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Application Notes

NIXIE® INDICATOR TUBE CHARACTERISTICS

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INTRODUCTION

The term NIXIE indicator tube applies to a family of multicathode, gas discharge, information display devices.[1] Each cathode in the indicator is formed into the shape of a numeral, a character, or a line segment. When a cathode is energized, a neon gas discharge appears near the surface of that cathode, thus displaying the corresponding character or line segment. This paper describes the equivalent circuit and some of the electrical and visual characteristics of the numeric NIXIE Indicator in the region of normal operating currents. Particular emphasis is given to the volt-ampere and visual characteristics of the inactive or "off" cathodes.

EQUIVALENT CIRCUIT AND V-I CHARACTERISTICS

Numeric NIXIE Indicators are generally tested in a circuit such as the one shown in Figure 1. The test conditions are represented by a fixed voltage supply, E_b, and a limiting resistor, R_L. All but one of the cathodes are disconnected and are, therefore, inactive. The tube operates as a two terminal device with test limits defined in terms of minimum and maximum cathode current, I_k. The test conditions and test limits for a typical tube such as the type B5991 tube are:

Conditions:	R_L	= 8200 ohms
	E_b	= 170V
Limits:	I_k	= 1.5 mA, minimum 3.0 mA, maximum

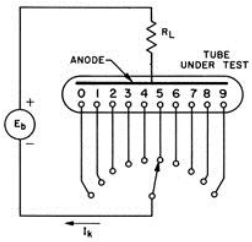

Figure 1. NIXIE TUBE TEST CIRCUIT (WITH ONE CATHODE CONNECTED).

1. NIXIE is a registered trademark of Burroughs Corporation

In this simple two terminal operation, the equivalent circuit of the NIXIE Indicator can be represented, as shown in Figure 2, by a voltage source, e_t, and an internal resistance, r_t. This circuit is only applicable within the normal operating region and, therefore, it does not indicate the small negative resistance region and hysteresis near the threshold of ionization. The internal resistance, r_t, becomes non-linear below the lower limit of the operating current, I_K, and increases as the current drops. These deviations occur outside of the normal operating region and are not pertinent to this discussion. Typical parameters for the type B5991 tube are e_t = 135 volts and r_t = 8000 ohms.

The V-I characteristics of the type B5991 tube are shown in Figure 3. From these characteristics, the equivalent circuit illustrated in Figure 2 can be derived. The slope of the tube characteristics represent the value of r_t, while their intersection with the ordinate gives e_t.

The limiting curves, 1 and 2, shown in Figure 3, were derived by first measuring r_t within the limits of I_K = 1.5 mA and I_K = 3.0 mA. The resistance r_t has a relatively small variation among tubes of a given type since it is primarily a function of the active cathode surface area which, in turn, must remain essentially constant within the normal operating region. Once r_t is determined, the worst case boundaries of the operating region are then found using the specified limits for I_k and the anode limiting resistor, R_L, as shown in Figure 3. A straight line extension of the characteristic curves 1 and 2 intersect the abscissa at the worst case limits of the equivalent tube voltage, e_t. The characteristic of a given cathode in a given tube will fall within the "normal operating region," which is shown in Figure 3, and will be parallel to curves 1 and 2.

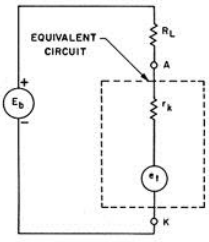

Figure 2. NIXIE TUBE EQUIVALENT CIRCUIT.

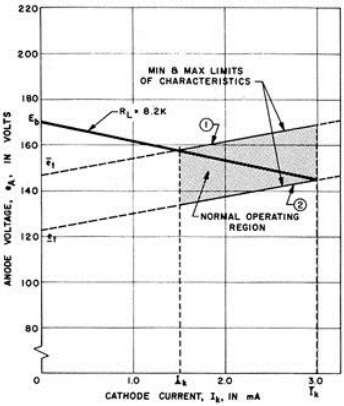

Figure 3. NIXIE TUBE V-I CHARACTERISTIC CURVES.

Once the normal operating region for a tube type is known, the value of limiting resistor, R_L, can be easily determined for any supply voltage, E_b, by drawing the new load line through the center of the "normal operating region." Figure 4 shows the characteristics for the same tube but with the appropriate load line for operation with a 200 volt supply.

