LB-803

GASEOUS DISCHARGE NOISE SOURCES FOR SHF

RADIO CORPORATION OF AMERICA

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Approved

Thornton Seeley

Summary

It has been shown that the gaseous discharge type of noise source, which utilizes the positive column of the discharge as a source of random electrical fluctuations, is useful throughout the s-h-f region. By mounting the discharge tube diagonally into the guide, the discharge provides an excellent untuned waveguide termination matched over the entire transmission bandwidth of the guide. It is suggested and evidence is offered for the hypothesis that the noise temperature corresponds to the positive column electron temperature. Through the use of pure gases, there is no dependence of the noise temperature upon the ambient temperature such as found when commercial fluorescent lamps are used. A study of the effects of fluctuations in the discharge has revealed the conditions under which the microwave effects of these fluctuations may be suppressed.

Introduction

The advantages of a standard noise source[1] for use in receiver noise measurements have become widely recognized. These advantages result, in part, from the fact that measurements, made using this technique, compare like signals whose energy content is similarly distributed over the frequency band. This makes a detailed knowledge of the frequency pass band of the receiver unnecessary. On the other hand, if a c-w (i.e., discrete frequency) signal is employed to measure the integrated noise components, it does become necessary to determine the receiver noise bandwidth, i.e., the region of the frequency spectrum over which the noise components are integrated.

Further advantages result from the fact that noise signals are generated at a low power level--approximately that level best suited for measurement. Thus the standard noise source does not require the extensive shielding and accurately calibrated attenuator common to c-w signal generators where the generated power level may be of the order of 100 decibels above that actually required for the noise measurements. These features of the noise source result in simpler measurement techniques and less costly instrumentation.

The temperature-limited diode[2] has been extensively employed as a standard noise source. At frequencies below 300 Mc conventional glass envelope tube construction may be used.[3,4] At higher frequencies, the lead inductances and tube capacitances associated with such constructions make the proper circuitry difficult to achieve. The usefulness of the temperature-limited diode has been extended through the ultra-high-frequency region (300-3000 Mc) by constructing the diode as part of the transmission system.[5,6] This method of attack meets with rapidly increasing difficulties[7] as the frequency is further increased into the super-high-frequency region (3,000 - 30,000 Mc).

W. W. Mumford[8] has shown that a gaseous discharge, such as that in a commercial fluorescent lamp, is a stable and uniform noise source at microwave frequencies near 4000 Mc and its available noise power is adequate for receiver measurement purposes. It is the purpose of the present work to extend the use of gaseous discharges for this application to other microwave frequencies, to show how a discharge tube may be matched to a waveguide over the entire recommended transmission bandwidth of the guide, to investigate briefly the properties of discharges in various gases, and to suggest and to provide experimental evidence for the hypothesis that the microwave noise power is a measure of the electron-temperature of the positive column of the discharge.

For this work, the discharge geometry is similar to that of a commercial fluorescent lamp and utilizes an elongated cylindrical envelope in which the positive column occupies 80 or more percent of the distance between electrodes. However, adjustments are made in the geometry, the kind of gas, the gas pressure, and the discharge current for optimum performance in the present application.

[1] The term noise source is used herein to denote a generator of random electrical fluctuations; that is, "fluctuation" noise as distinguished from "impulse" noise. The energy distribution is continuous and uniform throughout the portion of the spectrum of interest.

[2] W. Schottky, "Spontaneous Current Fluctuations in Various Conductors," *Ann. Physik*, Vol. 57, p. 541, 1918.

[3] J. Moffatt, "A Diode Noise Generator" *J.I.E.E.* (London) pt. IIIA, vol. 93, p. 1335.

[4] R. W. Slinkman, "Temperature-Limited Noise Diode Design," *Sylvania Technologist*, vol. 2, No. 4, p. 6, October 1949.

[5] H. Johnson, "A Coaxial Line Diode Noise Source for U-H-F" *RCA Review*, Vol. 8, p. 169, 1947.

[6] R. Kompfner et al, "The Transmission Line Diode as a Noise Source at Centimetre Wavelengths" *J.I.E.E.* (London) pt. IIIA, vol. 93, p. 1436.

[7] The authors have constructed experimental models of broad-band temperature-limited diodes as sections of ridge waveguide which were operable as calibrated noise sources near 10,000 Mc. The constructional difficulties were great and the geometry did not lend itself to a precise calculation of the available noise power.

[8] W. W. Mumford, "A Broad-Band Microwave Noise Source," *B.S.T.J.* Vol. 28, p. 608, 1949.

