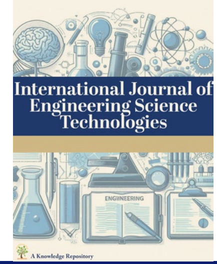
International Journal of Engineering Science Technologies

January-February 2026 10(1)

www.ijoest.com



Original Article

ROLE OF VLSI IN MODERN BIOMEDICAL APPLICATIONS

Saima Siddiqui [1*], **Neha Singh** [2]

[1] Department of Electronics and Communication Indira Gandhi Delhi Technical University for Women, New Delhi, India

[2] Assistant Professor, Electronics and Communication Department, Indira Gandhi Delhi Technical University for Women, New Delhi, India

ABSTRACT

Very Large Scale Integration (VLSI) means integrating a number of transistors in a single chip to create an electronic circuit. It has become the necessity of modern biomedical systems, in which many microprocessors, memory chips and Integrated circuits (ICs) are fabricated for continuous sensing of patient's health details and for data integration interface in which patient's data are transferred securely. This review summarizes recent advancements (2021–2025) regarding the role of VLSI circuits in facilitating the entire continuum of patient-centered healthcare, ranging from analog front-ends that capture micro-volt bio signals to edge-AI accelerators that provide on-device diagnosis while ensuring privacy. We organized the application of VLSI circuits in biomedicals like wearable monitoring (ECG/EEG), implantable therapeutics (pacemakers, neuro stimulators), biomedical imaging (ultrasound/X-ray readout SoCs), and neuromorphic/AI-enabled bio signal processing in a table. In modern biomedical applications, VLSI plays three major roles: (1) Miniaturization i.e. fitting a large number of ICs in a single small silicon chip which is easy to wear and implanted inside the body due to its small size. Wearable and Implantable devices are made using these techniques; (2) Reliability i.e. less number of failures and long-term usage; (3) Low power consumption by using low power VLSI design. This review paper gives an overview of evolution of VLSI in biomedical engineering, wearables and implantable devices integration, Imaging, neuromorphic and AI enabled VLSI system and at last some challenges that we face for low power VLSI design and its principles. In future, Biomedical, VLSI and AI engineers if combined together can give rise to many advancements in the clinical needs by scaling it with limited resources while keeping in mind that cost should also be low. The whole healthcare system should make a strategic tool for making biomedical devices less costly, safer, more accurate, and easier to use for patients and it can only possible by combining VLSI and AI in it.

Keywords: Very Large Scale Integration (VLSI), Biomedical, System on Chip (Soc), Application Specific Integrated Circuit (ASIC), Low Power VLSI Design, Wearable and Implantable Devices, Neuromorphic Computing.

INTRODUCTION

Life science and VLSI technology transforms the field of biomedical engineering to a great extent. The advancement in design of semiconductor and fabrication process changes a lot in these past two decades by integrating thousand to millions of transistors and other components like inductor, capacitor resistors etc. that are located on the single chip of silicon.

*Corresponding Author:
Email address: Saima Siddiqui (myselfsaima10@gmail.com), Neha Singh (nehasigdtuw@gmail.com)

Received: 09 November 2025; **Accepted:** 28 December 2025; **Published** 20 January 2026
DOI: 10.29121/IJOEST.v10.i1.2026.732
Page Number: 10-16
Journal Title: International Journal of Engineering Science Technologies
Journal Abbreviation: Int. J. Eng. Sci. Tech
Online ISSN: 2456-8651
Publisher: Granthaalayah Publications and Printers, India
Conflict of Interests: The authors declare that they have no competing interests.
Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.
Authors' Contributions: Each author made an equal contribution to the conception and design of the study. All authors have reviewed and approved the final version of the manuscript for publication.
Transparency: The authors affirm that this manuscript presents an honest, accurate, and transparent account of the study. All essential aspects have been included, and any deviations from the original study plan have been clearly explained. The writing process strictly adhered to established ethical standards.

