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Graduate School of Engineering and Management, Air Force Institute of Technology

AIR FORCE INSTITUTE OF TECHNOLOGY GRADUATE SCHOOL OF ENGINEERING & MANAGEMENT

AFIT ENGINEER

The Graduate School of the U.S. Air Force

June 2023 | Vol. 5, Issue 2

Quantum Information Science

AFIT QIS Research Supports USAF and USSF Quantum Workforce Development

What is Quantum Information Science (QIS)?

QIS is the study of information processing systems that use the superposition and entanglement of quantum states. QIS systems of interest provide greater capabilities (e.g., security, efficiency, and confidentiality) not possible with classical-only information processing systems. Subdisciplines include quantum computing, quantum networking and communication, and quantum sensing.

What is the Impact of QIS on National Defense?

The United States and its allies are engaged in a highly competitive quantum race with adversaries and strategic competitors. While several known quantum entanglement applications have the potential to serve as strategic surprise enablers, additional important quantum entanglement applications almost certainly remain to be discovered. High-technology readiness level (TRL) quantum interaction-based sensing and timing technologies already exist, and quantum entanglement may provide additional advantages.

Specific Capabilities Enabled by Advancements in QIS

Within the sub-discipline of quantum computing, increased robustness and qubit counts will render current public key encryption protocols and algorithms highly susceptible to attack (Shor's algorithm). Additionally, it will have widespread application in large-scale engineering and materials design (Variational Quantum Eigensolver) and enable dramatic speedups in important optimization problems (e.g., operational planning, personnel management, supply chain management, Quantum Approximate Optimization Algorithm and Grover's Search Algorithm).

Quantum networking and communications, advancements in components, noise robustness, free-space qubit through turbulence enabled by time-tagging, teleportation, entanglement swapping will allow developing integrated quantum networks to move beyond laboratory settings and provide secure field communications. Such networks could span quantum nodes on land, satellites and beyond. Many quantum sensing and timing developments that are poised for mission use could potentially exploit such quantum networks for distributed quantum sensing. Quantum sensing and timing using quantum metrology will enable improved timing and location accuracy for navigation of missiles, aircraft, space-domain etc., in GPS-degraded or GPS-denied environments.

How do AFIT QIS Activities Support USAF/USSF Missions?

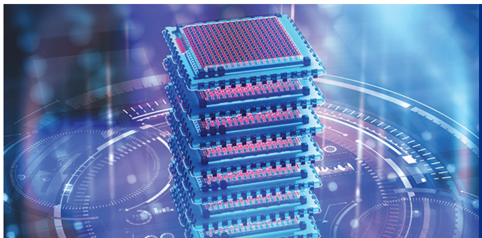
AFIT QIS activities support the Air Force Research Laboratory (AFRL), the National Air and Space Intelligence Center (NASIC), and Air Force Nuclear Weapons Center (AFNWC) missions by providing a QIS short course to support workforce development. AFIT supports AFRL's Information Directorate (AFRL/RI) by evaluating commercial quantum computing systems (e.g., the transmon-based IBM and trapped ion-based IonQ systems) and AFRL's Directed Energy Directorate (AFRL/RD) by developing high-fidelity free-space quantum communication and networking, including satellite-based qubit links. A proposed quantum network node is in the planning stages to be set up at AFIT's Quantum Optical Technology (QuOTe) Lab. In the near future, the node will connect through a dark-fiber based quantum network to the Quantum Information Science Engineering Center at The Ohio State University.

U.S. Air Force photo by Dr. Anil Patnaik

AFIT QIS students and interns at the Quantum Optical Technology (QuOTe) Lab.

INSIDE THIS ISSUE

Find past issues online at:
www.AFIT.edu/EN/afitengineer



Read about AFIT's latest QIS research developments on pages 14-22.

Breaking New Ground on Digital Transformation and Workforce Development

Welcome to the June 2023 issue of the AFIT Engineer. The year 2023, which feels as though it just recently came upon us, is fast departing from our calendar spreads. The year is already half gone. Fortunately, our mission accomplishments have kept pace with the flow of time on the lunar scale. Excuse the euphemism. AFIT continues to break new ground, even if we are not breaking ground for new buildings. Among our technical accomplishments is the research on Quantum Information Science, detailed on the cover page. This is a fast-emerging technology, in which AFIT is playing a leading role in workforce development to support the missions of the US Air and Space Forces. Another exciting development is the newly-established Digital Innovation and Integration Center of Excellence (DIICE), which is expected to provide interdisciplinary and multi-dimensional support for the digital transformation of the US Department of the Air Force. Please read the article on page 11 to learn more. All the new and emerging technologies are within the teaching, research, and consultation portfolios of AFIT. These include hypersonics, quantum science, artificial intelligence, machine learning, wireless signals, additive manufacturing, cyber security, internet of things, blockchain, and others. In each case, AFIT works within the nexus of technology, strategy, process, and people from the perspectives of future workforce development, enabled by digital systems engineering. I invite you to enjoy this newsletter issue and look forward to future issues of the AFIT Engineer. With technology and people, we move the mission forward.

Adedeji B. Badiru, Ph.D., PE
Dean, Graduate School of Engineering and Management

TEACHING WHAT WE RESEARCH. RESEARCHING WHAT WE TEACH.

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Engineers Week Activities Return to AFIT

The Graduate School of Engineering and Management returned to hosting its annual Engineers Week celebration in April at the AFIT campus after a two-year hiatus due to COVID restrictions on public events.

The popular outreach event was reinstated under the leadership of Lt. Col. Christopher Rondeau, Graduate School Associate Dean of Students, with assistance from AFIT Master's degree student 2d Lt. Dawson Friesenhahn. Planning and logistics were coordinated through AFIT student volunteers: 2d Lts. Ben Miller, Tanner Todd, Tom Kamp, Sean Quiterio, David Garcia, and Anthony Tolbert.

SPEAKERS DISCUSS STEM CAREERS

The Graduate School welcomed guest speaker Col. Mario A. Serna, Jr., Deputy Director for Innovation and Technology Integration, Field Support Unit of the Rapid Capability Office at Kirtland AFB, NM on 18 April for a presentation on STEM career success in the DOD. On 19 April, Brig. Gen. David J. Kumashiro, USAF, Ret., presented a discussion on the value of STEM graduate education to the total force and its impact on the realization of national-level strategy.

STEM OUTREACH TO LOCAL STUDENTS

Outreach activities continued on 20 April when the Graduate School hosted 84 students, grades 9 through 12, for STEM-related demonstrations. Students from five local schools (Miami Valley, CinDay Academy, CJ Catholic High School, Fairborn and Dayton Early College) were in attendance. The Department of Aeronautics and Astronautics presented an AIAA-sponsored straw rocket engineering activity for students. Dr. Marc Polanka, Professor of Aerospace Engineering, led this event with participation from Dr. James Rutledge, Associate Professor, and Dr. Jose Camberos, AFIT Associate Professor of Aerospace Engineering.

Lt. Col. Wayne Henry, Assistant Professor, and Dr. Timothy Lacey, Adjunct Assistant Professor, from the Department of Electrical and Computer Engineering, led the students through a cybersecurity introduction and demonstration in AFIT's Center for Cyberspace Research. Henry presented the fundamental principles and concepts of cybersecurity, emphasizing the alarming frequency of cyber attacks in today's digital age. He highlighted various types of attacks, and demonstrated a hack on the popular game Solitaire to achieve a high score – a playful illustration of the serious potential of these skills. The conversation also touched on the common tools used in the cybersecurity field and encouraged young enthusiasts to get involved, offering information on opportunities from high school through college.

Before returning to their local schools, visiting students attended a panel presentation at which current AFIT students relayed their perspectives on education, engineering, and careers.

DEAN'S DISTINGUISHED SPEAKER SERIES

Engineers Week 2023 concluded with the presentation of the Dean's Distinguished Guest Speaker Series for AFIT faculty and students. Dr. Adedeji Badiru, Dean, Graduate School of Engineering and Management, hosted an innovation panel discussion with University of Maryland guests Dr. Bala Balachandran, Distinguished University Professor, Minta Martin Professor, Department of Mechanical Engineering and Dr. Nii Attoh-Okine, Chair, Department of Civil and Environmental Engineering. Presentation topics included nonlinear dynamics: experiments and computations, and digital twins: data-driven approaches and critical infrastructure protection and cyber resilience.

The Graduate School looks forward to hosting another successful Engineers Week in 2024.

AFIT Hosts Hypersonic Conference Classified Day for Second Year

Photo by Defense Strategies Institute

The Air Force Institute of Technology hosted the 2023 Hypersonic Innovation Classified Day at its campus on May 4 in support of the local hypersonic conference for the second year in a row. AFIT faculty and leadership attended the main conference events on May 2-3. Shown in the photo from the left: Dr. James Rutledge, AFIT Associate Professor, and Dr. Darryl Ahner, AFIT Dean for Research, speak with attendees at the conference held at the Dayton Convention Center.

The annual Hypersonic Innovation Conference emphasizes the pressing needs to advance American hypersonic technologies and leverage these technologies to achieve U.S. National Security goals.

AFIT Professor Named AETC Outstanding Airman of the Year

Dr. Hengky Chandrahalim was selected as Air Education and Training Command's Outstanding Airman of the Year, Civilian Supervisory Category IV for 2022. Chandrahalim is an assistant professor of electrical engineering at the Air Force Institute of Technology and the faculty director of the AFIT Nanofabrication and Characterization Facility.

"To me, being an AETC award winner means that my efforts to provide my students with the knowledge and skills they need to succeed in their careers and to serve their country have been recognized and appreciated," said Chandrahalim. "Winning the AETC award is a great honor and privilege. This award is a testament to the hard work and dedication of my students, colleagues, and mentors. I am grateful for their support and encouragement."

Chandrahalim's research in microsystems engineering and nanotechnology produced revolutionary techniques in microfabrication with the potential to address key Department of the Air Force needs. He pioneered the development of a two-photon nanofabrication technique to create 3D functional microsystems on virtually any substrate. This technology created breakthrough solutions for multipurpose sensing in spatially constrained applications such as drones, fighter aircrafts, microsatellites, and autonomous underwater vehicles. The originality and creativity of this research has resulted in eight patents, more than 15 articles and received an invited talk at the Institute of Electrical and Electronics Engineers RAPID 2021 Conference.

Moreover, his research team is investigating novel thin-film electromechanical transducers such as solid dielectrics, liquid dielectrics, ferroelectric and piezoelectric thin-films to efficiently generate high-quality mechanical waves in solids. The results have enabled the realization of highly miniaturized, frequency-agile radio wave processors on an integrated chip-scale platform. At higher technology readiness levels, these devices can be used to facilitate the implementation of multifunction advanced data link in modern jet fighters and signal processing units in microsatellites with much lower power consumption and costs compared to the existing technology. These radio frequency microsystems can also directly support the four current Air Force Vanguard programs: Golden Horde, Navigation Technology Satellite 3 (NTS-3), Skyborg, and Rocket Cargo. The outcomes of this research have been disseminated in over 20 articles.

