An Introduction to Cochlear Implant Working

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Abstract— A cochlear implant is a small, complex electronic device that can help to provide a sense of sound to a person who is profoundly deaf or severely hard-of-hearing.
A cochlear implant is very different from a hearing aid. Hearing aids amplify sounds so they may be detected by damaged ears. Cochlear implants bypass damaged portions of the ear and directly stimulate the auditory nerve. Signals generated by the implant are sent by way of the auditory nerve to the brain, which recognizes the signals as sound. Hearing through a cochlear implant is different from normal hearing and takes time to learn or relearn. However, it allows many people to recognize warning signals, understand other sounds in the environment, and understand speech in person or over the telephone. This paper emphasizes on the working of cochlear implant.

Key words: Cochlea, Cochlear implant, Compressed-Analogue (CA) Approach, Continuous Interleaved Sampling (CIS) Approach

I. INTRODUCTION

It is estimated that 250 million people have disabling hearing impairment, i.e. moderate to severe hearing loss, representing 4.3% of the world's population. Deafness has many causes: congenital (the person is born with defects), middle ear infection, meningitis, drugs, noise exposure and old age being the most common. When only the middle ear is affected, but not severely, a simple amplifying hearing aid is enough to overcome the problem. If the middle ear is totally destroyed or there is a loss of hair cells from the cochlea, but the auditory nerve is still intact, then a cochlea implant may partially restore hearing.

II. COCHLEAR ANATOMY AND MECHANICS

A. *Anatomy of the Human Ear*

The human ear consists of three parts: the outer ear, the middle ear and the inner ear,as shown in Fig 1

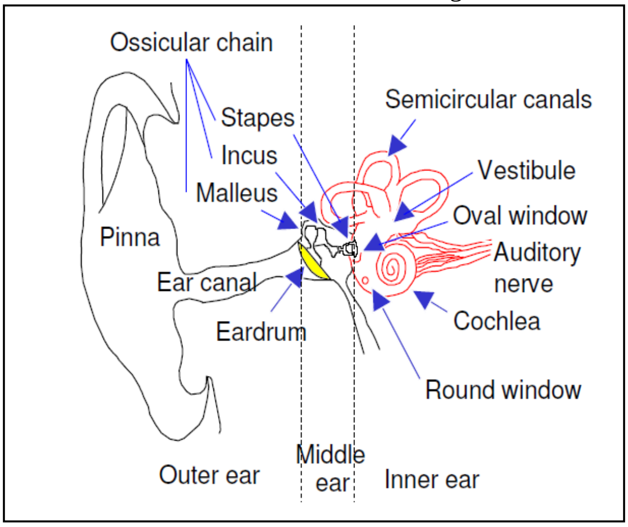

Fig. 1: Anatomy of human ear

courtesy http://ses.library.usyd.edu.au/bitstreamr

A sound wave enters through the ear canal. When it reaches the eardrum, it is converted to mechanical vibrations and transmitted to the oval window of the cochlea through a series of small bones called the ossicular chain in the middle ear. The movement of the oval window produces fluid pressure waves inside the cochlea. As the wave travels down the cochlea, its wavelength and amplitude change because of the gradient in the stiffness of the basilar membrane, which separates the cochlea into two chambers along its length. The wave reaches its maximum amplitude at a point which is determined by the frequency of the sound wave. Vibration of the basilar membrane causes the hair cells of the Organ of Corti to generate nerve signals, which the brain perceives as hearing.

1) *The Outer Ear*

The outer ear consists of the pinna and the ear canal. As the sound wave reaches the pinna and travels through the ear canal, its sound pressure is altered depending on its frequency and the location of the sound source, by being reflected at the pinna and resonated at the ear canal. Its main function is to be an auditory filter to provide cues for localising a sound source, as well as protecting the eardrum from the environment.

2) *The Middle Ear*

The middle ear is an air-filled cavity inside the skull. Three small bones called the Malleus, the Incus and the Stapes, which forms a chain called the ossicular chain, are suspended in the cavity by small muscles. The ossicular chain transfers vibrations at the ear drum to the oval window of the cochlea.

3) *The Inner Ear*

The inner ear is a fluid-filled bony structure. It consists of the semicircular canals, the vestibule and the cochlea. The semicircular canals and the vestibule are responsible for sensing the orientation and movement of the head, whereas the function of the cochlea is to sense sound travelling through the outer and the middle ear.

