Is tectorial membrane filtering required to explain two-tone suppression and the upward spread of masking?

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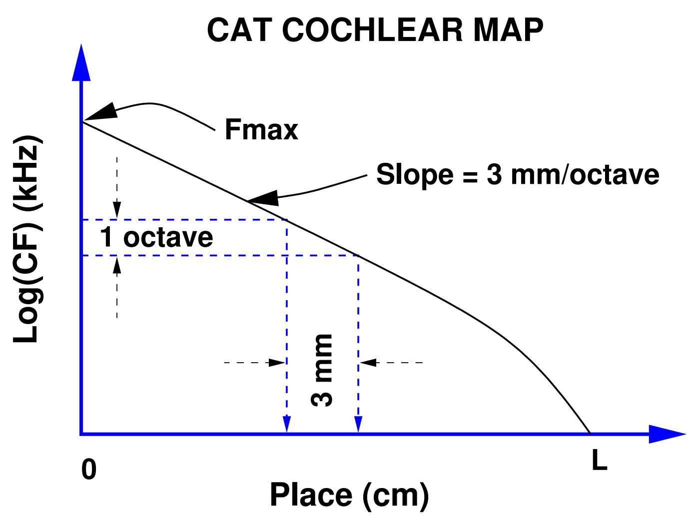
The place to frequency map

- The cochlear map describes the location of the frequency maximum of the tuning curve along the cochlear partition
- From basic theory $f_{cf} = \sqrt{K(x)/M}/2\pi = f_{max}e^{-ax}$

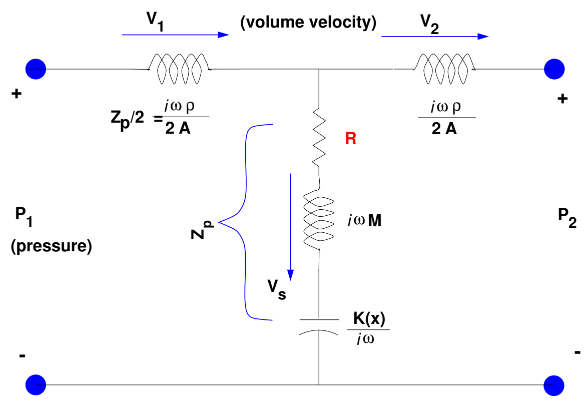


  - The constant $a = -0.231 \ \ (mm^{-1})$ for the Cat may be computed from the slope (3 mm/oct)

