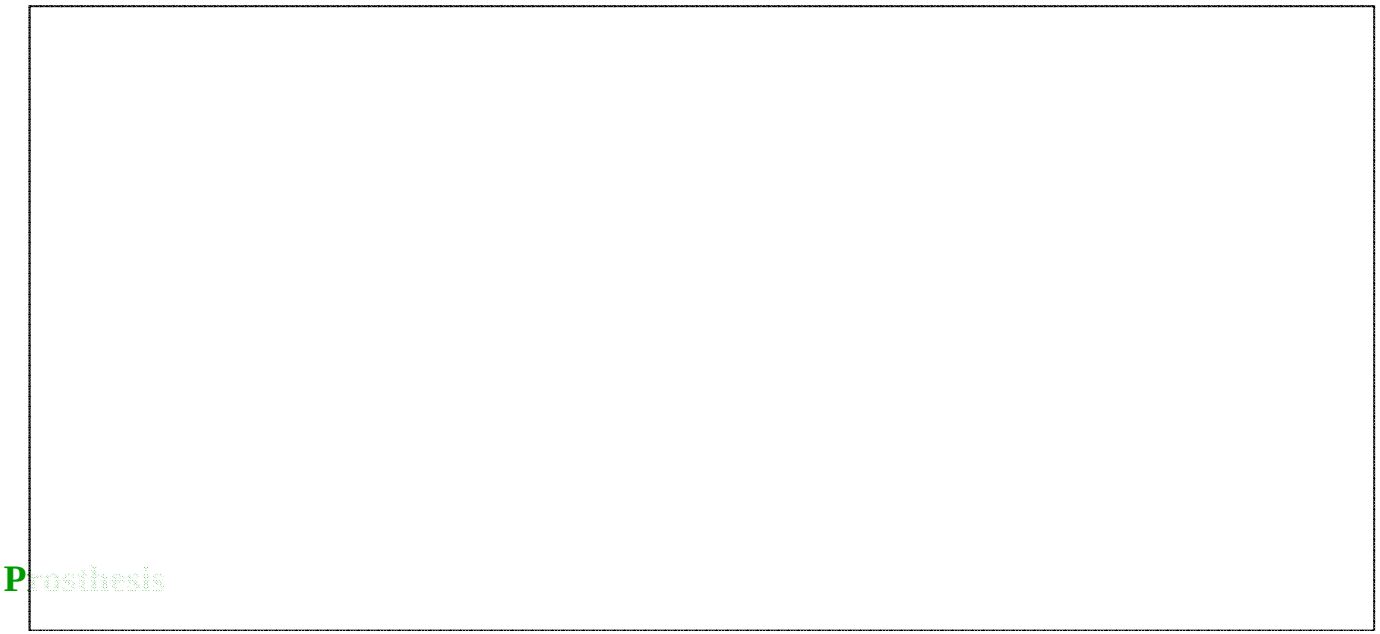
Mimicking the Human EAR



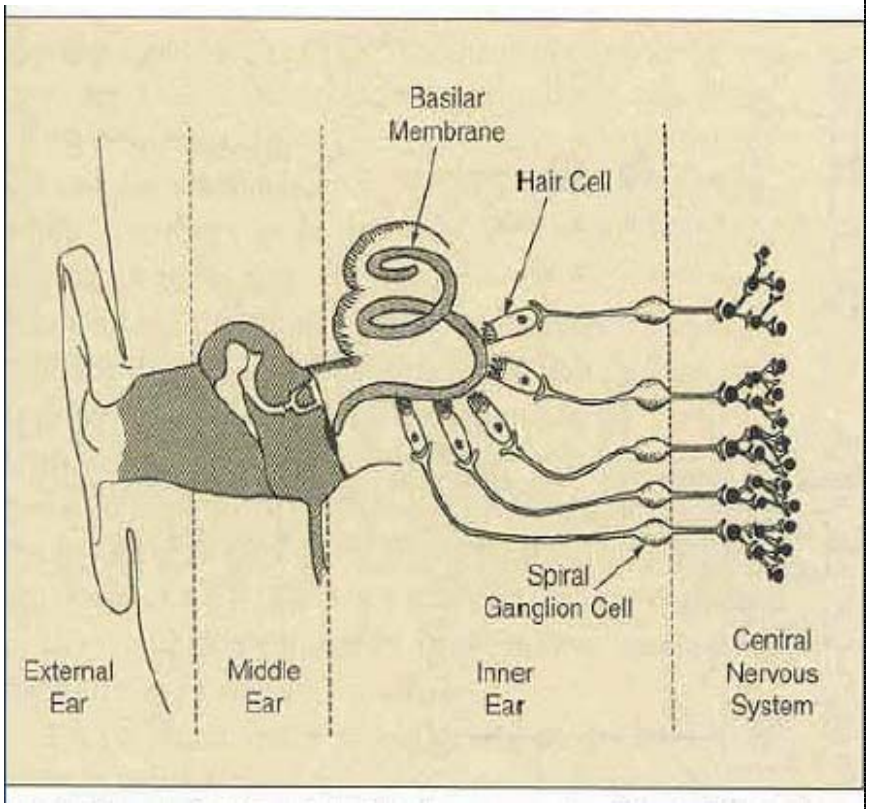
Signal processing

- Signal processing -> quite important role
- Designers of cochlear prosthesis were faced with the challenge of developing signal processing techniques that would mimic the function of a normal cochlea.