Biomedical instruments that were used in the past were large devices that required training from specialized person and a huge amount of power to operate. These instruments were rarely located in laboratories. ECG monitors, EEG analyzers, and medical imaging devices were exclusively accessible in hospitals and clinics, which made them difficult to acquire and expand. The utilization of VLSI technology has eliminated these obstacles by reducing the size, weight, and power consumption of objects. This has enabled the development of healthcare solutions that are implantable, wearable, and portable healthcare equipment. Diagnostic tests can now occur in small labs and outside of hospitals, as these new technologies are capable of monitoring and diagnosing patients in an easy manner. The advance architecture of Internet of Medical Things (IoMT) Srivastava et al. (2022) which integrate sensors, processors, and communication modules on a single device, has enhanced the functionality of remote and predictive healthcare systems. Through data driven interface, these systems establish connections between patients and physicians.

Currently, a biomedical electronic system is composed of numerous VLSI-based subsystems that operate in conjunction. Analog Front-End (AFE)Kledrowetz et al. (2022) circuits at the front end amplify, filter, and condition weak bio-potentials from the heart (ECG), brain (EEG), or muscles (EMGs). These analog signals, which are typically in the microvolt range, are highly susceptible to interference and noise. Precision VLSI design techniques, such as low-noise amplification and chopper stabilization, are employed to ensure that the signals are exceptionally distinct. the conditioned signals are digitized by high-resolution Analog- to-Digital Converters (ADCs). In order to conserve energy, these converters typically operate on supplies that are less than 1V Vafaei et al. (2022). The digitized data is directed to digital processing units, where machine learning algorithms or signal processing blocks identify clinically significant features such as arrhythmias, seizure patterns, or neural activity.

On-chip radios and wireless communication interfaces, such as Bluetooth Low Energy (BLE), Zig bee, and Near Field Communication (NFC), securely transmit processed data to other devices or cloud-based analytics servers that are located further down the signal chain. There is no need of different circuit boards for integrating various components into the architecture of single system on chip (SoC). This architecture reduces cost of manufacturing, power dissipation and system delay. More of this, in these days' semiconductor devices simplifies heterogeneous integration which enhances integration of analog, digital and memory devices on a single chip in an uninterrupted way. The dream of using personalized healthcare has become reality by this small yet powerful chip architecture.

VLSI design emerged as more effective as of recent advances in which VLSI architecture perform more function than only signal processing. Moreover, they can perform neuromorphic computation with AI. VLSI circuits that are enabled by AI are trained with hardware accelerators be able to perform intricate inference task like the disease classification like ECG signal classification for Arrhythmia detection or anomaly detection using machine learning on the semiconductor eliminating the usage of external servers. This is called edge intelligence Shankar et al. (2024). It improves privacy, reduces delay, and enhaces life-support systems to perform real-time decisions. Brain-computer interfaces (BCI) and prosthetic control application means if any one loses their body parts in an accident can be replaced by artificial prosthetics which can analyses signals in a manner that is both energy-efficient and flexible by utilizing neuromorphic VLSI architectures, which imitate the function of biological neurons.

The integration of both technologies give rise to the invention of intelligent healthcare ecosystems, in which diagnostic and therapeutic and self-contained devices. As for example an implantable neural stimulator can check brain activity and the data with the AI accelerator and it delivers a corrective stimulus within a fraction of second. These closed-loop systems have been made feasible by the capacity of VLSI design to reduce the size and intelligence of objects. They are the future of medicine that is both precise and personalized.

EVOLUTION OF VLSI IN BIOMEDICAL ENGINEERING

Like shrinking of semiconductors chips, biomedical electronics have also gone through many transformations over the course of time. With each new generation of technology, new concepts have been introduced in the field of medical tools. In the phase of 1970s and 1980s, a large number of biomedical devices were manufactured using hybrid analog boards. These boards had individual components such as different types of resistors, capacitors, and operational amplifiers. In the beginning, these circuits were quite large which consume so much power.

