

Review Article

Progress in the Design and Analysis of Electrical and Electronic Systems

Shivendra Kumar

Student, Civil Engineering Department, Barkatullah University, MP, India

I N F O

E-mail Id:

kumarshivendra88@gmail.com

Orcid Id:

<http://orcid.org/0000-0002-7242-9812>

How to cite this article:

Kumar S. Progress in the Design and Analysis of Electrical and Electronic Systems. *J Engr Desg Anal* 2024; 7(1): 19-25.

Date of Submission: 2024-05-06

Date of Acceptance: 2024-06-10

A B S T R A C T

The design and analysis of electrical and electronic systems, circuits, devices, and components are critical areas in modern engineering, impacting numerous industries such as telecommunications, healthcare, automotive, and consumer electronics. This review article explores recent advances in these fields, focusing on emerging technologies, innovative design methodologies, and cutting-edge analytical techniques. Key topics include the development of energy-efficient circuits, the integration of advanced materials, the implementation of artificial intelligence in circuit design, and the advancements in simulation and modeling tools. Furthermore, the article delves into the challenges associated with these advancements, such as the scalable production of new materials, ensuring reliability in sub-threshold circuit operation, and the complexities of AI integration in design processes. By examining these developments and their implications, this review provides a comprehensive understanding of the current landscape and future directions in electrical and electronic system design and analysis.

Keywords: Energy-Efficient Circuit Design, Advanced Materials in Electronics, Artificial Intelligence in Circuit Design, Electromagnetic Simulation Tools Finite Element Analysis (FEA) in Electronics

Introduction

The field of electrical and electronic engineering is undergoing rapid transformation due to the continuous evolution of technology. From the miniaturization of components to the implementation of smart systems, the advancements in this area are redefining what is possible. This article aims to provide a comprehensive overview of the latest trends and breakthroughs in the design and analysis of electrical and electronic systems, circuits, devices, and components.

Electrical and electronic systems form the backbone of modern technological infrastructure. They are integral to diverse sectors, including telecommunications, healthcare, automotive, aerospace, and consumer electronics. The relentless pace of innovation in these sectors demands

more efficient, reliable, and powerful electronic systems. The convergence of various technological advancements, such as the Internet of Things (IoT), artificial intelligence (AI), and renewable energy solutions, further amplifies the need for cutting-edge design and analysis methodologies.

In telecommunications, the push towards 5G and beyond requires the development of high-frequency, low-latency circuits and systems. These advancements are crucial for enabling faster data transmission and supporting the increasing demand for mobile data. Similarly, the healthcare sector is seeing a surge in wearable and implantable devices, necessitating the creation of ultra-low-power circuits to extend battery life and ensure patient safety.

The automotive industry is experiencing a paradigm shift

with the advent of electric vehicles (EVs) and autonomous driving technologies. These innovations rely heavily on sophisticated electronic control systems and power electronics to enhance performance and safety. In aerospace, the demand for lightweight, high-reliability systems drives the need for advanced materials and components that can withstand extreme conditions.

Consumer electronics, ranging from smartphones to smart home devices, continue to push the boundaries of what is possible with compact, multifunctional circuits and systems. The integration of AI into these devices is creating smarter, more responsive products that can adapt to user needs in real time.

Despite these advancements, several challenges persist. The miniaturization of components often leads to increased power density, raising concerns about heat dissipation and thermal management. The integration of new materials, such as graphene and other 2D materials, into mainstream production processes remains a significant hurdle due to scalability and cost issues. Additionally, the complexity of modern electronic systems necessitates sophisticated simulation and modeling tools to ensure accuracy and reliability in design.

This review article explores these challenges and the innovative solutions being developed to address them. It delves into the latest techniques for energy-efficient circuit design, the role of advanced materials in enhancing device performance, and the impact of AI on circuit design and predictive maintenance. Furthermore, it examines the evolution of simulation and modeling tools that are crucial for the accurate analysis and optimization of electronic systems.