Figure 4 also shows the typical supply voltage and resistor tolerances that are permissible. The worst case design tolerances are generally not as critical as Figure 4 may imply. When the tube is operated outside of the "normal operation region," catastrophic malfunction does not occur. Operating the tube at a cathode current somewhat above the upper limit increases the probability of the glow extending to the normally inactive cathode surfaces such as the leads or the pins. This extraneous glow may be objectionable for appearance but does not degrade the readability of the character. Similarly, operating the tube somewhat below the lower limit of cathode current may reduce the area of ionization over the cathode surface. This is known as a partially ionized cathode or a "partial." Only the more severe cases of partial ionization cause a character to be difficult to recognize.

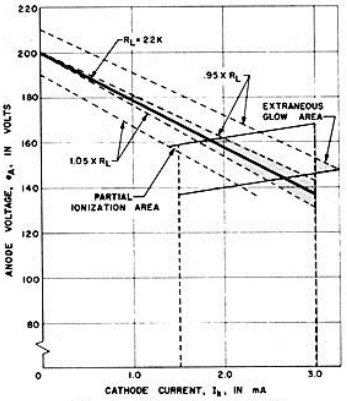

Figure 4. NIXIE TUBE LOAD LINES (FOR 200-VOLT OPERATION).

"OFF" CATHODE CHARACTERISTICS

Since the output of the NIXIE Indicator is visual, interest is in both the electrical and visual characteristics. The visual appearance of a NIXIE Indicator may be influenced significantly by the potential applied to the "off" cathodes.

NIXIE Indicators are most commonly driven by some semiconductor circuit. An NPN device per cathode, as shown in Figure 5, is best suited for this purpose. When the inactive cathodes are no longer open circuited, as shown in Figure 1, but are connected to other devices, it becomes essential to know the characteristics of these inactive cathodes and the way that the visual appearance of the display is affected by the electrical conditions present on the inactive or "off" cathodes. The requirements for the driver transistors then can be determined.

Figure 6 illustrates the equivalent circuit of a NIXIE Indicator when one cathode is energized and the remaining inactive cathodes are connected to signal sources represented by generators G_n. This circuit applies only within the normal operating region of the active character. The "off" cathodes can be represented by non-linear resistors, r'_{kn}, whose value is primarily a function of the terminal voltage of the corresponding generator, G_n. When this voltage is equal to e_n, the incremental value of r'_{kn}, designated as r_{kn}, is the highest.

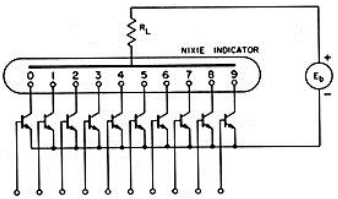

Figure 5. NIXIE TUBE TYPICAL DRIVE CIRCUIT.

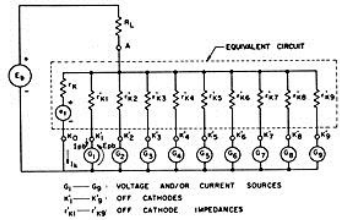

Figure 6. NIXIE TUBE EQUIVALENT CIRCUIT (INCLUDING ALL "OFF" CATHODES").

As the terminal voltage of G_n approaches zero, the incremental resistance, r_{kn}, approaches the value r_k, the resistance of an "on" cathode.

The "off" cathode characteristics for several NIXIE Indicator types were determined using the circuit shown in Figure 7. A constant current source, I_K, was used to maintain the "on" cathode current at its nominal value throughout the test. Another variable voltage supply, E, was used to adjust the "off" cathode, or prebias, voltage, E_{pb}, and then the current I_{pb}, was measured in the individual "off" cathode leads. The resulting characteristics for the type B5991 are shown in Figure 8. Two observations can be made after studying Figure 8 and Table 1, which lists the cathode-stacking order for several numeric NIXIE Indicators.

1. The prebias current, I_{pb}, of an "off" cathode at a fixed prebias voltage, such as E_{pb} = 70V, bears a relation to the relative stacking order of the cathodes. Generally, the closer an "off" cathode is to the "on" cathode, the higher the prebias current is at the "off" cathode.

