International Journal of
INTELLIGENT SYSTEMS AND APPLICATIONS IN ENGINEERING
IJISAE
ISSN:2147-6799 www.ijisae.org Original Research Paper

CMOS Transceiver Epiretinal Vision Restoration Retina Chipset using Wireless Inductive Coupling

Hima Bindu Katikala*[1], Telagathoti Pitchaiah[2], Gajula Ramana Murthy*[3]

Submitted: 05/02/2024 **Revised**: 13/03/2024 **Accepted**: 19/03/2024

Abstract: In medical implants the inductive coupling is the most common topology used for power transfer. Because of design complexity a wireless power transfer is mostly adaptable in the medical implants. In this paper, for the data progressing inside the implant a complementary metal oxide semiconductor transceiver (CMOS TRx) on-chip prototype is proposed with an inductive coupling power transfer for retina application. The CMOS TRx is an integrated device contains the data modulators, configured inductive, demodulator & epiretinal electrode array used to generate an action potential inside the retina. The binary phase shift modulator with class-E power amplifier is designed to transfer the data within two carrier cycles at the transmitter side to maintain high modulation rate than other modulation techniques. The proposed inductive coupling tuned to be resonant at the frequency of 13.56MHz as same as bpsk carrier frequency with more parallel receiver resonance (ωp) by considering the retina permittivity.

Keywords: CMOS transceiver, Binary phase shift keying, Inductive coupling, Retina chipset

1. Introduction

Numerous implantable stimulators, including pacemakers, cochlear implants, instrumented orthopaedic implants, and spinal cord stimulators, have been used to enhance patient quality of life. The usage of integrated circuits (ICs) in biomedical implants is expanding rapidly. ISM (industrial, scientific, and medical) bands, which are ideal for medical purposes, can be used to operate low-power RF circuits. Therefore high performance design linear circuits with sustainable linearity, bandwidth & low noise are majorly preferable in biomedical device application [1]. Scope of installing the biomedical implants on the patient body in different parts of organs is clearly given in Fig.1.1 [2]. Infact the insertion of implants is configured directly onto the tissues cells, skin, muscle, fat and also in the brain and retina. While the interior portion includes a voltage regulator and electrode array, the external portion is made up of a modulator and a power amplifier. A transcutaneous transformer used to transmit power and data into implants is another name for the inductive connection, an implanted biomedical device. Henceforth the transmitter drives the data, power & also maintains efficiency to receiver by means of modulator & PA.

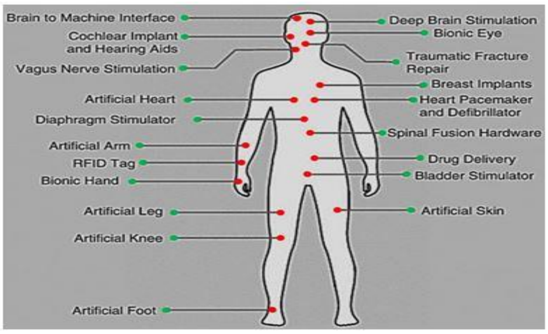


Fig 1.1. Diverse body location of implantable devices

Fig 1.2 gives the pictorial representation of data transmission from patient body to doctor when an implantable device is inserted through a inductive power transfer system [3-4]. Most advance transistor scaling CMOS technology is applicable in biomedical implantable device development because of its high performance. CMOS transceiver (TRx) contains the data synthesizers (modulators), power amplifiers, inductive wireless power transfer system, data recovery module, demodulator & voltage regulators [6-8]. Each block needs to produce and address high-magnitude pulses and modulations with good performance results in order to achieve high-performance TRx.

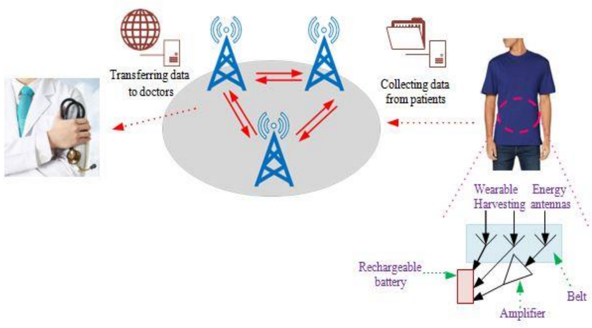


Fig 1.2. Pictorial representation of bidirectional data transceiver via antenna.