By providing a detailed examination of these topics, this article aims to offer valuable insights into the current state and future directions of electrical and electronic system design and analysis. It serves as a resource for engineers, researchers, and professionals in the field, highlighting the key trends, challenges, and opportunities that will shape the next generation of electronic technologies.¹⁻⁴

Energy-Efficient Circuit Design

One of the primary focuses in contemporary circuit design is energy efficiency. The increasing demand for portable and wearable electronics necessitates circuits that consume minimal power. Techniques such as sub-threshold operation, clock gating, and dynamic voltage and frequency scaling (DVFS) are widely used to reduce power consumption. These methods are crucial in extending battery life, reducing heat generation, and enabling the development of sustainable electronic devices.

Sub-Threshold Operation

Sub-threshold operation involves designing circuits that operate at voltages below the transistor's threshold voltage. This technique significantly reduces power consumption, as the exponential relationship between supply voltage and power dissipation allows for substantial energy savings. However, operating in the sub-threshold region presents challenges in maintaining performance and reliability due to the increased susceptibility to noise and variability in transistor behavior. Recent advancements have addressed these challenges by optimizing transistor sizing, leveraging advanced fabrication technologies, and employing error correction techniques to mitigate performance issues.

Clock Gating and DVFS

Clock gating is a technique where the clock signal is disabled in portions of a circuit that are not in use, thereby reducing dynamic power consumption. This method is particularly effective in reducing power usage in digital systems, such as microprocessors, where different functional units may not be active simultaneously. By selectively gating the clock, significant energy savings can be achieved without impacting overall system performance.

Dynamic voltage and frequency scaling (DVFS) adjusts the voltage and frequency according to the workload, optimizing energy usage dynamically. By lowering the supply voltage and operating frequency during periods of low activity, DVFS can reduce both dynamic and static power consumption. This technique is widely implemented in modern processors and system-on-chip (SoC) designs to balance performance and power efficiency. Recent developments in DVFS have focused on more granular control mechanisms and predictive algorithms that anticipate workload variations, further enhancing energy savings.

Ultra-Low Power Design Techniques

Beyond sub-threshold operation and DVFS, several other techniques contribute to ultra-low power design. These include:

- **Adiabatic Logic:** Adiabatic logic reduces power dissipation by recycling energy within the circuit. It uses reversible computing principles to ensure that energy is not entirely lost as heat during logical operations. This approach, while complex to implement, offers substantial power savings, especially in applications requiring repetitive operations.
- **Body Biasing:** Body biasing involves adjusting the substrate bias voltage of transistors to control their threshold voltage dynamically. This technique allows for power-performance trade-offs to be made on-the-fly, enabling circuits to operate in a low-power mode when full performance is not required.

- **Energy Harvesting:** Incorporating energy harvesting capabilities in circuits allows them to draw power from ambient sources such as light, vibration, or radio frequency signals. This approach is particularly beneficial for remote or embedded systems where replacing or recharging batteries is impractical.

Power Gating

Power gating is another effective technique for reducing static power consumption, especially in circuits with significant leakage currents. By disconnecting the power supply from inactive circuit blocks, power gating minimizes leakage currents that can drain the battery even when the device is not in use. Advanced power gating strategies involve fine-grained control and the use of multiple power domains within a single chip, allowing for more flexible and efficient power management.⁵⁻⁷

Case Studies and Applications

Several case studies highlight the successful implementation of energy-efficient circuit design techniques. For example, ultra-low-power microcontrollers used in IoT devices often combine multiple power-saving methods, including sub-threshold operation, clock gating, and DVFS, to extend battery life significantly. Wearable health monitors and fitness trackers utilize energy harvesting and body biasing to maintain continuous operation with minimal power consumption.

In high-performance computing, modern processors employ sophisticated power management units (PMUs) that dynamically adjust voltage and frequency based on real-time performance requirements. These processors achieve a delicate balance between delivering high computational power and maintaining energy efficiency, essential for data centers and supercomputers.

