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INFLUENCE OF BURST NOISE ON NOISE SPECTRA

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Abstract—A method of calculating the spectrum of multilevel burst noise has been given. Measured noise spectra of bipolar transistors with burst noise together with calculated characteristics have been presented. A comparison of the measured and calculated characteristics shows that burst noise is responsible for the noise spectrum deviations in the low frequency range. In the Appendix a practical method of burst noise spectral density calculation has been given.

1. INTRODUCTION

Burst noise together with $1/f$ noise is the basic type of audio and subaudio frequency noise in some semiconductor devices. Burst noise has a waveform of rectangular pulses with time duration from 0.1 ms to several minutes. The amplitude of burst noise at the output of bipolar transistors in the common emitter configuration is most frequently in the range from 100 μV to 1 mV. Basic types of burst noise are two-level (bistable) and three-level. Sometimes a multilevel burst noise occurs.

Usually burst noise is described as fluctuations superimposed on otherwise "clean" noise. The spectral density of burst noise is comparable with the spectral density of $1/f$ noise. A simple measurement of burst noise spectrum is very often impossible. The waveforms of burst noise then have to be recorded and next the spectrum has to be calculated analytically.

Assuming that burst noise is a stationary Markov process with two discrete levels, Martin[1] solved Kolmogorov equation and obtained a spectrum, which is described as follows

$$S(f) = \frac{4ab}{(a+b)^3}\frac{1}{1+(f/f_0)^2}, \tag{1}$$

in which

$$f_0 = (a+b)/2\pi.$$

Equation (1) is similar to that of Van der Ziel[2]. However it is impossible to calculate the absolute value of the burst noise spectral density using this equation. In addition, only the simplest two-level form of burst noise was taken into account.

This paper presents a method of determining the spectrum for burst noise with an arbitrary number of levels. The equations presented here give a possibility of calculating the noise power spectral density. Using these equations noise spectra of measured transistors have been calculated and will be shown.

The method is suitable for calculation of three-level burst noise which is the most frequent case of multilevel burst noise and as we can show[5] this is not a superimposed burst noise. For burst noise with more than three levels exhibiting several cut off frequencies (bendings, bumps) we must consider superimposed burst noise as a sum of two-level and (or) three-level burst noise.

2. THEORY

It is assumed, that processes under consideration are stationary with equal probability of signal presence on each existing level. However the author is aware that this assumption may be not a practical case. A method of correct calculation is given in the Appendix.

An equation for the burst noise spectrum is deduced in the following manner[3]. First, the autocorrelation function is calculated as a mean value of a product of signals at the moments t and $t+\theta$:

$$R(\theta) = \lim_{T\to\infty}\frac{1}{2T}\int_{-T}^{T} X(t+\theta)X(t)\,dt. \tag{2}$$

Assuming, that λ transitions from one level to another level occur in the unit of time, and that the mean square value of pulse amplitude is $\overline{U^2_{BNO}}$, we obtain for the autocorrelation function the following equation

$$R(\theta) = \overline{U^2_{BNO}}\,e^{-\lambda|\theta|}. \tag{3}$$

This is correct for an arbitrary distribution of amplitudes and moments of level changes.

On the condition

$$\int_{-\infty}^{+\infty} |R(\theta)|\,d\theta \le M, \tag{4}$$

where M is an arbitrary constant value, the Wiener-Kintchine theorem may be used[4]:

$$S(f) = 2\int_{-\infty}^{+\infty} R(\theta)\,e^{-j2\pi f\theta}\,d\theta. \tag{5}$$

In our case the spectral density of burst noise is

$$S(f) = \frac{4\overline{U^2_{BNO}}\,\lambda}{\lambda^2+(2\pi f)^2}. \tag{6}$$

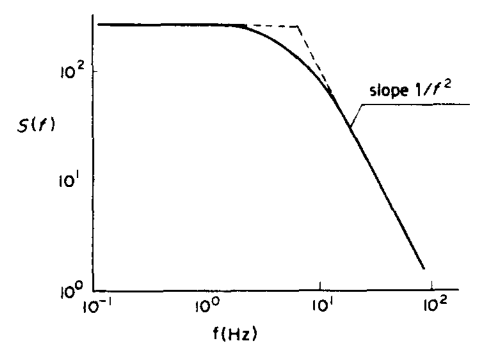

Fig. 1. Spectrum for burst noise.

A plot of this equation is presented on Fig. 1.

This equation makes possible a calculation of the spectral density of two-level, three-level and multilevel burst noise.

3. EXPERIMENTAL INVESTIGATIONS

For an estimation of the burst noise component in the total noise spectrum, the noise power spectral density for several bipolar transistors in the frequency range from 10 Hz to 10 kHz has been measured[5]. Measurements have been carried out for the common emitter configuration with a source resistance of 100 kΩ and an emitter current of 100 μA. The result of measurements for a BC107 transistor (No. 16) with three-level burst noise has been presented in Fig. 2 and for a BC109 transistor (No. 38) with two-level burst noise in Fig. 3.

Measurements of the burst noise amplitude U_{BNO} and of the mean number of transitions from one level to another level in the unit of time λ have made possible the calculation of the burst noise spectral density using eqn (6). The result of these calculations also has been presented in Figs. 2 and 3.