Chandrahalim led a research team in exploiting the unique properties of quantum dots to enable nondestructive testing of materials. Applications that can make use of this technology are non-contact testing of aircrafts, ground vehicles, and ships. The most near-term use of this technology is a new strain gauge for quality control, 3D printing, and in buildings and structures. This non-destructive, non-contact technology also has the potential to compete against another optical 2D strain-sensing technology called digital imaging correlation. At about 8% of the cost of a DIC system, this could save the Air Force approximately $32 million when buying a single system for up to 386 squadrons. The results of this study have been published in multiple venues and received serious attention from news media, such as *Nanotechnology Now* and *IEEE Spectrum*. This work also received special mention from the editor-in-chief of the *American Chemical Society's Applied Materials and Interfaces*.

Dr. Chandrahalim inspects a microelectromechanical chip outside the AFIT nanofabrication facility. The chip is a small, complex device that can be used to sense and control physical phenomena.

U.S. Air Force photo by Katie Scott

Chandrahalim has developed an innovative technology that utilizes the optomechanical properties of crystalline liquids to sense broadband acoustic waves. A good understanding of the interactions between light and sound waves in structured liquid crystalline materials has the potential to revolutionize current sensing technology and motivate other fundamental experiments. His team was the first to report chip-scale liquid crystalline optomechanical sensors that detect broadband acoustic signals using white light. This breakthrough enabled the development of small, low-power, cost-effective and geometry-independent broadband acoustic sensors. Their work was recognized as one of the best student paper finalists at the IEEE NEMS 2019 Conference and awarded a U.S. patent in 2022. It has also received special coverage from *TechLink News* in 2022.

His recent research contributions have been recognized as one of the top 30 breakthrough stories in *Optics in 2022*, among the 20 best papers in the *2022 Optical Sensors and Sensing Congress*, and as a 2020 highlight by the *IOPscience*.

Chandrahalim is very active in learning new materials, processes and methods to produce state-of-the-art microsystems that will elevate the research field to a higher level and deliver newer technologies to the Air Force. He hybridized the 3-D nanofabrication technique based on nonlinear light-matter interactions of ultrafast laser pulses and transparent materials with 2-D traditional photolithography to create photonic platforms that have new functionalities and superior performances. These recently developed devices have not only enabled numerous new applications in molecular and environmental sensing, healthcare monitoring, photoacoustic imaging, ultrasound detection and biophotonics but have also opened the door to the investigation of new physical phenomena, such as parity-time symmetry in optics and optically induced molecular magnetism.

"I believe in the mission of the USAF and the critical role that education plays in supporting that mission," said Chandrahalim. "As a faculty member at AFIT, I have the privilege of working with some of the brightest minds in the military, and it is an honor to be a part of their development as our future leaders and thinkers."

READ THE FULL ARTICLE ONLINE:

https://e.AFIT.edu/RRVVvwQJ

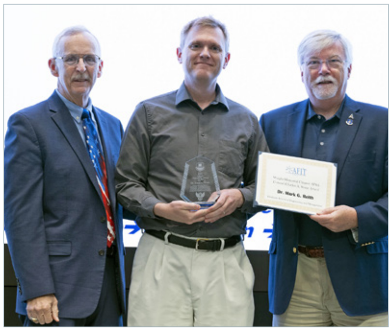
Graduate School Faculty Members Receive Annual AFA Sponsored Awards

Two Graduate School of Engineering and Management faculty members were honored by the Air and Space Force Association Wright Memorial Chapter on 18 May. The AFA sponsored awards were presented by Dr. Walter Jones, AFIT director and chancellor, and Mr. David Babcock, president of the ASFA Wright Memorial Chapter. The awards recognize faculty who advance aerospace power and technology through innovative efforts in education and research. The AFA has sponsored the awards since 1982.

2022 AFA Award nominees from the Graduate School included the following: Gage H. Crocker Outstanding Professor Award: **Dr. Edward White**, Professor of Statistics, and **Maj. Timothy Wolf**, Assistant Professor of Electrical Engineering; Professor Ezra Kotcher Award: **Lt. Col. David King**, Assistant Professor of Computer Science; General Bernard A. Schriever Award: **Dr. David Jacques**, Professor of Systems Engineering; Colonel Charles A. Stone Award: **Dr. Mark Reith**, Assistant Professor of Computer Science.

COLONEL CHARLES A. STONE AWARD

Dr. Mark Reith
Assistant Professor of Computer Science



Mr. David Babcock, Dr. Mark Reith and Dr. Walter Jones.

This award is given in recognition of an individual who has made outstanding contributions to furthering the AFIT mission through new and innovative efforts involving demonstrated personal leadership. The award is named in honor of Col. Stone, the dean of AFIT's School of Systems and Logistics from 1962-1966, who was instrumental in the school receiving accreditation to award master of science degrees.

Dr. Mark Reith is an assistant professor of computer science in AFIT's Graduate School of Engineering and Management where he teaches courses in agile software systems, cyber systems security and software engineering.

Reith championed several innovative efforts to modernize higher education at AFIT. He envisioned and guided the development of AVOLVE, a platform for sharing STEM education content across the DOD. He introduced game-based learning, assessment and attestation into educational courses to provide students with richly interactive technology, such as Battlespace Next and Software Engineering Digital Badges. He also invested in relationships with the Air Force Research Laboratory to found Hangar 18, an Air Force-recognized software factory, to provide new opportunities for students, faculty and staff to advance their teaching and research efforts.

GAGE H. CROCKER OUTSTANDING PROFESSOR AWARD

Maj. Timothy Wolfe
Assistant Professor of Electrical Engineering

Mr. David Babcock, Maj. Timothy Wolfe and Dr. Walter Jones.

This award is presented to the individual who made the most significant contribution to the AFIT mission through excellence in teaching, research, and service in order to maintain the excellence of AFIT's degree-granting academic programs. The award is named in honor of Col. Crocker who served as the dean of AFIT's School of Systems and Logistics from 1971-1972 and was a coauthor of papers on turbulence associated with blunt body flow.

Major Timothy Wolfe is an assistant professor of electrical engineering in AFIT's Graduate School of Engineering and Management with research efforts in atomistic modeling, ab initio modeling, computational chemistry, high power electromagnetics, plasma science, electronic materials and devices and directed energy.

He demonstrated excellence in teaching with a prolific year teaching three registered core courses following an unprecedented turnover in faculty within the Electrical and Computer Engineering department. He advised the cutting-edge research projects of seven master's students and two doctoral students in microelectronic reliability and computational electromagnetics. Wolfe volunteered for several initiatives to include serving as an industry partner for the nationally recognized Dayton Regional STEM Fellowship Program and as the outreach lead for the AFIT Chancellor's Strategic Action Team.

Congratulations

2022 Department of the Air Force STEM AWARD WINNERS

Department of Systems Engineering and Management Deputy Department Head Lt. Col. Warren Connell and Dr. Walter Jones

AFIT Systems Engineering Award

Mode-Based Autonomous Systems Engineering (M-BASED) Team

Capt. Charles Caines, Capt. Igor Gertsman, Capt. Jacob Hatzinger, Capt. Christopher Reed

Award Criteria: The AFIT Systems Engineering Award recognizes AFIT students or teams for outstanding achievements in furthering systems engineering understanding in the Department of the Air Force.

The M-BASED Team supported the Air Force Research Laboratory's Munitions Directorate by contributing novel research in autonomous systems development, modeling, and simulation. They designed, implemented, and tested a methodology to model behaviorally complex autonomous munitions using SysML and coded middleware to translate the system requirements to the Advance Framework for Simulation, Integration and Modeling environment. They applied rigorous analysis from over 200,000 trial runs to determine the optimal level of cooperation versus payload lethality for autonomous munitions during wide-area search.

Maj. Daniel Emmons and Dr. Walter Jones

DAF Outstanding Science and Engineering Educator Award

Maj. Daniel Emmons, Assistant Professor of Physics

Award Criteria: The award recognizes the efforts and achievements of the top U.S. Air Force instructor in the science and engineering fields, whose contributions and performance best characterize the principles of excellence in science and engineering education.

Maj. Emmons' demonstrated excellence in teaching and researching space physics. In addition to appointment as a Dean's Distinguished Teaching Professor, he advised two PhD and three Master's students resulting in a total of four peer-reviewed journal articles during this period. Additionally, he secured $950K in space weather research while directing the DOD's only graduate level space weather program.

Dr. Scott Nykl and Dr. Walter Jones

DAF Outstanding Scientist and Engineer Award – Junior Civilian Category

Dr. Scott Nykl, Associate Professor of Computer Science

Award Criteria: The award recognizes the efforts and achievements of the top U.S. Air Force Scientists or Engineers who make noteworthy and/or significant contributions to technology, engineering and/or solving technical problems in development, sustainment, testing, training, or advancement of AF systems.

Dr. Nykl developed a novel vision recognition algorithm which automates cross-DoD aerial refueling. His efforts led to deployed technology on the KC-46 and MQ-25 in both the Air Force and Navy, leading to a savings of over $10M annually and significant air dominance improvements in contested environments.

AFIT Graduate School's 2022 Air Education and Training Command (AETC) Level Award Winners

John L. McLucas Basic Research Award

Dr. Meir Pachter

Distinguished Professor of Electrical Engineering

Dr. Pachter's research led to the development of optimal strategies for air combat maneuvering in many-on-one encounters, swarm operations, and beyond visual range engagements. Additionally, his research has successfully transitioned to AFRL, evaluated in flight test campaigns, and tested at multinational exercises.

Harold Brown Award

Autonomy and Navigation Technology Center (ANT)

Team members: Dr. Clark Taylor, Dr. Aaron Canciani, Dr. Joe Curro, Dr. Rob Leishman. Dr. Aaron Nielson, Dr. Frank Van Grass, Dr. John Raquet, Mr. Taylor Lee, Mr. Daniel Clark, Mr. Mitchel Hezel, Mr. Luke Bergeron, Mr. Josh Hiatt, Mr. Jonnathan Bonifaz, Ms. Evelyn Boettcher, Mr. Jeremy Gray.

The ANT team developed and transitioned revolutionary positioning capability: magnetic anomaly-based navigation enabling aircraft to fly long distances in a contested environment without GPS while maintaining positioning, whether over water, land, or low-earth orbit.

Air Force Science and Engineering Award Engineering Achievement Category

2d Lt. Conor Wisentaner

Trainee, 14th Flying Training Wing, Columbus AFB, Miss.

Lt. Wisentaner devised new event based observing techniques for the space domain awareness mission. Lt. Wisentaner was the first to demonstrate a capability using commercial neuromorphic sensors to detect, track, and identify resident space objects and solve for their orbits. His innovative techniques reduced data overhead by seven times, increased observation rates by 67 times, and improving orbit determination accuracies by 500%. Lt. Wisentaner re-designed the experiment, removing known limitations, paving the way for employment with USSF assets.

Air Force Science and Engineering Award Advance Technology Development Category

CSRA Orbital Warfare Research Group

Team members: Maj. Costantinos Zagaris, Lt. Col. Bryan Little, Lt. Col. Robert Bettinger, Lt. Col. David Curtis, Lt. Col. Rachel Derbis, Maj. David Spendel, Maj. Jeremy Kaczmarek, Maj. Nicholas Yielding, Maj. Kullen Waggoner, Capt. Mark Mercier, Capt. Andrew Vogel, Capt. Charles Carr, 2Lt. Kyle Williams, 2Lt. Brendan Hennessey Rose, 2Lt Joseph Canoy, 2Lt. Nathan Cundiff, Mr. David Meyer, Mr. Thomas Fay, Mr. Nathan Boone.

