A Cathode-Coupled Triode Mixer

by

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9.3. Triode Mixer Design and Application. The triode mixer has not been used anywhere near the extent it deserves, because when properly employed it can have almost all the advantages of both the diode and the multigrid devices, without their disadvantages. It has a very low noise content, high conversion efficiency, can, with proper design, have excellent stability, and can isolate the oscillator from the incoming signal very effectively. The following paragraphs first show how the simple triode mixer is designed, and then discusses some of the more elaborate mixer circuits and their advantages.

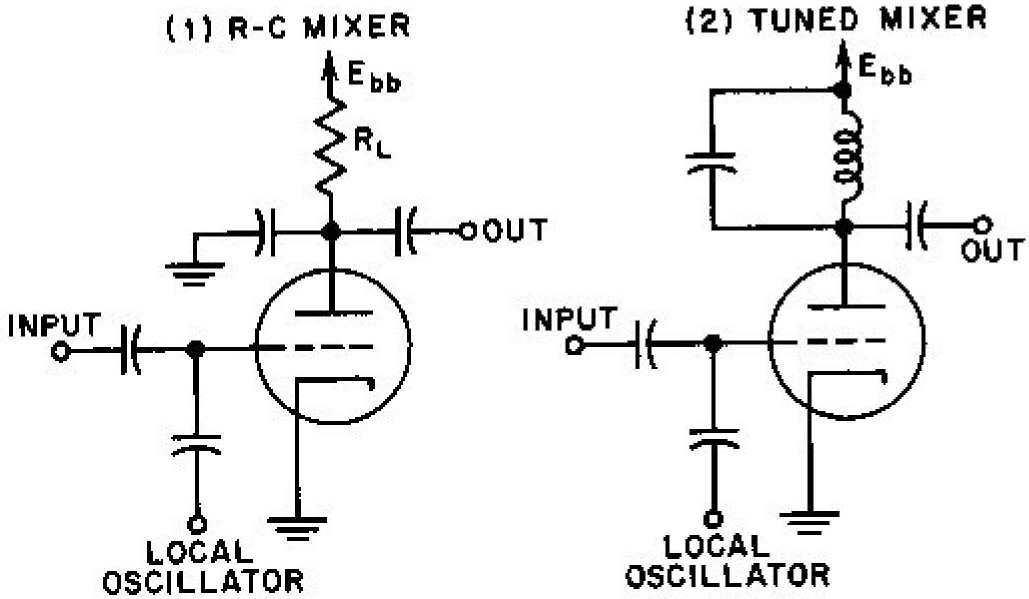
9.3.1. Design of the triode mixer. The triode mixer makes use of an ordinary triode amplifier under conditions of rapidly varying amplification; it obtains thereby the converter action required for efficient mixing. Like other mixers having conversion amplifications greater than unity, it obtains its mixing action through the development of a continuously varying amplification generated by the applied local oscillator voltage. The conversion gain, if the variation of amplification is reasonably linear, may be approximated by the use of the equation:

$$K_c = .025\,(K_p - K_n) \tag{1}$$

If the variation of the amplification is not linear, then the approximately equivalent straight line should be drawn, and the endpoint values of it used in Eq. (1).

Calculation of the amplifications at the positive and negative voltage limits of the signal for the triode mixer is fairly conventional once the proper load lines have been plotted and the impedance and conductance data tabulated. As a somewhat special technique is required in the establishment of the load lines, the next paragraph discusses the plotting of these; after that, the calculation of the conversion gain is discussed.

The load lines for a converter are unique in that the load impedance in the plate circuit of the mixer tube is always very close to zero for both the injected signals (the received signal and the local oscillator signal), to minimize their transmission through the mixer. The load circuit is designed to present a relatively high output impedance only to the desired set of output frequencies (the I-F frequencies), with the result that only they are amplified appreciably. The first step in establishment of the load lines is to plot the static load line corresponding to the plate-circuit resistance; with a tuned output (L-C) circuit this load line is nearly vertical, whereas with an R-C output circuit, it has a slope corresponding to the load resistance in use



(Fig. 9.3.1a).

Fig. 9.3.1a. Circuits for R-C and tuned mixers.

(The capacitor is then used to reduce the impedance to the input frequencies to a negligible value.) After the static load line has been plotted, several sample input load lines (load lines for the input signals) at different values of bias provided by the local oscillator signal, may be plotted. With a tuned output circuit, these input load lines coincide with the static line, whereas with an R-C output circuit, they do not.