$$2 = e^{-a\,3} \rightarrow a = -\log(2)/3 \ \ (mm^{-1})$$

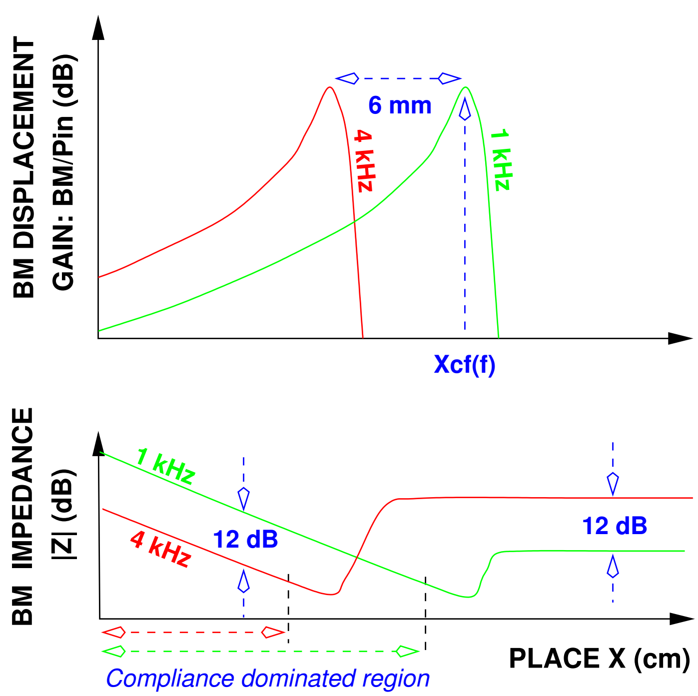
Transmission line model

- The 1D cochlear model



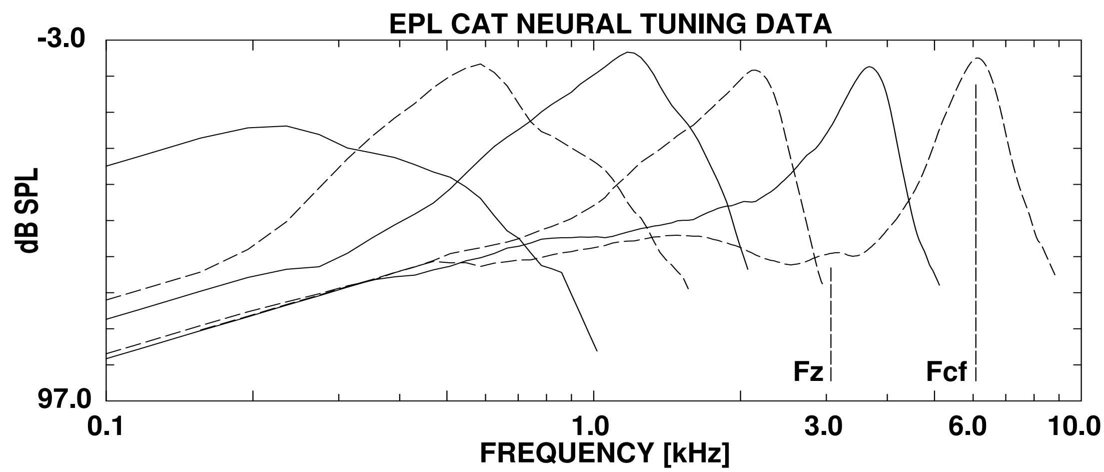
- The scala impedance: $Z_p = i\omega\rho/A$
- The cochlear partition impedance:

$$Z_p(x,\omega) = K_0 e^{-2ax}/i\omega + R_0 + i\omega M$$



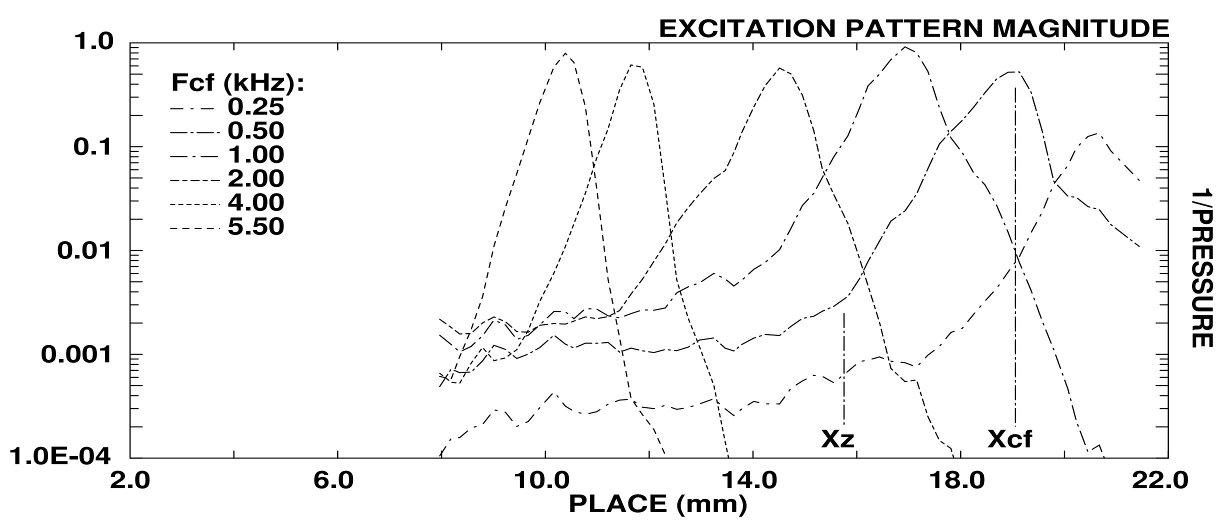
Neural excitation pattern

- Neural tuning curves along with the cochlear map allow us to estimate neural excitation patterns



- These frequency domain data were transformed to the place domain using Liberman's cochlear map

