International Journal of Electrical and Electronics Research ISSN 2348-6988 (online)
Vol. 2, Issue 4, pp: (38-46), Month: October - December 2014, Available at: www.researchpublish.com

Implementation of Analog Inner Hair Cell and Auditory Nerve IC in Neuromorphic VLSI Using Non-Invasive Technique

[1]Dr.J.Raja, [2]Saranya.SA

[1]Proffessor, ECE Department, Adhiparasakthi Engineering College, Melmaruvathur,TN,India
[2]II M.E (VLSI Design), ECE Department, Adhiparasakthi Engineering College, Melmaruvathur,TN,India

Abstract: **An analog inner hair cell and auditory nerve IC has been implemented using non-invasive techniques. Differential topology is used to remove the reverberations caused. A fully-differential current-mode arechitecture is used and the ability to correct channel mismatch is evaluated with matched layouts as well as with digital current tuning. Current mode architecture is developed to avoid CMOS mismatch. Brain machine interface based on non-invasive technique is implemented. The designed IC is used for ultra-low power biomimetic system. Speech synthesis is used for speech recogniation in noisy environment.Neural activity is measured using Brain machine interface (EEG).**

Keywords: **Non-Invasive Technique, spectrogram, hearing aids, low power, speech recogniation, neuromrophic, fully differential topology, Very large scale integration (VLSI).**

I. INTRODUCTION

Neuromorphic that mimcs the design and implementation of micro systems that emulates the the structure and function of the brain. Recognition of audio cues in mammalian cochlea for hearing in profoundly deaf patients. Neuromorphic engineering is an interdisciplinary discipline that takes inspiration from biology, physics, mathematics, computer science and engineering to design artificial neural systems, the physical architecture and design principles of which are based on those of biological nervous systems. In neuromorphic engineering, technology and neuroscience cross-fertilize each other. The designed processor Can be used for next-generation implants will be fully implanted inside the body of the patient and consequently have very stringent requirements on the power consumption used for signal processing. This IC is intended for use in such next-generation implants. Neuromorphic improves the performance of artificial systems through the development of chips and systems that process information collectively using primarily analog circuits. This paper presents the central concepts required for the creative and successful design of analog VLSI circuits. The discussion is weighted toward novel circuits that emulate natural signal processing. Unlike most circuits in commercial or industrial applications, these circuits operate mainly in the sub-threshold or weak inversion region Moreover, their functionality is not limited to linear operations, but also encompasses many interesting nonlinear operations similar to those occurring in natural systems. It includes noise analysis, and process technology. The architecture they have designed works in a similar way to neurons and can therefore be used to test various ways of reproducing the brain's processing ability. In addition, they are significantly more energy efficient than conventional chips. This involves in neuroscience, medicine, and computing a new foundation, to explore and understand the brain and the neural acyivity of the disabled person, and to use that knowledge to build new computing technologies. For these auditory systems, portions of the mammalian cochlea are often implemented using analog very large scale integration (VLSI).

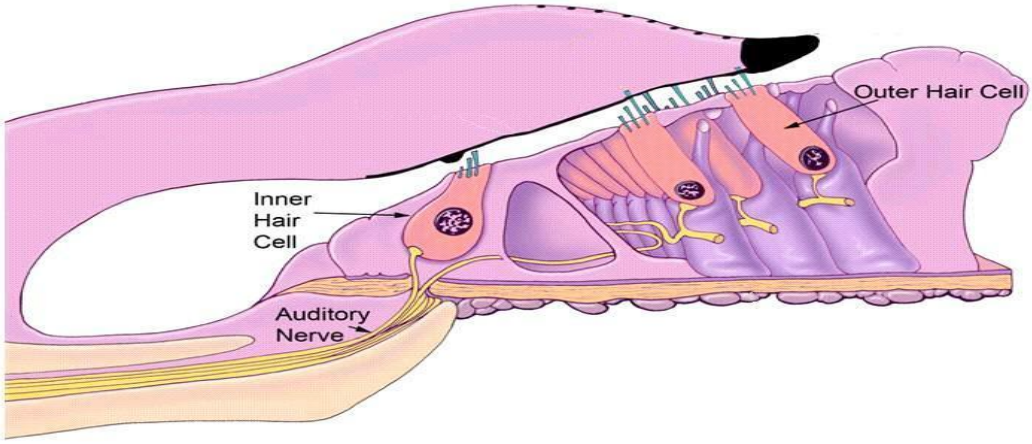

Figure 1: Human ear and inner hair cell (IHC) and Outer Hair Cell (OHC).The electrical impulses are sent to the auditory nerve. Mammalian cochlear hair cells come in two anatomically and functionally distinct types: the outer and inner hair cells. Damage to these hair cells results in decreased hearing sensitivity, i.e. sensorineural hearing loss.

