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Power optimization of Low Noise Amplifier (LNA) and DAC used in Closed Loop Deep Brain Neuro-Stimulator (CDBS) at 45nm using Cadence Virtuoso

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***Abstract*---**Deep-Brain-Stimulation (DBS) is a rapidly growing area which aims to enhance the lives of patients with different types of brain disorders. In regards of implanted devices, it's perhaps one of the most active research topics. This study describes a Low-Noise-Amplifier (LNA) and Digital-to-Analog Convertor (DAC) for biopotential collection on Deep Brain Stimulation.

***Keywords*---**CMOS, Deep-Brain-Stimulation (DBS), Digital-to-Analog Converters (DAC), Low-Noise Amplifier (LNA), low power.

Introduction

All signals in biological applications are physical in origin. Biomedical signals have a low frequency and milli volt level noise. Sensors are used to transform these signals into electrical signals. The sensor device is needed to detect biomedical signals produced by the body of the human, such as electromyography (EMG), electroencephalography (EEG) and electrocardiography (ECG) [1]. Electric signals from the human body must be transformed to digital signals after they have been detected. Signal processing takes place in the digital realm. In all biomedical applications, an analogue to digital converter (ADC) is necessary for this conversion. The ADC's primary function is to convert analogue signals to their digital equivalents. This digital signal is further processed before being sent out. Low power and extended battery life ADCs are required for these properties. The challenge is to create a low-power ADC with a low consumption of power architecture. They should be designed in a way which consume low power, have a

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medium resolution and also having an adequate sampling rate. DACs (Digital to Analog Converters) are used in a wide range of applications, involving biomedical diagnostics, robotics and communication systems and so on. When real-world signals are available, DACs are often used in most digital systems. Analog-to-digital converters (ADCs) convert real-time input waves which include pressure signal, analog signals such as speech, sound waves, temperature data and pictures into digital form. These signal waves are transformed back to analogue signal wave using Digital to analog converter after processing.

Scientists have suggested for years that electroencephalographic (EEG) activity may serve as a communication route between the brain and the computer [2]. Since then, the desire for additional functionality and compactness from technology's electronics has increased. Given the importance of leading with tiny biological signals, an amplifier must be designed which allows these signal components compatible with equipment like as Analog-to-Digital converters for subsequent computer processing. Selective amplification of the raw signal, rejection of superimposed noisy disturbances and interfering signal wave, and protection from harm obtained by higher frequency currents and voltages are all required for the amplifiers. [3].

The Electro-Cardio-Gram (ECG) is one of the most often utilized domains that involve the collection of biosignals in order for clinicians to diagnose cardiac problems [4-6]. Optogenetics is a new branch of research in which biosignals are collected from a particular part of the brain and that part may be activated with light at the same time [7-10]. A unique paradigm in optogenetics is the hypothesis of an electrode with an electronic chip placed at the tip, in which bio-amplifier along with related signal interface performs processing along with control electronics that simultaneously receive brain impulses and stimulate them with light. [11-12]. Deep-Brain Stimulation is another sort of emerging field of applications (DBS) [13]. Deep-Brain-Stimulation is a surgery that involves implanting a neurostimulator inside the brain (also known as a brain pacemaker) that transmits moderate pulses to particular parts of the brain via implanted electrodes [14]. The electrical signal used is very mild, and this is introduced into certain areas of the brain, the majority of which are deeper. Implantable electrode-tipped needles in specific locations across the brain, including the globus, pallidus, thalamus and subthalamic region [15]. Extension cables with metallic wires are then used to link the electrodes to the neurostimulator itself [16]. These electrodes are dispersed usually at the end of a semi-rigid tip injected inside the structure of the brain, guiding that to the targeted neuro-stimulation zones [17].