[1]Assistant Professor, Department of Electronics and Communication Engineering, Vignan's foundations for Science Technology and Research, India-522213. katikala.himabindu@gmail.com
[2] Professor, Department of Electronics and Communication Engineering, Vignan's foundations for Science Technology and Research, India-522213. tp1977_ece@yahoo.com
[3] Professor, Department of Electronics and Communication Engineering, Alliance College of Engineering and Design, Alliance University, Bangalore, India-562106, ramana.murthy@alliance.edu.in
* Corresponding Author Email: ramana.murthy@alliance.edu.in

Integration of Analog Front End (CMOS Image Sensor, Column amplifier (CA) and Analog to Digital converter) with the transceiver block for the data transmission onto the retina implantable chip is the proposed architecture of vision restoration bionic eye as in Fig.1.3. In general the system of bioelectric includes sensors, stimulation models; computing algorithm for data acquisition [5]. Therefore simulating, designing & integrating all these components require diverse experience, much attention as they were used as chips in medical application.

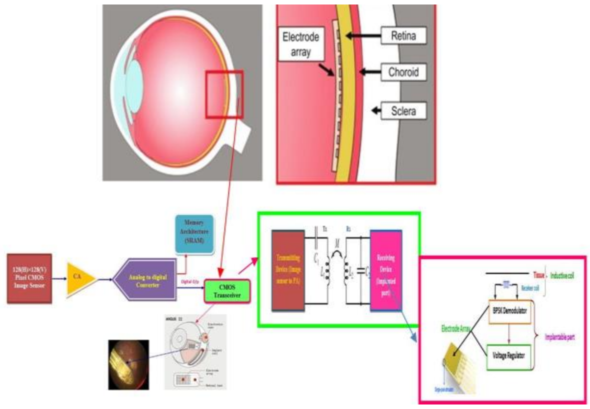


Fig 1.3. Proposed System Integration of Analog fronted End with CMOS Transceiver onto the retina to generate action potential (i.e., Vision Restoration Eye).

For protocol of communication a suitable modulator with high efficiency is used in CMOS TRx that can be Amplitude shift keying (ASK), Frequency shift keying (FSK) & Phase shift keying (PSK). Binary-PSK (PSK) is more suitable because of its constant amplitude of signal and fixed carrier frequency will provide stable power transfer. Benefit of the fixed carrier frequency in BPSK is to have optimal data transfer & power coupling by fixing the antenna size. BPSK with the load shift keying (LSK) is an ultra low power protocol act as feedback component to receive the signals from implant and sent it back to external controller monitor for doctor's examination. Short-range wireless communication is used in biomedical implants to prevent bio-fouling and infection that would occur if there were long wires and cables connecting the implant to the external controller. Especially the data interruption is more possible if the design is of more complex. The purpose of the external controller is to deliver the data and power to the implant in an efficient manner technically known as power telemetry. For data transmission a configured coupling link called as inductive line is used for power transfer from external controller to biological system. For data transmission a configured coupling link called as inductive line is used for power transfer from external controller to biological system as in Fig.1.4.

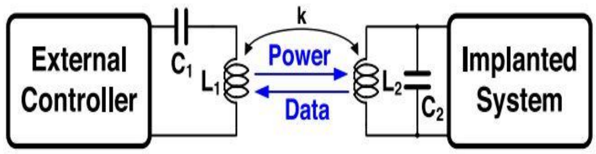


Fig.1.4. Power & Data transfer using single inductive link

2. Binary Phase Shift Keying (BPSK).

The modulating data rate of the implantable medical devices (IMD) is to be high in the range of mega bits per second (MBPS) is highly recommended. Simultaneous data and power transfer from external controller enables the low power consumption by IMD and also provide the high efficiency and data rate with minimal bit error rate (BER). To minimize electromagnetic field inclusion in the tissue and increase data rate, a low power and high data rate carriers are utilized with low attenuation frequency. To maintain high power transfer efficiency & data rate at the transmitter side requires high quality factor resonant circuit. The conventional modulation techniques like ASK [9], FSK [10-11], & PSK [12-13] cannot deal signal modulation with required constraints like high data rate, PTE with bandwidth. However the many attempts are in progress to resolve the aforementioned challenges using the convention modulation techniques. A proposed carrier width modulation (CWM) transmit both data and power using a single inductive link attenuates at 27.12 MHz & achieves data rate of 9.041 Mbps with minimal power consumption of 13.68 µW. In CWM converts pulse width (pw) to saw tooth peak (sp) using a circuit topology of current mirror, two alternative switches for charging and discharging the capacitor as in Fig.2.1 [14]. Despite of novelty, it only applicable for single inductance can't be utilized for dual purpose transceiver signal process (arbitrary single generator).

