Research Placement at WMI / TUM

FPGA-Based Fast Characterisation of Superconducting Qubits

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AFFILIATION	James Watt School of Engineering, University of Glasgow
HOST	Interfacing Quantum Systems Laboratory, Walther-Meißner-Institute (WMI), in association with Technical University of Munich (TUM), Garching, Germany
HOST SUPERVISOR	Dr Benjamin Lienhard
VISIT DATES (physically)	30 July–23 September 2026
AWARD	MacRobertson travel scholarship (£1,000) and David Fleming Brown travel scholarship (£400)
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Before presenting this report, I wish to express my deepest and most heartfelt gratitude to the University of Glasgow, the MacRobertson and David Fleming Brown travel scholarship selection committee, and everyone whose generosity, encouragement, and support made this extraordinary opportunity possible. There are some experiences in life whose value cannot be measured through academic achievements, research outcomes, or publications alone. My research placement in Germany was one of those rare experiences. It was filled with unforgettable memories, meaningful friendships, inspiring scientific discussions, and moments of profound personal reflection. From working alongside exceptional researchers at the Walther-Meißner-Institute and Technical University of Munich to experiencing German culture and reflecting on humanity and history at Dachau, this journey enriched me in ways I could never have anticipated. Words cannot adequately express how grateful I am. The generosity of those who supported this journey has given me something far more valuable than an opportunity to travel: it has given me experiences, relationships, and memories that I will treasure for the rest of my life. To the University of Glasgow, the scholarship sponsors and selection committee, my supervisors, my wonderful hosts at WMI/TUM, and everyone who contributed to making this journey possible: thank you, from the bottom of my heart. **I will always look back on this chapter of my doctoral journey with immense happiness, affection, and gratitude.**

Some journeys end when we return home. Others remain with us forever.

Executive overview

My doctoral work at Glasgow approaches quantum control through signals, digital hardware and system design. At WMI, I was able to examine those engineering decisions in the context of qubit characterisation, where timing, calibration, measurement statistics and the reliability of the complete experimental chain are inseparable.

The research theme was the possibility of making characterisation of superconducting-qubit lifetime and coherence faster, more repeatable and more hardware-efficient through FPGA-oriented sequencing and processing. My activities centred on understanding characterisation workflows, evaluating the role of deterministic timing, examining how hardware and software should divide responsibilities, and considering where data-driven methods might support physically interpretable analysis.

The period also strengthened a meaningful research connection between the University of Glasgow and the WMI/TUM community. A particularly welcome outcome of the wider collaboration is the acceptance of our paper,

"QBridge-S2G: Accessible, Offline Quantum-Control Education Through Signal-to-Gate Visualisation," at IEEE WIECON-ECE 2026. I am delighted by this achievement and encouraged by the opportunity to develop further publications together. The experience was important to me professionally, intellectually and personally; beyond the laboratory, a visit to the Dachau Concentration Camp Memorial Site left a lasting impression that I recount separately in this report.



Figure 1. Main entrance to the Walther-Meißner-Institute (WMI), Garching, Germany.

1. Background and purpose of the visit

My PhD research concerns the engineering of microwave control systems for superconducting qubits, from control waveforms and digital implementation to the way those waveforms translate into operations on quantum devices. Such systems sit at the intersection of electronics, RF and microwave engineering, embedded control, numerical analysis and quantum physics. A control sequence may be elegant mathematically, yet difficult to use

experimentally if it assumes unrealistically fast software communication, perfect synchronisation or instantaneous transfer of measurement results.

The research placement at WMI, hosted by Dr Benjamin Lienhard, was intended to bring this cross-layer perspective closer to practical superconducting-qubit characterisation. WMI's active experimental environment provided the opportunity to understand not only how a measurement is specified in principle, but also how it must be scheduled, triggered, repeated, acquired and interpreted under real operational constraints. The work was focused on the feasibility and design considerations of FPGA-assisted characterisation, particularly lifetime and coherence measurements.

I approached the visit with a central engineering question: when a qubit characterisation procedure is repeated many times, how much of its duration is dictated by the quantum experiment itself, and how much comes from avoidable control, communication and processing overhead? The answer cannot be inferred from raw FPGA clock speed. It requires understanding the entire workflow, which is why sustained interaction with the host research environment was so valuable.