The neuro-stimulator is a gadget that is about the size of a matchbox, with a battery connected to give power [18]. Figure 1 depicts the DBS idea [19], in which a bio-amplifier (often called as a Low-Noise-Amplifier (LNA) and its associated control along with processing of the signal and its interface electronics receive neural impulses and give stimulation at the same time. The neurostimulator is typically implanted in the chest or abdomen, with the complete device placed beneath the skin with no exposed or visible elements. The symptoms of a variety of illnesses is reduced when the system is turned on, the brain stimulation changes the activity of the neurons in and around the area. Parkinson's disease, Tremor, Morbid Obesity, Dystonia disorder, Obsessive-Compulsive Disorder(OCD), Tourette Syndrome, Chronic Pain are among the ailments associated with neurobehavioral and mobility disorders for which other treatments have failed [20].

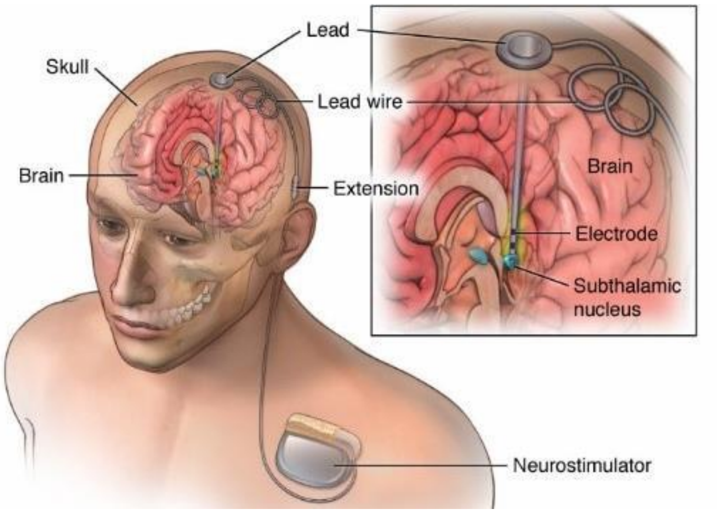


Figure 1. Deep Brain Stimulation Concept

Despite their widespread use, neurostimulator devices are nevertheless large electronics gadgets that involves using wires under the tissue cells that connect to the head and from there it leads to stimulation electrodes, need an invasive surgical operation to replace the power battery for about every 2 to 4 years. In order to reduce the expense of battery replacement and the inconvenience that the implantation causes the recipient, surgeries must become more self-contained and less obtrusive in the future. The medical industry along with the affected patient organization bodies want to lower the discomfort caused by the implant's by reducing its weight and size, as well as extend its life with an energy optimization system that provides added safety when conducting computed tomography (CT) or sometimes also referred to as Magnetic Resonance Imaging (MRI).

Deep-Brain -Stimulation (DBS) is classified accordingly into two paradigms: open-loop Deep Brain Stimulation (also referred as conventional DBS) and closed-loop Deep Brain Stimulation (also referred as adaptive Deep-Brain -Stimulation) [21]. Stimulation settings are physically adjusted for every three to twelve months after implantation by a neurologist in the category of open-loop Deep-Brain – Stimulation. The setting of stimulation parameters in closed-loop DBS, whereas, on the other hand it is done automatically based on the detected biomarkers. The obtained signals are referred to as biomarkers, and they can be of several types, including bioelectrical, psychological, and biological [21]. Biomarkers are important indications of the condition being treated with closed-loop DBS because they allow the signals utilized in neurostimulator to be adaptively reconfigured [19]. Biopotential acquisition is a critical component of closed-loop DBS.

Because of these factors, as well as the absence of miniaturized devices with the possibilities for safe implant placement on the market, the development of CMOS nanotechnology containing complete DBS systems has enormous social economic implications, in both terms of enabling new treatment techniques and in terms of boosting the market for medical instrumentation and healthcare. This work describes the construction of a CMOS based Low-Noise Amplifier (LNA) that can record bio-logical signals at frequencies range which is from sub-Hertz to 10 kilo Hertz. The internal architecture of Closed Loop Deep Neuro Stimulator [22] is as given in Figure 2 which is used for the treatment of neurological aliments which includes Obsessive Compulsive Disorder (OCD), Epilepsy, Parkinson's disease, Tumors, Chronic Pain and many more.

