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NOISE AS A TOOL FOR EVALUATING THE ACTIVATION OF CATHODES

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ABSTRACT

While measurements, at low frequencies, of the shot noise current from space charge limited cathodes always produce results substantially in excess of theoretical predictions (e.g., the reduction factor is less than 24 dB), measuring the ratio I_{eq}/S (I_{eq} - the equivalent shot noise $2eI_{eq}\Delta f$, S - the transconductance of the equivalent diode or triode) yields a relation $I_{eq}/S = 1.288\ V_k = 1.288\ kT_k/e$, independent of the operating point of the diode (triode) as long as all parts of the cathode have a full space charge controlled emission. Dahlke has shown in 1954 that this method is so sensitive as to permit detection of cathode temperature changes by 1^{o} K, thus allowing a powerful screening method between well and poorly activated cathodes, superior to "dip" tests and other current-voltage methods.

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At a Conference on Noise of the (German) Society of Radio Engineers in Munich, 1955, Walter Dahlke presented a paper entitled (after translation) "Shot Noise in Triodes," Ref. 1. This paper together with others presented at the conference was published (in German) in the NTF, 2/1955. The method and theory of noise as developed by Dahlke is of significance to the study of activation and quality of cathodes. I believe that the application of Dahlke's method offers a powerful and sensitive tool, superior to the "dip" test and other qualitative voltage-current tests, to the quantitative evaluation of the activation of cathodes. As a matter of fact Dahlke was able to observe effects equivalent to changes in cathode temperature by 1^{o} K, a precision which shows the unique advantage over other methods. To understand the physical basis of Dahlke's approach a short review of the theory of shot noise at low frequencies will be given. The review is presented as a summary of most important relations leading to the derivation of Dahlke's relation:

NOISE AS A TOOL FOR EVALUATING ACTIVATION OF CATHODES.

SHOT NOISE $\overline{i_s^2}$:

$$\overline{i_s^2} = \overline{(i - \bar{i})^2} = 2ei\,\Delta f = 2eI_a\,\Delta f \qquad \text{TEMP LIMITED EMISSION, SCHOTTKY 1918}$$

$$\overline{i_{sc}^2} = F^2\overline{i_s^2} \qquad \text{SPACE CHARGE LIMITED EMISSION}$$

$$F^2 = \frac{3\left(1 - \frac{\pi}{4}\right)}{\frac{V_a - V_m}{V_k}}\text{;} \quad \text{LOW FREQUENCIES, FOR } \begin{matrix} V_a = 10^4 \text{ V} \\ V_k = 0.11 \text{ V} \end{matrix} \quad F \approx -23.8 \text{ dB}$$

ACTUAL MEASUREMENTS ON $\overline{i_{sc}^2}$:

REDUCTION MUCH SMALLER THAN THEORETICAL PREDICTIONS

ELECTRON REFLECTIONS OF THE ANODE (EVEN IN FARADAY CAGE)

IMPERFECT ACTIVATION (ISLANDS WITH TEMP LIMITED EMISSION)

SENSITIVE MEASUREMENTS POSSIBLE WITH TRIODES

$$\overline{i_{sc}^2} = 2eI_aF^2\,\Delta f = 2eI_{eq}\,\Delta f$$

$$\overline{i_{sc}^2} = 2eI_a\frac{9\left(1 - \frac{\pi}{4}\right)}{\frac{V_a - V_m}{V_k}}\Delta f = 2I_akT_k\frac{9\left(1 - \frac{\pi}{4}\right)}{V_a - V_m}\Delta f = \frac{4kT_{eq}}{R_i}\Delta f$$

$$= 4kT_{eq}\frac{3}{2}\frac{I_a}{V_a - V_m}\Delta f$$

$$T_{eq} = 3\left(1 - \frac{\pi}{4}\right)T_k = 0.644\,T_k$$

$$\overline{i_{sc}^2} = 2eI_{eq}\,\Delta f = 4k \cdot 0.644\, T_k S\,\Delta f = 4 \cdot 0.644 \cdot eV_k S\,\Delta f$$