The CSRA Orbital Warfare Research Group develops organic Guardian expertise in orbital warfare, formulates algorithms for autonomous satellite proximity operations, and manages an orbital engagement training simulation. The team received 1.3M dollars in grants and published 24 research papers.

DAF Outstanding Scientist/Engineer Mid-Career Military Category

Maj. Peter Saunders

Assistant Professor of Atmospheric Science

Maj. Saunders' critical research had a direct and lasting impact to the warfighter. An example of his work includes enabling the Center for Technical Intelligence Studies and Research to employ the AF's first physics-based image-chain model used to generate synthetic electro-optical and infrared (EO/IR) sensor data with realistic lightning properties.

DAF Outstanding Scientist/Engineer – Senior Military Category

Maj. Richard Dill

Assistant Professor of Computer Engineering

Maj. Dill secured $800,000 in DOD research funding to support sensor fusion, wargaming, and mobile network security efforts. A subject matter expert in sensor data, his efforts led to the novel detection of drones through phone acoustic sensors as well as improved disaster recovery capabilities.

DAF Outstanding Scientist/Engineer Mid-Career Civilian Category

Dr. Scott Graham

Professor of Computer Engineering

Dr. Graham developed an advanced hardware security encryption which prevents adversary reverse engineering, improving the security of deployed military systems. Further, his advanced multi-channel communication protocol ensured that next-generation avionics networks operate both efficiently and securely.

DAF Outstanding Scientist/Engineer – Team Category

Nuclear Expertise for Advancing Technologies Center (NEAT)

Team members: LTC Andrew Decker, Dr. Juan Manfredi, LTC Christina Dugan, Maj. James Bevins, Dr. John McClory.

The NEAT team's critical research had a direct and lasting impact to the warfighter. An example of their work includes the development of novel fast photo-curable scintillator resins that polymerize in minutes, greatly accelerating radiation detector manufacture time while reducing cost.

DAF Outstanding STEM Outreach Champion Award

Dr. Mark Reith

Assistant Professor of Computer Science

Dr. Reith architected and developed the AVOLVE education platform hosting over 4,000 DOD users and publishing over 2,000 content items on cyberspace, artificial intelligence, and software engineering. Dr. Reith also led development over Hangar 18, an AF software factory promoting rapid prototyping solutions organizations across WPAFB. His efforts have been recognized by many leaders including the USNORTHCOM/J7 Chief, Joint Education Branch, and in the AFMC Focus Week article.

Air University Award Winner

Air University Field Grade Officer of the Year

Lt. Col. Wayne "Chris" Henry
Assistant Professor of Computer Engineering


Lt. Col. Wayne Henry

Lt. Col. Henry led 41 members in a DOD / Intelligence Community team advancing cybersecurity capabilities. His leadership and expertise ultimately defended $20M high-value satellite systems. He developed three new certificate programs that transformed the training pipeline for AFRL civilians. Henry initiated high-value collaboration between AFIT and Johns Hopkins University resulting in multiple cybersecurity initiatives leading to four publications.

AFIT Award Winner

2022 International Affairs Excellence Award – Junior Civilian Category

Mr. Michael Paprocki
International Military Student Officer

Mr. Paprocki managed all aspects of the AFIT international military students and exchange personnel programs, to include all processes from pre-arrival to post-graduation actions for over 30 graduate students and engineering and scientist exchange program personnel from U.S. international partner nations. He worked on a 10-member team that reviewed joint military training regulations and resulted in streamlined authorized courses and partner nation enrollment to support $50B in foreign military sales programs. Paprocki partnered with five defense agencies to optimize the state department visa certification process to facilitate exchange officer access to the U.S. In addition, he managed over $260,000 in lodging stipend payments for 10 international students, arranged emergency travel for two students, and created a feedback system for 25 exchange personnel to optimize the Air Force's communication with foreign partners supporting worldwide exchange opportunities.


Mr. Michael Paprocki and Dr. Walter Jones.

OPTICAL FIBER TIP MICRO ANEMOMETER

US PATENT #: 11,635,315

DATE: April 25, 2023

INVENTORS: Capt. Jeremiah C. Williams (M.S. Electrical Engineering, 2020) and **Dr. Hengky Chandrahalim**, Assistant Professor of Electrical Engineering

ABSTRACT: A passive microscopic flow sensor includes a three-dimensional microscopic optical structure formed on a cleaved tip of an optical fiber. The three-dimensional microscopic optical structure includes a post attached off-center to and extending longitudinally from the cleaved tip of the optical fiber. A rotor of the three-dimensional microscopic optical structure is received for rotation on the post. The rotor has more than one blade. Each blade has a reflective undersurface that reflects a light signal back through the optical fiber when center aligned with the optical fiber, the blades of the rotor shaped to rotate at a rate related to a flow rate.

LINK: https://microsystems.group/patents/11,635,315%2025Apr2023.pdf

METHOD OF EVANESCENTLY COUPLING WHISPERING GALLERY MODE OPTICAL RESONATORS USING LIQUIDS

US PATENT #: 11,650,370

DATE: May 16, 2023

INVENTORS: Dr. Hengky Chandrahalim, Assistant Professor of Electrical Engineering, and **Capt. Kyle T. Bodily** (M.S. Electrical Engineering, 2021)

ABSTRACT: The present invention relates to evanescently coupling whispering gallery mode optical resonators having a liquid coupling as well as methods of making and using same. The aforementioned evanescently coupling whispering gallery mode optical resonators having a liquid couplings provide increased tunability and sensing selectivity over current same. The aforementioned applicants' method of making evanescent-wave coupled optical resonators can be achieved while having coupling gap dimensions that can be fabricated using standard photolithography. Thus economic, rapid, and mass production of coupled WGM resonators-based lasers, sensors, and signal processors for a broad range of applications can be realized.

LINK: https://microsystems.group/patents/11,650,370%2016May2023.pdf

2022-2023 SOCHE Excellence Awards

SOCHE recognizes outstanding faculty and staff at member institutions on an annual basis. Academic officers at each member institution selected one Faculty Excellence Award winner based on demonstrated excellence in teaching, service, and/or scholarship. Similarly, Human Resource officers selected one Staff Excellence Award winner based on demonstrated excellence in student success, service, and/or assessment.

The 2022-2023 year saw the addition of a new award, the Campus Impact Award, which is based on performance that made a positive impact on the school or campus, as a whole. This category is open to faculty, staff, or administrators.

SOCHE Faculty Excellence Award

Dr. Edward White
Professor of Statistics


Dr. Edward White

Edward "Tony" White is AFIT's Faculty Excellence Award winner after being named the AFIT Mathematics and Statistics Department Instructor of the Quarter for the 2023 winter quarter. He had a phenomenal score of 4.83/5.0 on the student survey question, "Considering both the limitations and possibilities of the subject matter and the course, how would you rate the overall effectiveness of this instructor?" He also had a top result of 4.78/5.0 for overall average score on the entire series of eight questions on same survey. Tony served as thesis advisor to two GCA master's students who graduated in March 2023.

SOCHE Campus Impact Excellence Award

Dr. Alice Grimes
Director, AFIT Center for Innovation


Dr. Alice Grimes

As Director of the Center for Innovation, Dr. Alice "Betsy" Grimes is AFIT's Campus Impact Award winner this year. Dr. Grimes single-handedly established AFIT's Center for Innovation in 2021 as a quality improvement initiative identified during the institute's reaccreditation process through the Higher Learning Commission. A dynamic and unwavering leader, Dr. Grimes secured over $450,000 for two contractors, procured equipment to enhance the student learning environment and facilitated bed-down of the center in AFIT's library. She also executed a holistic approach to personal and professional development of faculty, staff and students across the entire institute.

STAT COE Publishes Several Best Practices in Fiscal Year 2022

By Corinne Weeks, CTR; Mr. Nicholas Jones, CTR; Mr. Kyle Provost, CTR
STAT Experts
Air Force Institute of Technology

Rigorous model validation is an ongoing challenge in the Department of Defense (DOD) and is only becoming more important as the DOD furthers adoption of digital engineering and model-based systems engineering (MBSE). The STAT COE is actively researching improvements to model validation methods and published several best practices in FY22. In the area of digital engineering, the STAT COE is developing Model Validation Levels (MVLs), which provide an objective, automatable framework for quantifying how much trust can be placed in the results of a model to represent the real world. The STAT COE is currently looking to partner with DOD programs in this area to demonstrate MVL application to real-word systems. Additionally, in MBSE, the STAT COE advocates for a Platform Independent Model (PIM) approach with a verification and validation (V&V)-driven system decomposition to increase opportunities for early testing.

Digital Engineering uses models as a continuum throughout the system lifecycle, and those models must be validated to be considered trustworthy for use. Traditionally, validation has been a onetime process which designates a model as either valid or not valid. However, as the DOD shifts toward digital engineering, a new paradigm is needed which allows model validity to evolve over the system lifecycle. The STAT COE developed MVLs to meet this need and recently published, "Elements of a Mathematical Framework for Model Validation Levels," authored by STAT COE contractors Mr. Kyle Provost, Ms. Corinne Weeks, and Mr. Nicholas Jones, and STAT COE Deputy Director, Maj Victoria Sieck. The paper expands upon previous work to detail the mathematical methods which factor into an MVL. A second best practice, "Constructing a Metric for Fidelity in Model Validation," authored by Ms. Weeks, Mr. Jones, and Dr. Melissa Key, describes the construction and mathematical behavior of the MVL fidelity metric. The team is currently working to develop an automated tool for computing MVLs as well as a comprehensive guide for using and understanding MVLs.

MBSE formalizes the application of models to the systems engineering process and is key in the shift toward digital engineering. The systems engineering process, however, typically excludes V&V planning up front, resulting in late discovery of risk. Mr. Chuck Rogal, STAT COE contractor, authored the STAT COE best practice, "Model Based Systems Engineering for Developmental System Verification and Validation." The paper illustrates the use of a Platform Independent Model (PIM) which facilitates V&V activities earlier in the lifecycle. Additionally, the paper defines a hierarchal set of models which map to the traditional V-model of systems engineering. Each modeling layer generates opportunities for V&V activities early in the development cycle, creating artifacts which can be passed forward to guide test and evaluation activities later in the lifecycle. Applying this approach can help produce more mature systems, promote artifact reuse, identify risk earlier, and expedite risk mitigation.

These best practices can be found at **https://www.AFIT.edu/STAT/**. Additionally, if your program would be interested in collaborating with STAT COE in applying MVLs, please reach out to **AFIT.ENS.STATCOE@us.af.mil**.

JOINING ACACEMIC FORCES

"AFIT is uniquely positioned to enhance USSPACECOM's educational and research goals. Our robust space-focused curriculum provides opportunities to advance USSPACECOM's mission in a variety of areas, to include space vehicle and mission design, cislunar dynamics and orbit modeling."

AFIT Joins U.S. Space Command's Academic Engagement Enterprise

The Air Force Institute of Technology was selected to join the United States Space Command's Academic Engagement Enterprise. AFIT joins 16 other universities and research centers working together to enhance the relationship between the Department of Defense and academia.

USSPACECOM's goal for the program is to provide collaboration opportunities with universities to shape the future workforce, increase space-applied research and innovation, expand space-focused analytic partnerships and enrich the strategic dialogue on space.