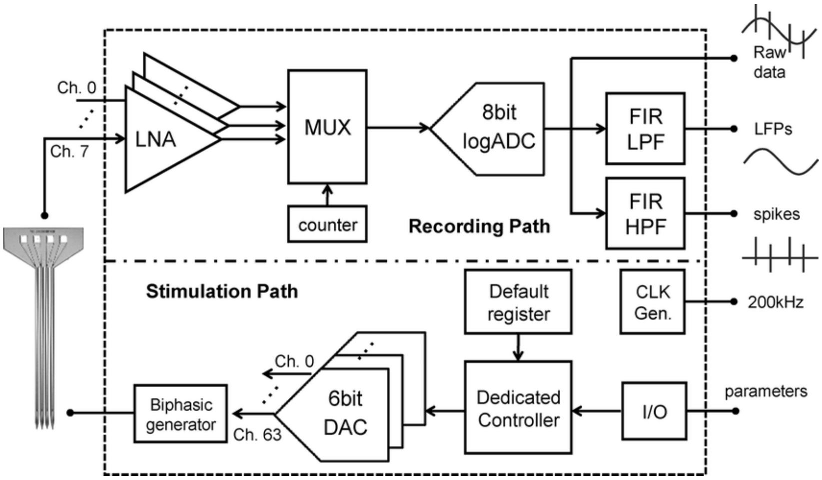


Figure 2. Block diagram of Closed Loop Deep Neuro Stimulator [22]

This research paper provides low power Low Noise Amplifier and Digital to Analog Converter implementation in Cadance Virtuoso. Paper describes the related work carried followed by the proposed work of LNA and DAC implementation with results.

Related Work

S. Guptha et al., describes an embedded based solar photovoltaic cell fabric that is based on bionics that transfers solar energy signal into electrical signal to charge a polymer embedded electronic circuit. The fabric integrated electronic circuit operates in two ways: it can detect tremors related to epilepsy and Parkinson's disease while also delivering medication to particular brain areas to avoid tremors [23]. J Jayeshkumar et al., proposed a high speed segmented current steering Digital-to-Analog-Converter that is used in neurostimulation application. This paper highlighted the simulation work carried at 180 nm technology node with a power dissipation of 22 mW having the power supply potential of 1.8 Volts and maximum rate of sampling of 200 MHz. Segmented DAC combined the advantages of both the binary-weighted DAC and unary-weighted DAC. For a DAC with N inputs is implemented using segmented with M bits using unary weigh and (N-M) bits using binary weight [24].

The researchers demonstrate an eight-channel multi-phasic current steerable brain stimulator with on-chip current DAC adjustment and residual nullifying for perfect energy balancing. Two sub-binary numerical DACs are accompanied by current buffers with a broad swing and maximum output impedance which offer moment supply and sink output terminals for cathodic and anodic stimulation on each channel. A separate integrator is used to fine-tune DAC parameters and match cathodic and anodic stimulus periods across all channels. After calibration, the divergent non-linearity is less than 0.3 LSB at 8-bit accuracy, and the two stimulus phases are within 0.3 percent of one another. [25].

T. Nordi et al., proposed a Low-Noise-Amplifier which acquires the biopotential on Deep Brain Stimulation. The paper emphasizes a low-power and a low-voltage CMOS technology based neurostimulator and is intended for use in implanted devices. The gain was 38.6 dB, with a -3dB bandwidth of 2.3 kilo Hertz, according to the stimulation achieved. The tests also revealed a 2.8 µ W of power consumption and a 3.9 V of RMS input-referred noise. The LNA takes up a micro device area of 122 m by 283 m thereby making it easier to implant [26].
X. Li et al., presents a calibrated 16-channel embedded biphasic neural stimulator chip. The simulations were carried and chip layout was accomplished. Computer assisted design (CAD) software had been used to technique known as Design Rules Checks (DRC) and Layout Versus Schematic (LVS) design checks on the chip layout. The test findings showed consistent current stimulation with a charge balance inaccuracy of less than 0.13 percent Least Significant Bit. This LSB inaccuracy persisted across a wider range of stimulation patterns and electrode load impedances. The ASIC was designed and implemented using 180nm technology [27].