Purpose

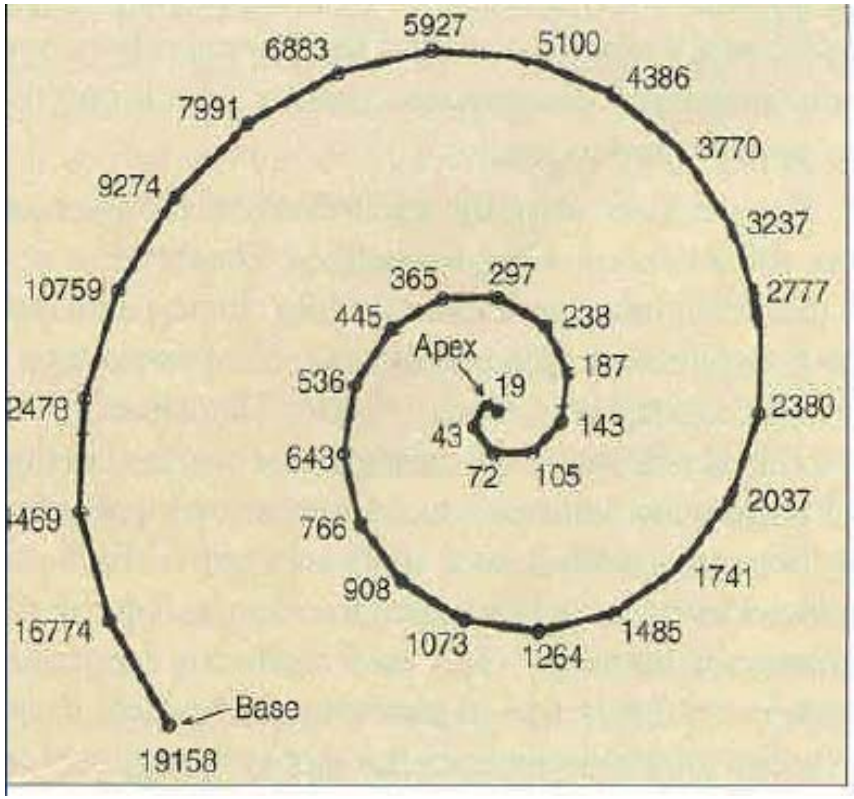
- The designers of cochlear prosthesis need to know what information in the speech signal is perceptually important
- Show various signal processing techniques that have been used for cochlear prosthesis over the past 25 years.

Can we use Cochlear?



- The most common cause of deafness -> The loss of hair cells
- This was very encouraging for cochlear implants because the remaining neurons could be excited directly through electrical stimulation.

The cochlea therefore acts like a spectrum analyzer



- Georg von Bekesy
- Place Theory
- Basilar membrane in the inner ear is responsible for analyzing the input signal into different frequencies.

Place,Volley theory

- This mechanism for determining frequency is referred to as place theory. The place mechanism for coding frequencies has motivated multi-channel cochlear implants.
- volley theory, suggests that frequency is determined by the rate at which the neurons are fired. According to the volley theory, the auditory nerve fibers fire at rates proportional to the period of the input signal. At low frequencies, individual nerve fibers fire at each cycle of the stimulus. At high frequencies, frequency is indicated by the organized firing of groups of nerve fibers.

Pitch and Loudness

- The implant can effectively transmit information to the brain about loudness of the sound, which is a function of the amplitude of the stimulus current, and the pitch, which is a function of the place in the cochlear being stimulated.

What factor ?

- Electrode design
- Type of stimulation - analog or pulsatile,
- Transmission link - transcutaneous or percutaneous,
- Signal processing - waveform representation or feature extraction.

Electrode design

- Electrode placement
- Number of electrodes and spacing
- Orientation of electrodes with respect to the excitable tissue
- Electrode configuration

Where?

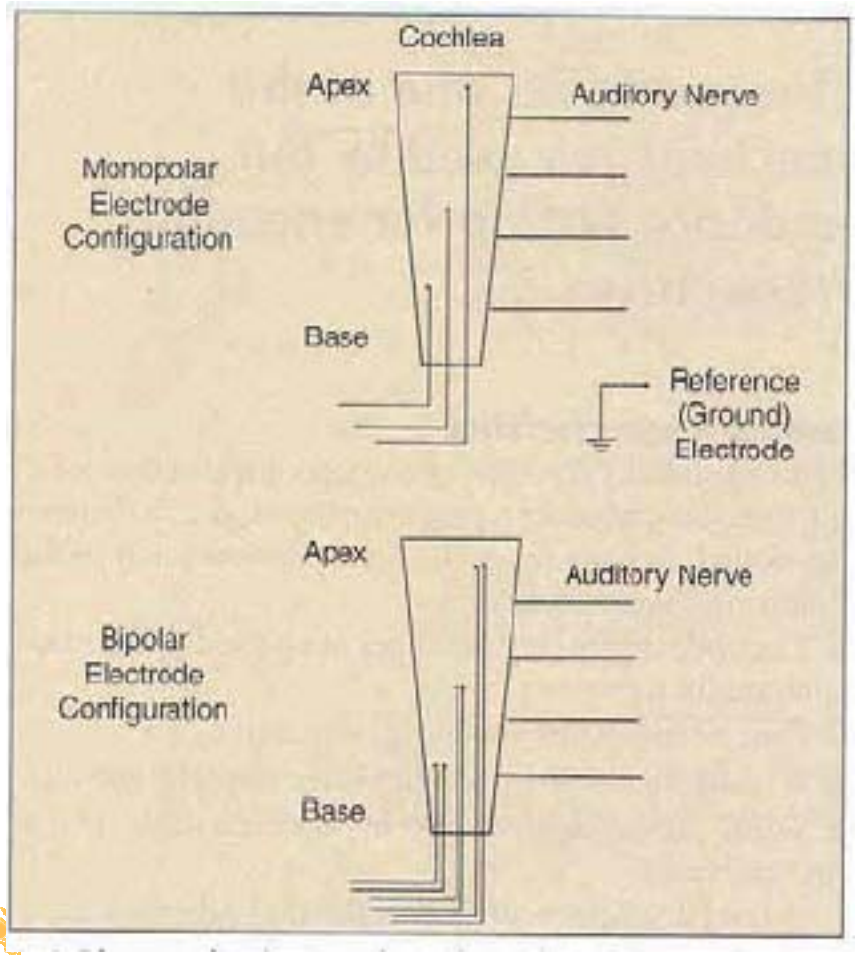
- Electrode Placement

  -Round window of the cochlea (extracochlear)
  -Scala tympani (intracochlear)
- Most commonly, the electrodes are placed in the scala tympani.
- The electrode arrays can be inserted in the scala tympani to depths of 22-30 mm within the cochlea

How many?