4) *The Cochlea*

A cross section of the cochlea through its core is shown in Fig 2. The cochlea is a snail-shaped, fluid-filled duct, coiled into a little over 2.5 turns. When uncoiled, the total length of the human cochlea is 35mm with a diameter of 10mm at its basal end. The external bony covering is very thin in some animals such as the chinchilla, the guinea pig and the gerbil, which facilitates their use for cochlear research. The central bony core of the cochlea is called the modiolus, through which nerve fibres and blood vessels enter the Organ of Corti.

The cochlea is divided into three longitudinal channels by the basilar membrane, which continues from a spiralling bony shelf called the spiral lamina, and Reissner's membrane. Reissner's membrane is very flexible and has little effect on cochlear hydrodynamics. Its main function is to provide an ionic and potential barrier. The uppermost channel, between the bony wall and Reissner's membrane, is called the scala vestibuli. The lowermost channel, between the bony wall and the basilar membrane, is called the scala tympani. The channel between Reissner's membrane and the basilar membrane is called the scala media. The scala media is closed at the apical end of the cochlea, leaving an opening called the helicotrema that allows communication between the two outer scalae, namely, the scala vestibuli and the scala tympani. The cochlea has two openings to the middle ear cavity. The oval window, located in the wall of the scala vestibuli about 1 – 2 mm from the base, is connected to the stapes. The other opening, called the round window, is a hole in the bony wall over the scala tympani, and is covered by a thin flexible membrane. The scala vestibuli and the scala tympani are filled with perilymph. Perilymph is a fluid that is high in sodium and low in potassium, and is similar to the composition of extracellular fluid. On the other hand, the scala media is filled with endolymph, which is, in contrast, high in potassium and low in sodium, and resembles intracellular fluid. Also, the potential of the fluid in the scala media is higher by about 90mV than the fluid in the other two scalae. These ionic and potential differences are maintained by the cells at the outer wall of the scala media called the stria vascularis, shown in the detailed cross section of the cochlea in Fig 2. The scala media contains the sensory and supporting cells for converting sound-induced mechanical vibrations to neural responses. The collection of these cells is called the Organ of Corti, which sits upon the basilar membrane.

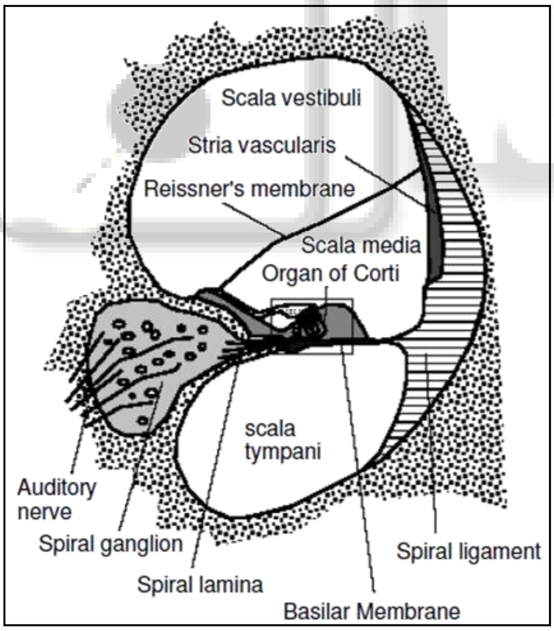

Fig 2: Detailed cross section of the cochlea. courtesy http://ses.library.usyd.edu.au/bitstreamr

B. *Hearing loss*

The bending movements of the hair cells in the vicinity of the basilar membrane are responsible for converting mechanical vibrations into electrical signals. If the hair cells are damaged, the auditory system is unable to properly convert sound into electrical impulses in the nerve. Because of this, the result is hearing impairment. Even if an audiogram looks "normal," there may be hearing loss if the person cannot understand spoken language. Simply, there is a broken link in the whole process. The acoustic wave is able to travel through the outer ear, middle ear and inner ear. However, the wave is unable to reach the auditory nerve and the brain because of the damaged hair cells. There are various types of diseases, drug treatments and other causes that contribute to degeneration in the hair cells. In majority of cases and most research, the common cause of hearing loss is damage to the hair cells, but not the auditory nerve. This problem has led to the development of cochlear implants. If a large number of hair cells of a particular person are damaged, the person is diagnosed as having a profound hearing loss.

III. COCHLEAR IMPLANT WORKING

Cochlear implants have been developed over the years to provide partial hearing to people with a severe to profound hearing loss. Fig 3 shows a diagram of a typical cochlear implant A cochlear implant system ('bionic ear') consists of a microphone, speech processor and transmitting coil worn behind the ear in the later devices, or with the speech processor in a pocket in earlier devices. Implanted in the mastoid bone behind the ear is a receiving coil. This is connected to a demultiplexer and in turn to a 22 electrode lead that is inserted into the inner ear (cochlea) (Fig 3 Fig 4).

