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NEURAL FIRING MODEL OF THE BASILAR MEMBRANE

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Introduction

This paper combines a space/time incremental model of the basilar membrane (BM) and a digital version of Schroeder's hair cell model to simulate neural firing patterns of the peripheral auditory fibres.

The model of the BM reported previously [1], is based on the circuit representation of the one dimensional transmission line introduced by Peterson and Bogert[2] and subsequently developed by Schroeder[3] and Hall[4]. The model is physiologically based and is implemented as seventy spatial increments, one every 0.5 mm from the base of the human cochlea. The circuit elements represent the mechanical parameters of the membrane. The frequency versus distance map was obtained from measurements made by Bekesy. There is an exponential decrease in frequency from base to apex (20KHZ-100Hz). The Q-factor variation with distance is a best fit of the available data, decreasing from about 4.0 at the base to 1.0 at the apex[5]. The capacitance has been calculated from Bekesy's static compliance measurements. Knowledge of the above allows calculation of the variation of inductance and resistance. The model is solved numerically, using the State Space method, on a VAX mini-computer. This requires the solution of an incremental matrix equation for each section and proceeds in the time domain.

Fig 1 is an isometric projection showing the deflection of the BM for an impulse at the stapes. The travelling wave starts at the base and proceeds to the apex with decreasing velocity. At each position on the membrane the deflection time waveform is a decaying sinusoid, the frequency of which corresponds to that of the cochlear map, and is the characteristic frequency (CF) of that point.

The frequency response at any point can be obtained by taking the Fast Fourier Transform (FFT) of the impulse response. Each point on the BM has a low pass frequency response. It has long been known that a discrepancy exists between the tuning properties of the BM and neural responses. The latter are more sharply tuned, and, more importantly, have a band pass characteristic. Some researchers, notably Nilsson[6] have cited spatial differentiation as a possible mechanism for this. Recent evidence, however, has suggested that the BM may be more sharply tuned than previously measured, removing the need for a second mechanical filter. Fig 2 shows how spatial differentiation transforms the low pass characteristic of the BM to that of a band pass filter.

Neural Model

Fig 3 shows the model chosen to simulate the neural response. It is a circuit analogue of the model proposed by Schroeder and Hall[5] and is physiologically orientated.

The stimulating signal, in this case the spatial derivative of deflection, somehow alters the permeability of a hair cell within the organ of Corti. This has the effect of modulating a current which flows within the cell and releasing an electrochemical substance, which causes an attached afferent nerve fibre to fire. As only displacement of the BM towards the tectorial membrane initiates a neural response, the permeability function assumes a half wave rectification law. Choice of circuit parameters determines the spontaneous and saturated discharge rates, typically 50HZ and 150HZ respectively. As observed in 95% of a nerve population, the dynamic range is limited to approximately 40dB.

The response of the model to sinusoidal stimulation shows many features observed in neurophysiological experiments. Initially the firing probability is very high due to the capacitance discharging through the conductance. This decays to a steady state firing rate with a time constant which depends on conductance and therefore the level of stimulation. For inputs >30dB the stimulus is half wave rectified, although the positive half cycle is somewhat distorted. When the input to the model is switched off the firing rate is suppressed below spontaneous, recovery time again dependent upon the stimulus level.

Fig 4 shows an isometric of firing probability for the combined BM and hair cell model, in response to an impulse at the stapes. As an initial step in the simulation of limited temporal resolution, the response of Fig 4 is low pass filtered.

Fig 5 shows firing probability histograms for three points on the membrane 1.0, 2.0 and 3.0 cm from the base. These compare favourably with post stimulus time (PST) histograms obtained by Kiang[8] in neurophysiological experiments.

