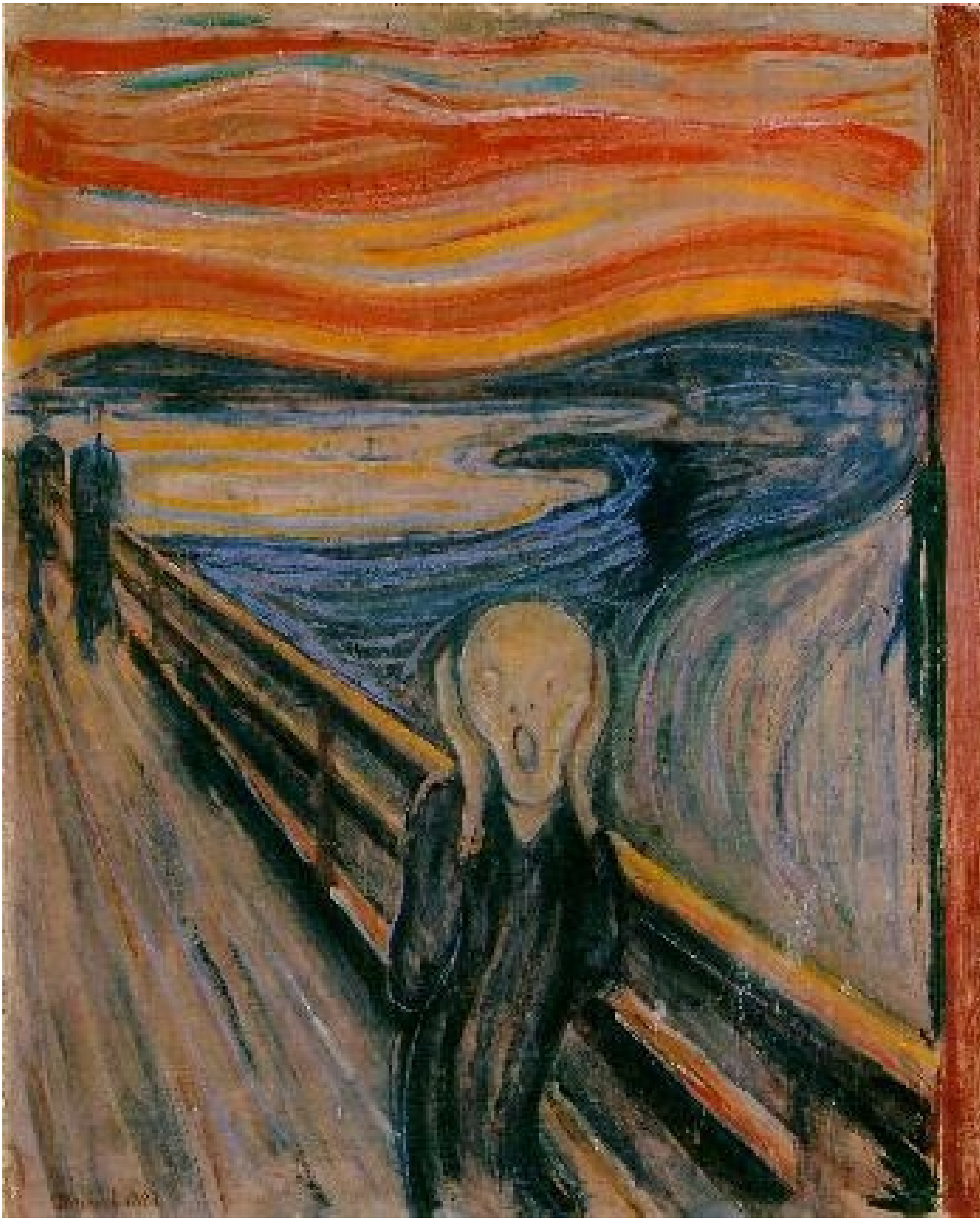

[Mu1]

Ear Type Systems

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Table of Contents

Motivations

Possible uses are

1. Noninvasive examination
2. New types of hearing aids
3. Design of filters using ear structure
4. Compensation for tinnitus
5. Antenna arrays of ears

Ear Type Systems - I

Our ear type systems are ones that either model or mimic physiological ears.

These systems are based upon the structure of the ear.

Kemp echoes, which are non-invasive stimulated emissions, are used as a basis for parameter determination when modeling.

VLSI circuits, recently of switched current type, with mems capacitor microphones, are the basis of mimics where arrays of n ears can be designed.

Ear Type Systems - II

Until recently models of the ear were based upon sinusoidal frequency resolutions.

Although useful for explaining many phenomena, through the use of Fourier series and transforms, the signals processed by the ear are rarely sinusoidal.

Thus, to explain Kemp echoes it has seemed more natural to investigate the differential equations describing system, particularly of the fluid flow In the cochlea and motions of the hair cells.

Ear Physiology - I

[Ga1, Fig 9-1]

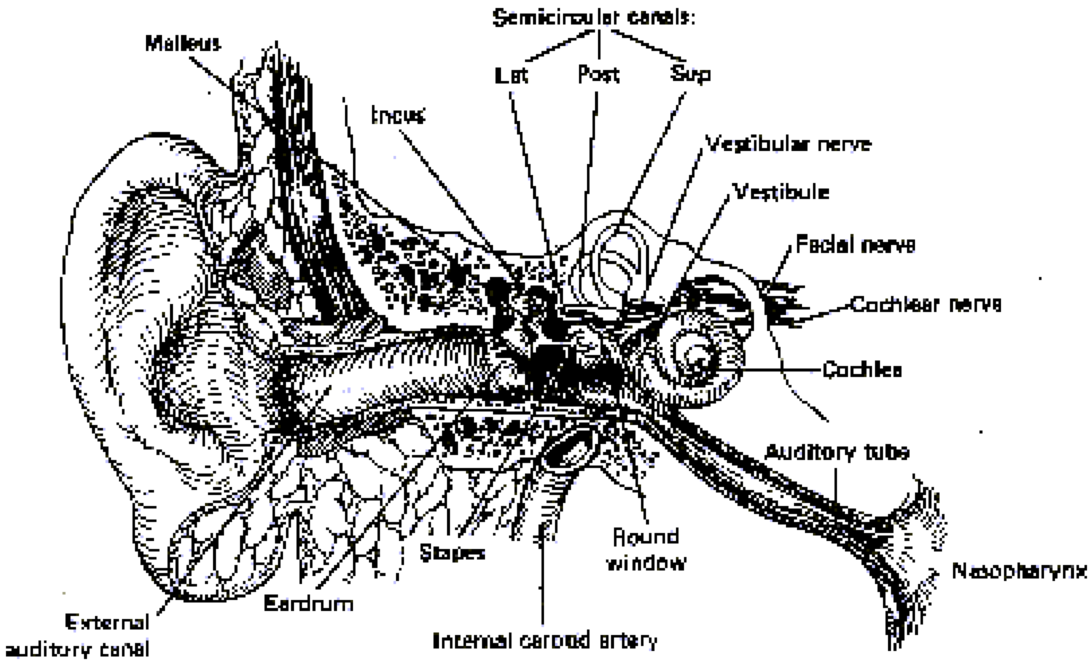
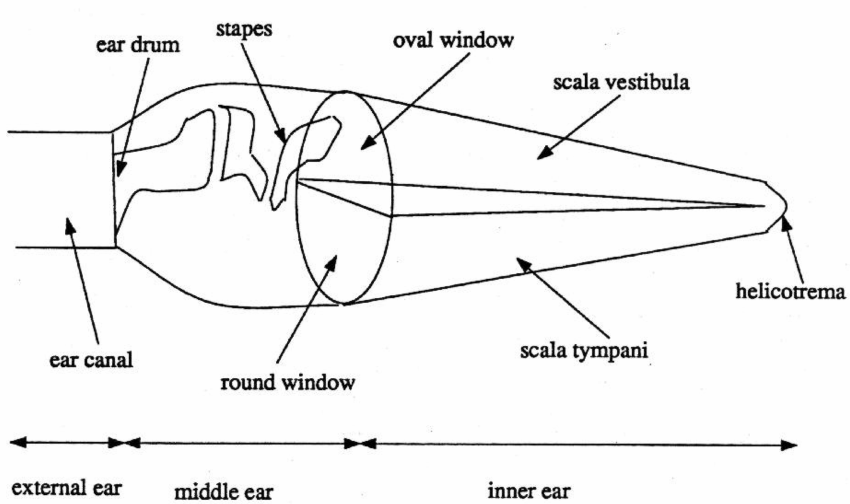


Figure 9–1. The human ear. To make the relationships clear, the cochlea has been turned slightly and the middle ear Sup, superior; Post, posterior; Lat, lateral.



Ear Physiology - II

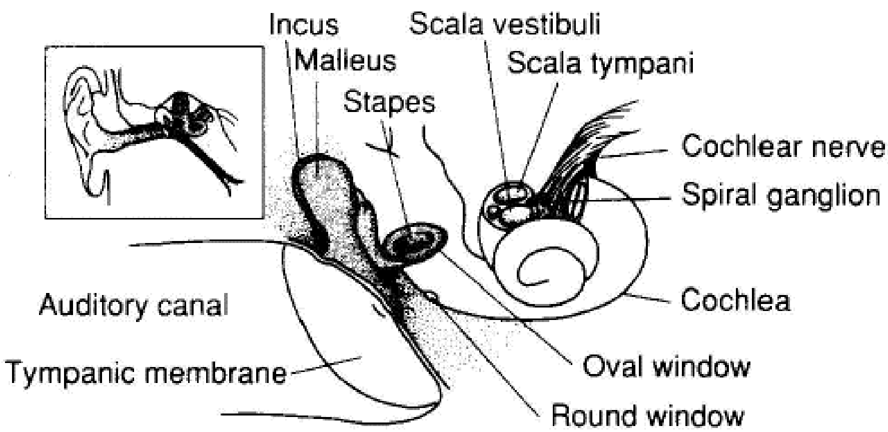


Figure 52–1. The tympanic membrane, the ossicular system of the middle ear, and the inner ear. [Gu1, p. 571]

Cochlea Cross Section

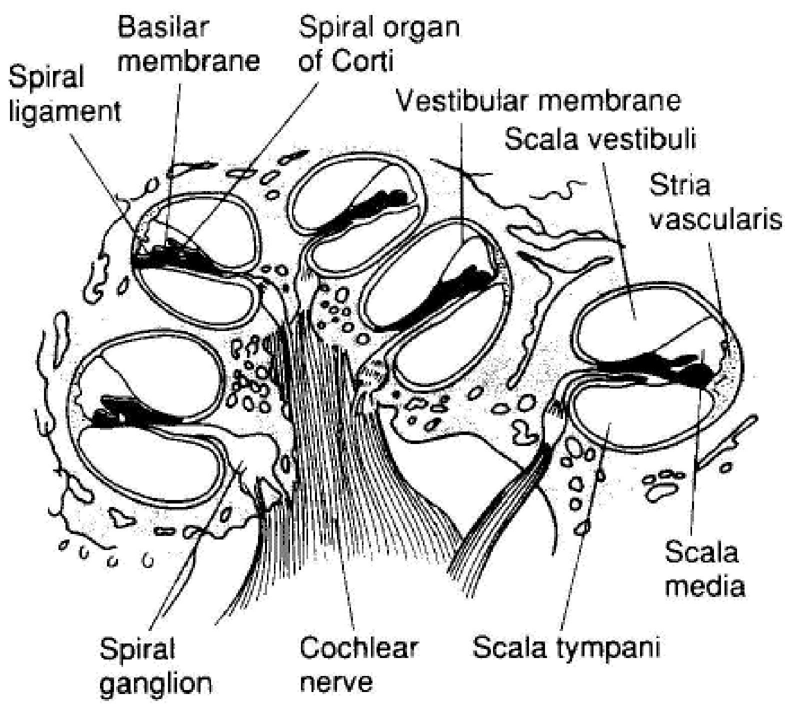


Figure 52 – 2. The cochlea. (From Goss, C. M. [ed.]: Gray's Anatomy of the Human Body. Philadelphia, Lea & Febiger.)

[Gu1, p. 571]

Ear Physiology - III

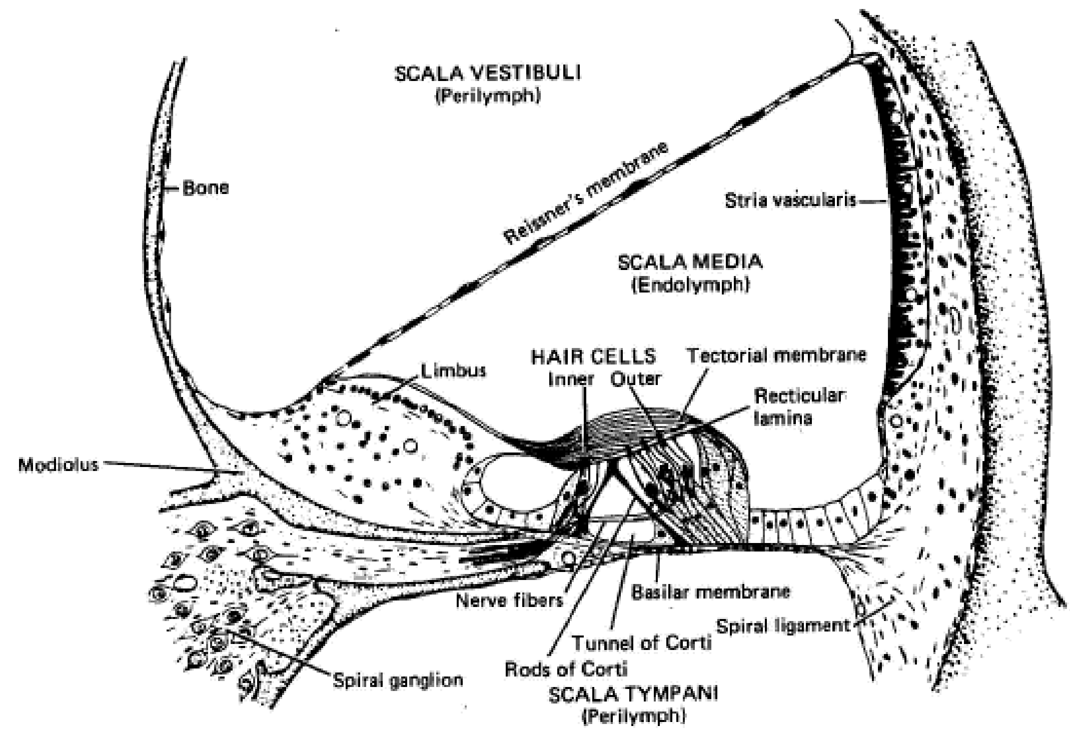


Figure 9–4. Cross section of one turn of the cochlea of a guinea pig. (Reproduced, with permission, from Davis H et al: Acoustic trauma in the guinea pig. *J Acoust Soc Am* 1953;**25**:1180.)

