RADIO-FREQUENCY NOISE IN HOT-CATHODE GAS DISCHARGE TUBES

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ABSTRACT

This paper describes the results of a experiments made with the radio-frequency noise (0.1-30 MC) in the hot-cathode gas discharge tubes. These results show that the gas, gas pressure and discharge current have some considerable influence on the noise. In the tubes containing argon gas and mercury vapour two different types of noise appear depending on the condition of discharge, while the tubes filled only with argon gas have one type only. The distribution of noise along the tube axis suggests a possible origin and mechanism of noise generation.

1. Introduction

The noise in gas discharge tubes such as fluorescent lamps has an increasing importance in connection with the interference to radio service, while in the communication measurements it is useful as a broad band noise source. Recently, several studies on the radio-frequency noise and oscillation in gas discharge tubes of low pressure have been reported.[1)-8)] In spite of these works the mechanism through which the noise and oscillations emanate in ionized gas is not yet quite clear because of the complexity of these phenomena.

2. Experimental Arrangements

2.1. Discharge Tubes

Seven glass-made tubes were used, all of them have the same dimmension of 2 cm diameter and 26 cm length. The one ends of them were mounted with oxide-coated cathode, heated by an external sourse until the discharge started. Four tubes contain argon gas and mercury vapour, and the pressures of argon gas are 1, 3, 5 and 10 mm Hg respectively (while the mercury vapour pressure is saturated at the temperature of the tube), and the three others contain argon gas only, the pressure of which are 1, 5 and 10 mm Hg respectively. Hereafter, the argon-mercury tube may be written as 1 AH (1 means argon pressure of 1 mm Hg), and the argon tube as 1 A. The 3 AH tube has a tungsten probe 2.3 cm apart from its cathode.

2.2. Technique of Measuring Radio-frequency Noise

A parallel tuning circuit composed of a coil and a condenser, and two 75 kΩ resistors were connected in series with the discharge tube. A portion of noise voltage across the tuning circuit was delivered to another coil coupled loosely to the coil of tuning circuit and connected to the input terminal of a noise meter.

Two resistors on each side of the tuning circuit were to avoid any undesirable oscillation due to the negative resistance of gas discharge. Owing to a stray capacitance parallel to the tube and a resistance in series with it, an unstable relaxation oscillation might occur. So, it was ascertained previously that the noise level was scarecely varied for different values of this series resistor.

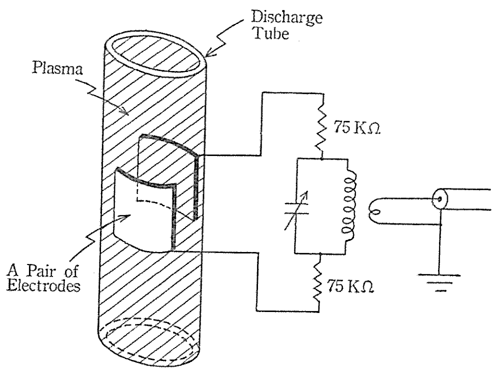


FIG. 1. A noise measuring circuit by a pair of small electrodes.

Noise meter used have an about 10 KC pass band, and the measured rms. noise voltages are expressed in decibel above 1 $\mu V/(KC)^{1/2}$.

A pair of small plane electrodes, each 1×1 cm, attached to the outside of the tube wall as shown in Fig. 1, were used to measure the axial distribution of noise.

3. Experimental Results

3.1. Noise Voltage Measured between Anode and Cathode

A. Frequency spectra of noise

In Fig. 2 the nearly linear portions below about 0.7 MC of the spectra for AH-tubes will be distinguished from the rest in their frequency characteristics. Let these portions be designated as the Type I noise and the rest as the Type II. The Type I noise always exists regardless of discharge condition and is represented by a relation $\overline{V}^2 = kf^{-\alpha}$ ($\alpha = 3 \sim 4.5$) but the Type II cannot always be seen depending on the condition near the cathode and has several peaks in its spectrum. By visual observations, when a number of small luminous spots flicker on the surface of

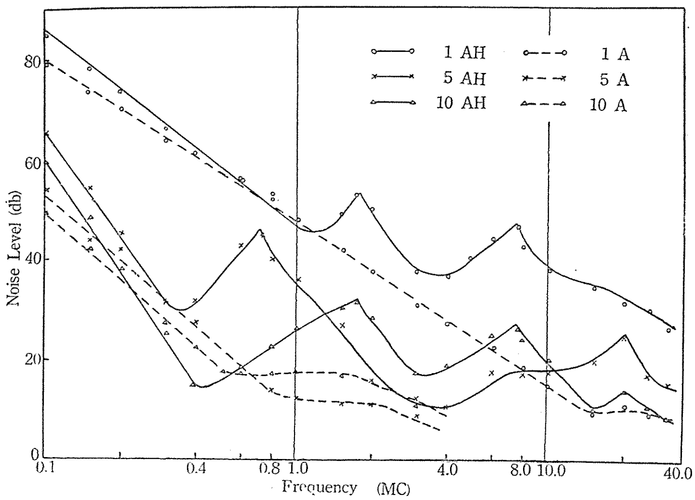


FIG. 2. Typical noise spectra of discharge tubes measured.

cathode and the cathode glow grows markedly the Type II noise appears, but, on the contrary, when the discharge current concentrates within a small incandescent cathode spot it cannot be seen.