The Gaseous Discharge as a Waveguide Termination

The Waveguide Mount

It has been found possible to utilize the positive column of a gaseous discharge as a broad-band untuned resistive termination for a waveguide. This has been accomplished in the present work by insertion of the discharge tube diagonally across the waveguide as shown in Fig. 1, for example. This figure shows the discharge tube inserted through the broad faces of the guide and in the plane formed by the vertical and longitudinal axes of the guide. This method of insertion will be referred to as an E-plane insertion. If the acute angle between the tube axis and the longitudinal axis of the guide is not too large, there is but very little reflection from the discharge. Since the attenuation through the discharge is of the order of 20 decibels or greater, an excellent waveguide termination results without the use of tuning elements. In particular, with a 10-degree insertion angle and a discharge through argon, the average voltage standing wave ratio over the recommended transmission bandwidth of the guide is about 1.07 with a maximum of about 1.1 (this value usually is found near the recommended low frequency limit).

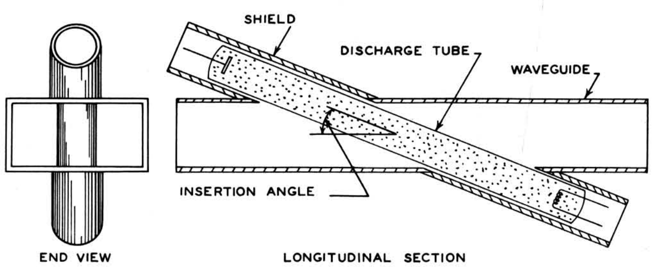

Fig. 1 - The E-plane waveguide mount for a discharge tube.

It is also possible to insert the discharge tube through the narrow faces of the guide in the plane formed by the horizontal and longitudinal axes of the guide. (H-plane insertion). As a waveguide termination, the performance in this case is generally not quite as good as that described above for the E-plane insertion. It seems probable that similar results would also be obtained for an insertion along a skew diagonal. However, the E-plane insertion is preferred since the greatest linear dimension of the cutaway portion of the guide wall is parallel to the current flow in the wall rather than normal to the current flow as in the case of the H-plane insertion. This leads to a minimum reflection when the discharge is turned off and transmission through the waveguide section containing the discharge tube may be accomplished with negligible loss.

The performance of the gaseous discharge as a reflectionless waveguide termination improves as the insertion angle is decreased. This is illustrated by the data of Fig. 2 which show the voltage standing wave ratios measured over a band of frequencies for insertion angles of 30, 15, and 10 degrees. Although these particular data were taken using an H-plane insertion, they serve to illustrate the general statement.

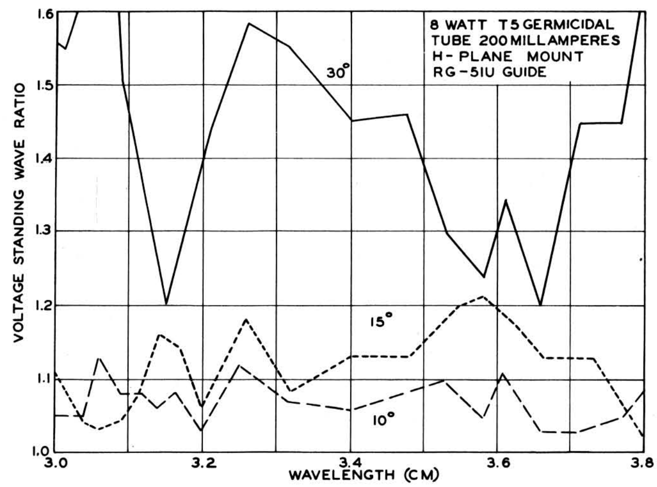

Fig. 2 - Illustrative data showing the effect of changing insertion angle.

The performance with respect to changes in the diameter of the discharge tube is not particularly critical but experience indicates that, in order to achieve an efficient design, the ratio of the discharge diameter to the inside width of the guide should lie between 1/4 and 1/3. This refers to an E-plane insertion and, under these conditions, a 10-degree insertion possesses a performance adequate for all but the most precise measurements. If the discharge diameter is too small, the tube length must be long (and the insertion angle very small) in order to achieve adequate attenuation. On the other hand, if the tube diameter is very large, the reflection due to the cutaway guide wall is increased and the insertion angle must again be small in order to obtain a gradual transition.

Variation of Discharge Parameters

The performance of the above type of termination has been studied to determine the effects of varying the discharge parameters such as the discharge current, the gas pressure and the kind of gas. In general, the performance is quite insensitive to such variations.