Advanced Materials and Devices

The integration of new materials into electronic devices has opened up new possibilities for performance enhancement and functionality. Advanced materials such as graphene, other two-dimensional (2D) materials, and wide bandgap semiconductors are revolutionizing the design and capabilities of electronic components. These materials offer superior electrical, thermal, and mechanical properties, enabling the development of high-speed, energy-efficient, and miniaturized devices.

Graphene and 2D Materials

Graphene, a single layer of carbon atoms arranged in a hexagonal lattice, exhibits exceptional electrical conductivity, mechanical strength, and thermal properties. Its high electron mobility makes it an ideal candidate for high-speed transistors and sensors. Graphene's flexibility and transparency also open up possibilities for flexible

and wearable electronics, transparent conductive films, and touchscreens.

Recent advancements in graphene-based devices include the development of graphene field-effect transistors (GFETs), which have shown potential for high-frequency applications beyond the capabilities of traditional silicon-based transistors. Additionally, graphene's sensitivity to various chemical and biological molecules makes it suitable for highly sensitive biosensors and gas detectors.

Other 2D materials, such as molybdenum disulfide (MoS₂) and hexagonal boron nitride (h-BN), complement graphene by providing semiconducting and insulating properties, respectively. These materials can be stacked to form heterostructures, creating devices with tailored electronic and optoelectronic properties. The combination of different 2D materials enables the creation of transistors, photo-detectors, and light-emitting diodes (LEDs) with enhanced performance.

Despite their potential, the scalable and cost-effective production of graphene and other 2D materials remains a significant challenge. Techniques such as chemical vapor deposition (CVD) and liquid-phase exfoliation are being refined to improve yield and material quality. Furthermore, integrating these materials into existing manufacturing processes requires advancements in transfer and patterning techniques.

Wide Bandgap Semiconductors

Wide bandgap semiconductors such as silicon carbide (SiC) and gallium nitride (GaN) offer superior performance in high-power and high-frequency applications. These materials have higher breakdown voltages, greater thermal conductivity, and faster switching speeds compared to traditional silicon, making them ideal for power electronics, radio frequency (RF) amplifiers, and optoelectronics.

Silicon Carbide (SiC): SiC is particularly advantageous in power electronics due to its ability to handle higher voltages and temperatures. SiC-based devices, such as Schottky diodes and MOSFETs, exhibit lower on-resistance and faster switching, leading to higher efficiency and reduced energy losses in power conversion systems. Applications include electric vehicle (EV) inverters, renewable energy systems, and industrial motor drives.

Gallium Nitride (GaN): GaN is known for its high electron mobility and high saturation velocity, making it suitable for RF and microwave devices. GaN transistors are used in high-frequency amplifiers for telecommunications, radar systems, and satellite communications. Additionally, GaN's efficiency in converting electrical power to light has made it a key material in LED technology, contributing to the widespread adoption of energy-efficient lighting.⁸⁻¹⁰

Emerging Materials and Techniques

The quest for advanced electronic materials is not limited to graphene and wide bandgap semiconductors. Several emerging materials and techniques are poised to further revolutionize the field:

Perovskites: Organic-inorganic perovskite materials have shown remarkable potential in photovoltaic applications due to their high absorption coefficients and tunable bandgaps. Perovskite solar cells have achieved impressive efficiencies, rivaling traditional silicon-based cells, and are being explored for use in LEDs and photodetectors.

Topological Insulators: These materials exhibit unique electronic properties, where the bulk acts as an insulator while the surface supports conductive states. Topological insulators hold promise for low-power, high-speed electronic devices and quantum computing applications.

Organic Electronics: Organic materials, composed of carbon-based molecules or polymers, are being developed for flexible and stretchable electronics. These materials are suitable for applications such as flexible displays, electronic skin, and wearable sensors due to their mechanical flexibility and ease of processing.