Differing from these, as will be seen from the figure, the noise spectra of A-tubes are simple and are considered to have the same origin as the Type I noise of AH-tubes.

B. Relation between noise level and discharge current

Fig. 3 shows this relation. All curves in the figure may be represented by a formula $\overline{V^2}=kI^{\beta}$, and the value of β is 1.8~2.5 and 2~4 in the case of Type I and II for AH-tubes respectively and is 1~2 in the case of A-tubes.

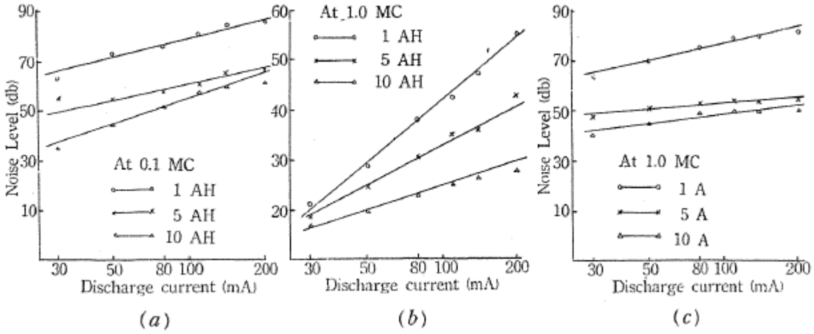


FIG. 3. Effect of discharge current on noise.
(*a*) Noise of AH tubes at 0.1 MC. (*b*) Noise of AH tubes at 1.0 MC.
(*c*) Noise of A tubes at 0.1 MC.

However, in the case of AH-tubes, the frequencies at which the noise peaks occur in Fig. 2 are altered neither by the discharge current and nor the gas pressure.

C. Effect of gas pressure

Generally speaking, as the gas pressure increases the noise level decreases over the whole range of frequency except near the peaks of the Type II noise.

3.2. Noise Voltage measured by Probe

The observation is made of 3 AH-tube, and from the current to voltage characteristic the space potential of the probe and the electron temperature prove to be about +17 volts to cathode and about 9.1×10^3 °K at 140 mA respectively. As far as the total current through the probe is negative the noise voltages measured between anode and probe, and between probe and cathode, are little affected by the probe current, but when the probe potential rises over the space potential the A-P (between anode and probe) noise voltage tends to increase and the P-K (between probe and cathode) noise voltage to decrease, as shown in Fig. 4 (*a*).

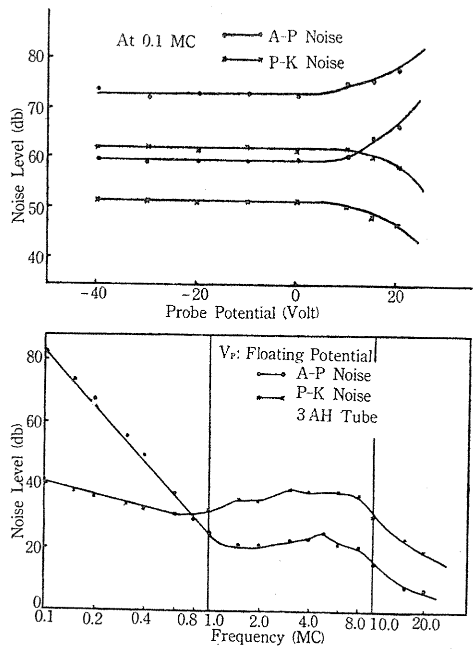
From the noise spectra obtained by the floating probe, as shown in Fig. 4 (*b*), we may get the consequence that the Type II noise for AH-tubes is chiefly produced in the cathode fall, while the plasma is responsible for the Type I, because the

P-K noise spectrum is much lower than that of A-P noise so far as the frequency is below 0.8 MC, and the former exceeds the latter by about 12 db at higher frequencies than 0.8 MC.

