1/*f* Noise in Ceramic Superconductors and Granular Resistors

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Abstract—**The authors have measured the current noise in some components of granular structure. The samples are ceramic superconductors, carbon-black graft-polymer resistors, and positive temperature coefficient (PTC) ceramics. All noise spectra are of the 1/*f* type. The temperature dependence of the noise level is measured and compared with the temperature dependence of the resistance. It is shown that in these components the temperature coefficient of the resistance is related to the noise level as predicted by our temperature fluctuating model.**

I. Introduction

The noise of the 1/*f* spectrum is widely found in electrical materials and components [1]. The presence of the 1/*f* noise is particularly troublesome, because its amplitude is much higher than that of thermal noise. The authors have previously reported the 1/*f* noise in static contacts [2] and thin films [3] and have proposed a model for the generation of the 1/*f* noise, which is based on the spontaneous fluctuation of temperature of the small conducting spots between metal surfaces.

In this paper, the noise characteristics of some components of granular structure are shown and the results are discussed with the spontaneous fluctuation of the resistance in the boundaries of the grains in the components.

II. Noise Measurement

The noise is measured with a spectrum analyzer with a switched-capacitor filter [2] and a noise intensity measuring system. The latter system is a correlation system arranged for measuring the small noise voltage. It consists of two amplifier and band-pass filter systems shown in Fig. 1. The noises generated in two systems are canceled out because they are independent each other. The input equivalent noise resistance decreases to as low as 15 Ω in this correlation system.

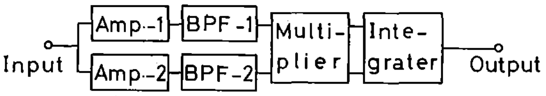

Fig. 1. Noise intensity measuring system.

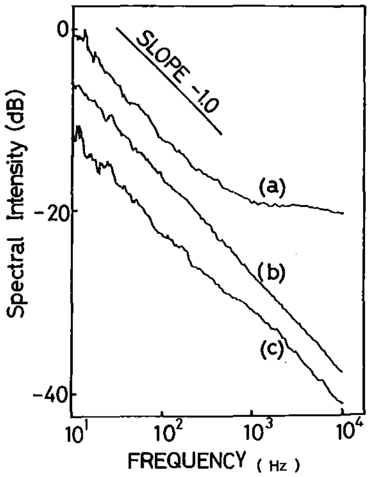

Fig. 2. 1/*f* noise spectra in low frequency range. These curves have been shifted vertically to avoid overlaps. $T = 300$ K. (*a*) Ceramic superconductor. (*b*) Carbon-black graft polymer. (*c*) PTC ceramic.

III. Samples and Noise Spectra

The superconductor is Y–Ba–Cu–O ceramic superconductor prepared by Nakamura Riken Industries Co., Ltd., and is formed in four-terminal shape: the noise is measured between noncurrent-carrying terminals while the constant current I is fed between current-carrying terminals. The typical length is 16 mm and the cross section was 3×3 mm^2. The critical temperature T_c is about 80 K. No noise is observed in the superconducting state.

The carbon-black graft-polymer sheet resistor is supplied by Achilles Co. and is also formed in four-terminals shape. The typical length was 25 mm and the width was 5 mm.

The positive temperature coefficient (PTC) ceramic is a commercial one. This component is of two terminals.

Fig. 2 shows the typical noise spectra in our components. It is noted that all noise spectra are of the 1/*f* type in the low frequency range.

IV. Temperature Dependence of Resistance and Noise

In order to characterize the noise, we equate

$$\overline{v^2} = 4kTR_n\Delta f \tag{1}$$

where Δf is the small frequency band width, k is Boltzmann's constant, and T is the absolute temperature. We call R_n the equivalent noise resistance [4].

A. Ceramic Superconductors

Fig. 3 shows the temperature dependence of the resistance, and Fig. 4 shows the measured noise level. It is noted that the noise level is anomalous just above the critical temperature.