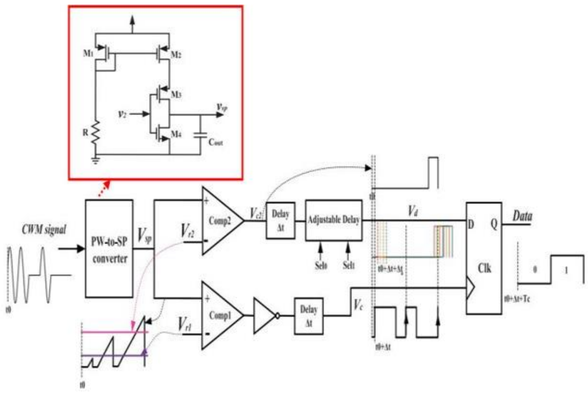


Fig.2.1. Architecture of CWM pw-sp conversion.

As [15] proposed a fully integrated new technique BPSK data & power telemetry utilized in cardiac micro simulator with supply voltage of 1v using charge pump topology with low power dissipation of 1.76 µW is designed. However to charge the IMD still an additional battery is requires certainly occupies additional space & the data rate is low as 16kbps. A single inductive energy recycling telemetry using a cyclic on-off keying (COOK) is proposed in [16] with low BER of <9.9×10-8 supports the backward data telemetry as in Fig. 2.2. And also provide self tuning LC tank to avoid the data loss and distribution by EM interception, therefore efficient power delivery is achieved by this designed. By adopting Time-based encoding for high data transmission that transmits 2 bits per 4 carrier cycles larger than conventional transmission encoding. Conflict is the power dissipation is more of 11.5 mW and low data rate of 6.78 Mbps.

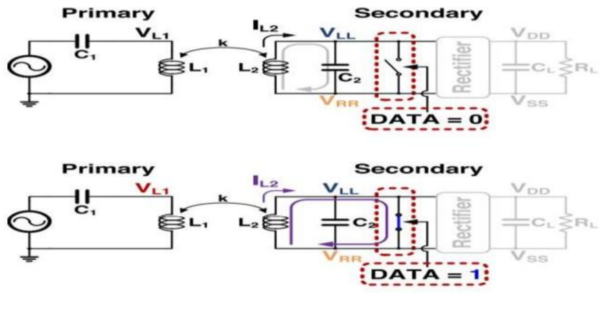


Fig.2.2 COOK modulation technique.

Finally a single die inductive link can efficiently transfer the power (tens of milli watts) but lacks in high data rate. Proposed TX device is a Class-E amplifier that is modulated using BPSK and can finish data modulation in two carrier cycles as in Fig.2.3 [17]. This method has a high Q factor and a high modulation rate. While the implanted RX performs power conversion and data demodulation, the TX transmits power and data as an external device. The data to be transferred is modulated and sent to the carrier on the TX side. A Class-E amplifier is then used to drive the primary coil with the modulated signal. High PTE and high bandwidth conflicts can be resolved by completing the BPSK modulation in two carrier cycles, regardless of the resonant network's Q-factor. This results in a high modulation rate and high PT at the same time.

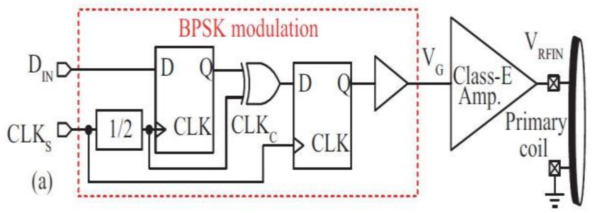


Fig.2.3. CMOS TRx BPSK Modulator

As in Fig. 2.3 the input data DIN changes, then the output of VG also changes; however, the output (VG) phase is binary modulated with respect to the data. VG is in deceleration mode when DIN is transitioning from 1 to 0, and it is in acceleration mode when DIN is transitioning from 0 to 1 and the modulator output is buffered before given to class E PA as shown in 3.2.

3. Proposed Retina Wireless Inductive Coupling Power Transfer (ICPT).

The wireless power transfer system [18-19], especially when employing inductive coupling power transfer (ICPT), offers the safest means of powering biomedical implants. The transfer of power in implants for short-range communication is effectively carried out by the ICPT, an established technology with a wide output power range consist of transmitter and receiver device. The ICPT employs two inductive coils that are mechanically strongly coupled, transferring energy from the transmitter coil side to the receiver coil side via a pair of inductances L1 & L2 connected by a mutual inductance M. as in Fig.3.1. ICPT is a two port network where the transmitter coil is the energy from source and the receiver coil is connected to the load. As Class-E PA used to drive the inductive power transfer links because of its less power loss in high frequency ranges.