Electrocardiograms (ECGs) signals classification as normal and abnormal heart beat, regulating hearing aids and controlling cardiac pacemakers were all biomedical applications, but the portability of these devices was not present in order to achieve reliability. When that time period occurred, the integration density was rather low, and the type of subsystem that was most prevalent was the analog subsystem. As a result, it was difficult for systems to develop and become more intelligent. The late 1980s and 1990s comes the revolution of Complementary Metal–Oxide–Semiconductor (CMOS) technology, which was a significant turning point in the history of semiconductor technology. By the time,low static power dissipation, good noise immunity, and great scalability, CMOS proved to be an ideal choice for biomedical instruments that required both precision and energy efficiency. During this time period, researchers began working on low-power integrated amplifiers, bio-potential sensors, and high-resolution analog-to-digital converters (ADCs) that were specifically designed for the collection of physiological data. The introduction of portable electrocardiogram (ECG) monitors and blood pressure sensors, which are both battery-powered and small in size, has made medical care far more accessible and affordable. A trend known as miniaturization emerged as a result of Moore's Law which made it feasible to include these circuits into smaller devices without compromising the quality of the signal. At the beginning of the twenty-first century, the technology of semiconductors had progressed to the point that it could support System-on-Chip (SoC) designs. These architectures were able to mix analog, digital, memory, and wireless modules on a mere silicon die. As a result of this modification, biomedical equipment went from being simple signal amplifiers to becoming intelligent platforms that might become connected to networks. By including analog front-ends (AFEs) for bio signal collecting, digital signal processors (DSPs) for feature extraction, and wireless transceivers for telemetry, SOCs were able to integrate sensing, computing, and communication into a single compact unit. This architecture was used as the foundation for implantable systems and wearable medical devices that were supposed to provide continuous real-time monitoring. At the same time, Application-Specific Integrated Circuits (ASICs) developed inexpensive methods of doing specific jobs such as controlling pacemakers, stimulating cochlear nerves, and recording neurological activity. The dependability and autonomy of biomedical systems were significantly improved as a result of these breakthroughs, which made it possible to provide healthcare that was both widespread and individualized.

The biomedical industry entered in a transition period between the years 2021 and 2025, which has been defined by three significant technological shifts that makes the way in which VLSI contributes to healthcare innovation: -

FROM COMPUTATION TO COGNITION

The goal of VLSI designs shifted from only computing data like mathematics to being able to think and learn means cognition. Through the implementation of on-chip neural networks and machine learning algorithms, devices are trained with physiological data in a frequent manner and make decisions according to dataset obtained from different hospitals. As an illustration, contemporary ASICs and SoCs are able to identify arrhythmias in real time, forecast seizures, and modify stimulation based on feedback from the patient's vital signs. The requirement for cloud connectivity is reduced thanks to edge AI accelerators that are embedded into hardware, which causes diagnostics to be completed more quickly and securely.

TRANSITIONING FROM RIGID TO FLEXIBLE ELECTRONICS

The transition from traditional rigid silicon wafers to flexible, stretchy, and biocompatible substrates has been a significant stepping stone in the field of biomedical very large-scale integration (VLSI) research. Circuits can be shaped to fit the shape of the body or the organs that are contained within it thanks to these new materials, such as polymer-based or thin- film transistors. The development of flexible VLSI systems has made it possible to manufacture skin-mounted sensors, electronics that are applied to the skin, and implanted devices that are able to bend and stretch with biological tissues without causing pain or mechanical failure. In addition to making patients feel more at ease, these kinds of advancements also make it feasible to monitor their health in a continuous manner and for an extended amount of time while they are in their natural physiological state.