$$\frac{I_{eq}}{S} = 1.288\, V_k \qquad \text{SPACE CHARGE LIMITED EMISSION}$$

IDEAL TRIODES

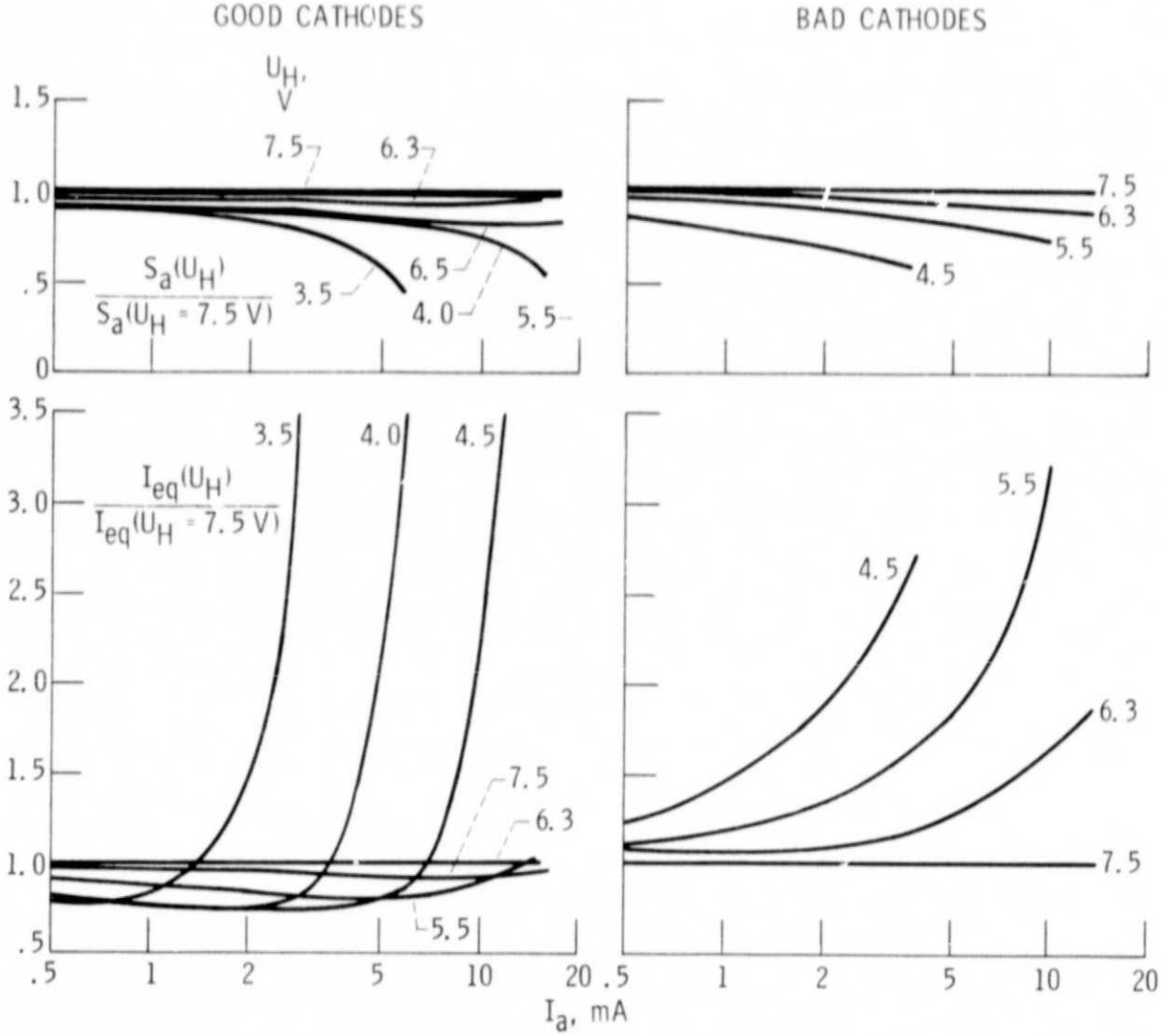
1. FINE GRID
2. $d_{k-g} \gg d_{k-m}$

$$\frac{I_{eq}}{S} = 1.288\, V_k$$ - INDEPENDENT OF I_a (SPACE CHARGE LIMITED EMISSION)

$$\frac{I_{eq}}{S} \to \infty$$ WITH INCREASING I_a (TEMP LIMITED EMISSION)

REF 1: W. DAHLKE (TELEFUNKEN CO., ULM, GERMANY)
NTZ, NTF 2/1955 (IN GERMAN)

COMPARISON OF CATHODES



We now summarize the conclusion from Dahlke's paper:

1. The ratio I_{eq}/S approaches it's theoretical limit $I_{eq}/S = 1.29\ V_k$ which is independent of the operating point of the tube as long as $I_a \ll I_T$ and the triode geometry otherwise that of an "ideal" triode resembles.

2. Absolute noise current measurements on diodes are, in general, not well suited for quanitative evaluation of cathodes.

The remaining problem now is to determine a practical approach to applying Dahlke's sensitive method to the evaluation of cathodes going into guns in TWTs and not into triodes. The latter can, of course, be evaluated directly. Without specifying actual details the following approach suggests itself. Since guns developed for expensive, long life TWTs are individually tested and evaluated in a beam tester it should be possible to design an arrangement for evaluating the cathode quality as a part of an "ideal" triode assembly first. Following that the cathode is withdrawn from the triode assembly and inserted into the gun fixture for the usual test. It is desirable to perform both operations in the same vacuum pump out, to avoid multiple exposure. If not possible, another activation would become necessary after discarding poorly activated cathodes from further testing.

Cathodes which demonstrate at the nominal heater power (cathode temperature) and somewhat below the theoretically predicted ratio $I_{eq}/S = 1.29\ V_k$ must be viewed as having an excellent activation. Since Dahlke's measurements were all done with oxide cathodes experience with impregnated cathodes is yet to be gained. The benefits from having, for the first time, a quantitative measure of the cathode quality by which to judge the cathodes appear very promising.