The loss in ability to communicate is considered one of the most disabling condition.A major cause of why acquired hearing loss is permanent in mammals lies in the incapacity of the sensory cells (epithelia) of the inner ear to replace damaged mechanoreceptor cells, or **hair cells**. Sensory hair cells are mechanoreceptors that transduce fluid movements generated by sound into electrochemical **signals** interpretable by the brain. VLSI analog electronic circuits that implement or include the functionality of the Inner Hair Cell

(IHC) and Auditory Nerve's (AN) adaptation have targeted mostly monaural system and multi-binaural systems and ultra-low-power monaural systems. Usually, hearing loss that is called "sensorineural" or "nerve deafness" is actually caused by problems with the cochlea, instead of the actual auditory nerve, but a very small percentage of hearing loss is caused by problems with the nerve, itself,usually related to acoustic neuromas (tumors) on the nerve covering. The auditory nerve and the vestibular nerve, which carries balance information from the semicircular canals to the brain, join together as they pass through the bony canals of your skull. Together, they are called the 8th cranial nerve, or the Vestibulocochlear nerve. Also passing through the same bony canals of your skull is the 7th cranial nerve, or the facial nerve, which supports facial expression and sensation. It's interesting to note that while many of the nerve fibers in this bundle do carry the sound signal to the brain, most (some estimates are as much as 2 thirds) of the nerve fibers actually carry information BACK to the cochlea from the brain. The cochlea can then use this information to suppress sound you are not interested in like background noise. This explains why hearing aids (which amplify sounds) can help you hear better, but they do not completely correct a hearing loss.It also explains why one of the biggest problems that hard of hearing people face is the effect of background noise. Even the best hearing aid can only amplify sound; it can't converse with your brain and help your brain eliminate background noise the way a normal working ear can do.Brain machine interfaced with EEG aims for giving nois less resolution.Some hearing aids use multiple microphones to to (somewhat) suppress background noise by suppressing omni directional sound and enhancing sounds from the front of the wearer, and that works well but not nearly as well as your cochlea does by communicating with your brain over the auditory nerve.

In this paper, we present an analog IHC and AN (AIHCAN) integrated circuit (IC) for use in low-power monaural and mulitiple binaural acoustic applications. The biomimetic IHC and AN we choose to implement in non invasive technique. Brain-machine-interface-based speech prostheses usage in IHC and AN function is a potentially important component of a front-end preprocessor for use in neuromorphic systems that perform sound localization resulted by a spectrogram..The developed IHC and AN circuit uses an average power less than 6.9 mW and minimizing the area and can result in reduced CMOS mismatch. This capability makes fabrication of large AIHCAN circuits for use in embedded systems practical.

II. NON-INVASIVE TECHNIQUE

A medical procedure is strictly defined as non-invasive when no break in the skin is created and there is no contact with the skin break, or internal body cavity beyond a natural or artificial body orifice. For example, deep palpation and percussion is non-invasive but a rectal examination is invasive. Likewise, examination of the eardrum or inside the nose falls the definition of non-invasive procedure. There are many non-invasive procedures, ranging from simple observation, to specialized forms of surgery, such as radio surgery. BMIs based on electroencephalography (EEG) have been shown to give some sort of communication capability to the patients. Unfortunately, EEG systems use electrodes placed on the scalp to measure neural activity occurring deep inside the brain; as a consequence, the recorded information is noisy. BMIs based on functional magnetic resonance imaging (fMRI) overcome this problem because they can record neural activity occurring deep inside the brain with high spatial resolution. Currentlly, fMRI systems are large and impractical and cannot create a viable speech prosthesis. In addition fMRI measurements are inherently slow and, consequently, it is almost impossible to achieve real-time production of speech. Perhaps noise suppression algorithm is developed to degrade the background noise. The discovery of the first modern non-invasive techniques based on physical methods, electrocardiography and X-rays, dates back to the end of the 19th century. Since then, non-invasive methods which penetrate the body nonetheless, but by electromagnetic or particle radiation rather than a scalpel have continuously enlarged the scope of medical technology. Non-invasive techniques commonly used for diagnosis of hearing aids are MEG signals were first measured to reduce the magenetic background noise, covering most of the head. In this way, MEGs of a subject or patient can now be accumulated rapidly but is impractical. The EEG signals derive from the net effect of ionic currents flowing in the dendrites of neurons during synaptic transmission be thought of as current dipoles, i.e. currents with a position, orientation, and spatial extent.

Many patients with physiological disorders such as Amyotrophic Lateral Sclerosis (ALS) or injuries such as high-level spinal cord injury suffer from disruption of the communication path between the brain and the body. People with severe motor disabilities may lose much of their voluntary muscle control. The disabled people with the above mentioned problems are forced to accept a reduced quality of life, resulting in dependence on caretakers and escalating social costs. Most of the existing assistive technology devices for these patients are not usable because these devices are dependent on motor activities from specific parts of the body. Alternative control paradigms for these individuals are thus desirable. The electrophysiological signals generated from the brain can be used to command different devices, provided that the person who will control the device should also be able to control the generation of these signals. Studies showed that with sufficient training, people can control the generation of certain brain signals. Having generated these signals, they can be conditioned and processed to perform the specific work for which they are generated. In other words, the interface can be made able to adapt and understand the meaning of these signals and work accordingly. If this type of Brain-Machine Interface (BMI) is successfully implemented, they can be used in developing sophisticated assistive devices.

(such as, hearing machine) to help the people with distortionless signal. Previous works in development of BMI show that the signal acquisition and processing are getting complicated with the growing availability of more sophisticated recording devices. To overcome these complexities rather simple method is required to couple easily recordable neuronal signals with the neuromorphic micro devices.