[Ga1, p. 134]

Ear Physiology - IV

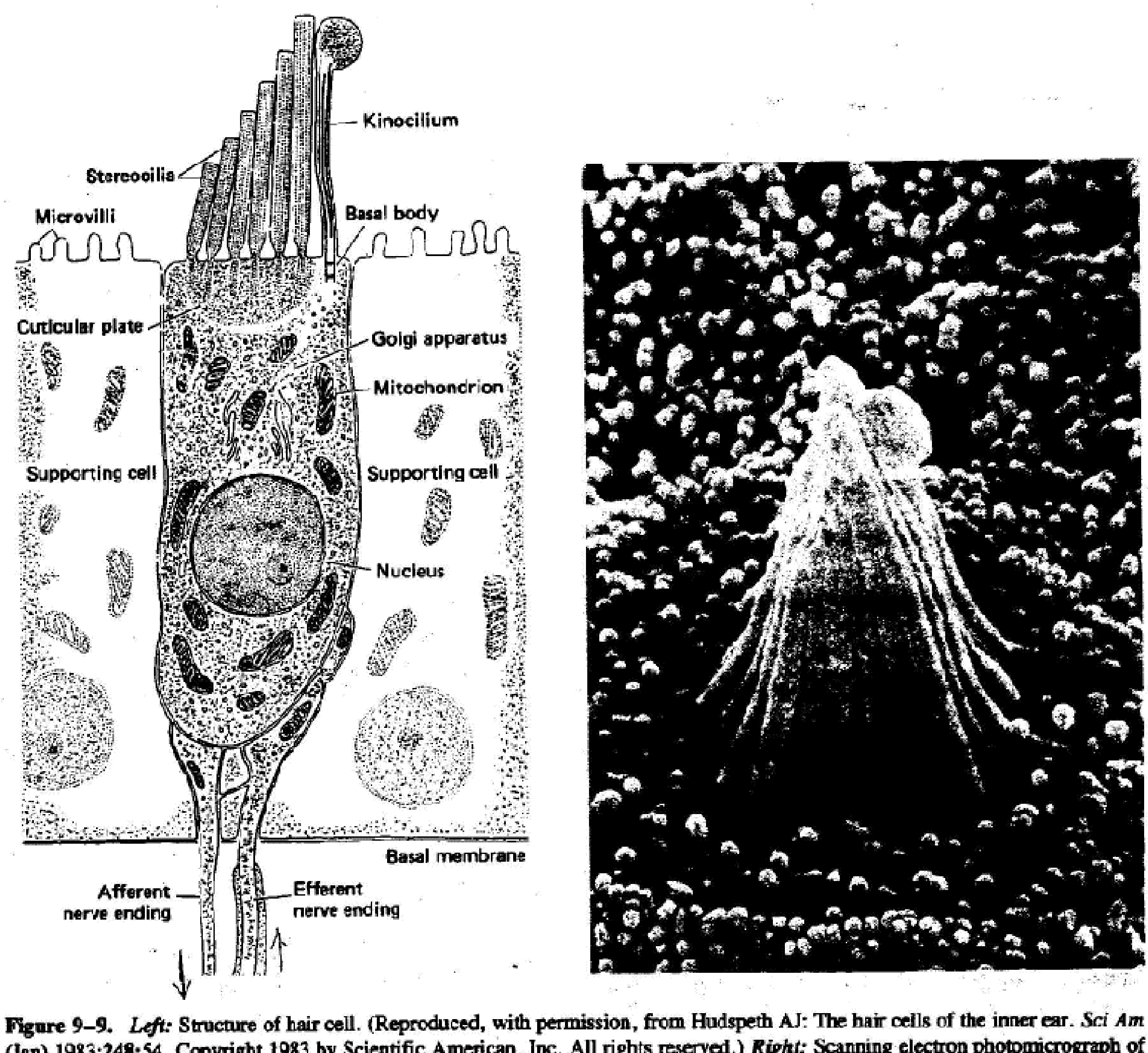


Figure 9–9. *Left:* Structure of hair cell. (Reproduced, with permission, from Hudspeth AJ: The hair cells of the inner ear. *Sci Am* (Jan) 1983;**248**:54. Copyright 1983 by Scientific American, Inc. All rights reserved.) *Right:* Scanning electron photomicrograph of processes on a hair cell in the saccule of a frog. The small projections around the hair cell are microvilli on supporting cells. (Courtesy of AJ Hudspeth.)

[Gu1, p. 137]

Ear Physiology - V

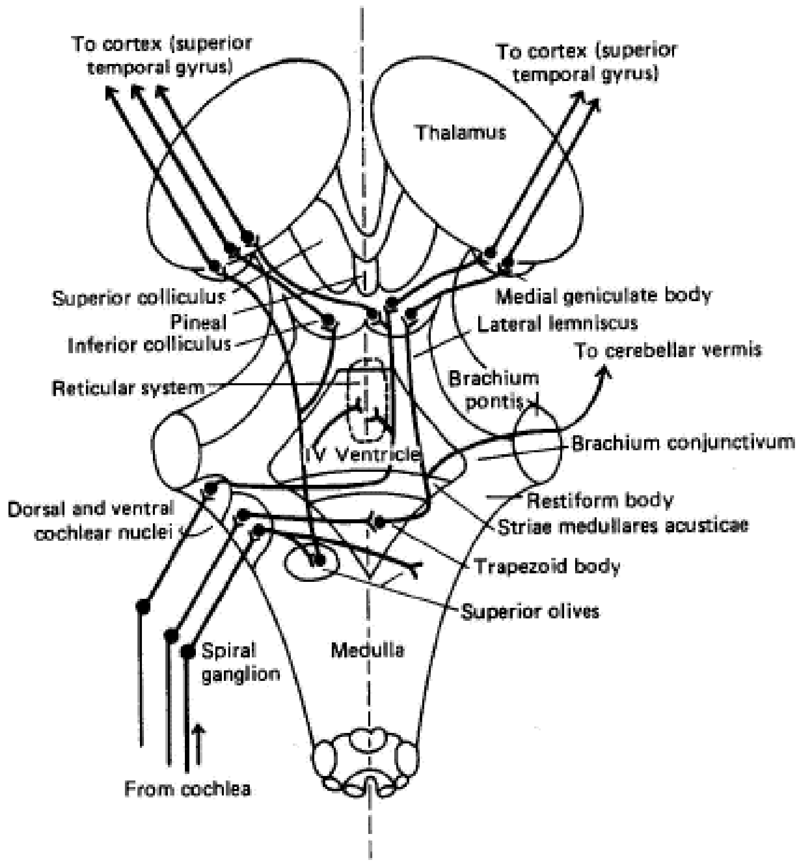
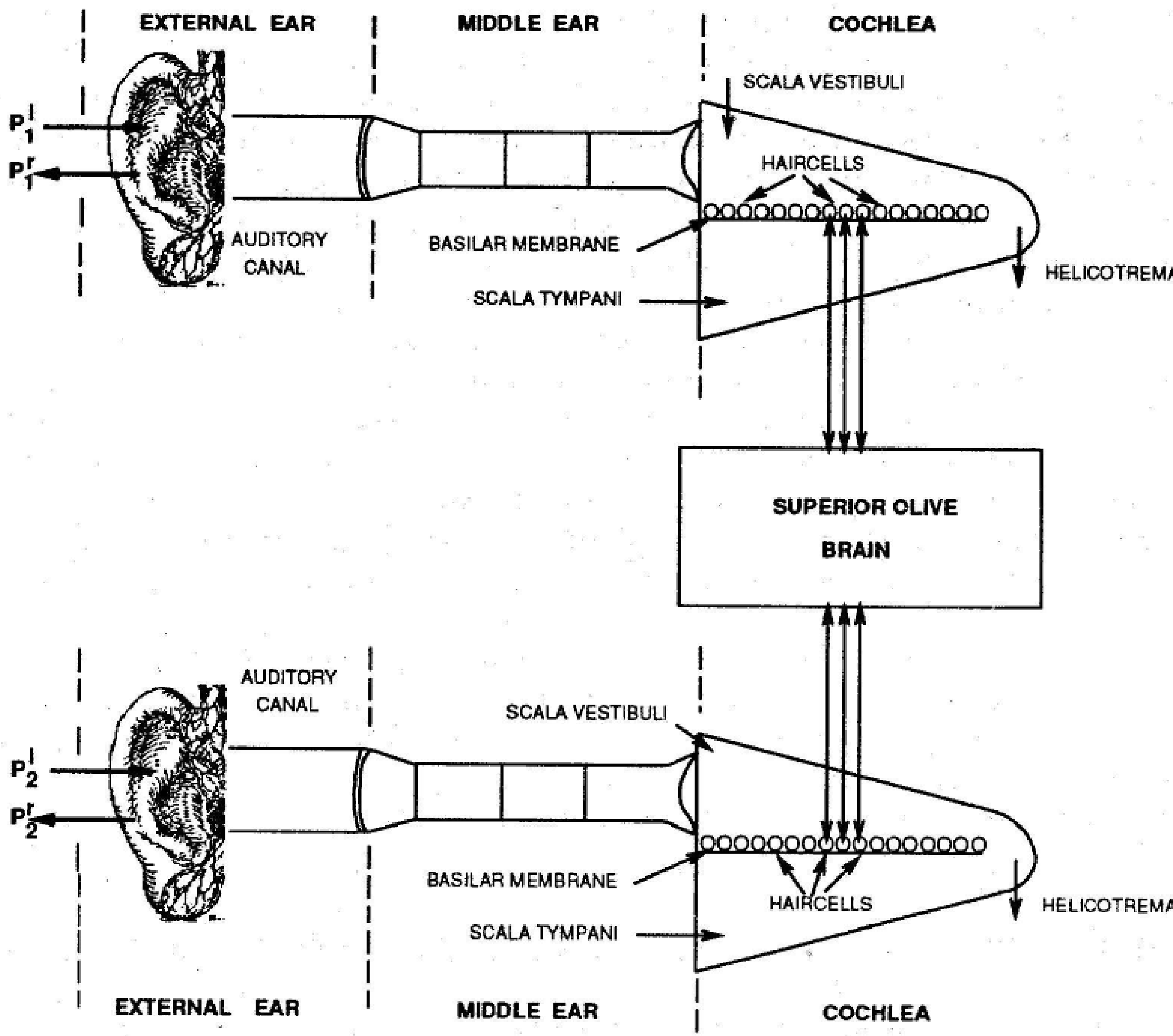


Figure 9–5. Simplified diagram of main auditory pathways superimposed on a dorsal view of the brain stem. Cerebellum and cerebral cortex removed.