3. 3. Noise Measured by a Pair of Small External Electrodes

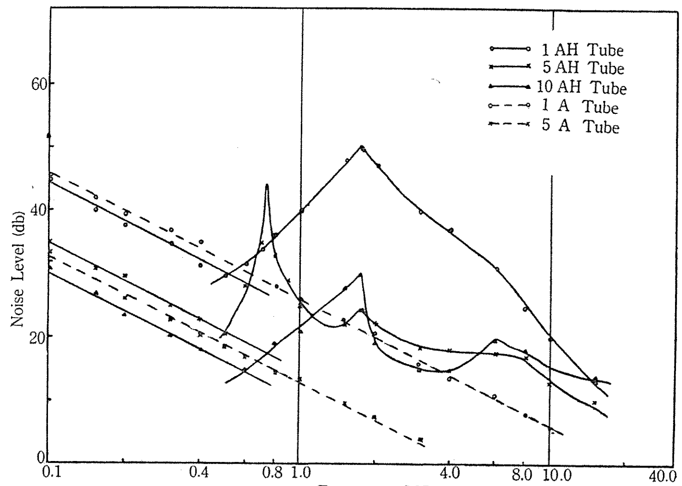
The typical spectra obtained by this method explicitly indicate the discrepancies between the Type I and II noise for AH-tubes, as shown in Fig. 5, that the noise level of the Type I is much reduced with compared to the case of Fig. 2, whereas it is little varied in the Type II.

The noise distributions along the tube axis measured by this method are shown in Fig. 6. It will be seen that the Type I noise for AH-tubes is similar in nature to the noise of A-tubes. The fact that the Type II noise for AH-tubes has a uniform distribution and a strong dependence on discharge current (not shown in Fig. 6) seems to be contradictory



Discharge current = 140 mA

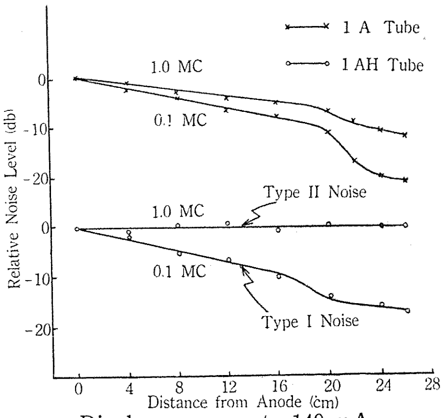
FIG. 4. (*a*) Effect of probe potential on noise. (*b*) Noise spectra measured between probe and anode, and between probe and cathode.



Discharge current = 140 mA

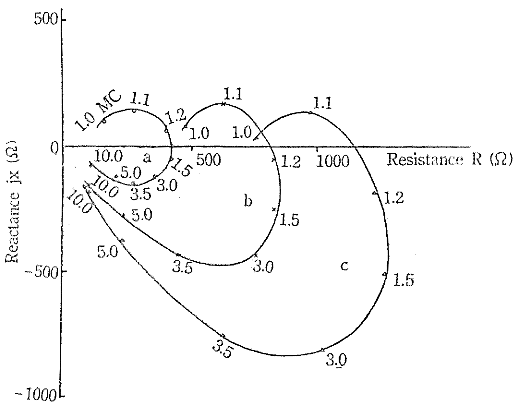
FIG. 5. Noise spectra measured by a pair of small electrodes located 10 cm apart from anode.

with the early statement that its origin is located near the cathode. However, if we assume that the so-called growing space charge wave[9)10)] might exist, the fluctuation near the cathode could be transmitted along the tube axis without any appreciable attenuation.



Discharge current = 140 mA

FIG. 6. Distribution of noise along axis of tube.



Argon at 10 mmHg.
Discharge current = 200 mA (a),
= 140 mA (b),
= 100 mA (c).

FIG. 7. A example of impedances of discharge tubes observed.

3.4. Impedance of Gas Discharge Tubes

The typical examples are shown in Fig. 7. The impedance is varied with discharge current but not always depends on the gas and gas pressure. It is worthy to note that the impedance of several tubes varies from inductive to capacitive within 1~2 MC. However, we cannot easily conclude this impedance variation to be related to the oscillation of the tube.

4. Discussion

4.1. On the Type I Noise

As the origins of the noise in gas discharge tubes, the following two may be considered: (i) the random motion of individual electrons, and (ii) the group motion such as the plasma oscillations and the interaction of well-defined streams of charged particles.

Under the assumption that the velocity of an electron after collision is not correlated with that before collision, Parzen and Goldstein[3)] have deduced an equation representing the mean square noise voltage per unit frequency. In the case of the 1 A-tube, if the electron temperature is 10^4 °K the collision frequency is calculated to be 2.3×10^3 MC. For such a value of collision frequency, Parzen and Goldstein equation shows that the noise temperature is equal to the electron temperature, the noise level is about $2\ \mu V/(KC)^{1/2}$ and the noise spectrum is uniform up to very high frequency. These are contradictory to our results.

Against the apprehension that the shot effect may be appreciable, a calculation indicates that it is only about $4\ \mu V/(KC)^{1/2}$ in temperature limited condition and actually it would be far less due to the suppression by space charge.