1. Electroencephlography

BMI based EEG signals originate from the same neurophysiological processes, there are important differences. Electric fields are less distorted than magnetic fields by the skull and scalp, which results in a resolution with noise. Whereas this paper presents spectogrm image of the sound heared by the disabled person in scalp EEG is sensitive to both tangential and radial components of a current source in a spherical volume conductor, MEG detects only its tangential components. Scalp EEG can, therefore, detect activity both in the sulci and at the top of the corti, EEG is, therefore, sensitive to activity in more brain areas, but the neural activity of the brain resulted in Electroencephalography (EEG) is the recording of electrical activity along the scalp. EEG measures voltage fluctuations resulting from ionic current flows within the neurons of the brain. In clinical contexts, EEG refers to the recording of the brain's spontaneous electrical activity over a short period of time, usually 20–40 minutes, as recorded from multiple electrodes placed on the scalp. Diagnostic applications generally focus on the spectral content of EEG, that is, the type of neural oscillations that can be observed in EEG signals.

EEG is most often used to diagnose, in EEG readings but this use has decreased with the advent of high-resolution anatomical imaging techniques such as MRI and CT. Despite limited spatial resolution, EEG continues to be a valuable tool for research and diagnosis, especially when millisecond-range temporal resolution (not possible with CT or MRI) BMI with speech synthesis is required.

2. Neuromorphic Noiseattenuator

For speech enhancement, a neuromorphic noise attenuator is used to preserve speech and attenuate background noise depending on the characteristics of human hearing system and the onset feature of consonant. In addition, the neuromorphic noise attenuator also employs multiplication for time - domain gain smoothing to reduce the artificial noise problem of traditional spectral subtraction algorithm. Finally, considering the power limitation of the systems and the latency tolerance of user (about 10 ms 15 ms) the proposed algorithm is simplified to reduce the computational complexity is in process for futher work.

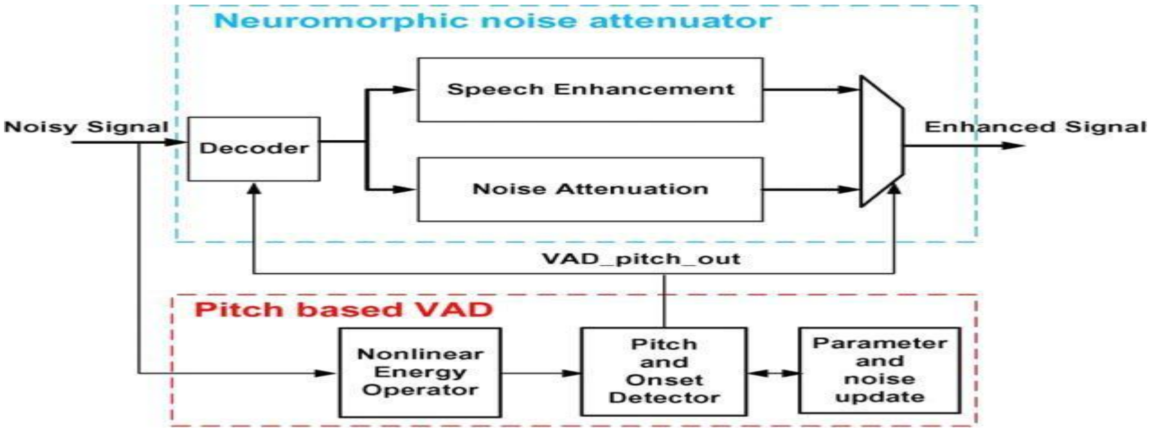

Figure 2: Neuromorphic Noise Attenuator

III. CURRENT MODE IMPLEMENTAION OF AIHCAN IC

A. Inner Hair Cell

In the biological cochlea, the inner hair cells transduce vibra-tion in the cochlea into a neural signal. This function is modeled by a novel inner hair cell circuit shown in Fig. 3. A transconduc-tance amplifier transforms the differential cochlear output into a single ended current, to which a dc offset may be added using V_I A cur-rent mirror rectifies the current signal before passing it through a low-pass filter. This half wave-rectified current is as a first ap-proximation given from the circuit.

