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Medd, W. J.

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ARGON NOISE SOURCE TUBES AS SECONDARY STANDARDS OF MICROWAVE NOISE POWER AT S-BAND

W. J. MEDD

OTTAWA

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ABSTRACT

The characteristics of the argon plasma noise source tube are discussed with reference to its use as a secondary standard of noise power. With attention confined mainly to the type-A148 tube operating at 2885 mc/s, measurements are described on the absolute value of noise emission, internal stability, and consistency between individual tubes.

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ARGON NOISE SOURCE TUBES AS SECONDARY STANDARDS OF MICROWAVE NOISE POWER AT S-BAND

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INTRODUCTION

The plasma discharge tube has been widely used as a source of microwave noise power, primarily because of its broad band match, high noise emission, and simplicity of operation. Although in many practical applications accuracy of the order of 20 or 30 percent has been sufficient, these tubes are capable of meeting much more stringent requirements. The possibility of using them as precise secondary standards of noise power requires more extensive information as to their effective noise temperature, stability of operation over various periods of time, and the error to be expected from changing tubes in operating equipment. It is important to obtain this information because the primary standard, which consists of a heated resistive element, or "hot load", is for many practical applications limited in range and inconvenient in use.

In the initial work on plasma noise tubes, Mumford [1] used a commercial fluorescent lamp containing a mixture of mercury and argon. This type of tube has been calibrated to accuracies of 5 or 10 percent by Mumford and others [2, 3, 4] with results varying from 9500 to 11,400°K for the effective noise temperature. There are, however, uncertain and inconsistent waveguide temperature corrections that must be applied, inconsistencies between individual tube samples, and also inconsistencies within the same tube over a period of time. These difficulties were thoroughly examined by Mumford and Schafersman [5] and in view of their results, and the work of Johnson and DeRemer [6], who investigated different gases at various pressure and discharge currents, the use of mercury-argon gas has been generally discontinued in favour of pure argon. (Neon is also used because of its relatively higher emission.) The commercial models of the argon lamp apparently follow the experimental models of Johnson and DeRemer (A146 to A149, inclusive), and are standardized as to gas pressure, operating current, size of tube, and waveguide mount. These tubes are sufficiently stable in operation to warrant specific numerical description of their properties. They were originally calibrated, and found to be approximately equal in emission, to an accuracy of 2 decibels; and one calibration by Sees and Corbett [6] with a probable error of 6 percent, has also been reported. The British type-CV1881, which is physically similar to the type-A147, although not exactly the same, has been carefully examined by Hughes [4] at 2860 mc/s, and by Sutcliffe [7] at X-band.

It is the purpose of this report, by no means exhaustive in scope, to present some further information obtained from experiments on the type-A148 tube, which were made in the course of designing equipment for applications in radio astronomy.

ABSOLUTE VALUE OF THE EFFECTIVE TEMPERATURE OF TYPE-A148 TUBE

The available noise power from an argon discharge tube is determined from a comparison with a heated resistive element, where Nyquist's formula, $P = KTdf$, applies. (P is the available noise power from the resistor, K is Boltzmann's constant, T is the temperature in degrees Kelvin, and df is the frequency bandwidth.) For the discharge tube an effective temperature T_D is assigned such that the available power, $P_D = KT_D df$, without necessarily considering what physical process may be responsible for the noise emission. As the terms K and df are common to both equations it is then convenient to express the noise emission in terms of the single parameter T_D. (It is also customary in the literature to express the available noise power as a "noise temperature" ratio, t_g, where t_g, in decibels, is $10 \log_{10} \left(\frac{T_D}{T_o}\right)$, and $T_o = 290°K$. Some authors, however, use $(t_g - 1)$ or $10 \log_{10} \left(\frac{T_D - T_o}{T_o}\right)$ decibels, which is an expression that often enters into the determination of noise figures. Neither of these two conventions will be used in the present report.)

