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Michiyuki Nakamura
November 14, 1956

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ABSTRACT

A fast scaler is described that employs a fast flip-flop circuit of unique design. With techniques applied to fast trigger circuits, this flip-flop circuit has been triggered at a rate higher than 50 megacycles per second and has a double-pulse resolution of 20 millimicroseconds. A 40-megacycle scaler, with a scale of eight and employing this fast flip-flop as a basic element, has been built at this Laboratory.

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INTRODUCTION

The search for fast scalers has gone on for many years. Fast scaling circuits have been devised in the past, but in general, they have been quite complex in their structure and have left something to be desired in the way of stability. Some of the techniques used in the past are discussed.

The use of "peaking" coils in the plate circuit of flip-flops has extended the switching-speed range of some flip-flops. Cathode followers have been used to decouple the opposing grid input circuit from the plate circuit, and switching speeds have been appreciably increased. Clamping the plate swings and the grid swings of a flip-flop to narrow limits has also appreciably increased switching speeds. Circuits embodying the above techniques either singly or in combination soon approached their limits in switching speeds. These limits were on the order of 30 Mc.

Very fast switching speeds can be attained by the use of secondary-emission type tubes of high transconductance. The main drawback with circuits using secondary-emission type tubes is the problem of stabilizing the drifts associated with these tubes.

A circuit that has fast switching speeds is described. Fast switching is attributed to high-gain, low-output impedance, and to clamping techniques. The clamping techniques also contribute to the stability of the circuit.

DESCRIPTION OF CIRCUIT AND CIRCUIT OPERATION

Figure 1 shows the basic circuit of the fast flip-flop. The action of the circuit is described by reference to Fig. 1. As an initial condition, assume that V3 is cut off and that V1 is conducting as indicated. The trigger pulse, applied at the cathode of V4, is transmitted to the grid of V1, tending to cut V1 off. The current flowing through Z_{k1}(R_{k1} plus the reactive impedance of L_{k1}) decreases, creating the derivative polarity conditions indicated. This derivative condition causes the grid-to-cathode polarity of V2 to become more positive. This action tends to "boot strap" the cathode voltage of V2 upward toward E_{bb}. This action is transmitted to the grid of V3, which tends to make V3 conduct. The current in Z_{k2} tends to increase, creating the derivative polarity across Z_{k2} as indicated. This action tends to cut V4 off, allowing the cathode voltage of V4 to fall. As the cathode voltage of V4 falls, the grid of V1 is further cut off. The entire action described above is regenerative, and the action is completed when V1 is cut off and V3 is conducting.

In retrospect, additional comments may be made concerning the action of the circuit. The action across Z_{k2} may be thought of as aiding the switching speed in the following manner. Not all the electrons conducted by V3 flow through V4 because V4 is tending to cut off. These electrons may now "concentrate" on charging the capacitances associated with the plate circuit of V3 and the grid circuit of V1.

The action across Z_{k1} makes the cathode of V2 a low-impedance discharge point for the electrons that had gone into charging the capacitances associated with the grid of V3. The output impedance at the cathode of V2 (Z_{out}) is expressed as

$$Z_{out} = \frac{r_{p2}\,(r_{p1} + Z_{k1})}{r_{p1} + r_{p2} + (\mu_2 + 1)\,Z_{k1}}\,, \qquad (1)$$

where

r_{p1} = plate resistance of V1,

r_{p2} = plate resistance of V2,

μ_2 = amplification factor of V2.