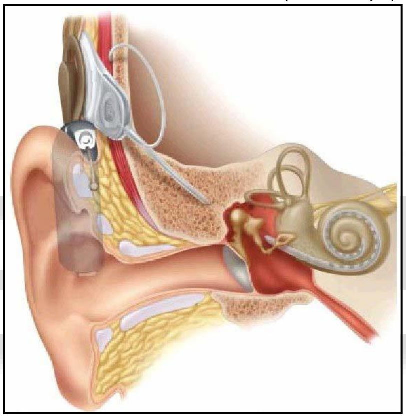

Fig. 3: Model of cochlear Implant Image courtesy of Cochlear Ltd.

Fig. 4: Cochlear Implant image courtesy of Cochlear Ltd.

A. *How the cochlear implant system works*

1) Sound is picked up by a directional microphone.
2) Sound is sent from the microphone to the speech processor.
3) The speech processor analyses and digitises the sound into coded signals.
4) Coded signals are sent to the transmitter via radio frequency.

5) The transmitter sends the code across the skin to the internal implant.
6) The internal implant converts the code to electrical signals.
7) The signals are sent to the electrodes to stimulate the remaining nerve fibres.
8) The signals are recognized as sounds by the brain, producing a hearing sensation.

Several cochlear implant devices have been developed over the years. All the implant devices have the following features in common: a microphone that picks up the sound, a signal processor that converts the sound into electrical signals, a transmission system that transmits the electrical signals to the implanted electrodes and an electrode or an electrode array (consisting of multiple electrodes) that is inserted into the cochlea by a surgeon. In single-channel implants only one electrode is used. In multichannel cochlear implants, an electrode array is inserted in the cochlea so that different auditory nerve fibers can be stimulated at different places in the cochlea, thereby exploiting the place mechanism for coding frequencies. Different electrodes are stimulated depending on the frequency of the signal. Electrodes near the base of the cochlea are stimulated with high frequency signals, while electrodes near the apex are stimulated with low frequency signals. The signal processor is responsible for breaking the input signal into different frequency bands or channels and delivering the filtered signals to the appropriate electrodes.

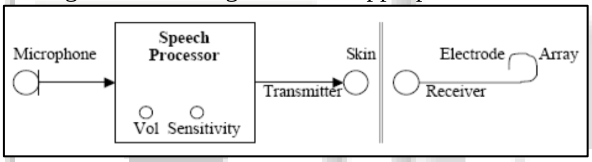

Fig 5. : Components of cochlear implant system image courtesy of Cochlear Ltd

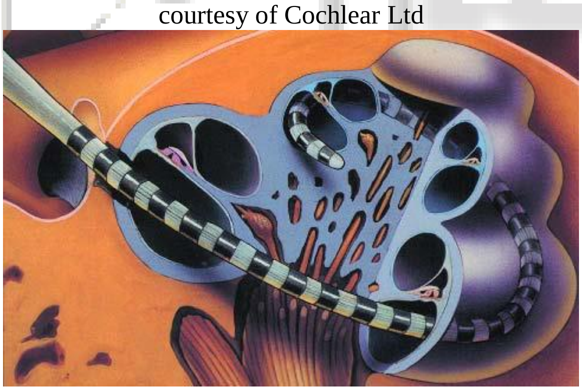

Fig. 6: Straight electrode array inserted in the cochlea (artist’s impression); image courtesy of Cochlear Ltd.

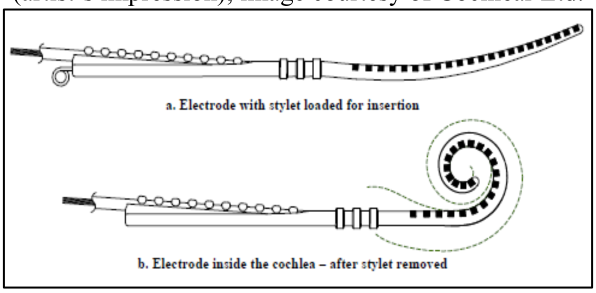

Fig 7: Pre-curved electrode array(a) Electrode with stylet loaded for insertion (b)Electrode inside the cochlea-after stylet removed image courtesy of Cochlear Ltd.