An absolute calibration was carried out on the Bendix type 6358/TD-12 tube, designated by Johnson and DeRemer [6] as type-148*, with the equipment as shown schematically in Fig. 1. The usual discharge current of 250 milliamperes was maintained through the tube. The noise power emitted was reduced by about 16 decibels on passing through the directional coupler, thus permitting operation over a range of the variable attenuator least critical to setting adjustments. The temperature of the attenuator was assumed to be equal to that of the neighbouring air, and measurements were obtained by inserting thermocouples inside the waveguide.

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* Several manufacturers supply this tube with associated waveguide mount and power supply, as equipment for S-band noise-figure measurements.

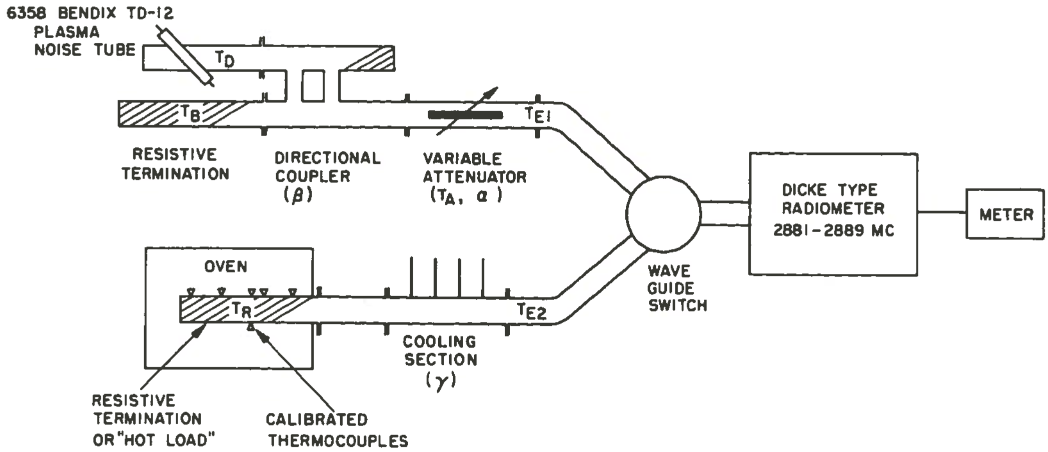

FIG. 1. SCHEMATIC OF EQUIPMENT FOR ABSOLUTE CALIBRATION

The hot load consisted of a commercial "dummy load" with a ceramic resistive material on the inside waveguide walls. This was enclosed in an oven and heated to some 250°C. By using thermostatic control, and suitably adjusting the power to different heating elements, the temperature during the course of the experiment was maintained constant, and uniform over the length of the resistive termination, to within one-third of one degree, or better. All temperature measurements were made with calibrated thermocouples.

The plasma noise source and hot load were alternately connected through a waveguide switch to a Dicke-type radiometer [8, 9] which served to amplify and detect the noise power. A ferrite isolator was used to reduce any zero error effects [10] that might remain after the various components were matched to 1.06 or better in power standing-wave ratio. The local oscillator was set at 2855 mc/s, the intermediate-frequency amplifier was centered on 30 mc/s, and a band-pass filter incorporated to reject the lower frequency "side-band"; the radiometer thus accepted energy over a range of frequencies about 8 mc/s wide centered on 2885 mc/s.

The effective temperature, T_{E1}, at the output of the plasma noise source side of the equipment is given by the equation of transfer as,

$$T_{E1} = \left[T_D \cdot \frac{1}{\beta} + T_B\left(1 - \frac{1}{\beta}\right)\right]\frac{1}{\alpha} + T_A\left(1 - \frac{1}{\alpha}\right),$$

where β is the attenuation, expressed as a ratio, through the directional coupler,
α is the attenuation (ratio) through the variable attenuator,
T_A is the (ambient) temperature of the variable attenuator, and
T_B is the (ambient) temperature of a resistive termination associated with the directional coupler.

The temperature of the hot load is T_R. Because of attenuation in the cooling section the effective output temperature, T_{E2}, may differ from this, depending on the temperature distribution along the guide. Complete expressions for the necessary corrections are given by Sees [11], but for small corrections one may, without serious error, assume a linear drop in temperature which approximates the actual measured temperature variation, and a uniform waveguide attenuation over this section. Then,

$$T_{E2} \cong T_R - \tfrac{1}{2}(\Delta T \cdot \gamma),$$

where ΔT is the total temperature drop and γ the total attenuation in the cooling system.