FROM CLINIC TO COMMUNITY

Current digital transformation in healthcare sector is made possible and feasible by the downsizing of VLSI, which allowed the relocation of diagnosis and continuous monitoring from hospitals to homes and to communities. The increased adoption of VLSI based electronic mobile devices and telemedicine platforms have enabled users to monitor their vital signs even from a distance and reduce the gap with healthcare providers and patients in real time. This resulted in more accessible healthcare facilities to all the users specifically those who are living in remote areas and are deprived of sufficient resources and facilities. This all happened because of built-in VLSI systems, that allow healthcare providers to operate remote diagnostics, predict potential issues and start preventative care. All these facilities are coming in light because of Internet of Things connectivity secure data transmission and AI-driven analytics.

IMPLANTABLE AND WEARABLE VLSI SYSTEMS

There are two most useful applications of Very large-scale integration (VLSI) technology with respect to medicine are implantable and wearable VLSI system. At the same time, both categories are concerned with ensuring that biological processes and technological intelligence are able to communicate with one another without any complications. However, when it comes to design priorities, operating environments, and system restrictions, they are significantly different from one another by a significant margin. Wearable devices need to be able to monitor physiological parameters in daily life without being overly visible or difficult to use, while implantable devices need to be able to function safely inside the body for years without requiring any maintenance.

IMPLANTABLE SYSTEMS

Application Specific Integrated Circuits (ASIC) play a significant role in implantable medical devices (IMDs), which include cardiac pacemakers, implantable cardioverter- defibrillators (ICDs), cochlear implants, retinal prosthesis, and deep-brain stimulators (DBS)Shah et al. (2022). Controlling sensing, signal processing, actuation, and feedback are all functions that they are employed for. The circuits must be very small, use very little power (less than 5 mW), safe from electromagnetic interference, and work for a long time. Maximizing the operational life of a device is a main design goal because replacing it often requires surgery.

A mix of circuit-level and system-level methods is used to make power use more efficient. Sub-threshold logic uses transistors that work below the threshold voltage to save up to 90% of energy, but it does so at a slower speed, which is fine for physiological signals that don't change very often. Adaptive biasing changes the current levels based on how active the signal is, making sure that power is only used when computation or communication is needed. Also, energy harvesting circuits that use RF induction, piezoelectric motion, or body-heat thermoelectric conversion to get energy are being used more and more in implantable systems. This means that the systems don't need to rely as much on internal batteries. Inductive power links, for example, let energy be sent wirelessly and allow two-way communication. This means that you can recharge your device and change its settings without having to go through any invasive procedures.

In implantable systems, multi-channel analog front-ends (AFEs) Ansari et al. (2019) and closed-loop feedback mechanisms are used to get and control signals. For instance, in pacemakers, VLSI-based sensors find irregular heart rhythms, digital controllers figure out when to stimulate the heart, and actuators send precise electrical pulses to the heart tissue. Deep-brain stimulators also use on-chip amplifiers and signal classifiers to find bad neural patterns, like those that happen in Parkinson's disease, and send corrective stimuli in real time. Combining these sensing and stimulation functions on one ASIC reduces latency, makes sure that everything is in sync, and improves the accuracy of the treatment.

WEARABLE SYSTEMS

The significant differences of wearable medical devices from implants are that they provide more comfort, flexibility and wireless connectivity. These benefits allow users to check heart rate, oxygen saturation, temperature, blood glucose levels and muscular activities in real time. Contemporary modern wearable circuits are designs using flexible CMOS and polymer based substrates. These wearable devices can adjust accordingly to the skin and do not even cause irritation to the skin. These devices catch bio signals even if a user is in moving state.

Wireless communication is a key part of how wearables work. VLSI circuits that combine Bluetooth Low Energy (BLE), Near-Field Communication (NFC), or Zig bee transceivers make it possible to send data to smartphones or medical gateways using very little power. For instance, BLE-based systems use duty- cycled protocols to keep data flowing all the time while using only microwatts of power.