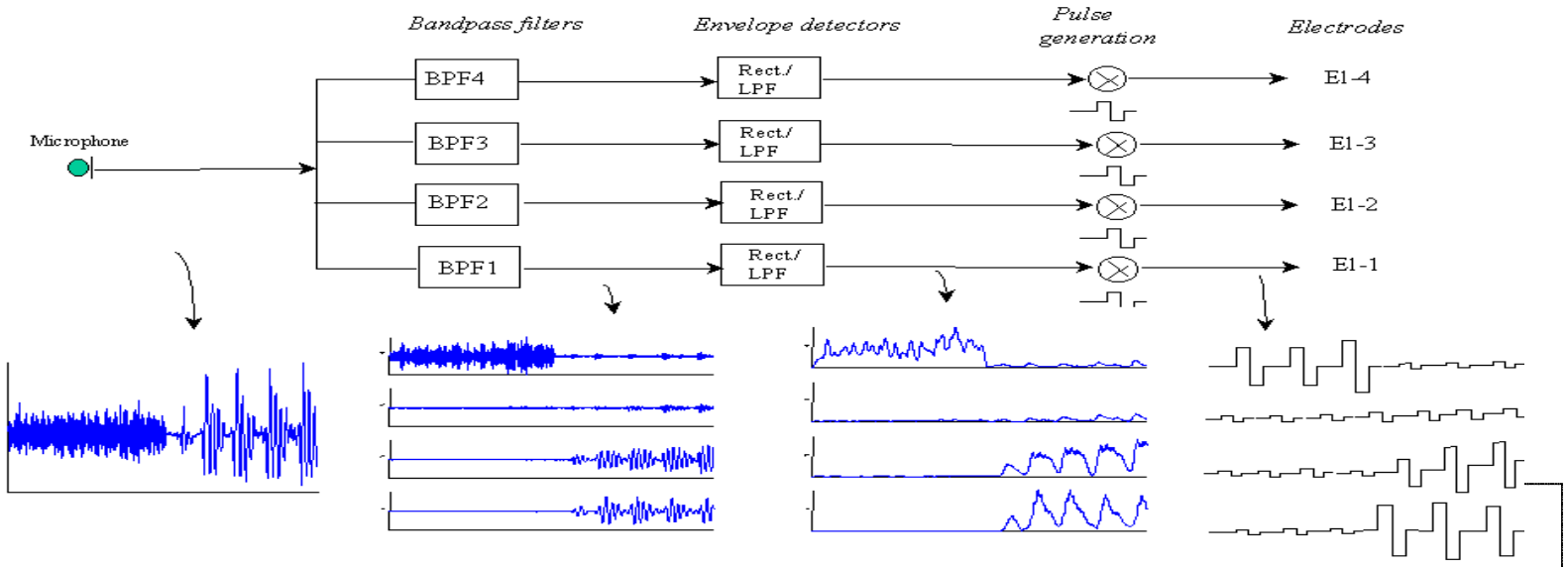
- The number of electrodes - > the place resolution for coding frequencies.
- (1) number of surviving auditory neuron (2) spread of excitation associated with electrical stimulation.

Orientation of Electrodes



- Monopolar
- Bypolar
- Bipolar electrodes have been shown to produce a more localized stimulation than monopolar electrodes

Type of Stimulation



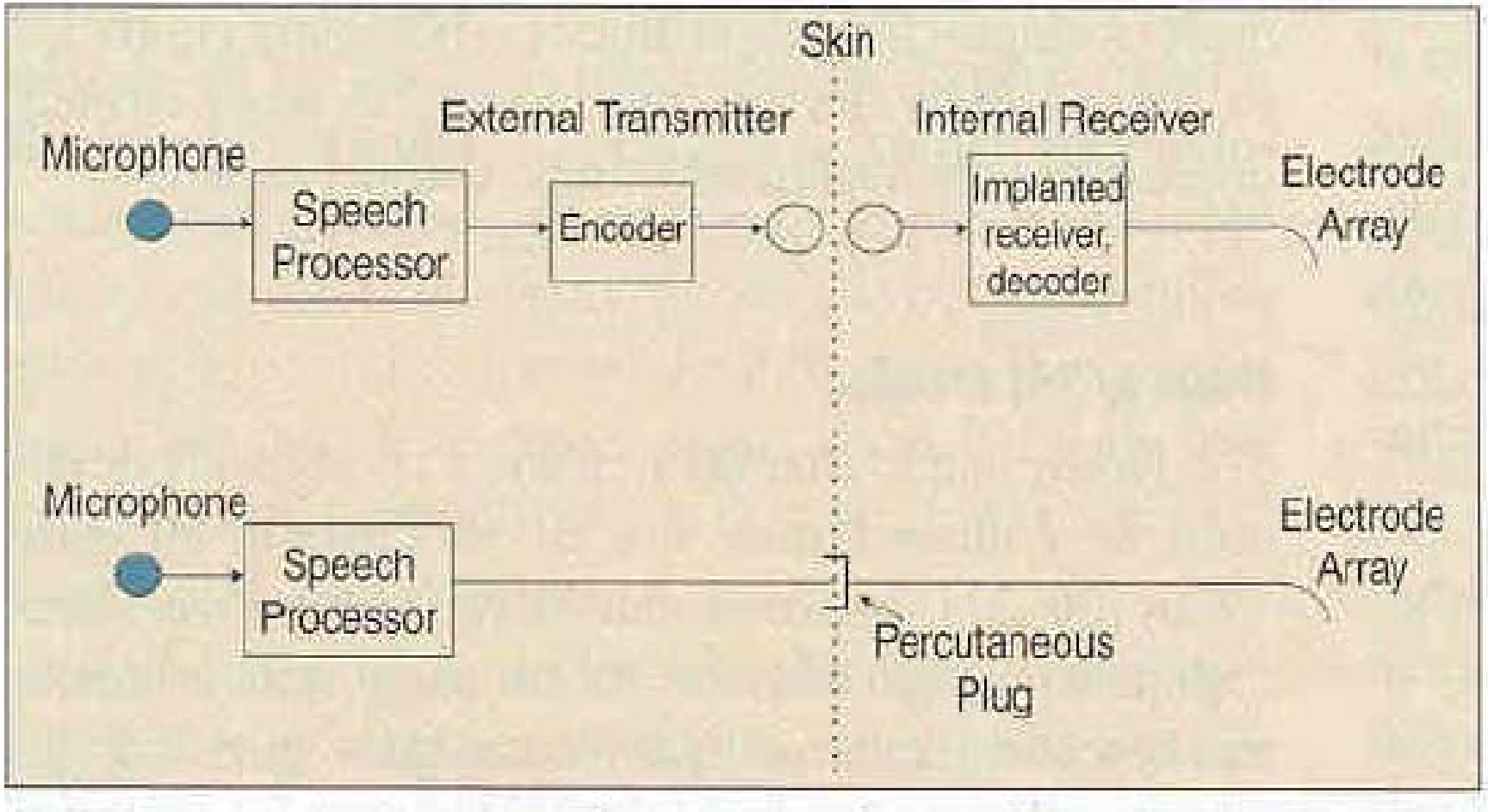
- Analog ->make use of all the information contained in the raw acoustic waveforms.
- Pulsatile-> Sample and Pulse shape

Analog VS Pulasatile

- Analog
  advantage -> acute signal
  disadvantage -> channel interactions.