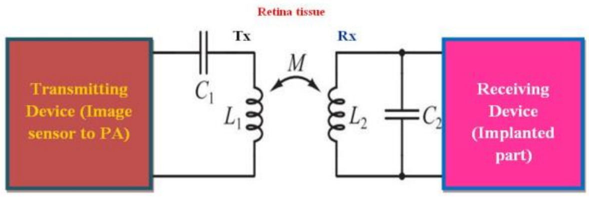


Fig.3.1. Configured Inductive Coupled Power Transfer

The receiver inductance with tuned resonant frequency captured in the series parallel combination (ωp > ωs) of class E PA delivers the same power to the remaining receiver components. Majorly power amplifier sends out power from the external coil L1 to the implanted reception coil L2 at a frequency of 13.56MHz, which is also the carrier frequency of the BPSK signal. The resultant transmitter to receiver signal is in Fig.3.2 by considering the retina permittivity as 8.01E+1 with dielectric constant of retina.

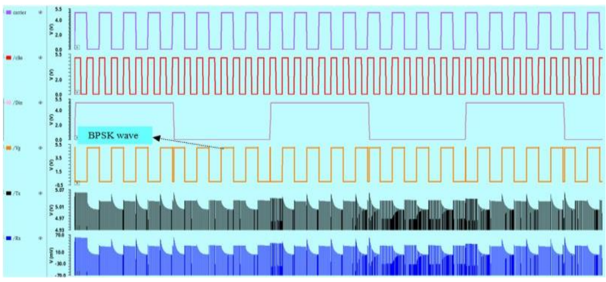


Fig.3.2. Transient response of BPSK modulator & transmitter-receiver signal

4. Receiving device- Epiretinal Retina Chipset

With the integration of electronics and biomedical technology, a retina chipset is proposed which works in the submicron region ultimately generates action potential that can stimulus the remaining neurons inside the retina and progressively provide some sight of vision. Proposed signal transmission of retinal implant in Fig. 1.3 has two divisions external unit include CMOS image sensor, analog to digital converter, Memory Unit (SRAM), modulator, power amplifiers (PA) & inductive power transfer links while internal unit contain demodulator, regulator & retina encoder block with electrode array. Major most the inductive link named as transcutaneous transformer used to deliver power and data into implants constantly. Different retinal regions, such as the epiretinal, subretinal, and Suprachoroidal regions, can accommodate electrode array placement as in Fig 4.1.

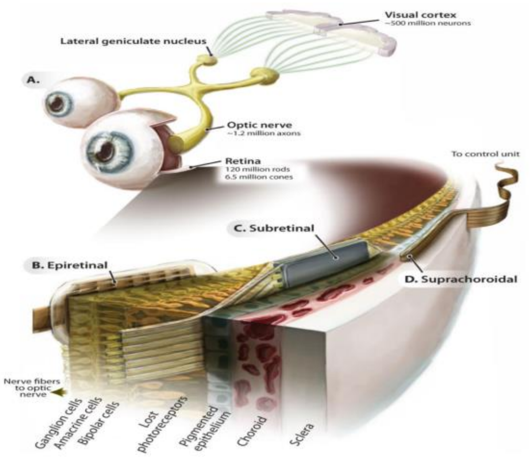


Fig.4.1. Implantable retina region.

Despite clinical evidence supporting improved performance in the early stages of development, epiretinal prostheses like Epi-Ret [20] and the IMI implant [21] naturally induce spikes in the prosthesis due to the electrode array's long-duration pulses. To activate the surviving neuron cells for synchronizing the visual circuitry, or as the normal eye, electrodes are positioned in subretinal prosthesis between the injured photoreceptor layer and the epithelium, much closer to amacrine-bipolar cells. Impairment is a partial blockage of oxygen diffusion and shows the serene leakage of blood vessels into retinal neurons [22-23].

The electrodes in choroidal vascular prosthesis are positioned in the outermost layer of the eye, known as the white eye [24]. As long as the risk of infection is reduced and only a nominal surgical intervention is required in contrast, the electrical stimulus may cause intermittent tingling in the choroidal nerve [25-26] .Table 1 depicts retinal implants clinically tested with a series of electrodes placed in different regions of the retina to stimulate the electrical pulse.

