NEW MICROWAVE NOISE GENERATOR FOR THE 2000 MC/s BAND

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I. General considerations

When determining the sensitivity, *i. e.* to be more exact: the noise-factor of a receiver, either a signal generator, or a noise generator could be used as a signal source. Signal generators have an output power a great deal higher, than is actually needed, therefore, two problems arise in connection with them. First: a frequency-independent power divider must be used between the oscillator and the receiver. Second: the oscillator must be excellently screened. The output power of noise generators on the other hand is generated on the very level needed, therefore, the problems mentioned above do not arise in connection with them. Moreover, certain types of noise generators have an additional advantage, too: their output power is the function of either such physical quantities which can readily be determined only, or of data easily measurable macroscopically. Thus the noise generators need no calibration. Since it is easy to determine the output power of a noise generator to an accuracy of a few tenth of db, it is advisable to use a noise generator instead of a signal generator to check highly sensitive receivers, especially microwave receivers. The most generally used microwave signal sources are: thermal noise, shot effect and excess noise of semiconductors.

A readily attainable signal source, using the thermal noise, is to place a body of high temperature — mostly a heater filament — into the transmission line [1]. The noise temperatures that can be reached with this kind of noise generator lie around 2500 K°. A gas discharge tube placed in a transmission line will produce thermal noise, too [2]. The noise temperatures of such generators are about 10 000—12 000 K°.

The noise generators used mostly in the lower frequencies work with a saturated diode and make use of the shot effect. The noise temperature of these is the function of the direct current flowing in the tube alone. Owing to different disturbing effects (series resonance, interelectrode capacitances, difficult matching conditions), common diodes cannot be used in the microwave region without certain disadvantages [3]. Coaxially-built noise diodes have been developed especially for microwave use. The noise klystron also makes use of the shot effect [4]. Since this is a multielectrode tube, a certain amount of partition noise is present besides the shot noise. Therefore, its output noise power cannot be calculated accurately enough, such a noise generator must be calibrated.

Crystal diodes are also used as noise sources. In this case the excess noise, characteristic to semiconductors is made use of [5]. The noise temperature of such a generator cannot be determined from the working conditions, therefore, they need calibration quite often.

Having compared the above-mentioned types with each other, the result could be summed up in the following: the thermal noise sources are very good for microwave purposes, because their noise level can be accurately calculated and it is rather easy to match a transmission line with them. Considering the average microwave receiver, the output level of the heater-filament noise generator is too low, therefore, the gas discharge tube noise generator is the one which is especially suitable for this purpose. The microwave noise generators generally work with gas discharge tubes. The coaxial diode lacks a few of the above-mentioned disadvantages, but because of its complexity it is rather expensive.

The crystal diode as a noise source cannot be relied on and should, therefore, be used only as a workshop control apparatus. The noise klystron is relatively expensive and needs calibration.

1. Noise of gas-discharge phenomena

In the plasma of a gas-discharge there are free electrons, ions and gas atoms. The electrons may move around, can collide with the ions or atoms resp. These collisions may result in a recombination or a new ionization. Since the mass of ions is several magnitudes greater than that of the electrons, they are much less mobile, so that their effect is negligible in respect to both conduction and noise.

The noise produced by the plasma can be calculated from the following reasoning [6].

The noise is fully determined, if for example, the spectral distribution of the noise current is known. The noise current is made up of current pulses which are affected by the movement of single electrons. The spectral distribution of the noise current, in this case can be determined the most simply with the help of the Fourier spectra of the single pulses.

The mean square of the noise current, $\overline{i^2}$ can be expressed with its Fourier spectrum:

$$\overline{i^2} = w\,(f)\,df$$

As is known from literature [6]:

$$w\,(f) = \frac{4e^2\,\overline{N}\,\tau_0}{d^2\,(1+\omega^2\,\tau_0^2)}\;\overline{v_x^2} + a_x^2\,\tau_0^2\,\frac{3+\omega^2\,\tau_0^2}{1+\omega^2\,\tau_0^2} \tag{1}$$

where $\bar{N}$ = the average number of electrons
d = the distance between anode and cathode
τ_0 = the average time between two collisions
$\overline{v_x^2}$ = the mean square of the initial velocity of the electrons in the x direction
a_x = the acceleration of the electrons in the x direction
ω = the frequency

The x direction coincides with the axis of the discharge.

