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Hspice 를 사용한 달팽이관 생역학의 모델링

장순석
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Modeling of cochlear biomechanics using Hspice

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요약

본 논문은 Hspice 를 사용한 달팽이관 생역학의 능동적이며 선형적인 1 차 그리고 2 차원 모델링을 보여준다. Hspice 모델링의 장점은 달팽이관 생역학을 아날로그 IC 칩으로 구현할 수 있다는 점이다. 즉 Biochip 으로 설계하는데 활용된다. 본 논문은 달팽이관 생역학을 어떻게 전기회로 모델화한 뒤, 다시 어떻게 Hspice 코드로 표현하는 가를 보여준다. 달팽이관 회로가 Hspice 코드 실행을 위해 변형되어야만 하는 과정을 상세히 보여준다. 1 차원의 결과와 2 차원의 결과를 비교하고 있다.

1. 서론

This paper shows one and two dimensional active linear modeling of cochlear biomechanics using Hspice [1]. The cochlear biomechanical modeling is based on the deductive approach as others but is processed using Hspice which is the most popular analog electric circuit simulator among electrical and electronic engineers. Because Hspice is so generally used for active filter design, the shortage of the present cochlear model may be supplemented with analog active filters added to the present model. This extra filtering may be arbitrary so as to be called as second filters. The advantage of the Hspice modeling is that the cochlear biomechanics may be implemented into an analog IC chip. This paper explains in detail how to transform the physical cochlear biomechanics to the electrical circuit model and how to represent the circuit in Hspice code.

2. 방법

The basic idea of Neely and Kim [2] for the cochlear biomechanics may be described as Fig. 1. Two masses coupled with four springs describe a simplified model of the segmented cochlear partition. Both the BM and the tectorial membrane (TM) are attached at the spiral ligament and the spiral limbus respectively. This can be described as two masses attached at a reference ground by two damped springs. The OHC and the stereocilia connect the BM with the TM. This can be also described as the two masses coupled by two damped springs in series. This mechanical system of two masses with four springs results in the fourth order dynamic mechanics. The active force generated by the OHC is transferred directly to the BM as well as indirectly to the TM through the stereocilia. The forth order passive resonating system is actively tuned by the extra force. Neely and Kim suggested that the OHC generates the active force in proportion to the velocity of the OHC stereocilia [2].

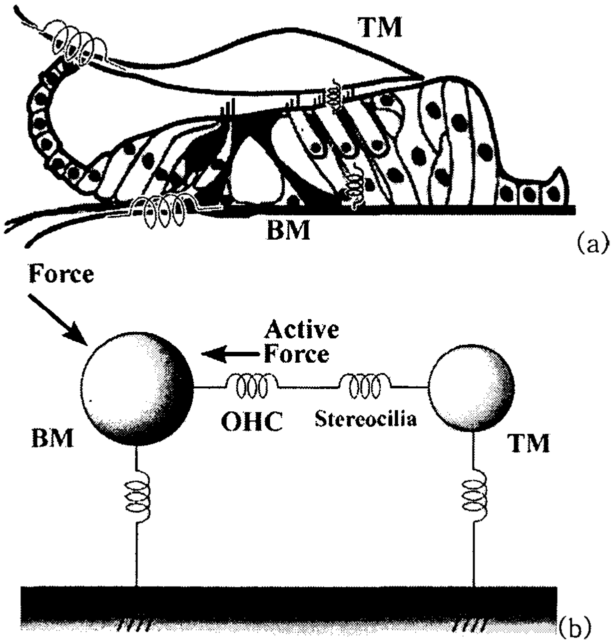


그림. 1 (a) The cross section of the segmented cochlear partition. (b) Two masses coupled with four springs describe a simplified model of the cochlear biomechanics. BM: Basilar Membrane, TM: Tectorial membrane. The OHC and the stereocilia connect the BM with the TM.

