AN INCREMENTAL MODEL OF THE BASILAR MEMBRANE

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1. INTRODUCTION This contribution describes an incremental model of the Basilar Membrane (BM) which is being used as a basis for a computer simulation of Membrane behaviour. The model is both space and time incremental. The space increment is chosen purely for convenience, and the BM is represented by 35 equally spaced points. The time increment is constrained to be equal to the time taken for the pressure wave in the cochlea to travel between two points. Since an average BM is 35 mm in length, and the velocity of sound in the fluid medium is approximately 1.4 10^3 metres/sec, the time increment is 0.7 μs. By using such a small increment of time between computations it is possible to consider each point on the membrane to be influenced only by the two adjacent points. It is not, therefore, necessary to solve a 35 element equation at each time step, but only 35 x 3 element equations. This greatly simplifies the calculations and the main problem is in storing the large amount of output data generated, even for quite small time durations.

The main motivation for this work has been to investigate possible mechanisms for well known perceptual phenomena, such as combination tones and critical bands. A secondary motivation is to develop more realistic filter bank models of BM behaviour. For example, the simple second order filter bank proposed in Ref (1), is obviously inadequate in modelling transient behaviour.

2. THE MODEL The model is based on the 1-dimensional longwave transmission line introduced by Peterson (2) and subsequently developed by Schroeder (3) and Hall (4). The BM is divided into a number of "T" sections each stem of which is a series connection of a resistor, capacitor and inductor and the two branches are inductors. The values of the components, which are related to the mechanical properties of the BM and the cochlea fluid vary from section to section simulating the resonant properties of the membrane.

A typical section is analysed and expressions are obtained for node voltage (representing pressure difference across the membrane) and capacitor voltage (proportional to displacement) in terms of nodal voltages of neighbouring sections. These are transformed into the Z-domain using the backward difference approximation and an extra delay is incorporated to simulate the propagation time of the pressure wave from base to apex. A computational procedure is performed on a mainframe computer to obtain the response for the complete line, for as many time increments as necessary.

3. RESULTS Figure 1 shows graphs of displacement versus time for four points on the BM, due to an impulse at the stapes. The shape is not the usual 'ringing' associated with the impulse response of an isolated filter, ie the decay is not logarithmic and the frequency does not remain constant. This effect is due to the interconnection of neighbouring sections. The frequency at a given point decreases with time as the higher frequencies are attenuated first and the section is then forced to respond at the characteristic frequency of a

more apical point. Figure 2 contains graphs of displacement versus section, for four time instants. This shows the wave travelling from base to apex for an impulse input.

The response to a 4 kHz sinewave is indicated in Figure 3 for phases of 0, 90^o, 180^o and 270^o, relative to the input. In this case the model is run for 100 cycles of input to allow time for transients to die away. Figure 4 is the envelope of maximum displacement for each section for a 4 kHz input.

4. FUTURE WORK The model has already shown that the response of a section can be influenced by its neighbours due to the inherent coupling of the pressure wave. It is believed that by implicitly introducing membrane coupling certain psychoacoustical phenomena can be explained. Due to the incremental nature of the model this can easily be achieved, eg the compliance of a section can be made to depend on a previous displacement of a neighbouring section. Saturation of parameters is also easily incorporated.

5. REFERENCES

1. R. LINGGARD and I. BOYD 1979 Proc. Inst. Acoustics, Autumn Conf. Real-time, spectral analysis of speech.

2. L.C. PETERSON and B.P. BOGERT JASA Vol. 22(3) 369-381. A Dynamical Theory of the Cochlea.

3. M.R. SCHROEDER, JASA Vol. 53(2) 429-434. An Integrable Model of the Basilar Membrane.

4. J.L. HALL JASA Vol. 61(2) 520-524. Spatial differentiation as an auditory "second filter": Assessment on a non-linear model of the basilar membrane.

