MIRELAI

MIcroelectronics RELiability driven by Artificial Intelligence

DC NEWSLETTER (Issue 2)

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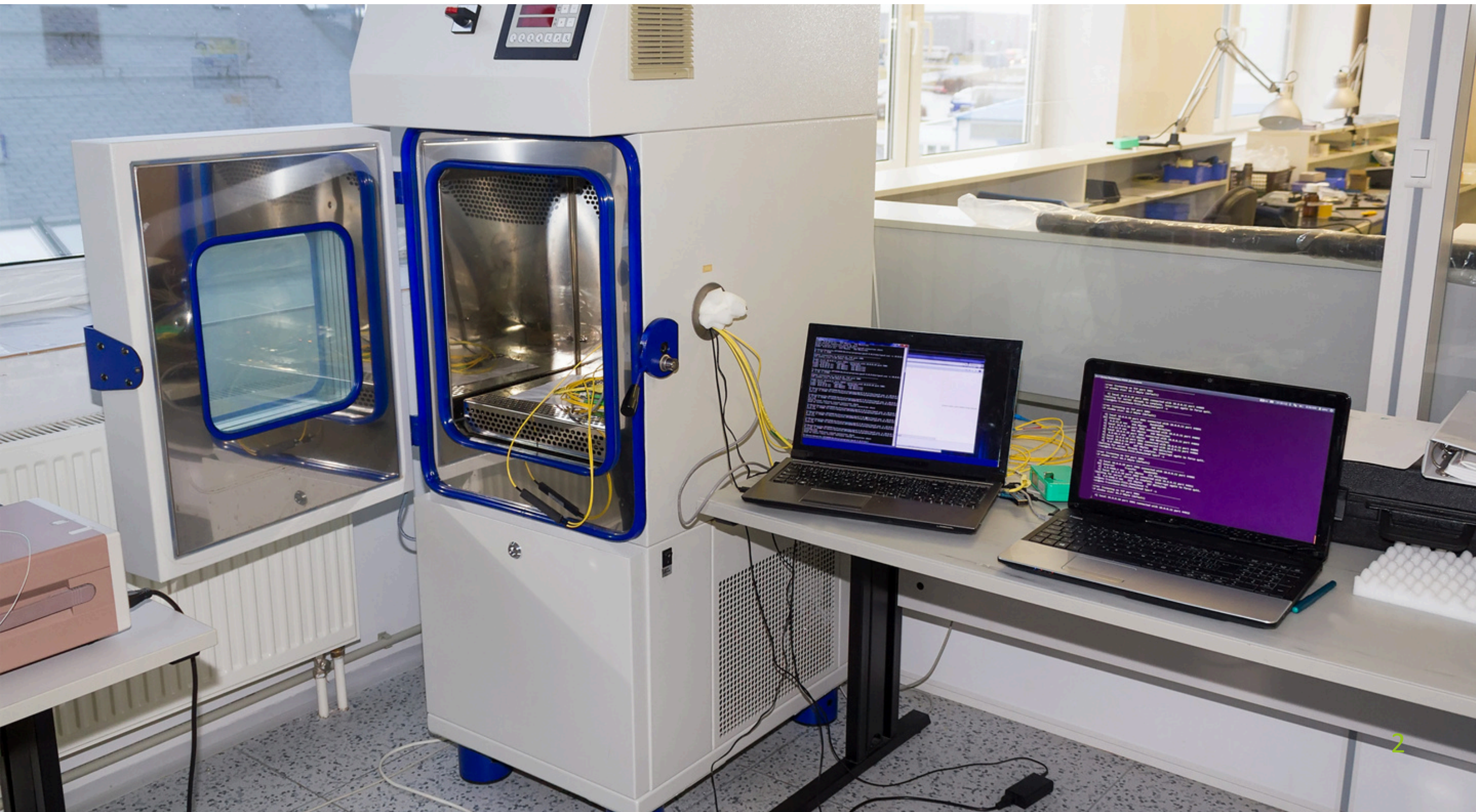
WELCOME TO OUR SECOND EDITION

We are delighted to welcome you to the second edition of the MIRELAI newsletter. This edition highlights the journey of innovation, collabration and progress in mocroelectronics relaibility within the MIRELAI network. A lot of improvements and advancements have been made in research and innovation, with several milestones achieved by doctoral researchers and partners since our first MIRELAI newsletter.