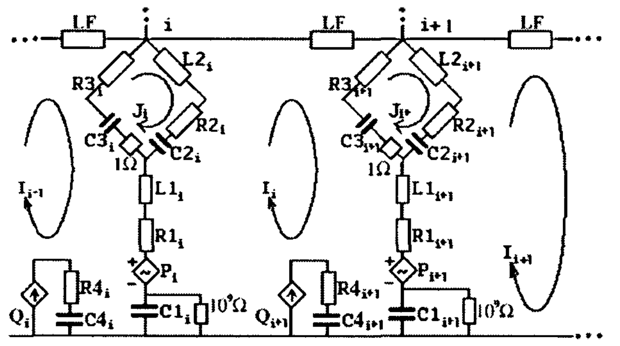


그림 2 Hspice version of each sectional impedance, $Z_i(x)$

2. 결과

Hspice codes of the cochlear model are written at Appendix 2. Hspice program was executed at SUN10 Unix workstation. Fig. 7 shows the simulation results of the one dimensional cochlear model. The input frequency is 5 kHz and the amplification gain (γ) is 1.0. Cochlear fluid mass, LF, is 5E-3 [H]. Fig. 7 (a) shows the displacement amplitude response of the basilar membrane vibration. X-axis is the distance from the base to the apex [cm]. Y-axis is the displacement magnitude in decibel scale with reference of nanometer 10^{-9} [m]. The magnitude has its peak at about 0.92 [cm] and it has about 80 dB sharp tuning bandpass filter shape. The figure shows some slight fluctuation just before the sharp increase of the peak and the magnitude decreases very rapidly after the peak. If the amplification gain is increased the figure becomes sharper but it produces more fluctuation at the base side. This fluctuation means the backward transmit of the actively amplified biomechanical energy from the peak to the base. Therefore the amplification gain should be adjusted not to produce the fluctuation.

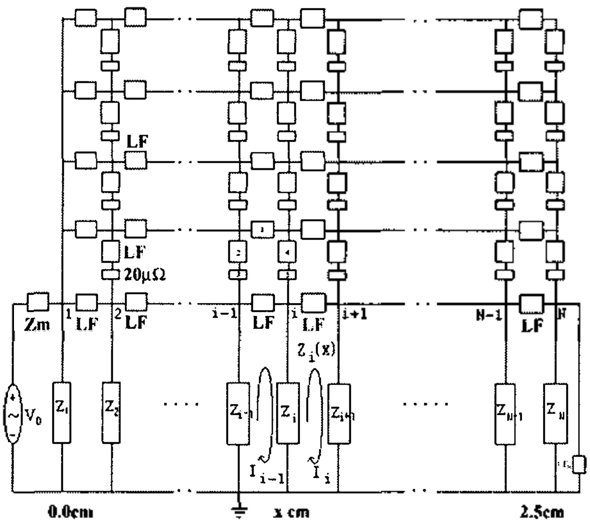
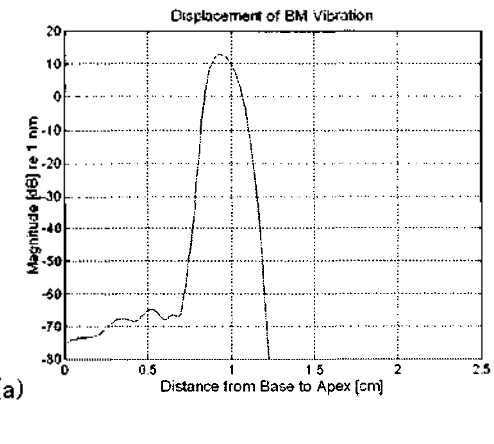
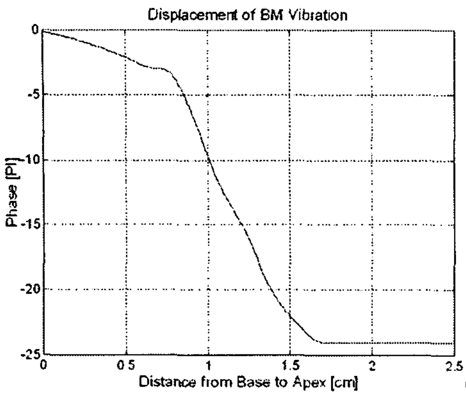