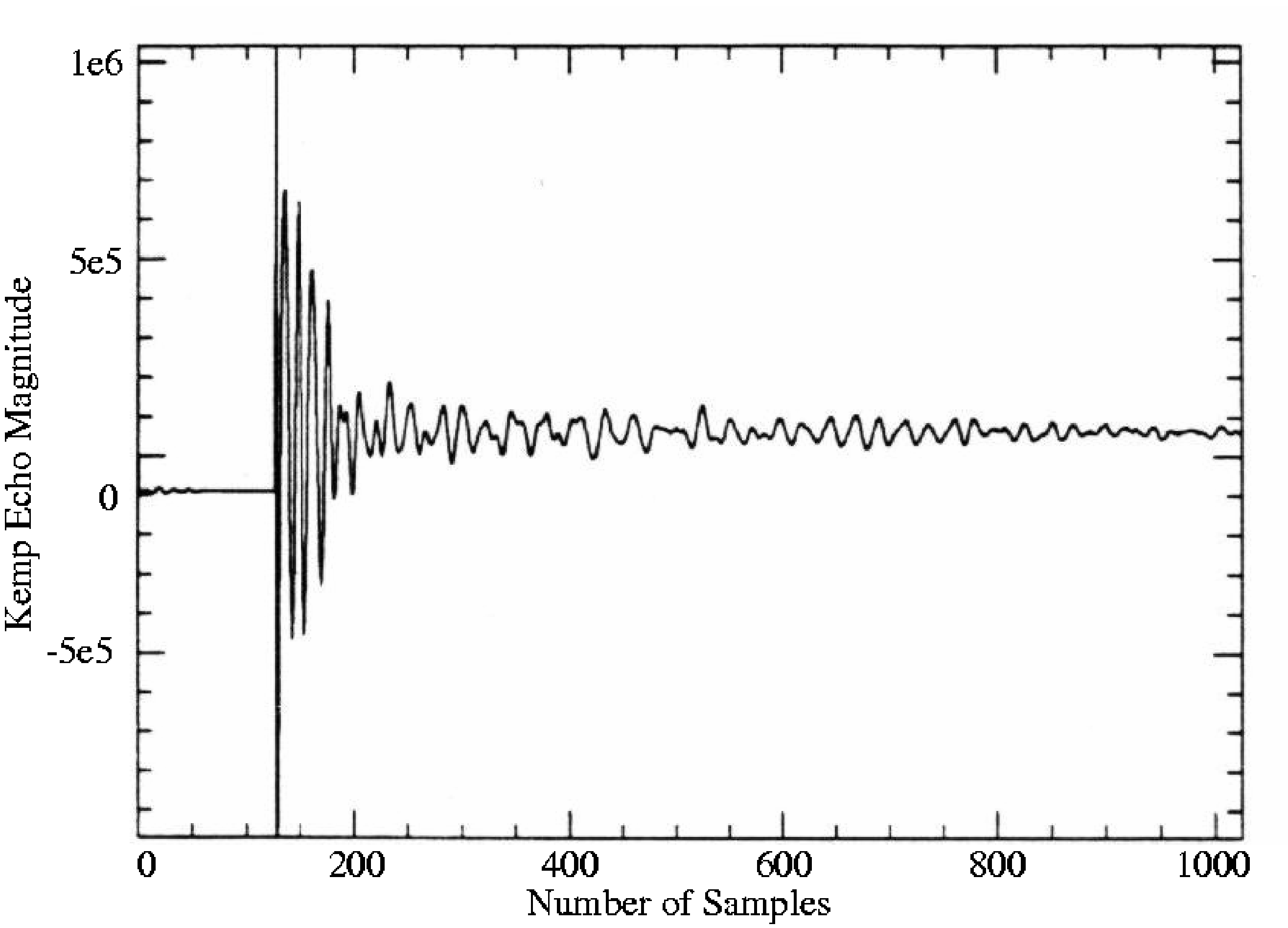
[Ga1, p. 134]

Maybe better fig 52-10 of Guytan

Ear Physiology-VI



Kemp Echo - I



Source = Dr. H. P. Wit, Netherlands

In some ears these last for days;
Tinnitus = ringing in the ear
Now used to test babies.

Ear Type Block Diagram

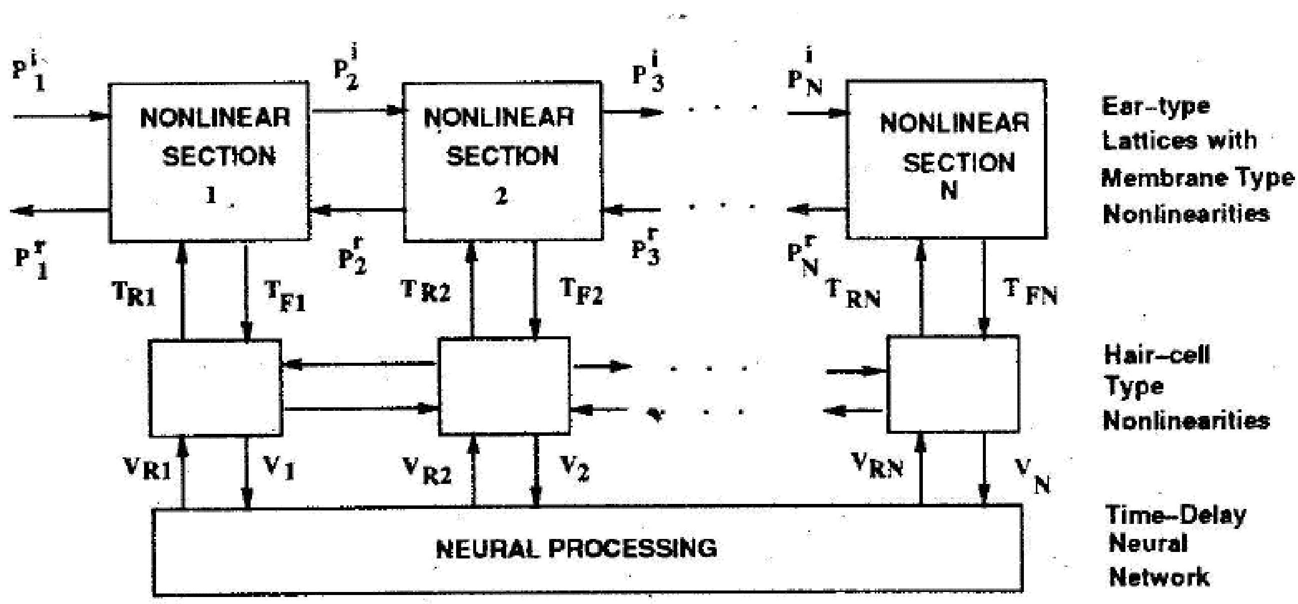


Figure 1: Ear-type signal processing system.

Inputs to cochlea lattices are pressures with those on the left coming from pressure transducers.

All signals can be vectors for ear arrays.

Hair Cell Model - I

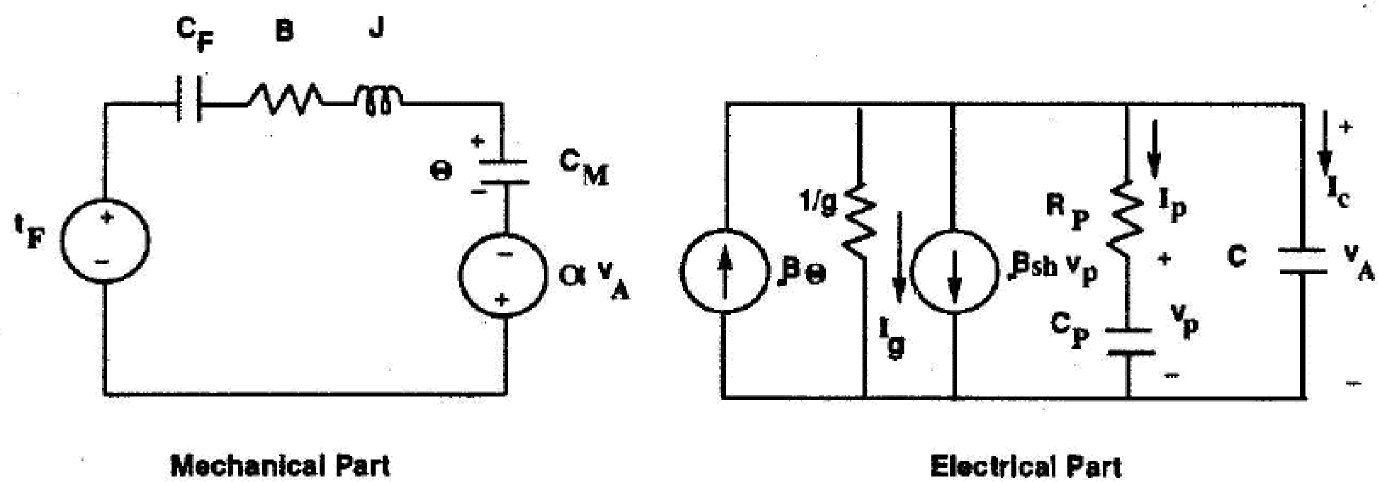


Figure 9: The electrical equivalent nonlinear model of a hair cell.

Hair Cell Model - II

Membrane potential due to a force applied to the model hair cell

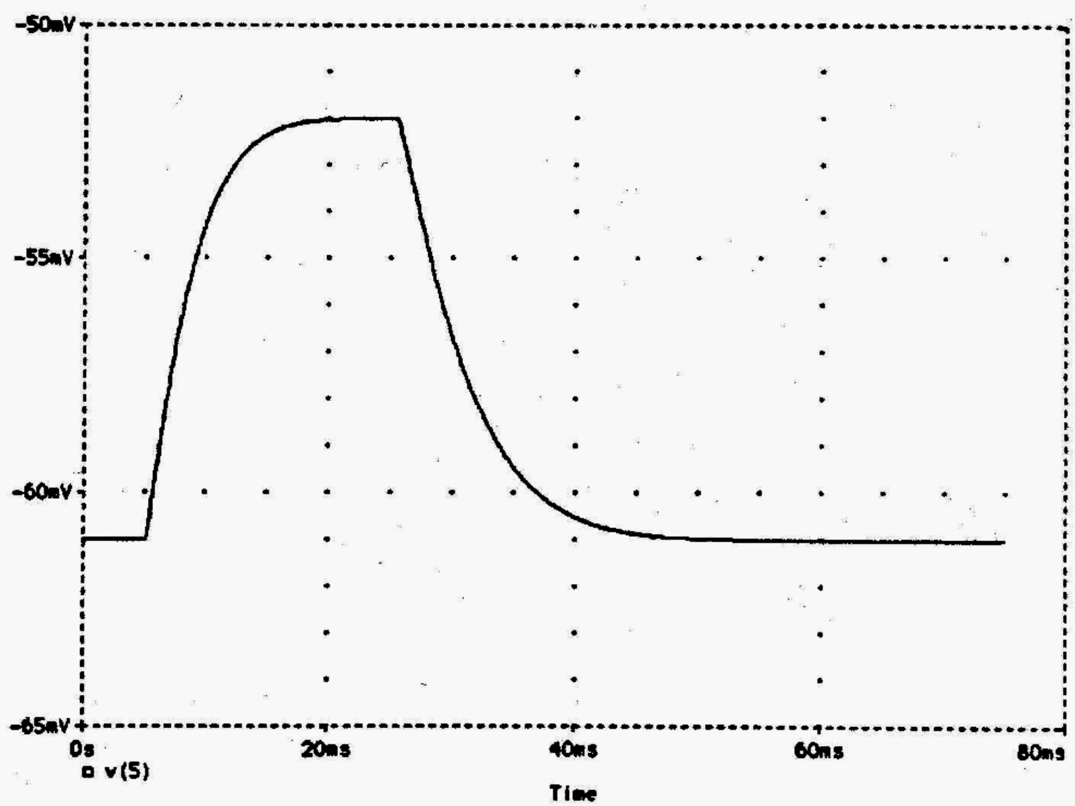
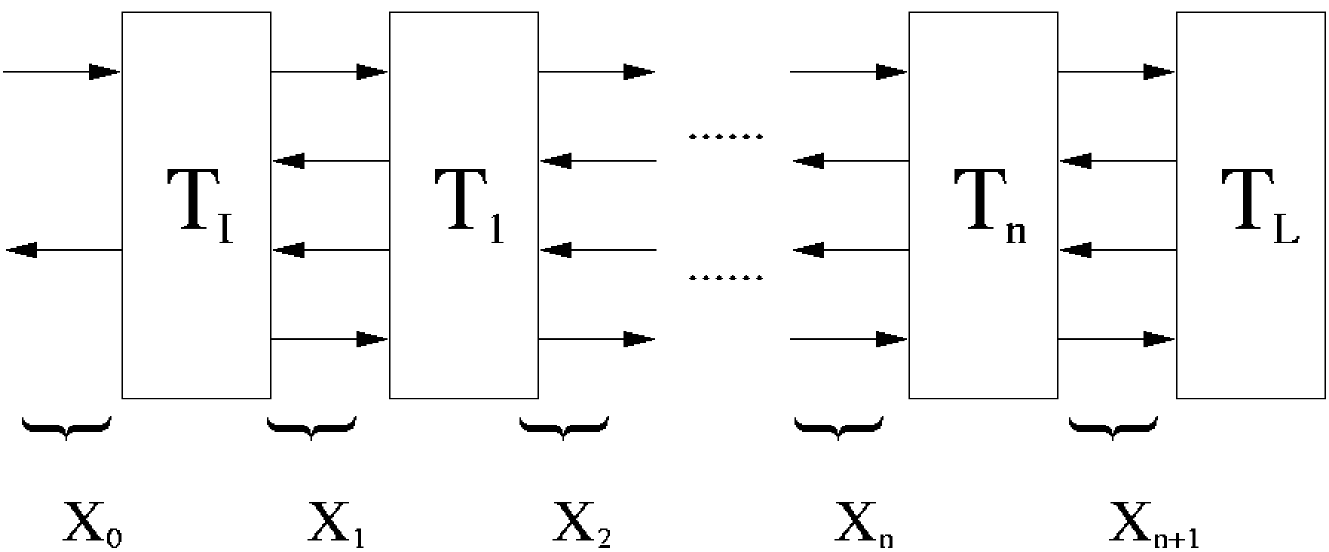


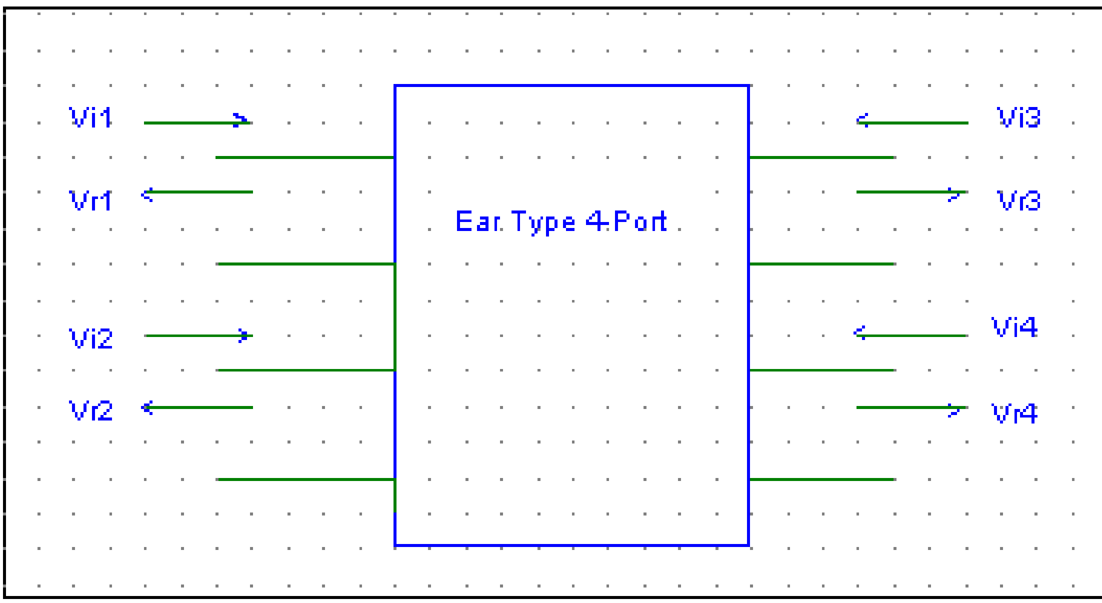
Figure 10: Membrane potential V_A.