Spintronics: Spintronic devices exploit the intrinsic spin of electrons, along with their charge, to achieve high-speed and low-power operation. Materials like magnetic tunnel junctions (MTJs) are used in spintronic memory and logic devices, offering non-volatile storage and enhanced data processing capabilities.

Artificial Intelligence in Circuit Design

Artificial intelligence (AI) is revolutionizing the design process of electronic circuits, introducing unprecedented levels of efficiency, optimization, and innovation. By leveraging machine learning (ML) algorithms and data-driven approaches, AI enhances various stages of circuit design, from initial concept to final implementation. This section explores the key areas where AI is making a significant impact, including design automation, predictive maintenance, and the development of novel circuit architectures.

Design Automation

AI-driven design automation tools have transformed how engineers approach circuit design. These tools utilize ML algorithms to optimize circuit layouts, identify optimal configurations, and automate complex design tasks, significantly reducing the time and effort required.

Reinforcement Learning and Genetic Algorithms: AI techniques such as reinforcement learning (RL) and genetic algorithms (GA) are employed to explore the vast design space of electronic circuits. RL models learn to optimize circuit parameters by interacting with the design environ-

ment and receiving feedback on performance metrics. GAs mimic the process of natural selection, evolving circuit designs over successive generations to achieve desired characteristics. These approaches allow for the discovery of innovative design solutions that might be overlooked by traditional methods.

Schematic Generation and Layout Optimization: AI tools can automatically generate schematics and optimize layouts, ensuring efficient use of space and resources. By analyzing large datasets of existing designs, ML models can learn the best practices and apply them to new projects. This capability is particularly valuable in designing integrated circuits (ICs), where maximizing performance and minimizing area are critical.

Behavioral Modeling and Simulation: AI enhances the accuracy and speed of behavioral modeling and simulation. Predictive models can simulate circuit behavior under various conditions, identifying potential issues early in the design process. This capability reduces the need for extensive physical prototyping and accelerates the development cycle.¹¹⁻¹³

Predictive Maintenance

Machine learning models can analyze data from electronic systems to predict potential failures before they occur. This capability is crucial for maintaining the reliability of critical systems such as medical devices, aerospace electronics, and industrial machinery.

Anomaly Detection: AI algorithms can detect anomalies in circuit performance by continuously monitoring operational data. By comparing real-time data with historical patterns, these models can identify deviations that may indicate impending failures. This proactive approach enables timely maintenance and prevents costly downtime.

Fault Diagnosis: In the event of a failure, AI can assist in diagnosing the root cause by analyzing the sequence of events leading up to the fault. Machine learning models trained on extensive datasets of fault scenarios can pinpoint the most likely causes, facilitating rapid and accurate repairs.

Lifetime Prediction: AI models can predict the remaining useful life of electronic components based on usage patterns and environmental conditions. This information helps in planning maintenance schedules and optimizing the lifespan of devices, reducing the total cost of ownership.

Development of Novel Circuit Architectures

AI is also driving innovation in the development of novel circuit architectures, pushing the boundaries of what is possible with traditional design approaches.

Neuromorphic Computing: Inspired by the human brain, neuromorphic computing architectures aim to replicate

the brain's neural structure and functionality. AI plays a key role in designing these architectures, optimizing the arrangement and connectivity of artificial neurons and synapses. Neuromorphic circuits offer significant advantages in terms of energy efficiency and processing speed, making them suitable for applications such as pattern recognition, sensory processing, and autonomous systems.

Quantum Computing: Quantum circuits operate based on the principles of quantum mechanics, offering the potential for exponential increases in computational power. Designing quantum circuits is a complex task that AI can assist by optimizing qubit arrangements and error correction schemes. Machine learning algorithms are instrumental in identifying optimal configurations for quantum gates and circuits, accelerating the development of practical quantum computing systems.