2. Objectives and working approach

During the research placement, I explored superconducting-qubit characterisation through a combination of literature review, technical discussions with researchers, exposure to experimental laboratory workflows, and examination of FPGA-based implementation approaches. Particular attention was given to identifying opportunities for improving the efficiency, precision, and repeatability of characterisation procedures through hardware acceleration and automated measurement techniques. Working closely with the experimental research environment at WMI provided valuable insights into the practical challenges of quantum-control systems, including measurement sequencing, timing synchronisation, data acquisition, and hardware–software integration. These activities helped establish a clearer technical direction for developing and evaluating faster characterisation methods, while identifying promising opportunities for future experimental investigations. The experience significantly enriched my doctoral research, strengthened my understanding of experimental quantum computing, and provided a valuable foundation for continued collaboration and research development.

3. Research activities and technical learning

3.1 Understanding what a characterisation experiment really measures

A major part of my time was devoted to developing a better understanding of how established superconducting-qubit characterisation routines are structured. Lifetime and coherence properties cannot be obtained from a single waveform or a single readout event. They depend on preparation and manipulation sequences, controlled delays, repeated measurements, parameter sweeps and subsequent inference from acquired data. The quality of the extracted result therefore depends on both the physical protocol and the machinery used to execute it.

I examined how the intended scientific quantity is connected to the digital instructions that generate an experiment. This meant considering the number and organisation of repeats, the range and ordering of sweep parameters, the delays between operations, the timing of measurement windows, and the form in which observations are recorded. I found it particularly useful to separate the sequence into operations that must be exact in time and tasks that can be performed more flexibly, such as plotting, post-processing and some aspects of parameter estimation.

For example, relaxation and dephasing studies generally require a controlled relationship between preparation, waiting time and measurement. If the delay schedule is inconsistent, or if the association between a delay value and its acquired measurement is uncertain, a fitted lifetime or coherence time may become difficult to trust. Conversely, improvements in control efficiency are valuable only if the experiment retains sufficient sampling, calibration and statistical reliability. This shaped my understanding of what a genuinely useful accelerator would need to preserve, rather than merely what it should execute more quickly.

The most important lesson was that characterisation is an end-to-end information process: an experimental question becomes a pulse and timing schedule, the physical system responds, measurement electronics generate data, and analysis returns an estimated parameter with uncertainty. Each transition in that chain can introduce overhead or ambiguity. This was a more informative perspective than treating pulse generation and data fitting as unrelated technical tasks.

3.2 FPGA-oriented sequence execution and deterministic timing

The central engineering strand of the placement concerned how repeated characterisation sequences might be organised around FPGA control. A host computer is flexible and convenient for configuring experiments, but software-driven loops can add communication overhead and variability when the same short operation must be launched many times. In contrast, an FPGA can provide tightly scheduled operations, repeatable triggering and local handling of selected control tasks, provided that the architecture is designed around the laboratory's actual requirements.

An important element was understanding the granularity at which hardware assistance becomes useful. Moving every aspect of an experiment into programmable logic would not necessarily be desirable; the more useful question is which time-critical or heavily repeated operations justify hardware implementation while maintaining experimental flexibility.

This led to a clearer distinction between three layers of responsibility. At the experiment-planning level, higher-level software remains appropriate for selecting protocols, specifying sweep ranges and managing calibration records. At the time-critical execution level, digital logic can enforce precise ordering and repeated actions. At the analysis level, suitable software or accelerated routines can estimate physical parameters and decide what should be measured next. The interfaces between these layers—rather than the computation in any one layer alone—often determine whether an integrated system is practical.

3.3 Analysing measurement throughput rather than clock speed alone

The placement encouraged me to think about acceleration in terms of complete experiment time rather than isolated instruction latency. In a repeated characterisation routine, elapsed time can include experiment configuration, physical pulse and delay periods, readout integration, reset or waiting intervals, repeated-shot overhead, data movement and numerical analysis. Some of these terms are intrinsic to the measurement and cannot simply be compressed by increasing FPGA clock frequency; others may be reduced through more efficient scheduling or batching.