"AFIT is uniquely positioned to enhance USSPACECOM's educational and research goals," said Lt. Col. Robert Bettinger, head of AFIT's astronautical engineering degree program. "Our robust space-focused curriculum provides opportunities to advance USSPACECOM's mission in a variety of areas, to include space vehicle and mission design, cislunar dynamics and orbit modeling, and model-based systems engineering."

To join the enterprise, institutions must be a two-year, four-year, or post-graduate degree institution with programs aligned to study and work in space. AFIT's Graduate School of Engineering and Management currently offers several certificates and degree programs in space-related fields including graduate certificates in space systems and space vehicle design, and master's and doctoral degree programs in astronautical engineering and space systems.

Founded in 2012, AFIT's Center for Space Research and Assurance (CSRA) delivers responsive and reliable space capabilities to the DOD and Intelligence Community. Faculty and students research and produce cutting-edge space technology development, science, and experiments to meet future challenges in the areas of astrodynamics, guidance, navigation, optimal control, propulsion, systems architectures, as well as structures and materials.

"Our graduates have mastered the next-generation STEM skills that will enable them to be key leaders critical to the success of future USSPACECOM endeavors," said Col. Nate Terry, senior military professor and CSRA Director. "CSRA supports cutting-edge graduate research to provide future Air and Space Force leaders with critical expertise to contribute to upcoming space capabilities."

MORE DETAILS

USSPACECOM's Academic Engagement Enterprise
Online at https://e.AFIT.edu/GJJ65T

AFIT's Center for Space Research and Assurance
https://www.AFIT.edu/CSRA/

U.S. Air Force photo by Katie Scott

The Digital Innovation and Integration Center of Excellence (DIICE) team from left: Mr. Richard Sugarman, Head of the Department of Software and Systems Engineering Management, School of Systems and Logistics (LS) and DIICE LS School Lead; Col. Jason Anderson, DIICE Director; Lt. Col. Paul Beach, DIICE Deputy Director; and Lt. Col. Amy Cox, Program Chair of Systems Engineering, Graduate School of Engineering & Management (EN) and DIICE EN School Lead.

AFIT Plans Interdisciplinary Center of Excellence to Support Military's Digital Transformation

By Stacy Burns
Air Force Institute of Technology

The Air Force Institute of Technology is planning a new center of excellence to be added to its academic, research, and consulting portfolio. The Digital Innovation and Integration Center of Excellence (DIICE) will support the Department of the Air Force's ongoing digital transformation.

Sponsored by Air Force Materiel Command, the DIICE will generate digital solutions centered around model-based systems integration efforts that result in improved execution of weapon acquisitions and support across the AFMC enterprise in support of the warfighter. The DIICE's mission is to be accomplished through four lines of effort: education excellence, research and technology transfer, consulting, and best practices.

"Our vision for the DIICE is to be the premier provider of advanced digital solutions to the Air Force. We will be digitally capable, fostering a culture of innovation, and be at the forefront of digital engineering advancements that provide the Air Force with integrative solutions for a decisive advantage in the digital battlefield," said Col. Jason Anderson, DIICE Director.

"We will enable our team of experts to push the boundaries of what is possible and develop solutions that drive real value for the warfighter and the nation. Our center will be a hub of connection and knowledge sharing, attracting the brightest minds and fostering partnerships with industry and academia."

In a recent *Dayton Business Journal* press release, Anderson explained that the digital capabilities of the center will allow the Air Force to build, test, simulate and validate all weapons systems within a digital world. This will create greater efficiencies and cost savings for the Air Force.

"We're trying to create the next generation of aircraft and sustainability of current aircraft. Weapons systems (mainly aircraft) average 15 years from concept to delivery. Through some of this digital, we've seen great leaps to reduce that dramatically. In some cases down to three years," said Anderson.

The DIICE will function as an interdisciplinary center of excellence, taking advantage of faculty expertise from both AFIT's Graduate School of Engineering and Management and its School of Systems and Logistics. Col. James Anderson, DIICE Director, is an Assistant Professor of Logistics and Supply Chain Management within AFIT's Department of Operational Sciences. Mr. Richard Sugarman is the Head of the Department of Software and Systems Engineering Management, School of Systems and Logistics (LS), and DIICE LS Lead. Lt. Col. Paul Beach, Assistant Professor of Systems Engineering, joins the center of excellence as Deputy Director. Lt. Col. Amy Cox is the Systems Engineering Program Chair, Graduate School of Engineering and Management (EN), and DIICE EN Lead.

AFIT GRADUATE SCHOOL FY22 EXTERNAL SPONSOR FUNDING

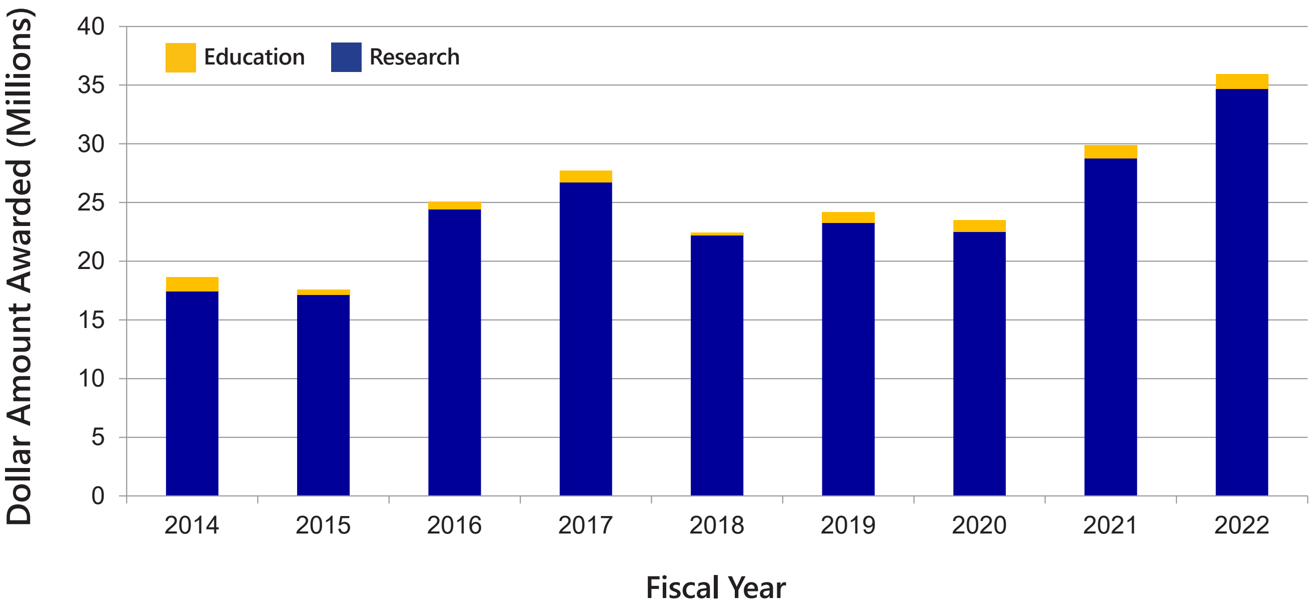
Many of the Graduate School of Engineering and Management's theses and research projects completed under faculty supervision are funded in part by other Department of the Air Force, DOD and government units and agencies. Often, this funding results from collaboration between faculty and thesis sponsors and occurs when the research project can be leveraged by the purchase of equipment or services not otherwise available. The table directly below summarizes external funding awards for FY22, while the bar chart at the top of the next page shows new funding received per fiscal year from FY14-FY22. The pie charts at the bottom of the next page show the breakdown of FY22 external awards by sponsor with a more specific breakdown by AFRL Technology Directorates.

FY22 External Funding Awards

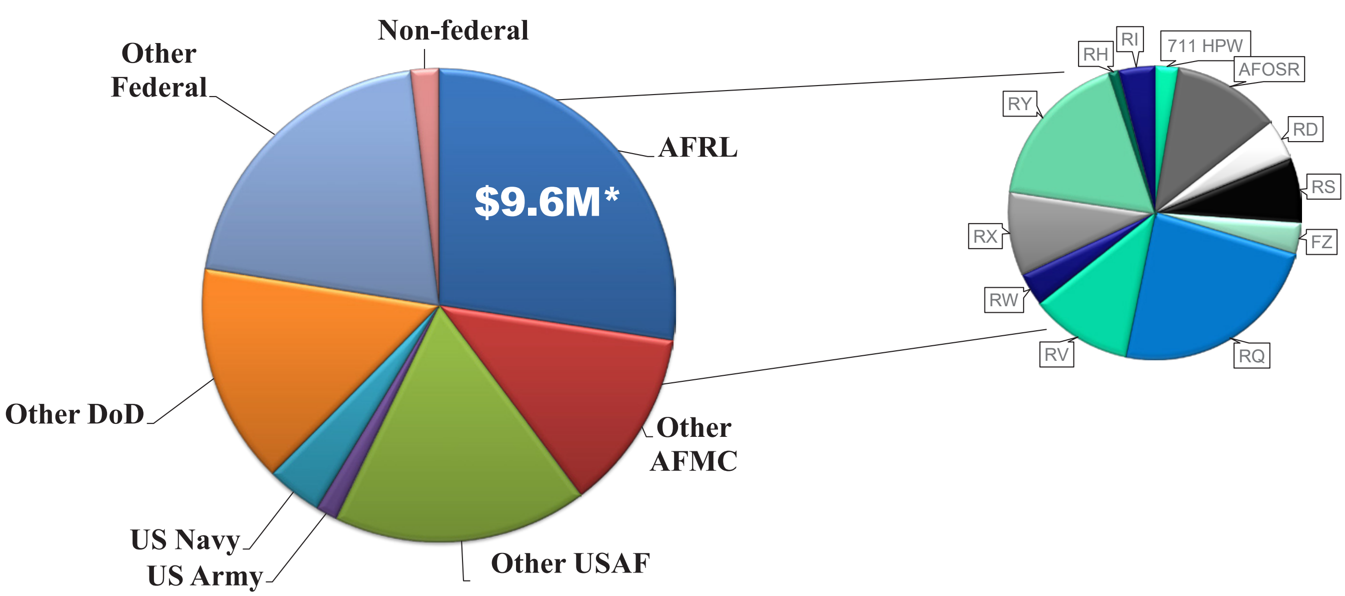
	Total FY22 Newly Awarded Projects			Total FY22 Research Expenditures
DEPARTMENTS	**#**	**$k**		**$k**
Mathematics & Statistics (ENC)	4	312		124
Electrical & Computer Engineering (ENG)	53	7,442		6,867
Engineering Physics (ENP)	56	9,959		8,943
Operational Sciences (ENS)	29	12,463		11,857
Systems Engineering & Management (ENV)	11	1,090		1,216
Aeronautics & Astronautics (ENY)	39	4,627		3,515
TOTAL	**192**	**35,893**		**32,522**

RESEARCH CENTERS	**#**	**$k**		**$k**
Autonomy and Navigation Technology (ANT)	29	6,333		6,088
Center for Cyberspace Research (CCR)	14	755		488
Center for Directed Energy (CDE)	22	2,420		2,503
Center for Operational Analysis (COA)	1	109		228
Center for Space Research and Assurance (CSRA)	10	1,575		2,128
Center for Technical Intel Studies & Research (CTISR)	16	4,882		3,784
Scientific Test And Analysis Techniques (STAT)	11	9,447		1,802
Nuclear Expertise for Advancing Technologies (NEAT)	10	21,822		8,424
TOTAL	**113**	**27,343**		**25,445**

New Funding Received Per Fiscal Year FY14-FY22



FY22 External Awards by Sponsor



Total Funding: ~$35.9 Million

***AFRL is AFIT's largest single sponsor:**
$9.6 Million from multiple components

Quantum Information Science

continued from cover

AFIT faculty and researchers foresee the potential to expand activities to support other U.S. Air and Space Force missions, such as securing mission-driven quantum communications for Air Force Nuclear Weapons Center (AFNWC), optimizing resource utilization for Air Force organizations such as: Air Combat Command (ACC), Air Education and Training Command (AETC), Air Force Global Strike Command (AFGSC), Air Force Special Operations Command (AFSOC), Air Mobility Command (AMC), Pacific Air Forces (PACAF), United States Air Forces in Europe – Air Forces Africa (USAFE), optimizing supply chain and maintenance scheduling for Air Force Materiel Command (AFMC), and optimizing personnel management for Air Force Reserve Command (AFRC).