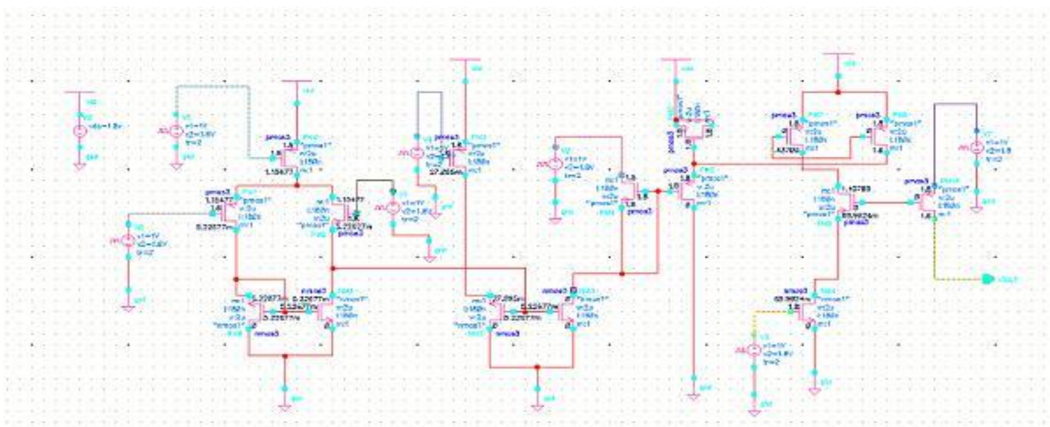

Figure 3. Inner Hair Cell Circuit

This half wave-rectified current is as a first approximation given by

$I_{HWR} = \max(0, gm(v_{c1}-v_{c2})+I_{OFF})$

where g_m is controlled by V_{ain} and I_{off} by $V_{I,off.}$ The bias currents I_0 and $2I_0$, respectively. C3, implemented as a pMOS capacitor, should have been implemented with an nMOS capacitor because the voltage is quite close to V_{dd} . Nonetheless, the circuit still operates cor-rectly as the voltage swing is small and the pMOS capacitor acts almost linearly. The cutoff was set around 1 kHz as in the real inner hair cell, modeling the reduction in phase-locking ob-served on real auditory nerves at frequencies greater than 1 kHz. The two control signals V_{ref} and V_{ref0} are slightly below V_{dd} to allow the two pMOS transistors providing $2I_0$ to operate in satu-ration. Any voltage difference between V_{ref} and V_{ref0} will show up as a current gain depending exponentially on this voltage difference. In the results shown in this paper, both voltages were equal to 4.5 V, resulting in a gain of 1.

The biological inner hair cell exhibits adaptation to an on-going stimulus, therefore it responds more strongly to the onset of stimulation than the sustained part of the stimulus and its response is suppressed temporarily after the offset of stimulation. This adaptation has been modeled in but it was considered too complex and too large for inclusion on the current chip. However, we intend to include this in future versions.

B. Dual AGC Model

The dual AGC model has been implemented on a variety of electronic platforms including computer software simulations, discrete analog electronics,DSPs using Analog Device's Tiger SHARCs, FPGAs, and digital ASICs. The current power envelopes of these platforms limit their usage in mobile applications where acoustic sensors can have the most impact. To overcome this power constraint, an analog VLSI inner hair cell and auditory nerve circuit, known as the AI-HCAN circuit, is implemented using current-mode CMOS circuits. The dual AGC model is transformed into the current do-main with the model constants K_1 and K_2 having analogous terms in the current domain and the time constants τ_{IHC} , τ_1 , and τ_2 taken directly from the dual AGC model. Instead of relying on the copious amounts of gain that voltage-mode circuits provide, we rely on the matching of CMOS current-mode circuits to implement low-power electronics with sufficient dynamic range despite today's low supply voltage technology. It should be stated that most current-mode IHC circuits, use weak inversion MOSFETs in log-domain filters to achieve large dynamic ranges and to perform translinear multiplication. Precisely because of the poor matching properties of weak inversion MOSFET's, which cannot be overcome with compensated layout techniques such as common centroid layouts, usage was kept to a minimum by only using weak inversion MOSFETs in the low-pass filter's operational transconductance amplifier (OTA). By focussing on current-mode CMOS circuits that are not operating in weak inversion, we primarily concern ourselves with the non-ideal current mirroring of CMOS transistors. This has the beneficial effect of allowing differential-mode circuit topology because we can rely on the higher degree of current mirroring as compared to weak inversion MOSFETs. By using a differential structure for the entire circuit, we can reject unwanted common-mode signals. No IHC and AN circuits to date have been reported to use a fully differential current-mode architecture.

The current mirror is the fundamental building block for most, if not all, current-mode circuits. Its precision determines many design requirements such as necessary power, required area, and interface types. Passive techniques to increase the precision of current mirroring can be accomplished via large transistor sizes.

