Re: Physical model of cochlear frequency discrimination

Source: http://sci.tech−archive.net/Archive/sci.physics/2004−07/5379.html

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From: zigoteau (*zigoteau_at_ausi.com*)
Date: 07/17/04

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Date: 17 Jul 2004 09:32:33 −0700
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zigoteau@ausi.com (zigoteau) wrote in message
news:<9da9cba1.0407150849.2fd4b5ab@posting.google.com>...

Hi all again,

First: apologies, Tony − I've just realised that your surname is
Jefferies not Jeffs.

Many Google searches later, I'm getting up to speed with the cochlea.
I have found the following links useful:

http://www.geocities.com/medinotes/auditory_system.htm
http://www.iurc.montp.inserm.fr/cric/audition/english/corti/corti.htm
http://ctl.augie.edu/perry/ear/ear.htm

Rave continued:

I have realised from those websites that the stirrups and oval window do not couple directly to the basilar membrane, but to the fluid on one side. There are three compartments, separated by the two membranes (basilar and Reissner's). The outer two compartments connect via the apex.

As an electronics man, it looks to me a bit like a ribbon cable: the hydraulic structure is balanced. It can be modelled electrically by a ladder network. Due to its symmetry, it will have two modes: common mode and differential mode. It's not clear whether there is some clever mechanism ensuring that the common mode is not excited, but in any case the organ of Corti will only be stimulated in response to the differential mode component.

Tianying Ren seems to be wrong on something fairly basic. He shows the distance from the base of the point of maximum basilar membrane response as increasing with frequency (Figure 4 in his 2002 PNAS paper: PDF file available on request). All web pages I have found treat "base" as synonymous with "stirrup" and "oval window" − at the big end of the cochlea − and agree with one another that the peak response is closest to the stirrup at high frequencies, furthest from the stirrup at low frequencies. The little end furthest from the stirrup is the "apex". AFAICS, Ren's figure only makes sense if all occurrences of the word "base" are replaced by "apex". Could someone comment?

His plots of phase shift versus position for different frequencies then make sense. The wave is propagating in from the big end/stirrups/oval window. The wavevector decreases progressively, reaching zero near the point of maximum response. (Here, I am not making any judgement about the detailed lateral distribution of pressure and velocity of the various membranes and in the fluid compartments).

There is therefore a big difference with respect to my suggestion of an electron spectrometer. In the case of electrons and microwaves in a waveguide, high frequencies (energies) propagate, and low energies are evanescent. In the ear in contrast, low frequencies "propagate", while high frequencies are evanescent.

>From the Tianying Ren Figure 4, giving phase shift versus position at two frequencies, it is possible to estimate group velocities, which are of the order of 1 m.s^−1. The velocity of sound in water, 1.540 km/s, is so much higher than the group velocity that it is effectively infinite. The velocity of sound is determined by the interplay of density and compressibility. The common mode will have high velocity, but the differential mode can have a much lower velocity as a result of the elastic deformation of the basilar and Reissner's membranes. For this mode the water is essentially incompressible, and just provides inertia.

This suggests an equivalent ladder circuit in which the water is represented by inductances along the two sides and capacitors in the rungs. With such strong coupling to the fluid, it is hard to see how the BM can show any resonant response by itself. However on the face of it, this equivalent circuit would not give the required evanescent behaviour at high frequencies

Franz, if by any chance you're reading this, do you happen to have, or could you get access to, Lighthill's papers as PDF files you could send me? It is starting to look as if the fluid is an essential part of the mechanism, providing the inertial component. Maybe he has already solved the problem (but in that case why didn't Ren cite him?).

Cheers,

Zigoteau.