The experimental procedure consists of setting T_{E1} equal to T_{E2} by adjusting α, whence

$$T_D = \left[\left(T_R - \frac{\Delta T}{2}\gamma\right) - T_A\right]\alpha\beta + \left(T_A - T_B\right)\beta + T_B \, .$$

An average value of T_D = 10,700°K has been obtained.

The probable error was estimated as about 1.5 percent, or 150 degrees. The thermocouples were originally calibrated to one-tenth of one degree, and the final temperature readings were considered accurate to one-half of one degree. The term $\left(T_A - T_B\right)\beta$ is small, and the error introduced in the final answer, about 0.2 percent or less. The term $\tfrac{1}{2}(\Delta T \cdot \gamma)$ was not very accurately determined but it was small in comparison with T_R, and the error in $\left(T_R - \frac{\Delta T}{2}\gamma\right)$ was estimated as one degree. $\alpha\beta$ was obtained to an accuracy of 0.015 db (or 0.35 percent) from a calibration of the variable attenuator and directional coupler in combination. In setting T_{E1} equal to T_{E2} there are further uncertainties because of residual noise fluctuations of the receiver, mismatch effects, zero error effects, and possible asymmetry of the waveguide switch. These were checked and individually estimated as 0.5 percent or less. The effect of some of these errors was reduced by repeating the experiment eleven times at different fixed values of T_R between 200°C and 275°C. The individual determinations of T_D were, with one exception, within one percent of the average. The variation that exists between individual tube samples (about 0.3 percent) was also included as an experimental error, in order to make the final result representative of any individual type-A148 tube. Incidentally, this variation between tubes, combined with their limited life, sets a practical limit to which the accuracy of the experiment might profitably be improved.

An earlier calibration on the British type-CV1881 tube at a comparable frequency of 2860 mc/s, has been reported by Hughes [4]. In order to obtain a comparison with his results, measurements were taken on three type-CV1881 tubes with the equipment shown in Fig. 1, but using the type-A148 tube as a reference. At the same discharge currents, the type-CV1881 was found to be about 300 degrees lower in noise emission than the type-A148, and for I_D = 180 ma the absolute value of T_D obtained for the type-CV1881 was approximately 240 degrees lower than that given by Hughes (see Table I). Such a difference may be indicative of an unappreciated systematic error, but in view of the probable errors of the two experiments it is not seriously significant.

NOISE EMISSION AS A FUNCTION OF FREQUENCY

Less accurate calibrations were taken at a few different frequencies in the S-band range, using as before the type-A148 (6358 Bendix TD-12) tube at a discharge current of 250 ma. The "side-band" filter was omitted, and energy was therefore received from two frequency bands centered 30 mc/s to each side of the local oscillator frequency. The results appear in Table II.

TABLE II

SUMMARY OF RESULTS

Local Oscillator Frequency (mc/s)	T_D (°K)	Number of Measurements
2910	10,770	2
2885	10,380	14
2802	10,350	1
2750	10,530	1

The fact that 14 measurements were taken at 2885 mc/s center frequency is not very significant, as most of these were earlier attempts with inferior equipment. The probable error for each of the above figures was roughly 300°K, and for such an order of accuracy there is no definite evidence of frequency dependence over this range.

TABLE I

SUMMARY OF ABSOLUTE CALIBRATIONS ON ARGON DISCHARGE TUBES

Frequency Range (mc/s)	Tube*	Commercial Models†	Discharge Current (ma)	Frequency of Calibration (mc/s)	T_D (°K)	Probable Error (°K)	Reference
2600-2900	A148	Bendix TD-12	250	2885	10,700	150	present report
		CV1881	180	2885	10,900	160	present report
		CV1881	180	2860	11,140	130	Hughes [4]
3900-8100	A147	Bendix TD-10 } Philco L1306A	250	6975	10,300	600	Sees and Corbett [6]
8100-10,000	A149	Bendix TD-11	200				
		CV1881	180	?	11,200	~200†	Sutcliffe [7]
20,000-25,000	A146	Bendix TD-13	200				

NOTES

* As specified by Johnson and DeRemer [6].