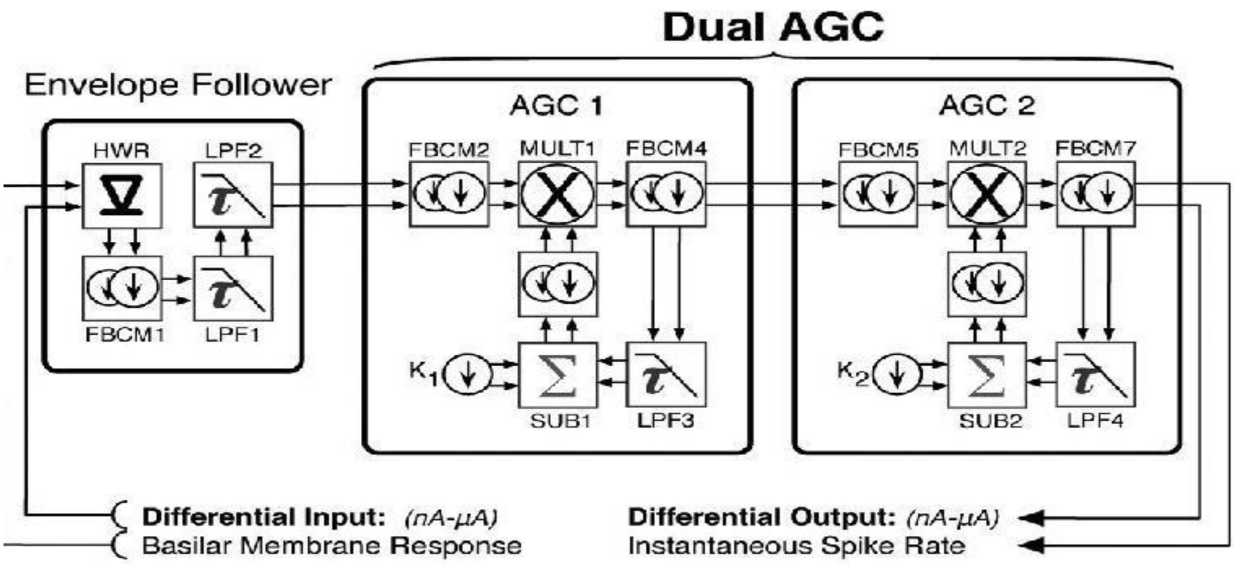

Figure 4. Fully Differential Dual AGC Current-Domain Circuit

The fully differential dual AGC current-domain circuit begins with an envelope follower that consists of a half-wave rectifier (HWR) that is buffered with a fully-balanced current mirror (FBCM). The buffered signal feeds two stages of low-pass filtering. Adaptation is performed in the dual AGC stage where both pre- and post- synaptic effects are replicated. Fully-balanced current mirrors (FBCM) provide impedance matching for the multiplier (MULT) and low-pass filter (LPF) circuits. Subtraction (SUB) circuits in the AGC provide a reference current level, K_1 or K_2 , from which the filtered feedback signal is compared.

C. Fully Balanced Current Mirror

The fully balanced current mirror (FBCM), shown in Fig. 4, is a general current-mode building block that does not require voltage-mode op- amps for high linearity, which makes it useful for current-mode signal processing. The FBCM, by Karl makes a small modification to the differential current mirror by Zele *et al.* Specifically, the source connections of M_3 and M_{10} , which were connected to constant current bias sources in, were replaced with mirrored signal currents. For the positive half, current is mirrored from M_6 through M_4 to M_7. For the negative half, current is mirrored from M_{13} through M_{11} to M_{14}. These connections enhance common-mode rejection by reducing the voltage swing at the sources of M_3 and M_{10}.

Through the combination of its low input and high output impedances, the FBCM has demonstrated upwards of 60 dB of common-mode signal rejection. This allows the FBCM to act as a buffer for circuits that do not have high output impedances and in the AIHCAN IC the FBCM is used to buffer almost every circuit. The FBCM's transfer function is shown.

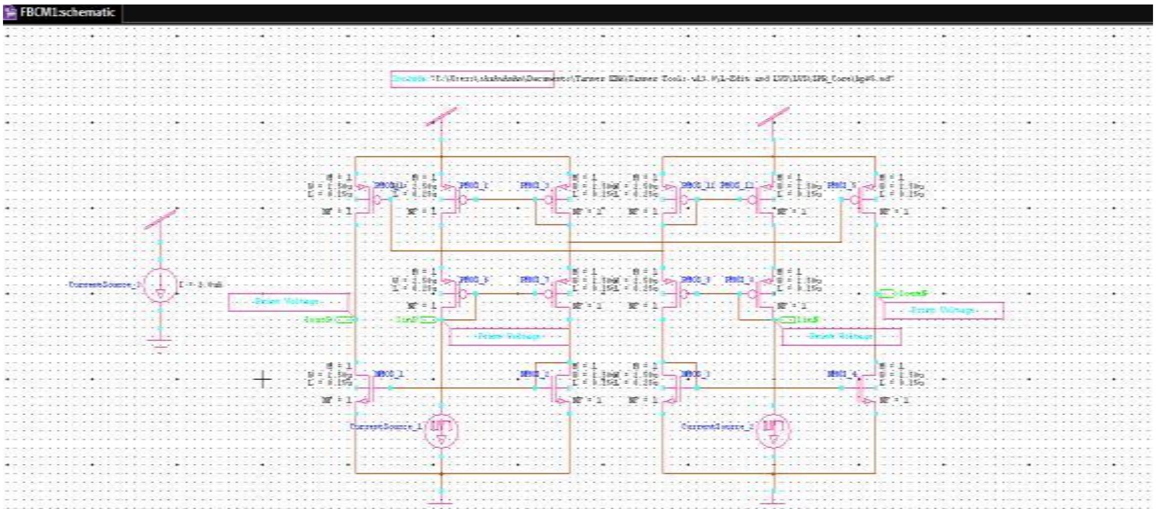

Figure 5. FBCM circuit

The FBCM circuit is composed of two halves, each containing a Wilson mirror input connected to a complementary current mirror on the output. By cross-coupling the output stages, the differential output affects both sides and the signal path becomes fully balanced because the transistors M_1 , M_5 , M_8 , and M_{12} are the only ones with W/L ratios of 1/2; this configuration results in a current gain of one. The circuit is also fully balanced because the positive and negative, or left and right, signal paths are identical and controlled by one or both halves of the circuit. Finally it should be noted that the FBCM's regularity allows mismatch-compensated layouts that are made using interdigitated NMOS and PMOS mirrors.