In microelectronic assemblies, significant progress has been made in enhancing prediction of failure modes through advanced simulation and modelling techniques. The regular MIRELAI Doctoral Webinar series has also become a key platform within network. During these sessions, the doctoral candidates have great opportunity to present their research, receive constructive feedback and to engage with the academic and industry experts.

We also feature the secondments of our researchers at various academic and industrial partner institutions which will be highlighted in subsequent sections. These secondments have played a critical role in advancing research requirements, collaborate with the leading mentors and also provide a valuable insight into real world issues in microelectronics and systems integration. To illustrate, Vikram has completed his secondment in **TU Delft** and Musadiq in **PCCL**. It was not only under the academic supervision but also received the exposure at the industrial level. We are also going to examine Thermal Virtual Sensing (TVS) work of Matteo in **IMEC** and the inspiring journey of Qiulin in PCCL who started to learn the basics of coding and turned into one of the leading researchers. We will also discuss one thought article from Marco in **KU Leuven** and how our doctoral students are actively involved in presenting their research in some of the most prestigious electronics conferences.

As we move forward, we remain committed to sharing the stories of collaborative and innovative research in future editions of the MIRELAI newsletter. We are grateful to have you with us on this exciting MIRELAI journey.



MIRELAI: A Vision for the Future of Microelectronics Reliability

IMIRELAI project is a pioneering exploration into transforming the way we model, understand and enhance the reliability of microelectronic systems. As devices become smaller and greater functionality, the conventional way of designing and testing is not sufficient to disseminate the complex failure mechanisms. MIRELAI addresses this gap by combining experimental investigations with advanced digital modeling techniques, enabled by artificial intelligence. Researchers are now able to forecast degradation behavior, stress responses, and thermal effects with a precision never experienced before by using AI-based models that compliments and enhance the physics-based simulations. The combination of research data and AI enables quicker analysis and better insights, as well as learning how to adapt to real-life data using this combination. High-stakes areas such as aerospace, automotive and consumer electronics all need such predictive capability, with a system malfunction being not only costly but potentially catastrophic.

Figure 1 MierlAI network at the 3rd annual meeting of consourtium held in POLIMI (Milan), Itlay

What make MIRELAI truly unique are its strong investments in people. The project is not only related to technological advancements, but also on developing a new generation of professionals, who are able to squeeze the gap between the academia and industry. Doctoral students receive a strong technical training, international secondments, and engage directly with real-world engineering problems as an integral part of their development. To reflect the latest trend, the current projects such as Thermal Virtual Sensing (TVS) and a digital twin modeling are providing researchers with the chance to investigate the dynamics of electronic systems in an environment where