† The commercial models of these tubes are believed to be identical with the experimental models of Johnson and DeRemer [6], with the exception of type-CV1881, for which see Houlding and Miller [12].

‡ Sutcliffe gives a "possible error" of 800.

Taken in conjunction with previous work these results also indicate that noise emission is not highly sensitive to operating frequency between different waveguide ranges, although a certain amount of variation must be expected from the use of different tubes and different discharge currents. Parameters such as tube diameter, gas pressure, and glass loss cannot be entirely neglected [6, 12]. The values obtained in the present and previously reported calibrations are summarized in Table I, and show an overall consistency to within ten percent. In the absence of further data, and aside from theoretical considerations [13], this may perhaps be taken as indicative of the accuracy with which a value of T_D obtained by calibration at one frequency, can be arbitrarily used at some considerably different operating frequency.

NOISE EMISSION AS A FUNCTION OF DISCHARGE CURRENT

Typical curves showing relative temperature differences as a function of discharge current for four different type 6358 Bendix TD-12 tubes at 2885 mc/s, are given in Fig. 2. The curves are arbitrarily displaced to avoid confusion, and the absolute values are not shown. It will be noted that although the emission as a function of discharge current is usually considered linear, this does not hold in detail over this particular range. Around 250 ma, which is the usual operating point, the curves are fortunately quite flat, and small changes in discharge current, such as may be experienced from the use of unregulated supplies, are quite tolerable.

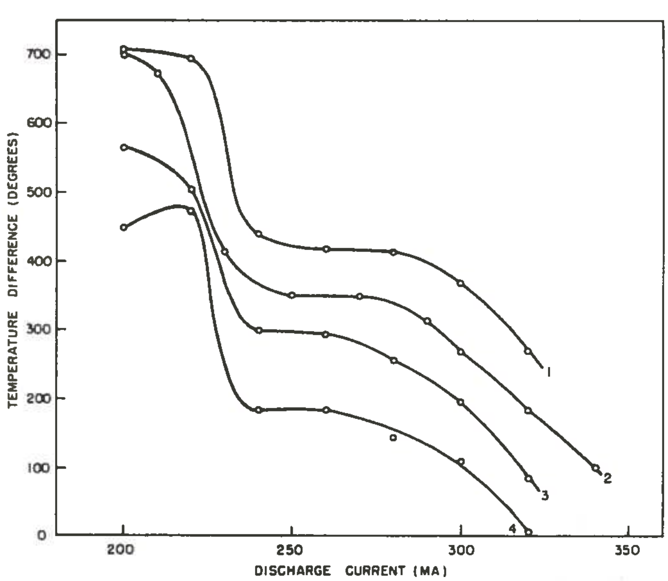

FIG. 2. VARIATION IN EMISSION WITH DISCHARGE CURRENT

A few tests were also made using a radiometer with a bandwidth of 500 mc/s centered on 3250 mc/s. In this case the curves of discharge current versus output were similar to those shown in Fig. 2, except that the flat portion occurred between 260 and 300 ma.

NOISE EMISSION AS A FUNCTION OF INDIVIDUAL TUBE SAMPLES

Twelve type-A148 tubes were intercompared by connecting them to the arms of the waveguide switch shown in Fig. 1, and making successive substitutions. Eight type-A147 tubes mounted and matched in S-band waveguide, were also available. Of these 20 tubes, the difference between any two was about 50°K or less, with an extreme of 80°K between the highest and lowest. The type-CV1881 tube has been similarly tested by Hughes [4] with essentially the same results.

In making these tests the tubes were matched by means of a waveguide plunger and tuning screw. However, each tube presents the same impedance to the waveguide, and the standard waveguide mount, short-circuited at the far end, would be sufficient.