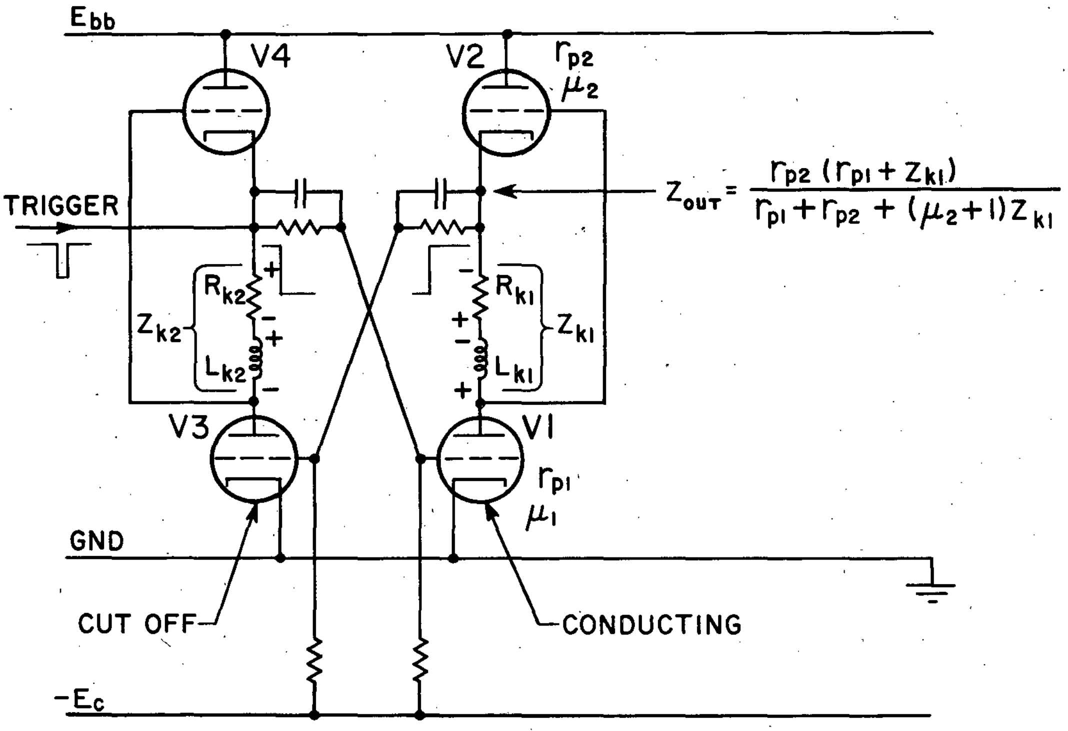

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Fig. 1. Basic circuit of fast flip-flop.

The voltage gain (without load) at the cathode of V2 over the signal applied to the grid of V1 is

$$\text{Gain} = \frac{-\mu_1 (r_{p2} + \mu_2 Z_{k1})}{r_{p1} + r_{p2} + (\mu_2 + 1) Z_{k1}} , \qquad (2)$$

where

μ_1 = amplification factor of V1.

(See the appendix for the derivations of the above expressions for the output impedance and for voltage gain without load.)

Figure 2 shows the first binary circuit of the 40-megacycle scaler, which was built at this laboratory. The swing of the cathodes of the upper tubes is clamped in order to decrease the switching time of the binary.

Figure 3 shows the setup used to test the rise time and the double-pulse and triple-pulse resolution of the binary. The mercury pulser is capable of delivering pulses with very fast rise times. The pulse length is determined by the length of open cable shown extending above the pulser. Double and triple pulses may be produced by using various lengths of cable as indicated to delay the pulses, and by recombining them again into a single cable. The resistors shown at the junctions of the cables minimize the cable-impedance mismatches that the signals "see" as they approach the junctions.

Figure 4 shows the input triggers and the output waveforms of this binary. The sweep speed is 20 mμsec/cm and the vertical deflection sensitivity is 5 v/cm. Figure 4a shows a single-pulse input trigger and Fig. 4b shows the output waveform. Because the oscilloscope is triggered at a rate of 60 cps from the mercury pulser, and because the beam of the cathode-ray tube returns to the same "zero" spot before each trigger, the picture obtained is as shown in Fig. 4b.

Figure 4c shows the input waveform in which the two input triggers are 45 mμsec apart. Figure 4d shows the output waveform. Figure 4e shows the triple-pulse input triggers, which are 23 mμsec apart. Figure 4f shows the output waveform.