The first part of Equ. (1) is the function of only the initial square velocity of the electron, this represents its thermal noise. According to the equipartition law, the average value of the noise energy is

$$\bar{E}_{\mathrm{th}} = \frac{1}{2} m \overline{v_x^2} = \frac{1}{2} k \tau_e \tag{2}$$

where τ_e is the temperature of the discharge and k the Boltzmann's constant. Equ. (2) may be regarded as the definition of the electron temperature.

According to Nyquist's theorem, the mean square value of the thermal noise current is

$$\overline{i_{\mathrm{th}}^2} = 4k\, \tau_e\, G\, df \tag{3}$$

By combining Equ. (2) and Equ. (3) with the first part of Equ. (1), the conductivity of the gas discharge results:

$$G(\omega) = \frac{e^2 \bar{N} \tau_0 / m d^2}{1 + \omega^2 \tau_0^2} \tag{4}$$

The second part of Equ. (1) gives the spectral distribution of the shot noise of the discharge. The a_x acceleration can be eliminated from this expression by simple physical considerations. In this way the mean square of the noise current is

$$\overline{i^2} = \left[4k\, \tau_e\, G + \frac{4P\tau_0}{\bar{N}}\, G \left(1 + \frac{2}{1 + \omega^2 \tau_0^2}\right)\right] df \tag{5}$$

and the output noise power:

$$P_N = \frac{1}{4} \frac{\overline{i^2}}{G} = \left[k\, \tau_e + \frac{P\tau_0}{\bar{N}} \left(1 + \frac{2}{1 + \omega^2 \tau_0^2}\right)\right] df \tag{6}$$

where P is the power dissipated in the discharge. The part giving the thermal noise is the function of the electron-temperature only, while the part giving the shot noise is the function of the dissipated power in the tube (of the tube current) and of the frequency as well.

The foregoing considerations are valid only for homogeneous gas discharge, since the different parts of the gas discharge may have different electron temperatures. The electron temperatures are generally the function of outside parameters (pressure, conduction current, outside temperature, etc.), except the electron temperature of the positive column. This — according to practice — depends on the quality of the gas only, and is reasonably independent of other parameters.

2. The characteristics of a gas discharge tube placed in a transmission line

Equ. (3) gives the conductivity of the gas discharge. The same result can also be achieved, if instead of considering the thermal fluctuations — as it was done above — the movement of a colliding electron moving in a d. c. and high frequency field is investigated. From these calculations the reactive part of the impedance can be detected, too. In this way the whole impedance is:

$$Z = \frac{md^2}{e\,N\,\tau_0}\,(1 + j\,\omega\tau_0) \tag{7}$$

As the conduction of the discharge is finite, a gas discharge tube placed into a transmission line will act as a lossy conductor or as a lossy dielectric.

Let us consider the propagation of the noise in a transmission line generated by a gas discharge. Moving electrical charges generate electromagnetic waves, the direction of the electrical field is determined by the acceleration direction of the charges. In a transmission line the direction of the electrical field is an unanimous function of the mode of propagation. Therefore, the generated waves will propagate only if the particles have an acceleration component in the direction of the possible electrical field. According to the equipartition law the thermal noise-energy is independent of the axis position of the gas discharge tube. The shot noise power is proportional to the square acceleration, so if we only consider that component, which will propagate in the transmission line, $a_x \cos\vartheta$ should be written in place of a_x in Equ. (1), ϑ being the angle between the axis of the discharge and the direction of the E field. So the maximum noise power propagating in the transmission line is

$$P_{N\tau} = \left[k\,\tau_e + \cos^2\vartheta\,\frac{P\,\tau_0}{N}\left(1 + \frac{2}{1 + \omega^2\tau_0^2}\right)\right]df. \tag{8}$$

3. Design considerations

When designing noise generators using a gas discharge tube, the following requirements should be met: the noise generator must be placed in such a transmission line through which propagation on the working frequency is possible; the noise generator should not need calibration, *i. e.* the output noise power should be the function of known physical quantities only and be independent of outside circumstances. By using the above results, the design of the noise generator is already possible.