- Pulasatile
  advantage -> This type of stimulation is that the pulses can be delivered in a non-overlapping (i.e., non-simultaneous) fashion, thereby minimizing channel interactions.
  disadvantage -> loosing information

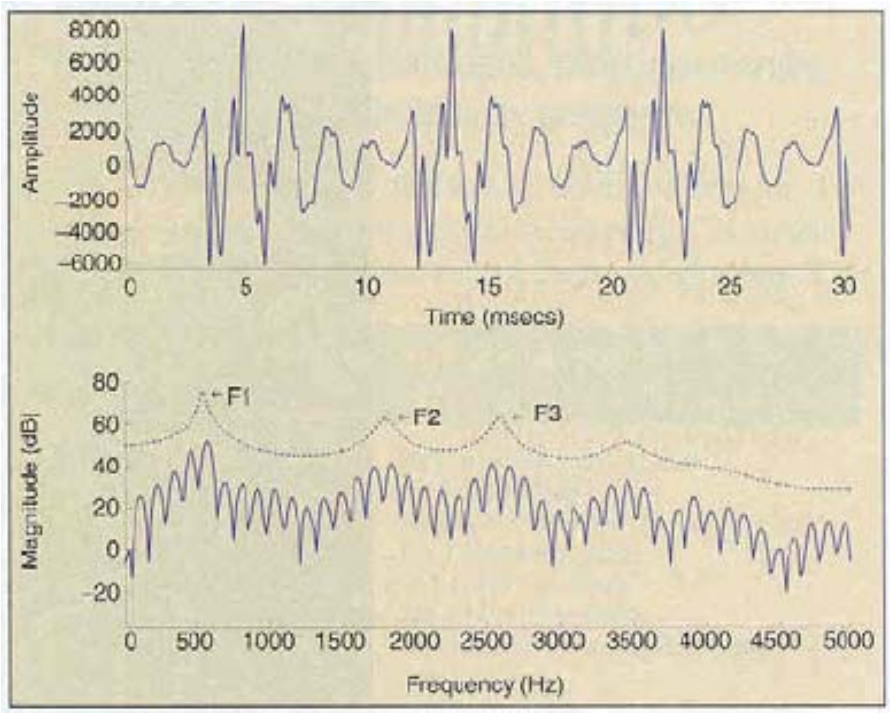
Transmission link



Signal Processing

- Some of these techniques are aimed at preserving waveform information, others are aimed at preserving envelope information, and others are aimed at preserving spectral features (e.g., formants).

Formant



- The formants carry some information about the speech signal.

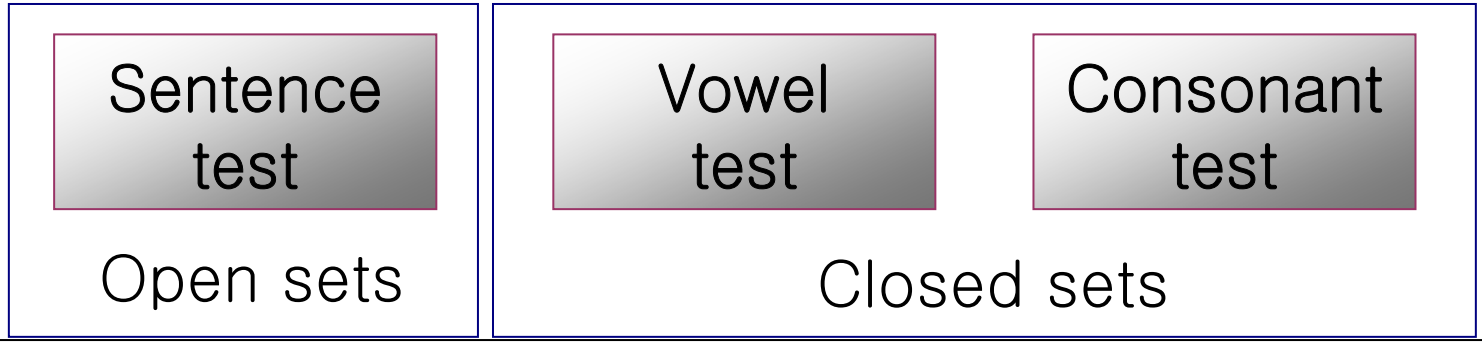
Who Can Be Implanted?

1. Profound & bilateral hearing loss

- measured at 500, 1k, 2kHz

2. Obtain sentence recognition score of 30% correct or less

Evaluating Performance



- **Standardized tests**

- Northwestern University
- Central Institute for the Deaf (CID)
- Iowa test
- Tests for children

Single-Channel Implants

- House/3M Device

- Vienna/3M Device

Single-Channel Implants

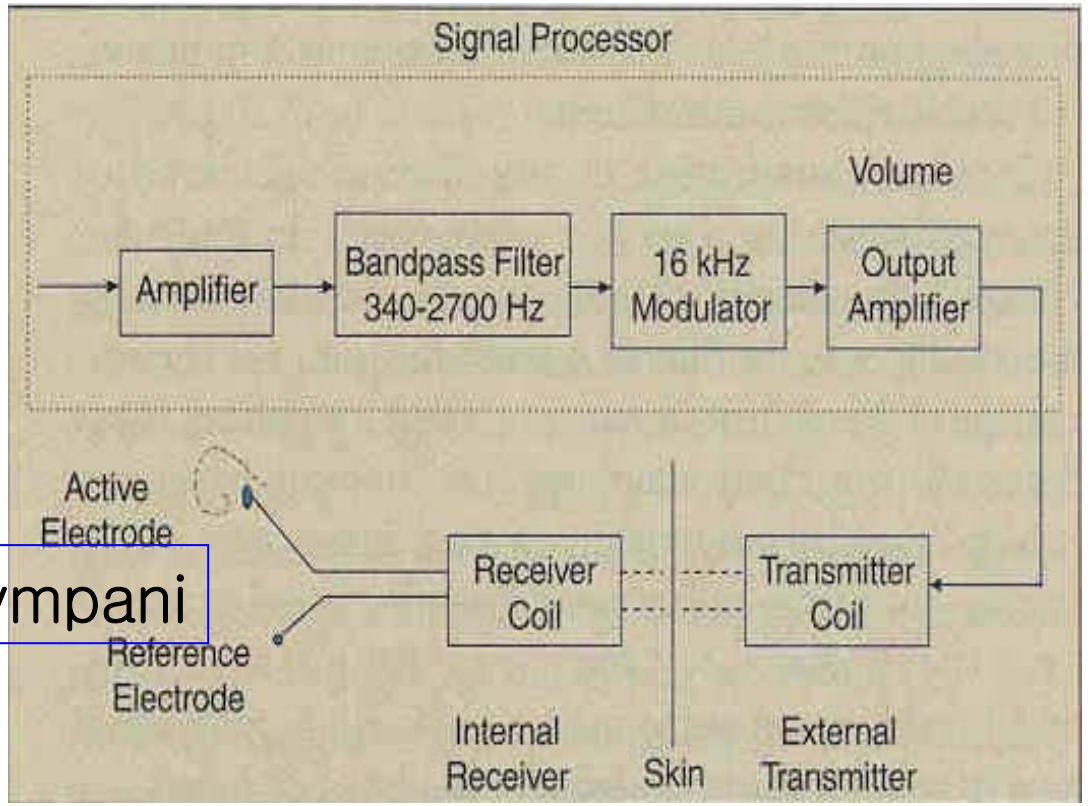
- provide electrical stimulation at a **single site** in the cochlea using a **single electrode**
- **Advantages**

