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A METHOD FOR STABILIZING SCALING CIRCUITS

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SUMMARY

The stability of a circuit exhibiting more than one stable state can be improved through the use of nonlinear silicon carbide resistors. With these resistors, vacuum tube life expectancy in scaling and computing circuits can be increased considerably.

The stability of a scaling stage can be considerably improved through the use of certain nonlinear resistors in the plate-to-grid coupling circuits. This substitution is simple and inexpensive, yet greatly extends the life expectancy of the tubes normally used in scalars. Alternatively, this modification permits increasing the speed of a binary scaler for the same vacuum tube life expectancy.

Figure 1a is typical of the commonly used binary scaling circuits. A complete description of the operation of this scaler is available from many sources.^{1,2,3} Normally, one tube is conducting while the other tube is cut off. This condition is stable provided that the bias on the nonconducting tube is sufficient so that the over-all gain of the scaler, considered as a two-stage feedback amplifier, is less than unity. One of the most common causes of tube failure in this circuit is decrease of emission in either or both triodes; i.e., one tube cannot draw enough current through its plate resistor (and thus lower the plate voltage sufficiently) to adequately cut off the other tube.

It should be noted that even with a very weakly emitting tube, the change in plate voltage would be enough to cut off the other tube if the entire plate voltage shift could be applied to the opposite grid. For example, the

¹W. C. Elmore and M. Sands, Electronics - Experimental Techniques (McGraw-Hill Book Co., Inc., New York, 1949), p. 208.

²B. E. Phelps, "Dual-Triode Trigger Circuits," *Electronics*, Vol. 18, No. 7, 110 (July, 1945).

³B. Chance, et al., Waveforms, M. I. T. Radiation Laboratory Series, 19 (McGraw-Hill Book Co., New York, 1949), p. 604.

plate voltage change from nonconducting to full conduction is about 115 volts for a normal tube drawing about 6.5 milliamperes (Figure 1a). With a weak tube, which may deliver no more than possibly 2.5 milliamperes, the plate voltage swing is only 50 volts. This would be sufficient to cut off the opposite tube if it could be applied to the grid without attenuation. The plate voltage swing is reduced to about one-third ($0.11/0.11 + 0.24 = 0.315$ in Figure 1a) by the plate-to-grid resistor divider coupling, so that the voltage change applied to the grid in the latter case is less than 16 volts. A minimum of 20 volts bias is required to maintain a stable state.

By using certain nonlinear resistors in place of R_2 , it is possible to transfer a larger fraction of the plate voltage change to the opposite grid (Figure 1b). These resistors, which are made with silicon carbide (SiC) and are available under various trade names,* have a characteristic of the form

$$R = KE^{-n} \quad \text{or} \quad I = \frac{1}{K} E^{n+1} \quad (\text{Figure 2}).$$

The exponent "n" varies from 2.5 to as much as 6, depending upon the method of manufacture. A value of three is typical. So far as is known, change of resistance with voltage does not involve any time lag. From "load lines" similar to those often used for vacuum tube analysis it is evident that these resistors, when used with a series linear resistor, tend to stabilize the voltage across themselves (Figure 2). For example, a 40% change in supply voltage is reduced to 18% change across the SiC resistor.

The improvement effected by using the nonlinear resistors is readily determined from the curves in Figure 3. With a linear 240K resistor in series with a 110K grid resistor, the grid voltage changes from 74 volts to 38 volts as the plate voltage varies from 235 to 120 volts (Figure 3a). With the nonlinear resistor in series with the same grid resistor and with the same change in plate potential, the grid swings from 72 to 14 volts (Figure 3b). With the latter circuit the tube need draw only 3.5 milliamperes (dropping the plate voltage to about 175 volts) in order to give the same shift in grid voltage as does the circuit using linear components and a normal tube.

The circuits shown in Figures 1a and 1b were constructed with closely matched components in order to test empirically the relative merits of the latter circuit. The circuits are identical except for the SiC resistors used in place of the 240K plate-to-grid coupling resistors. Experiments were conducted in which the plate resistors, grid resistors, and cathode resistors were altered until the first circuit failed to scale properly. In every case the same

*"Thyrite" (General Electric), "Varistor" (Western Electric), "Type BNR" (Carborundum Co.)

tube in the nonlinear circuit using corresponding components continued to operate reliably. In most cases the changes that disabled circuit 1a had to be considerably increased in order to affect circuit 1b seriously. The most striking difference in behavior occurred with optimum resistors and condensers, but using vacuum tubes that had undergone extensive use. Out of a batch of 100 12AU7's that had been rejected for various reasons after long service, there were 16 that did not function at all in circuit 1a. Every one of these tubes scaled successfully in circuit 1b, even though the emission in some cases was so low as to give a reading of less than 100 micromhos in both sections on a conventional tube checker. Since cathode interface effects are particularly troublesome in scalars,⁴ it is interesting to note that the nonlinear circuit operated properly with as much as 5K inserted between one cathode and the 10K cathode resistor.

Nonlinear resistors can be profitably applied to other circuits employing direct plate-to-grid coupling. In a ternary or ring-of-three scaling circuit, for example, each grid might be connected to the plates of two other tubes through appropriate resistors (Figure 4). For proper operation, T_1 should be conducting when both T_2 and T_3 are cutoff, but T_1 should be cut off when either T_2 or T_3 is conducting. Design of this circuit is more difficult than design of a binary scaler, since the plate voltage swing available to the grid is effectively halved because of the connection to the nonconducting tube. With one plate held fixed at 228 volts, the grid goes from 86 to 64 volts as the other plate varies from 228 to 110 volts (Figure 4a). With a nonlinear resistor in the coupling circuit, the grid voltage changes from 86 to 52 volts for the same plate voltage shift (Figure 4b). Similar considerations hold for scaling rings of higher order.

The nonlinear resistors should be particularly useful in fast scaling circuits where tube failures are relatively frequent. In fast circuits the plate voltage swing is generally limited, either through the use of smaller plate resistors or deliberately through the use of diode clamps.^{1,3,5} In such cases a more efficient plate-to-grid coupling is very desirable.

⁴J. R. Weymouth, Jr., J. Appl. Phys. 22, 80 (1951).

⁵A. S. Bagley, "A 10 Mc Scaler for Nuclear Counting and Frequency Measurement," Hewlett-Packard Journal 2, No. 2 (October 1950).

(a)

(b)

FIGURE 1.

TYPICAL BINARY SCALER (a) MODIFIED (b)
FOR INCREASED RELIABILITY.

FIGURE 2.
I-E CHARACTERISTIC OF NON-LINEAR RESISTORS.

FIGURE 3. COMPARISON OF LINEAR (a) AND SiC (b) CIRCUITS.

(a)

(b)

FIGURE 4.

PARTIAL SCHEMATIC OF TERNARY SCALER (a)
MODIFIED FOR GREATER STABILITY (b).