J. Lee et al., describes a neurostimulation integrated circuit that is utilised in sophisticated closed-loop neurostimulation techniques like deep brain stimulation (DBS) for the diagnostic and therapeutic applications of neurodegenerative diseases including Parkinson's disease. The complete gadget, which is made of 180 nm CMOS technology node, is 2.7 mm in length and makes use of 89 Watts in regular operation and 271 Watts in configuration mode when powered by a 1.8 Volts of supply voltage. With eight pre-amplifiers, a 200 kS/s 8-bit log ADC, digital filters, this system detects and also screens brain activity, as well as 64 configurable current-stimulation channels [28].

Proposed work

The need of Low Noise Amplifier is to amplify the weak signals sensed from brain. There are several challenges that a low noise amplifier faces that it should amplify low frequencies and low amplitude signals having a midband gain if approximately 40 dB and range of Band-Width(BW) varies from sub hertz to 10 Kilo hertz. Figure 3 shows the CMOS schematic of Low-Noise- Amplifier(LNA) and figure 4 depicts the test schematic of Low Noise Amplifier which uses two pairs of capacitors C1 and C2, symbol of LNA and a pair of resistor, where C1=20 pF and C2=200 fF. The voltage gain of this Low Noise Amplifier is Av $= \frac{C1}{C2} = \frac{20\ \mathrm{pF}}{200\ \mathrm{fF}}$ =100=40 dB.