This binary has been triggered by an rf source at a rate of more than 45 Mc. With optimum clamping and adequate driving signal, this binary has been driven at a rate of 60 Mc.

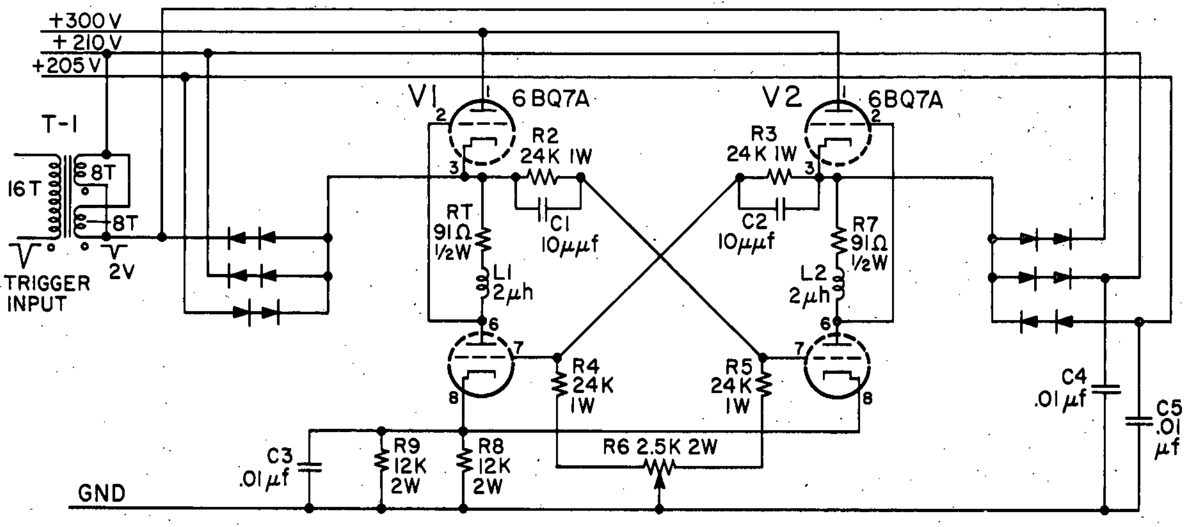

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Fig. 2. 40-Mc binary.