The output load lines (or load lines at the output frequency) may next be plotted at typical points on the static load line. The slope of these lines corresponds to the impedance of the load circuit at the output frequency. With the mixer using a tuned output, a series of these lines must be plotted cutting across the static load line at different values of local oscillator voltage, whereas with the R-C output, the output load line coincides with the static. These conditions are shown graphically in Figs. 9.3.1b and 9.3.1c.

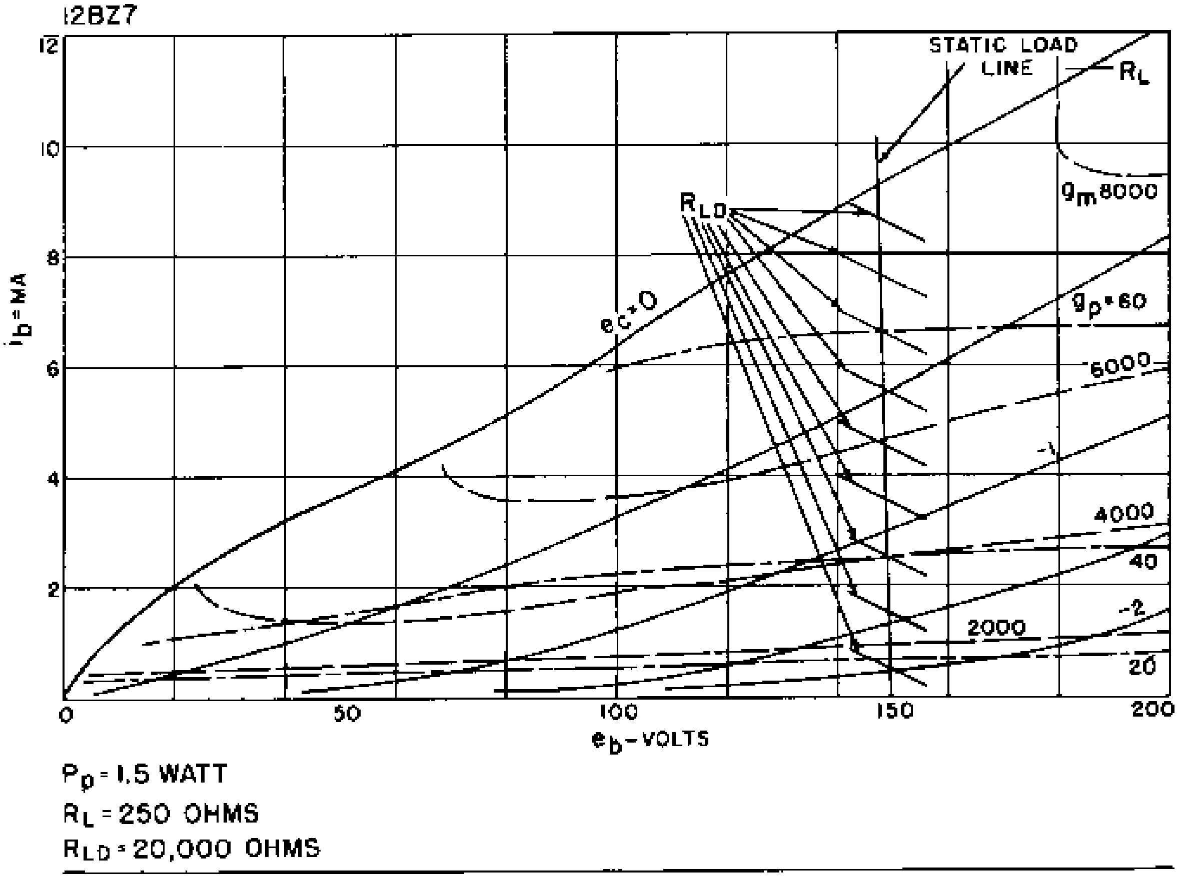


Fig. 9.3.1b. Design technique for an L-C mixer.