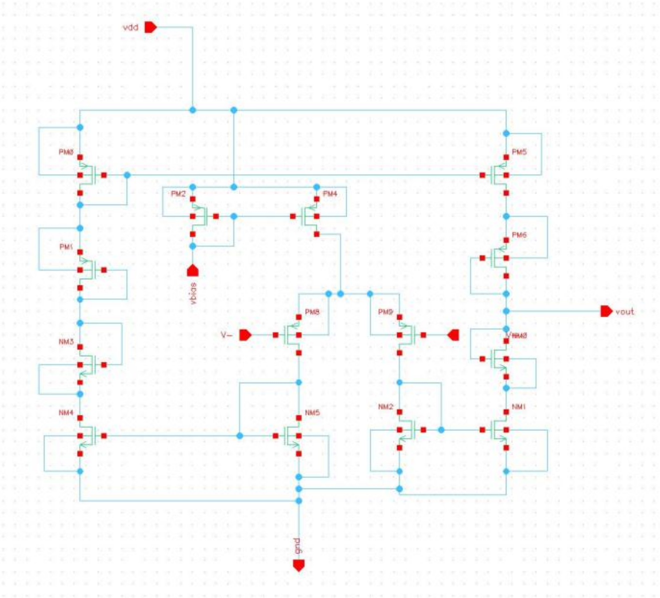


Figure 3. Schematic of Low Noise Amplifier

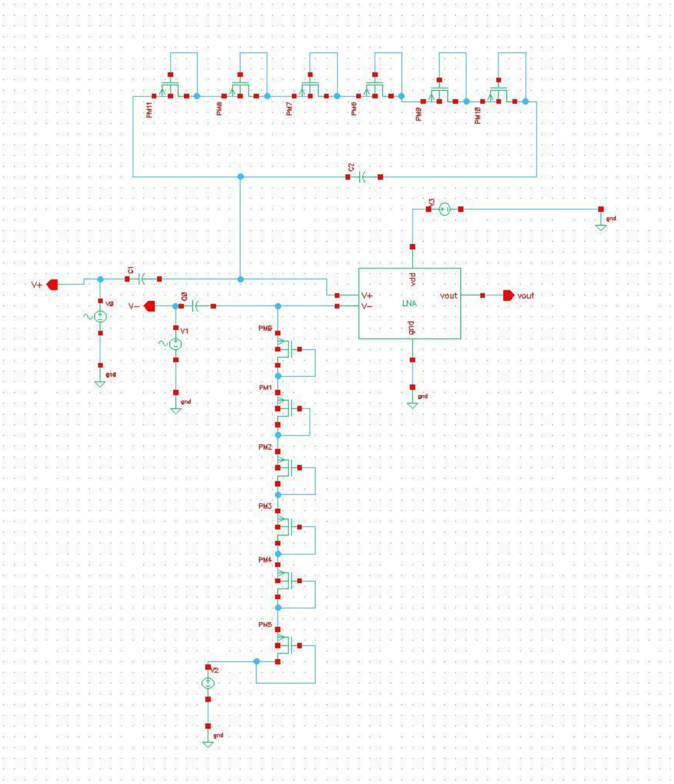


Figure 4. Test Schematic of Operational Amplifier used for LNA

Digital-to-Analog (DAC) convertor is yet another module in a Deep Brain Neurostimulator. The various types of DAC that are used in neurostimulator are

Binary weighted resistor digital to analog converter, Binary ladder or R-2R ladder converter, Segmented Digital to Analog Converter and Delta-Sigma DAC. The research paper proposes a 4 bit R-2R DAC and its schematic as shown in figure 5 comprising of three PMOS transistors and five NMOS transistors. DACs (Digital to Analog Converters) are utilized in a wide range of domains, which includes biomedical diagnostics, telecommunication networks, robotics, and so on. A Digital-to-Analog Converter (DAC), often known as D/A or D2A, is an instrument that converts binary numbers (zeros & ones) in a collection of continuous output potentials that is analogue in nature.

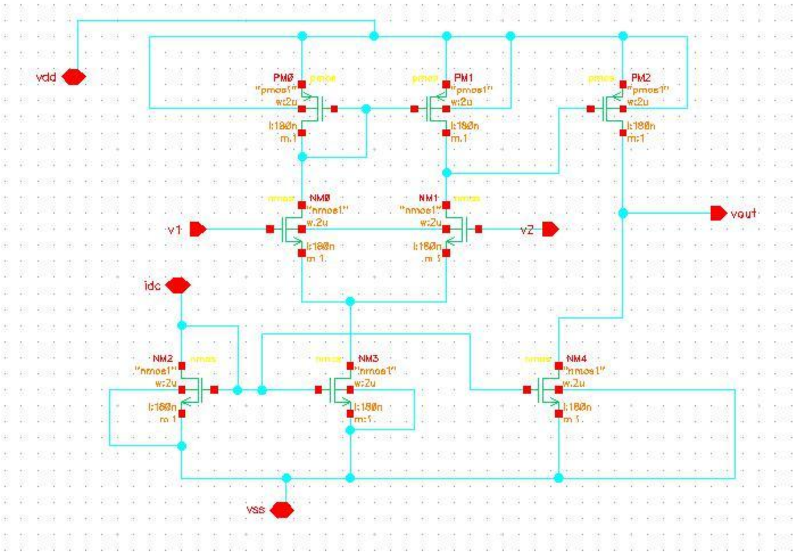


Figure 5. Schematic of OP-AMP in Cadence used for 4 BIT R2R DAC

The test schematic of 4 bit R2R DAC is as shown in the Figure 6 with the following specifications as given below having considered the pulse voltages.

D0; V1=0, V2=2V, PERIOD=2*t, PULSE WIDTH=t.
D1; V1=0, V2=2V, PERIOD=4*t, PULSE WIDTH=t.
D2; V1=0, V2=2V, PERIOD=6*t, PULSE WIDTH=t.
D3; V1=0, V2=2V, PERIOD=8*t, PULSE WIDTH=t.
Idc=50 uA, supply voltage=2.5 V, gnd=-2.5 V