- simplicity in design
- low cost
- do not require much hardware
- could be packaged into a behind-the-ear device.

- However, a **lot of skepticism**

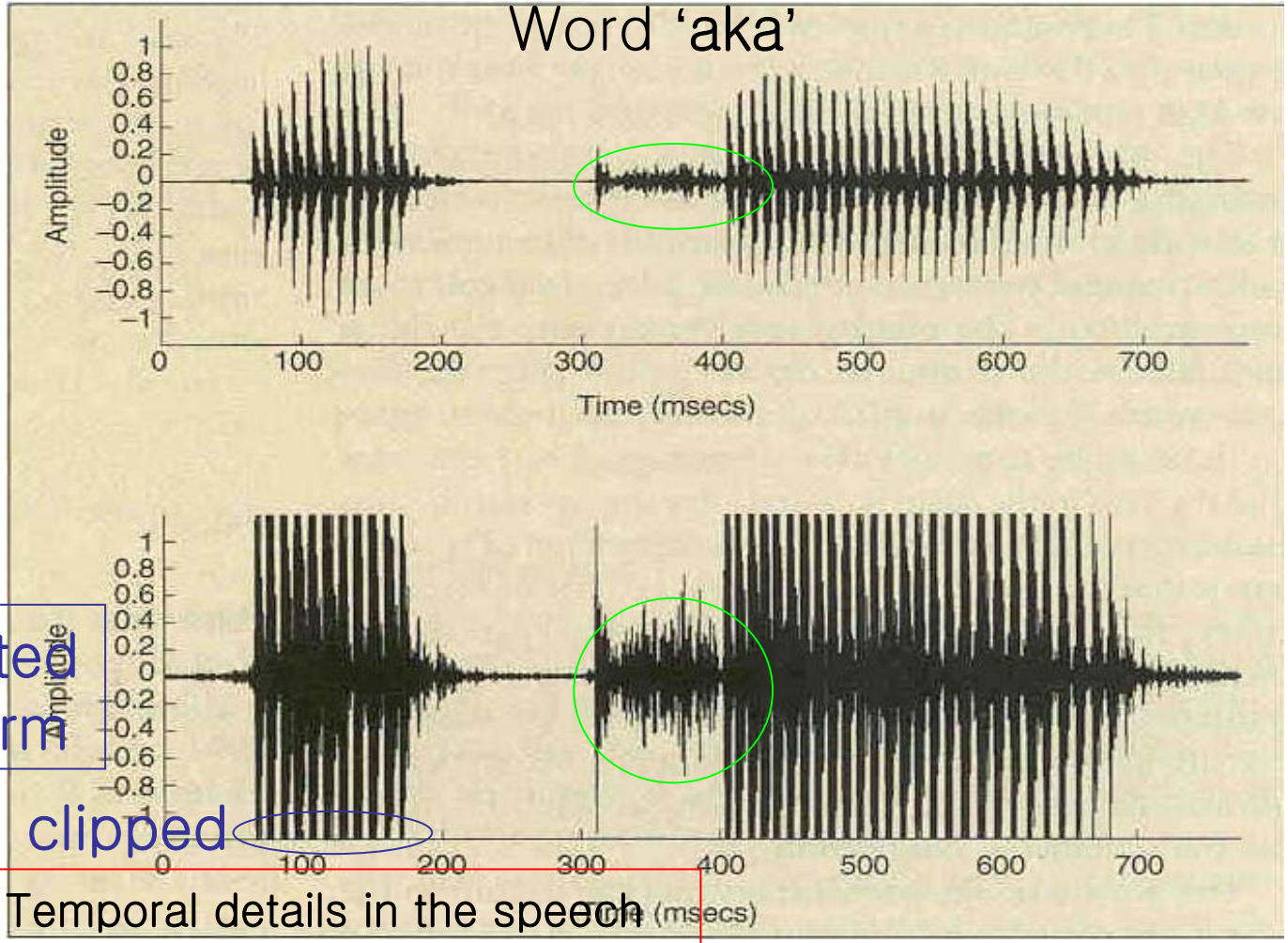
House/3M Device

- Developed by **William House and his associates** (early 1970s)