Table.1 Clinical-tested retina implantable devices

Implant name	*Retina region with specification*	*Electric stimulus count*	*Device development*
Second Sight Argus-II	*Epiretinal array of electrode*	*60 pt electrode (6×10 array size)*	*USA*
Pixium Vision Prima VRS	*Subretinal photodiode chip*	*IrOX electrode array*	*USA, Paris*
IRIS II	*Epiretinal array of electrode*	*150 pt array of electrodes*	*Australia*
Alpha AMS	*Subretinal photodiode pixel chip*	*1600 30µm IrOX electrodes*	*Germany*
Nano Vision	*Subretinal*	*Silicon nanowire electrodes*	*US*

Finally the proposed prototype in Fig.4.2 generates an action potential of 62.009µV by insertion of platinum electrode array (as of second sight ARGUS-II) in the region of Epiretinal which is suitable for vision restoration in RP patients. Generated electrode action potential in Fig.4.3 is from design integration of initial CMOS image sensor to voltage regulator of implantable chip.

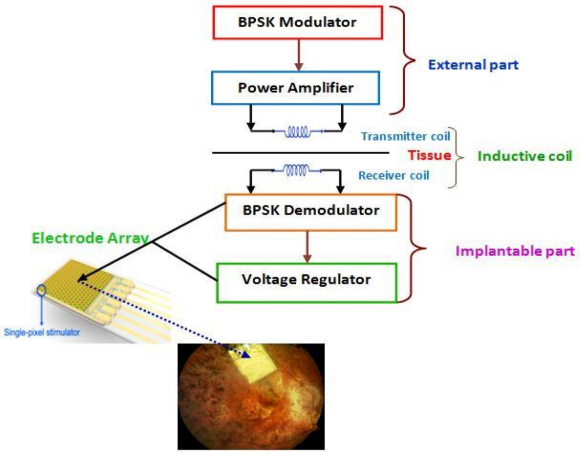


Fig.4.2. Proposed Prototype of CMOS TRx with Retina Chipset.

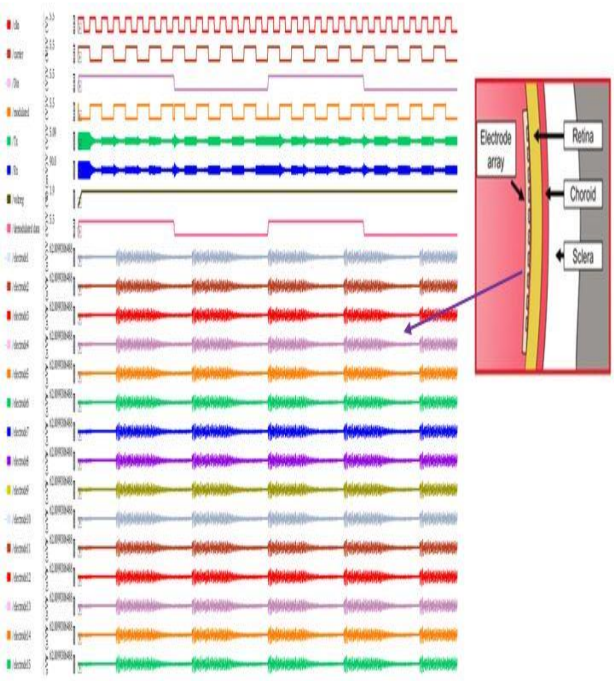


Fig.4.3 Generated action potential from the proposed Epiretinal Retina Chipset Prototype.

The CMOS Image sensor proposed pixel circuit is designed [27] & its parameters are evaluated using the layout configuration as in Fig.4.4. The pixel propagates the large charge accumulation (full well capacitance) and maintains the linearity with high factor of 52%.

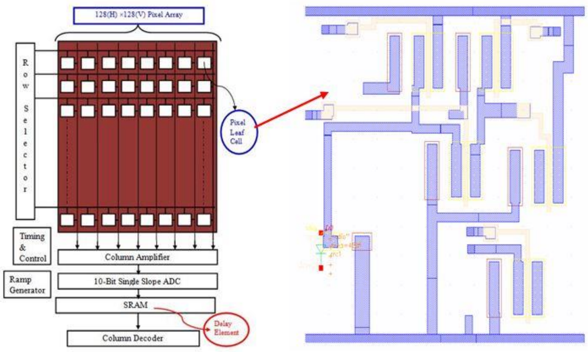


Fig.4.4 Layout Configuration of proposed pixel circuit.