Cascade of Ear Type Sections



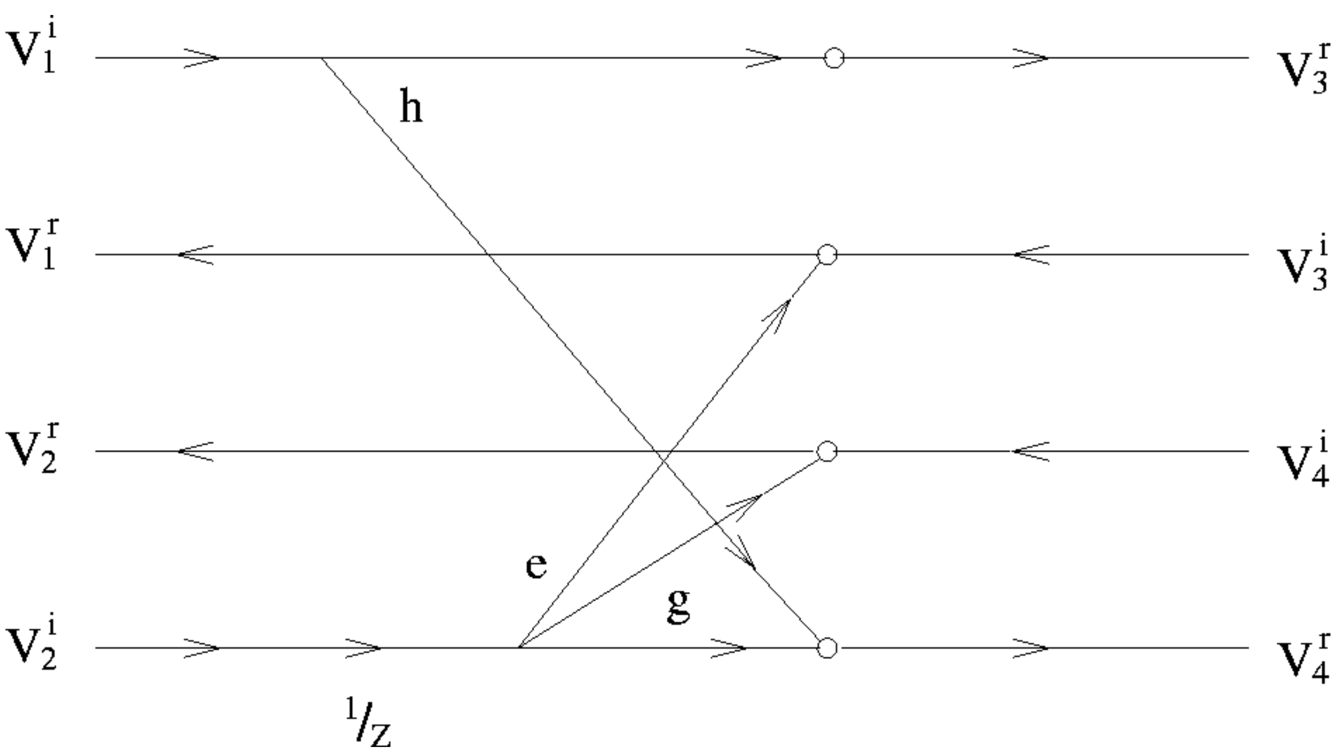
Describe by transfer scattering matrices since they multiply for cascades and are in terms of waves, as in the cochlea

Reverse Transfer Scattering Matrix



$$\begin{bmatrix} V_3^r \\ V_3^i \\ V_4^i \\ V_4^r \end{bmatrix} = T \begin{bmatrix} V_1^i \\ V_1^r \\ V_2^r \\ V_3^i \end{bmatrix}$$

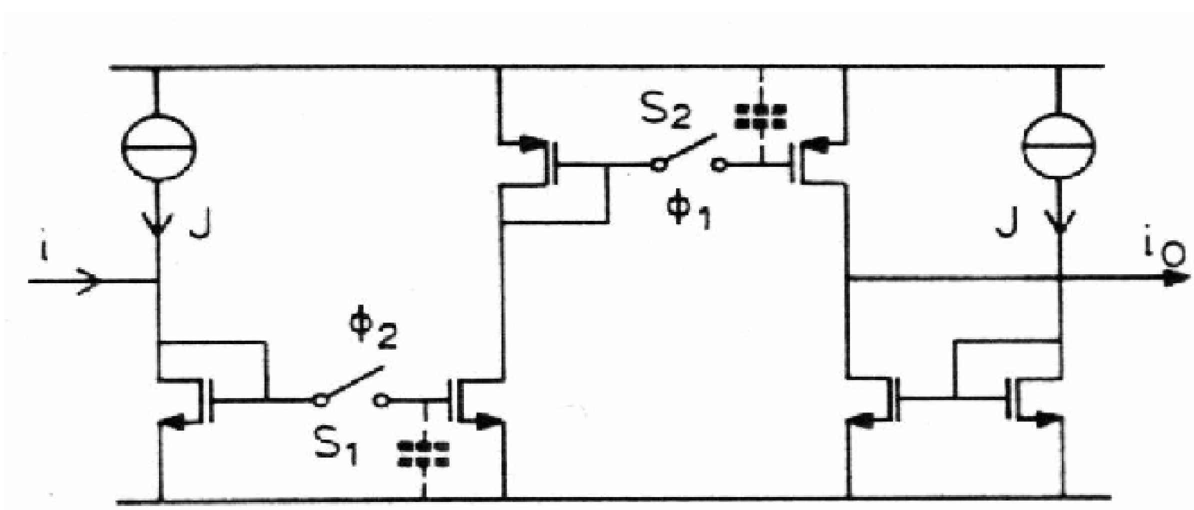
AR Section



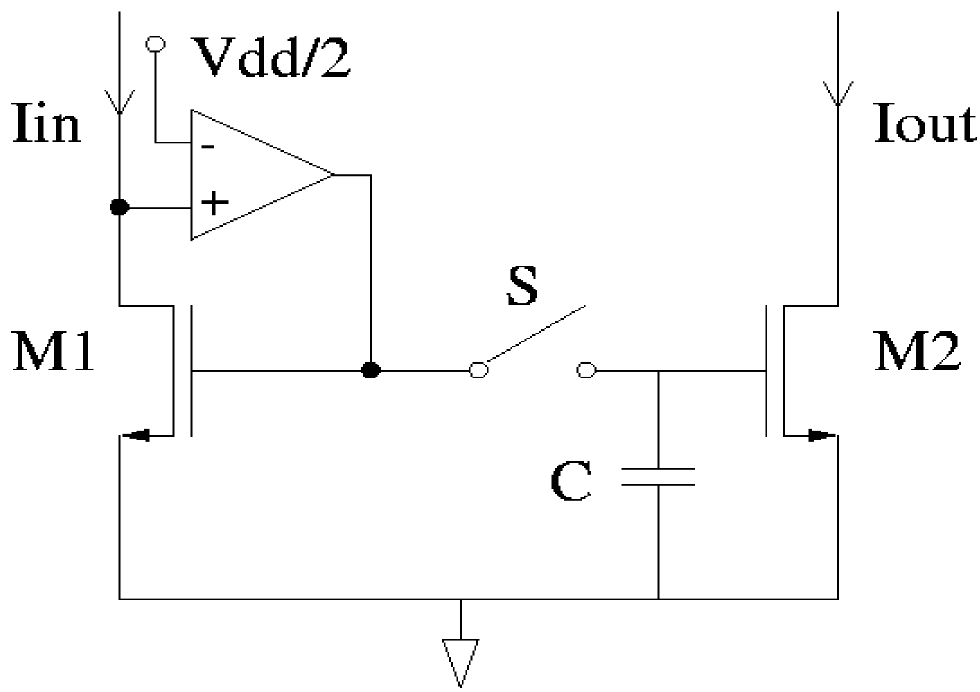
$$T_{AR} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & -ez^{-1} \\ 0 & 0 & 1 & -gz^{-1} \\ h & 0 & 0 & z^{-1} \end{bmatrix}$$

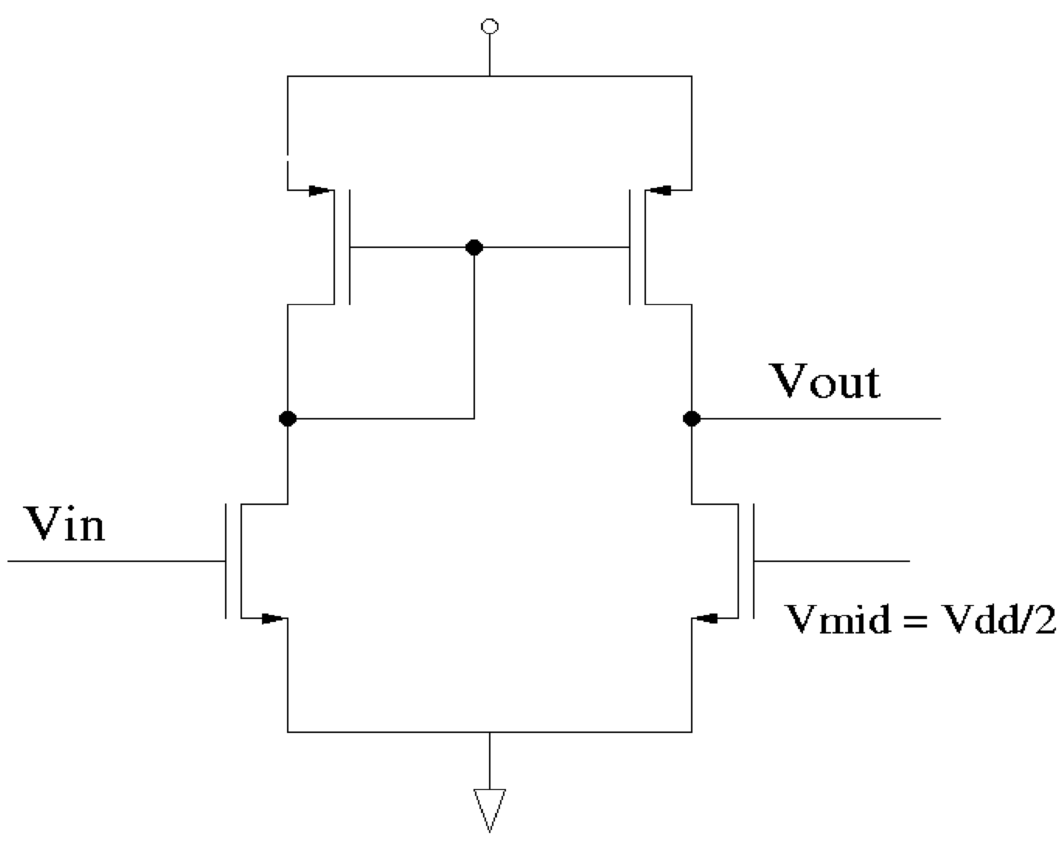
SI Delay Circuit

[Hu1]