4. References

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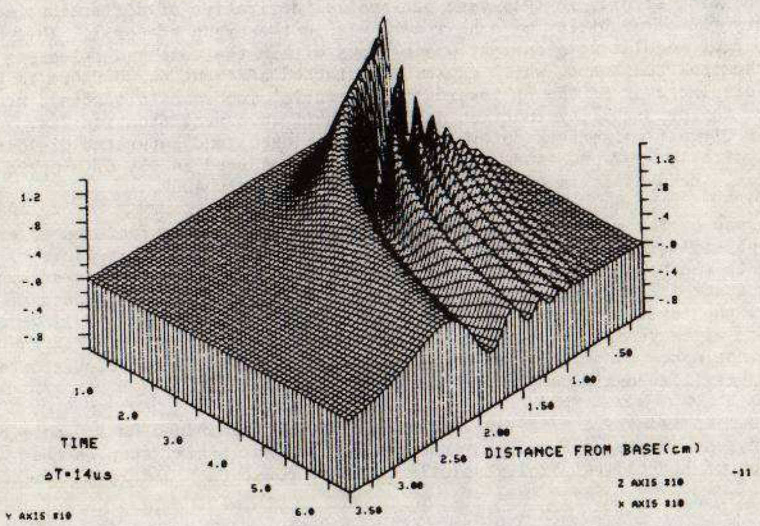

FIG-1 DEFLECTION OF THE BASILAR MEMBRANE DUE TO AN IMPULSE AT THE STAPES.

FIG-2 FREQUENCY RESPONSE OF A POINT 1.0cm FROM THE BASE
a) deflection
b) spatial derivative of deflection

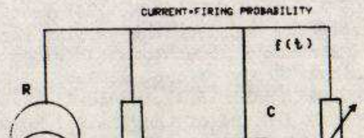

FIG-3

CIRCUIT REPRESENTATION OF THE MODEL FOR MECHANICAL TO NEURAL TRANSDUCTION

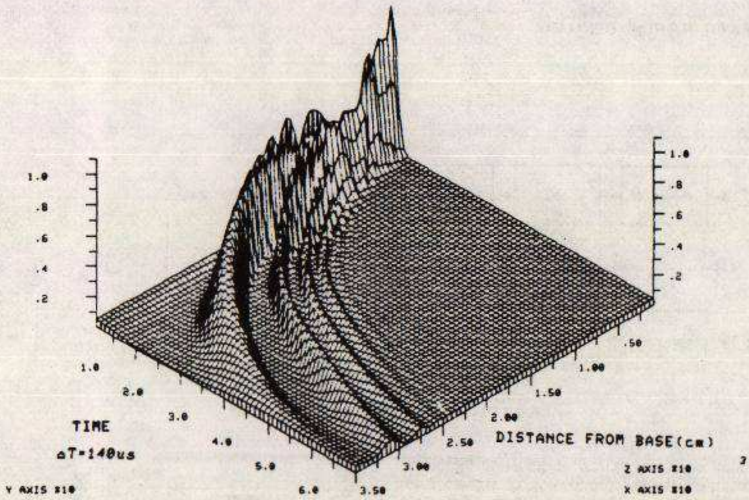

FIG-4 NEURAL FIRING PROBABILITY DUE TO AN IMPULSE AT THE STAPES NEGATIVE SPATIAL DERIVATIVE OF DEFLECTION SF=100

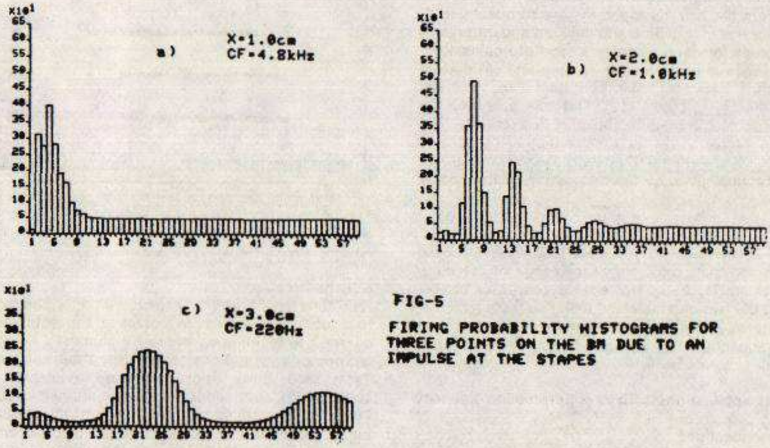

FIG-5

FIRING PROBABILITY HISTOGRAMS FOR THREE POINTS ON THE BM DUE TO AN IMPULSE AT THE STAPES