AUDITORY SENSATION TO THE DEAFENEDPERSON USING COCHLEAR IMPLANT SYSTEM WITH COMPUTERIZED FPGA SPEECH/SOUND PROCESSING UNIT

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ABSTRACT:*In recent years, FPGAs (field-programmable gate arrays) have become increasingly attractive as sound/speech processing engines, sometimes used alone and sometimes in conjunction with a processor chip. When we detect sounds, or noise, our body is changing the energy in sound waves encoded into nerve impulses which the brain interprets as sound/speech. Sound Waves are produced when the air is mechanically disturbed. A cochlear implant system with Computerized FPGA based speech processing unit is a surgical implantable device which restores some hearing in severely-to-profoundly deaf people when the organ of Corti has not developed or is destroyed by disease or injury to such an extent no comparable hearing can be obtained with a hearing aid. This paper presents how the sound/speech signals processed by Computerized FPGA based speech processing unit and sends the processed information to the brain with implantable system for making auditory sensation.*

KEY WORDS: *Cochlear Implant, Speech/Sound processor, FPGA, Hearing Aids, Encoding.*

INTRODUCTION

The Cochlear Implant or Auditory Prosthesis is an electronic device that allows deaf and hard of hearing children and adults access to sound. “A cochlear implant is a surgically implanted electronic device that can help provide a sense of sound to a person who is profoundly deaf or severely hard of hearing.” The Auditory Prosthesis does not amplify sounds like a regular hearing aid however; it bypasses the damaged part of the inner ear, replacing it with electrodes, allowing the profoundly deaf individual access to sound.

When we hear a sound, this is what actually takes place: Sound Waves enter the ear canal and cause the eardrum to vibrate. Vibrations pass through three connected bones in the

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middle ear. This motion setsfluid moving in the inner ear. Moving fluid bends thousands of delicate hair-like cells which convert the vibrations into nerve impulses. Nerves impulses are carried to the brain by the auditory nerve. In the brain, these impulses are converted into what we "hear" as sound/speech as shown in Fig 1.

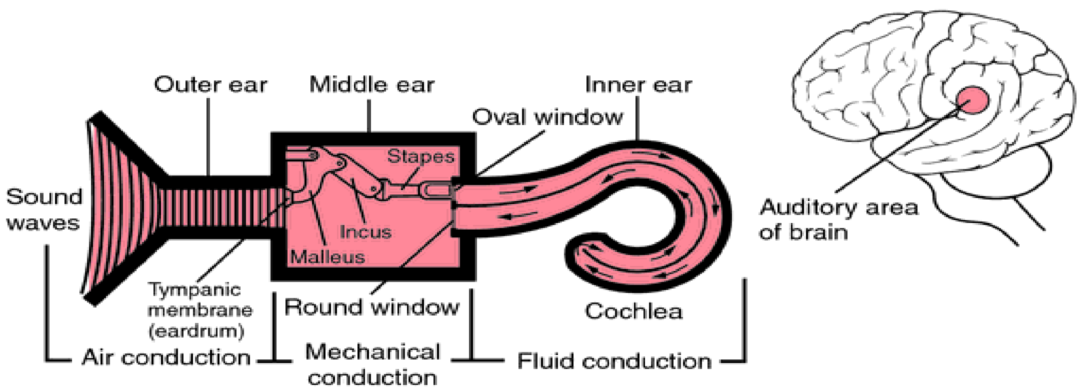

Fig 1: Block representation of ear with auditory portion of brain.

The Cochlear Implant System mainly comprises of external Body Worn Speech Processor **(BWSP)**, and internal Implantable Receiver Stimulator **(IRS)** with an electrode array as shown in Fig 2. BWSP receives an external sound or speech and generates encoded speech data bits for transmission to IRS via radio frequency transcutaneous link for exciting the electrode array by continuously executing speech/sound processing program embedded in BWSP. The IRS receives the ASK modulated encoded speech/sound information, demodulates the ASK signal, decodes the information and stimulates the selected electrode in the electrode array with the appropriate electric stimuli as bi-phasic current pulses by continuously executing decoded speech/sound and electrode stimulation program embedded in IRS to recognize the speech/sound by the deafened person.