Generative Design: Generative design leverages AI to create multiple design iterations based on defined performance criteria. By exploring a wide range of design possibilities, AI can identify innovative solutions that meet or exceed specified requirements. This approach is particularly useful in creating custom circuit designs for specialized applications, where traditional design methods may be limited.

Case Studies and Applications

Several case studies highlight the successful application of AI in circuit design:

Intel's AI-Driven Design Automation: Intel has implemented AI-driven design automation tools in its chip design process. These tools use machine learning to optimize power, performance, and area (PPA) metrics, resulting in more efficient and powerful processors. By automating repetitive and complex tasks, Intel has reduced design times and improved overall design quality.

IBM's Predictive Maintenance for Data Centers: IBM uses AI to monitor and predict the health of its data center infrastructure. Machine learning models analyze sensor data to detect anomalies and predict failures in power supplies, cooling systems, and servers. This proactive maintenance approach has enhanced system reliability and reduced operational costs.

NVIDIA's Neuromorphic Chip Design: NVIDIA is at the forefront of neuromorphic computing research, leveraging AI to design and optimize neuromorphic chips. These chips mimic the structure and function of the human brain, offering significant improvements in energy efficiency and processing capabilities for AI and machine learning tasks.

Advances in Simulation and Modeling Tools

Simulation and modeling are indispensable in the design and analysis of electrical and electronic systems. These tools enable engineers to predict the behavior of circuits

and devices before physical prototypes are built, saving time and resources. Recent advancements in simulation and modeling tools have significantly improved their accuracy, efficiency, and usability, driving innovation in the field.

Finite Element Analysis (FEA)

Finite Element Analysis (FEA) has become more powerful with the integration of multiphysics simulations, allowing for the simultaneous analysis of electrical, thermal, and mechanical properties. This holistic approach ensures that designs are robust and optimized for various operating conditions.

Multiphysics Simulations: Modern FEA tools can handle complex interactions between different physical phenomena. For example, in power electronics, FEA can simulate the interplay between electrical currents, heat dissipation, and mechanical stresses to optimize the design of components such as heat sinks, printed circuit boards (PCBs), and packaging. Tools like COMSOL Multiphysics and ANSYS provide comprehensive platforms for such integrated simulations.

High-Performance Computing (HPC): The advent of HPC has significantly accelerated FEA simulations. Leveraging parallel processing and cloud computing, engineers can now run large-scale simulations that were previously infeasible. This capability enables more detailed and accurate modeling of complex systems, leading to better design decisions.

SPICE Enhancements

The Simulation Program with Integrated Circuit Emphasis (SPICE) remains a cornerstone in circuit simulation. Recent enhancements to SPICE include improved algorithms for faster convergence and the ability to handle larger and more complex circuits.

Improved Algorithms: Enhanced numerical algorithms have been developed to improve the convergence speed and stability of SPICE simulations. These advancements allow for faster simulations of large-scale integrated circuits (ICs) and systems-on-chip (SoCs), enabling quicker design iterations and optimizations.

Behavioral Modeling: The integration of behavioral modeling languages such as Verilog-A with SPICE has expanded its capabilities in analog and mixed-signal simulations. Behavioral models provide a higher level of abstraction, allowing designers to simulate complex systems more efficiently without detailing every transistor and component.

Machine Learning in Simulation

Machine learning (ML) is increasingly being integrated into simulation and modeling tools to enhance their capabilities and performance.

Surrogate Modeling: ML techniques are used to create surrogate models that approximate the behavior of complex systems. These models significantly reduce the computational load of simulations by providing quick, approximate solutions that are sufficiently accurate for many design tasks. Surrogate models are particularly useful in optimization processes where multiple iterations are required.

Anomaly Detection: ML algorithms can analyze simulation results to detect anomalies and potential design flaws. By training models on large datasets of simulation outputs, these tools can identify patterns and outliers that might indicate issues, allowing designers to address them early in the development process.