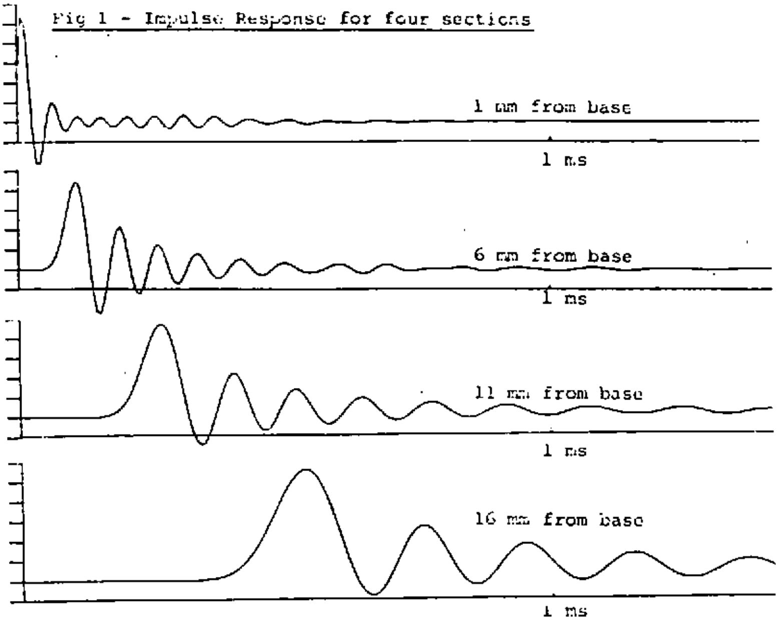

Fig 1 - Impulse Response for four sections

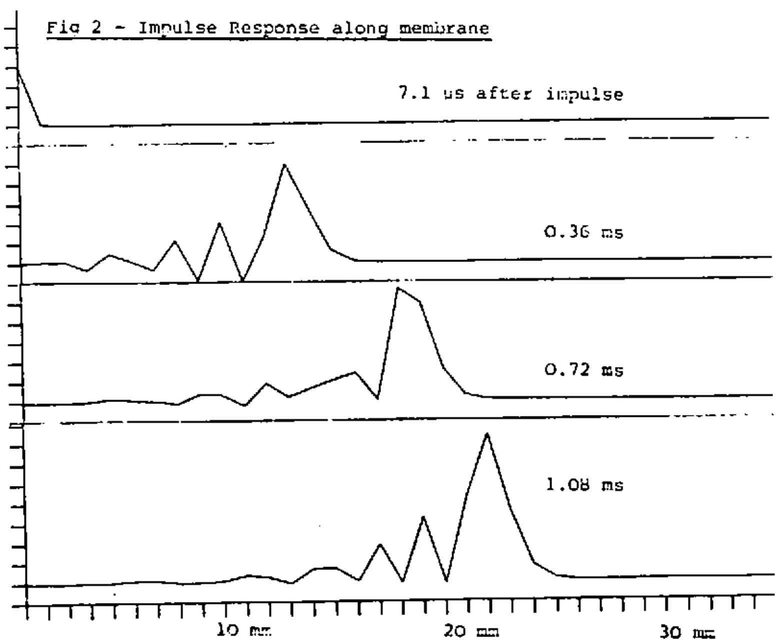

Fig 2 - Impulse Response along membrane

Fig 3 - 4 kHz Input

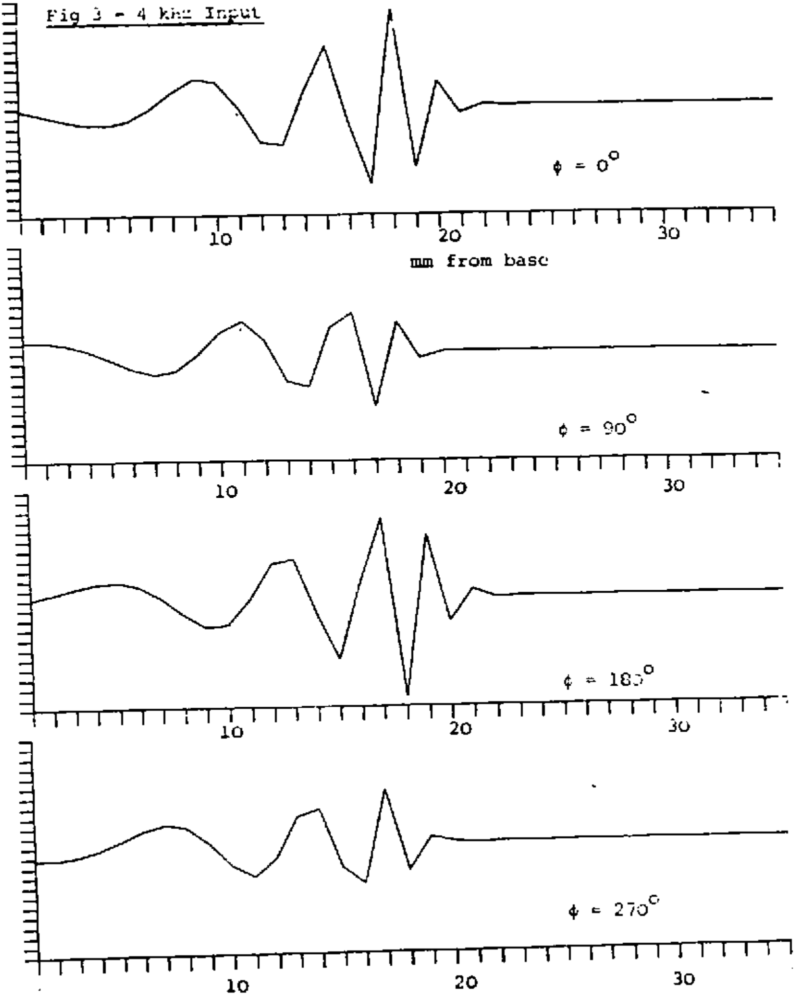

Fig 4 - Envelope of maximum displacement