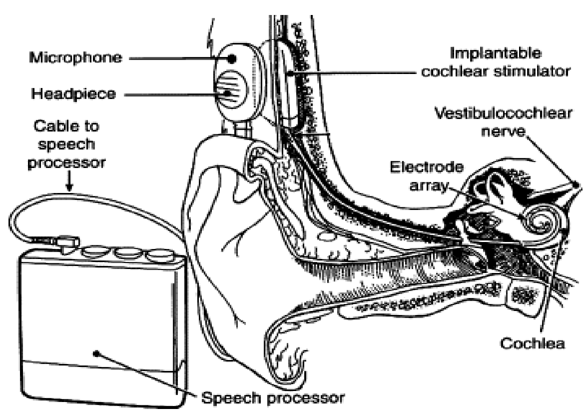

Fig 2: Block diagram of Speech Processor with Implantable Receiver stimulator

HARDWARE DESIGN

The Cochlear Implant system works by using the tonotopic organization of the basilar membrane, the basilar membrane within the cochlea of the inner ear is a stiff structural element that separates two liquid-filled tubes that run along the coil of the cochlea, the scala media and the scala tympani of the inner ear. "Tonotopic organization", also referred to as a "frequency-to-place" mapping, is the way the ear sorts out different frequencies so that our **brain** can process that information.The cochlear implant bypasses the hair cells and stimulates the cochlear nerves directly using electrical impulses. This allows the **brain** to interpret the frequency of sound as it would if the hair cells of the basilar membrane were functioning properly. The Cochlear Implant System primarily encompasses external components with implantable internal components as shown in fig 3.

External Components – the microphone, speech processor, transmitter and power supply are all parts of the external devices of the cochlear implant (Moore&Teagle, 2002).

Batteries – are the power supply for the cochlear implant. They can be either rechargeable or alkaline depending on the type of device that is used.

Cables – deliver the sound from the microphone to the speech processor

Coils – contain magnets that hold the implant to the head and transfer the signals from the speech processor via radio waves through the skin into the internal device.

Microphone – picks up the incoming signals.

Speech Processor – The speech processor is an electronic device using VLSI technology and to provide FPGA solution, that filters the input signal from the microphone and converts it into a series of electrical signals to be delivered to the internal device within the cochlea.

Internal Components – The Internal parts of the cochlear implant system are placed under the skin behind the ear (Chute & Nevins, 2002).

Channels – A channel is a single electrode (Christiansen & Leigh, 2002).

Electrodes – "Actively delivers the signal to the cochlear nerve endings"(Chute & Nevins, 2002).

Electrode positioning system – guides the electrodes into the cochlea (Advanced Bionics, 2000).

Internal electrode array – "Electrodes placed in pairs on a carrier wire and inserted into the cochlea." (Tye-Murray, 2004).

Internal receiver – part of the implant that is placed under the skin behind the ear that includes that magnet and antenna (Chute & Nevins,2002).