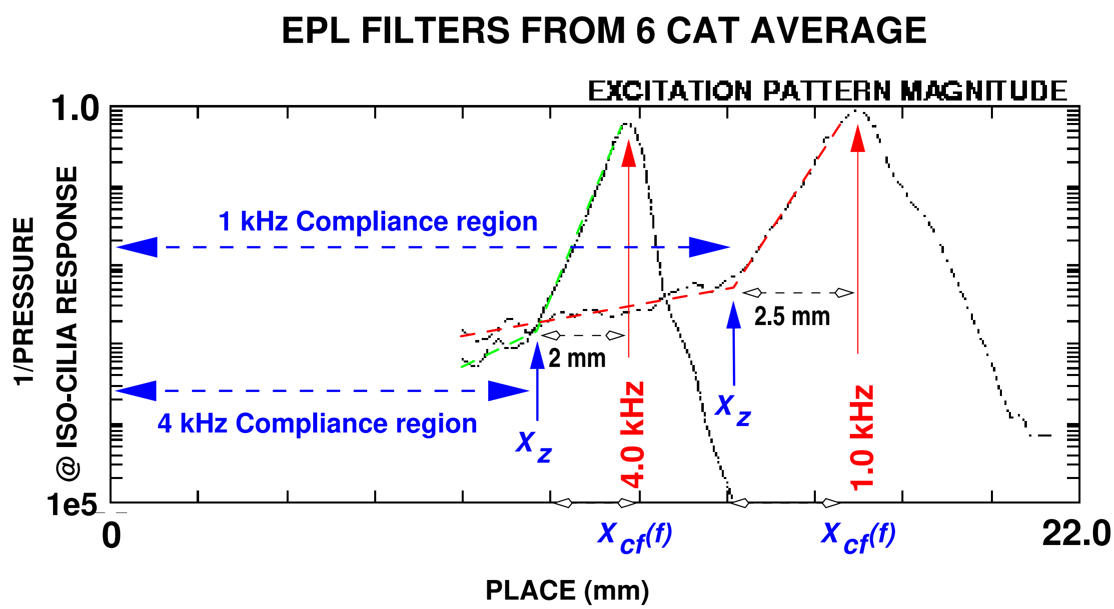
$$f_{cf} = 456\left[10^{2.1(1-x/L)} - 0.8\right]$$



Stiffness dominated tail region

- For each pure tone stimulus, the partition impedance is compliance dominated from the stapes to $X_z(f_{cf})$ (i.e., a few mm basal to the CF)

$$Z_p(x,\omega) \approx K_0 e^{-2ax}/i\omega$$



- Hooke's Law relates partition pressure $P(x)$ and displacement $D(x)$

$$P(x) = K_0 e^{-2ax} \;\; D(x)$$

Cochlear Pressure for a tone

- From the WKB solution method, the spatial pressure distribution of a tone stimulus in the base of the cochlea is given by

$$\begin{aligned} \frac{P(x,\omega)}{P(0,\omega)} &= \sqrt{\frac{Z_{char}(x)}{Z_{char}(0)}}\; e^{-i\omega \int_{\xi=0}^{x} d\xi/c(\xi)} \\ &= e^{-ax/2}\, e^{-i\omega\tau(x,\omega)}. \end{aligned}$$

- Conclusion: From Hooke's Law, since
  - The partition pressure magnitude decays as

$$|P(x)| \propto e^{-ax/2} \quad (-1\ dB/mm)$$

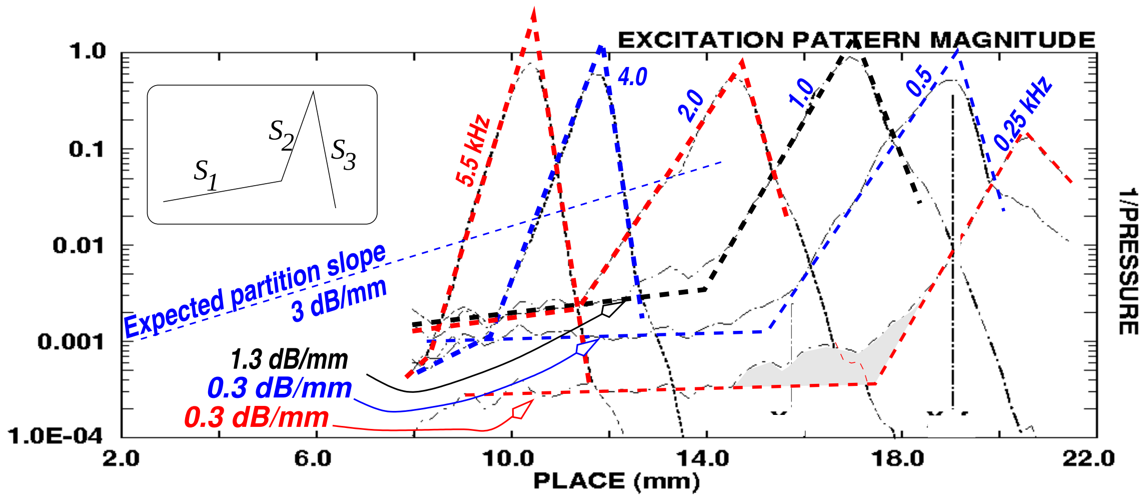
  - It follows that: The partition displacement magnitude increases as

$$|D(x)| \propto e^{3ax/2} \quad (+3\ dB/mm)$$

- Since the inner haircell is a displacement detector above about 1 kHz the cat the cilia (neural) response should grow as 3 dB/mm