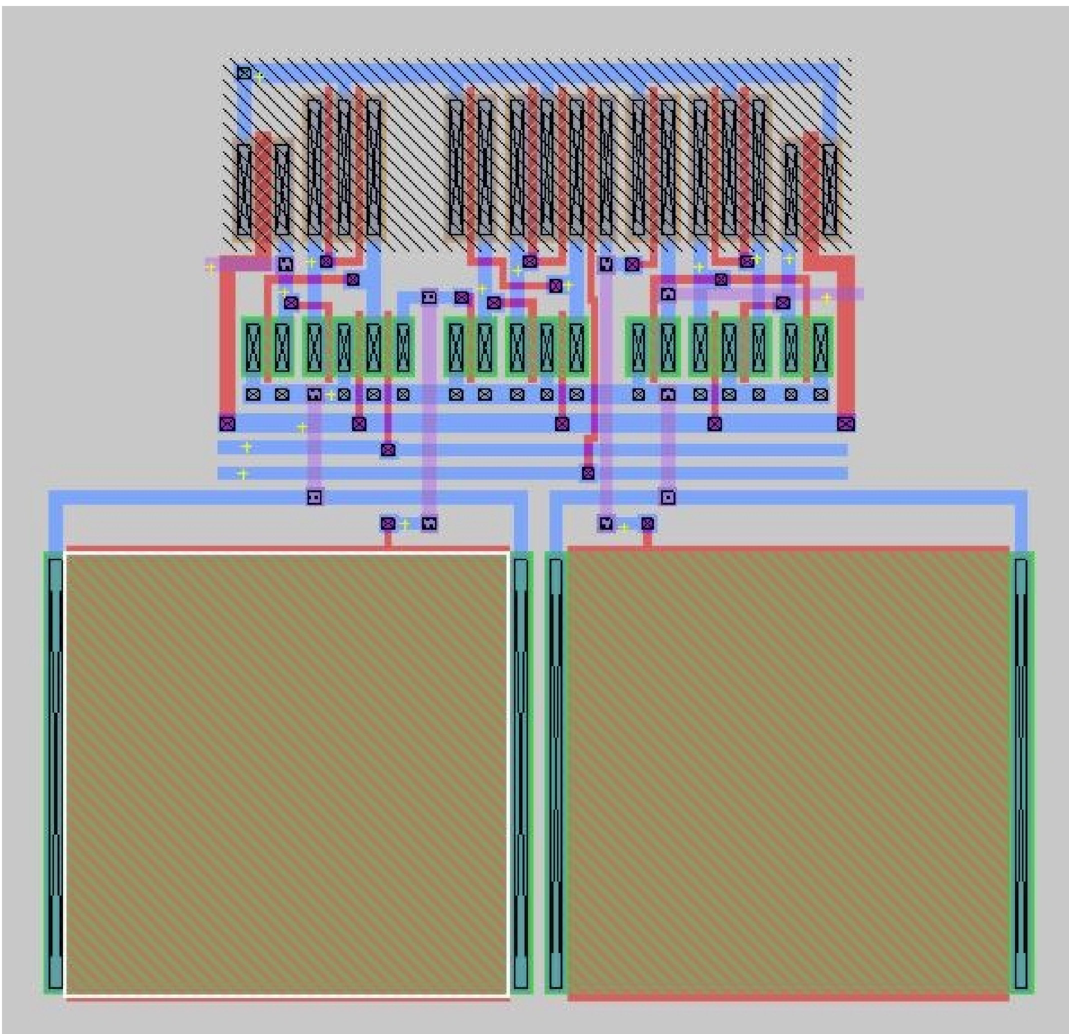


SI Half Delay Circuit

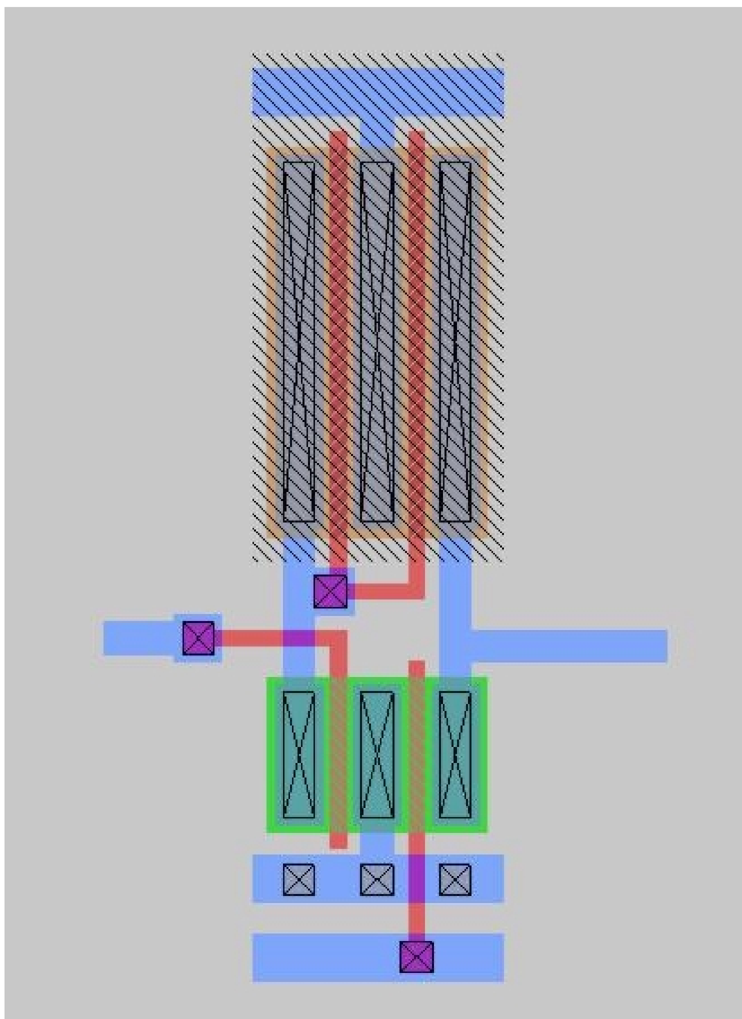




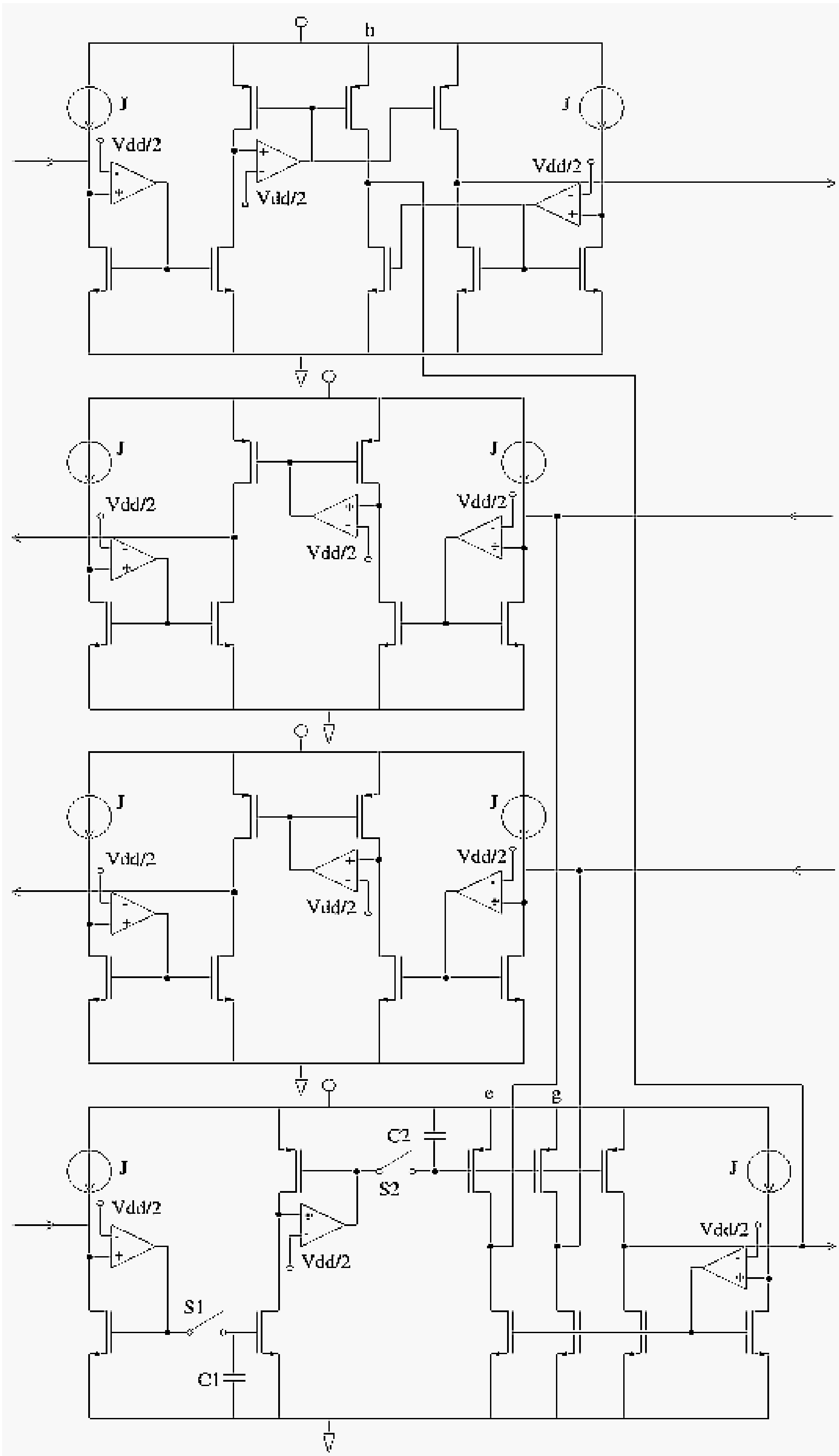
SI Delay Layout



SI Circuit Amp Layout

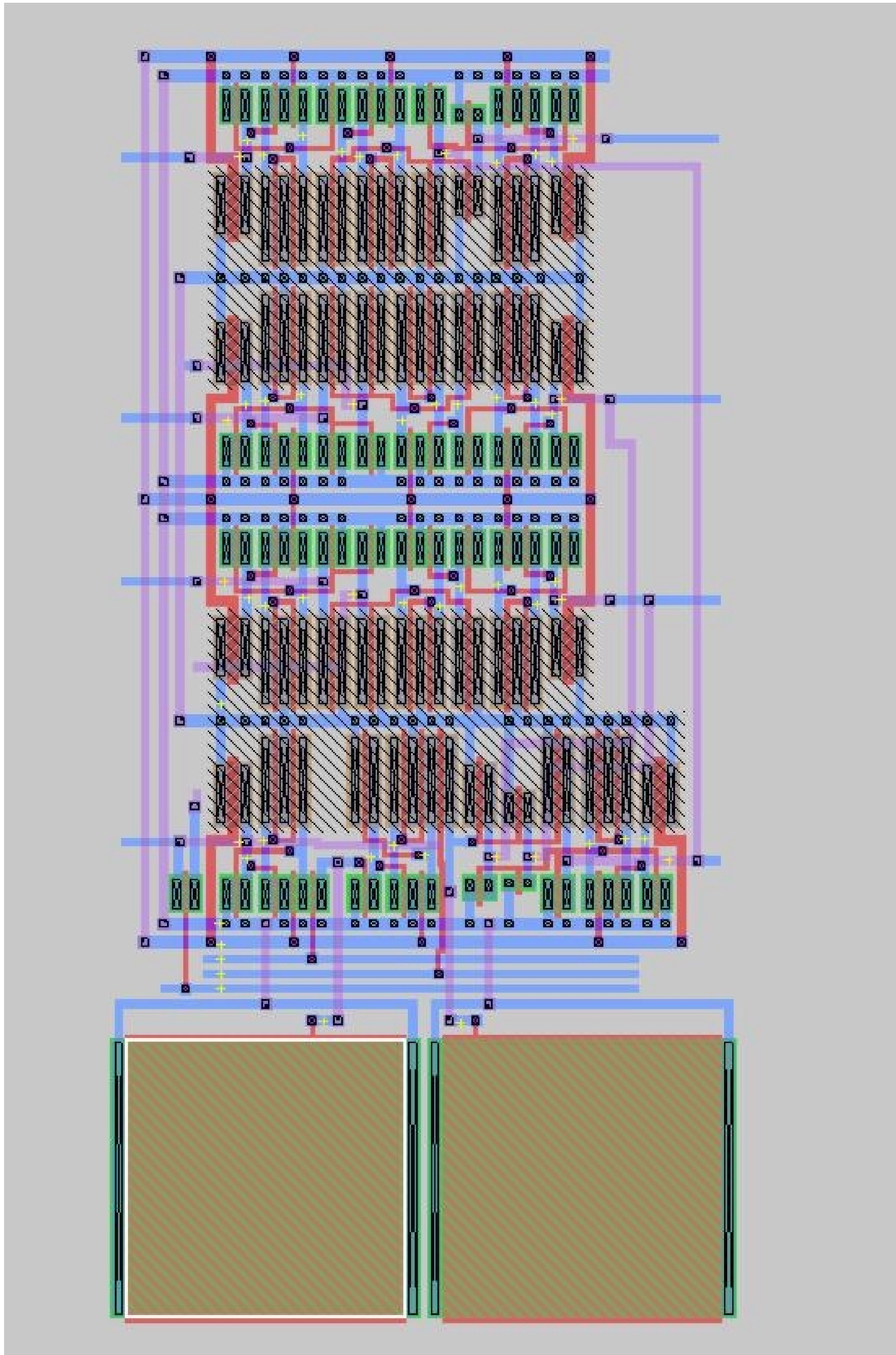


AR SI Circuit

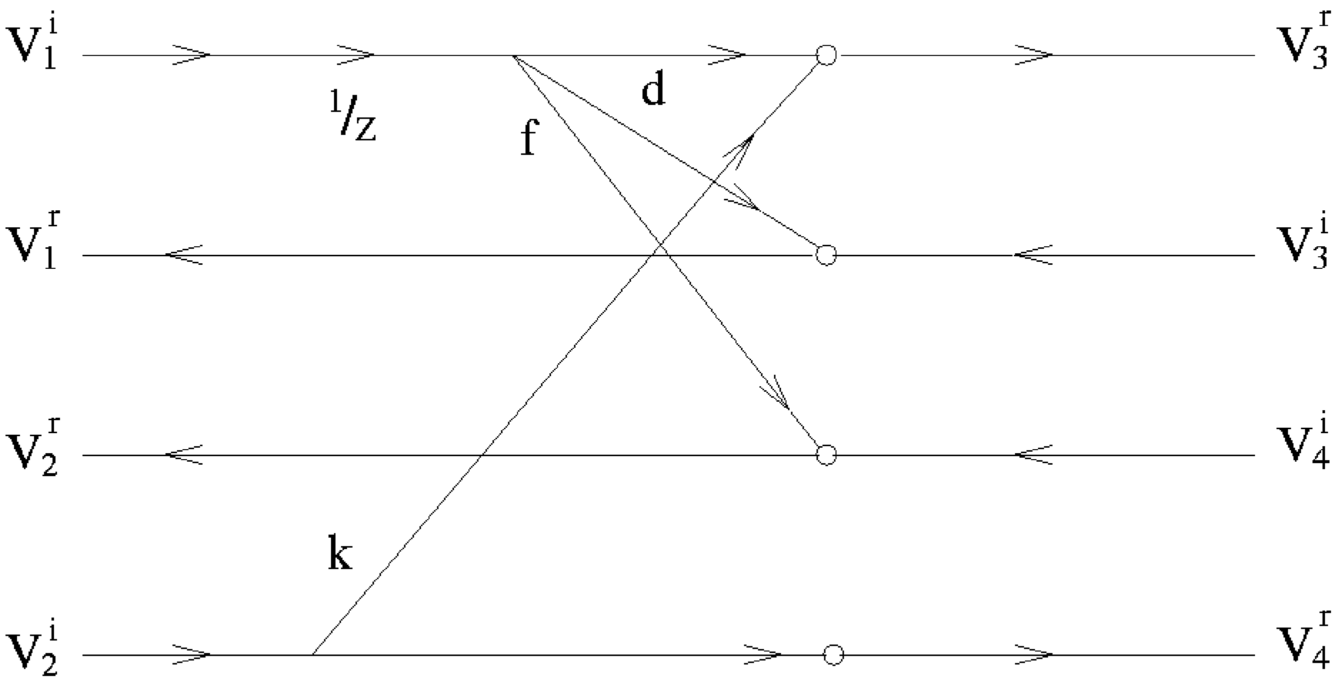


