J. Membrane Biol. 26, 405–406 (1976)

Letters to the Editor

Correlation Analysis of Membrane Noise

Received 13 November 1975

Kolb, Läuger and Bamberg (*J. Membrane Biol.* **20**:133, 1975) have used the correlation function to analyze spontaneous current fluctuations about an imposed dc-current from a lipid bilayer in the presence of gramicidin A. The common problem in such measurements is one of dynamic range of the amplifiers, which must have high gain for the noise, but which gain is too high for the dc-current. The solution they and others use is to ac-couple the high gain stage. There is little practical significance to the autocorrelation function when the coupling frequency is far below the frequencies of interest. However, it may not always be possible to couple at sufficiently low frequencies. In addition, to assume that frequencies lying above or below the coupling point are insignificant is to presuppose information about the membrane noise. It therefore seems reasonable to derive the exact effect of this coupling on the measured autocorrelation function.

Consider a simple RC high-pass, low-pass network with f_1 as the ac-coupling frequency (lower cut-off) and f_2 as the upper cut-off frequency, corresponding to the settings on the PAR 113 amplifier used by Kolb *et al.*

On-off kinetics implies a power spectral density of the form:

$$S(f)=\frac{c}{1+(f/f_c)^2} \tag{1}$$

where $\tau_c=1/2\pi f_c$ is the chemical relaxation time. The correlation function corresponding to Eq. (1) is:

$$C(\tau)=\int_0^\infty S(f)\cos(2\pi\tau f)\,df=\frac{c\pi}{2}f_c\,e^{-2\pi\tau f_c} \tag{2}$$

which is equivalent to Kolb *et al.*, Eq. (16).

It can be shown that the actual correlation function, in which the membrane process (f_c) is modified by the amplifier (f_1, f_2), is given by:

$$C(\tau)=\frac{c\pi}{2} f_c^2 f_2^2 \left\{ \frac{-f_c e^{-2\pi\tau f_c}}{(f_c^2-f_1^2)(f_c^2-f_2^2)} - \frac{f_2 e^{-2\pi\tau f_2}}{(f_2^2-f_1^2)(f_2^2-f_c^2)} - \frac{f_1 e^{-2\pi\tau f_1}}{(f_1^2-f_2^2)(f_1^2-f_c^2)} \right\}. \tag{3}$$

Suppose that f_2 is much greater than both f_1 and f_c. Then Eq. (3) reduces to:

$$C(\tau)=\frac{c\pi}{2} f_c^2 \left\{ \frac{f_1 e^{-2\pi\tau f_1} - f_c e^{-2\pi\tau f_c}}{f_1^2-f_c^2} \right\}. \tag{4}$$

This correlation function goes through zero when:

$$\tau_0=\frac{\ln f_c/f_1}{2\pi(f_c-f_1)} \tag{5}$$

and at $\tau=0$:

$$C(0)=\frac{c\pi}{2} \frac{f_c^2}{f_1+f_c}. \tag{6}$$

When $f_1=0$, Eq. (4) reduces to Eq. (2).

Using values from Kolb *et al.*, of $\tau_c=0.6$ sec ($f_c=0.265$ Hz) and $f_1=0.03$ Hz, then $\tau_0=1.47$ sec. Switching the ac-coupling to $f_1=0.1$ Hz shifts the zero crossing to $\tau_0=0.94$ sec. These results are not consistent with their Fig. 3, or the check mentioned in "Materials and Methods," paragraph one.

We wish to point out that it is relatively easy to include the effect of simple ac-coupling by using Eq. (4), and that inclusion of this effect may be critical to the accurate determination of the true membrane time constant.

Louis J. DeFelice
Barry A. Sokol
Department of Anatomy
Emory University
Atlanta, Georgia 30322