Scalar tympani

House/3M Device



Modulated waveform

clipped

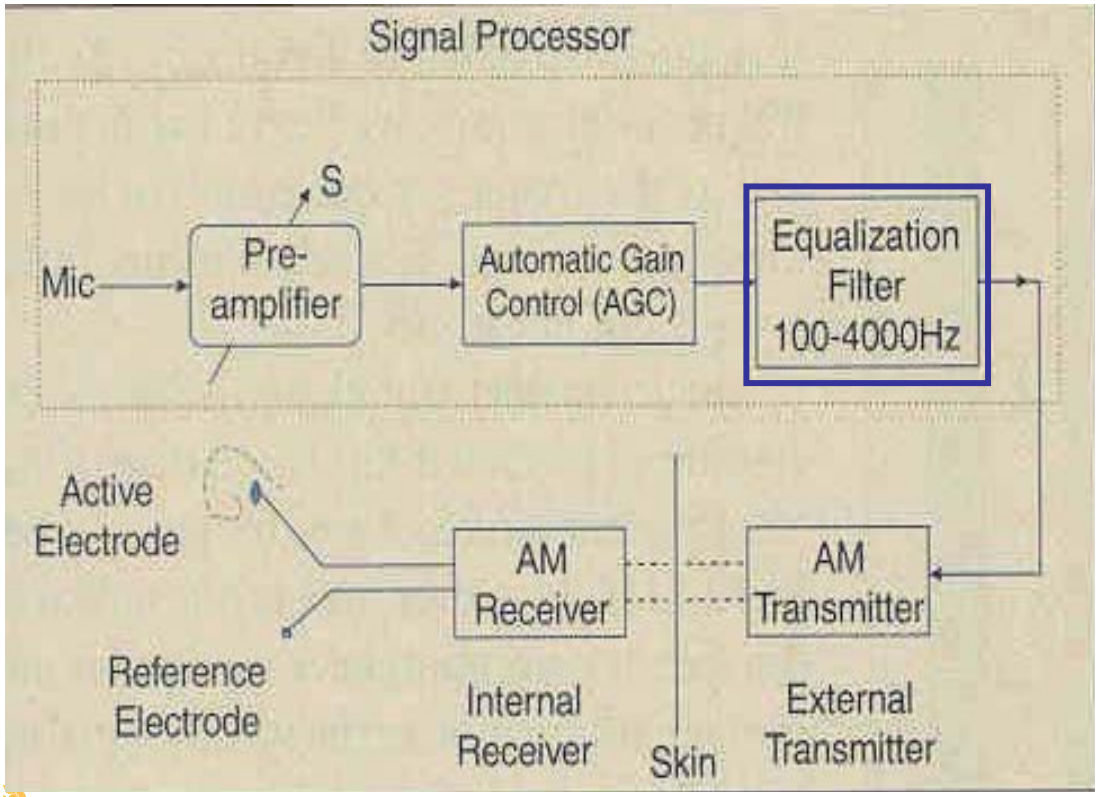
Temporal details in the speech signal may be distorted

Vienna/3M Device

Designed for

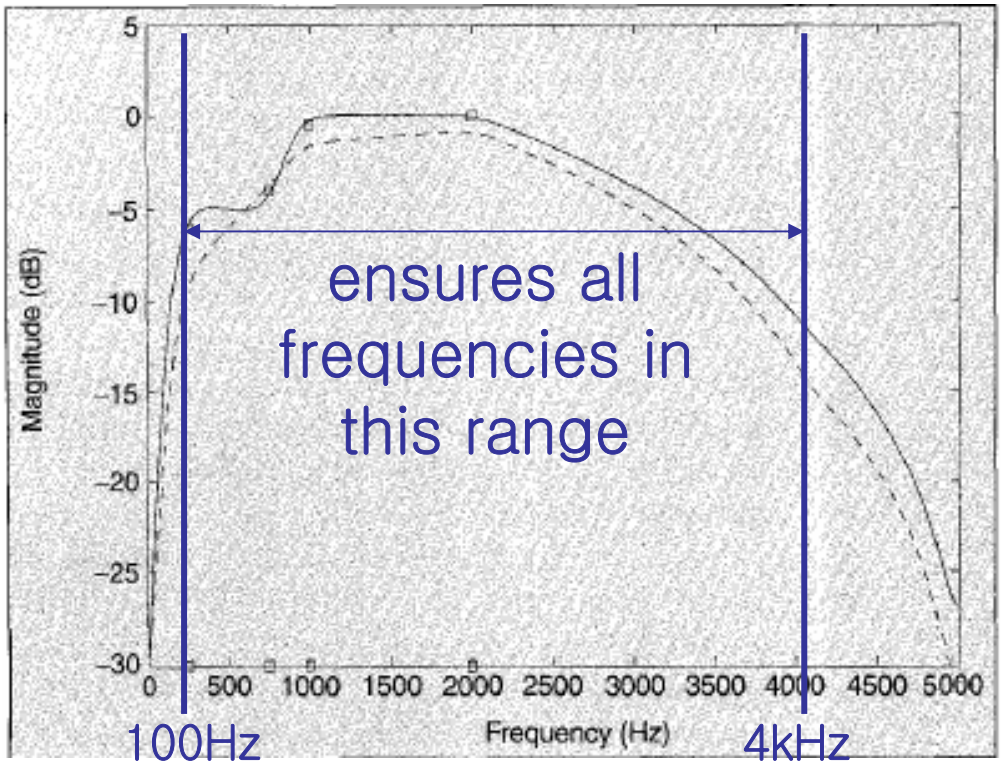
(1) the temporal details would be preserved

(2) 100-4,000 Hz would be audible to the patients.



Developed at the Technical University of Vienna, Austria. (early 1980s)

Vienna/3M Device



Equalization filter

low frequencies
- low electrical threshold
high frequencies
- high electrical threshold

After the filter
- Sound with frequencies in the range of 100 Hz to 4 kHz is **equally** loud

Speech Perception **Using Single-Channel Implants**

- **conveying time/envelope information and some frequency Information**

- f1, f2 (voiced sound, prosody)

- **transmitted frequency information is limited and insufficient for speech recognition**

- does not exploit '*place code mechanism*'
- single nerve restricted to **1kHz**
- there is important information up to **4kHz and beyond**