QIS Forecast for the Future

Quantum Computing: As research in quantum computing progresses, it is anticipated that research will be primarily focused around the development of key technologies to enable the transition from the Noisy Intermediate-Scale Quantum computing (NISQ) era to that of reliable large-scale quantum computing. Private industry and academia within the U.S., its allies, and its strategic competitors, are leading the way in several of these technologies, including more reliable qubits and quantum gates. IBM's roadmap, for example, targets a 4,158-qubit machine with error suppression and mitigation by 2025.

Quantum Networking / Internet: In the area of quantum networking and internet, it is expected that future research in quantum-optical technology will enable secured quantum networking components (such as on-chip teleportation, quantum storage, repeater, entanglement distiller) for satellite and fiber based resilient quantum information sharing. These developments lead toward distributed and integrated quantum network and internet.

What is the Current State-of-the-Art in QIS?

Quantum Computing: Several companies, both domestic (Google, IBM, Microsoft, Amazon, Intel, IonQ, etc.) and foreign (Alibaba (China), Baidu (China), Origin Quantum (China), etc.) have become involved in quantum computing. One of the most advanced quantum computers to date is IBM's Osprey, which contains 433 quantum bits. The number of classical bits that would be necessary to represent a state on the IBM Osprey processor far exceeds the total number of atoms in the known universe.

Quantum Networking / Internet: As with quantum computing, many commercial companies (Cisco, Aliro Quantum, Qunnect) are participating in the advancement of quantum network and internet. Additionally, the Chicago Quantum Exchange is a growing intellectual hub for the science and engineering of quantum information, U.S. Department of Energy labs are connecting with scalable quantum internet, and AFRL is working to enable satellite-based daytime space-Earth quantum communications. Noteworthy foreign countries participating in the advancement include Austria, Germany, Canada, and China, that have integrated quantum communications based on satellite and thousands of miles of fiber.

GRADUATE SCHOOL FACULTY QIS RESEARCH EFFORTS

Dr. Larry W. Burggraf (ENP) – Topological Qubits

Dr. Michael R. Grimaila (ENV) & Dr. Douglas D. Hodson (ENG) – Quantum Networking and Quantum Key Distribution (QKD) Modeling and Simulation

Maj. Leleia A. Hsia (ENG) – Quantum Hardware Verification and Security, Quantum Hardware Radiation Survivability

Dr. Laurence D. Merkle (ENG) – Quantum Circuit Optimization, Quantum Circuit Layout, Quantum Error Correction, Post-Quantum Cryptography

Dr. Michael V. Pak (ENP) – Physics of Qubits, Topological Quantum Computing

Dr. Anil K. Patnaik (ENP) – Free-Space Qubit Propagation, Quantum Network Component Development, Quantum-Optical Science and Technology

Dr. David E. Weeks (ENP) – Quantum Error Detection and Correction, Characterization of Entanglement

Quantum Hardware Verification with Physically Unclonable Characteristics

By Maj. Leleia A. Hsia, PhD, USAF
Assistant Professor of Electrical Engineering
Air Force Institute of Technology

Computational advancements offered by quantum computers show great promise as an opportunity for technological improvements across multiple industries, especially the defense industry. In order to ensure the success of using quantum computers for various defense applications, it is important to develop countermeasures against threats to the supply chain of quantum computing hardware. One emergent quantum computing technology is based on the transmon (Figure 1), a type of superconducting qubit. One countermeasure currently in development for future application to quantum transmon processors is that of physically unclonable characteristics (PUCs), a method of quantum hardware verification inspired by classical physically unclonable functions (PUFs).

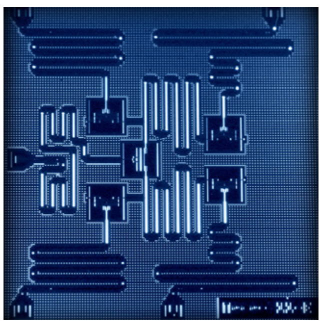


Figure 1 – IBM superconducting quantum processor [1]. Fabrication variations, environmental noise, and temperature fluctuations cause inter-qubit and intra-qubit variations.

PUFs (Figure 2) do not directly apply to the transmon processor, but they do follow a cause-and-effect paradigm, where the causes are fabrication variations, and the effect is inter-chip variation in performance parameters. The object of verification for PUFs is a function of performance characteristics.

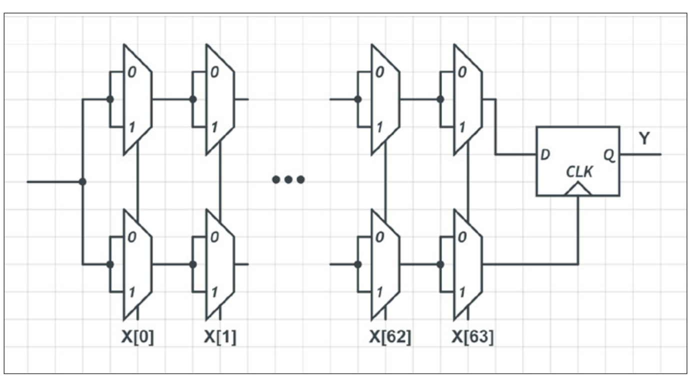


Figure 2 – Arbiter PUF circuit (adapted from [2]). Challenge bits are implemented through a set of multiplexers, and the output depends on which signal propagates the fastest due to fabrication variations. The output verifies the unique identity of a device.

Similarly, the causes for PUCs are fabrication variations and noise, and the effects are inter-qubit and intra-qubit performance variations. The objects of verification for PUCs include both functions of performance characteristics and the performance characteristics themselves.

The role of PUFs is to contribute to supply chain security by serving as a technique to track and verify classical components. An objective for PUCs is to serve in the same role for the quantum computing domain. Consider the situation (Figure 3) in which a manufacturer fabricates a transmon processor, collects N1 sets of characteristic data for each qubit, and sends the processor and characteristic data to a customer at the next stage of the supply chain through separate channels. After the processor is delivered to the customer, the customer collects N2 sets of characteristic data. The customer then compares their data to the manufacturer's data using PUCs to ensure that a third party did not change or replace the processor. In this way, PUCs capitalize on fabrication variations that affect qubit characteristics to discriminate between qubits.

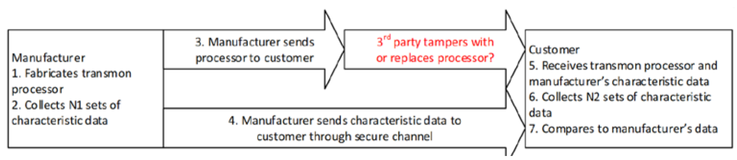


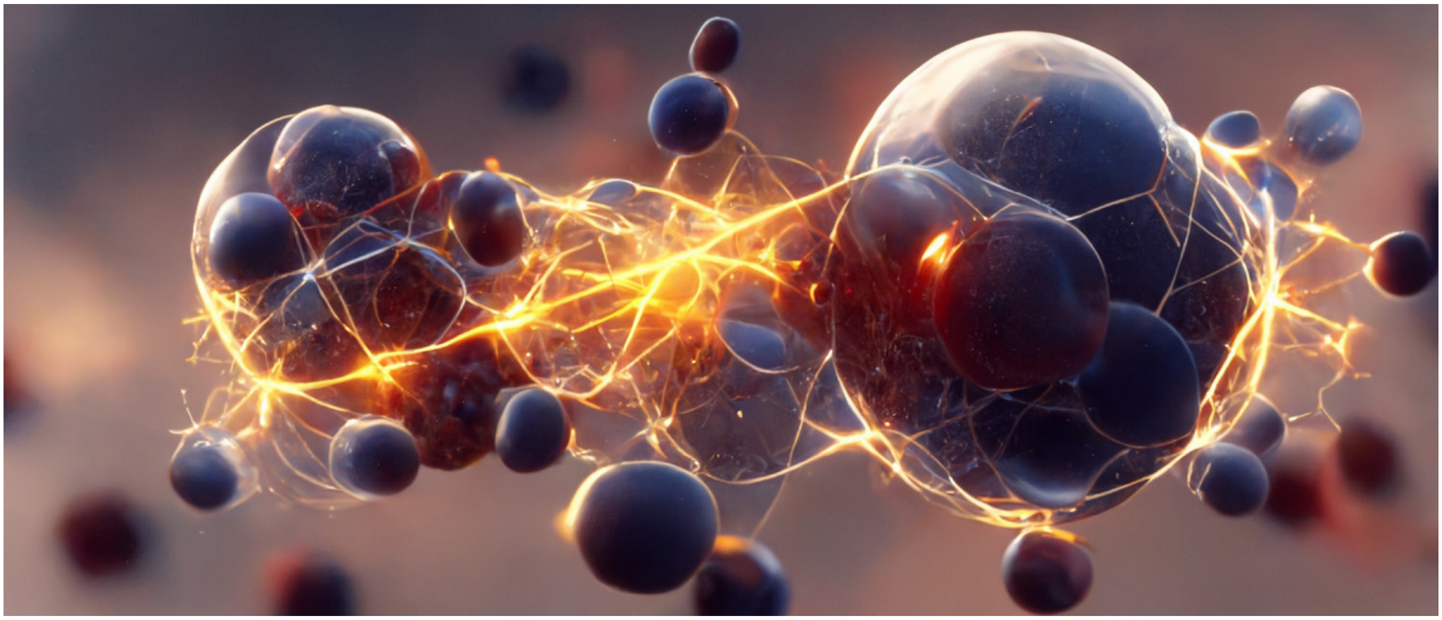
Figure 3 – Concept diagram of use case scenario for PUCs

The development of PUCs requires selecting/testing various characteristics and selecting/testing various qubit discrimination methods. To date, the characteristics selected and tested are calibration data (T1 and T2 coherence times and single-qubit, multi-qubit, and readout error), quantum process tomography metrics (for the X, H, CX, SWAP, CCX, and CSWAP gates), and randomized benchmarking metrics (1-qubit, 2-qubit, and 3-qubit metrics, with one seed of data and with five seeds of data). Qubit discrimination methods selected and tested are the t-test, one-dimensional Kolmogorov-Smirnov (KS) test, two-dimensional KS test, Jensen-Shannon divergence, and quadratic discriminant analysis. The best results thus far have been observed with the one-dimensional KS test for all characteristics. However, better results can possibly be achieved with further refining of some of the qubit discrimination methods or with other characteristics and qubit discrimination methods that have not yet been tested.