The effect of a variation in discharge current is illustrated by the typical data of Fig. 3 which shows the voltage standing wave ratios measured over a band of frequencies for several values of discharge current. Above a minimum current of about 60 milliamperes in this case, the change in performance is negligible. However, at the lower currents, the attenuation through the discharge may not be entirely adequate.

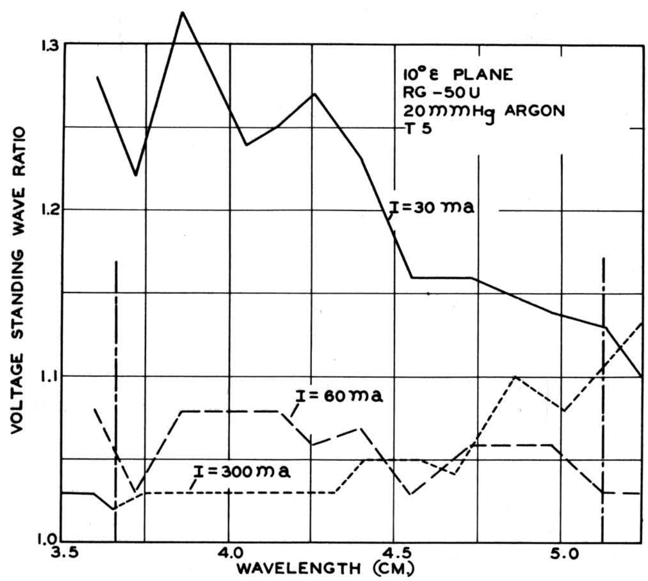

Fig. 3 - Typical data showing variation in performance with discharge current.

Similarly, there appears to exist no critical optimum gas pressure. For example, discharges in argon at pressures between 3 and 30 mm Hg give substantially equivalent results (at a discharge current of 200 milliamperes). Below a pressure of 3 mm Hg, the performance rapidly deteriorates. Over the range of pressures tested (up to 30 mm Hg), no upper limit was found.

While the specific data given above have referred to discharges in argon, the general results apply in a qualitative manner to discharges in the other inert gases.[9] Similar performance has been observed for discharges in helium, neon and xenon. The principal effect of a change in the kind of gas seems to be associated with changes in the mean-free-path. Thus, a change to a lighter gas may be compensated for by an increase in gas pressure. In this way, the termination performance figures quoted here for argon may also be readily[10] obtained for other gases.

Typical Results for SHF Band

The above results have been successfully applied to the construction of untuned waveguide terminations for use as s-h-f noise sources throughout most of the s-h-f band (3000 to 30,000 Mc). A collection of waveguide mounts with a 10-degree E-plane insertion angle is shown in Fig. 4 for various waveguide sizes.

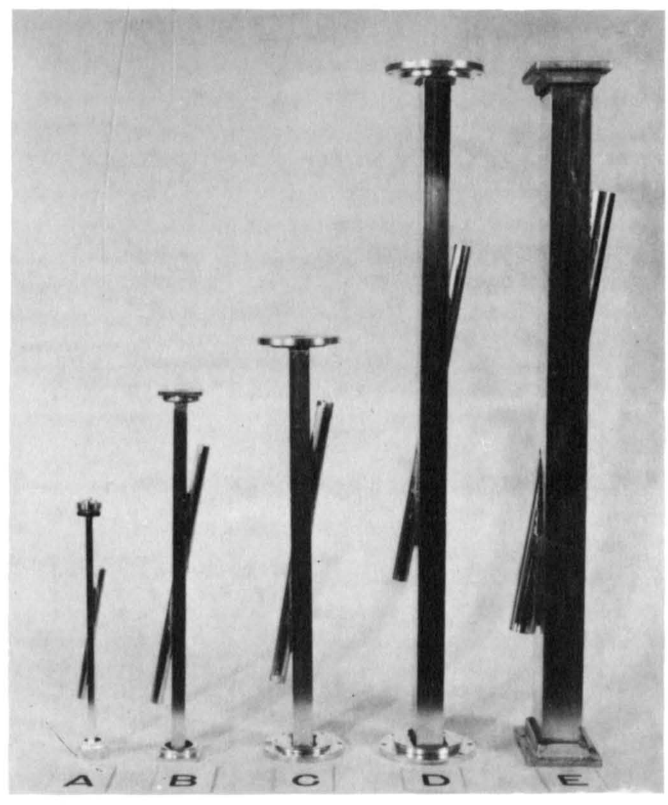

Fig. 4 - Collection of waveguide mounts.