Multi-channel Implants

- Compressed-Analog (CA) Approach

- Continuous Interleaved Sampling (CIS) Approach

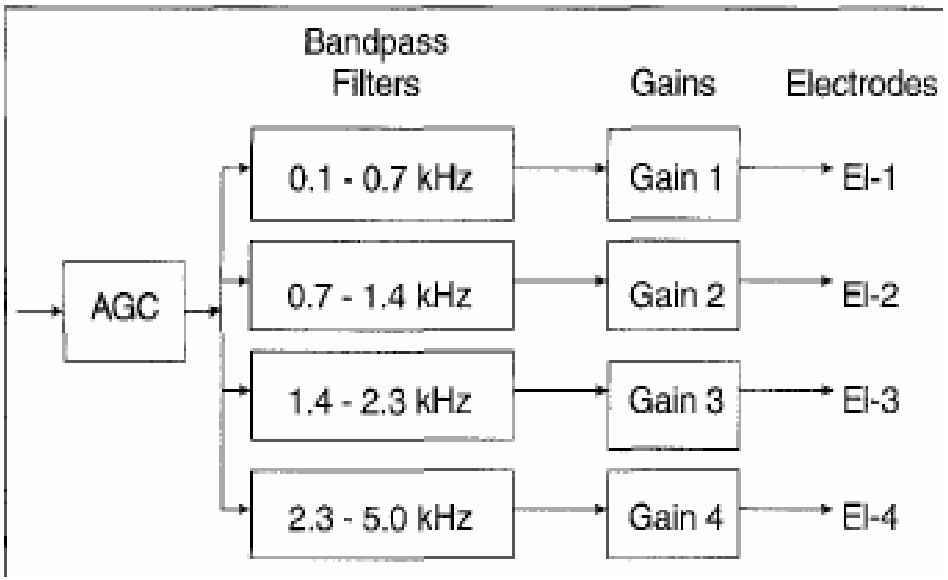
- Nucleus Multi-Electrode Implant

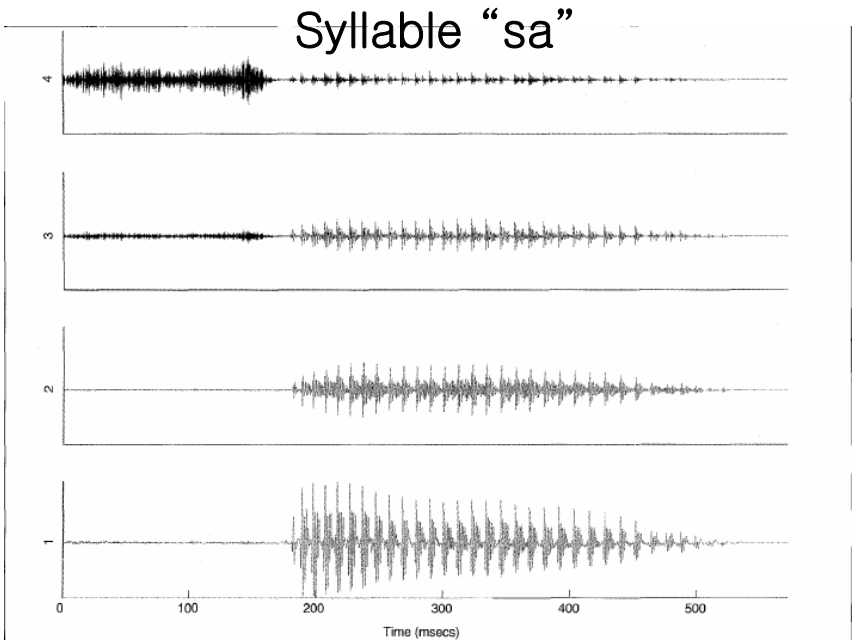
Multi-channel Implants

- How many electrodes should be used ?
- What kind of information should be transmitted to each electrode?

CA Approach

- **Ineraid** device manufactured by **Symbion, Inc., Utah**

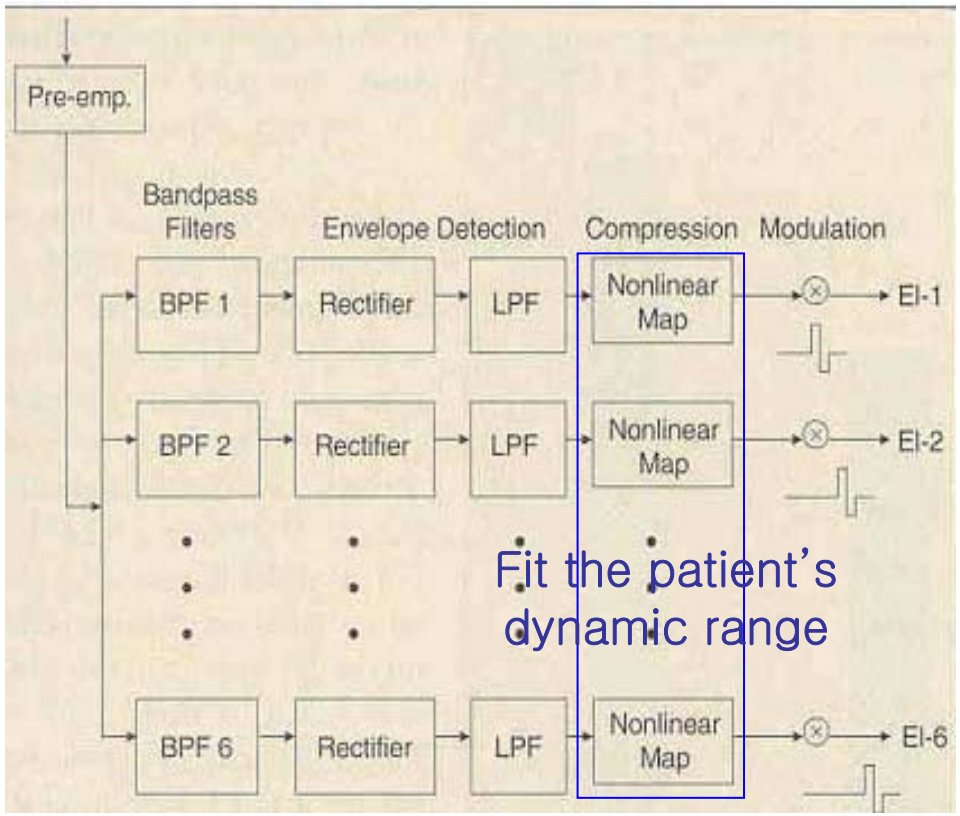




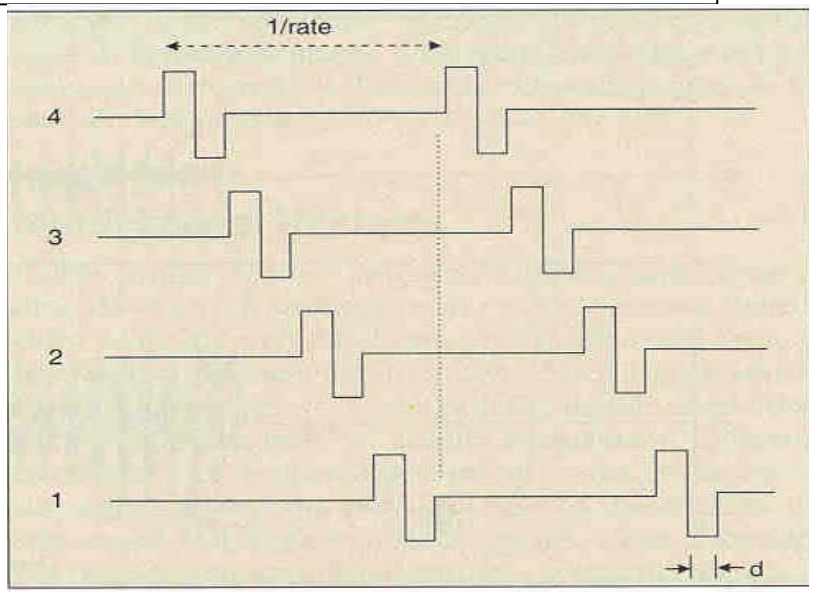
- **It enabled** many patients to obtain **open-set speech** understanding (Dorman et al.)