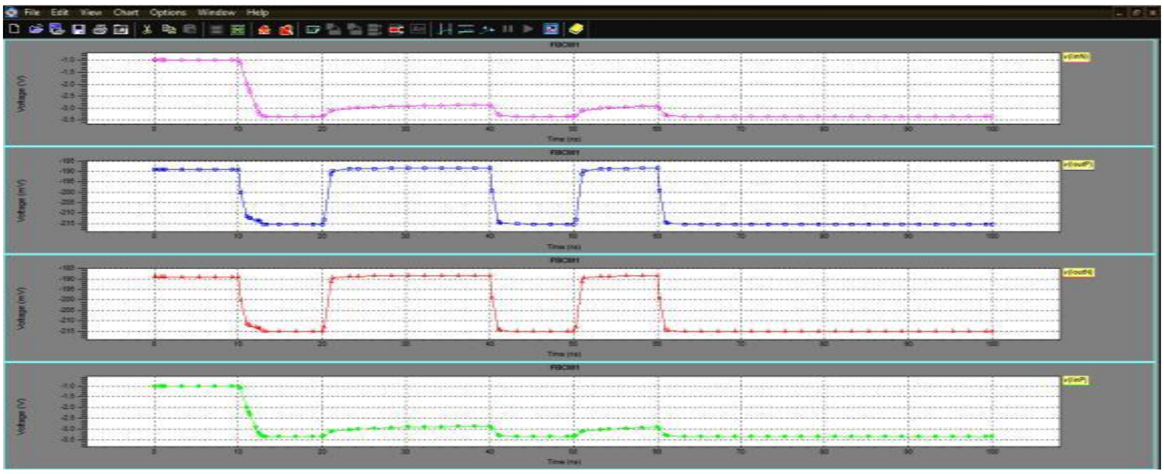

Figure 6. Output Waveform

It shows the FBCM circuit act as a buffer circuit which has boost up the low input current source to high output current source with equal with of pmos and nmos and gain is equal to one.

Waveform for FBCM:

Current source settings in input side:

Bias DC Current Source (I) = 2.0 uA

Main DC Current Source (I) = 2.0uA

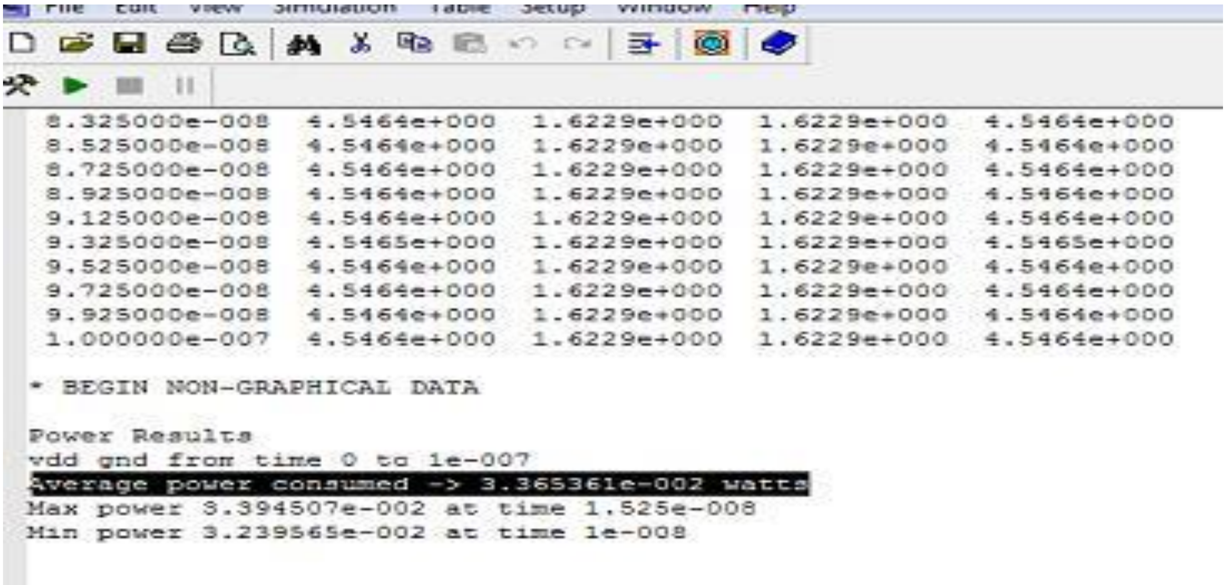

Figure 7. Power consumption of FBCM circuit.

D. Bipolar CMOS

The advent technologies which also include BiCMOS combines the strengths of two different process technologies into a single chip: Bipolar transistors offer high speed and gain in the IHC circuit, which are critical for high-frequency analog sections, whereas CMOS technology excels for constructing simple, low-power logic gates.The analog and digital parts on a single chip, BiCMOS SiGe (Silicon-Germanium) technology drastically reduces the number of external components while optimizing power consumption.