Fig. 5 shows a collection of experimental discharge tubes designed to be mounted in the various guide sizes extending from RG-53U ($\frac{1}{4}$" x $\frac{1}{2}$") to RG-48U ($1\frac{1}{2}$" x 3"). These tubes are filled with argon and the pertinent data are given in Table I.

[9] These general statements also apply qualitatively to discharges in certain gas mixtures such as the mercury-argon mixture of commercial fluorescent lamps. The performance of certain other mixtures (e.g., hydrogen-neon) are more sensitive to the discharge parameters.

[10] The d-c power requirements increase rapidly for the lighter gases. See A. v. Engel and M. Steenback "Elektrische Gasentladungen" Vol. II, p. 109.

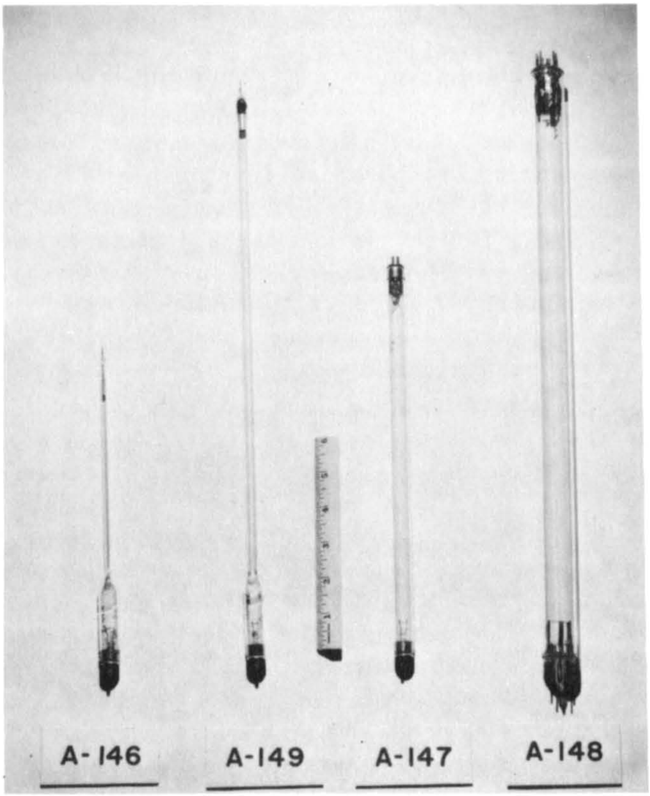

Fig. 5 – Collection of experimental discharge tubes.

Table I

Experimental Argon Discharge Tube Data

Experimental Designation	Waveguide Application	Nominal Bulb Size*	Gas Pressure (mm Hg)	Recommended Operating Current (ma)	Power Consumption (watts)
A 146	RG-53U	T 1½	20	200	15
A 147	RG-50U				
	RG-49U	T 5	20	250	18
A 148	RG-48U	T 8	20	250	22
A 149	RG-52U	T 3	30	200	18

*This designation refers to the nominal diameter (in eighths of an inch) of the envelope along the useful portion of the tube.

Collected voltage standing-wave ratio (VSWR) data showing the performance of these tubes as waveguide terminations is shown in Fig. 6 for various sizes of guide. The tube insertion in each case is a 10-degree E-plane insertion. It is seen that the continuous data extend from 2600 to 10,000 Mc with an average voltage standing-wave ratio of 1.07. Additional data indicating equal performance is shown between 21,000 and 25,000 Mc. The gap in frequency coverage is due to the lack of measuring equipment. The transmission characteristics (the discharge turned off and the guide terminated in a well-matched load) are shown in Fig. 7.

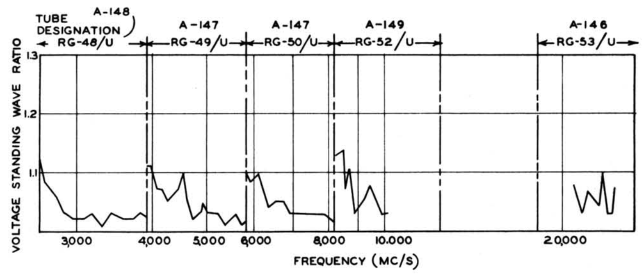

Fig. 6 – The performance of argon discharge tubes as waveguide terminations. 10° E-plane insertion.