INTEGRATION AND OUTLOOK OF WEARABLE AND IMPLANTALE SYSTEMS

Both implantable and wearable biomedical systems show how VLSI has made it possible to provide care that ranges from hospital-grade accuracy to the ease of use at home. Implantable give direct treatment, while wearables give information that can help prevent problems and predict them. As materials science, microfabrication, and AI co-design keep getting better, future systems are likely to combine these two ideas into semi- implantable and hybrid architectures. These are devices that can be worn on the outside but interact with the body in a deeper way. This will lead to a generation of healthcare electronics that are smart, use less energy, and work perfectly with the human body. This will make personalized, connected, and autonomous medicine possible in the future.

IMAGING, NEUROMORPHIC, AND AI-ENABLED VLSI SYSTEMS

The incorporation of Very-Large-Scale Integration (VLSI) technology into biomedical imaging and artificial intelligence (AI) systems has significantly transformed diagnostic, therapeutic, and assistive healthcare. Biomedical imaging systems have become faster, more energy-efficient, and much smaller thanks to the creation of custom Application-Specific Integrated Circuits (ASICs) and System-on-Chip (SoC) architectures. This means that diagnostic tools that used to only be available in hospitals can now be used in portable and point- of-care devices. Neuromorphic and AI-enabled circuits have both made progress at the same time, which has led to hardware architectures that can interpret data in real time, learn on their own, and make decisions in closed loops. These changes have moved healthcare from just watching to smart, context-aware intervention.

VLSI IN BIOMEDICAL IMAGING SYSTEMS

To make high-quality images from complicated biological data, biomedical imaging needs a lot of accuracy and speed. Ultrasound, X-ray, computed tomography (CT), magnetic resonance imaging (MRI), and optical imaging are all examples of traditional imaging methods that use arrays of sensors and high-speed signal-processing units. This makes them perfect for VLSI-based implementation.In ultrasound imaging, modern beamforming ASICs integrate analog front-end (AFE) channels, transmit/receive (T/R) switches, time-gain compensation amplifiers, and digital demodulation blocks on a single chip. These VLSI designs cut down on unwanted noise, make signal paths shorter, and allow for huge amounts of parallelism across hundreds of channels. The recent “Fast volumetric ultrasound facilitates high-resolution 3D mapping of tissue compartments” Park et al.

(2023),256-channel ultrasound SoC is an example of how on-chip beamforming can greatly improve image quality while cutting power use by more than 30% compared to separate architectures.

For X-ray and CT imaging, column-parallel ADC architectures are now the standard VLSI solution for reading out detectors. These circuits allow thousands of pixels to be digitized at the same time, which greatly speeds up frame rates while keeping the dynamic range high. Mixed-signal ASICs control gradients, compress data, and digitize sensor outputs at high speeds in MRI and nuclear imaging. This makes it possible to build small scanners and mobile diagnostic platforms. New optical biosensors based on VLSI, like CMOS image sensors and photodiode arrays, make it possible to image cells and molecules. Because they have high pixel densities and built-in digital interfaces, they can be used for fluorescence microscopy, pulse oximetry, and retinal diagnostics with real- time feedback. VLSI has changed biomedical imaging from heavy lab machineries to portable and AI-assisted imaging-on- chip systems.

NEUROMORPHIC VLSI FOR BIOMEDICAL INTELLIGENCE

Neuromorphic VLSI architectures allow biological neural networks to process bio signals with more efficiency. With the help of synaptic and spiking neurons they send information by asynchronous event driven signaling, a process which is very similar to the communication mechanism followed by the neurons of human brain. Significant features of this design are low power, fault tolerance and parallel computation. These designs are very great for medical devices which require continuous monitoring and lack heavy power sources.

There are some newly designed neuromorphic chips like resistive random-access memory (RRAM) or memristor-based crossbar arrays which can perform in memory computing allowing data storage and processing occurring in the same physical space. This reduces the bottleneck which occurs when data moves between memory and logic units, which significantly cut down the energy usage and latency. For bio signals classification, RRAM-based in-memory computing framework Krause et al. (2021) resulted in a 40-fold reduction in energy consumption. Neuromorphic circuits are getting popular in real-life biomedical applications such as brain-machine interfaces (BMIs) and neuoprosthetic system.