NOISE EMISSION AS A FUNCTION OF TIME

The equipment used in this phase of the work is shown schematically in Fig. 3. Any deviation in either tube A or tube B will appear as a deviation from the near null reading of the recording meter, unless both tubes vary by equal amounts in the same sense and at the same time. Changes of gain in the receiving equipment will introduce negligible error. The equipment was run continuously with periodic checks on receiver sensitivity.

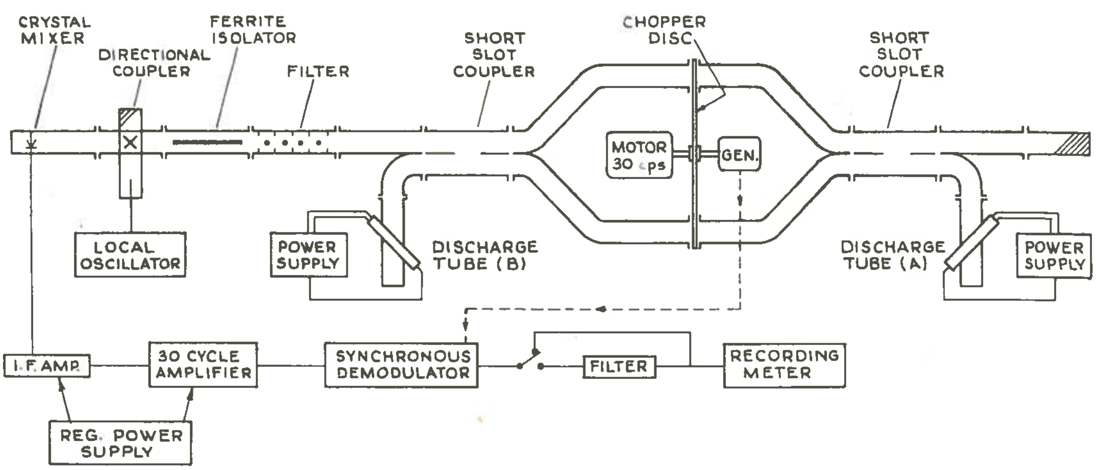

FIG. 3. SCHEMATIC OF EQUIPMENT FOR RELATIVE MEASUREMENTS, WITH DETAILS OF RADIOMETER

When operating the tubes at the usual discharge current of 250 ma, deviations up to an equivalent of 50°K occurred intermittently over periods of a few hours. Increasing the discharge current to 300 ma produced a marked improvement. A typical record then showed deviations of only 1 part in 2000 or 3000 over selected two-hour periods, and extreme deviations of 1 part in 1000 over a 15-hour period. The discharge current was increased because of the observation that the audio-frequency oscillations, characteristic of these tubes [6], became correspondingly less intense and less irregular. Presumably, at 250 ma these oscillations have some effect on receiver response through variations of the radio-frequency impedance and perhaps this was aggravated by the use of a sub-harmonic of 60 cycles/second as the switching frequency. Incidentally, the type-A147 tube operated satisfactorily at its rated discharge current, and difficulties of this nature may occur only with the type-A148 tube.

Several tubes were rechecked periodically after continuous operation, intermittent operation, or shelf life of several months. In some cases emission appeared to have changed by about 50°K when retested, but these changes were not clearly related to the history of the tube. The emission of one tube increased 50°K, and that of another remained unchanged after being repeatedly fired several thousand times. One tube that was used very infrequently appeared to have changed emission by 40°K. No changes larger than 50°K were measured on any of the tubes, some of which failed completely very shortly after being retested.

CONCLUSION

The absolute value of the effective noise temperature of the type A147 and A148 tubes was measured at 2885 mc/s as 10,700 ±150°K. To an accuracy of about 5 percent, there is no experimental evidence of a variation of emission with frequency. The emission of individual tubes was found to differ by 50°K or less, with an extreme of 80°K, or roughly 1 percent. They have been operated over periods of 15 hours with a stability of emission of 1 part in 1000; with receiving equipment as used in these tests the type-A148 tube must, however, be set to 300 ma discharge current where regulation of the power supply would become desirable (see Fig. 2). Whether this relative accuracy can be maintained over longer periods was not established, but accuracies of at least 1 part in 200 may be expected over periods of several months.

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