Ignoring the fine fluctuations and noting the phenomena which have longer mean correlation time τ_m we get

$$\overline{V^2(\omega)} \propto \tau_m \overline{I}^2 \left\{ (\omega\tau_m)^{-2} + \frac{n-2}{2} (\omega\tau_m)^{-4} + \cdots \right\} \quad \text{for} \quad \omega\tau_m \gg 1, \qquad (1)$$
$$\propto \tau_m \overline{I}^2 \qquad\qquad \text{for} \quad \omega\tau_m \ll 1.$$

From this equation it is seen that $\overline{V^2(\omega)}$ is proportional to f^{-2} and $\overline{I}^2$ in the frequency range higher than $(2\pi\tau_m)^{-1}$ and increases with τ_m at sufficiently low frequency. The life time of an electron in the positive column and the time interval between successive collisions may be considered as τ_m.

From the result by Bradbury and Nielsen[11] the mean transit time (τ_T) of an electron proves to be of the order of 5×10^{-5} sec., when the length of the positive column is 20 cm and the velocity of electron is about 4×10^5 cm/sec. (argon 1 mmHg, potential gradient 2 volts/cm). Thus, the noise power spectrum is expected to be proportional to f^{-2} at above 0.1 MC and the noise level will be reduced more rapidly as the gas pressure increases.

4.2. On the Type II Noise

Because of the conspicuous peaks at the specified frequencies in the noise spectra, the Type II noise for AH-tubes is considered to be closely related to some oscillation. Three types of oscillation could subsist in gas discharge tubes. The two types of them, plasma oscillation[8)10)] and so-called cathode oscillation,[7)] are inherent in gas discharge and the rest one is ordinary relaxation oscillation depending upon external circuit.

According to Tonks and Langmuir,[8)] the frequency of plasma ion oscillation in our case is about 3.3 MC for argon ion, and about 1.5 MC for mercury ion.

If we consider the longitudinal plasma wave which has non-zero group velocity, this velocity will be about 1.4×10^5 cm/sec. for Ar ion and about 6.4×10^4 cm/sec. for Hg ion. Therefore the frequencies for this type of plasma wave may extend from 1.4×10^3 KC down to 2.8 KC for Ar ion and from 6.4×10^2 KC down to 1.2 KC for Hg ion.

A potential minimum might exist in just front of the cathode due to negative space charge. Assuming a parabolic distribution of potential with the gradient of electric field from 10^2 to 10^3 volts/cm^2 and neglecting the collision of positive ion with gas molecule, the frequencies of the cathode oscillations spread in the range from about 0.35 to about 1.1 MC.

Thus the peak frequencies of the Type II noise could be illustrated by the plasma ion oscillation as well as the cathode oscillation. However, since (i) the emanation of the Type II noise is closely associated with the discharge conditions near the cathode which are considered to show the existence of a potential minimum, (ii) the peak frequencies are hardly varied by the discharge current and are not directly related to gas pressure, (iii) the distribution of noise along the tube axis shows this type of noise to be produced near the cathode, we suppose that the cathode oscillation is possible origin of the Type II noise for AH-tubes rather than the plasma ion oscillation.

When a sinusoidal oscillation (frequency f_0) is interrupted by the collision with gas molecule which may occur at the averge rate f_c per second, and the time interval between successive collisions veries with exponential distribution law, the noise spectrum having two peaks at f_0 and f_0-f_c and one valley at f_0+f_c is expected. These peaks are marked particularly when $f_0\gg f_c$, but are not apparent when $f_0 \simeq f_c$. (In the latter case the value of the peak is only twice as large as that of sufficiently low frequency.) However, if we assume the n th-order Γ distribution for the time interval, the spectrum may give ramarkable peaks even when $f_0 \simeq f_c$.

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References

1) W. W. Mumford: B.S.T.J. **28**, 608 (1949).
2) H. Johnson and K. R. Dremer: P.I.R.E. **39**, 908 (1951).
3) P. Parzen and L. Goldstein: Phys. Rev. **82**, 724 (1951).
4) J. D. Cobine and C. J. Gallagher: J. App. Phys. **18**, 110 (1947).
5) H. Martin and H. A. Wood: Proc. Phys. Soc. B **68**, 292 (1955).
6) T. Donahue and G. H. Dieke: Phys. Rev. **81**, 248 (1951).
7) N. R. Labrum and E. K. Bigg: Proc. Phys. Soc. B **65**, 356 (1952)
8) L. Tonks and I. Langmuir: Phys. Rev. **33**, 195 (1929).
9) V. A. Bailey: Aust. J. Sci. Res. A **1**, 351 (1948).
10) D. Bohm and E. P. Gross: Phys. Rev. **75**, 1851, 1864 (1949).
11) Bradbury and Nielsen: Phys. Rev. **49**, 338 (1936); **51**, 69 (1937).