At the transmitter side of retina chip set a memory processor is required for the examination of data flow in terms of read & write operation. For this purpose a memory architecture is designed i.e., static random access memory (SRAM) is chosen. In SRAM architecture a non-overlap clock generator (NOCG) with delay element is designed to perform both read & write operation in a synchronous mode. Though conventional linear delay based NOCG circuits enhances the memory functionality but susceptible to power consumption. This challenge can be addressed by the Digital Programmable Delay Elements (DPDEs) architectures. DPDEs are a set of variable delay elements which are dynamically control the rise time and fall time of the signals. They exhibit controllable delay characteristics, improved non-linearity and also able to withstand against voltage and temperatures variations compared to the existing linear delay elements. The proposed delay elements of current starved inverter enhance the functionality and maintain the full power swing as in Fig 4.5(a) with the corner (Regular-R, Low-L, High-H & Threshold Voltage-Vt) analysis done by post-layout simulation as in Fig.4.5 (b). The obtained delays and power of the modified variable CS delay cell based NOCG are RVt-9.825ns, LVt-10.06ns, HVt-8.857ns,RVt- 480.966fw,HVt 451.237fw,LVt-490.913fw respectively.

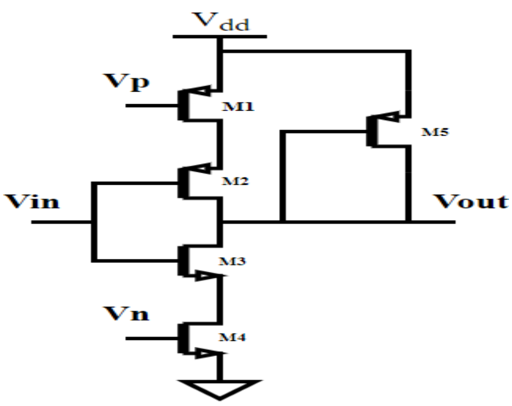


Fig.4.5 (a) Current starved based delay cell element.

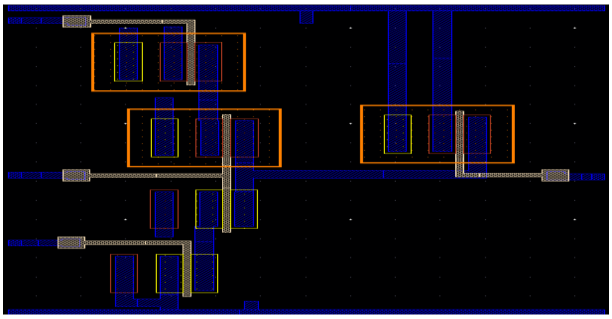
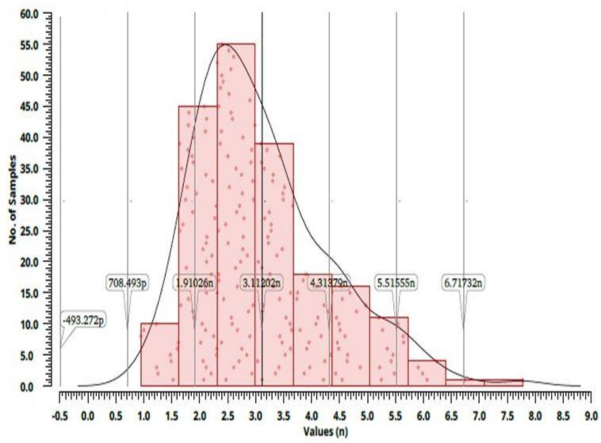


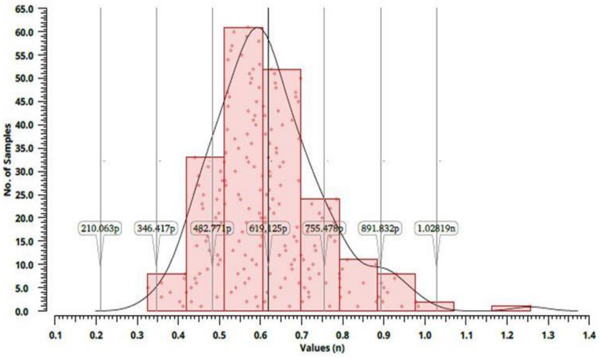
Fig.4.5 (b) Current starved based delay cell element layout.

