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Transverse and longitudinal noise

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Analytic functions are derived for the spectral noise voltage density between two circular sensor electrodes on a two-dimensional isotropic conductor, placed either transversely or longitudinally to a homogeneous electric field. The sensor electrodes are far removed from both the bias electrodes and the boundaries. The relations have been checked experimentally for $1/f$ conductivity fluctuations. Both the transverse and longitudinal noise are proportional to $I^{-2} |\mathbf{J} \cdot \mathbf{j}|^2 ds$ where $\mathbf{J} \cdot \mathbf{j}$ represents the dot (scalar) product of the homogeneous current density $\mathbf{J}$ and the adjoint current density $\mathbf{j}$, and the current through the bias electrodes is $I$. It is found that the transverse noise is somewhat smaller than the longitudinal noise.

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I. INTRODUCTION

This paper is concerned with the effects of electrode position and diameter on the noise voltages measured between the electrodes. The systems have the sensor electrodes far removed from bias electrodes and boundaries, in a uniform isotropic material in a homogeneous electric field. The electrodes are either placed precisely in line with the direction of bias current (longitudinally) or on a line perpendicular to the direction of the bias current (transversely). The noise between transversely or longitudinally placed sensor electrodes is often called transverse and longitudinal noise, respectively. The electrode configurations are given in the inset of Fig. 1. Transverse and longitudinal noise consists of a thermal noise term and a conduction noise term. The thermal noise is proportional to the real part of the impedance between the sensor electrodes. For sensors far removed from bias electrodes and from the boundaries, the impedance between the sensors is a function only of the sheet resistivity, the sensor diameter, and the distance between the sensors. So, the transverse thermal noise and the longitudinal thermal noise are the same when the sensor diameter $2r$ and the distance $2b$ are kept constant. The resistance $R$ between such an electrode pair is given by Vandamme and Groot\textsuperscript{1} and the thermal noise between the sensors is then $4kTR$.

When a constant current is passed through the sample, the conductivity fluctuations cause voltage perturbations which can be observed either in the direction of the current flow or at right angles to it. The conduction noise term is proportional to the square of the bias current $I$. Thus, above a certain current level the noise at the sensors is dominated by the conduction noise term.

Here we consider only transverse noise and longitudinal noise due to conductivity fluctuations. The advantages of measuring transverse noise rather than longitudinal noise at very low frequencies were already mentioned by Hawkins and Bloodworth.\textsuperscript{2} General relations for the noise voltage between arbitrarily shaped and placed sensor electrodes on a conductor when a constant current or voltage is applied to another pair of arbitrarily shaped and placed driver electrodes is given by Vandamme and van Bokhoven.\textsuperscript{3} A computer approach solving the transverse noise and longitudinal noise in samples submitted to homogeneous fields is also treated.\textsuperscript{3}

We report on analytic functions and measurements for
the transverse noise and longitudinal noise between two cir-
cular sensor electrodes in two-dimensional conductor sub-
mited to a uniform field when the noise is dominated by 1/f 
noise. The modification required in the equations for a gen-
eration-recombination spectrum is presented.

II. CALCULATION OF TRANSVERSE NOISE AND 
LONGITUDINAL NOISE POWER DENSITIES \( S_{\nu i} \) 
AND \( S_{\nu j} \)

The inset of Fig. 1 shows circular sensors having diame-
ters \( 2r \), with \( 2b \) the distance between the centers. The length 
and the width are denoted by \( L \) and \( W \), respectively. The 
conductor is assumed to be homogeneous and isotropic in its 
macroscopic as well as its statistical properties. We assume 
the conductance fluctuations between very small subareas 
are uncorrelated.

The electrodes are assumed to be ideal, which means 
that the resistivity is negligible. We take the sensors far from 
the boundaries and the driver electrodes, and the diameter \( 2r \) 
is less than one-tenth of the sample dimensions \( L \) and \( W \). The 
ratio \( b/r \) is chosen larger than 1.4, to avoid deviations of the 
macroscopic as well as its statistical properties. We assume 
the conductance fluctuations between very small subareas 
are uncorrelated.

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macroscopic as well as its statistical properties. We assume 
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For a pair of point electrodes at a distance \( 2a \) apart and placed longitudinally to \( J \), the adjoint current density \( J_\nu \) becomes

\[
J_{\nu}(x,y) = \frac{I a xy}{\pi r_1^2 r_2^2},
\]

where \( r_1 \) and \( r_2 \) are the distances from a point \((x,y)\) in the 
two-dimensional conductor to the point sources at \((-a,0)\) and 
\((a,0)\). Equation (2) follows from simple superposition of 
current densities due to two-point current sources of opposite 
sign placed at a distance \( 2a \) apart. If a pair of point electrodes 
at a distance \( 2a \) is placed transversely to \( J \), then \( J_\nu \) becomes

\[
J_{\nu}(x,y) = \frac{I 2axy}{\pi r_1^2 r_2^2}.
\]
\[
\frac{S_{\parallel}}{S_{\perp}} = \frac{W}{L} \left( \frac{1}{2\pi} (-\sinh^2 v_i + \frac{1}{2} \sinh 2v_i + v_i) \right) \tag{13}
\]

and

\[
\frac{S_{\parallel}}{S_{\perp}} = \frac{W}{L} \left( \frac{1}{2\pi} (\sinh^2 v_i - \frac{1}{2} \sinh 2v_i + v_i) \right). \tag{14}
\]

The function between \(b/r\) and \(v_i\) is given by:

\[
v_i = \ln \left| \frac{b}{r} + \frac{2}{b/r^2} - 1 \right|^{1/2}.
\]

Using Eqs. (11) and (12), the ratio \(S_{\parallel}/S_{\perp}\) becomes

\[
\frac{S_{\parallel}}{S_{\perp}} = \frac{2v_i + [1 - \exp(-2v_i)]}{2v_i - [1 - \exp(-2v_i)]}. \tag{16}
\]

This ratio is plotted versus that of the distance between the centers of the sensor electrodes \(2b\) and the sensor diameter \(2r\), as a line in Fig. 1. The dots represent the experimental results on resistors made of carbon sheet which is something like Teledeltos. The distance between the sensors was constant. The diameter of the sensors was increased step by step.

## III. CONCLUSIONS

The longitudinal noise \(S_{\parallel}\) is at least as large as the transverse noise \(S_{\perp}\) in homogeneous and isotropic samples submitted to uniform fields. The ratio \(S_{\parallel}/S_{\perp}\) is independent of the type of conduction fluctuations (1/f or generation-recombination noise).

The value of the integrand in Eq. (1) is higher in the neighborhood of the spot sensors due to a higher value of \(\mathbf{J}\). So the conductivity fluctuations in the neighborhood of the spot sensors contribute more than conductivity fluctuations far away from the sensors. The small contribution from areas far away from the sensors is even smaller in the calculation of \(S_{\perp}\) due to the fact that in the area between the sensor, \(\mathbf{J}\) is about perpendicular to \(\mathbf{J}\). This leads to a very small dot product \(\mathbf{J} \cdot \mathbf{J}\) which explains that \(S_{\perp}\) is always smaller than \(S_{\parallel}\).