AR Section Layout

50u
X
3001u
In 1.6u
process

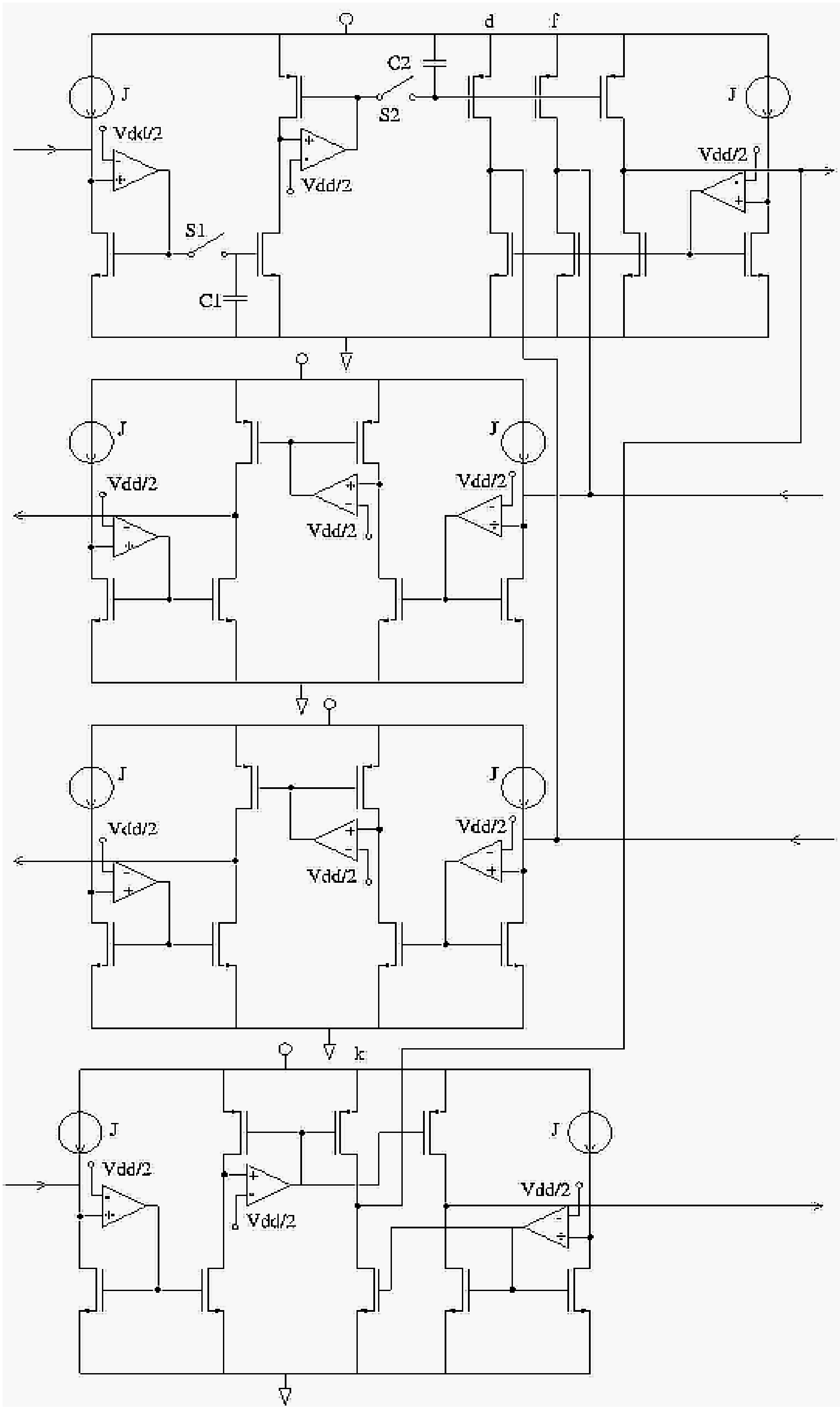


MA Section



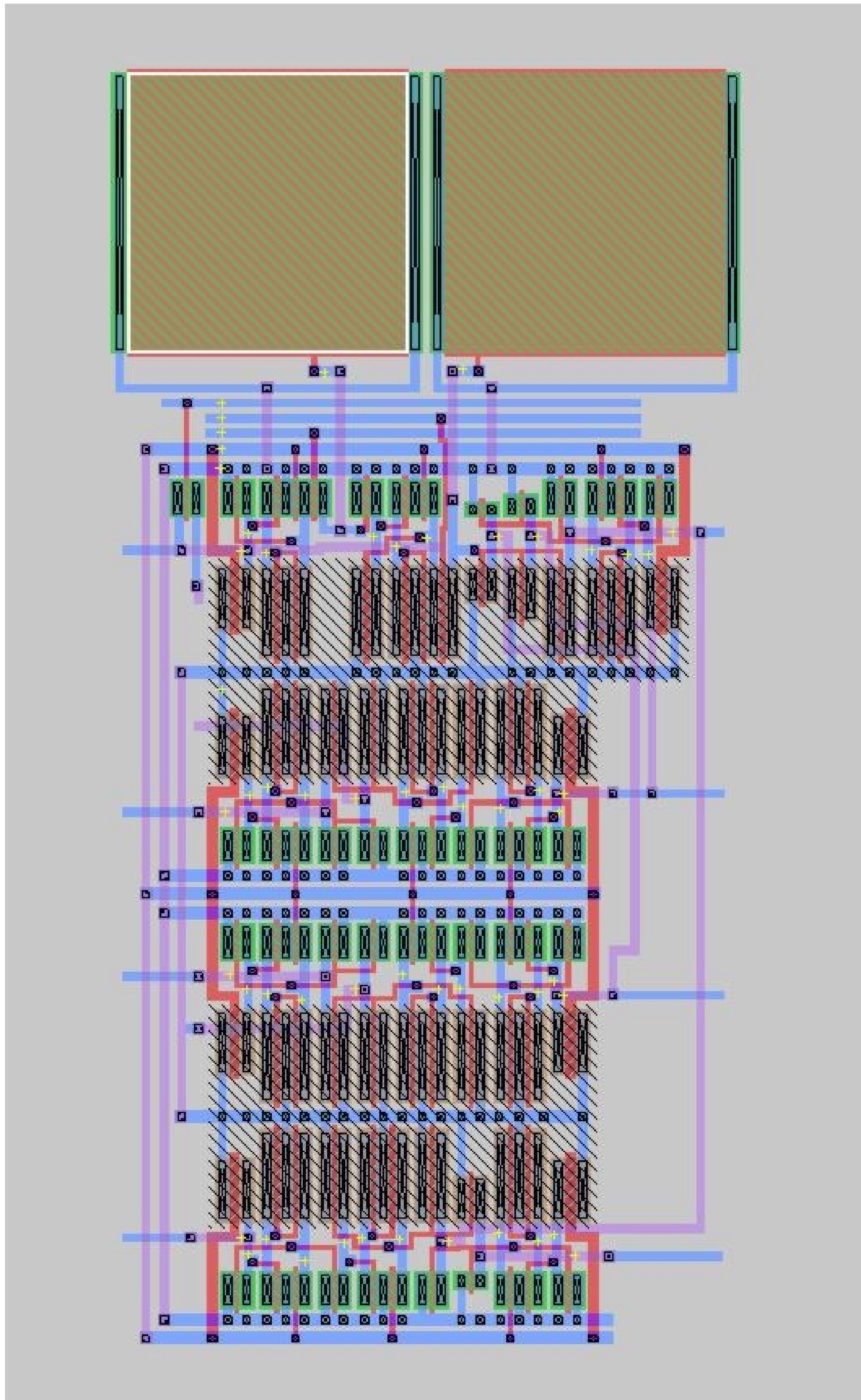
$$T_{MA} = \begin{bmatrix} z^{-1} & 0 & 0 & k \\ -dz^{-1} & 1 & 0 & 0 \\ -fz^{-1} & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