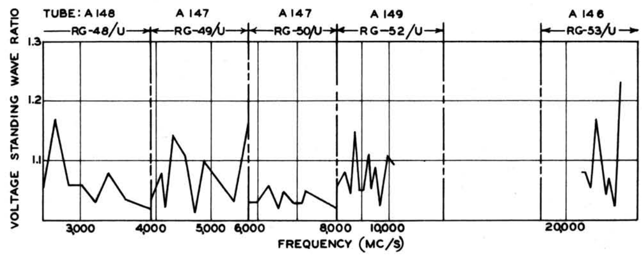

Fig. 7 – Transmission characteristics of 10° E-plane waveguide mounts. Waveguide terminated in a matched load beyond mount.

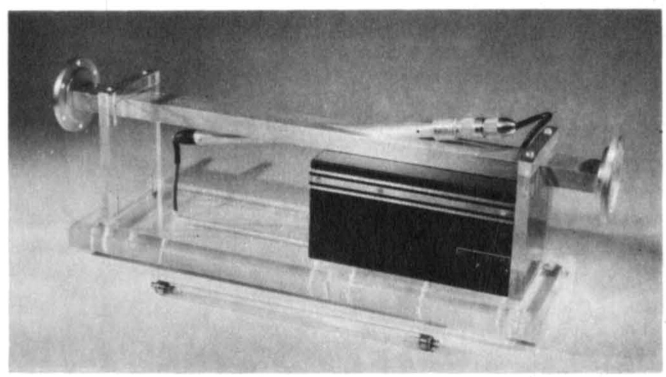

Fig. 8 – Assembled unit showing discharge tube, waveguide and associated power supply.

The compactness and simplicity of an assembled unit is shown in Fig. 8 which shows a discharge tube (A 147) mounted in a RG-50U guide with the associated power supply mounted beneath the guide.

Extended Frequency Systems

The performance of the above systems deteriorates rapidly at frequencies lower than that corresponding to about 0.8 of the cutoff wavelength of the guide (this is approximately the lower recommended transmission frequency of the guide). This is presumably due to the rapid increase in guide wavelength at frequencies below this limit. This situation may be alleviated and satisfactory operation obtained at frequencies closer to the cutoff frequency of the standard guide through the use of a ridge[11] as shown in the sketch of Fig. 9.

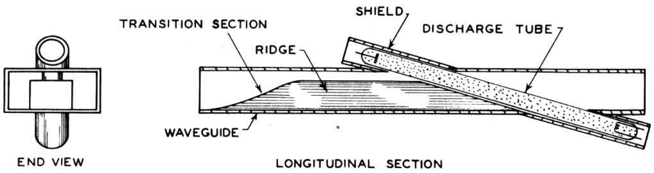

Fig. 9 – Waveguide mount employing ridge to improve low-frequency performance.

It is also possible to mount the discharge tube on the top of a ridge as shown in Fig. 10. Through the utilization of the wide transmission bandwidth of a ridge waveguide, a very wide frequency range may be covered with one mount. For example, the A-149 tube mounted on the top of a 0.300" x 0.217" ridge in a standard RG-52U guide (½" x 1") gave an average standing-wave ratio of 1.12 over the measured range of 3 to 7.5 cm. Thus, the possibility of utilizing a single tube and mount over a bandwidth comparable to that covered by three standard guides is clearly demonstrated.

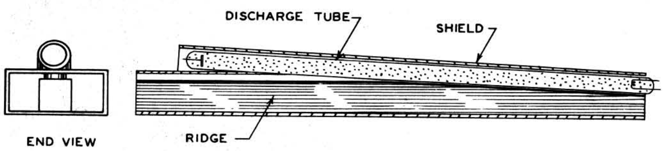

Fig. 10– Very wide band ridge waveguide mount.

This ridge guide technique may also be used to obtain improved matching performance. For example, a 20-inch T5 discharge tube mounted on the top of a 0.75" x 0.94" ridge in RG-48U guide gave an average VSWR of only 1.03 over the recommended transmission bandwidth and at 0.9 of the cut-off wavelength the VSWR had only risen to 1.08.

Fluctuation Phenomena

Electrical discharges through gases are often accompanied by oscillations or fluctuations and the present case is no exception. The present fluctuations occur at an audio frequency rate, i.e., a few thousand cycles per second. Their presence may affect the instantaneous match presented by the discharge to the guide.

[11] S. B. Cohn, "Properties of Ridge Waveguide," *Proc. IRE*, Vol. 35, p. 783, August 1947.

Many microwave mixers allow considerable local oscillator energy to travel towards the antenna. If a gaseous discharge has replaced the antenna, the fluctuations in this discharge, since they modulate the match presented by the discharge, return more or less local oscillator energy to the crystal and thus modulate the crystal excitation. This appears in the receiver output as a low-frequency modulation of the noise. There is no direct evidence that the noise output of the gaseous discharge itself has been modulated.