A useful outcome was the recognition that future benchmarking must start with an explicit time budget. The baseline should record how the existing software-controlled workflow spends time and how much of that cost changes when selected activities move into deterministic logic. Improvements should be reported alongside measurement quality. Shortening an experiment that yields a less stable or biased estimate would not necessarily represent progress.

3.4 The complete microwave-control and readout chain

My technical discussions and exposure to the host environment also deepened my understanding of how FPGA-based control sits within the larger microwave and measurement chain. Digital waveform generation is only one stage. A practical experiment also depends on timing references, microwave conversion, signal delivery, qubit response, readout acquisition and calibration.

This cross-layer perspective is particularly relevant to my doctoral research. I have been interested in how signal-level design decisions translate into operations on superconducting qubits. The placement reinforced why useful control-system design must consider where a signal is defined, where it is realised electrically and how its effect is inferred from the experiment. It also made the need for careful traceability more concrete: one should be able to follow an experiment from the intended protocol and programmed sequence to the observations and the analysis that support a scientific claim.

During the placement, I also had the opportunity to assist with the setup of a dilution refrigerator, gaining valuable firsthand exposure to the specialised cryogenic infrastructure used in superconducting-qubit research. This practical experience strengthened my appreciation of the experimental complexity involved in operating quantum systems and of the importance of integrating control electronics, measurement equipment and cryogenic hardware within a reliable laboratory environment.



Figure 2. Me Assisting with the setup of a dilution refrigerator at the Walther-Meißner-Institute (WMI), Garching, Germany.

3.5 Data-driven methods and machine-learning-assisted characterisation

A further part of the placement concerned whether data-driven approaches could contribute to faster or more efficient characterisation. The possibility is attractive because experimental time is valuable and established routines may require large numbers of repeated measurements. However, an accelerated estimate is useful only when it remains connected to a trustworthy physical quantity and its uncertainty. Any future method would require comparisons with appropriate established procedures, separation of training and test evidence, and evaluation of its behaviour under changes in calibration or device conditions.

This caution was itself an important lesson. A system that looks faster on a limited data set could fail when the operating point moves, when noise changes, or when an apparent pattern reflects an artefact of the acquisition process. I therefore regard interpretability, uncertainty reporting and robust validation as essential requirements for any machine-learning-assisted characterisation strategy. The placement helped move this idea from an attractive possibility toward a more disciplined research question.

3.6 Research achievements and future opportunities

The placement provided me a strong technical foundation for advancing FPGA-based superconducting-qubit characterisation. Through detailed examination of measurement protocols, experimental workflows, and hardware implementation strategies, I identified promising opportunities to improve measurement efficiency, timing precision, automation, and repeatability. The experience also helped establish practical directions for future implementation and experimental evaluation. These outcomes have significantly strengthened my doctoral research and opened valuable opportunities for continued technical development, experimental investigations, and collaborative publications with researchers at WMI and TUM.

4. Research outcomes and future directions

The placement helped connect theoretical and engineering approaches to superconducting-qubit characterisation with the realities of laboratory operation. My work developed a clearer understanding of measurement workflows, repeatable FPGA sequencing, experimental automation and efficient data management. Together, these insights provide a strong basis for developing practical methods to improve characterisation efficiency while maintaining reliable experimental results.

4.1 Future research and collaboration

Building on the experience gained, I aim to further develop FPGA-based characterisation methods, explore automated and adaptive measurement techniques, and investigate their experimental performance. The successful acceptance of our collaborative paper, QBridge-S2G, at IEEE WIECON-ECE 2026 represents an encouraging milestone and provides a strong foundation for additional joint research and publications with WMI and TUM.

4.2 Impact on my doctoral research

The placement significantly enriched my doctoral research by strengthening the connection between microwave control, FPGA implementation, and experimental quantum systems. Working within an internationally recognised quantum research environment broadened my technical perspective, strengthened my research confidence, and provided valuable opportunities for interdisciplinary collaboration. I am particularly enthusiastic about building on these achievements and translating the knowledge and research relationships developed during the visit into future scientific contributions.

