivity) is tolerable.

Figure 10 shows an experimental balanced-mixer circuit. This unit was used in conjunction with the single-sideband generator of Figure 9. An intermediate amplifier was also required for experimental work

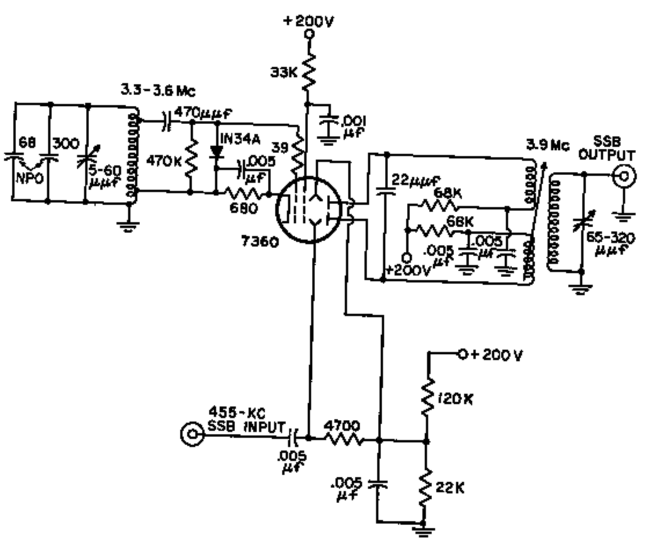

Fig. 10—Schematic of experimental balanced mixer using 7360.

because the mechanical filter was incapable of enough output to drive the mixer adequately.

The beam-deflection tube is also used as a variable-frequency oscillator made stable by the well-known technique of tapping the tube down on a stable, high-Q, tuned circuit having fairly high C/L ratio. Single-sideband input of up to 5 volts peak-to-peak is fed, single-ended, to one deflecting electrode. The push-pull plate circuit is arranged so that the currents from the two plates flow through separate 68,000-ohm resistors to stabilize balance. The plate coils of the output transformer are bifilar-wound to assure tight coupling and accurate center tap for good balance. This output circuit was double-tuned for adequate selectivity; a low-impedance output was used to minimize detuning when various experimental uses were made of the output.

Observations made with limited equipment indicated that the distortion was low even at signal levels considerably higher than those normally possible with other types of mixers. The simplicity of using a single tube as oscillator and balanced mixer is evident. In some transmitter systems it may be possible to eliminate frequency multipliers for the CW signal because the relatively large signal levels handled by the beam-deflection tube may make conversion on harmonics of the CW signal practical despite the lower gain.

Product Detector Application

Another very promising modulator application of the beam-deflection tube is as the product detector used in single-sideband receivers. The "beat-frequency oscillator" (BFO) signal is applied to the control grid. The 7360 may serve as its own oscillator as in the above applications. The intermediate-frequency signal is applied to the deflecting electrodes, preferably in push-pull, and the demodulated output is taken from the plates either single-ended or push-pull.

Although considerable input signal can be handled with low distortion, a sharp overload point is reached at slightly higher levels so that good limiting of impulse noise is provided in the detector. Even at overload, however, the deflection characteristics are symmetrical, and there is little undesired signal rectification or "envelope detection." The detector has substantial gain and enough output to drive a power amplifier directly. The BFO signals are in phase at the plates and may be balanced out with the use of a suitable output transformer. The transformer requirements are especially practical with low intermediate frequencies, which are difficult to filter adequately when unbalanced detectors are used.

Figure 11 shows the schematic diagram of an experimental product detector. This unit was built as an adapter for a war-surplus communication receiver having a 910-kilocycle intermediate frequency.