Thus, the fluctuations may be observed as a modulation of the crystal excitation as well as at the terminals of the gaseous discharge tube. It has been found that there is not necessarily a one-to-one correspondence between such observations. That is, under certain conditions the microwave effects of the fluctuations may be negligible although the fluctuations across the discharge tube are of large magnitude. The inverse has not been observed. This suppression of the microwave effects may be accomplished in a number of ways which tend to increase plasma density, for example by:

1) increase in discharge current.
2) decrease in tube diameter.
3) increase in gas pressure.

or by 4) the use of an inert gas of greater atomic weight.

For a given tube, then, there exists a "critical" current above which the microwave effects of the fluctuations are suppressed. These critical currents have been measured over a wide variety of conditions and the experimental data have been surprisingly consistent. Fig. 11 shows the critical current plotted against the log of the pressure for discharges

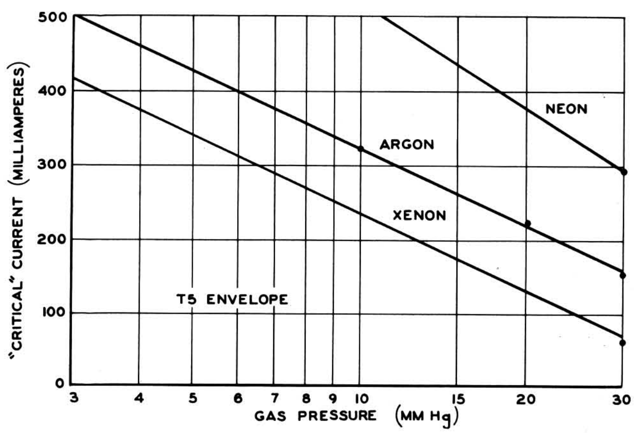

Fig. 11– "Critical" current versus gas pressure.

through various gases in a T5 envelope. A linear relation between the critical current and the log of the pressure appears to exist. Note that the critical current decreases with increasing pressure and with increasing atomic weight of the gas.

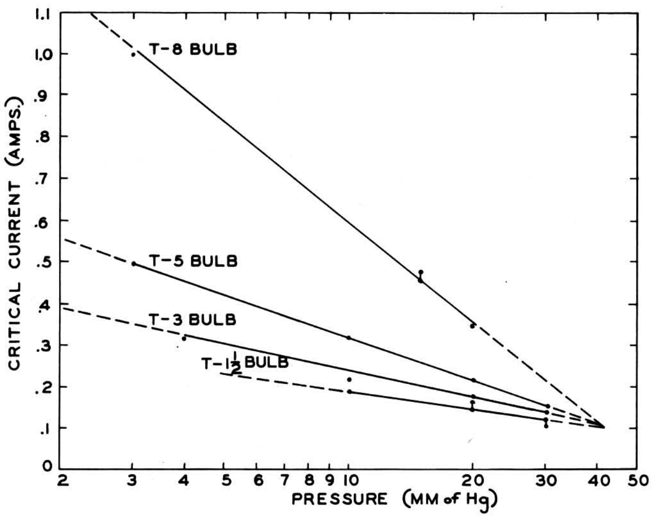

Fig. 12- Graph showing critical current for stopping fluctuations in microwave 3 cm. match as a function of gas pressure for argon.

A change in tube diameter results in a change in slope of the lines of Fig. 11. This is shown in Fig. 12 for discharges through argon for various discharge tube diameters. The data for argon have been collected and the empirical relation

$$\frac{I-0.11}{0.13+0.56\,R^2} = \log_{10}\frac{42}{P}$$

between the critical current, discharge tube radius and pressure has been found. This is shown in Fig. 13 together with the experimental data. The data are quite consistent.

Another method of suppressing fluctuations in the discharge is the use of gas mixtures. In this case it is possible to suppress the fluctuations completely. That is, the fluctuations no longer exist across the tube terminals.[12] An example of such a tube is the commercial fluorescent lamp containing argon and mercury. To secure reliable operation, i.e., to insure the presence of an adequate density of vaporized mercury, the operating temperature should be somewhat higher than that given by standard operating conditions. Other possible gas mixtures which have been successfully tested are hydrogen in neon and nitrogen in neon. In all of these cases the ionization potential of the added component approximates the metastable level of the inert gas.