5. Value of the international collaboration and research environment

The visit strengthened my confidence in cross-institutional collaboration. I was able to connect my interest in control waveforms, FPGA architectures and systems engineering with the practical experience of colleagues working closely with superconducting-qubit platforms. Dr Benjamin Lienhard's support and the opportunity to interact with WMI/TUM researchers helped build a relationship that I hope will continue through technical exchanges, manuscript development and, where feasible, future joint studies.

For me, the value of the scholarship is therefore not limited to the activity carried out between arrival and departure. I returned with a sharper research direction, a more demanding approach to validation, a broader network of colleagues and the encouragement of an accepted collaborative publication. These benefits will continue to shape my doctoral work after the placement itself has ended.

5.1 Accepted IEEE conference paper: QBridge-S2G

A particularly encouraging outcome of the wider collaboration is the acceptance of our paper, “QBridge-S2G: Accessible, Offline Quantum-Control Education Through Signal-to-Gate Visualisation,” at the 2026 IEEE International Women in Engineering Conference on Electrical and Computer Engineering (WIECON-ECE). The paper brings together contributions from the University of Glasgow and collaborators including Dr Benjamin Lienhard at WMI/TUM. I am delighted that our collaboration has produced an accepted IEEE contribution, and I hope it will lead to further joint research.

QBridge-S2G is an offline-capable educational platform designed to help learners understand the connection between classical microwave control signals and introductory single-qubit operations. It connects pulse envelopes, in-phase and quadrature components, rotation angles, Bloch-sphere trajectories, and measurement probabilities in coordinated visualisations. Eight guided learning modules include both gate-to-pulse and pulse-to-gate activities, supported by explanatory feedback, assessment, accessibility options and local report generation. It can operate on an ordinary computer without quantum hardware or a continuous internet connection.

The paper reports checks of mathematical and software consistency for its ideal two-level model, including discretisation benchmarks and diagnostic-feedback tests. Its educational effectiveness will be evaluated in future studies with learners and educators. Accepted for the October 2026 conference, the paper is currently expected online in January 2027, and has been added to the Glasgow enlighten publications record. I hope it marks the beginning of further WMI/TUM–Glasgow collaborations.

6. Responsible research practice and laboratory photography

I was intentionally careful about photography in the host laboratory. Although a scholarship report benefits from a visual record, an active quantum-research laboratory requires particular attention to confidentiality, unpublished research and intellectual property. Instrument screens, experimental arrangements, device-related information and ongoing technical work can reveal sensitive details that may not be immediately apparent in a photograph.

For that reason, I was often reluctant to take photographs while experiments and technical work were underway. Respecting the trust extended by the host research group was more important to me than obtaining an extensive photographic record. The images included here concentrate on the setting and selected activities rather than unpublished data or proprietary experimental details. I will seek any necessary host approval before sharing laboratory photographs beyond the intended scholarship-report context.

7. Experiencing Munich and Bavarian culture

Living and working in the Munich region also gave me the opportunity to experience aspects of local culture beyond the research environment. One memorable moment was visiting the entrance to Oktoberfest 2026, where the lively setting and traditions offered a different perspective on the region in which I was undertaking my placement. Experiences such as this helped make the visit not only an important research opportunity, but also a rewarding period of cultural exchange and personal growth.