Estimation of basal EP slope

- Neural excitation pattern estimated from FTC



- Slopes S_1, S_2, and S_3 (*dB/mm*)

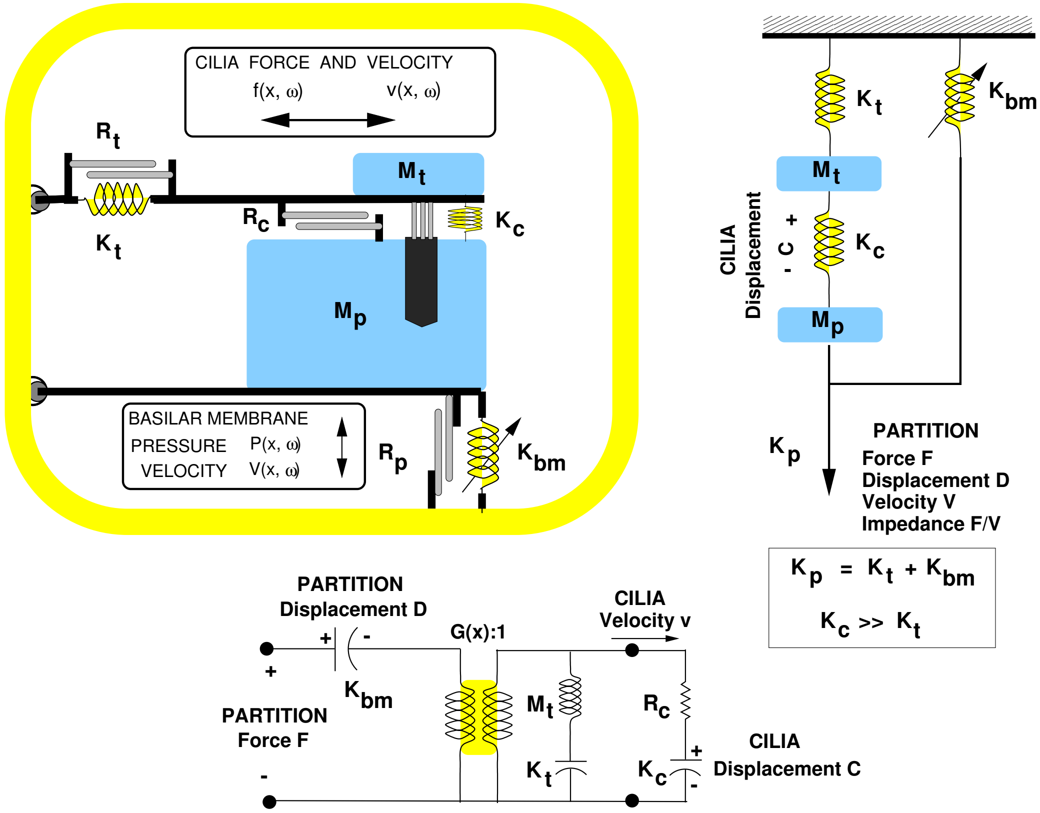
CF	S_1	S_2	S_3
kHz		*SLOPE** (dB/mm)	
5.0	**	32.7	-66.1
4.0	**	26.3	-69.3
2.0	1.3	15.2	-34.5
1.0	1.2	17.4	-25.6
0.5	0.3	14.8	-34.5
0.25	0.3	17.1	-11.0

$*$ Mult by 3 mm/oct to convert to dB/oct

$**$Not enough data.

A natural solution to the transduction filter problem

- I propose that the partition stiffness is dominated by the tectorial membrane stiffness $K_t(x)$



- The partition impedance is: $K_p = \frac{K_t K_c}{K_t + K_c} + K_{bm}$
  - Assume: $K_t/K_c \propto e^{-3ax/2}$ and $K_{bm} \approx K_t$
- This gives the two cochlear maps:

$$f_z(x) \equiv \frac{1}{2\pi}\sqrt{K_t/M_t} = f_{cf}(x)/\sqrt{2}$$

and the $e^{3ax/2}$ BM displacement growth is canceled

$$H \equiv \frac{C}{D} = K_t/K_c \approx e^{-3ax/2}$$

FINAL CONCLUSION:

- There must be a transduction filter $H(x, f)$ to account for the slope difference of 3 dB/mm for $D(x, f)$ and 0.3-1.3 dB/mm for the cilia EP $C(x, f)$
- The basal slope must be small to match the threshold data for the USM and 2TS