LETTERS TO THE EDITOR

1/f Fluctuation in Membrane Potential as Related to Membrane Theory

Dear Sir:

Many—possibly all—electrical conducting media in which there is a potential barrier, exhibit $1/f$ noise: that is, a random potential fluctuation having a power spectrum varying inversely with frequency. Semiconductors provide the best-known example of such media. Neural membranes have also been found to generate such noise in their potential (1).

An obvious hypothesis for the source of $1/f$ noise is the random walk. As applied to membrane noise, this assumes that ions traverse the membrane potential barrier randomly in the two senses. Each ion traversing the barrier produces a step in the potential existing across the membrane.

The trouble with this simple hypothesis is that the power frequency spectrum of such a random walk of potential varies as $1/f^2$, and not as $1/f$. On this basis Bell (2) rejected the random walk hypothesis, and proposed a queuing theory of $1/f$ noise. Such a theory could have important implications in the neural case, when one recalls that Hodgkin and Huxley (3) proposed a queing theory of cation penetration of the axonal membrane, to account for the steep change of conductance with transmembrane voltage. Thus, if the queuing theory were to be substantiated, it would tend to substantiate this model of axonal activity, and the separate K^+ and Na^+ channels implied thereby.

Bell's analysis of the random walk neglected an essential factor. A simple random walk of the potential is physically impossible, since it would result in an ever increasing departure of the potential from its steady-state value. The probability of current carriers crossing the potential barrier is however no longer equal in the two senses, when the random motion of the carriers has caused the system to depart from its steady state. An increase in the carrier concentration on either side proportionately raises the probability that the carrier will move to the other side, producing an osmotic drift towards the steady state. The collection of carriers on either side will also result in an electric field, which will further increase the probability of ionic countermovement, producing a coulombic drift towards the steady state. These two factors: the osmotic and the coulombic drift, may be considered as a general drift of all the carriers, causing the potential to return exponentially towards its steady-state value. If this factor is included, the power spectrum of the net potential produced by a random walk does have the $1/f$ spectral distribution.

This is shown by a computer simulation. A random walk of 1000 steps was generated. After each step, the displacement was reduced by 15%, equivalent to a time constant of reequilibration equal to 6.7 steps. The power spectrum of the resultant time series was then taken, and each harmonic amplitude multiplied by its order. The resultant product shows the large fluctuation to be expected from a random process, but this is reduced by summing a number of separate terms. Thus in one run, the sum of the terms for harmonics 31–210 was 325.4; while for 211–390 it was 319.6. The first 30 harmonics were eliminated because of the finite length of the series; harmonics over the 390th were not computed, to avoid the Nyquist aliasing frequency.

A similar calculation, but omitting the drift factor, results in a clear demonstration of the $1/f^2$ law for this case.

While this analysis indicates that $1/f$ noise should be generated wherever the motion of a current carrier across a potential barrier will result in a change in potential, the absolute amplitude of the potential fluctuations has not been considered. The amplitude should increase with increased probability of random crossings of the barrier, but decrease with increasing drift current. The net effect will be that $1/f$ noise will only be observable if it is significantly greater than other sources of fluctuation, such as Johnson noise.

It is thus demonstrated that the random potential variation to be expected from ions traversing the potential barriers of a membrane will have a $1/f$ power spectrum. The existence of such a noise spectrum cannot, therefore, be used to substantiate any particular theory of membrane activity.

The application of the calculations to semiconductors is published elsewhere (4).

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Distortion in Coulter Counters and the Applicability of the Collins-Richmond Principle

Dear Sir:

It has been recognized only recently that cell volume distributions obtained with Coulter counter-analyzer systems are distorted by the radial dependence of electric current and voltage near the mouth of the counting aperture (Grover, Naaman, Ben-Sasson, and Doljanski. 1969; Thom, Hampe, and Sauerbrey, 1969). The degree of distortion is nearly constant for cells or particles of different sizes and therefore has little effect upon the determination of average volumes by comparison to known standards. However, this distortion results in a modification of the shapes of distributions for cells and particles that invalidates detailed calculations from them. In particular, these distributions cannot be used, without correction, to determine the kinetics of growth of cells during the generation cycle by the method