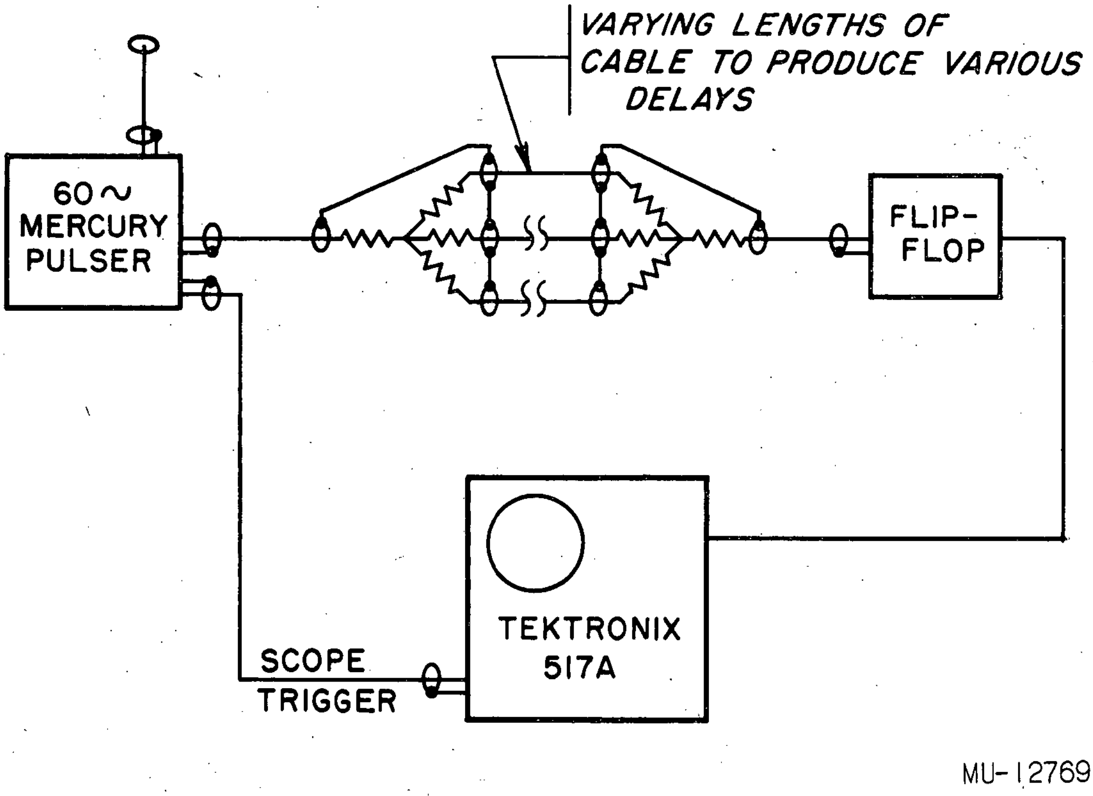
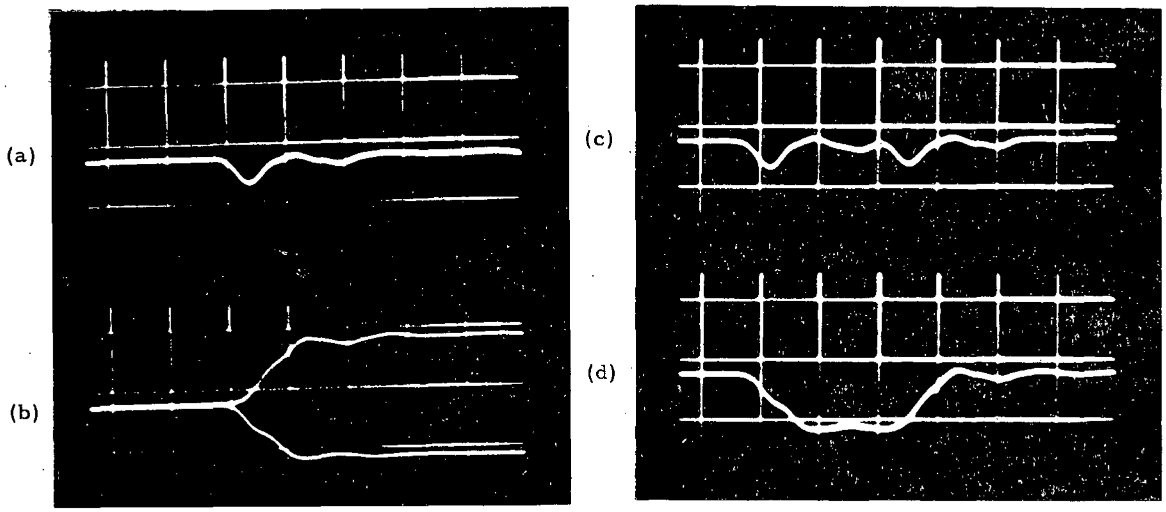
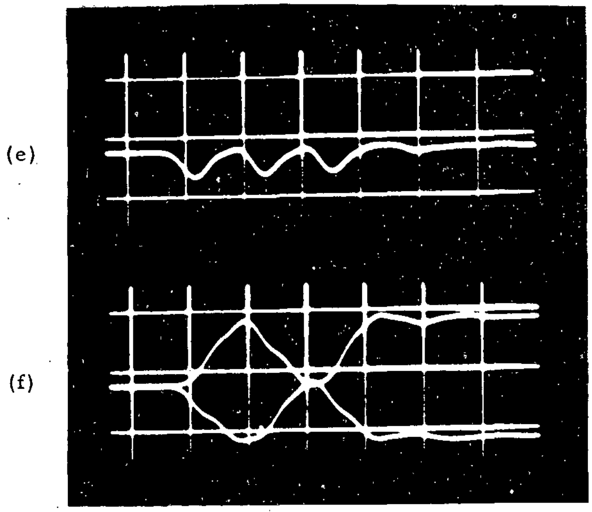


Fig. 3. Diagram showing setup used to determine triple-pulse resolution of flip-flop.