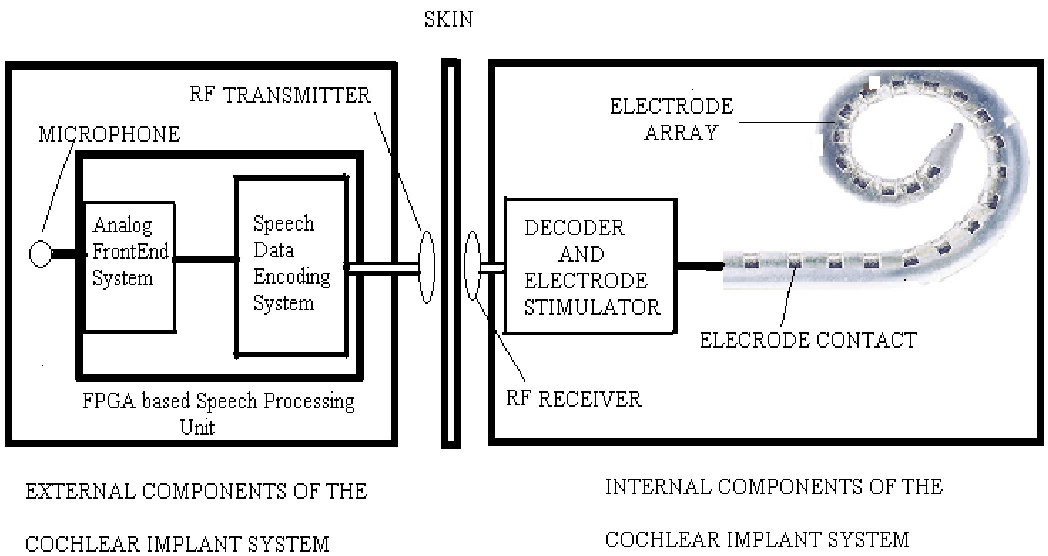

Fig 3: Simplified block diagram of Cochlear Implant System

The Xilinx spartan3 FPGA is used as the central processing system running at a rate of 326 MHz of core clock frequencyand Densities as high as 74,880 logic cells. Up to 1872 Kbits of total block RAM ,up to 520Kbits of distributed RAM, Three separate power supplies for the core (1.2V), IOs (1.2V to 3.3V), and Special function(2.5V) eliminating the need for power- consuming external RAM in auditory implant applications. The on-chip peripherals consist of SCI-a Serial Communications Interface, a parallel Host Interface, and a Timer Module and relevant control signals are used to access external memories, as well as the encoder in this application. The mode pin logic levels are automatically altered when the programming cable is connected to the processor. The designed prototype to product development model ofspeech processing design with FPGA architecture can accept speech or audio signals and transform into digital format and encode that speech information with data encoder for Radio Frequency Transmitting Antenna as shown in fig 4 for the Implantable Receiving Antenna for the human understandable processed speech or audio with an implantable auditory receiver-stimulator of 12 electrodes as shown in fig 5 for making the deaf person to understand the speech or audio tones.

SOFTWARE DESIGN

Several researchers proposed and attempt to develop a low-cost cochlear implant system but none of these products are available in the market.The development of cochlear implant system involves the strategies of mechanical engineering, physiology, electronics engineering and computer science and engineering.The FPGA based digital speech processing system software comprises of two important functional modules, namely Programmable Speech Processing modules and Speech Data Encoding modules shown in fig 6 and the programmable modules of Implantable Receiver Stimulator shown in Fig 7.These programming modules are implemented with the help of Verilog Hardware Description Language and of MATLAB Tools.

Fig 4: Prototype to Product Model of FPGA based Speech Processing System with RF Transmitting Coil.

Fig 5: Prototype to Product Model of Implantable Receiver Stimulator with RF Receiving Coil.