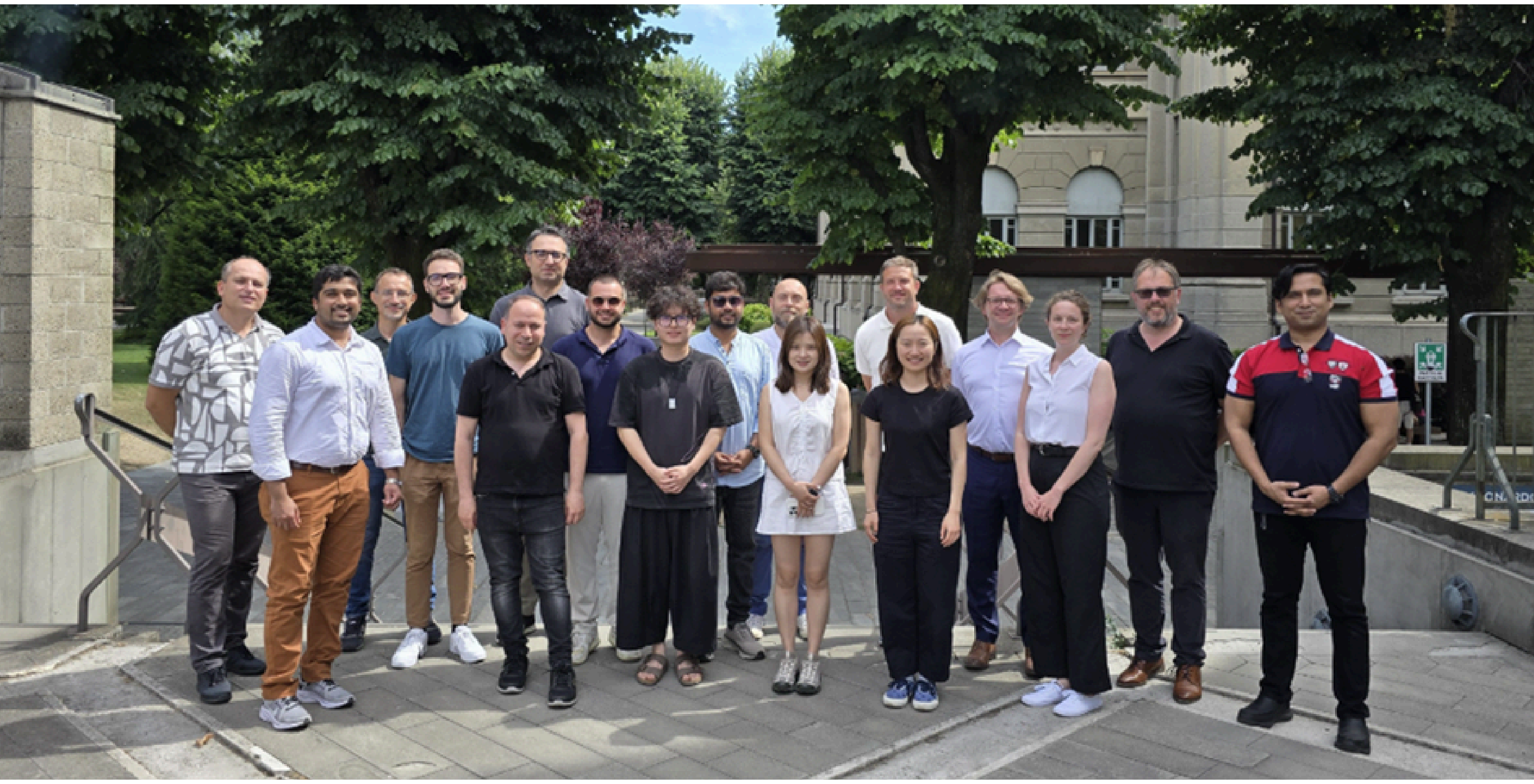


Figure 1 MierlAI network at the 3rd annual meeting of consourtium held in POLIMI (Milan), Itlay

their physical perception is not feasible. The research is not only scientifically exciting but is extremely practical as innovations it introduces can change the face of monitoring, maintenance, and optimization of electronic devices.

The significance MIRELAI has is much greater than a mere academic interest. Electronics are increasingly finding their way into all spheres of modern life, and nowadays it is no longer just electric vehicles and medical equipment that require well-functioning and long-lasting systems but also the everyday technologies like smartphones, smart homes and industrial automation. MIRELAI is on the edge of what is not yet possible in reliability engineering, because it provides some tools, knowledge, and collaborations to make microelectronic systems safer, smarter and more sustainable. You are a student in search of an innovative research place, a company interested in successful cooperation, or a policymaker concerned with the future of European leadership in technology , then MIRELAI presents a fascinating tale of innovation, education and practical real-world application.

Innovation in Action: Research Secondment Experiences

Experience at PCCL by Muhammad Musadiq: From Data to Discovery

I had the privilege of spending one month at PCCL (Polymer Competence Center Leoben GmbH) as part of my secondment program, where I worked under the supervision of Dr. Gernot Oreski and his team. The primary goal of this placement was to enhance my skills in data treatment and analysis, and to gain exposure to a collaborative research environment. This opportunity provided me with valuable insights into how data is collected, organized, and interpreted in real-world research projects, and how teamwork and structured problem-solving contribute to successful outcomes.