Input (a) and Output (b) waveforms for single pulse

Input (c) and Output (c) waveforms for double pulse



Input (e) and Output (f) waveforms for triple pulse input

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Fig. 4. Input and output waveforms of 40-Mc binary (sweep = 20 mμsec/cm; vertical deflection sensitivity = 5 v/cm). The photograph was made with a 5-sec exposure (300 sweeps).

In the construction of the 40-Mc scaler, the binaries are followed by a cathode follower and a stage of amplification to trigger the following binary. Three binaries are used in this scale-of-eight scaler. "Read-out" is accomplished by use of a microammeter. Reset is done by connecting the cathode of the upper tube through a resistor to the +300-volt line.

CONCLUSIONS

The use of a series tube in the plate circuit of a flip-flop has appreciably increased the switching speed of the flip-flop. The gain of the circuit is kept high while the output impedance of the circuit for driving the grid of the opposing tube is lowered. The fundamental concept of the Eccles-Jordan trigger circuit is maintained, and thereby the design of the circuit is kept simple. The use of this binary in combination with the accepted practice of clamping plate swings in a flip-flop has achieved fast switching speeds without the complexity usually associated with other binaries of comparable speed. Clamping also lends stability, which is lacking in many high-speed circuits.

ACKNOWLEDGMENTS

The work on this scaler was conducted in the Counting Development Group at the University of California Radiation Laboratory, Berkeley, Mr. Dick A. Mack in charge. Mr. Mack's aid and encouragement contributed to the development of this scaler.

The Counting Development Group work is done under the auspices of the U. S. Atomic Energy Commission.

APPENDIX

The derivations for the expressions above for voltage gain (without load) and the output impedance are shown.

For deriving the equivalent impedance of the upper tube circuit, it is helpful to analyze the behavior of a simple triode amplifier with a cathode resistor, as shown in Fig. 5.

From the equivalent circuit in Fig. 5b, we see by inspection that, if $R_L = \infty$, the open-circuit voltage Δe_L may be expressed as

$$\Delta e_L = \mu(-\Delta e_g), \tag{3}$$

since $\Delta i_p = 0$. The open-circuit voltage gain becomes

$$\Delta e_L / \Delta e_g = -\mu. \tag{4}$$

To determine the short-circuit current gain of the amplifier, let us set $R_L = 0$. Then, Δi_p becomes

$$\Delta i_p = [\mu(-\Delta e_g - \Delta i_p R_k)]/(R_k + r_p), \tag{5}$$

and clearing fractions, we have

$$\Delta i_p[r_p + (\mu+1)R_k] = -\mu \Delta e_g. \tag{6}$$

From Eq. 6 we see that the short-circuit current gain becomes

$$\frac{\Delta i_p}{\Delta e_g} = \frac{-\mu}{r_p + (\mu + 1)R_k} \tag{7}$$

The output impedance of the circuit is the ratio of the open-circuit voltage gain, Eq. (4), to the short-circuit current gain, Eq. (7), which is

$$\frac{\Delta e_L}{\Delta i_p} = r_p + (\mu + 1) R_k, \tag{8}$$

Figure 6(a) shows an amplifier using a series tube as a plate load. The upper tube circuit may be represented by an equivalent impedance $r_{p2} + (\mu_2 + 1) R_k$ as shown in Fig. 6(b). From Fig. 6(b), we see that the expression for the current change Δi_p is

$$\Delta i_p = \frac{\mu_1 (-\Delta e_g)}{r_{p1} + r_{p2} + (\mu_2 + 1) R_k}. \tag{9}$$