1. The outside load is to match the inner resistance defined by Equ. (7). (The inner resistance naturally contains a factor depending on the geometry.) The generator matched in this way will not generally match the wave impedance of the transmission line.

2. The plasma is to be coupled to the transmission line alone. Therefore, the position of the gas discharge tube and the attenuation of the plasma. resp., should make possible the attenuation of the additional noises produced by other parts of the tube and by transmission line parts being at ambient temperatures.

3. The axis of the discharge is to form an angle with the electric field-lines which makes the shot noise negligible in respect to the thermal noise, the former being heavily dependent on outside circumstances.

The noise generator fulfilling these requirements will have an equivalent noise temperature equal to the electron temperature with good approximation, which can be determined by measuring physical constants and are known for several gas types [7], [8].

II. Noise generator design

The earlier microwave noise generators were made generally in wave-guide form, mainly, because the discharge tube can easily be placed into a line not having an inner conductor. The best type has proved to be the one in which the tube has a tilted position in respect to the *E*-plane, the angle being approximately 10° [7].

On another type the gas discharge tube was put in the transversal plane, perpendicular to the *E*-field [2]. The first type fulfills the requirements outlined in Chapt. I.3. while this latter one has much more disadvantages, since matching is done here with separate elements and the attenuation of the plasma is small because of the configuration. Therefore, the effective noise temperature is influenced by those parts of the transmission line which are at room-temperature. (This latter disadvantage can be reduced by terminating the line with reactance, instead of resistive load.)

In the 2000 MC/s band these types are not favourable from the practical point of view. The dimensions of the wave-guides in this band are too big and such a noise generator would be unreasonably large. (*E. g.*: the standard wave-guide dimensions at 2000 MC/s are 109 × 54.5 mms. A discharge tube put into this at 10° would be 1/2 meter long.) Because of the large dimensions only coaxial or other transmission lines using the TEM mode are used in this frequency band. In case of coaxial line it is practically impossible to place the gas discharge tube in a tilted fashion because of the inner conductor. The other possibility in which the discharge tube faces the magnetic field-lines would also be very difficult to realize in a coaxial line, since this would involve the use of a curved discharge tube.

There is a workable solution for this frequency band published in the literature [9], where a transition is made from the coaxial line to a helical one and the discharge tube is placed into the latter. This solution of the problem meets all the requirements mentioned above, however, its mechanical structure is relativly complicated, and besides, the matching of the transition must be solved in a broad frequency band.

1. The microwave circuit

The noise generator developed by the authors is made of a coaxial line using the TEM mode. The gas discharge tube is used as a lossy conductor and is an integral part of the inner conductor. A schematic drawing is given in Fig 1.

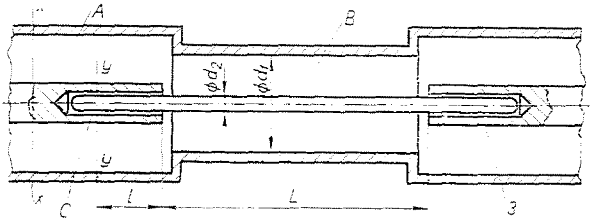

Fig. 1

The noise generator is made of a standard 7/8″ coaxial line The gas discharge tube is placed so that it forms the inner conductor of the coaxial line. Mechanically it is clamped by two conducting sections: "*C*". Noise is generated by the section "*B*" of the gas discharge tube.

The "*C*" sections — as will be shown — can at the same time be used for matching the noise generator. Both d_1 and d_2 diameters are chosen so, that the cut-off frequencies are higher than the working frequency of the noise generator. The filament voltage reaches the tube through a broad band metal extension, not shown on the drawing. The anode of the tube is directly connected to the inner conductor. The output of the generator is at the cathode-side of the discharge tube. The other side of the transmission line may be arbitrarily terminated, *e. g.* by a short circuit. The discharge tube itself contains argon at a pressure equal to 4,5 mms of mercury and mercury vapour. The temperature of such a plasma, according to the literature is 11 500 K° [8].