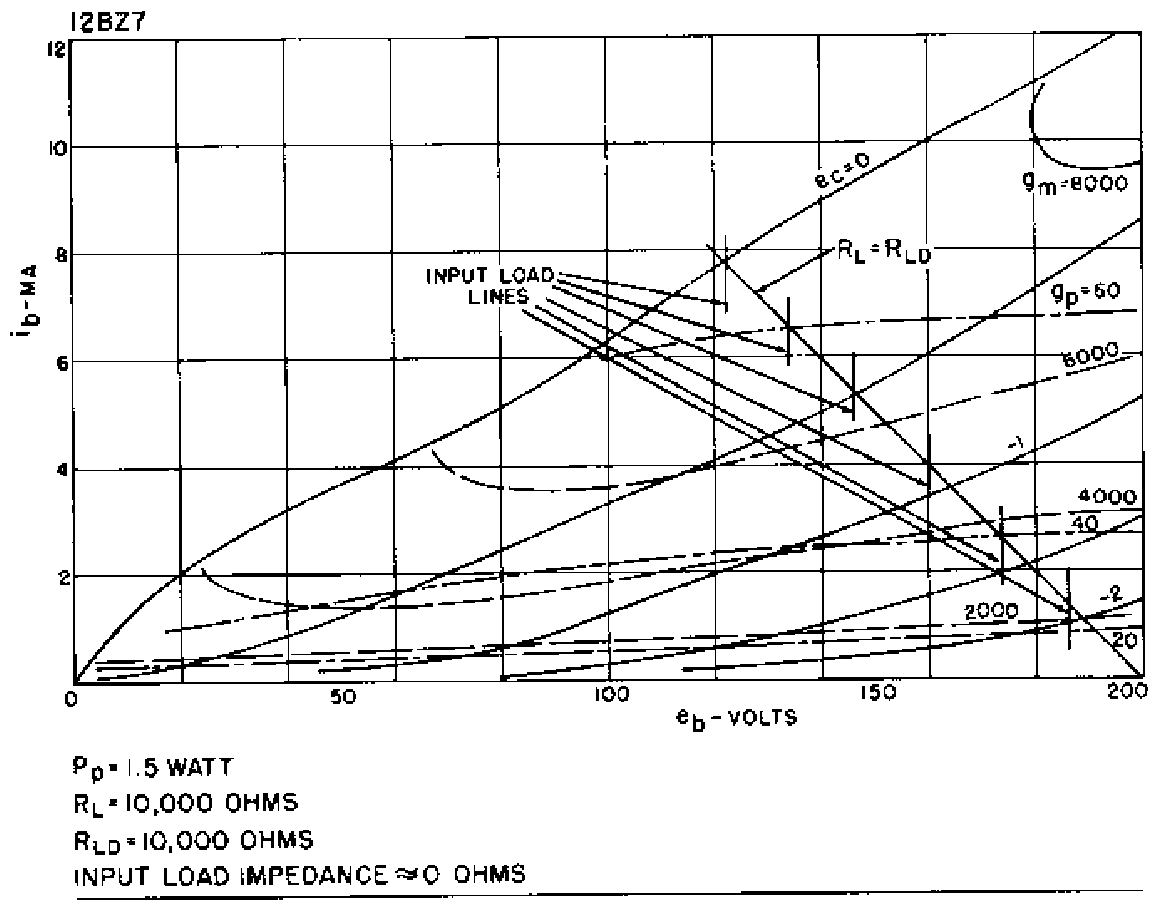


Fig. 9.3.1c. Design technique for an R-C mixer.

The first shows the load lines required for use with a tuned-output circuit, and the second for the R-C-output circuit. The local oscillator voltage provides the switching among the various static and output load lines, with the result that the effective transconductance and plate conductance applied to the incoming signal are altered by the local oscillator signal. The values of the small-signal parameters at the successive intersections between the load lines should be tabulated, and the amplifications at each point calculated. Then the conversion gain equation, Eq. 9.3.1 (1), may be used.

The calculation of plate-power dissipation both under normal signal and under conditions of loss of local-oscillator signal, is important with all types of mixers. The use of grid rectification bias makes certain that the mixer tube is used at maximum transconductance, and also keeps the average bias sufficiently high that relatively high plate voltages can be used. As a result, unless a cathode bias resistor is used, the mixer tube may often be damaged from excessive dissipation if the local-oscillator voltage is removed. Protection of the tube either by a selection of lower supply voltages, or by the introduction of a bias resistor is usually desirable.

Example 9.3.1. Calculate the conversion gains of the two mixers shown in Figs. 9.3.1b and 9.3.1c. For (b), R_{LD} = 20,000 ohms, R_L = 250Ω, and for (c), R_{LD} = 10,000 ohms.