그림 3 Two dimensional transmission line model of the cochlea. N=250. LF=0.5 mH. LF_N =2mH



(a)



(b)

Fig. 7 (a) One dimensional cochlear model displacement amplitude response. (b) Displacement Phase response. Input frequency = 5 kHz. Amplification Gain (γ)= 1. LF=5E-3 [H].

Fig. 7 (b) shows the displacement phase response of the basilar membrane vibration. The phase is unwrapped with respect of the distance. The total phase shift from the base to the apex is about 24π [radians]. The pattern of the phase response may be divided into three parts; the slow slope from the base to about 0.75 [cm] position where the phase is slightly reversed, the rapid slope from about 0.75 [cm] position to about 1.7 [cm] position, the saddled slope after about 1.7 [cm] position. Therefore the one dimensional cochlear model is not good enough for the simulation of the cochlear biomechanics.

Fig. 8 the simulation results of the two dimensional cochlear model. The input frequency is 5 kHz and the amplification gain (γ) is 1.0. Cochlear fluid mass, LF, is 5E-4 [H]. Fig. 8 (a) shows the displacement amplitude response of the basilar membrane vibration. The magnitude has its peak at about 1.0 [cm] and it has about 30 dB sharp tuning bandpass filter shape. The figure shows no fluctuation just before the sharp increase of the peak and the magnitude does not decrease very rapidly after the peak. If the amplification gain is increased the bandpass filter shape becomes sharper. It should be noticed that there is an amplitude notch just before the sharp increase of the peak. This notch may indicate the prohibition of the backward transmit of the actively amplified biomechanical energy from the peak to the base.

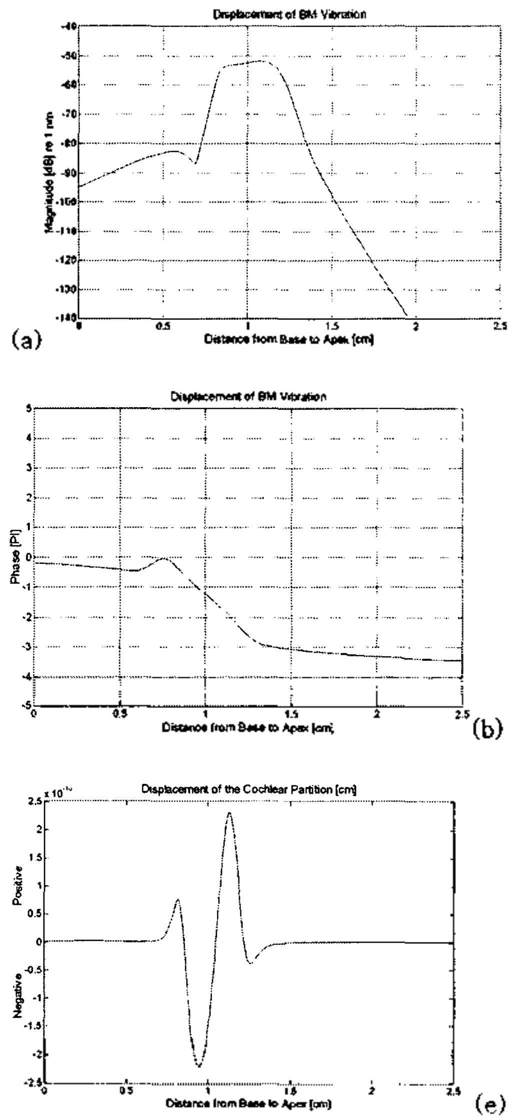
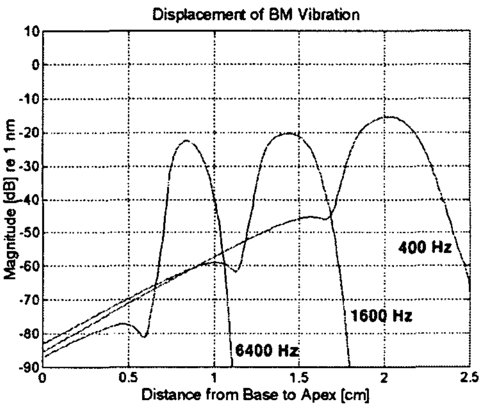