As regards to matching, the impedances must be checked. From the "*x*" plane onwards the noise generator can be substituted by the circuit given on

Fig. 2. The length of the transmission line containing the discharge tube is so long, that it can be regarded as being terminated by its characteristic impedance. The shorter line section, "*C*" is terminated by an open circuit. The cathode side plane of the plasma can with good approximation be regarded as the effective plane of the open circuit ("*y*" plane on Fig 1.), since the resistance of the cathode-fall immediately following this is a great deal higher than that of the plasma.

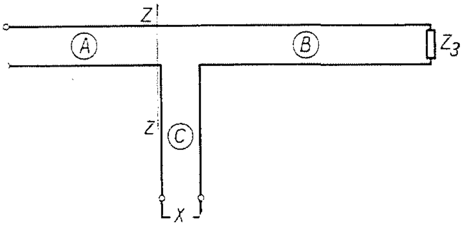

Fig. 2

In the equivalent circuit according to Fig. 2 both "*B*" and "*C*" lines contain a separate noise generator (Fig. 3). In Fig. 3 $Z_2 = Z_{02} = R_{02} + jX_{02}$ is the characteristic impedance of the "*B*" line, $Z_3 = R_3 + jX_3 = Z_{03}\, cth\, \gamma l$ is the open circuit impedance of the "*C*" line, if γ is the propagation constant measured in the "*C*" line, $\overline{v_1^2}$ and $\overline{v_2^2}$ are each noise generators with the same electron temperature and R_{02} and R_3, resp., being the inner resistances of the generators. The voltage sources of the generators — since they are not in correlation with each other — can be squared and added. In this way the inner impedance of the resulting noise generator will be $Z_i = Z_2 + Z_3$ while its electron temperature T_e remains the same. The output power of the noise generator is effectively $\frac{\overline{v^2}}{R_i}$ if the terminating impedance at the "*z*" plane is

$$Z = Z_i^* \tag{9}$$

This condition can always be fulfilled with the use of proper matching elements, but as has been pointed out before, the generator will not be generally matched to the transmission line, either.

From the point of application it is absolutely essential to have a good match between the noise generator and the transmission line, since the input impedance of the receiver in most cases is equal to the wave impedance of the line, and the noise factor measured depends on the matching of the generator.

It is, therefore, advisable to choose the impedances in such a way that matching between load and generator, and between generator and transmission line, resp., should be simultaneously fulfilled. In the equipment under discussion this is possible even without any additional matching elements. This is because the inner resistance of the generator — between certain limits — can be freely chosen. If the impedances of the two generators on Fig. 3 are chosen in such a way that their sum is real and equal to the wave impedance of the 7/8″ line, than the above requirement is fulfilled. The match should be realized so that the following will be valid:

$$R_{02} + R_3 = Z_{01}; \; X_{02} = -X_3 \tag{10}$$

By making proper choice of dimension "L" on Fig. 1, the attenuation of the plasma can be kept high enough to have those noises arbitrarily well attenuated which originate at the line terminating impedance and at the anode side of the discharge tube, resp., both being noises at different temperatures than T_c.

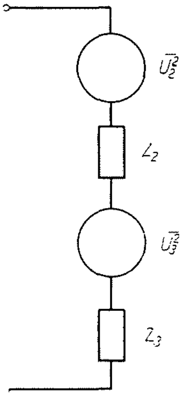

Fig. 3

The attenuation of the undesired noises originating on the cathode side depend on the l dimension of the plasma. According to the above reasoning the length l cannot be freely chosen, in practice, however, the length necessary for the matching gives enough attenuation.

It follows from Equ. (8) that the shot noise, which is proportional to $\cos^2 \vartheta$ is in first approximation not present at all, since the discharge tube is perpendicular to the electrical field. In practice, however, the finite conductivity of the plasma results in a small axial E component, but the shot noise thus generated is negligible beside the thermal noise.