The oscillator uses the principles discussed above for frequency stability and for grid-voltage conditions to secure optimum detection linearity. Balanced signal input is used to minimize coupling of signal to the oscillator grid and to minimize coupling of the oscillator into the i-f amplifier. Coupling of the signal to the oscillator grid tends to lock the oscillator on the signal frequency. In the test circuit, the oscillator did not lock until a CW signal of normal amplitude was brought to within about 5 to 10 cycles of the oscillator frequency. If

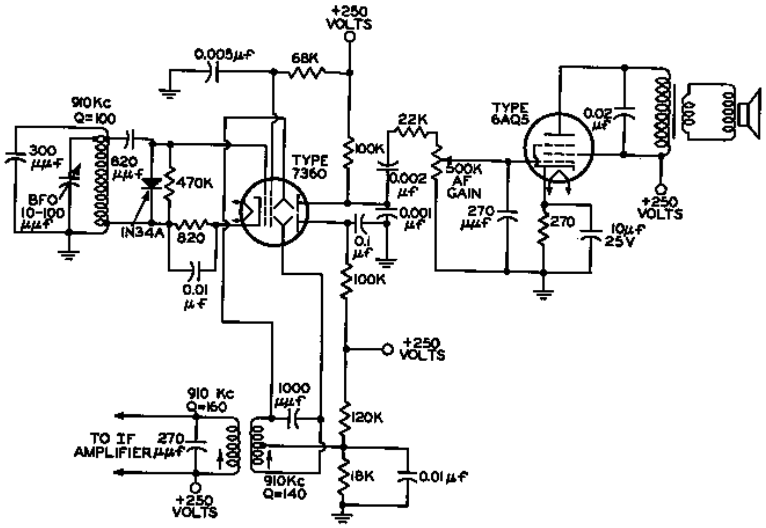

Fig. 11—Schematic of experimental product detector using 7360 for single-sideband or CW reception.

desired, the locking tendency could be reduced by provision for adjustable neutralizing of the signal-to-oscillator coupling or by use of a separate oscillator. Oscillator locking was used for synchronous

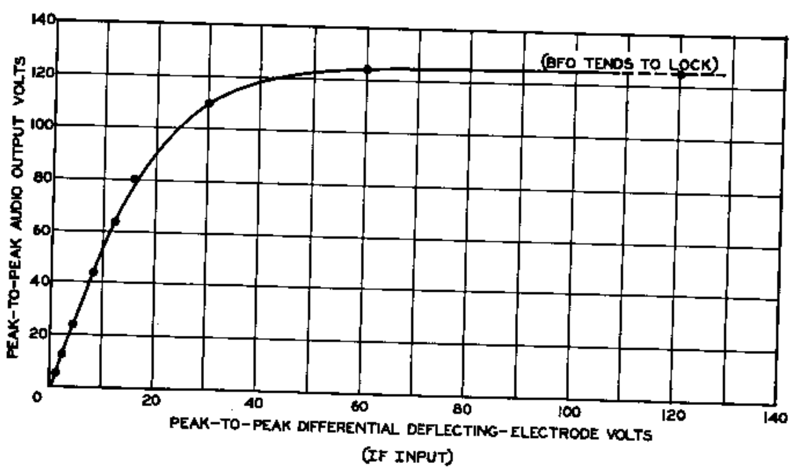

Fig. 12—Curve showing linearity and overload characteristics of product detector circuit (Figure 11).

detection of AM signals by including a switch (not shown) to lower the oscillator-circuit Q and to add resistive signal-to-oscillator coupling so that the oscillator would lock in the proper phase on a carrier within about 200 cycles of the natural oscillator frequency.

RC filtering was sufficient to attenuate the BFO frequency in this instance, and single-ended output to a power amplifier tube formed a simple circuit arrangement. Note that equal plate-load resistors are used to obtain the proper d-c voltages, but that one plate is bypassed for audio frequencies. This bypassing permits full differential r_p to be obtained and, thus, increases the gain at the plate used for output.

Conversion voltage gain, linearity, and limiting characteristics are shown in Figure 12.

Other Circuit Applications

There are many possible circuit applications outside of the communications field. The tube may be useful in pulse-combining circuits. The deflecting-electrode characteristics are such that a signal may be clipped at both positive and negative peaks at the same time. Two signals may be added in well-isolated inputs by feeding one signal to each deflecting electrode. Output signals of both polarities are obtained, and the effective polarity of an input signal can be changed by switching it from one deflecting electrode to the other.

Acknowledgment

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