CIS Approach

CA approach : delivers four wave **simultaneously** -> **interaction** between channels -> **distort speech spectrum information**



Fit the patient's dynamic range

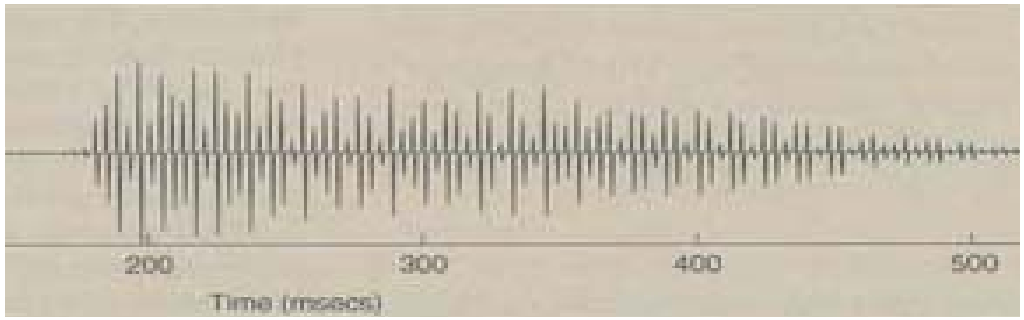


Non-sinusoidal

Interleaved pulse

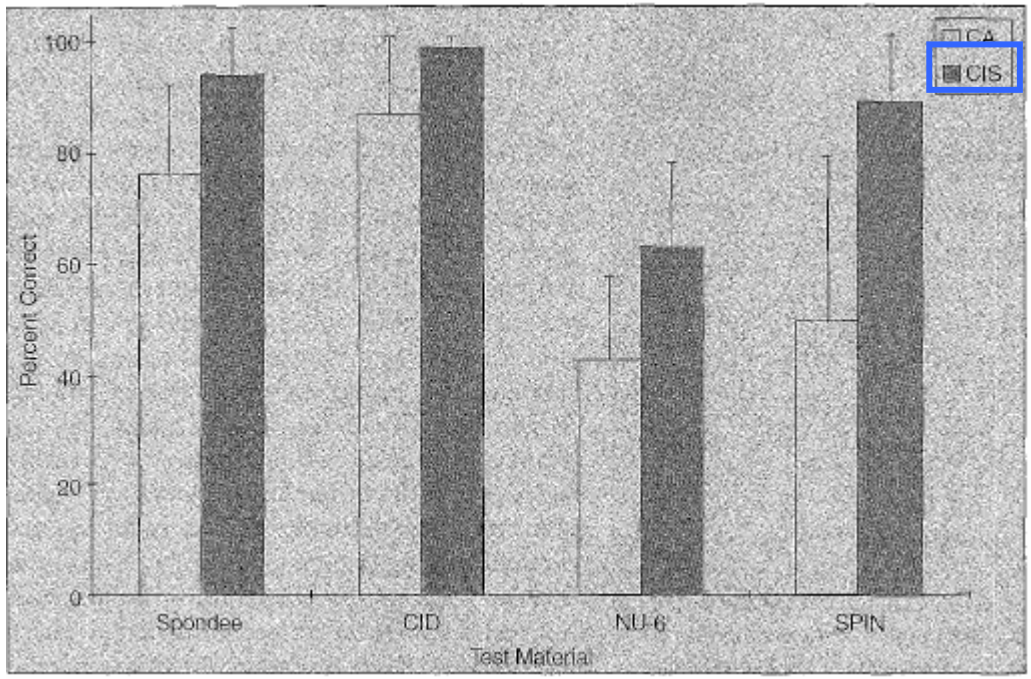
Researchers at the Research Triangle Institute (RTI)

CIS Approach



High pulse-rate stimulation typically yields better performance than low pulse-rate stimulation

the mean scores obtained with the CIS processor were significantly '**higher**' than the CA approach



Comparison between CA and CIS approach

CIS Approach

- **Several factors for the success of the CIS approach**

(1) use of **non-simultaneous stimulation** that minimizes channel interaction

(2) use of **six channels** rather than four

(3) representation of rapid envelope variations with the **use of high pulse-rate stimulation**.

- **CIS approach is currently being used** in

- Clarion device, Med-El device, new Nucleus CI24M device and Neurobiosys device(Fig.1)

Fig.1

CIS Approach ***(CIS parameters)***

- **Pulse rate and pulse duration**.
- **Stimulation order.**

- apex-to-base order (1-2-3-4-5-6)
- “staggered” order (6-3-5-2-4-1)

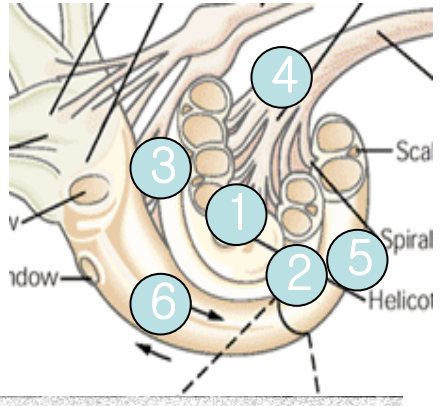
- **Compression function**.

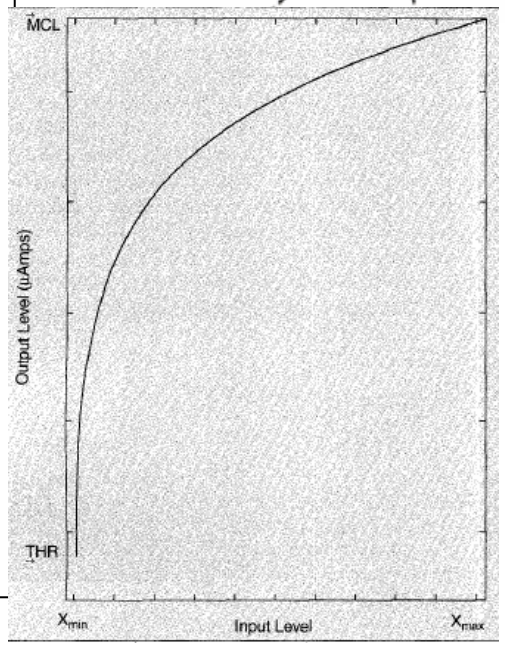
Y = A log(x) + B

$$A = \frac{MCL - THR}{x_{max}^{p} - x_{min}^{p}}$$

T

M $B = THR - Ax_{min}^{p}$ le level





Example of a logarithmic compression map