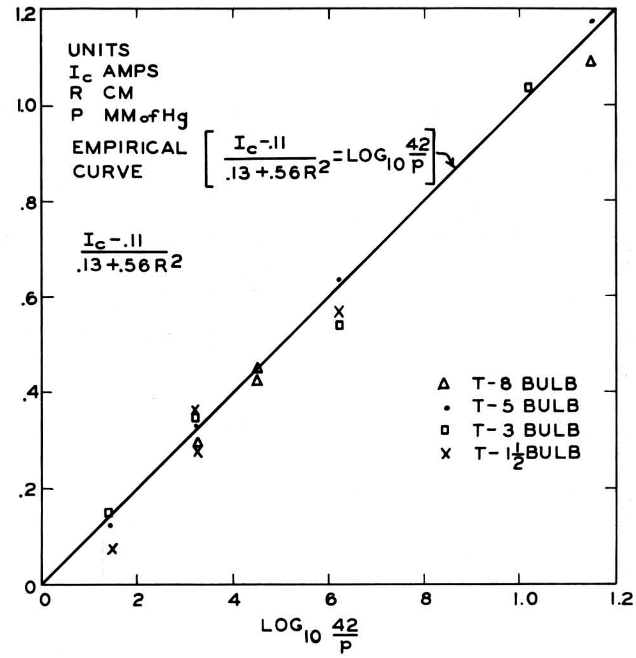

Fig. 13- Graph showing correlation with empirical curve of experimental points relating critical current, tube interior radius, and gas pressure for argon.

Noise Aspects

The operation of a gaseous discharge waveguide termination as a noise source will be described in terms of its apparent noise temperature. That is, the available noise power from such a waveguide termination is a number of times greater than that from the waveguide terminated in a resistive load at a room temperature of 290 degrees K. The discharge, therefore, may be considered to act as a resistive termination at a temperature that is a number of times greater than room temperature. This ratio will commonly be expressed in decibels since it is proportional to a power ratio.

It is suggested that the noise temperature exhibited by a gaseous discharge employed as above is a measure of the electron temperature of the positive column of the discharge.[13] On this basis, one would anticipate noise tempera-

[12] It may, however, be necessary to suppress fluctuations due to a multipath instability in the anode region by other means to obtain complete freedom from fluctuations.

[13] P. Parzen and L. Goldstein, "Current Fluctuations in a D-C Gas Discharge Plasma" *Bull. American Phys. Soc.* V. 25 n3, April 27, 1950.

tures on the order of those shown in Fig. 14 which was taken from A. v. Engel and M. Steenbeck.[14] It will appear that the measured noise temperatures approximate these calculated electron temperatures.

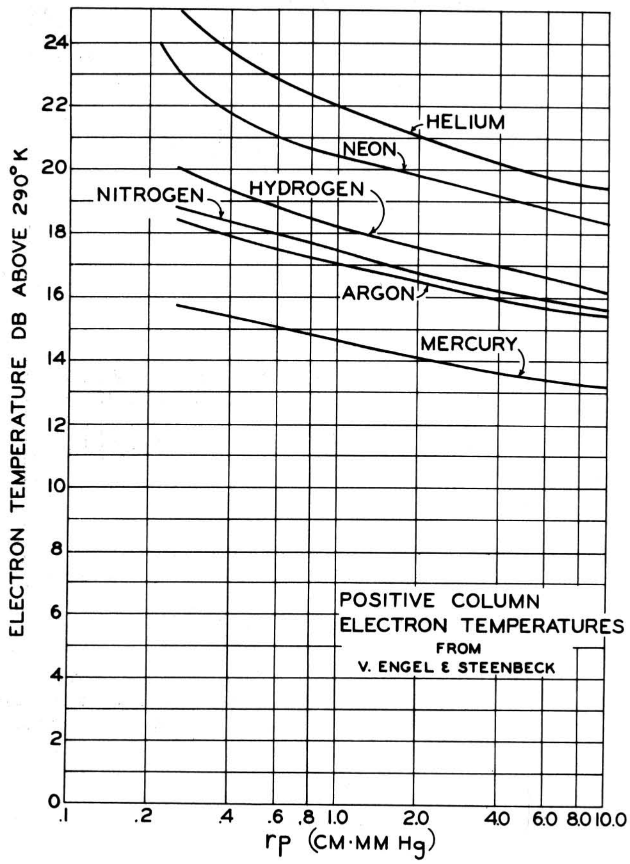

Fig. 14.