5. Performance analysis of proposed CMOS TRx based on MC.

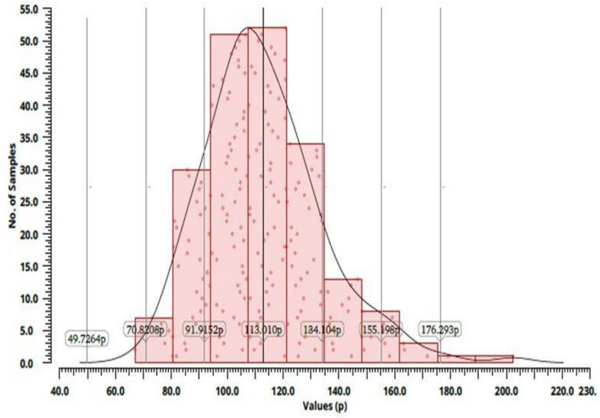
Monte Carlo (MC) analysis is a statistical analysis used for integrated circuits in which the circuit device parameters and mismatch are varied randomly. MC is a designer convenience simulation allows possible random variation effects of circuit parameters over its performance. MC analysis is carried out by varying the Width and Length of transistor of each one for 30 feasible solutions more than 1000 runs for different threshold levels, and considering a Gaussian distribution with 10% Deviation. Hence the output of the final response is altered in accordance with the challenges and inputstimulus for different processing corners like high (H), regular (R), low (L). For the proposed CMOS TRx architecture, we have estimated the output in different threshold voltage (Vt) levels such as HVt, RVt and LVt respectively. From the obtained histograms the performance observed such as 42%, 45% and 46% for HVt, RVt and LVt for CMOS TRx retina chip set as in Fig.5.1 (a), (b), (c). Table.I gives the summary of retina chip set proposed topology.



(a)



(b)



(c)

Fig.5.1. Histogram of CMOS TRx receiver signal
(a). HVt (b). RVt (c). LVt

Table.I Specifications summary of proposed retina chipset

Parameters	***Details***
Technology	CMOS 180nm
Design	Epiretinal retina chipset
Uplink model	CMOS Transceiver
Modulation technique	Binary phase shift keying
Data & power transfer	Wireless Inductive coupling
Carrier frequency	13.56MHz
Process variation	Monte Carlo analysis
Configuration steps	10-bit
Stimulation Current of chip	4.5μA

6. Conclusion

A design method was proposed for the propagation of action potential inside the retina neuron by integrating the inductive power transfer method from external source to the implant. A CMOS transceiver block is designed for the data transmission using two inductive links knows as primary and secondary considering the secondary resonance to be high than primary resonance. Further for modulation the binary phase shift keying is carried with frequency of 13.56MHz modulates within two carrier cycles to achieve high data rate. And the performance of the resultant signal is measured using Monte Carlo analysis in 180nm technology considering different corners.

Conflicts of interest

The authors declare no conflicts of interest.

References

[1]. Kim, J.; Ko, H. Self-Biased Ultralow Power Current-Reused Neural Amplifier with on-Chip Analog Spike Detections. IEEE Access 2019, 7, 109792–109803. [CrossRef]

[2]. Different Parts of Body Suitable for Implanted Devices. Available online:http://technologyandsociety.org/implantabletechnology/ (accessed on 25 January 2022)

[3]. Kouhalvandi, L.; Matekovits, L.; Peter, I. Magic of 5G Technology and Optimization Methods Applied to Biomedical Devices: A Survey. Appl. Sci. 2022, 12, 7096. [CrossRef]

[4]. Komolafe, A., Zaghari, B., Torah, R., Weddell, A.S., Khanbareh, H., Tsikriteas, Z.M., Vousden, M., Wagih, M., Jurado, U.T., Shi, J. and Yong, S., 2021. E-textile technology review–from materials to application. Ieee Access, 9, pp.97152-97179.

[5]. Stanslaski, S.; Herron, J.; Chouinard, T.; Bourget, D.; Isaacson, B.; Kremen, V.; Opri, E.; Drew,W.; Brinkmann, B.H.; Gunduz, A.; et al. A Chronically Implantable Neural Coprocessor for Investigating the Treatment of Neurological Disorders. IEEE Trans.Biomed. Circuits Syst. 2018, 12, 1230–1245. [CrossRef]

[6]. Chiu, C.Y.; Zhang, Z.C.; Lin, T.H. Design of a 0.6-V, 429-MHz FSK Transceiver Using Q-Enhanced and Direct Power Transfer Techniques in 90-nm CMOS. IEEE J. Solid-State Circuits 2020, 55, 3024–3035. [CrossRef]

[7]. Liu, X.; Zhu, H.; Zhang, M.; Wu, X.; Richardson, A.G.; Sritharan, S.Y.; Ge, D.; Shu, Y.; Lucas, T.H.; Van der Spiegel, J. A fullywireless sensor-brain interface system to rest ore finger sensation. In Proceedings of the 2017 IEEE International Symposium on Circuits and Systems (ISCAS), Baltimore, MD, USA, 28–31 May 2017; pp. 1–4. [CrossRef]

[8]. Lee, J.; Lee, K.R.; Ha, U.; Kim, J.H.; Lee, K.; Gweon, S.; Jang, J.; Yoo, H.J. A 0.8-V 82.9 μW In-Ear BCI Controller IC with 8.8 PEF EEG Instrumentation Amplifier and Wireless BAN Transceiver. IEEE J. Solid-State Circuits 2019, 54, 1185–1195. [CrossRef].