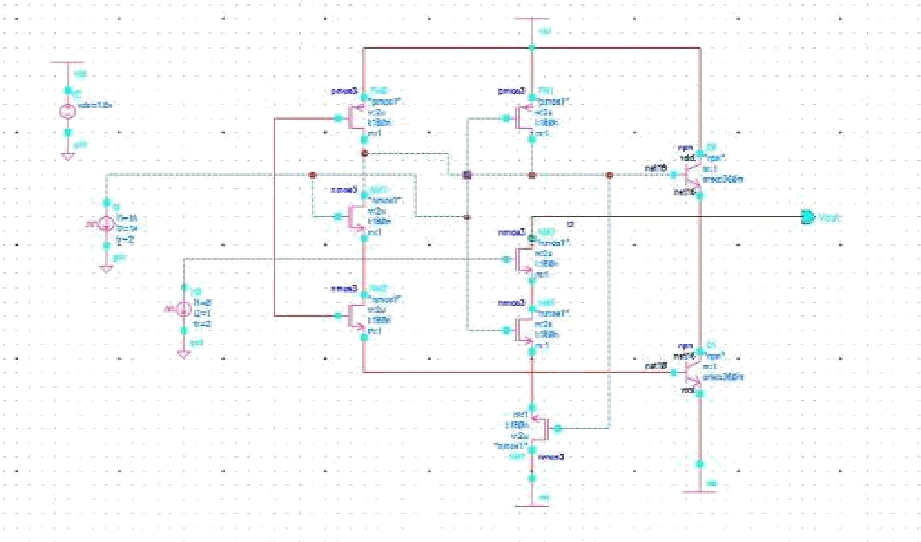

Figure 8. Shows Bicmos circuit used in AIHCAN IC offers high speed.

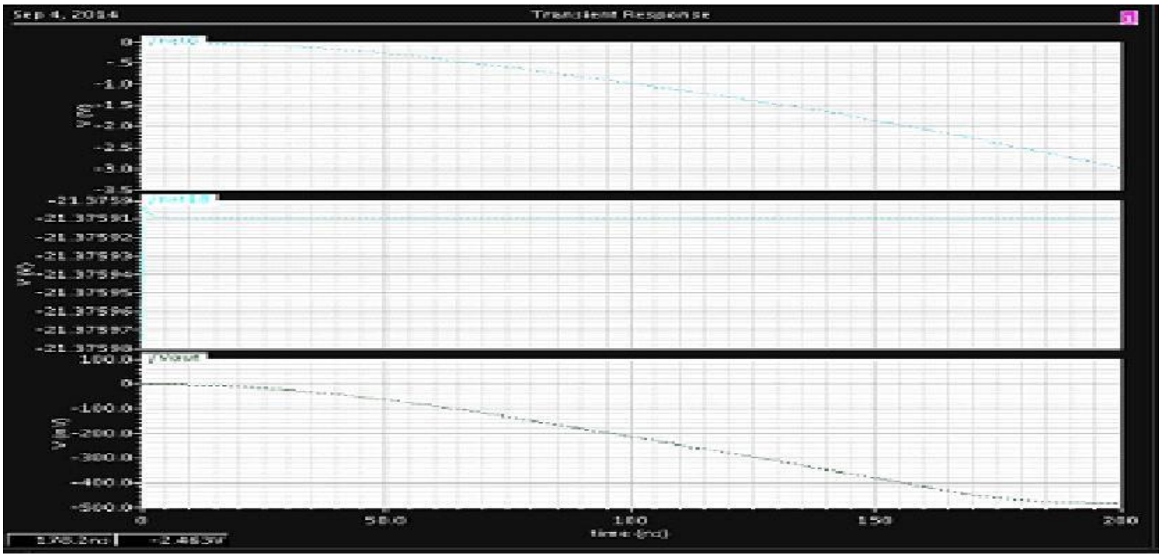

Figure 9. Transient Response of Bicmos shows the measured curves were the power reduces in linearrange of operation.

IV. RESULT

A. Testing Platform

The AIHCAN IC has been modified to reduce the power using Analog CADENCE tool with equal width and length of PMOS and NMOS(0.35 μm). The Tanner eda tool used supply voltage for the AIHCAN IC is 2 A and the average current used by the AIHCAN circuit is less than 3.36 mA. Signal are generated, acquired, and displayed at the sample rate channel via a graphical application running in the CADENCE environment. Synchronized input signals to the AIHCAN IC are provided via analog voltage output, DC response is selected and the obtained output gives transient response.

B. System Response

The AIHCAN IC's response to the frequency tone bursts to examine outputs at the FBCM circuits because they can easily be used to mirror output currents via independent transistors. The dynamic range of the system was measured to be 43 dB. This value is lower than the simulated system response of 60 dB, but is still a useful range for an IHC and AN circuit. When com-pared to the IHC and AN models of AIHCAN IC's performance have typical dynamic ranges of 40-to-50 dB. It is possible that the measurements from the test setup described are under representing the capabilities of the AIHCAN IC in biomemtics.

C. CMOS Mismatch

The matching of many AIHCANs is a critical design criteria. To illustrate the importance of input channel matching we can reliably extract important binaural cues. The AIHCAN IC was also an exercise in understanding the use of passive techniques such as using very large MOSFET areas and regular layout methodologies to minimize CMOS mismatch. CMOS mismatch has a dramatic effect on current mirroring and can compromise the performance of electronic analog circuits. The machines that have evolved over time to target the rapid growth of digital CMOS devices.