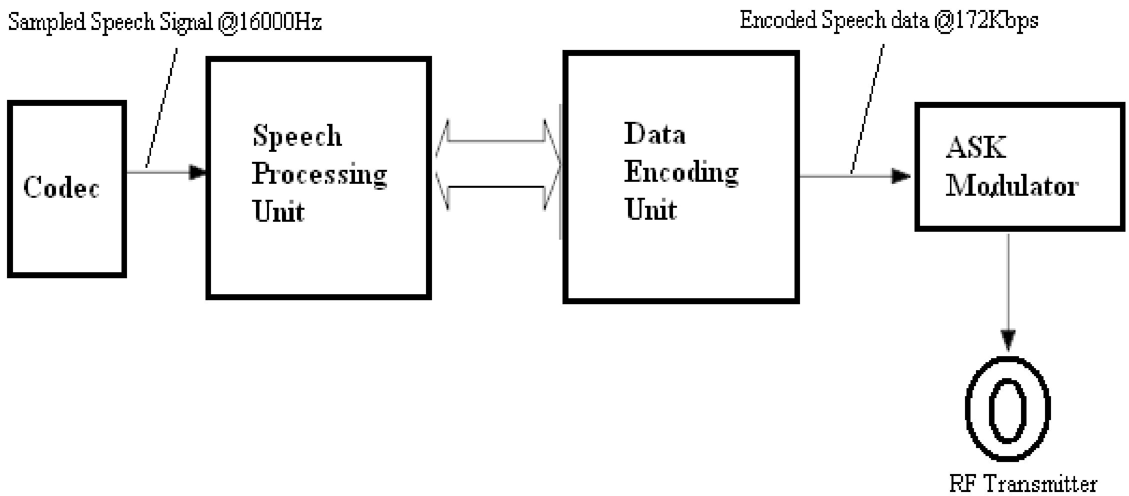

Fig 6: Programming Modules of FPGA based Digital Speech Processing System

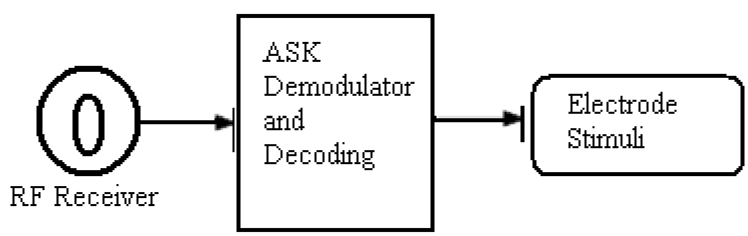

Fig 7: Programming Modules of Internal Implantable Receiver Stimulator

The Programmability of the speech processing system design described herein provides the means to develop and test 8 Channel CIS(Continuous Interleaved Sampling) speech processing algorithms with frequency bands (in Hz) shown in Table 1. It provides flexibility and programmability according to patient‘s active electrodes. By using the impedance telemetry and clinical programming software, the audiologist identifies the active electrodes and sends this information to the Speech Processing module via Speech Data Encoding module of Xilinx spartan3 FPGA device.

The encoding strategy is based on programming XC3S1500-4FG456C (Xilinx spartan3 FPGA), and is used to encode the compressed envelopes of each channel and send to the radio frequency transmitter where it transmits serially to the receiver-stimulator. The main role of encoding module is to receive all the electrodes information parallel, encodes it, and sends all electrodes information serially to the RF transmitter. The RF transmitter sends the data to receiver-stimulator circuit via transcutanious RF link where it is decoded and exited the corresponding electrode and sends information to brain with the help of auditory nerve system.

Table 1: 8-FIR BPF Frequency Bands for CIS Speech Processing Strategy

Channel Number	Lower Frequency	Upper Frequency	Center Frequency
1	200	315	255
2	315	495	400
3	495	779	640
4	779	1225	1000
5	1225	1927	1576
6	1927	3031	2479
7	3031	4768	3900
8	4768	7500	6130

RESULTS

A test program was run on FPGA based speech processor with core frequency at 326 MHz as the main processing unit, the ADC sampling rate at 16 kHz and the encoding module of FPGA formatting and transmitting two data frames via the RF coil. A 128th order FIR program containing 8 band-pass filters runs on Xilinx Spartan3 FPGA processing unit. The input symbol ―P to the speech processor is received from the microphone and observed in digital Scope Coder as shown in fig-8.