[9]. H. Yu and K. Najafi, "Low-power interface circuits for bioimplantable microsystems", Technical Digest, IEEE Int. Conf. Solid-State Circuits, San Francisco CA, February 2003.

[10]. M. Ghovanloo and K. Najafi, "A high data-rate frequency shift keying demodulator chip for the wireless biomedical implants," Proc. IEEE Int. Symp. Circuits and Systems (ISCAS), vol. 5, pp. 45-48, May2003.

[11] M. Ghovanloo and K. Najafi, "A fully digital frequency shift keying demodulator chip for the wireless biomedical implnats," Proc. IEEE Southwest Symp. Mixed-Signal Design, pp. 223-227, Feb. 2003.

[12]. C.-S.A. Gong, M.-T. Shiue, K.-W. Yao, T.-Y. Chen, "Low-power and area-efficient PSK demodualtor for wirelessly powered implantable command receivers," Electronics Letters, vol. 44, Issue 14, pp. 841-842, July 2008.

[13] F. Asgarian, A.M. Sodagar, "A high-data-rate low-power BPSK demodulator and clock recovery circuit for implantable biomedical devices," Proc. 4th Int.

IEEE/EMBS Conf. Neural Eng., pp. 407-410, April 29 – May 2, 2009.
[14]. Trigui A, Ali M, Ammari A C, et al. A 1.5-pJ/bit, 9.04-Mbit/s carrier-width demodulator for data transmission over an inductive link supporting power and data transfer. IEEE Trans Circ Syst II, 2018, 65: 1420–1424
[15]. Lee S-Y, Hsieh C-H, Yang C-M. Wireless front-end with power management for an implantable cardiac microstimulator. IEEE Trans Biomed Circ Syst, 2012, 6: 28–38
[16]. Ha S, Kim C, Park J, et al. Energy recycling telemetry ic with simultaneous 11.5 mW power and 6.78 Mb/s backward data delivery over a single 13.56 MHz inductive link. IEEE J Solid-State Circuits, 2016, 51: 2664–2678
[17]. Chen, M., Pan, L., Lin, Q., Cheng, L. and Ming, D., 2023. A70%-power transmission efficiency, 3.39 Mbps power and data telemetry over a single 13.56 MHz inductive link for biomedical implants. Science China Information Sciences, 66(2), p.122406.
[18]. Rush A D, Troyk P R. A power and data link for a wireless-implanted neural recording system. IEEE Trans Biomed Eng, 2012, 59: 3255–3262
[19]. Akram MA, Yang KW, Ha S. Duty-Cycled Wireless Power Transmission for Millimeter-Sized Biomedical Implants. Electronics. 2020 Dec;9(12):2130
[20]. Roessler G:, "Implantation and explanation of a wireless epiretinal retina implant device: observations during the EPIRET3 prospective clinical trial". Investigative ophthalmology & visual science, 50(6), 3003–3008, (2009).
[21]. Keserü M:, "Acute electrical stimulation of the human retina with an epiretinal electrode array". Actaophthalmologica, 90(1), (2012).
[22]. Kitiratschky V.B:, "Safety evaluation of “retina implant alpha IMS”—a prospective clinical trial". Graefe's Archive for Clinical and Experimental Ophthalmology, 253(3), 381–387, (2015).
[23]. Linsenmeier R.A., Zhang H.F:, "Retinal oxygen: from animals to humans". Progress in retinal and eye research,58(1), 115-151, (2017).
[24]. Fujikado T:, "One-Year Outcome of 49-Channel Suprachoroidal–Transretinal Stimulation Prosthesis in Patients With Advanced Retinitis Pigmentosa". Investigative ophthalmology & visual science. 57(14), 6147–6157, (2016).
[25]. Fujikado T:, "Testing of semichronically implanted retinal prosthesis by suprachoroidal- transretinal stimulation in patients with retinitis pigmentosa". Investigative ophthalmology & visual science, 52(7), 4726–4733, (2011).
[26]. Delbeke J., Oozeer M., Veraart C:, "Position, size and luminosity of phosphenes generated by direct optic nerve stimulation". Vision research, 43(9), 1091–1102, (2003).
[27]. Katikala, Hima Bindu, Telagathoti Pitchaiah, and G. Ramana Murthy. "Low Readout Noise Photodiode based CMOS Image Sensor with High Fill Factor for Biomedical application." In 2022 IEEE Delhi Section Conference (DELCON), pp. 1-5. IEEE, 2022.