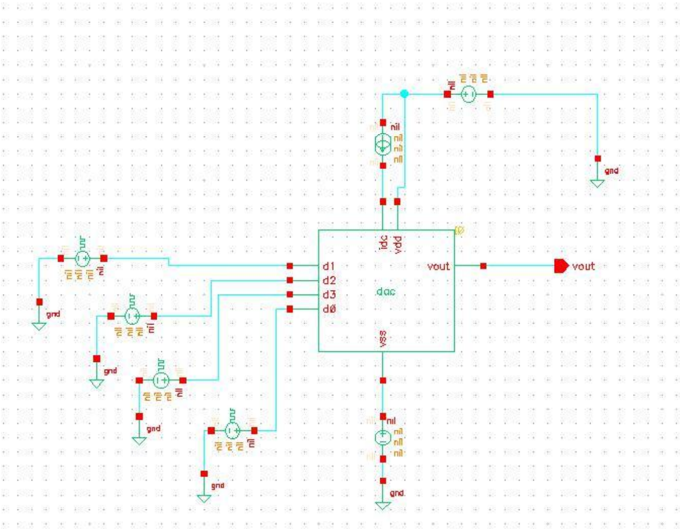


Figure 6. Test Schematic of 4 bit R2R DAC

Results and Discussions

The simulation is carried in cadence virtuoso tool at 45 nm technology node and the transient analysis of LNA is as show in figure 7 which depicts the amplification of the input signal where the mirco-volt signal is amplified to mili-volt range.

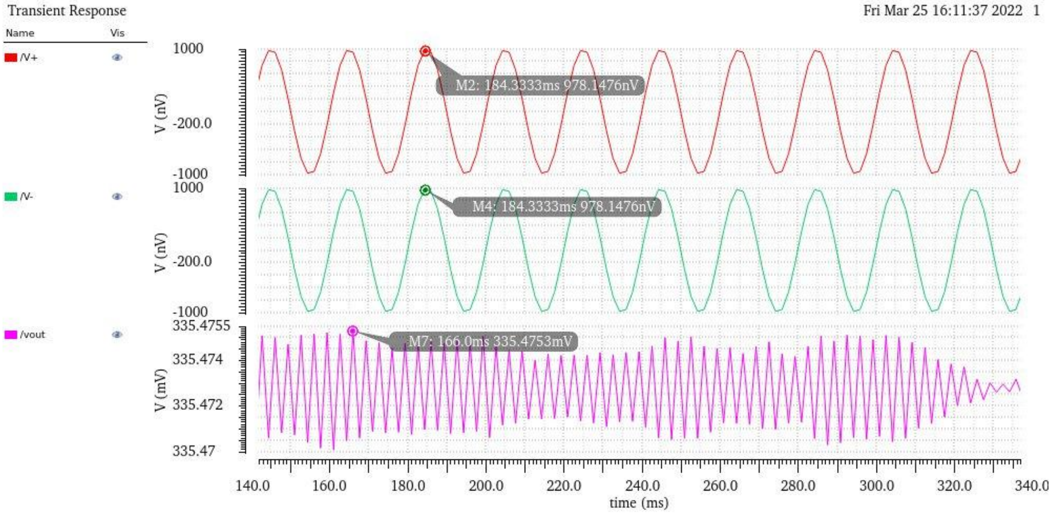


Figure 7. Transient Response Analysis of LNA

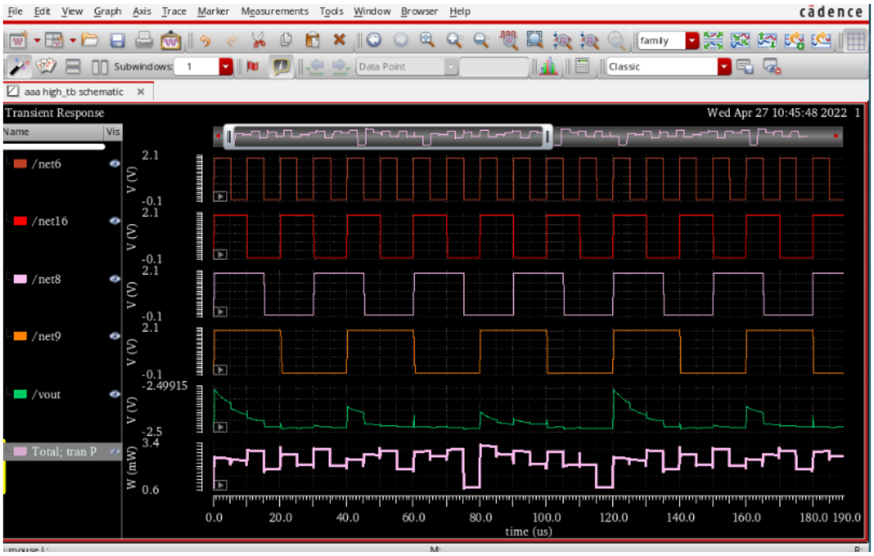
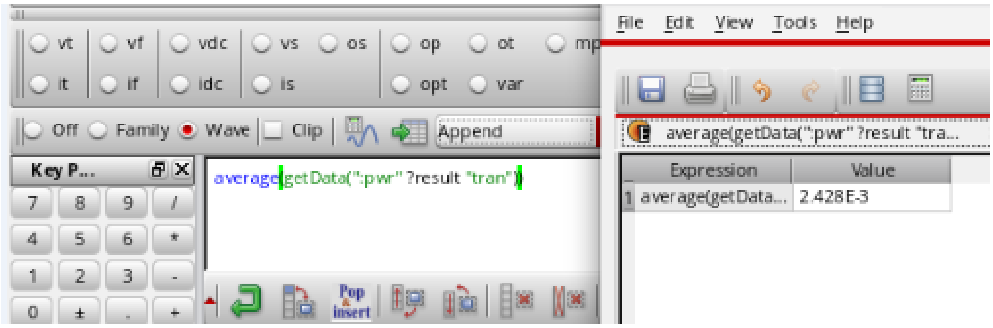