Additional characteristics that have been selected for future testing include anharmonicity, probability of measuring |0> for a qubit prepared as a |1>, probability of measuring |1> for a qubit prepared as a |0>, ID error, crosstalk, and resonance response curves. Additional qubit discrimination methods selected for future testing include the three-dimensional KS test and multiple discriminant analysis with maximum likelihood. Other future work includes exploring the application of PUCs to the trapped ion qubit and other qubit technologies.

[1] R. Courtland, “IBM Puts a Quantum Processor in the Cloud,” *IEEE Spectrum*, May-2016.

[2] C. Herder, M. D. Yu, F. Koushanfar, and S. Devadas, “Physical unclonable functions and applications: A tutorial,” *Proceedings of the IEEE*, vol. 102, no. 8. pp. 1126–1141, Aug-2014.



System-level Error Mitigation in Quantum Computing

By Dr. Laurence D. Merkle
Air Force Institute of Technology

Key quantum computing technology metrics such as qubit count and qubit decoherence times, as well as the reliability of state preparation, quantum operations, and quantum measurements are not yet sufficient for large scale reliable applications. During this so-called Noisy Intermediate Scale Quantum computing (NISQ), the private sector is making steady progress in improving these metrics. However, for the foreseeable future, obtaining the most reliable possible execution of quantum circuits will require various error mitigation techniques.

Another article in this newsletter discusses an algorithm-level technique whereby logical quantum states are encoded using multiple physical qubits. This allows for detection of the most likely types of errors and rejection of the corresponding results. One advantage of this technique is that quantum programmers can use it on existing systems. However, at present it requires the programmer to fully understand its application and manage its complexity along with that of the desired logical quantum computation. Several of my past and present master's students have instead worked towards system-level error mitigation techniques. These efforts have focused on three levels of abstraction.

At the lowest level, Lt. Claire Badger and later Lt. Brett Martin each advanced the state-of the art in the system-level use of quantum error-correcting codes analogous to Hamming codes in the case of classical communication. Specifically, their work added to our understanding of the use of deep neural networks in the efficient and effective decoding of surface code error syndromes to determine the necessary quantum operations to correct the underlying errors. Lt. James Wang is now continuing their work by investigating the use of similar techniques for recently proposed types of codes that generalize the surface code using ideas from group theory and topology.

Next, it is an inconvenient reality that reliability varies between qubits, as well as between qubit links, so that the mapping from logical qubits to physical qubits affects execution reliability. Previous work framed this NP-Compete combinatoric optimization problem as a search for a single permutation of the logical qubits onto the physical qubits that persists over the execution of the circuit. Lt. Brian Curran explored the possibility of changing the permutation between the layers of the circuit, thereby allowing for the possibility of higher reliability execution, but greatly expanding the search space. He then used both evolutionary computation and the Variable Neighborhood Descent technique to explore the expanded space, in the process demonstrating the potential value of his framing of the problem.

Finally, one way to obtain more reliable results is to simplify the quantum circuit, thereby reducing operation count and execution time while preserving the ideal effect of the computation. The simplest example of circuit simplification is removing occurrences of operations followed immediately by their inverses without use being made of the intermediate result. More generally, any subcircuit that is equivalent to the identity operation may be removed without affecting the ideal effect of the circuit. Still more generally, if a sequence of layers can be represented by the matrices $L_1, L_2, \ldots, L_k$ and there exist $L_{k+1}, L_{k+2}, \ldots, L_n$ such that $L_n L_{n-1} \cdots L_1 = I$, then $L_k L_{k-1} \cdots L_1 = L_{k+1}^\dagger L_{k+2}^\dagger \cdots L_n^\dagger$ (where $L^\dagger = L^{-1}$) since matrices representing quantum operations are unitary). Thus, the subcircuits represented in the last equality are interchangeable.

Current circuit transpilation tools leverage these simplification techniques. Additionally, they are able to identify cases in which adjacent subcircuit layers commute, which can expose more opportunities for simplification. Recently, Capt. Brenna Cole won the Dean's Award for her master's thesis, in which she demonstrated the existence of 3-, 4-, and 5-qubit subcircuits for which a layer commutes with the composition of either the preceding or succeeding pair of layers. She also built exhaustive template libraries of such subcircuits. Lt. Cristian Grauberger is now building on her work by developing an algorithm to search for such subcircuits within a larger circuit and integrating the algorithm into current transpilation tools.

Modeling and Simulation of Quantum Networks and Systems

Dr. Michael R. Grimaila, Professor of Systems Engineering, and Dr. Douglas Hodson, Professor of Computer Engineering, are leading a five-year research project, sponsored by the Laboratory for Telecommunication Sciences (LTS), that is focused on modeling and simulation of Quantum Networks. Current PhD student 1st Lt. Brett Martin and master's degree students Maj. Kurt Spranger, 2nd Lt. Takashi Joubert, and Mr. Blake Perkins are working with Grimaila and Hodson to develop, construct, document, build, and evaluate open source-based software to facilitate the efficient and accurate modeling and simulation of Quantum Networks and their related systems.

Quantum Networks (QNs) are an emerging technology that offers the ability to distribute and share quantum information securely among quantum computers, clusters of quantum sensors, and other related devices at regional, national, and international distances. QNs can also be used to distribute ultra-precise time signals, an important capability in many scientific endeavors.

The development of a robust quantum networking modeling and simulation environment capability will facilitate the engineering of quantum communication systems that can reliably exchange data over long distances, across topologically complex networks built on heterogeneous technologies, and managed by multiple independent organizations. While many modeling and simulation tools exist for the modeling and simulation of classical computing systems and networks, few tools and methodologies exist for modeling quantum computing systems and networks. Existing modeling and simulation tools for quantum mechanical systems tends to be specialized and are focused upon simple use cases which abstract important details out of the model. This is a consequence of the "curse of dimensionality" which causes larger scale simulation models to be infeasible to simulate in a reasonable time.

The developed quantum networking modeling and simulation capability will be used to

engineer design decisions, evaluate design trade-offs, forecast the impact of future technologies, create technology roadmaps used to drive technology investment resourcing decisions, and to develop an overall better understanding of quantum internetworking technologies. Furthermore, models can be developed of components that are not yet possible to physically realize allowing an analyst to consider the impact of technology capabilities of our adversaries.

The AFIT research project directly supports Topic 4 of the recently announced DC-Area Washington Metropolitan Quantum Network Research Consortium (DC-QNet) whose stated goal is to create, demonstrate and operate a quantum network as a regional test bed in the DC-Area. The six lead DC-QNET agencies are the U.S. Army Combat Capabilities Development Command Army Research Laboratory (DEVCOM ARL), the U.S. Naval Research Laboratory (NRL), the U.S. Naval Observatory (USNO), the National Institute of Standards and Technology (NIST), the National Security Agency/Central Security Service Directorate of Research (NSA/CSS-RES), and the National Aeronautics and Space Administration (NASA). In addition, there are two out-of-region affiliates: U.S. Naval Information Warfare Center Pacific (NIWC Pacific) and the U.S. Air Force Research Laboratory (AFRL). AFIT faculty and students are currently working with DC-QNet consortium members to model and simulate the initial segments of the quantum network as they are implemented.

WHAT ARE QUANTUM NETWORKS?

Quantum Networks (QNs) are an emerging technology that offers the ability to distribute and share quantum information securely among quantum computers, clusters of quantum sensors, and other related devices at regional, national, and international distances. QNs can also be used to distribute ultra-precise time signals, an important capability in many scientific endeavors.

Improved Quantum Circuit Statistics Using Quantum Encoding

By David E. Weeks and Nicolas Guerrero
Quantum Information Science Group
Air Force Institute of Technology

Current state of the art quantum computers are unable to perform useful calculations because they become overwhelmed by various types of noise. Quantum encoding employs multiple physical qubits to describe a single logical qubit and can be used to improve the statistical performance of noisy quantum circuits. For example, one possible two qubit encoding identifies the logical qubit $|0\rangle_L$ using two physical qubits as $|01\rangle$ and the logical qubit $|1\rangle_L$ as $|10\rangle$. If during the final measurement a $|00\rangle$ or $|11\rangle$ is observed the states are no longer properly encoded and an error is declared. Individual shots on a quantum computer for which the encoding is not preserved are not included in subsequent analysis with an associated improvement in the statistical analysis of the circuit. An application of quantum encoding is made to the Greenberger-Horne-Zeilinger (GHZ) circuits with the goal of improving the circuit statistics. The GHZ circuits produce highly entangled states, for example the $N = 2$ GHZ circuit generates the well-known Bell state $|\beta_{00}\rangle = (|00\rangle + |11\rangle)/\sqrt{2}$. For $N = 3$, the corresponding GHZ circuit generates the state $|\beta_{000}\rangle = (|000\rangle + |111\rangle)/\sqrt{2}$ and so on for higher values of N. To study the effect of quantum encoding, GHZ circuits are run on the transmon based IBM quantum computers for $N \in \{2,3,4,5\}$ logical qubits and $Q \in \{1,2,3,4,5\}$ physical qubits per logical qubit. The GHZ(N, Q) circuits are compared with results from GHZ(N, 1) circuits and exhibit a significant improvement in the circuit statistics for $Q \in \{2,3,4\}$. The circuits were specifically run on the 27 qubit ibmq_Montreal quantum computer with a topology shown in figure 1.

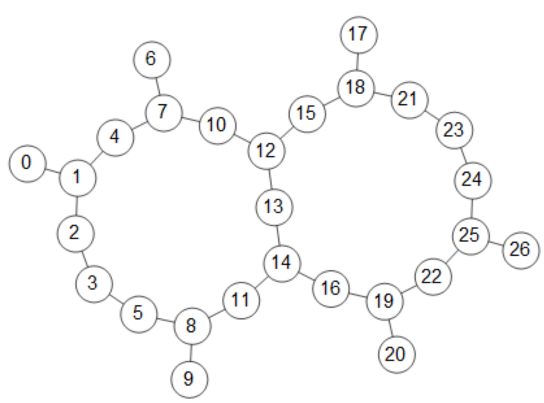


Figure 1) Topology of the 27 qubit *ibmq_Montreal* quantum computer the numbered circles identify qubits and the lines between circles identify pairs of qubits that can be entangled.

A simple quantum circuit is shown in figure 2 that generates an $N = 2$ GHZ state, also known as a Bell state. Here the qubits are initialized in the state $|00\rangle$, the Hadamard gate labeled H operates on the state $|00\rangle$ to yield the state $(|00\rangle + |10\rangle)/\sqrt{2}$, followed by the controlled not gate to yield the Bell state $|\beta_{00}\rangle = (|00\rangle + |11\rangle)/\sqrt{2}$. For perfect circuits with no noise or error, there is a quantum probability of exactly 50% to measure 0 and 0 for the two qubits corresponding to the state $|00\rangle$, and a quantum probability of exactly 50% to measure 1 and 1 for the two qubits corresponding to the state $|11\rangle$. If the circuit is run a sufficiently large number of times, the circuit statistics will yield measurements of 0, 0 for half of the runs and 1, 1 for the other half.