From the very beginning, the PCCL team made me feel welcome and supported. They introduced me to various ongoing projects and assigned me small but meaningful tasks that helped me gradually develop my understanding of data handling processes. These tasks were well-structured and designed to build my skills step by step. Through their guidance, I learned how to approach data-related problems more effectively, check for accuracy, and interpret results in a meaningful way. The supportive nature of the team encouraged me to ask questions and seek feedback, which helped me gain confidence in applying new methods and analytical tools.

Figure 6. Muhammad Musadiq in Leoben

Working at PCCL also gave me the chance to experience a professional research environment where collaboration, communication, and critical thinking are highly valued. Observing how the team worked together to solve challenges and share ideas was truly inspiring. I realized how important teamwork is in achieving research goals and how much can be learned from open discussion and cooperation. This experience not only strengthened my technical and analytical skills but also improved my ability to adapt to new situations and work efficiently in a team setting.

Beyond the professional experience, my stay in Leoben was very enjoyable. It is a charming and peaceful town surrounded by beautiful landscapes, which created a pleasant and motivating atmosphere for both work and leisure. Living there allowed me to appreciate the local culture and enjoy the warm hospitality of the people. Overall, my secondment at PCCL was an excellent learning experience that contributed significantly to my personal growth and professional development. I am grateful to Dr. Oreski and his team for their guidance and support throughout my stay, which made this experience both productive and memorable.

Experience at TU Delft by Vikram: A Valuable Step in My MIRELAI DC1 Project

At TU Delft, my primary research focus was on microvia reliability, which is essential for ensuring the durability and long-term performance of microvias in electronic circuits. Microvias play a crucial role in connecting different layers of a PCB, but their small size makes them susceptible to various failure mechanisms, such as thermal cycling, mechanical stress, and material fatigue.

Working under the guidance of Prof. Willem van Driel, I was able to dive deep into understanding the various factors that affect the reliability of microvias. Prof. Willem's mentorship and guidance were instrumental in refining my research and helping me develop new perspectives on the issue. His valuable insights not only helped me improve my research methodology but also encouraged me to explore innovative approaches to enhance microvia durability.

One of the most rewarding aspects of my secondment was the opportunity to collaborate with researchers and staff members from diverse backgrounds. TU Delft is home to a multidisciplinary research community, and I had the privilege of working alongside experts in materials science, electrical engineering, and nanotechnology.

During my secondment, I had the incredible opportunity to visit NXP Semiconductors and the Chip Integration Technology Center (CITC). These visits were a game-changer for my research. The insights gained from these visits have undoubtedly shaped my approach to research, providing me with a practical understanding of the issues I am studying.

My time at TU Delft was not only academically enriching but also personally fulfilling. The city of Delft, with its picturesque canals and rich history, offered a perfect balance between work and leisure. During my stay, I had the opportunity to explore the city, engage with the local culture, and network with professionals from various fields. The academic community in Delft is vibrant, and I found it inspiring to be surrounded by such motivated and passionate individuals.

As I continue my work in the field of microvia reliability, I carry forward not only the knowledge I gained but also the connections and experiences that will undoubtedly shape my future endeavors. The secondment was truly a rewarding and enriching experience that I will cherish for a long time.

From Research Novice to Independent Thinker: Experiences and Lessons in Machine Learning Research

Throughout my research journey, I have gradually realized that mastering advanced technological tools is only the first step. The real challenge lies in how to apply these tools to solve problems, verify hypotheses, and make rational decisions in an environment full of uncertainties. From initial confusion to independent thinking, my research experience has been full of trial and error, reflection, and growth.

When I first entered the field, I had almost no programming experience, yet data analysis was at the core of my work. Faced with massive datasets and complex machine learning models, my initial approach was to look for existing code and tutorials, hoping to get started quickly. However, I soon discovered that copying others' code does not equate to true understanding.

Figure 3. On Job Article by Qiulin

Through constant debugging and failures, I realized that real research is not just about running a model, but about understanding data characteristics, selecting appropriate methods, optimizing algorithms, and interpreting results. Programming is just a tool—the key lies in developing a sound way of thinking.