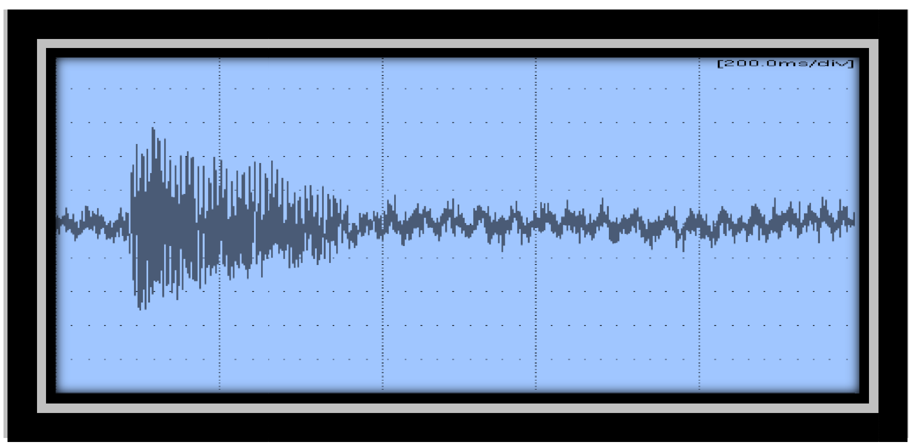

Fig 8: The input symbol 'P' to the microphone

The corresponding response from channels for the input symbol 'P' is observed as shown in fig-9. Since the sampling rate is fixed at 16 KHz, we get 16000 samples for every second (i.e. 16 samples for every 1ms). These samples are fed to the filter bank, containing 8 band pass filters with frequencies ranging from 200Hz to 7500Hz. Rectified signals are generated from each filter, which are then fed to the low pass filter with cutoff frequency of 200Hz for envelope outputs.

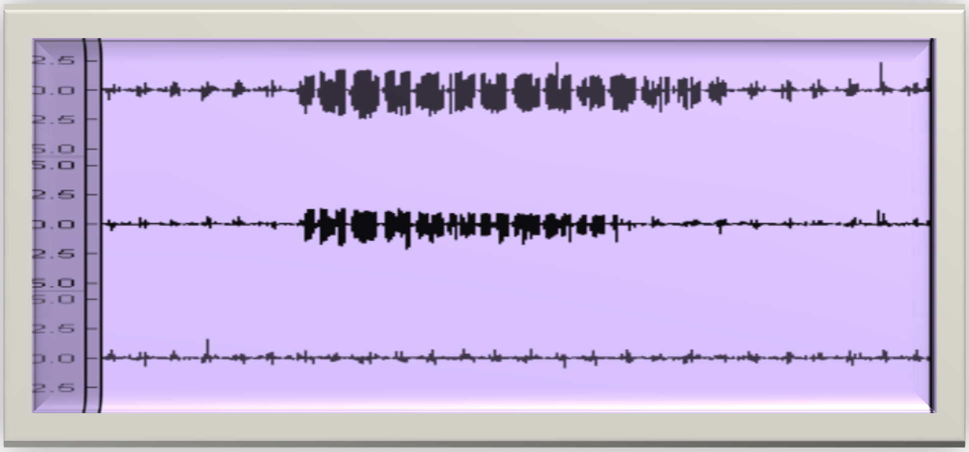

Fig 9: Channels Response for the input symbol ‘P’

CONCLUSIONS

The large electronic design automation (EDA) industry continually drives the development of FPGA test and verification tools. It does not have a comparable counterpart in the software development world. This may change, as the industry realizes the enormous costs and challenges in software verification, but for now, the practical software solution is to keep downloading the latest patch.However, it is certain that a patient getting a cochlear implant will have marked improvements in communicating with the others. He will be able to enjoy his life more with the 'sound life'.Cochlear implant is really a great invention. In the past, those who were suffering from sensorineural deafness had no hope to restore hearing except miracles. Now, cochlear implant technology is their miracle. It lets them get into the lovely hearing world. However, no matter how good the technology is, cochlear implant is still not better than normal ears. Therefore if we are lucky to have normal functioning ears, we should look after them carefully and treasure the ability to hear.

ACKNOWLEDGEMENTS

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