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FPGA Implementation of a Cochlear Implant Using Phased Array Stimulation with an Electrode Weighting Scheme

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THESIS PROPOSAL

Contents

Chapter 1

Introduction

1.1 Research Questions

1) Can the implementation of the electrode weighting scheme be implemented digitally in "MyHDL" hardware description language simulating it's operation?

2) Can this be synthesized and implemented on an FPGA, driven by a CP900 processor?

1.2 Scope

Chapter 2

Literature Review

2.1 Cochlear Implant Stimulation

2.1.1 Normal Hearing and Deafness

Sound undergoes a series of transformations as it travels though the human ear, consisting of the outer, middle and inner ear then through the auditory nerve and into the brain. The outer ear captures acoustic pressure waves which are subsequently converted to mechanical vibrations via the middle ear. Once passing through to the inner the, the cochlea, a snail-shaped cavity filled with fluid, transforms these vibrations in such a way that it leads to the displacement of the basilar membrane. Attached to this membrane are hair cells that are bent according to the respective change in displacement of the membrane, causing a release in an electrochemical substance causing neurons to fire, signaling the excitation of a particular section of the inner ear. Thus, these neurons communicate with systems in the brain and transmit the acoustic signal information[3]. If these hair cells are damaged, the auditory system has no way of transforming the acoustic pressure to neural impulses, leading to a hearing impairment. However, the neurons can still be excited directly through electrical stimulation, thus a purpose for the Cochlear Implant.

Multiple cochlear implants have been developed over the years with all implant devices having the following features: a microphone to capture sound, a signal processor to convert the sound into electrical signals, a transmission system that transmits these signals to the electrode array inserted inside the cochlea [3]. The electrodes can be stimulated in many ways, some are outlined in this review.

2.1.2 Monopolar Stimulation

In today's cochlear implant (CI) systems, monopolar (MP) electrode stimulation is predominantly used. In this method of stimulation, current flows between an intra-cochlear electrode (ICE), known as the active electrode and one or more extra-cochlear electrodes (ECE), known as the reference electrode. In monopolar stimulation mode, channels are defined respectively to the active electrode. Thus, *channel one* is defined as the first electrode in the array. When applying stimulation to this channel, this means applying a current between the first electrode and its corresponding reference electrode [5]. In challenging situations, such as listening to a talker in the presence of multiple competing voices, there can be large performance gaps between CI and normal acoustic hearing. It has previously been demonstrated that the speech understanding with a CI improves with an increasing number of electrodes until approximately 7-8, where speech-in-noise performance saturates [1]. A potential cause of the saturation in CI speech-in-noise performance at this electrode number, may be the spread of excitation from the relatively broad current flow produced by the monopolar stimulation modes used in clinical CIs. This current spread may lead to large overlaps in the neural excitation patterns elicted by nearby electrodes, limiting the number of effective channels and spectral resolution. Reducing the spread of excitation is advantageous as it reduces interference with other channels.

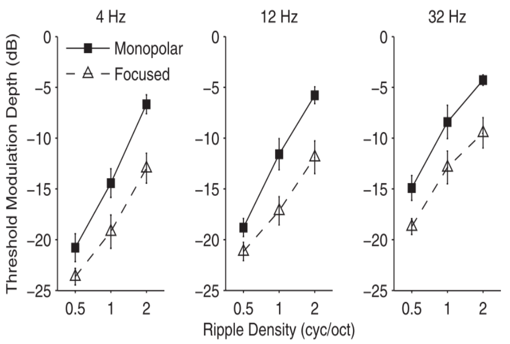
2.1.3 Multipolar Stimulation

Multipolar stimulation, also referred to as phased array stimulation or all-polar (AP) stimulation uses most, if not all, of the electrodes in the array to deliver stimulation to the recipients cochlea incorporating an optimised weighting unit to minimize simultaneous channel interactions. In this mode, each channel calls for electric current to be applied to one of the active electrodes in varying proportions[5].A main limitation of the CI is the spread of current induced by each intra-cochlear electrode: thus each electrode may activate an inappropriately large range of sensory neurons, cause uncontrolled loudness and spectral shape distortions. This limits the ability to simultaneously present spectral or temporal information at more than once cochlear site[2].Thus, multipolar stimulation is advantageous due to that it incorporates multiple current sources which could potentially reduce the spread of excitation.