The voltage change Δe_p becomes

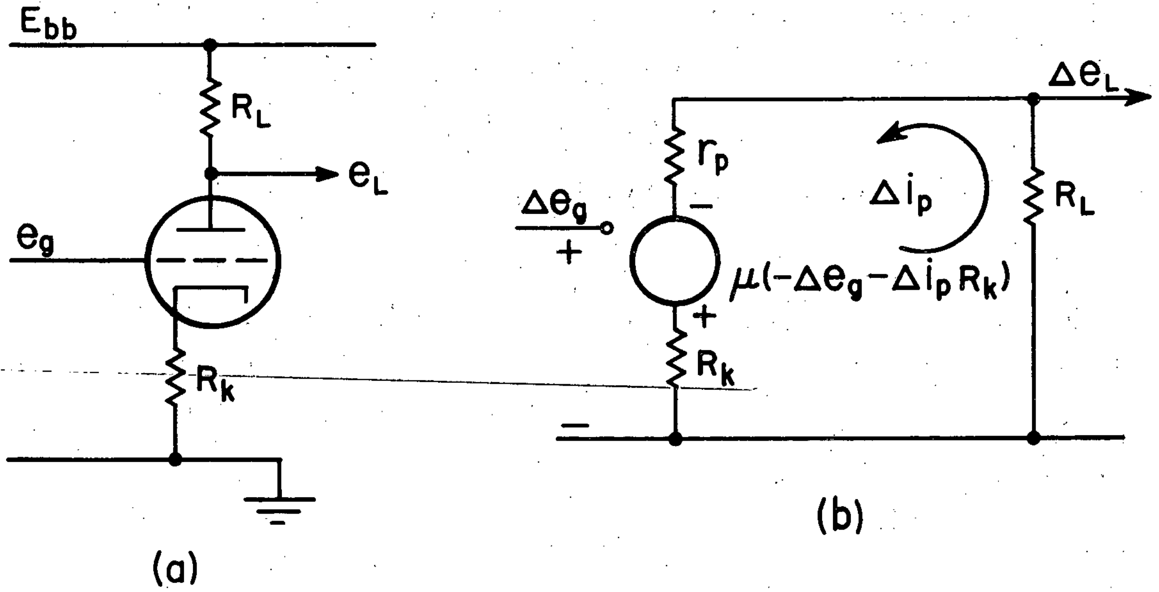

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Fig. 5. Actual and equivalent circuits of a triode amplifier with cathode resistor R_k.

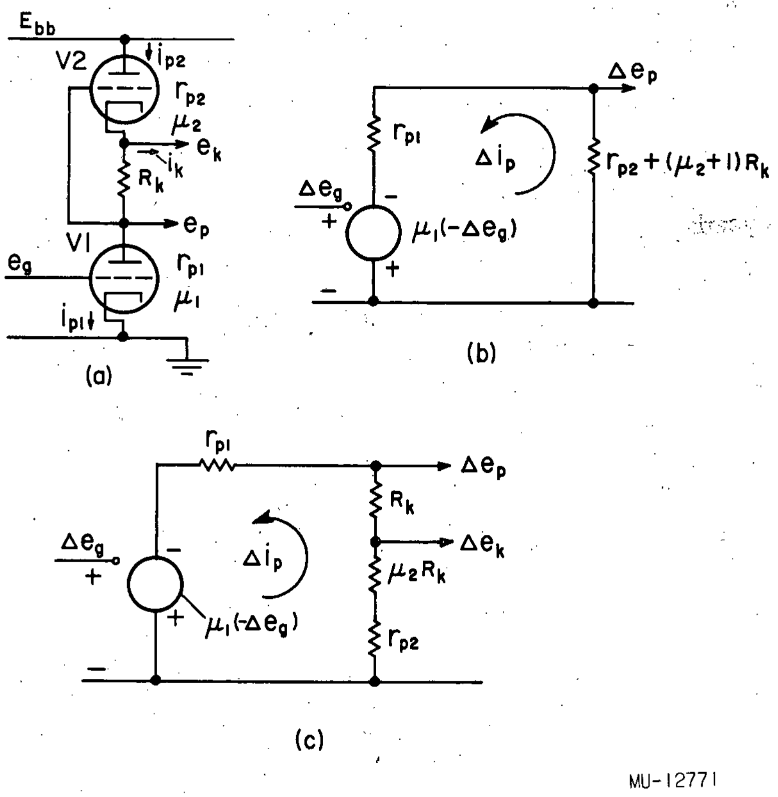

Fig. 6. Amplifier circuit with a series tube as the plate load.