2. The D. C. circuit

The D. c. circuit of the noise generator is made in the usual way and is shown on Fig. 4.

The D. c. voltage-drop on the discharge tube is in the order on 50—100 volts, the ignition voltage is appr. 1000 volts. It is advisable to generate the relatively high ignition voltage at the moment of ignition only. In the circuit shown on Fig. 4 this is realized in the following way: by closing and then opening switch K, there appears a high-voltage pulse on the L inductance (its value being appr. 10 henries), which then ignites the tube. By changing the limiting resistor, R, it is possible to set in the necessary tube current. There is no need for good filtering of the supply voltage, since the fluctuation of the current does not produce a change in the noise temperature [7]. The anode point is grounded, as it is connected with the transmission line.

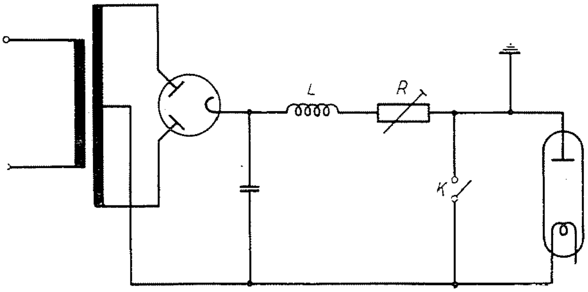

Fig. 4

3. Measurement results

The following measurements were made: checking the match of the noise generator, measuring the noise power and the attenuation of the line section containing the plasma. The working frequency band was 1800—2200 MC/s.

If an uncertainty of .5 db is permitted on measuring the noise figure, then the voltage standing wave ratio caused by the noise generator does not exceed the $r = 2$ value. Six tubes were checked: Table I contains the average values of the measurements.

Table I

VSWR as a function of anode current and frequency

	$f^{kMC/s}$	1,8	1,85	1,9	1,95	2,0	2,05	2,1	2,15	2,2
	100	2.15		1,77		1,84		1,9		2,4
I^{mA}	125	2,05	2	1,72	1,77	1,64	1,77	1,74	2	2,05
	150	2,06	1,9	1,74	1,69	1,61	1,68	1,77	1,82	1,86

The dependence of the output noise power on the tube current was measured with a receiver having a mixer input stage, its i. f. being 30 MC/s, the bandwidth 4 MC/s. A self-compensating, a. c. thermistor bridge was used as a detector. Table II shows the average data obtained from the six tubes. The difference of the noise powers of the six tubes was within 5 db. Above 120 mA anode currents, no output variation of the noise power could be detected.

Table II

The output noise power as a function of the tube current

I^{mA}	80	100	120	140	160
P_n degrees	29	29.5	30	30	30

By comparing the results of these two measurements, it was found, that the noise generator works best at 150 mA anode current, therefore, this current was chosen for working current.

The output of a noise generator working with 150 mA was compared with that of a microwave signal generator. The deviation of the measured value from the expected one was within 5 db.

With one of the tubes the attenuation of the noise generator was measured as a function of frequency and anode current. Table III shows the results.

Table III

The attenuation in db of the noise generator as a function of anode current and frequency

I^{mA}		100	125	150
$f^{kMC/s}$	1,9	24,5	21	18
	2,0	24	20,5	18
	2,1	22	19	18
	2,2	17	15	15

4. Conclusions

The microwave noise generator discussed in the article has small dimensions, it is simple and easy to operate. The output noise power depends only on the noise temperature of the plasma. Its advantage over the helical line or wave-guide types is, that no special, additional matching elements are required.

If the gas discharge tube is inactive, the noise generator does not match the connecting transmission line. This is rather an inconvenience than a disadvantage. The described noise generator can be used theoretically in a very broad band with the use of proper matching elements.

Summary

The paper discusses the design of a microwave noise generator applied to a coaxial line, using a gas discharge tube. The gas discharge tube is built into the inner conductor of the coaxial line. It is theoretically proved that the noise power of the generator is the function of the noise temperature of the electrons alone.

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