Electromagnetic Simulation Tools

Electromagnetic simulation tools have advanced significantly, providing more accurate and detailed analyses of electromagnetic fields and their interactions with electronic components.

3D Electromagnetic Simulation: Tools like CST Studio Suite and HFSS offer three-dimensional (3D) electromagnetic simulation capabilities, enabling precise modeling of complex geometries and materials. These tools are essential for designing high-frequency components such as antennas, RF circuits, and waveguides.

Time-Domain and Frequency-Domain Analysis: Modern electromagnetic simulators can perform both time-domain and frequency-domain analyses, providing comprehensive insights into the behavior of electronic systems. Time-domain simulations are useful for transient and broadband signals, while frequency-domain simulations are ideal for analyzing steady-state behavior and resonance phenomena.

Thermal and Mechanical Simulations

Thermal and mechanical simulations are crucial for ensuring the reliability and longevity of electronic devices.

Thermal Management: Advanced thermal simulation tools, such as FloTHERM and Icepak, allow engineers to model heat generation and dissipation in electronic systems accurately. These tools help optimize thermal management strategies, such as heat sink design, thermal vias, and forced convection cooling, to prevent overheating and ensure stable operation.

Mechanical Stress Analysis: Mechanical simulations assess the stresses and strains experienced by electronic components under various conditions. Tools like Abaqus and SolidWorks Simulation can model the impact of thermal expansion, mechanical vibrations, and shock loads on PCBs, solder joints, and encapsulation materials. These analyses are vital for designing robust and reliable electronic devices.¹⁴⁻¹⁶

Future Directions

The future of simulation and modeling tools in electrical and electronic design is poised for further advancements, driven by emerging technologies and increasing computational power.

Quantum Computing: As quantum computing technology matures, it holds the potential to revolutionize simulation and modeling. Quantum computers can solve certain types of complex problems much faster than classical computers, enabling more accurate and efficient simulations of electronic systems, particularly at the quantum level.

AI-Enhanced Simulations: The integration of AI and ML into simulation tools will continue to grow, providing more intelligent and adaptive simulation capabilities. AI can help optimize simulation parameters, predict outcomes, and even generate new design insights based on historical data and trends.

Virtual and Augmented Reality (VR/AR): VR and AR technologies can enhance the visualization and interaction with simulation results. Engineers can immerse themselves in 3D models of their designs, gaining a more intuitive understanding of the spatial relationships and interactions within their systems. This immersive experience can lead to better design decisions and faster identification of potential issues.

Real-Time Simulation: Advances in real-time simulation will enable the continuous monitoring and analysis of electronic systems during operation. This capability is particularly useful for applications such as autonomous vehicles, smart grids, and IoT devices, where real-time feedback and adaptation are critical for performance and safety.¹⁷

Conclusion

Advances in simulation and modeling tools are driving significant improvements in the design and analysis of electrical and electronic systems. Enhanced FEA capabilities, improved SPICE algorithms, the integration of machine learning, and advanced electromagnetic, thermal, and mechanical simulation tools are enabling engineers to create more efficient, reliable, and innovative designs. As technology continues to evolve, these tools will play an increasingly vital role in the development of next-generation electronic devices, ensuring they meet the growing demands for performance, efficiency, and sustainability.

References

1. Ji B, Song X, Sciberras E, Cao W, Hu Y, Pickert V. Multiobjective design optimization of IGBT power modules considering power cycling and thermal cycling. *IEEE Transactions on Power Electronics*. 2014 Oct 28;30(5):2493-504.
2. Zhang X, Pu Z, Su X, Li C, Zheng H, Li D. Flexible organic field-effect transistors-based biosensors: progress and