During my data analysis journey, I encountered several challenges, including: Delays in Data Availability, Data Quality Issues Model Selection and Interpreting Results. These challenges pushed me to think critically about data rather than just focus on getting the code to run. I began paying more attention to data preprocessing, feature engineering, and model interpretability rather than simply chasing higher accuracy.

Research is not just about mastering programming and machine learning tools—it is about transforming the way we think. From initially copying code to later critically analyzing approaches and eventually independently optimizing models, my journey has shown me that true research capability is not measured by the number of lines of code written, but by the ability to rationally analyze problems, continuously refine methods, and navigate uncertainty.

I believe that this ability to think independently and critically will not only be valuable in research but will also become one of the most important assets in my future career and life decisions.

Research Is Not Just About Technology, But Also About Thinking and Also About Evolving Thought Processes

Bridging Physics and Data: Enhancing Degradation Predictions with PINNs

Thought Article by Marco (DC8)

Ensuring the reliability of electronic components has become a major challenge due to increasing system complexity and miniaturization. Plated Through Holes (PTHs), fundamental elements in Printed Circuit Boards (PCBs), are particularly susceptible to degradation under thermal cycling. Predicting their Remaining Useful Life (RUL) is crucial for avoiding failures and optimizing maintenance strategies.

Traditionally, RUL prediction has relied on two distinct approaches: physics-based models, which use fundamental laws to describe material behavior, and data-driven models, which leverage machine learning (ML) to detect degradation trends from experimental data. However, both methodologies have limitations. While physics-based models ensure interpretability, they require extensive calibration and computational effort. Data-driven models, on the other hand, can learn complex degradation patterns but often lack physical consistency and generalizability beyond the training data.

In our recent work, we proposed a Physics-Informed Neural Network (PINN) that bridges the gap between these two paradigms. Our methodology combines Finite Element Method (FEM) simulations and real experimental data to improve degradation predictions for PTHs. A Feedforward Neural Network (FFNN) is first trained on FEM-generated data to predict the number of cycles to failure, embedding the physics of the problem into a structured dataset. Simultaneously, a Long Short-Term Memory (LSTM) network is trained on resistance evolution data collected from real PCB boards. By integrating the physical knowledge from FEM simulations into the loss function of the LSTM, the PINN ensures that predictions remain both data-driven and physics-consistent.

The results demonstrate a significant improvement in prediction accuracy, with the PINN reducing errors by up to 63% compared to a purely data-driven approach. This advancement underscores the potential of hybrid methodologies in reliability engineering, paving the way for more robust and scalable predictive maintenance solutions in electronics.

Our work highlights how integrating physics-based constraints into ML models can enhance both accuracy and interpretability, offering a promising direction for next-generation reliability assessment tools

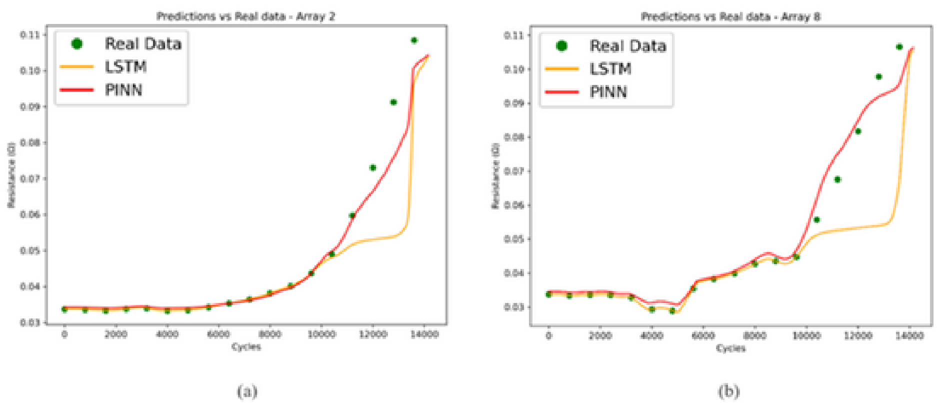


Figure 4. Time series prediction. Comparison between LSTM and PINN approaches for the resistance curves in the test set, corresponding to the second and eighth arrays on the board: (a) Configuration A, d = 300 µm and (b) Configuration C, d = 300 µm