At zero bias, the transconductance is 7600 μmhos, the plate conductance is about 70; at –2.5 volts bias, both are essentially zero. The maximum amplification is about 63, the minimum zero, giving a conversion amplification of almost 16. The maximum dissipation at zero bias is about

1.35 watts, a value rather high for safety. Introduction of a static bias of 1 volt would limit dissipation to less than one-half watt, but would not guarantee full use of the available transconductance, as a small decline in local oscillator voltage from the 2.5 volts peak-to-peak would eliminate rectification bias. A static bias of about 0.75 volts would be better. A bypassed cathode resistor having a resistance of 180 ohms is adequate.

For the second mixer, Fig. 9.3.1c, approximately –3.5 volts bias reduces the gain to zero, and at zero bias, the transconductance is about 7300 μmhos, and the plate conductance is about 60. The maximum amplification is 45, the conversion about 11. Maximum dissipation, at zero bias, is 1 watt, with the result that at least one-half volt of cathode bias is desirable, to limit the dissipation to about 0.75 watts. The cathode bias resistance required is nominally 93 ohms; 91 ohms would be used.

9.3.2 The Cathode-Coupled Mixer. The undesirable features normally encountered in triode as compared to multigrid mixers, can usually be overcome by using a form of cathode-coupled amplifier in this capacity. The arrangement has one principal disadvantage — ***TWO dual-triode*** tubes are required to accomplish the mixing equivalent to that obtained from a multigrid mixer. The basic circuit is shown in Fig. 9.3.2a.

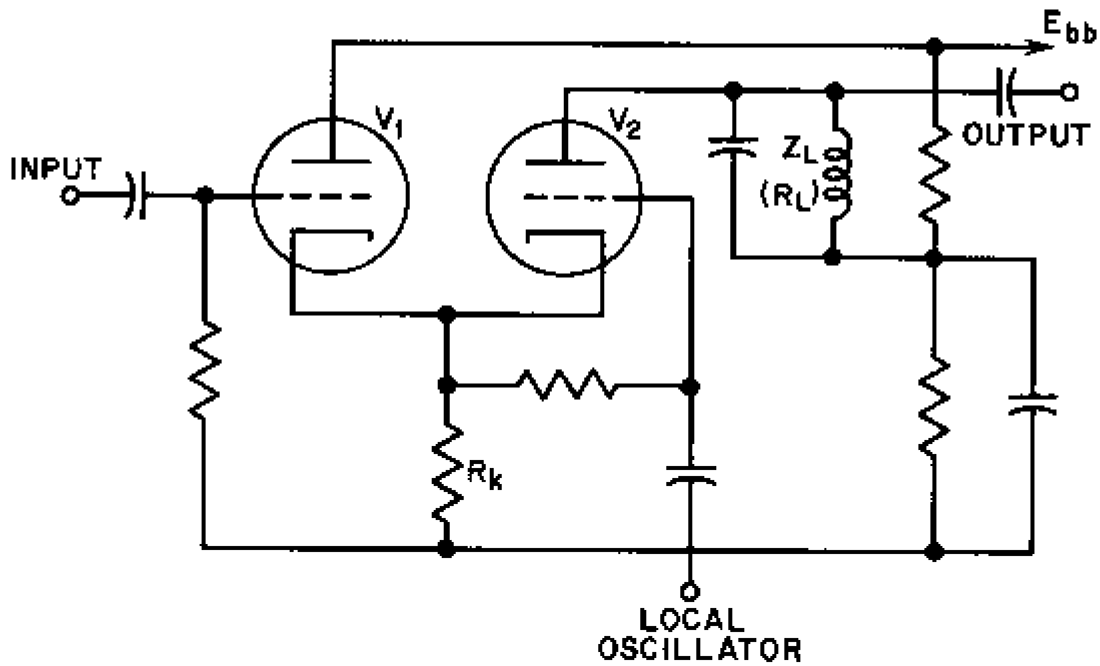


Fig. 9.3.2a. Circuit of a cathode-coupled mixer.

<u>Isolation of the input from the local oscillator is obtained by the use of the two cathode followers, one to inject the received signal into the cathode of the mixing triode, and the other to inject the local oscillator voltage into the grid.</u> The remaining triode section is used as the local oscillator itself.