Consider first the experimental noise measurements shown in Fig. 15. These measurements were made at 4000 Mc and the reference level of the left-hand scale refers to the noise temperature of a germicidal tube.[15] The right-hand scale is an absolute scale against which the calculated and measured electron temperatures were plotted. The reference level of the left-hand scale was placed at an absolute level of 15.5 db on the basis of the published data of W. W. Mumford.[16] For the most part, the variation of noise temperature with a change in pressure varies qualitatively in the manner predicted by theory. A serious deviation from this statement occurs for the very low pressure neon tubes. While these tubes were difficult to match, a sufficient number of tubes are included to believe that this was the actual state of affairs in this experiment.

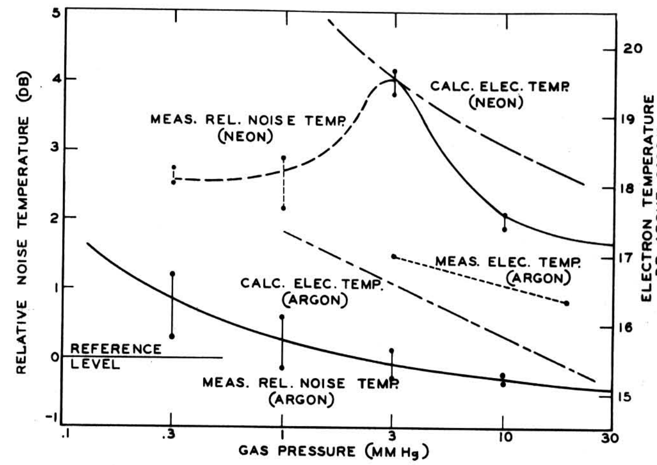

Fig. 15- Graph showing relative noise temperatures measured at 4,000 Mc as a function of gas pressure for argon and neon. Calculated data for electron temperature are also shown.

It is noted that the noise temperatures of the neon tubes lie above those for argon approximately the amount predicted by an electron-temperature hypothesis. A single helium tube (not shown on the figure) of 3 mm Hg pressure was also measured. Its relative noise level was +5.2 db in good agreement with theory. Discharges in xenon give a noise temperature approximately 2 db below the reference level. Thus, insofar as relative measurements are concerned, the relative measured noise temperatures respond to a change in the kind of gas and to a change in the gas pressure in a manner that is in qualitative agreement with that predicted by an electron-temperature hypothesis.

On the other hand, if the absolute level is established, as above, by reference to the published data of Mumford, the absolute noise temperatures lie up to about a decibel below the calculated (and also the measured) electron temperatures.

It should be pointed out that the inert gas discharge tubes exhibit no dependence of the noise temperature upon the operating temperature such as that found[17] in commercial fluorescent (germicidal) lamps due to the change in mercury vapor pressure with temperature. The noise temperature is similarly independent of the magnitude of the discharge current.

[14] loc. cit. p. 86.

[15] This is an argon-mercury tube similar to a fluorescent lamp but without a fluorescent coating.

[16] loc. cit.

[17] W. W. Mumford loc. cit.

Absolute noise measurements have been attempted at various frequencies throughout the s-h-f region. Standard signal generators were used as a calibrated standard. The results of of these measurements are shown in Table II.

Table II

Frequency (Mc.)	Tube Designation	Calculated Electron Temp. (db above 290° K)	Measured Noise Temp. (db above 290° K)	Signal Generator
2930	A148	15.3	15.5	"A"
2930	A147	15.4	15.5	"A"
4000	A147	15.4	15.5	"A"
5990	A147	15.4	16.6	"B"
6670	A147	15.4	17.4	"B"
6930	A147	15.4	16.0	"B"
9500	A147	15.4	17.3	"B"
9500	A149	15.4	17.3	"B"
24000	A146	16.3	16.0	"C"

The accuracy of the above measurements is probably of the order of ± 2 db (roughly the accuracy of the calibration of the standard signal generators). These measurements provide evidence that the noise temperature is substantially uniform over the s-h-f region and, within the accuracy of measurement, the measured noise temperatures show fair agreement with the electron temperatures. Also within the accuracy of measurement, agreement with published data is found at those frequencies for which such data exist.[18]

[18] W. W. Mumford, loc. cit.

Conclusions

The above work has demonstrated that the gaseous discharge type of noise source introduced by Mumford is useful throughout the s-h-f region. By mounting the discharge tube diagonally into the waveguide, it has been shown that the discharge provides an excellent untuned waveguide termination which is matched over the entire transmission bandwidth of the guide. The hypothesis that the noise temperature of the discharge corresponds to the positive column electron temperature has been suggested and experimental evidence offered in its support. Through the use of discharges through pure gases, there is no dependence of the noise temperature upon the ambient temperature. A study of the effects of fluctuations in the discharge has revealed the conditions under which the microwave effects of these fluctuations may be suppressed.

Acknowledgment

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