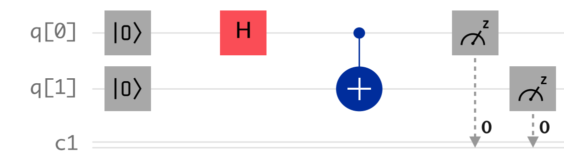


Figure 2) A simple GHZ(2,1) circuit used to produce the Bell state $|\beta_{00}\rangle = (|00\rangle + |11\rangle)/\sqrt{2}$.

When the two physical qubits in figure 2 are treated as two logical qubits, each encoded with two physical qubits the circuit becomes a four qubit circuit as shown in figure 3. In this circuit, the logical qubits are encoded using Pauli X gates labeled by the + sign. These encoding gates transform the initial state $|0000\rangle$ to an encoded state $|00\rangle_L = |0101\rangle$. The second set of gates in figure 3 form the logical Hadamard gate and transforms the encoded state into $(|00\rangle_L + |10\rangle_L)/\sqrt{2} = (|0101\rangle + |1001\rangle)/\sqrt{2}$. The circuit concludes with the logical C_x gate to yield and encoded Bell state, $|\beta_{00}\rangle_L = (|00\rangle_L + |11\rangle_L)/\sqrt{2} = (|0101\rangle + |1010\rangle)/\sqrt{2}$. Note that the first C_x in the logical Hadamard can be eliminated and the two Pauli X gates on qubit q_3 will cancel.

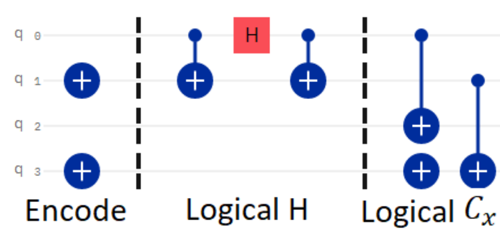


Figure 3) This GHZ (2, 2) circuit encodes the $N = 2$ bell state for $Q = 2$ physical qubits per logical qubit with code words $|0\rangle_L = |01\rangle$ and $|1\rangle_L = |10\rangle$.

Actual circuits run on the IBM transmon based quantum computers are noisy and exhibit significant error. A metric of circuit performance is given by the similarity measure, $\mu = 1 - \sum_{n=0}^{2^k-1} |P_n - P_n^e|/2$ where n is the decimal label of the quantum state, P_n is the probability that the state n was measured over the course of 2^{13} shots on the quantum computer, and P_n^e is the exact probability known *apriori* for the simple GHZ circuits. The similarity measure is shown in figure 4 for the unencoded GHZ (2, 1) circuit in figure 2 using orange bars. The green bars in figure 4 are the similarity measures for the encoded GHZ(2, 2) circuit in figure 3 where all of the encoded measurements are used to compute the similarity measure. The blue bars in figure 4 are the similarity measures for the encoded GHZ(2, 2) circuit in figure 3 where only those runs that retain proper encoding are used to compute the similarity measure. Here we see that when all the measurements are retained regardless of encoding, the larger circuit in figure 3 with more gates has a lower similarity measure when compared to the smaller circuit in figure 2 with fewer gates. However, when an encoding filter is applied for the circuit in figure 3 to eliminate shots that failed to maintain proper encoding from the similarity measure, the circuit statistics are improved.

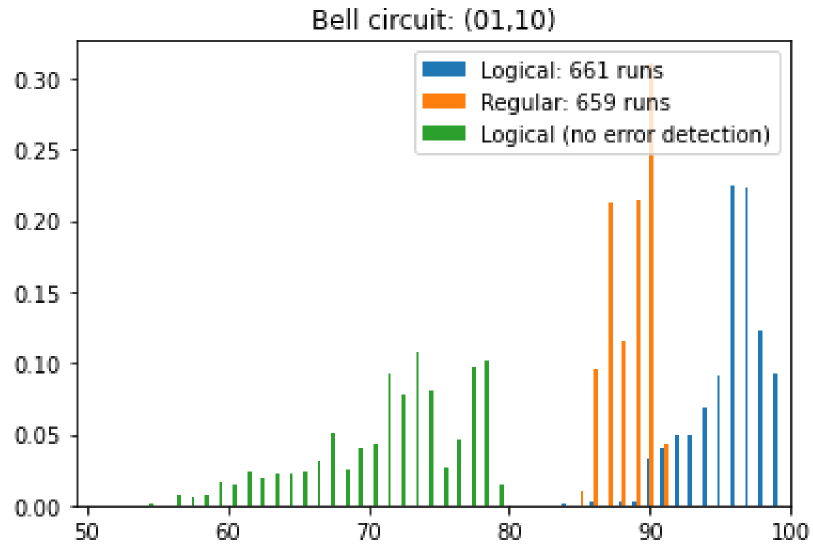


Figure 4) The similarity measure μ for the unencoded GHZ(2, 1) circuit in figure 2 (orange), the encoded GHZ(2, 2) circuit in figure 3 with no encoding filter (green), and the encoded GHZ(2, 2) circuit in figure 3 with an encoding filter (blue).

A systematic study of the similarity measures for GHZ(*N*, *Q*) circuits with $N = 2, 3, 4, 5$ and $Q = 1, 2, 3, 4, 5$ is performed by running each circuit for 2^{13} shots. This is repeated for 200 runs to yield 200 values of μ for each circuit. In Figure 5a no encoding filter is applied and all 2^{13} shots are used to compute μ for each run. The 200 values of μ are then averaged for each circuit and as *N* and *Q* increase, the circuits get larger and μ decreases. In figure 5b an encoding filter is applied and only those shots that retain the encoding pattern are included when computing μ. In this case, values of μ for the encoded $Q = 2, 3, 4$ circuits have improved significantly compared to the unencoded $Q = 1$ circuit. It is interesting to note that improvements in μ are greater for even numbers of qubits that encode using a balanced state with the same number of qubits in the states $|0\rangle$ and $|1\rangle$. This ameliorates an asymmetry between the naturally stable ground state of the qubit $|0\rangle$ and the excited state of the qubit $|1\rangle$ which decays into the ground state over time. It is also interesting to note that the similarity measure of the GHZ(4, 5) circuit containing 20 entangled qubits increases from 2.8 in figure 5a to 90.4 in figure 5b. This improvement comes a cost where the percentage of shots that pass the encoding filter is shown in figure 5c. For the GHZ(4, 5) circuit, only 2.81% of the shots are retained.

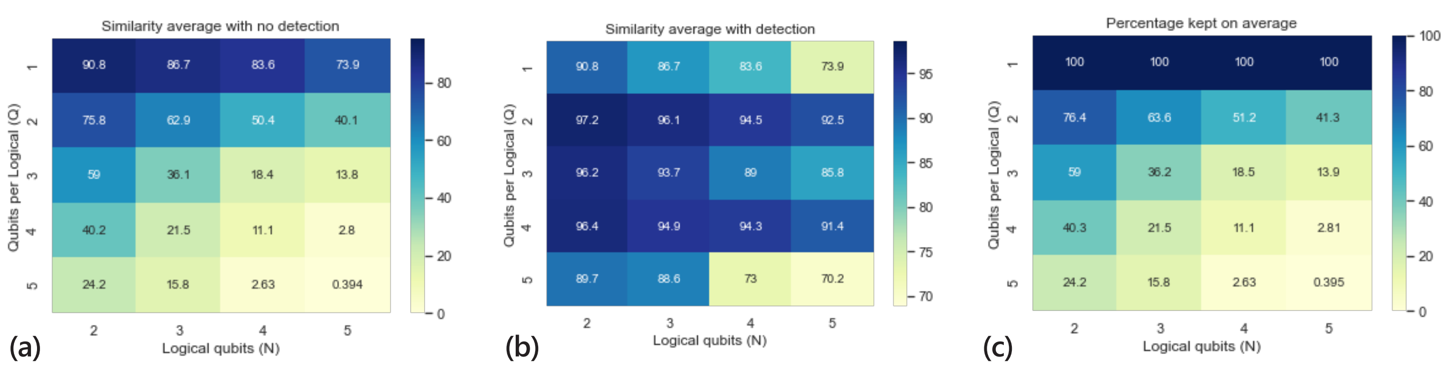


Figure 5) GHZ(*N*, *Q*) circuits for $N = 2, 3, 4, 5$ and $Q = 1, 2, 3, 4, 5$ are run for 2^{13} shots to yield a value of the similarity measure μ. This is repeated for 200 runs to yield 200 values of μ for each circuit. In (a) no encoding filter is applied and all 2^{13} shots per run are used to compute μ. In (b) an encoding filter is applied and only those shots that retain the encoding pattern are included in the average. The percentage of shots that pass the error detection test is shown in (c).

Piecing Together the Quantum Legos for Quantum Network

By Dr. Anil Patnaik, Maj. Keith Wyman, Capt. Billie DeLuca, Lt. Noah Everett, Mr. Robert Von Holle, Alex Ressue and Vishwa Ramesh

Quantum information is undeniably the future of the information age. In fact, the Air Force's S&T 2030 has identified the resilient and affordable architecture as critical mission needs. Adversaries in other countries have advanced in developing the secure quantum communication technologies. Hence, to counter the adverse consequences on the national security and avoid tech surprises, it is critical that the advanced quantum technologies be developed in-house. Global-scale quantum communication via satellite-based quantum nodes, quantum ground transceivers and possibly with quantum computing nodes (qcnodes) could become a reality in a few decades with free-space quantum networks.

While a myriad of developments happened in the quantum computing, quantum networking (both fiber and free space propagation) in last decade, quantum network is at best in its nascent stage. The quantum lego pieces to connect each of the quantum nodes and seamless flow of information between them is still a dream. The pioneers Drs. Clauser, Aspect and Zeillinger received Nobel prize in 2022 for the fundamental developments in photonic quantum information. A team with two PhD students and a MS student led by Dr. Patnaik at AFIT has been successfully stood up the quantum optical technology (QuOTe) laboratory from ground up with a specific goal to address the knowledge gaps in implementation of the quantum networking. This laboratory has been established with funding support from AFRL/RDS, AFRL/RI, NSA and AFIT Graduate School funds. The idea is to employ photonic qubits (quantum bits) as the carrier of the quantum information to connect to the quantum computing nodes.

Quantum communication is the future of secured information exchange. Free-space quantum networks can enable global-scale quantum communication via satellite-based nodes and quantum ground transceivers. This could facilitate distributed quantum communication and computation, quantum-assisted imaging, sensing and precise timing. The lego block that enables any of the free space quantum communication or network is a photonic qubit. Although the state-of-art classical free space communication has advanced enough to operate with high fidelity using almost entire spectrum of light (or electromagnetic field), the rule of the game changes completely for the free-space quantum communication and network.

In classical communications, where the classical bit stream – the sequence of presence or absence of the electromagnetic field determine the classical signal 1 or 0, respectively [see Fig. 1(a)]; however, in the quantum communication, the quantum state of each of the photons (the quantas of electromagnetic field) carry the quantum information of interest, which typically is a superposition of the states 0 and 1 [see Fig. 1(b)]. A typical difference of classical and quantum communication is depicted in Figure 1. The qubit state $|q\rangle = \alpha|1\rangle + \beta|0\rangle$ is a typical superposition of state represented using the Bloch sphere, as shown in the inset of Fig. 1(b). Since individual photonic state can change significantly during its propagation through atmosphere, specifically in the presence of atmospheric turbulence (a problem that still poses a challenge for classical communication), the possible information loss or leak through photons that wandered through turbulence could cause a critical risk to information security in quantum communications.