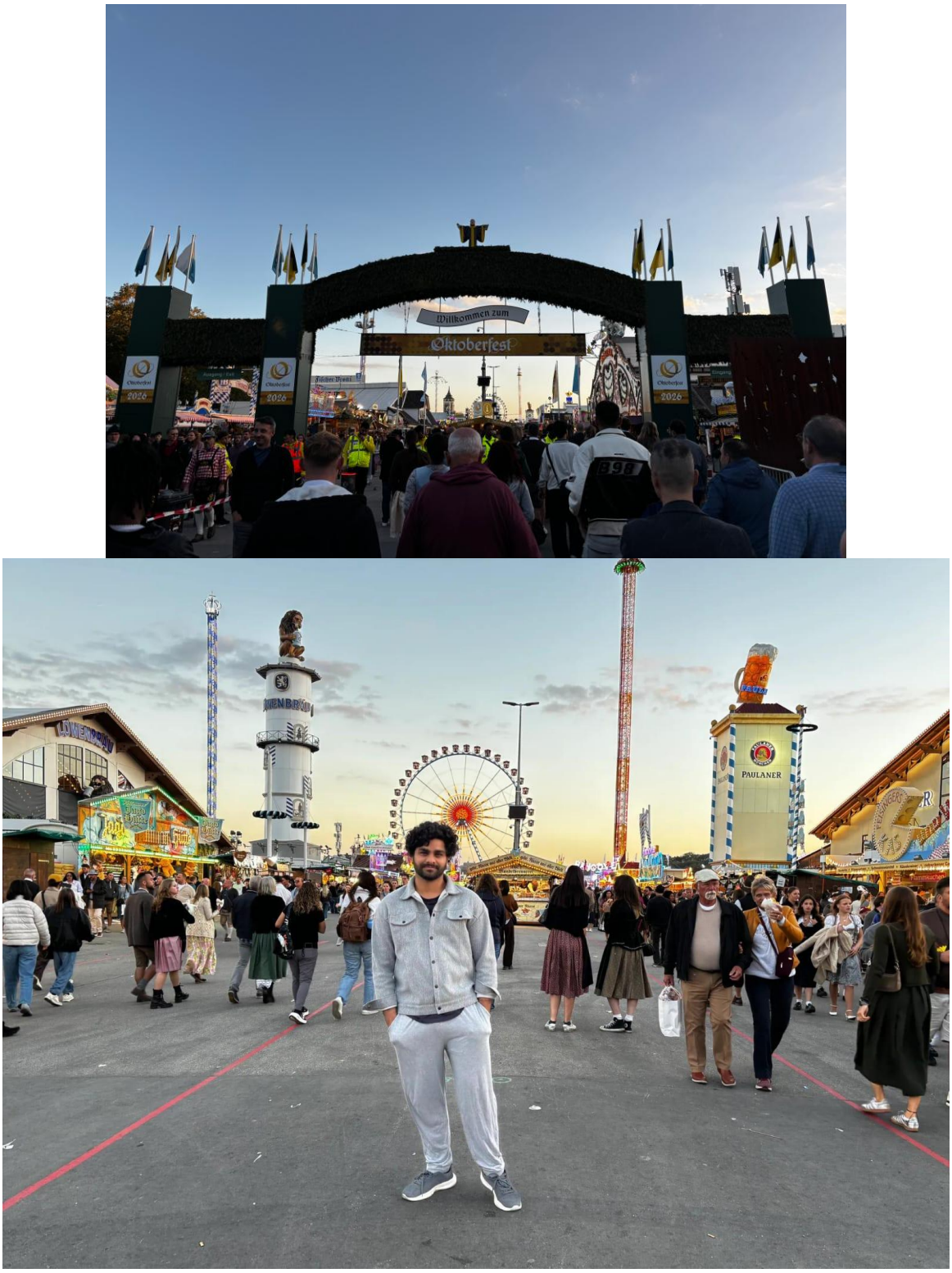

Figure 3. At the entrance to Oktoberfest 2026, Munich, experiencing Bavarian culture during my research visit to Germany.

8. A personal visit to Dachau: remembrance beyond the research programme

Not every journey is remembered for the places we visit. Some are remembered for the questions they leave behind.

During my research placement in Germany, I visited the Dachau Concentration Camp Memorial Site to pay my respects to those who suffered and lost their lives under Nazi persecution. I had travelled to Germany as a researcher, eager to learn about quantum technologies, scientific discoveries, and the possibilities of human knowledge. Yet at Dachau, I encountered another dimension of human history, one that demanded not scientific curiosity, but silence, humility, and reflection.

There are places where words seem insufficient. Dachau was one of them.

I had read about the Holocaust and Nazi persecution before. Like many others, I knew the historical accounts, the photographs, and the terrible numbers. But standing at the memorial brought home something that no statistic could fully convey. History is not made only of dates, nations, and events. It is made of human beings. Every person who suffered there had a name, a family, a language in which they dreamed, people they loved, and a future that mattered. Behind every number was a life that could never be replaced.

What stayed with me most was the thought of everything that could never be restored. We can preserve testimonies, protect memorials, teach history, and speak the names of those who suffered. But we cannot return stolen years, reunite every broken family, or give back the lives that were taken. I felt an overwhelming sadness, accompanied by gratitude for those who work to ensure that these histories are neither forgotten nor denied.