Calculation of the conversion amplification of this circuit may be accomplished by use of the equation for the amplification of a cathode-coupled amplifier, in conjunction with the load-line and mixer techniques just described. The equation for amplification of the circuit, in simplified form, has been shown to be:

$$K = g_{m1}\, g_{m2}\, R_k\, R_L / [1 + (g_{m1} + g_{m2})\, R_k] \qquad (1)$$

To obtain linear mixing with this circuit, the value of g_{m1} over the range of operation should be large compared to g_{m2}, and $g_{m1} * R_k$ should have a value in excess of 3. Then Eq. (1) is approximately linear in g_{m2}, the grid on which the local oscillator is introduced. If grid rectification is used to establish the proper operating conditions on the tube V_2, it is necessary that the supply voltage for V_2 be appreciably less than that for V_1; otherwise the transconductance for the first section cannot exceed the maximum value for the second. As the total resistance in the output circuits for both V_1 and V_2, under static conditions, consists of the cathode resistance, R_k, the load lines for both tubes have a slope corresponding to the value of R_k. Because R_k has a resistance of at most a few hundred ohms, for practical purposes the load lines may be drawn vertically on the curves for the tube, each at its correct supply voltage.

The supply voltage for the input tube of the group should be chosen sufficiently high to bring its transconductance to a value appreciably larger than for the second tube. This may be accomplished as shown in Fig. 9.3.2b,

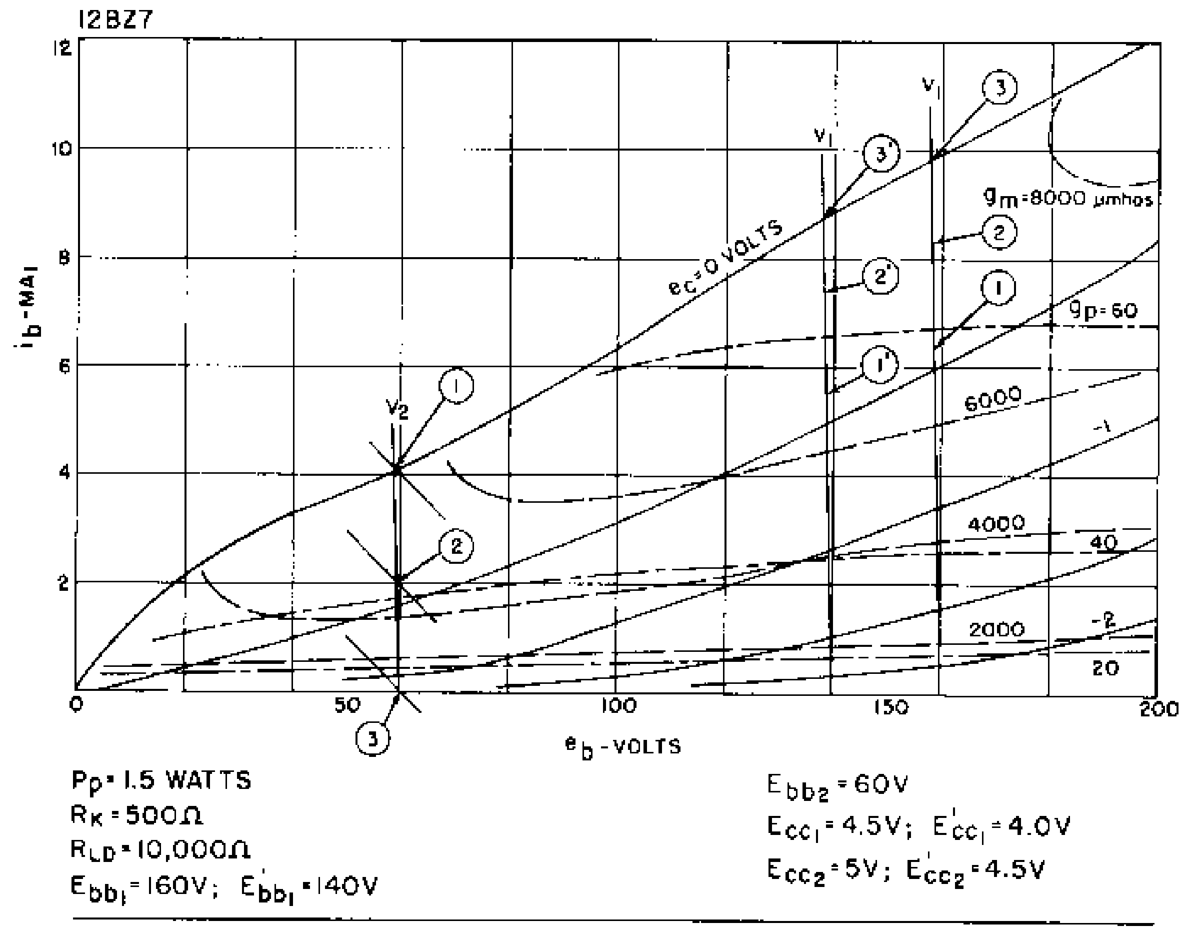


Fig. 9.3.2b. Design technique for a cathode-coupled mixer.