To minimize the current mismatch from variations in voltages, widths, and lengths the large size of a single AIHCAN circuit it demonstrates the event that matching of large area current-mode circuits was unable to prevent DC mismatch, the AIHCAN IC was designed to be able to correct this DC mismatch after the fabrication.

D. Area and Energy Efficiency

The use of the AIHCAN circuit, had an estimated order of magnitude reduction in power consumption as shown in Table I. Additionally, by using a differential signal path, power dissipation remains constant under varying signal conditions for relevant frequencies. An additional reduction in power of over 10% could be realized if one were to remove additional structures and output blocks that were used for testing the circuit. To eliminate bias circuitry concerns while studying the effects of mismatch on the fabricated IC, the bias current circuitry was designed to minimize current variation.

The AIHCAN IC was designed to use a purposely large area with the intent to understand use in acoustic applications. It was possible to re-duce mismatch effects, but it was not sufficient to rely on passive techniques alone. Mismatch will create DC offsets, thus solutions like the DACCOR circuit, must be used, especially before any signal multiplication. The DACCOR circuit currently uses 8-bits and 0.02 mm^2 of area. AIHCAN circuit would occupy an area of only 78% of a single DACCOR circuit used in the AIHCAN IC. Therefore, minimization of the DACCOR circuit is possible. The AIHCAN circuit's 2.3 mm^2 area does not allow auditory processors with a reasonable number of microphone and frequency channels to be fabricated, but with DACCOR, it may be possible to reduce the circuit to less than 0.09 mm^2 so that 64 AIHCAN circuits can be placed in an area of 5.76 mm^2 .Accordingly, transistor, capacitor, and interconnect dimensions would be reduced by a factor of five. The widths and lengths of the transistors on the AIHCAN IC are so large that this reduction will still leave the dimensions of the transistors in the multi-micron range.

These simulation results imply that scaling of the AIHCAN IC is feasible with the inclusion of DACCOR tuning until transistor dimensions approach the sub-micron range. By removing any DC offsets, a miniaturized AIHCAN circuit could be used on a mixed-signal auditory processor with tens to hundreds of channels.

V. CONCLUSION

This Brain-machine interface based on the EEG demonstrated here is a proof-of-principle to reduce the noise using algorithm, that is gradually prevailing upon the very potential field of rehabilitation. By applying this technique it is possible to provide mobility to the disabled people. We also described an IC that can be used for hearing synthesis. The IC will consume less power, lower than 6.9 mW of average power and can be integrated into an implantable/wearable prosthetic system. The dual AGC model has been transformed into the current domain using differential current -mode circuits and can be used with ultra low power. The ability to tune the system to remove DC offsets allows CMOS mismatch to be compensated for in the signal pipeline. The low-power envelope, real-time processing, and behavior flexibility from various levels of tunability make the AIHCAN IC a practical module for use in biomimetic processing, especially in mobile and battery powered applications where the AIHCAN IC can be easily integrated into existing and future systems. It is very much possible to adapt and extend the BMI model to use any other type of signal (voluntary or involuntary) through proper signal processing techniques capable of transforming the input signal to a binary decision signal. The work in progress is to extend this technique to control assistive devices for the disabled.

REFERENCES

[1] David.S Freedman, *Member, IEEE*, Howard I. Cohen Socrates Deligeorges, Christian Karl, and Allyn E. Hubbard "An analog VLSI implementation of inner hair cell and auditory nerve using dual AGC model" *IEEE Trans.Biomed.Circuits Syst.,vol.5,no.4,pp.240-256,2014*

[2] K. H. Wee, L. Turicchia, and R. Sarpeshkar, "An articulatory silicon vocal tract for speech and hearing prostheses," *IEEE Trans. Biomed.Circuits Syst., vol. 5, no. 4, pp. 339–346, 2011*

[3] A.Hubbard, H. Cohen, C. Karl, D. Freedman, D. Mountain, L.Ziph-Schatzberg, M. Nourzad Karl, S. Kelsall, T. Gore, Y. Pu,Z. Yang, X. Xing, and S. Deligeorges, "Biologically inspiredcircuitry that mimics mammalian hearing," in *Proc. SPIE Conf.Ser., 2009, vol.7321.*

[4] Y. Shao, Z. Jin, D. Wang, and S.Srinivasan, "An auditory-based feature for robust speech recognition," in *Proc. IEEE Int. Conf. Acoustics,Speech, and Signal Processing, 2009, pp. 4625–4628.*

[5] V. Chan, S.-C. Liu, and A. van Schaik, "AER EAR: A matched silicon cochlea pair with address event representation interface," *IEEE Trans.Circuits Syst. I, Reg. Papers, vol. 54, no. 1, pp. 48–59, 2007.*

[6] R. Sarpeshkar, C. Salthouse, J.-J. Sit, M. Baker, S. Zhak, T.-T. Lu, L.Turicchia, and S. Balster, "An ultra-low-power programmable analog bionic ear processor," *IEEE Trans. Biomed. Eng., vol. 52, no. 4, pp.*711–727,2005

[7] A.McEwan and A. van Schaik, "An alternative analog VLSI implementationof the Meddis inner hair cell model," in *Proc. IEEE Int.Symp. Circuits and Systems, 2004, vol. 4, pp.928–931.*