The neural activity is decoded in real time which eases users with prosthetic limbs, or paralyzed people, making adaptive deep-brain stimulation an easy task. These circuits allow learning from feedback allowing it for closed-loop neuro therapeutic systems which changed therapy based on the functioning of brain. These Neuromorphic processors based on VLSI are creating a big impact in biomedical areas connect electronic intelligence and biological computation allowing machines and humans to work together.

AI-ENABLED VLSI AND EDGE INTELLIGENCE

The recent rise of AI has made VLSI's job much bigger than just digital design. VLSI systems with AI have special hardware accelerators for machine learning models like Convolutional Neural Networks (CNNs), Recurrent Neural Networks (RNNs), and Long Short-Term Memory (LSTM) architectures. These accelerators use parallel multiply-accumulate (MAC) arrays, weight quantization, and data reuse methods to do deep learning inference on biomedical devices. For instance, CNN accelerators for arrhythmia classification are now built into wearable ECG systems, and on-chip neural networks for organ segmentation and tissue characterization are now built into portable ultrasound probes.

The development of AI-VLSI co-design is also helping personalized medicine to grow. By combining local inference with cloud-assisted learning, systems can keep data safe while constantly changing models to fit each patient. Researchers are looking into using Explainable AI (XAI) modules Sadeghi et al. (2024) built into hardware to make medical decision-making more open and honest, which is necessary for clinical use to meet ethical and legal standards.

LOW-POWER VLSI DESIGN CHALLENGES AND PRINCIPLES

In biomedical devices, how much energy they use has a direct effect on how easy they are to use and how comfortable they are for patients. Implantable devices like pacemakers or deep- brain stimulators can stay in the body for more than ten years. On the other hand, wearable monitors need to work all the time for days or weeks on small batteries. The goal of low-power design is to reduce power use in all of the analog, digital, memory, and communication subsystems without affecting the accuracy of diagnostics or the quality of the signal.

Three things make up most of the power budget for a typical wearable or implantable system:

Signal acquisition (Analog Front-End, AFE) – amplifiers, filters, and ADCs;

Computation (DSP or AI accelerator) – extracting features or putting them into groups;

Communication (wireless radio) means sending data over BLE, NFC, or inductive links.

Designers often trade continuous streaming for local processing and event-driven transmission because radios and computers use a lot of power. Edge intelligence is the name of this method. It lets systems send only useful diagnostic events instead of raw data streams, which can cut power use by up to 90%.

Several well-known methods make up the basis of low-power biomedical VLSI design at the circuit level:

Sub-threshold and near-threshold logic: When MOS transistors work below or close to the threshold voltage, dynamic power drops by a factor of four with supply voltage. Sub-threshold circuits use less than 10 μW of power, which is very low and good for implantable, but they are slower than other circuits. Compensation networks are used by designers to deal with the process and temperature changes that are common in this regime.

Dynamic Voltage and Frequency Scaling (DVFS): DVFS makes sure that computation only uses as much energy as it needs by changing the supply voltage and clock frequency based on the workload. For example, a pacemaker can lower the frequency of processing when the heart rhythm is stable and raise it when it detects an arrhythmia.

Power Gating and Clock Gating: High-Vt sleep transistors are used to disconnect idle logic blocks from supply rails, which almost completely stops leakage current. Clock gating stops unnecessary toggling in sequential circuits, which saves dynamic energy.

In-Memory Computing and Data Locality: Modern biomedical chips cut down on data movement, which is the main source of energy in AI workloads, by putting computation and memory close together (for example, by using SRAM/RRAM arrays). This method makes things faster and extends battery life, especially for wearable health trackers with built-in CNN and RNN accelerators.