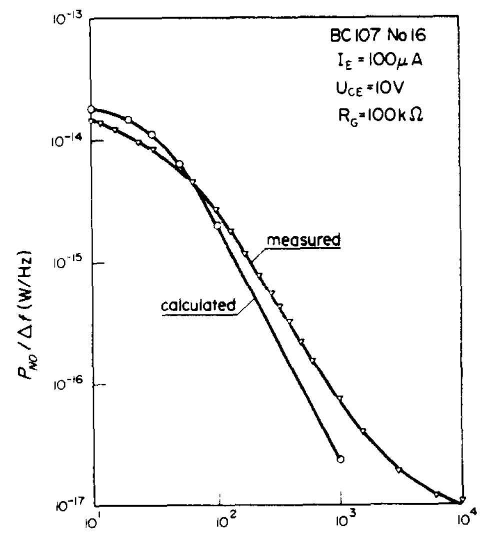

Fig. 2. Burst noise power density spectrum at the output of a common emitter stage with the BC107 transistor.

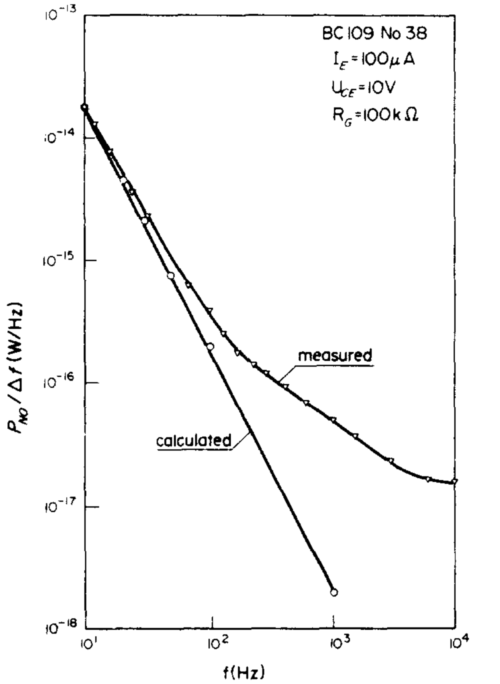

Fig. 3. Burst noise power density spectrum at the output of a common emitter stage with the BC109 transistor.

Measured characteristics show the influence of burst noise on the total noise spectrum. The deviation from a $1/f$ dependence shown in Fig. 2 is related to the bending of the burst noise characteristic and the deviation in Fig. 3 is related to the $1/f^2$ slope of burst noise characteristic.

Only some transistors with burst noise show a deviation of spectral density characteristic from a $1/f$ dependence. This is caused by the mutual dependence of $1/f$ noise level and burst noise level. We note that it is possible to observe a double and a triple bending in the case of multilevel noise.

For transistors without burst noise we have never observed deviations from the $1/f$ dependence.

4. CONCLUSIONS

It becomes evident, that very often the burst noise plays a main role in the low frequency spectrum. In order to explain the noise spectrum deviation from the $1/f$ dependence, we should first examine the burst noise influence.

Measurements of noise spectra deviated from the $1/f$ dependence in the frequency range below 10 Hz could be very interesting and proper investigations should be continued. One should expect, however, that for lower frequencies the bending of the characteristic would vanish in favour of restoring the simple $1/f$ dependence.

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APPENDIX

A practical method of burst noise spectral density calculation

Equation (6) describes the square of the noise voltage and for a calculation of the noise power it has to be divided by $4R_d$, where R_d is the matched resistance dissipating the power.

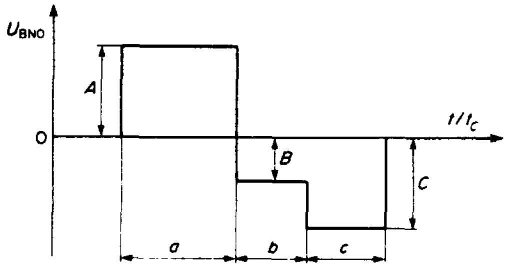

Fig. 4. Sum of three-level burst noise pulses.

We obtain

$$S_p = \frac{\overline{U_{BNO}^2}\,\lambda}{R_d[\lambda^2 + (2\pi f)^2]}. \tag{7}$$

In this equation λ and $\overline{U_{BNO}^2}$ can be determined experimentally. λ can be counted in a simple manner but a determination of $\overline{U_{BNO}^2}$ is more complicated. Here we present a method of calculating for example three-level burst noise.

Summation of higher, lower and intermediate pulses gives the result shown in Fig. 4, where t_c is the total time of observation. Area under and below axis should be equal. Letters a, b, c indicate the probability that the signal is present on one of the three possible levels, so

$$a + b + c = 1. \tag{8}$$

For derivation of eqn (6) an equal probability of signal presence on each of the three possible levels was assumed. This is not satisfied in practice and $\overline{U_{BNO}^2}$ is calculated as follows

$$\overline{U_{BNO}^2} = aA^2 + bB^2 + cC^2. \tag{9}$$

A calculation of the spectral density for multilevel burst noise is only a little more complicated.