I went there to remember. I left knowing that remembrance itself carries a responsibility.

Perhaps because I come from South Asia, where histories of migration, belonging, and separation have shaped generations, this experience also awakened memories from another part of my life.

For me, the Partition of India and Pakistan in 1947 has never been merely a historical event. It is woven into my family's story. My grandfather travelled from Delhi to Lahore during Partition. I often think about what it means to leave a city that has been part of one's world and begin again somewhere else. I cannot presume to know everything he experienced or felt, but the journey remains part of the history through which I understand my own roots.

Dilli se Lahore tak ka safar sirf do shehron ke darmiyan ka faasla nahin tha; woh yaadon, bichharne aur ek nayi zindagi ke aaghaz ka safar tha.

Translation: The journey from Delhi to Lahore was not merely the distance between two cities; it was a journey of memories, separation, and the beginning of a new life.

Delhi and Lahore are more than two cities on a map. They belong to a shared cultural world of language, poetry, music, literature, affection, and memory. Political boundaries transformed their relationship, but they could not erase the histories that had connected their people for generations. Lahore, especially, holds a place in my imagination through my family's history. *Lahore, Lahore hai!* There is something wonderfully affectionate about that expression, as though an entire relationship with a city could be contained in three simple words.

Perhaps this is why the literature of the subcontinent has always meant so much to me.

I have often returned to Saadat Hasan Manto, particularly his extraordinary short story *Toba Tek Singh*. Through the bewilderment of Bishan Singh, Manto exposes the absurdity and anguish of a world in which political boundaries can suddenly unsettle the most fundamental questions of identity and belonging. His writing reminds me that the human consequences of Partition cannot be understood through maps and political decisions alone.

I also think of Amrita Pritam, who called upon Waris Shah in *Ajj Aakhaan Waris Shah Nu* to bear witness to the suffering of Punjab. And of Faiz Ahmed Faiz, whose *Subh-e-Azadi* reflected upon a moment of freedom shadowed by anguish and unfulfilled hopes. In different ways, these writers understood something essential: that a nation can celebrate a historical moment while countless individual lives carry its sorrow.

Yet my connection with South Asia is not shaped by sorrow alone. It is equally shaped by its traditions of love, music, poetry, and spiritual longing.

There is something deeply beautiful about the idea of *ishq* in our literary and Sufi traditions. In the poetry of Bulleh Shah, love becomes a language through which human beings can question divisions and recognise something greater than themselves. In a different, contemporary musical expression, I find a similar emotional intensity in Kailash Kher's *Dilruba* and *Teri Deewani*. The longing, devotion, and tenderness carried by such music remind me why the artistic traditions of the subcontinent continue to speak so powerfully across languages and generations.

Perhaps that is what I treasure most about our shared cultural inheritance: that poetry can travel where politics cannot, and a song can touch hearts on either side of a border without asking for a passport.

Ganga–Jamuni tehzeeb ki khoobsurati hi yahi hai ke mukhtalif zubaanon, riwayaton aur aqeedon ne milkar ek aisi mushtarka saqaafat ko janam diya, jiska husn aaj bhi hamare adab, shayari aur mausiqi mein zinda hai..

Translation: The beauty of Ganga–Jamuni culture lies in how different languages, traditions and beliefs contributed to a shared cultural heritage whose richness still lives in our literature, poetry and music.

These convictions are also reflected in my involvement with the India–Pakistan Dosti Group and my belief in friendship, reconciliation, and dialogue across borders. I have always felt that the shared cultural and human inheritance of India and Pakistan deserves to be cherished, particularly when political disagreements threaten to obscure it. The stories of ordinary families, the poetry we read, and the music we share offer possibilities for understanding that are sometimes absent from public discourse.

At Dachau, I took photographs that I will always regard with particular care. They are not ordinary travel souvenirs. To me, they are reminders of lives that mattered, of suffering that must never be diminished, and of the responsibility to preserve memory with dignity. I have included selected photographs separately from those of my research activities out of respect for the meaning of the site.

I returned from Germany with new scientific knowledge, meaningful friendships, and memories of an extraordinary research environment. But I also returned with something more difficult to describe: a renewed sense of the fragility of human dignity, the importance of historical memory, and the possibility of building understanding across differences.