TRENDS IN BIOMEDICAL VLSI DESIGN (2021–2025)

This table summarizes VLSI implementations developed between 2021 and 2025 across diverse biomedical applications:

Table 1

Table 1

Application Domain	Title of research paper	Use of VLSI in the paper	Year
ECG/EEG Acquisition	Ultra-Low Power Programmable Bandwidth Capacitively- Coupled Chopper Instrumentation Amplifier Using 0.2 V Supply for Biomedical Applications Pham et al. (2023)	0.18 μm CMOS technology process, chip area of 0.083 mm2, power consumption of 0.47 μW at 0.2 and 0.8 V supply	2023
Wearbles / Implantable	From Wearables to Implantables: Harnessing Sensor Technologies for Continuous Health Monitoring Koruprolu et al. (2025)	Low power analog and mixed signal VLSI circuit, VLSI for miniaturization	2025
Neural Stimulator	A Highly Miniaturized, Chronically Implanted ASIC for Electrical Nerve Stimulation Shah et al. (2022)	Biomedical ASIC integrates analog, digital, and power circuits into a tiny implantable SoC (Silicon on chip) for neural stimulation	2022
Wearable ECG Classifier	A configurable hardware- efficient ECG classification inference engine based on CNN for mobile healthcare applications Zhang et al. (2023)	VLSI design are used for CNN architectures using ASICs or FPGAs	2023
Ultrasound Imaging	A 48-Channel High-Resolution Ultrasound Beamforming System for Ultrasound Endoscopy Applications Yun et al. (2023)	ASIC-based beamforming system for ultrasound endoscopy	2024
Pacemaker Controller	Robust neuromorphic coupled oscillators for adaptive pacemakers Krause et al. (2021)	Mixed-signal neuromorphic VLSI processor to generate coupled oscillation	2021
Portable MRI System	A Miniature Multinuclei NMR/MRI Platform With a High-Voltage SOI ASIC Fan et al. (2025)	ASIC using High Voltage Silicon on Insulator (HV- SOI). The SOI-based VLSI implementation provides superior electrical isolation	2025

CONCLUSION

The old designed early analog boards have transformed into ultra-low power CMOS SoCs and ASICs which integrate AI accelerators, neuromorphic cores and secure radios which delivers hospital grade functions in mobile implantable devices. With the help of VLSI complete signal chains across biomedical modalities can be achieved. Accurate bio signal acquisition can be achieved with the help of low noise analog front ends and high-resolution ADCs. Compact DSP and ML engines allow real time classification with micro joule level energy budgets. In the areas of medical image beam forming ASICs and column parallel readouts have simplified ultrasound and X ray procedures. Neuromorphic and in memory computing architectures now allow embed learning directly near sensors which reduce latency and power required.

FUTURE PERSPECTIVE

The trio of Biomedical, VLSI and AI engineers leads to great advancements in healthcare sectors which are now coming closer these days and after a decade if they combine leads to more advanced medical facilities in healthcare sectors.

ACKNOWLEDGMENTS

None.

REFERENCES

Ansari, M. S. (2019). Analog Front-End Design for Biomedical Signal Acquisition Systems. CSIT, 7(3), 199–204. https://doi.org/10.1007/s40012-019-00232-z

Chen, W., Qi, Z., Akhtar, Z., and Siddique, K. (2021). Resistive-RAM-based in-Memory Computing for Neural Network: A Review. Electronics, 11(22), 3667. https://doi.org/10.3390/electronics11223667

Fan, S., Zhou, Q., Lei, K.-M., Martins, R. P., and Mak, P.-I. (2025). A Miniature Multinuclei NMR/MRI Platform with a High-Voltage SOI ASIC. IEEE Journal of Solid-State Circuits, 60 (6), 2013–2024. https://doi.org/10.1109/JSSC.2024.3485123

Kledrowetz, V., Prokop, R., Fujcik, L., and Haze, J. (2022). A Fully Differential Analog Front-end for Signal Processing from EMG Sensor in 28 nm FDSOI Technology. Sensors, 23(7), 3422. https://doi.org/10.3390/s23073422

Koruprolu, A., Hack, T., Ghadami, O., Jain, A., and Hall, D. A. (2025). From Wearables to Implantables: Harnessing Sensor Technologies for Continuous Health Monitoring. IEEE Transactions on Biomedical Circuits and Systems.