Thermal Virtual Sensing

Improving remaining useful life monitoring with Digital Twins

Failures in electronic systems are predominantly caused by high temperatures and temperature cycles. Consequently, temperature monitoring is crucial for assessing the remaining useful life of such systems. In particular, it is essential to know the temperature in specific system locations upon which their reliability depends. Unfortunately, given the nature of electronic components, these locations are often inaccessible to sensors. By contrast, numerical models allow the evaluation of the temperature at every system location but are often unreliable due to modeling uncertainties.

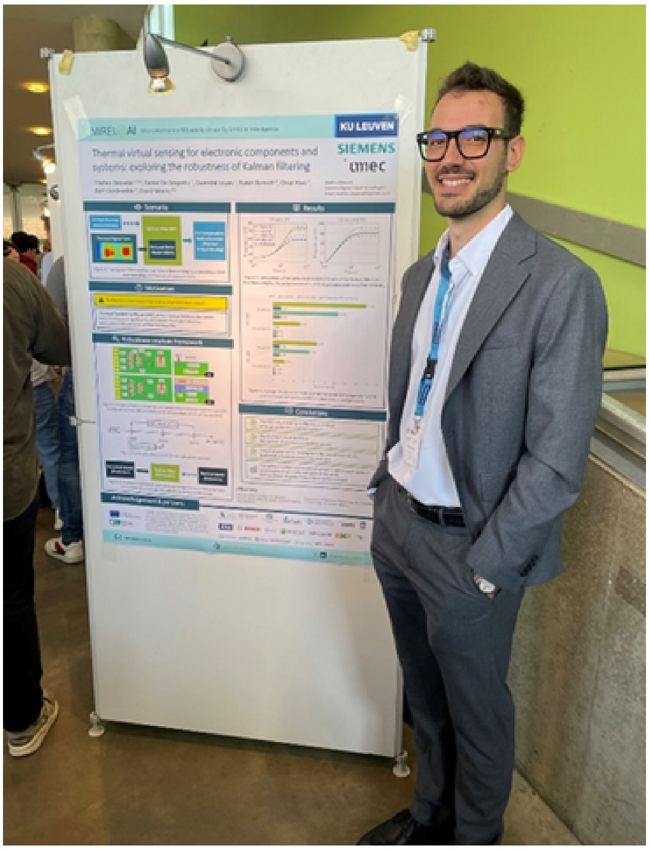


Figure 5. Matteo Depaola (SISW/Imec) at USD2024

In this context, Matteo's research aims to explore the use of Digital Twins (DT) to combine the benefits of highly detailed numerical models of electronic systems and real measurements. DTs are advanced tools that recursively estimate the state of a system depending on the error between model predictions and measurements. They enable Thermal Virtual Sensing (TVS), that is the estimate of temperature in non-instrumented locations exploiting measurements from a limited number of sensors.

Figure 3. Matteo Depaola (SISW/Imec) at USD2024

The initial stage of his work focused on assessing the robustness of this methodology and its limitations for electronic systems, using generated, synthetic data. A simplified model of an FR4 PCBA with six test-chips was designed for the purpose. The system was assumed to be laying on a cold plate resulting in a high Heat Transfer Coefficient (HTC) at the bottom surface, which is a common and inherently uncertain model parameter for thermal simulations.

A perturbation of ±50% of the HTC led to an 18% maximum error between simulated measurements and model predictions in the virtual sensors located in the die-attaches between the chips and the board.

By providing the DT with simulated measurements from four spots of the system, the maximum percentual error was reduced to 2%. The research was presented in the form of a poster at USD2024, in Leuven.

Although the first results looked promising, they also highlighted the importance of the number and locations of sensors. The correction capabilities of the methodology and the heat source coupling between virtual sensors and real sensors appeared to be correlated. Therefore, the research moved on addressing the problem of Optimal Sensors Placement to further enhance TVS performance. Moreover, the approach will be validated with experimental data for which a board was designed starting from the mentioned simplified design.

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