I am a student, but I am also someone shaped by the stories, poetry, languages, and memories of South Asia. My grandfather's journey from Delhi to Lahore, the unsettling humanity of Manto's writing, the sorrow and hope expressed by Faiz and Amrita Pritam, and the enduring language of love in our music and poetry are all part of the cultural inheritance through which I understand the world.

Standing at Dachau did not make these different histories the same. It reminded me why each must be remembered truthfully, why every human life deserves dignity, and why we must never allow the suffering of others to become distant or abstract.

We cannot rewrite the tragedies of the past. But we can choose how we remember them, how we speak to one another, and what kind of world we hope to leave behind.

And perhaps, somewhere between history and memory, between silence and poetry, lies one of the most important lessons of being human.



Figure 4. Historical exhibition at the Dachau Concentration Camp Memorial Site, documenting Nazi persecution during 1939–1942.



Figure 5. Paying my respects at the Dachau Concentration Camp Memorial Site, reflecting on remembrance, peace and human dignity.

9. Scholarship support and practical benefits

I am sincerely grateful for the generous support of the MacRobertson travel scholarship (£1,000) and the David Fleming Brown travel scholarship (£400) towards my travel, accommodation, and living expenses during the research placement. This funding played an important role in enabling me to undertake an extended research visit to the Walther-Meißner-Institute (WMI) and Technical University of Munich (TUM). The opportunity to work within an internationally recognised quantum research environment was immensely valuable, allowing me to engage directly with experienced researchers, participate in technical discussions, and deepen my understanding of experimental superconducting-qubit systems.

Beyond its financial contribution, the scholarship represented a significant investment in my academic and professional development. The extended placement enabled me to build meaningful international research relationships, broaden my technical expertise, and explore new directions for collaborative research. The acceptance of our joint IEEE conference paper further highlights the value of the academic connections strengthened during this visit. I am particularly delighted by the opportunities this experience has created for future research, publications, and continued collaboration between the University of Glasgow and WMI/TUM. I consider this scholarship one of the most rewarding opportunities of my doctoral journey, with benefits that will extend well beyond the duration of the placement.

10. Final reflection and acknowledgements

My research placement at the Walther-Meißner-Institute (WMI) and Technical University of Munich (TUM) has been one of the most enriching and memorable experiences of my doctoral journey. It provided an exceptional opportunity to deepen my understanding of superconducting-qubit characterisation, FPGA-based control systems, and experimental quantum technologies while working within a world-class research environment. Beyond the technical knowledge gained, the experience broadened my research perspective, strengthened my confidence, and inspired new ideas for future scientific investigations and international collaborations.

One of the most rewarding outcomes has been the acceptance of our collaborative paper, QBridge-S2G, at IEEE WIECON-ECE 2026, with online publication expected in June 2027. I am genuinely delighted by this achievement and particularly grateful for the opportunity to collaborate with such talented researchers. I sincerely hope this marks the beginning of many more joint publications and meaningful scientific contributions in quantum control, FPGA-based characterisation, and quantum engineering education. The friendships, professional relationships, and research opportunities developed during this placement are among its most valuable and lasting outcomes.

I extend my heartfelt gratitude to the University of Glasgow and the PGR Travel Scholarship Selection Committee for making this opportunity possible. My special thanks go to Dr Benjamin Lienhard and the wonderful researchers at the Interfacing Quantum Systems Laboratory, WMI and TUM, for their warm welcome, generosity, encouragement, and invaluable scientific discussions. I am equally grateful to my doctoral supervisors, research collaborators, and the James Watt School of Engineering for their continued guidance and support.

Finally, this journey offered much more than academic development. From the excitement of scientific discovery and the joy of new friendships to the deeply moving experience of paying my respects at Dachau, my time in Germany was filled with moments that will remain with me throughout my life. I returned to Glasgow not only with greater technical knowledge and renewed research ambitions, but also with a deeper appreciation of international friendship, human dignity, and the responsibility that accompanies scientific progress. I will always remember this placement with immense gratitude, happiness, and the hope that the connections established here will continue to grow into lasting friendships and meaningful contributions to science and society.