2. When the shape of an "off" cathode is similar to the shape of an "on" cathode, the prebias current will be higher than if there is a minimal conformance in the shape of the two cathodes.

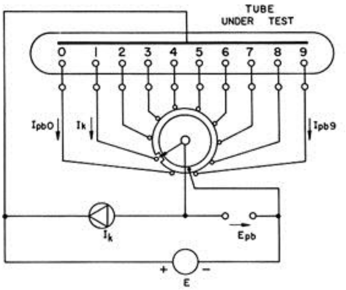

Figure 7. NIXIE TUBE TEST CIRCUIT (FOR PLOTTING V-I CHARACTERISTICS).

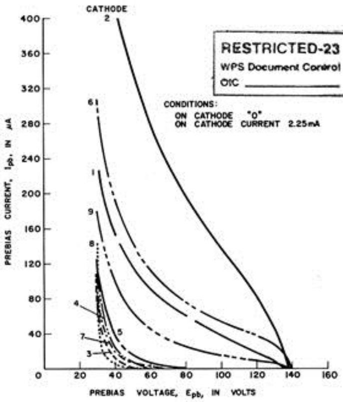

Figure 8. NIXIE TUBE TYPE B5991, "OFF CATHODE" (WITH NUMERAL 0 AS "ON CATHODE") V-I CHARACTERISTIC CURVES.

As shown in Figure 8, the top portion of cathode 2 is shaped similar to the adjacent cathode 0. Consequently, the prebias current at cathode 2 is quite high. Numeral 1 is also adjacent to 0 but the shapes of these two cathodes have a minimal conformance. The numeral 1 prebias current is, therefore, considerably lower. Cathode 6 is two positions removed from the "on" cathode 0, but it has a large factor of conformance. The prebias current for cathode 6 is, therefore, even higher than for the adjacent numeral 1.

From these results, one expects that a different set of "off" cathode characteristics would result whenever another numeral is chosen as the "on" cathode. Figure 9, in which numeral 2 is the "on" cathode, bears this out. Of all the 90 possible characteristics, the limiting curves are of primary interest. For the type B5991 tube, these characteristics are shown in Figure 10. Figures 11 and 12 illustrate the limiting characteristics for the type B5440 tube and the type B5850 tube respectively.

B5991	B5440	B5850
Front of Tube		
3	3	6
4	8	7
8	4	5
7	7	8
5	5	4
----------	----------	----------
9	9	3
6	6	9
2	2	2
0	0	0
1	1	1
Rear of Tube		

NOTE: Center anode shown as dash line (__________)

Table 1. CATHODE STACKING ORDER.

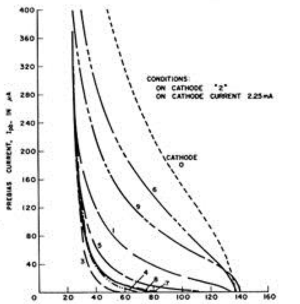

Figure 9. NIXIE TUBE TYPE B5991, "OFF CATHODE" (WITH NUMERAL 2 AS "ON CATHODE") V-I CHARACTERISTIC CURVES.

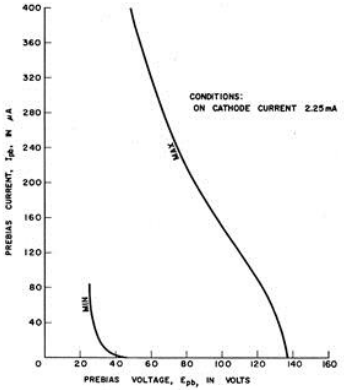

Figure 10. NIXIE TUBE TYPE B5991, "OFF CATHODE" PREBIAS CHARACTERISTIC CURVES.

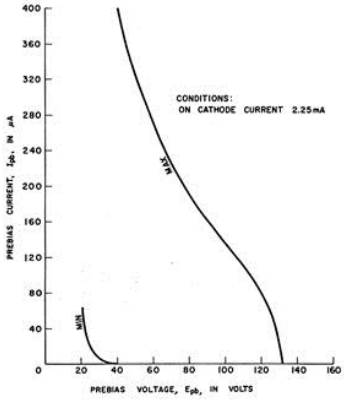

Figure 11. NIXIE TUBE TYPE B5440, "OFF CATHODE" PREBIAS CHARACTERISTIC CURVES.