B. *Waveform strategies*

Development of the speech processor encoding the signal before it is transmitted through the skin has been one of the most challenging parts of the device. The physiology of speech is not fully understood and discoveries made by continual research experiments in patients have meant that the speech processors are in a constant state of flux with many different techniques being used. The number of active electrodes has varied between different manufacturers and has ranged from 1 to 4 to 6 and to 22 in the case of the Cochlear device.

1) *Compressed-Analogue (CA) Approach*

The Ineraid device, manufactured by Symbion Inc. used the Compressed-Analogue (CA) approach in its speech processor (Fig 8). The signals were retained in analogue form from the microphone through all the processing until they were delivered to the electrodes in the cochlea. This is in contrast to the Cochlear device in which all processing and delivery to the cochlea electrodes was in digital format. This is in contrast to the Cochlear device in which all processing and delivery to the cochlea electrodes was in digital format

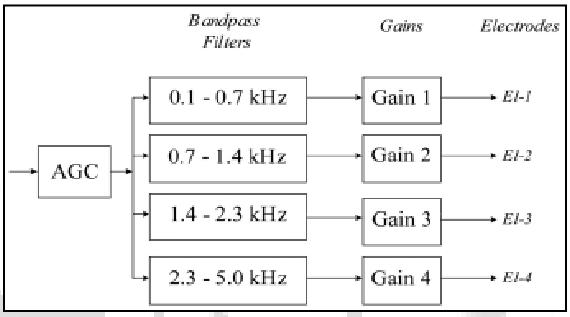

Fig. 8: Compressed Analogue (CA) Approach.

The signal is first compressed using an automatic gain control and then filtered into four contiguous frequency bands, with centre frequencies at 0.5, 1, 2 and 3.4 kHz. The filtered waveforms than go through adjustable gain amplifiers and are then sent directly through a percutaneous connector (one that pierces the skin) to four intracochlear electrodes, where they are delivered simultaneously. The electrodes are 4 mm apart and operate in monopolar configuration. (Fig.9) shows an example of the signals carried by the four channels for the syllable “sa”.

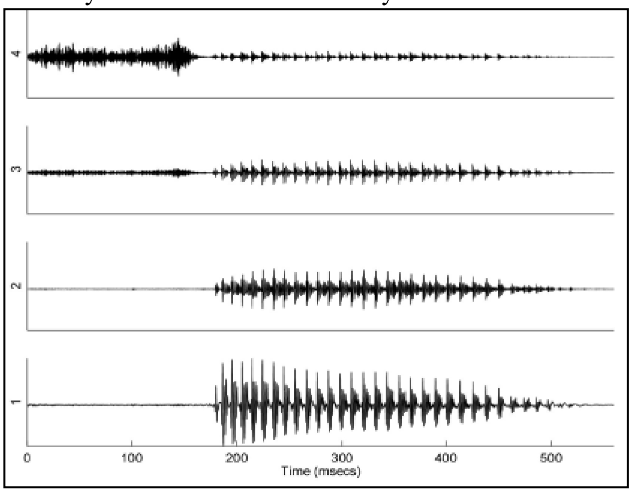

Fig. 9: Bandpassed waveforms of the syllable “sa” produced by a simplified implementation of the compressed analogue approach.

2) Continuous Interleaved Sampling (CIS) Approach

One of the problems with the CA approach is that there is a spread of electric fields and resulting interaction between channels, degrading speech perception. The CIS approach, developed at the Research Triangle Institute, uses non-simultaneous interleaved biphasic pulses delivered in trains so that only one electrode is stimulated at a time (Fig 10). The amplitudes of the pulses are derived from the envelopes of the bandpassed waveforms.

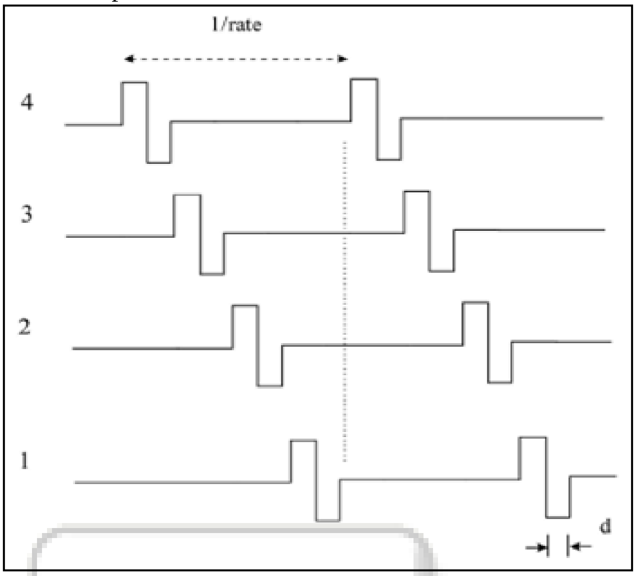

Fig. 10: Continuous Interleaved Sampling (CIS) Approach.