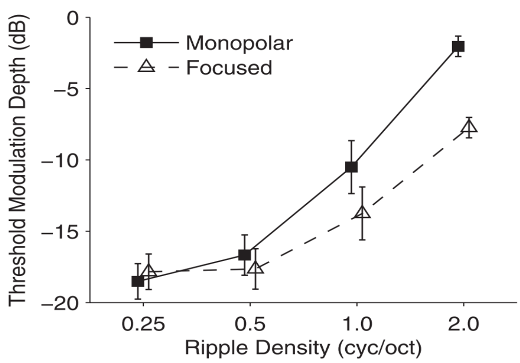
2.1.4 Spectral Resolution

Psychophysical results show that current focusing significantly improves subjects' ability to discriminate spectral features, suggesting that focused multipolar stimulation can increase the number of effective channels with a cochlear implant. A study was conducted that compared monopolar stimulation versus focused stimulation, using multipolar channels, to test if current focusing can increase spectral resolution. In this study, two experiments were conducted to provide information on the comparison on these two channel configurations. The first experiment involved spectral ripple stimuli used to measure spectral ripple phase discrimination thresholds. These stimuli had a bandwidth ranging between (120-7680 Hz), covering the full input frequency range of CI processing. Four ripple densities were tested: 0.25, 0.5, 1.0, 2.0 cycles/octave. The second experiment involved, dynamic ripple stimuli being used to measure spectrotemporal modulation[4].

Stimulation levels for the different CI maps were set for each channel configuration separately, mapped to the appropriate threshold (T) current levels and comfort (C) current levels. For analysis, modulation depth is 0 dB for a fully modulated signal and increasingly negative for smaller modulations.



(a) Dynamic Ripple Detection Threshold [4]



(b) Spectral Ripple Phase Threshold [4]

Discuss these results

2.2 Electrode Weighting Unit

In current hearing protheses, the command module determines the magnitudes of current to apply to each respective electrode in order to achieve appropriate stimulation on the channel. This results in the command module transmitting a data word for each electrode array during multipolar stimulation, which potentially reduces the number of individual applications of current to a channel per unit of time; known as a pulse rate. A recent US Patent Application by inventor Brett Swanson of Cochlear Limited outlines a system and method of performing a weighting operation inside the stimulation module of a stimulation prosthesis, which ameliorates this problem. [5]. In accordance with this embodiment, a stimulation module includes a receiver that is configured for receiving stimulation data transmitted by the command module which includes a channel and amplitude value. It also includes weighting unit configured for calculating, based on the channel and amplitude value, a set of magnitudes and an arrangement of current-sources and switches configured for applying current to the array of electrodes based on the calculated set of magnitudes [5]. Thus, the stimulation module determines the individual electrodes and magnitudes of current to apply to each respective channel, thereby reducing the amount of data transmitted between the command and stimulation module per pulse, allowing for higher pulse rates.

Represented in Figure 2.2.1, is a simulation prothesis including the command and stimulation module. A typical command module includes such components as a processor, memory storage, and a RF interface. In this review, the focus command module of a cochlear implant system also contains at least one microphone to process an audio signal, working in conjunction with a particular sound coding strategy. In the cochlear implant system, the command module transmits information of a serial RF inductive data link, which in some cases also provides power to the stimulation module.

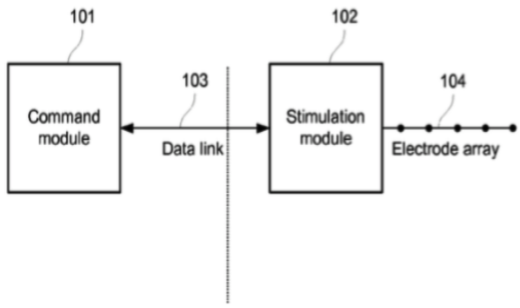


Figure 2.2.1: Command and Stimulation Module[5]

For brevity in this review, the current applied on a channel will be referred to as having an amplitude, whilst the current applied to an individual electrode will be referred to as having a magnitude.

Chapter 3

Methodology

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