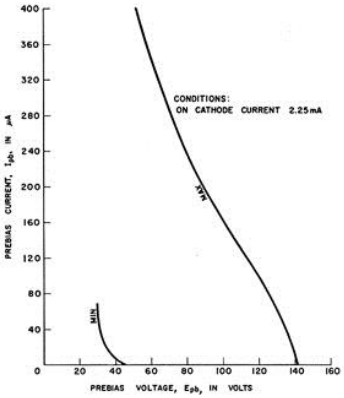

Figure 12. NIXIE TUBE TYPE B5850, "OFF CATHODE" PREBIAS CHARACTERISTIC CURVES.

Another characteristic of interest is the appearance of an "off" cathode as its electrical conditions are altered. For this purpose, the test circuit shown in Figure 13 was used. In this circuit, only one of the nine "off" cathodes is connected to the variable voltage supply, E. The test consisted of varying voltage E until a faint glow was noticed on the corresponding "off" cathode while the "on" cathode was maintained at its nominal current. This is a very subjective test and various observers would not come up with identical results. Nevertheless, the results shown here shed some light on the general relation between the off numeral voltage and the visual appearance of these tubes.

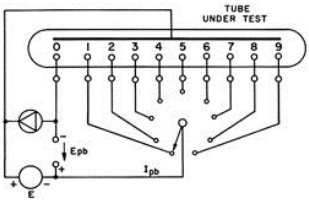

Figure 13. NIXIE TUBE TEST CIRCUIT (FOR DETERMINING VISUAL EFFECT OF PREBIAS VOLTAGE).

Figure 14 shows segments of "off" numeral characteristics for the type B5991 tube, as taken with the circuit shown in Figure 13. The lower end points of the curves in Figure 14, designated by solid discs, represent the conditions where the "off" cathode begins to exhibit a barely noticeable glow. As the voltage of the "off" cathode is reduced, a condition is reached, designated by a circle, where the glow around the same cathode becomes quite noticeable and perhaps objectionable. Figure 14 indicates these two points along each of the nine "off" cathode characteristic curves when the numeral 0 is energized. Similar sets of curves are obtained with any of the other cathodes energized. Figures 15 and 16 show segments of "off" numeral characteristics for the type B5440 and B5850 tubes, respectively.

Figure 17 shows an array of circles which represent those points on the "off" cathode characteristics where that cathode begins to exhibit an objectionable glow. These points correspond to the points represented by the circles shown in Figure 13. All 90 possible points are shown for the type B5991 Tube. These circles can be enclosed within a boundary, with the area to the left and above the boundary being an undesirable operating region. To prevent the appearance of extraneous glow on any of the "off" cathodes, the electrical condition for the "off" cathodes should be maintained to the right and below the group of circles as shown in Figure 17.

A similar array of circles is given for the type B5440 tube in Figure 18, and for the type B5850 tube, in Figure 19.

DRIVE TRANSISTOR REQUIREMENTS

The combined visual and electrical characteristics of the NIXIE Indicator "off" cathodes now can be used to establish the requirements for the driver circuit. According to Figures 14 through 16 and 17 through 19, the collector breakdown voltage of an NPN driver transistor should be at least 60 volts. This voltage will result in a slight glow under some combinations of "on" and "off" cathodes.

Since the test for establishing the boundaries in these figures was a subjective one, their exact location is somewhat uncertain. It is, therefore, desirable to use transistors having greater than 60 volts of collector breakdown voltage to assure freedom from extraneous glow. However, the intensity of extraneous "off" numeral glow is a rather smooth function of the prebias voltage and, for this reason, transistors with somewhat less than 60 volts of collector breakdown could be utilized with some degradation of the readability of the NIXIE Indicator.

One should always keep in mind that specifying a minimum breakdown voltage for the drive transistors does not necessarily mean that all transistors will exhibit a voltage breakdown near that limit. It is likely that the actual voltage breakdowns will assume a distribution centered above the specified limit and only a small percentage of the devices will approach the low limit. If this assumption is correct, then the actual performance of the tube will be better than what the worst case limit implies.

Another factor should also be kept in mind, which will make operation in the actual circuit worse than what the curves shown in Figures 17, 18, and 19 imply. The circles, shown in Figures 17, 18, and 19 were obtained by connecting only one of the nine "off" cathodes to the voltage source, E. Therefore, if all "off" cathodes are connected, there may be more than one of them near an objectionable glow condition, in which case the effects tend to be additive.