by placing the supply voltage for V_1 at 140 volts, that for V_2 at 60 volts. Then the fixed bias applied to V_2 should be nearly that required at point 1, and the voltage at point 3 set to provide zero bias on V_1, and cutoff on V_2. If the voltages are set correctly, grid rectification will adjust the voltages to the exact values required.

The equations for determining the corresponding points on the load lines are:

$$e_{c1} = e_i - (i_{b1} + i_{b2}) R_k$$
$$e_{c2} = e_s - (i_{b1} + i_{b2}) R_k, \qquad (2)$$

where e_i is the voltage on the input grid of V_1, and e_s the voltage on the grid of V_2, the local oscillator input. A value of e_i may be selected, and a value of e_{c1}, and the corresponding value of i_{b1}, chosen. Then in the first of the two equations, only i_{b2} is unknown, and it may be found by solving the equation. The resulting value of i_{b2} may be substituted in the second equation, the corresponding value of e_{c2} read from the tube curves, and the value of e_s determined.

Once the corresponding points on the two lines have been located, the data on the small-signal parameters may be tabulated and the amplifications calculated. Then the conversion gain is determined by the use of Eq. 9.3.2 (1).

Example 9.3.2. Design a cathode-coupled mixer using a 12BZ7 tube, with the supply voltage for the input tube 160 volts, for the output, 60 volts. Use a cathode resistance of 470 ohms. Adjust the design so that point 3 on the input tube corresponds to cutoff on the output tube.

The first step is to find the forward bias required on the input tube. Using the plate current i_{bi} = 9.7 ma, and e_{c1} = 0, with i_{b2} = 0, gives, by the first Eq. 9.3.1 (2), e_i – 4.6 volts. Repeating with i_{bi} = 8 ma and e_{c1} = -0.25 volts, gives 2.32 ma. Then e_{c2} is –0.35 volts, giving a value of e_s of 4.5 volts. The corresponding value for e_s for i_{b2} = 0, is e_s = 3.1 volts. In a similar manner the remaining values for the voltages and currents may be calculated. They are included in the following table:

Point	1	2	3
e_{c1}	0 v	−0.25	−0.40
i_{p1}	9.7 ma	8.0	6.7
e_1	4.6 v	4.6	4.6
i_{p2}	0.0 ma	2.32	3.95
e_{c2}	−1.5 v	−0.35	−0.0
e_s	2.6 v	4.5	5.0

Now, if the input grid is returned, through a grid leak, to a bias of about 4.5 volts, and the output grid to a bias of about 4.0 volts, grid leak action on both grids will establish the correct bias values with an applied local oscillator signal of 2.5 volts peak-to-peak.

The average dissipation for the input tube, 1.28 watts, is somewhat high, indicating that a redesign for using 140 volts as the supply voltage for the input tube should be made. The dissipation for the output tube is satisfactory.

The conversion gain for the mixer as a whole may now be found by the use of Eq. (1). The gain at point 3 being zero, the gain at point 1 is the only one to be determined. The data follow:

g_{m1}	g_{m2}	R_k	R_L	K
7100	6200	470	10,000	28.5

As can be seen, R_k has been taken as 470 ohms, and R_L as 10,000 ohms. Dynamic load lines may be plotted on the contour for the second tube as can be seen on the load line for V_2. The conversion amplification is approximately 0.25 K, or 7.1 for this example.

9.3.3. ***Advantages of the Cathode-Coupled Mixer.*** The cathode-coupled mixer, in addition to providing a mixing action with negligible detuning of the local oscillator, is free of partition noise effects, with the result that it has a much lower noise content than in the corresponding multigrid mixer. The improvement resulting is more than sufficient to justify the use of the additional complexity in the circuit.

The local oscillator signal required with this mixer, depending on the type of tube used, may be as small as 2 to 5 volts peak-to-peak. The sensitivity of the two input grids are nearly the same, since nominally identical triodes are normally used for both tubes. The amplitude of the local oscillator signal should be sufficient to switch the grid of triode V_2 from zero bias to plate current cutoff.