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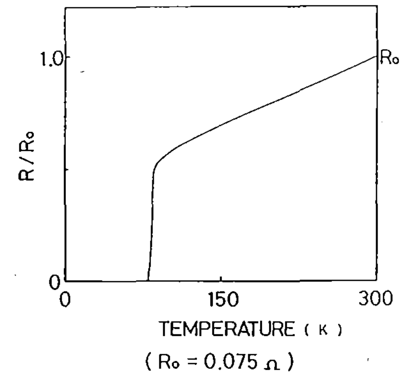

Fig. 3. Dependence of resistance on temperature in ceramic superconductor.

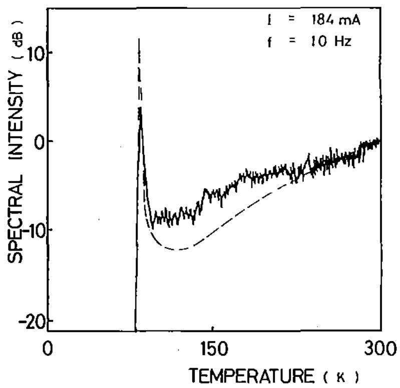

Fig. 4. Dependence of noise on temperature in ceramic superconductor.

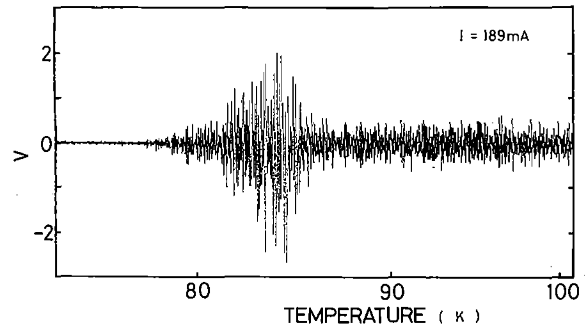

Fig. 5. Relative noise voltage versus temperature in ceramic superconductor. Increasing temperature rate is 14 K/min.

This depends on the increasing temperature rate. A typical noise voltage variation while increasing the temperature is shown precisely in Fig. 5.

B. Carbon-Black Graft-Polymer Resistors

Carbon-black graft-polymer [5] has a stable resistance. The measured temperature dependence is shown in Fig. 6. The temperature coefficient of the resistance varies from negative to positive for a temperature rise and is zero near 80°C [6]. The resistance deviation is small through the temperature range. The measured temperature dependences of the noise at 1 kHz are also shown in Fig. 6. Note that the noise level shows a dip at 80°C. It has been shown that the noise in granular resistors is proportional to the square of the resistance [2]; however, in our resistors, the decrease in the square of the resistance is only 4%. The large dips as shown in Fig. 6 cannot be explained merely by such a small decrease in the square of the resistance; so we should consider the contribution of the temperature coefficient of the resistance to the noise level as predicted by our model [2]. This is discussed in the next section.

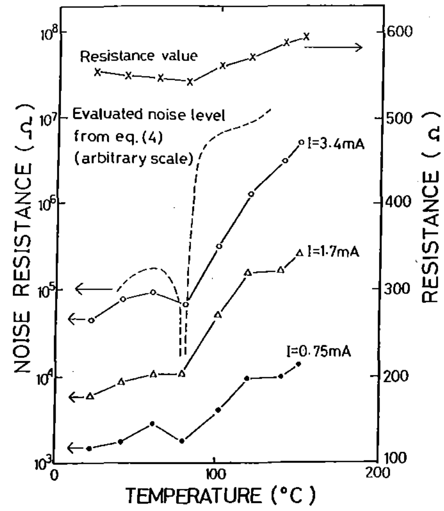

Fig. 6. Dependences of resistance and noise ($f = 1$ kHz) on temperature in carbon-black graft-polymer resistor.

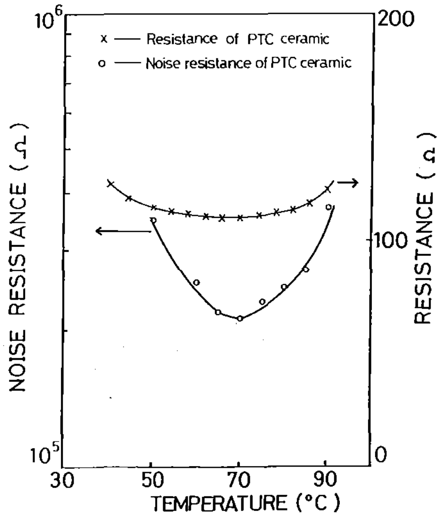

Fig. 7. Dependences of resistance and noise ($I = 3.5$ mA, $f = 10$ Hz) on temperature in PTC ceramic.