Numerals which are remote from the ionized cathode are represented by the circles near the bottom of Figures 17, 18 and 19. To minimize the appearance of glow on these numerals the current at the corresponding terminals should be kept below about 2 μA when these terminals are below 40 volts. However, this level of leakage current should not be difficult to achieve with most currently available silicon transistors. To account for the effect of temperature on transistor leakage current, the maximum leakage current limit should be specified at the maximum operating temperature. If the leakage current is to be specified at room temperature, then it should be scaled down from its high temperature value to its room temperature value ■

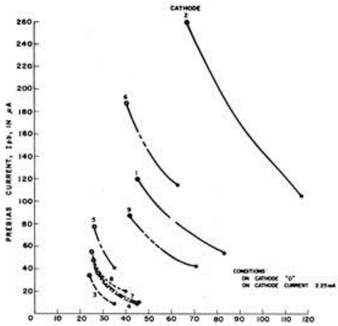

Figure 14. NIXIE TUBE TYPE B5991, "OFF CATHODE" GLOW CHARACTERISTIC CURVES.

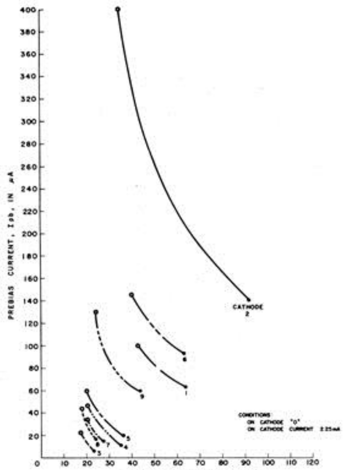

Figure 15. NIXIE TUBE TYPE B5440, "OFF CATHODE" GLOW CHARACTERISTIC CURVES.

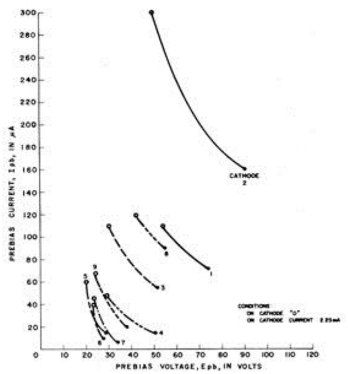

Figure 16. NIXIE TUBE TYPE B5850, "OFF CATHODE" GLOW CHARACTERISTIC CURVES.

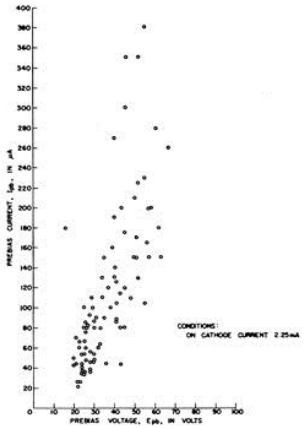

Figure 17. NIXIE TUBE TYPE B5991, "OFF CATHODE" OBJECTIONABLE GLOW REGION DIAGRAM.

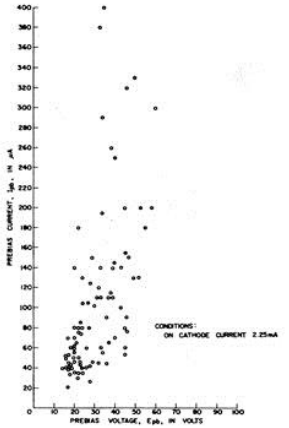

Figure 18. NIXIE TUBE TYPE B5440, "OFF CATHODE" OBJECTIONABLE GLOW REGION DIAGRAM.

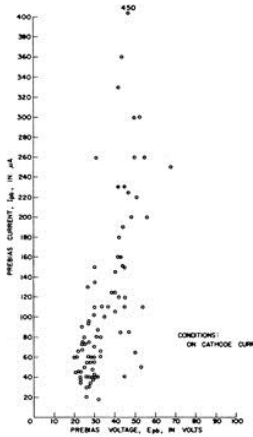

Figure 19. NIXIE TUBE TYPE B5850, "OFF CATHODE" OBJECTIONABLE GLOW REGION DIAGRAM.

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