The signal is first pre-emphasised (Fig 11), and then passed through a bank of bandpass filters. The envelopes of the filtered waveforms are extracted by full-wave rectification and low-pass filtering (typically with 200 or 400 Hz cut-off frequency). The envelopes are then compressed with a non-linear function, usually logarithmic, to fit the patient's dynamic hearing range, and the output is used to amplitude modulate the trains of charge-balanced biphasic pulses delivered to the cochlear electrodes. The pulses are delivered at a constant rate, in a non-overlapping fashion (Fig10). The lack of overlap ensures that the electric fields at the electrodes also do not overlap so that there is no cross-modulation between electrodes. The rate at which the pulses are delivered to the electrodes has been found to have a major impact on speech recognition. High pulse-rate stimulation typically yields better performance than low pulse-rate stimulation. Several studies have shown that the CIS strategy is superior to the CA approach in terms of speech recognition by patients. Parameters that can be varied to optimise hearing for individual patients in the CIS strategy include the pulse rate and pulse duration, stimulation order (of channels) and the compression function.

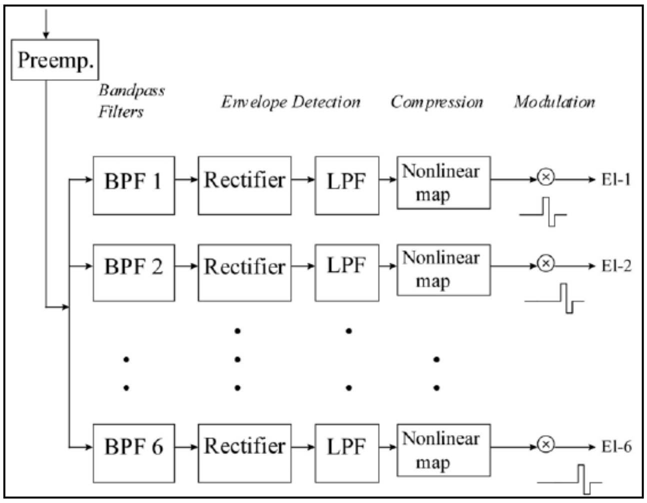

Fig. 11: Block diagram of CIS strategy.

An example of the pulsatile waveforms produced for the syllable "sa" using a simplified CIS strategy is shown in Fig 12.

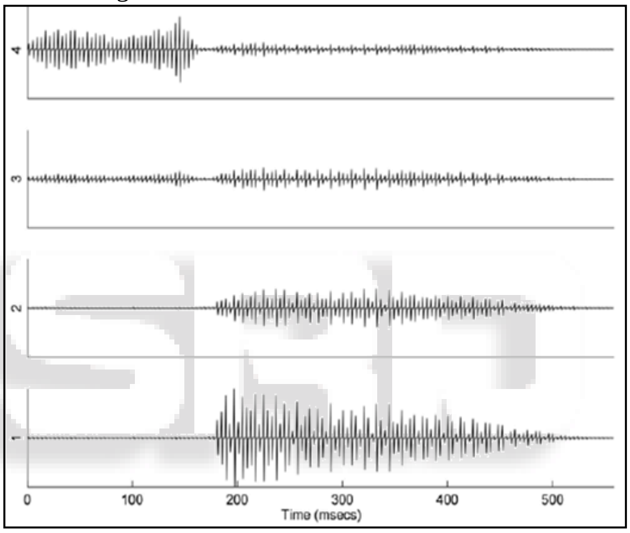

Fig. 12: Pulsatile waveforms of the syllable "sa" produced by a simplified implementation of the CIS strategy using a four-channel implant. The pulse amplitudes reflect the envelopes of the bandpass outputs for each channel. The pulsatile waveforms are shown prior to compression.

IV. CONCLUSION

The expectations of how well a cochlear implant will help someone hear have to be addressed prior to implantation, as although the device can help the person hear better and detect environmental sounds, it is not as good as the quality of sound processed by a natural cochlea and therefore will not restore hearing to normal levels. However it can be a significant improvement for the person in comparison to any previously tried hearing aids. Generally speaking if the person being implanted has lost their hearing after they have learnt language, cochlear implants can be a great help, in particular for people who have recently lost their hearing.

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