(a) Actual circuit

(b) Equivalent circuit

(c) Equivalent circuit redrawn

$$\Delta e_p = \Delta i_p \left[r_{p2} + (\mu_2 + 1)R_k\right]. \tag{10}$$

The equivalent circuit in Fig. 6b is redrawn in Fig. 6c. The voltage change at e_k is

$$\begin{aligned}\Delta e_k = \Delta e_p - \Delta i_p R_k &= \Delta i_p\left[r_{p2} + (\mu_2 + 1)R_k\right] - \Delta i_p R_k \\ &= \Delta i_p\ (r_{p2} + \mu_2 R_k).\end{aligned} \tag{11}$$

The expression for the voltage gain (with no load) at e_k can be found by solving Eq. (9) and Eq. (11) for $\Delta e_k/\Delta e_g$, which becomes

$$\frac{\Delta e_k}{\Delta e_g} = \frac{-\mu_1(r_{p2} + \mu_2 R_k)}{r_{p1} + r_{p2} + (\mu_2 + 1)R_k}. \tag{12}$$

For finding the short-circuit current gain, e_k is held fixed. The expression for the current change through V1 (Δi_{p1}) is

$$\Delta i_{p1} = \frac{-\mu_1 \Delta e_g}{r_{p1} + R_k}. \tag{13}$$

This change in current Δi_{p1} lowers the grid of V2 by an amount

$$\Delta i_{p1} R_k = \frac{-\mu_1 \Delta e_g R_k}{r_{p1} + R_k}. \tag{14}$$

The current change in V2 (Δi_{p2}) becomes

$$\Delta i_{p2} = \frac{-\mu_2 \Delta i_{p1} R_k}{r_{p2}} = \frac{\mu_1 \mu_2 R_k \Delta e_g}{r_{p2}(r_{p1} + R_k)} \tag{15}$$

The net short-circuit current gain at the cathode (i_k) is determined from Eqs. (13) and (15); it is:

$$\frac{\Delta i_k}{\Delta e_g} = \frac{-\mu_1}{r_{p1}+R_k} - \frac{\mu_1 \mu_2 R_k}{r_{p2}(r_{p1} + R_k)}$$

$$= \frac{-\mu_1(r_{p2} + \mu_2 R_k)}{r_{p2}(r_{p1} + R_k)}. \tag{16}$$

The output impedance (Z_{out}) at the cathode of V2 is the ratio of the open-circuit voltage gain, Eq. (12), to the short-circuit current gain, Eq. (16); it is

$$Z_{out} = \frac{r_{p2}(r_{p1} + R_k)}{r_{p1} + r_{p2} + (\mu_2 + 1)R_k} . \qquad (17)$$

Equations (1) and (2) are equivalent to Eqs. (17) and (12); in the latter two, Z_{k1} is replaced by R_k.

BIBLIOGRAPHY

Chance, Hughes, MacNichol, Sayre, and Williams, Waveforms, Radiation Laboratory Series 19, McGraw-Hill, 1949.

Valley and Wallman, Vacuum Tube Amplifiers, Radiation Laboratory Series 18, McGraw-Hill, 1948.

Gene H. Leichner, A Summary of High Speed Vacuum Tube Circuit Work, Armed Services Technical Information Agency, AD-86661, Dec. 12, 1955.

Lewis and Wells, Millimicrosecond Pulse Techniques, McGraw-Hill, 1954.

Fischer and Marshal, A Ten-Millimicrosecond Scaler, Proceedings of the National Electronics Conference 9, Feb. 1954.