Figure 8. Output Waveforms of 4bit R2R DAC

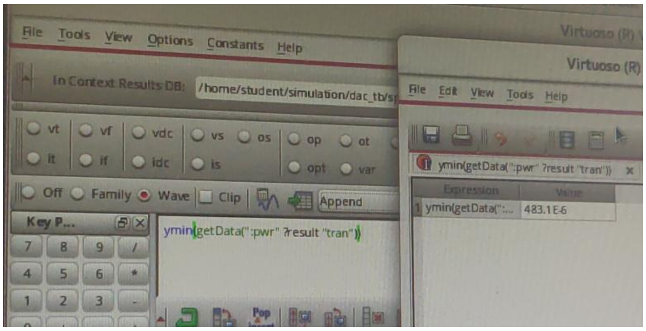
Figure 8 shows the transient analysis of 4 bit R-2R DAC simulated using cadence virtuoso tool. Power signal is considered for analysis of the average power and leakage power using the calculator. Figure 9 represents the sample calculation of average power and Figure 10 depicts the Leakage power calculation in Cadence.



average(getData(":pwr" ?result "tran"))

Expression	Value
1 average(getData...	2.428E-3

Figure 9. Average power calculation in Cadence Virtuoso Tool



In Context Results DB: /home/student/simulation/dac_tb/s

ymin(getData(":pwr" ?result "tran"))

Expression	Value
1 ymin(getData(":...	483.1E-6

Figure 10. Leakage power calculation in Cadence Virtuoso Tool

The analysis is carried using normal threshold voltage transistors as well as high threshold voltage transistors at 180 nm and 45 nm technology nodes. The power analysis is carried for both the low and high Vth transistors and it's observed that using the high threshold voltage transistors yields lower power consumption than the low or normal threshold voltage transistors. The total average power and leakage power is calculated & analyzed.

Table 1
Comparison of Total Average power and Leakage power at 180 nm and 45nm technology

	@180nm		@45nm	
	Normal V_{th}	High V_{th}	Normal V_{th}	High V_{th}
Average Power	2.204 mW	2.428 uW	1.308 mW	1.989 mW
Leakage Power	483.1 uW	710.6 uW	283.8 uW	536 uW

Conclusion

This study describes a Low-Noise-Amplifier (LNA) and Digital-to-Analog Convertor (DAC) for biopotential collection on Deep Brain Stimulation. The paper describes Low noise amplifier with transient response and the voltage gain of 40 dB. It also describes R-2R digital to analog converter with transient analysis. The power analysis is carried using normal threshold voltage transistors as well as high threshold voltage transistors at 180 nm and 45 nm technology nodes. It is observed that using the high threshold voltage transistors yields lower power consumption than the low or normal threshold voltage transistors.

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