MA SI Circuit

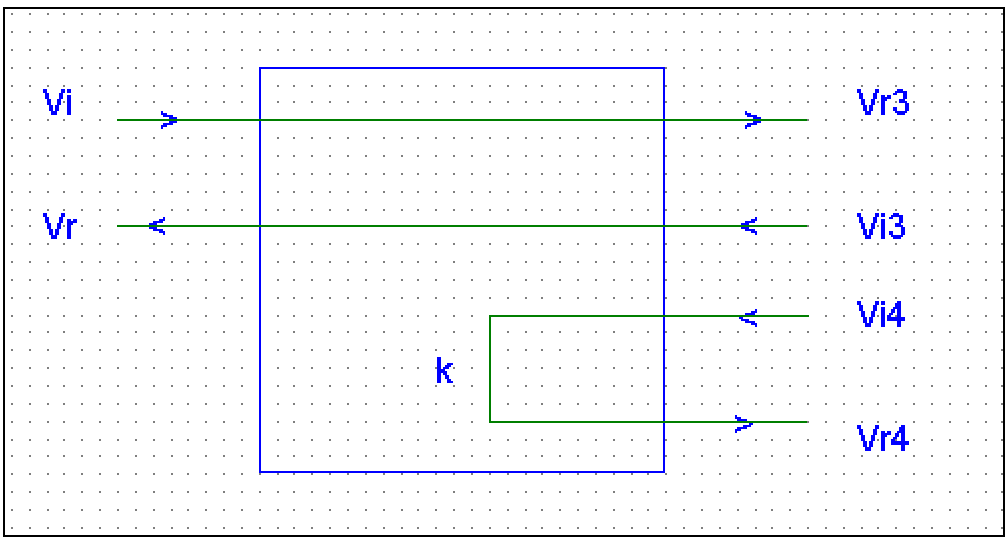


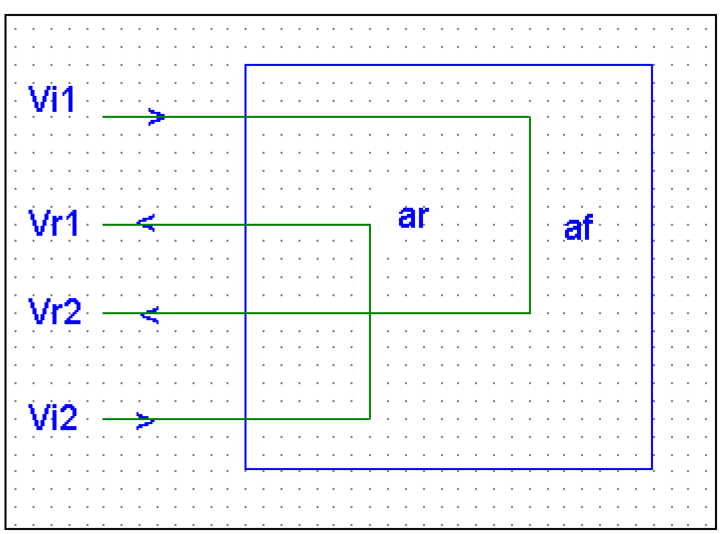
MA Section Layout

50u
X
3001u
In 1.6u
process

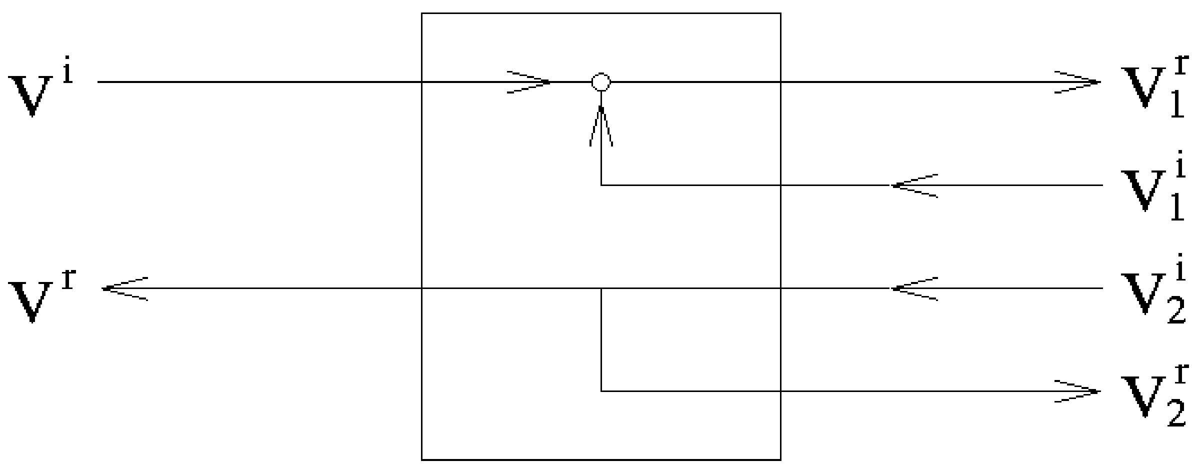


Ear Type Input & Load

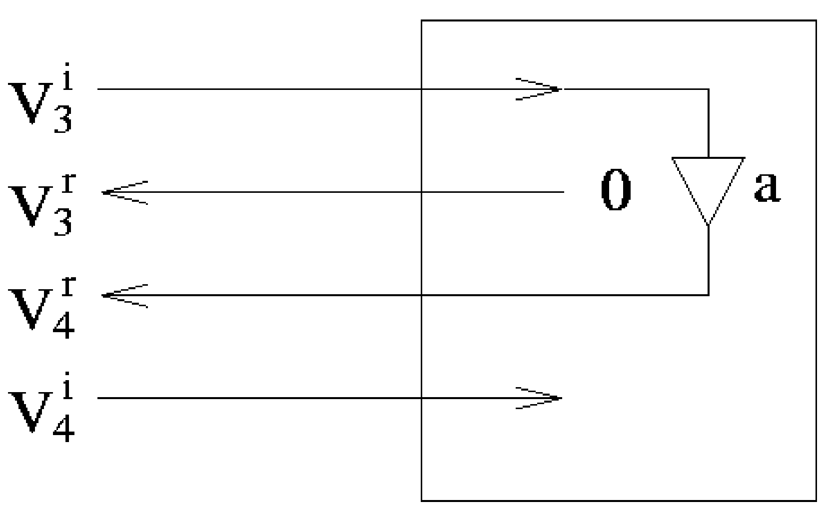




Filter Input & Load



(a)



(b)

[Mi1, p. 622, Fig. 6]

S(z) Filter Design - I

$$s(z)=\frac{\sum_{i=0}^{m} a_i z^{-i}}{\sum_{j=1}^{n} b_j z^{-1}}=\frac{a-p(z^{-1})}{1+cp(z^{-1})+(1+ac)t(z^{-1})}$$

with $b_0 \neq 0$; choose

$b_0=1, a_0=a,\ c\neq -1/a,$ so that

$$p(z^{-1})=-\sum_{i=1}^{m} a_i z^{-1}$$

$$t(z^{-1})=\frac{1}{1+ac}\left[\sum_{j=1}^{n} b_j z^{-1}-cp(z^{-1})\right]$$

$$T=\begin{bmatrix} 1 & 0 & 0 & 0 \\ cp(z^{-1}) & 1 & 0 & ct(z^{-1}) \\ p(z^{-1}) & 0 & 1 & t(z^{-1}) \\ d_1 & d_2 & d_3 & d_4 \end{bmatrix}$$

with d_i don't care entries

S(z) Filter Design - II

If m=n reduce to the case n>m by

$$T = T^0 \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ q & 0 & 0 & 1 \end{bmatrix}$$

$$T^0 = \begin{bmatrix} 1 & 0 & 0 & 0 \\ cp'(z^{-1}) & 1 & 0 & ct(z^{-1}) \\ p'(z^{-1}) & 0 & 1 & t(z^{-1}) \\ d'_1 & d'_2 & d'_3 & d'_4 \end{bmatrix}$$

with

$q = a_n / b_n$; $p' = p(z^{-1}) - qt(z^{-1})$

d'_i don't care entries

S(z) Filter Design - III

AR Decomposition; case of n>m

$$
T=\begin{bmatrix} 1 & 0 & 0 & 0 \\ cp(z^{-1}) & 1 & 0 & ct(z^{-1}) \\ p(z^{-1}) & 0 & 1 & t(z^{-1}) \\ d_1 & d_2 & d_3 & d_4 \end{bmatrix}
$$

$$
=\begin{bmatrix} 1 & 0 & 0 & 0 \\ p''(z^{-1}) & 1 & 0 & ct''(z^{-1}) \\ p''(z^{-1}) & 0 & 1 & t''(z^{-1}) \\ d''_1 & d''_2 & d''_3 & d''_4 \end{bmatrix}\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & -ez^{-1} \\ 0 & 0 & 1 & -gz^{-1} \\ h & 0 & 0 & z^{-1} \end{bmatrix}
$$

$$
p''(z^{-1})=c\sum_{i=1}^{m-1} p''_i z^{-i};\quad t''(z^{-1})=c\sum_{j=1}^{n-1} t''_j z^{-1}
$$

with

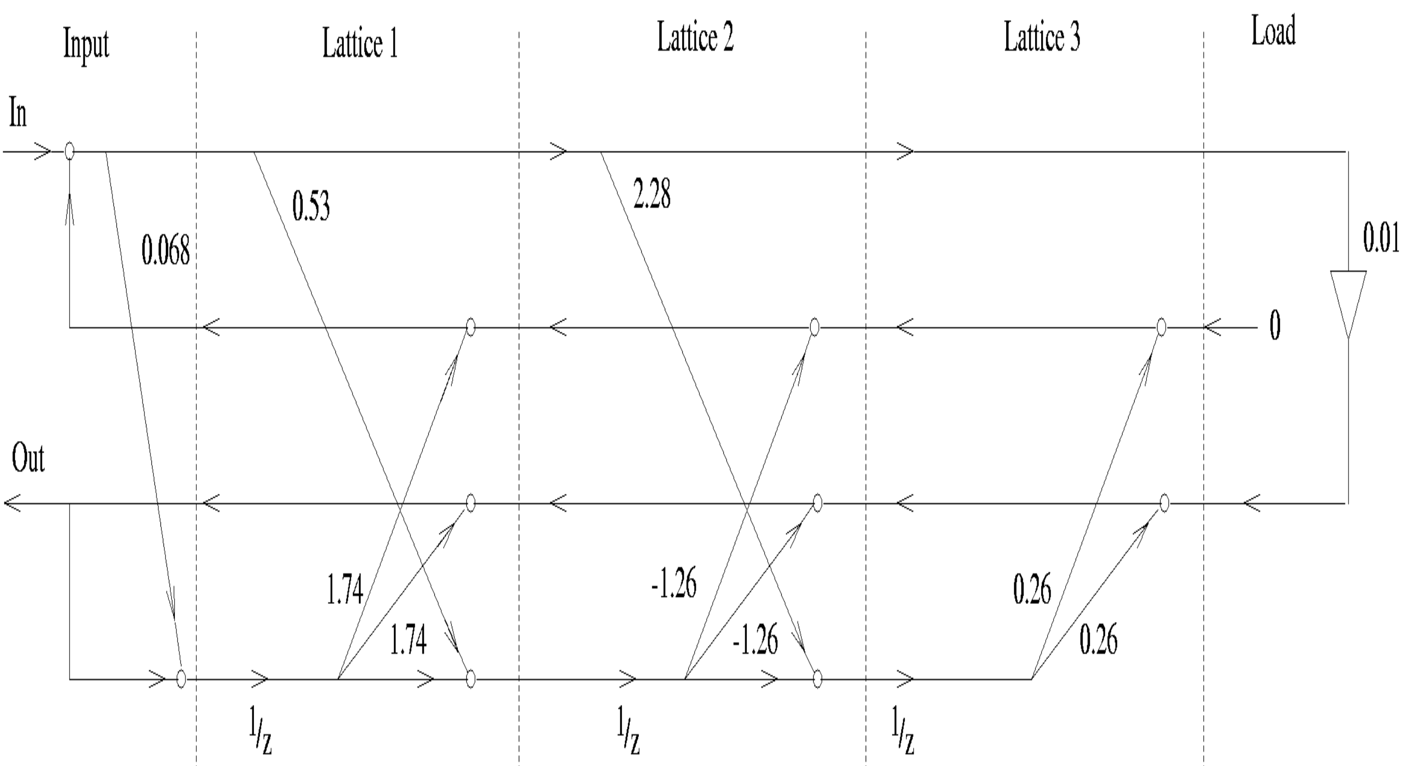
$h=p_m/t_{m+1};\ p''_i=p_i-ht_{i+1};\ t''_i=t_{i+1};\ e=t_1;\ g=ce$

MA to AR

$$\begin{bmatrix} 0 & 0 & 0 & 1 \\ ct(z^{-1}) & 1 & 0 & cp(z^{-1}) \\ t(z^{-1}) & 0 & 1 & p(z^{-1}) \\ d_1 & d_2 & d_3 & d_4 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ cp(z^{-1}) & 1 & 0 & -ct(z^{-1}) \\ p(z^{-1}) & 0 & 1 & -t(z^{-1}) \\ d_4 & d_2 & d_3 & -d_1 \end{bmatrix} \begin{bmatrix} 0 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -1 & 0 & 0 & 0 \end{bmatrix}$$

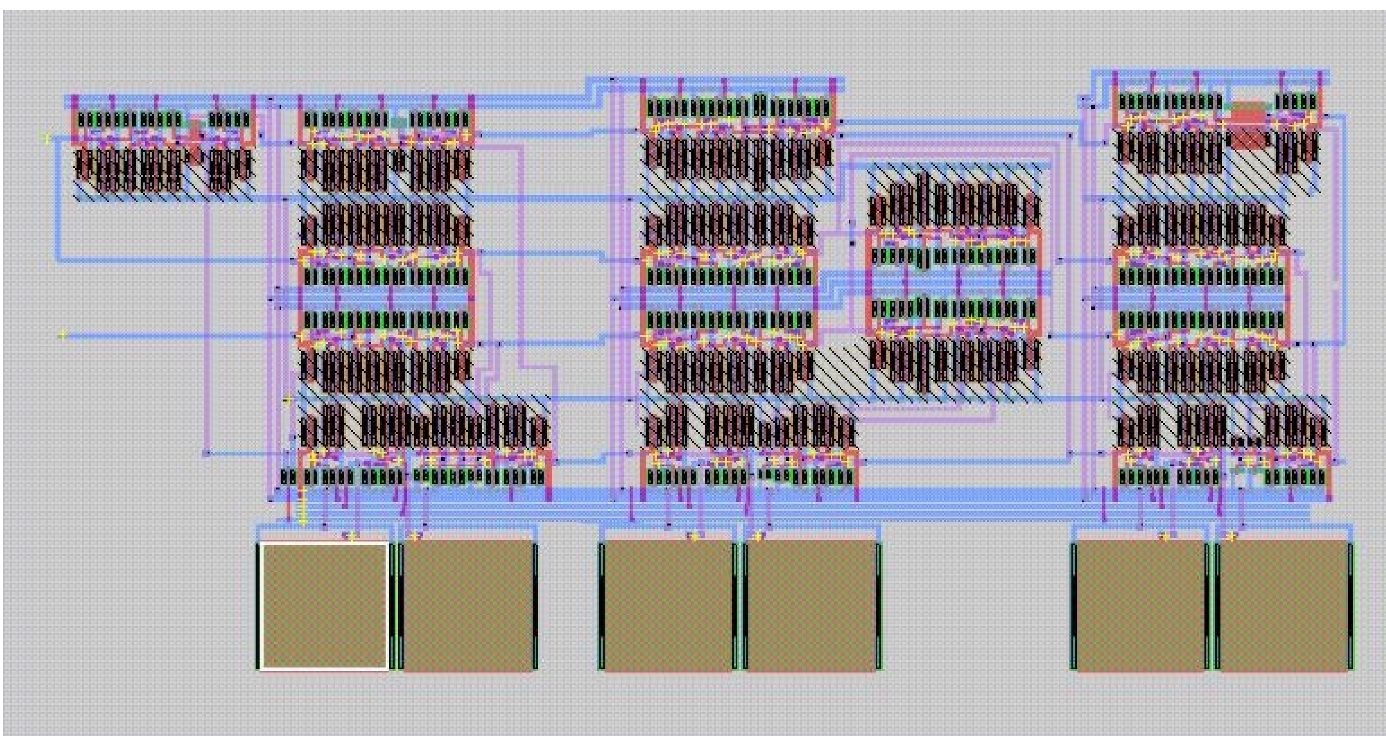
Note that m>n for AR, m<n for MA but only a permutation with a sign change is needed to go between the two