- perspectives. *Analytical and Bioanalytical Chemistry*. 2023 Apr;415(9):1607-25.
3. Frank M, Drikakis D, Charissis V. Machine-learning methods for computational science and engineering. *Computation*. 2020 Mar 3;8(1):15.
 4. Balarac G, Basile F, Bénard P, Bordeu F, Chapelier JB, Cirrottola L, Caumon G, Dapogny C, Frey P, Froehly A, Ghigliotti G. Tetrahedral remeshing in the context of large-scale numerical simulation and high performance computing. *Mathematics In Action*. 2022;11(1):129-64.
 5. Haj-Yahya J, Alser M, Kim J, Yağlıkçı AG, Vijaykumar N, Rotem E, Mutlu O. SysScale: Exploiting multi-domain dynamic voltage and frequency scaling for energy efficient mobile processors. In 2020 ACM/IEEE 47th Annual International Symposium on Computer Architecture (ISCA) 2020 May 30 (pp. 227-240). IEEE.
 6. Sharma A, Sohal H. Considerations for ultra-low-power VLSI design—A survey. *Journal of Nanoelectronics and Optoelectronics*. 2017 Jan 1;12(1):1-21.
 7. Yüce F, Hiller M. Condition monitoring of power electronic systems through data analysis of measurement signals and control output variables. *IEEE Journal of Emerging and Selected Topics in Power Electronics*. 2021 Nov 8;10(5):5118-31.
 8. Langpoklakpam C, Liu AC, Chu KH, Hsu LH, Lee WC, Chen SC, Sun CW, Shih MH, Lee KY, Kuo HC. Review of silicon carbide processing for power MOSFET. *Crystals*. 2022 Feb 11;12(2):245.
 9. Zhong G, Zi M, Ren C, Xiao Q, Tang M, Wei L, An F, Xie S, Wang J, Zhong X, Huang M. Flexible electronic synapse enabled by ferroelectric field effect transistor for robust neuromorphic computing. *Applied Physics Letters*. 2020 Aug 31;117(9).
 10. Cho CH, Chen CY, Chen KC, Huang TW, Hsu MC, Cao NP, Zeng B, Tan SG, Chang CR. Quantum computation: Algorithms and applications. *Chinese Journal of Physics*. 2021 Aug 1;72:248-69.
 11. Le HT, Haque RI, Ouyang Z, Lee SW, Fried SI, Zhao D, Qiu M, Han A. MEMS inductor fabrication and emerging applications in power electronics and neurotechnologies. *Microsystems & nanoengineering*. 2021 Aug 11;7(1):59.
 12. REDDY G. Design, synthesis and applications of novel hole transporting materials for Perovskite solar cells (Doctoral dissertation, RMIT University).
 13. Del Giudice D, Bizzarri F, Linaro D, Brambilla AM. Modular Multilevel Converter Modelling and Simulation for HVDC Systems: State of the Art and a Novel Approach.
 14. Andersh D, Moore J, Kosanovich S, Kapp D, Bhalla R, Kipp R, Courtney T, Nolan A, German F, Cook J, Hughes J. Xpatch 4: The next generation in high frequency electromagnetic modeling and simulation software. In Record of the IEEE 2000 International Radar Conference [Cat. No. 00CH37037] 2000 May 12 (pp. 844-849). IEEE.
 15. Pathumudy RD, Prabhu KN. Thermal interface materials for cooling microelectronic systems: present status and future challenges. *Journal of Materials Science: Materials in Electronics*. 2021 May;32:11339-66.
 16. Shaik JB, Singhal S, Picardo SM, Goel N. Impact of various NBTI distributions on SRAM performance for FinFET technology. *Integration*. 2022 Mar 1;83:60-6.
 17. Tan S, Yang Y, Leopold C, Robeller C, Weber U. Augmented Reality and Virtual Reality: New Tools for Architectural Visualization and Design. *Research Culture in Architecture*. 2019 Dec 16:301-10.
 18. Shrestha R, Nam SY, Bajracharya R, Kim S. Evolution of V2X communication and integration of blockchain for security enhancements. *Electronics*. 2020 Aug 19;9(9):1338.