Krause, R., Van Bavel, J. J., Wu, C., Vos, M. A., Nogaret, A., and Indiveri, G. (2021). Robust neuromorphic coupled oscillators for adaptive pacemakers. Scientific Reports, 11, Article 97314. https://doi.org/10.1038/s41598-021-97314-3

Park, Y., Cai, X., Foiret, J., Bendjador, H., Hyun, D., Fite, B. Z., Wodnicki, R., Dahl, J. J., Boutin, R. D., and Ferrara, K. W. (2023). Fast Volumetric Ultrasound Facilitates High-Resolution 3D Mapping of Tissue Compartments. Science Advances. https://doi.org/10.1126/sciadv.adg8176

Pham, X. T., Kieu, X. T., and Hoang, M. K. (2023). Ultra-low Power Programmable Bandwidth Capacitively-Coupled Chopper Instrumentation Amplifier Using 0.2 V Supply for Biomedical Applications. Journal of Low Power Electronics and Applications, 13(2), 37. https://doi.org/10.3390/jlpea13020037

Sadeghi, Z., et al. (2024). A Review of Explainable Artificial Intelligence in Healthcare. Computers and Electrical Engineering, 109, 109370. https://doi.org/10.1016/j.compeleceng.2024.109370

Shah, J. V., Quinkert, C. J., Collar, B. J., Williams, M. T., Biggs, E. N., and Irazoqui, P. P. (2022). A Highly Miniaturized, Chronically Implanted ASIC for Electrical Nerve Stimulation. IEEE Transactions on Biomedical Circuits and Systems, 16(2), 233–243. https://doi.org/10.1109/TBCAS.2022.3153282

Shah, J., Quinkert, C., Collar, B., Williams, M., Biggs, E., and Irazoqui, P. (2022). A Highly Miniaturized, Chronically Implanted ASIC for Electrical Nerve Stimulation. IEEE Transactions on Biomedical Circuits and Systems, 16(2), 233–243. https://doi.org/10.1109/TBCAS.2022.3153282

Shankar, V. (2024). Edge AI: A Comprehensive Survey of Technologies, Applications, and Challenges. In 2024 1st International Conference on Advanced Computing and Emerging Technologies (ACET) (1–6). IEEE. https://doi.org/10.1109/ACET61898.2024.10730112

Srivastava, J., Routray, S., Ahmad, S., and Waris, M. M. (2022). Internet of Medical Things (Iomt)-Based Smart Healthcare System: Trends and Progress. Computational Intelligence and Neuroscience, 2022, 7218113. https://doi.org/10.1155/2022/7218113

Vafaei, M., Hosseini, M., Abiri, E., and Salehi, M. (2022). A 0.2-V 1.2-nW 1-KS/s SAR ADC with a novel comparator structure for biomedical applications. Integration, 88, 362–370. https://doi.org/10.1016/j.vlsi.2022.10.016

Yun, S., Lee, S., and Bae, J. (2023). A 48-Channel High-Resolution Ultrasound Beamforming System for Ultrasound Endoscopy Applications. Electronics, 13(3), 568. https://doi.org/10.3390/electronics13030568

Zhang, C., Li, J., Guo, P., Li, Q., Zhang, X., and Wang, X. (2023). A Configurable Hardware-Efficient ECG Classification Inference Engine Based on CNN for Mobile Healthcare Applications. Microelectronics Journal, 141, 105969. https://doi.org/10.1016/j.mejo.2023.105969