C. PTC Ceramics

PTC ceramics are used for temperature sensors and current-limiting resistors. They are characteristic of abrupt increase in resistance with increasing temperature [7]. Fig. 7 shows the temperature dependences of the resistance and the noise at 10 Hz. Both temperature dependences are qualitatively the same as those in the carbon-black graft-polymer resistor.

V. QUALITATIVE EVALUATION OF THE NOISE FROM THE TEMPERATURE FLUCTUATING MODEL

If the fluctuating temperature ΔT in a resistor modulates the resistance R through the temperature coefficient p of the material, the fluctuating voltage in the resistance will be

$$\Delta V = pR\Delta TI \qquad (2)$$

where I is the flowing current.

The granular resistor consists of many granules and their boundaries contact each other. The current flows in the contacts of the granules. Consequently, the noise in the granular resistors would arise from the same type of mechanism as in the static contacts. On the other hand, a static contact itself consists of many conducting spots [8] with temperature fluctuation in each spot. The spectral intensity of the spontaneous temperature fluctuation of a small body is given by the Lorenzian spectrum [9]. Assuming that this fluctuating temperature modulates the spot resistance through the temperature coefficient p of the material and the spot sizes are distributed uniformly, the contact noise voltage spectral intensity is obtained by integration over the contact surface and is shown as follows [2]:

$$S_{vc}(f) \propto p^2T^2R_c^5I^2/f \tag{3}$$

where R_c is the contact resistance. The noise spectrum of (3) is of the $1/f$ type.

Assuming that each granule is a conducting sphere and their boundaries are contacting each other, the noise spectral intensity is expressed as follows [2]:

$$S(f) \propto p^2T^2I^2R^2/f \tag{4}$$

where R is the resistance of the resistor.

Calculating the temperature coefficient p from the measured result in Fig. 3 and using (4), the noise level is obtained and plotted in the broken line in Fig. 4. It is noted that the calculated one agrees qualitatively with the measured one in the superconducting ceramics.

The noise level in carbon-black graft-polymer resistor is also qualitatively calculated from the measured resistance in Fig. 6 and (4) and plotted in the broken line in Fig. 6 by an arbitrary logarithmic scale. It is also noted that the calculated one agrees qualitatively with the measured ones except for the dip magnitude. The calculated noise level at 80°C is zero because the temperature coefficient is zero, so that only white noise (mainly thermal noise) will remain, and consequently the equivalent noise resistance will be reduced to 600 Ω. However, the measured dip magnitudes are not so large. This difference would be explained as follows. The composition of the material may be inhomogeneous, so that the local temperature coefficient in small sections of the sample may not be the same over the sample. It may be negative in some sections and positive in the other sections, although the resulting overall coefficient is zero near 80°C. Further, the temperature distribution may not be uniform over the sample. For these reasons, the level of the $1/f$ noise generated in most sections of the sample is not zero at that temperature and the total noise level integrated over the sample is not zero. From Fig. 7 the same qualitative evaluation will be made.

As the above discussion is qualitative, detailed quantitative studies should be carried out. However, our temperature fluctuating model is presumed to be one of the most plausible noise generation mechanisms.

VI. CONCLUSION

The $1/f$ noise has been measured in ceramic superconductors, carbon-black graft-polymer resistors, and PTC ceramics. It was found that all noise spectra are of the $1/f$ type and the noise level is proportional to the square of the flowing current. The granular resistors consist of many discrete grains and their boundaries contact each other; so the noise in the granular resistors may arise from the same type of mechanism as in the static contacts [2]. The measured results qualitatively agree with calculated ones based on our temperature fluctuation model [2]. Quantitative and detailed studies have to be carried out more extensively on the $1/f$ noise model.

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