Degree 3 Max Flat - I



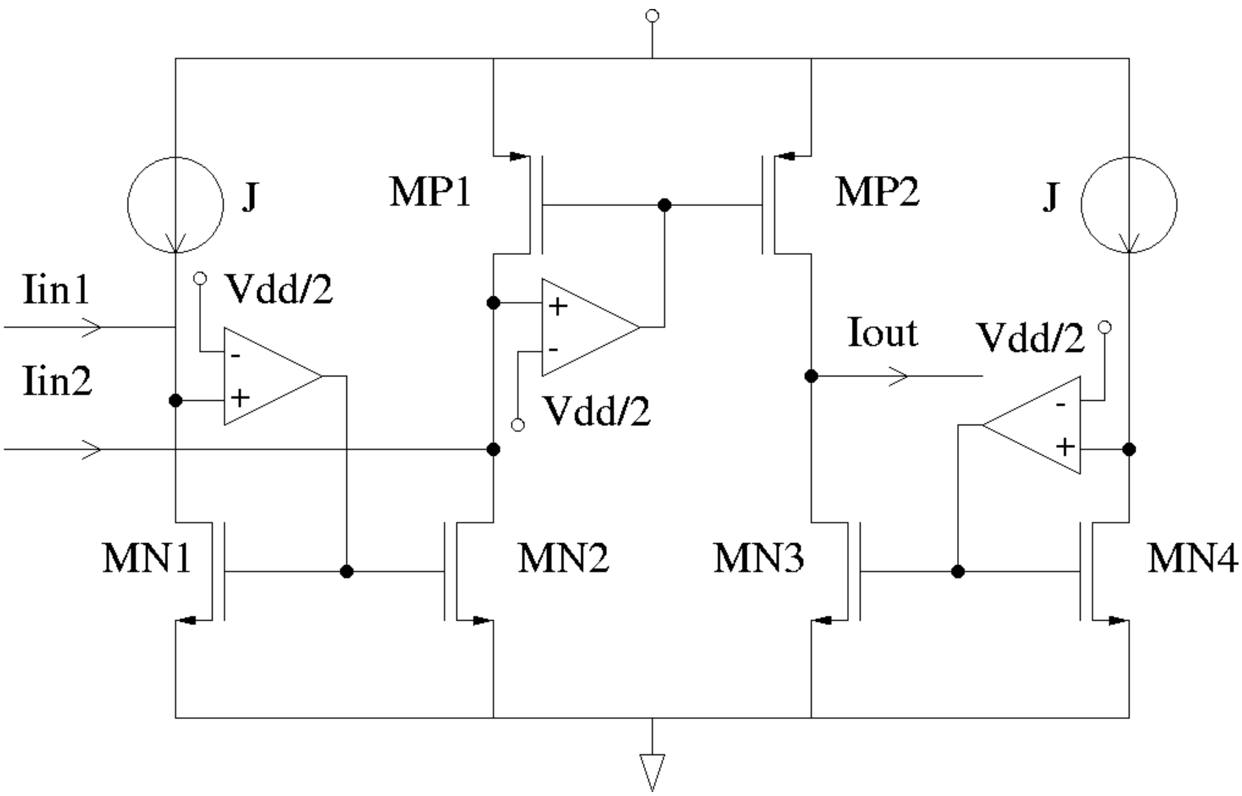
Degree 3 Max Flat - II

1000u x 450u for 1.6u process
Clocked at 100KHz; Vdd=5v
About 10milliW

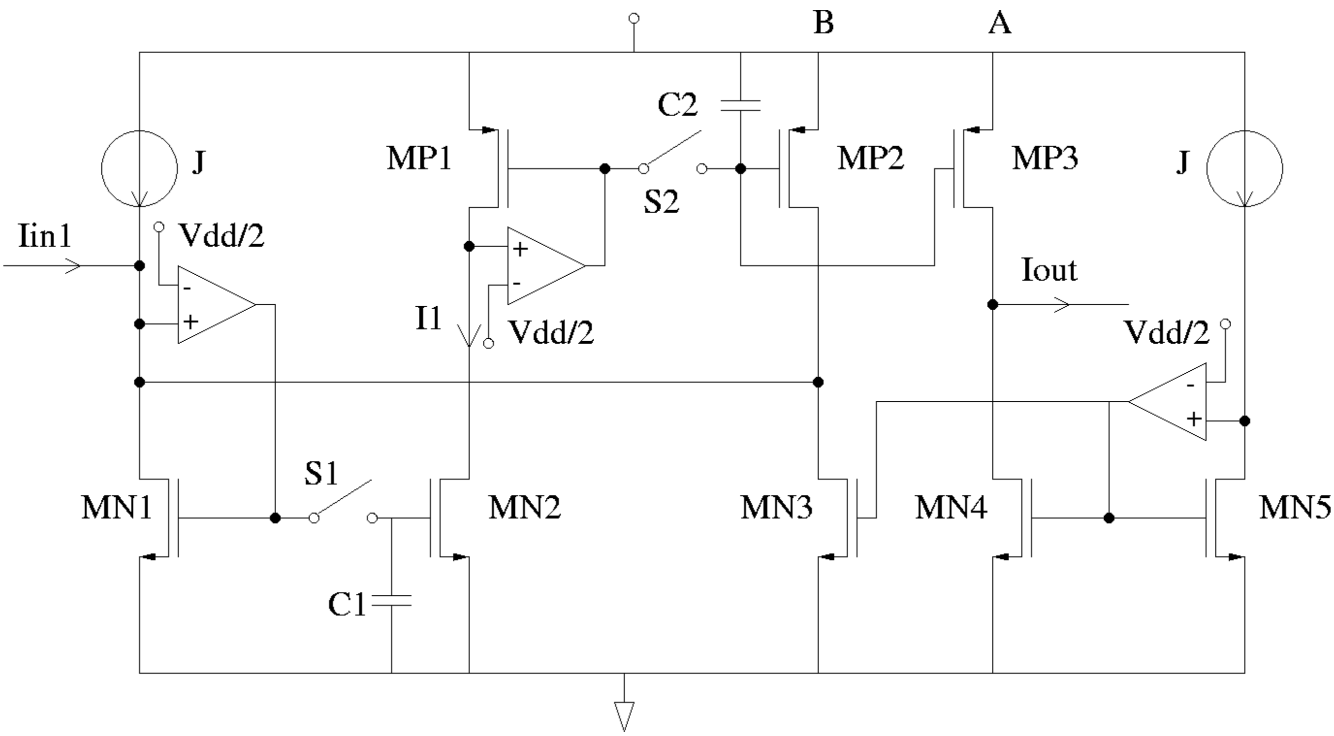


Active Current Mirror

Main idea from [Jo1]

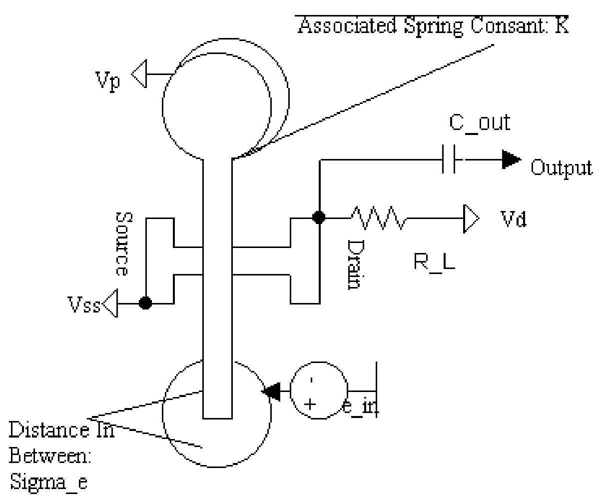


1/z Realization

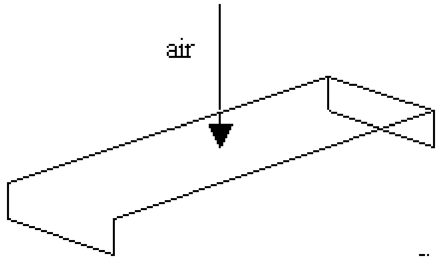


Mems Microphone - I

Start from Nathanson's RGT

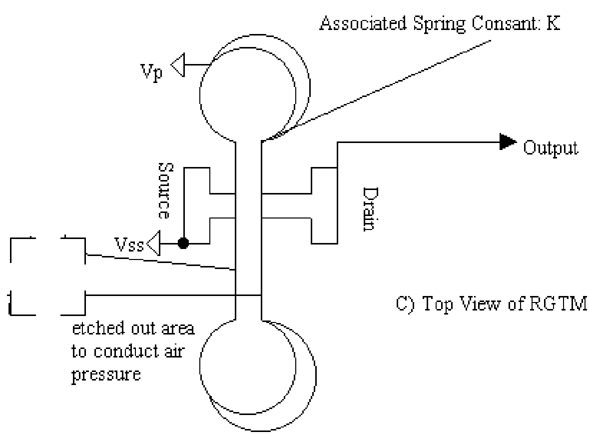


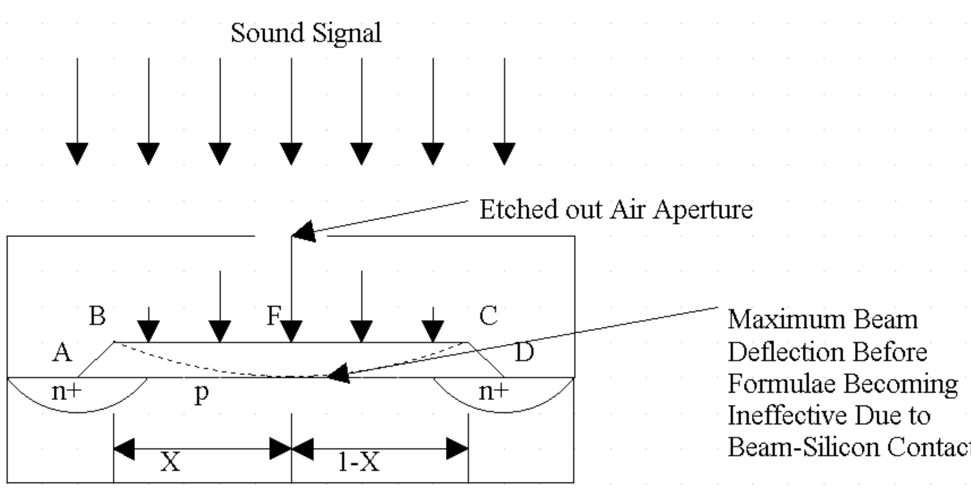
Change gate excitation from voltage to air pressure



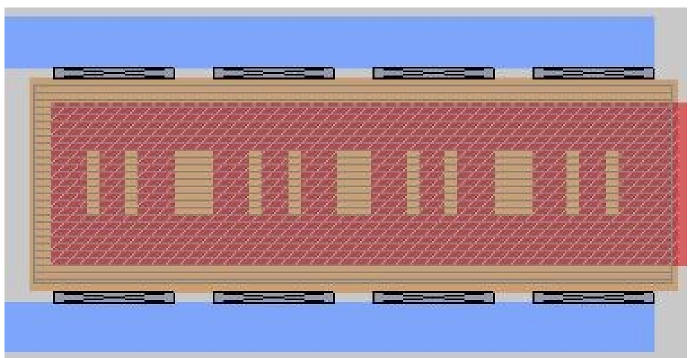
Mems Microphone - II

Modulate gate capacitance





Mems Microphone Layout



Kemp Echo S(z)

S(z)=N(z)/D(z), 1/z=unit delay

$N(z)=0.1575130z^{-32}-1.182959z^{-31}+0.327421z^{-30}+0.430116z^{-29}+0.738268z^{-27}-1.354292z^{-27}-1.809802z^{-26}+0.970980z^{-25}+0.923793z^{-24}+1.418271z^{-23}+0.098415z^{-22}-0.295472z^{-21}+0.312645z^{-20}-0.630343z^{-19}-1.440973z^{-18}-1.869601z^{-17}+4.462128^{-16}$

$D(z)=180(0.139683z^{-32}-0.286068z^{-31}+0.174111z^{-30}-0.135610z^{-29}+0.010562z^{-27}+0.163818z^{-27}-0.150255z^{-26}+0.088931z^{-25}+0.031265z^{-24}-0.050757z^{-23}-0.155118z^{-22}-0.123422z^{-21}-0.063228z^{-20}+0.097258z^{-19}+0.216830z^{-18}-1.137432z^{-17}+2.769446^{-16}-1.603863z^{-15}-0.583684z^{-14}-1.661542z^{-13}+2.207658z^{-12}+1.978895z^{-11}-2.653648z^{-10}+0.392582z^{-9}-1.000299z^{-8}+1.166679z^{-7}+0.328678z^{-6}-1.447006z^{-5}+0.440116z^{-4}+1.684127z^{-3}+3.255450z^{-2}-9.090247z^{-1}+5.005533)$

Next: VLSI realization of this!

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[Gu1] A. C. Guyton, "Textbook of Medical Physiology," Eighth Edition, W/B. Saunders Company, Philadelphia, 1991

[Hu1] J. B. Hughes, N. C. Bird, and I. C. Macbeth, "Switched Currents – A New Technique for Analog Sampled-Data Signal Processing," Proceedings of ISCAS, Portland, 1989, pp. 1584 – 1587.

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[Mi1] Y. Miyanaga, N. Nagai, and N. Miki, "ARMA Digital Lattice Filter Based on New Criterion," IEEE Transactions on Circuits and Systems, Vol. CAS-34, No. 6, June 1987, pp. 617 - 628

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[Se1] L. Sellami and R. W. Newcomb, "Ear-Type Analog and Digital Systems," Recent Research Developments in Circuits & Systems, Vol. 1, 1996, pp. 59 - 83

Thanks

This motivation which started this work was the birth into deafness of the son of one of RWN's doctoral students, Dr. Manjula Bhushan Waldron. The primary initiating work was carried out in the doctoral dissertations of Victoria Rodellar and Pedro Gomez. Our laboratory under their direction at UPM, Spain, continues to be key in this area. Primary to following this up has been the continuing work of Dr. Louiza Sellami who has been instrumental in developing the transfer scattering formulation using data, supplied by Dr. Hugo Wit under our three country program. Dr. Tianshea Cheng developed the 4-port Lattices, Mr. Lin Jia put them into VLSI and Mr. Mosheh Moskowitz has greatly Contributed to many aspects.

Many Ear Type Devices