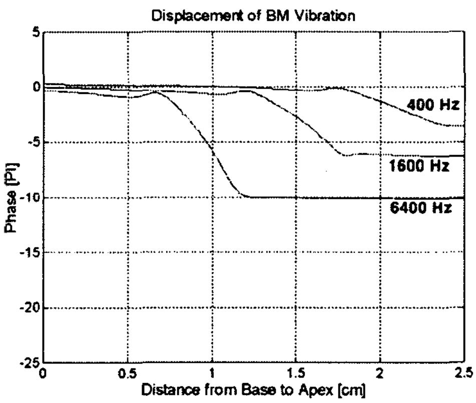
Fig. 8 (a) Two dimensional cochlear model displacement amplitude response. (b) Displacement Phase response. (e) Displacement time response. Input frequency = 5 kHz. Amplification Gain (γ)= 1. LF=5E-4 [H].

Fig. 8 (b) shows the displacement phase response of the basilar membrane vibration. The total phase shift from the base to the apex is about

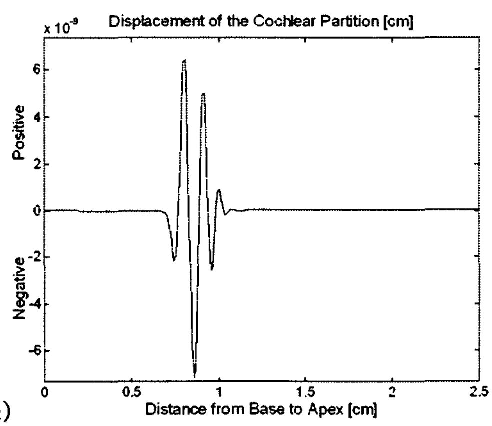
3.5π [radians]. One significant pattern of the phase response is that the phase is reversed at about 0.75 [cm] position where the amplitude rapidly increases. And Fig. 8 (e) is the displacement temporal response of the basilar membrane vibration. The 3.5π [radians] phase shift around about 1.0 [cm] position significantly shows 2 cycles of vibrations which are physically reasonable. Therefore the two dimensional cochlear model looks better than the one dimensional simulation of the cochlear biomechanics.



(a)



(b)



(c)

Fig. 9 (a) Two dimensional cochlear model displacement amplitude responses. (b) Displacement Phase responses. (c) Displacement time response (6400 Hz). Amplification Gain (γ)= 1. LF=3E-3 [H].

Fig. 9 shows the simulation results of the two dimensional cochlear model with different frequencies; 6400 [Hz], 1600 [Hz], 400 [Hz]. The amplification gain (γ) is 1.0. Cochlear fluid mass, LF, is 5E-3 [H]. Fig. 9 (a) and Fig. 9 (b) are the displacement amplitude and phase responses respectively. As the input frequency decreases, the peak moves toward the apex. The increase of the cochlear fluid mass not only increases the sharpness of the bandpass filter shape but also increases the amount of the phase shift. The increase of the sharpness is more significant than the increase of the phase shift. Fig. 9 (c), Fig. 9 (d) and Fig. 9 (e) show the displacement temporal responses of the basilar membrane vibration at each different input frequency respectively.

감사의 글

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참고문헌

[1] Hspice User's Guide , 2002.

[2] Neely S.T., Kim D.O., "A model for active elements in cochlear biomechanics", J. Acoust. Soc. Am., vol. 79, pp:1472-1480, 1986.