The complexity is compounded in quantum communication because entangled photon pairs $|\psi_{photon\ pair}\rangle = \frac{1}{\sqrt{2}}(|1,0\rangle + |0,1\rangle)$ are used as nonlocally-correlated qubit pairs that enable critical quantum networking protocols, such as, quantum repeater, entanglement distillation and swapping. Thus, how free-space propagation photonic qubit affects the entanglement is crucial for developing a robust quantum network. At the QuOTe lab, lab scale studies are being performed to study how qubits transform during their propagation through turbulence. Modelling the effects and develop methods to mitigate the quantum information loss are investigated. This study will enable developing the required techniques for secure and high-fidelity satellite communications to ground base or another satellite.

A proposed quantum network node is in progress to be established at AFIT. The plan would be to set up a quantum node at AFIT's QuOTe Lab, which will be connected through a dark-fiber based quantum network with the Quantum Information Science Engineering Center at The Ohio State University in near future.

Photon as a Qubit

The smallest quanta (electromagnetic energy wavepacket) of light known as photons – have emerged as the only promising information carrier of quantum signal for transferring quantum info from one node to another. The preference of using photons stems from the fact that they have longest coherence times compared to any of the other quantum particles. Photonic qubit (p-qubit) holds the key to the quantum communications, quantum network, and quantum internet. The quantum information of interest is encoded into a photonic state by swapping entanglement from source to a target photon. Since individual photonic state can change significantly during its propagation through atmosphere, specifically in presence of atmospheric turbulence (still a challenge for classical communication), the possible information loss or leak through photons that wandered through turbulence could cause a critical risk to information security in quantum communications. The propagation of qubits and their transformation when passing through turbulence are being studied through laboratory and field-based experiments. This investigation will enable developing the required knowhow and techniques for secure and high-fidelity satellite communications to ground base or another satellite.

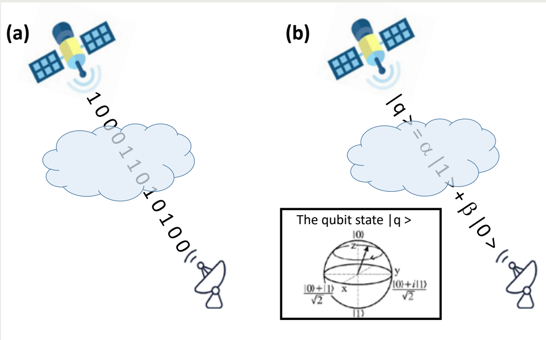


Figure 1 Schematics of satellite and ground station link with (a) classical communication sending classical bits and (b) quantum communication sending quantum bits or qubits. Inset: A qubit could be any vector in the Bloch sphere.

AFIT's Quantum Optical Technology (QuOTe) Laboratory for Quantum Network

A quantum information laboratory is built to study the critical parameters involved in a ground-to-space link. Specifically, we have built an atmospheric turbulence simulator (ATS) to study the effects of atmospheric turbulence on the quantum network. The photons arriving at a satellite may loose the strong non-local correlations (entanglement) that exist between two photons due to atmospheric turbulence. To mimic atmospheric turbulence, discrete thin layers are used to replicate the statistics of a continuous slab of turbulence that are then combined with lenses to scale long-distance propagation (with a few meters of lab scale propagation). For the laboratory, the discrete thin layers can be represented by spatial light modulators (an electro-optic device that sends an electrical signal to a pixel array that orients liquid crystals in such a way to impart a spatial-dependent phase onto the photons) or a near-index-matching phase plate (two optical materials sandwiched together with some arbitrary surface profile at their interface).

For a local quantum network, a fiber network is generally considered as the medium to transmit quantum information. To explore the parameter space of a local quantum network, AFIT acquired a fiber-based quantum key distribution (QKD) system as a donation from the AFRL. This QKD system implements a decoy state protocol operating at the telecom wavelengths (1550nm). The system sends about 20k bit long keys at a QKD rate of ~40k keys per second with a quantum bit error rate on the order of a percent or two post processing.

At QuOTe laboratory, we hope to make measurements on physical observables associated with the photons. With the ATS, we can observe how a noisy environment effects these measurements with the hopes of improving upon or developing a theoretical model that describes these effects as a function of turbulence parameters. This theoretical model will be used to drive the requirements for a planned QKD experiment between AFRL and the Canadian space agency.

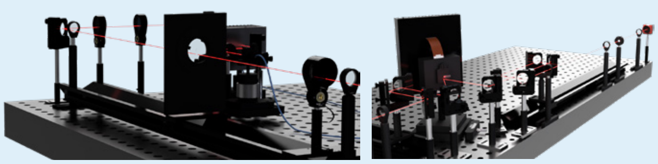


Fig. 2: AFIT QuOTe laboratory's atmospheric turbulent simulator (ATS) setup. Graphic on the left shows the first afocal system which consists of two lenses, a field lens, and a Lexitek phase plate. In the background, the beam expander and a steering mirror are seen. The graphic on the right shows two lenses, a field lens, a Meadowlark SLM, and two optical trombones. In the background, an iris and imaging system are visible.

Maj. Keith Wyman, a PhD student in AFIT's Department of Engineering Physics, joined as PhD student after his assignment at Starfire that holds the honor of being the innovator of the adaptive optics to deal with the atmospheric fluctuations. He has worked through his dissertation work while setting up the QuOTe laboratory from ground up.

Component Optimization in Quantum Communication Systems

Quantum computers (QC) are being rapidly developed in both the government and private sectors, and quantum communications networks will be needed to connect these revolutionary QCs to each other and to their users. Spontaneous parametric down conversion (SPDC) is a popular source for entangled photons, which are a vital component of many quantum information applications. These sources are often treated as single photon pair sources when used with weak pump lasers since a single pair of photons is the most likely output. However, multiple pairs are always possible and create a vulnerability to cryptographic attacks like the photon number splitting attack. Capt. DeLuca worked with Capt. Nicholas Guerrero and 1st Lt. Adrian Scheppe developed an exact theoretical quantification of the error introduced by the higher order photon contributions for a simple detection experiment with SPDC photons. Noteworthy that this project was evolved as an extension to the final exam of PHYS 845 (Quantum Optics and Quantum Information) course offered by Dr. Patnaik.

In addition to reliably producing qubits, quantum networks will also need to be able to robustly store qubits long enough to establish connections between remote locations. In quantum optics, light storage has been realized employing electromagnetically induced transparency (EIT), which is a technology that offers the dual advantage of cheap implementation and relatively long storage time (on the order of micro- to millisecond). While there are numerous experimental demonstrations of this storage, theoretical predictions of the effect of storage on the qubit have previously been limited to Gaussian light pulses. Capt. DeLuca developed an analytical framework for the prediction of pulse retrieval for arbitrary shape of light pulse. Developing a formalism called coherent atomic transfer (CAT) function analogous to Fourier transfer function, she implemented a numerical script that reduced the calculation time for the retrieved pulse from hours to minutes. This result will allow development of a crucial enabling technology of storage and retrieval of pulsed qubits or more complex quantum information embedded in photonic states.

Capt. Billie DeLuca, a PhD student in AFIT's Department of Engineering Physics, is working on fundamental technologies for quantum information science. Capt. DeLuca came with astronomical imaging background and implementing her expertise in Fourier imaging into quantum optical systems to work on a variety of components required for quantum networking.

Topological Quantum Computing and Error Mitigation in Superconducting Qubits with Topological Materials

By 1Lt. Adrian D. Scheppe, Capt. Seth Hyra, Dr. Michael V. Pak
Air Force Institute of Technology

Quantum computing is a steadily advancing field of research both in the commercial and national defense arenas with both civilian and governmental organizations pushing the computational boundaries by building bigger systems with more "quantum bits" (qubits). The conventional qubit which forms the basis of the largest systems is based on fundamental superconducting properties, namely the Josephson effect, which is a zero-resistance current that exists between adjacent superconductors (SC). The Josephson junction formed from this effect acts as a non-linear inductive element for a Quantum Anharmonic Oscillator (QAHO) which forms the basic structure for SC qubits. It is difficult to overstate the importance of this effect in relation to the field of quantum information because, without it, there wouldn't be any obvious qubit alternatives that perform nearly as well. The Josephson effect and superconductivity are the very foundation that currently support the entire global project of quantum computing. Without an apparent alternative system, we ask the question: How far can we push our only option?

As with any technology, SC qubits carry their own share of engineering challenges which are continually addressed through various mitigation strategies. For example, as with classical bits, environmental perturbations can cause the qubit state to drift away from what we want it to be; ones can become zeros suddenly. However, unlike their classical counterparts, interaction with the environment can also cause decoherence which essentially destroys the qubit state and causes the total loss of contained information. In the first case, error correction strategies are under continuous development and refinement to undo the drifting qubit state, but the second case of decoherence is irreversible. Furthermore, these effects compound with the addition of more and more qubits, meaning there may exist an absolute ceiling for the scalability and tolerances of SC qubit systems. These environmental effects are fundamentally unavoidable for any energetically coupled qubit basis, and for this reason, we need to imagine a better qubit which is robust in the face of environmental influence.

The AFIT topological quantum computing group, led by Dr. Michael Pak, works on various possible applications of exotic topological phases of matter to realize topological protection of quantum information. Topological materials are an astounding class of condensed matter systems which have been receiving large amounts of attention in the past decade due to their somewhat bizarre nature and intriguing properties, especially when paired with superconductors. Topological states are stable with respect to arbitrary local perturbations, ensuring that the ground state wave function could be manipulated for the purpose of performing a quantum computation in a manner that avoids decoherence.

1Lt. Adrian Scheppe, a PhD student in AFIT's Department of Engineering Physics and Capt. Seth Hyra, an M.S. student in the same department, are part of an effort to build a better qubit by developing the theoretical aspects of composite SC – topological material heterostructures. The topological character of topological insulators (TI) guarantees symmetry protected robust boundary localized conduction states, meaning the surfaces of such 3D materials are a 2D metal while the internal bulk is insulating. Other topological characters impart material phases exhibiting other exotic behaviors, such as the manifestation of the Fractional Quantum Hall Effect (FQHE) and its resulting non-Abelian anyons. These topological materials dramatically change the quantum landscape for a given system, and through their creative inclusion in the prototypical SC qubit, one can develop computational states which are decoherence proof or fault tolerant in some respects.

1Lt. Scheppe and Capt. Hyra are currently investigating one promising direction which simply modifies the Josephson junction in a SC qubit with a TI substrate thereby forming a topological Josephson junction. This construction utilizes the superconducting proximity effect to induce p-type SC in the conducting surface state of the TI in the junction which, under particular parameters of the junction, will host SC vortices induced by Josephson vortices. These vortices represent the non-Abelian anyonic quasi-particles of the FQHE, and therefore form a degenerate ground space manifold which can play host to topological quantum computation protected by the topological phase gap. Such computation is enabled by the action of the Braid group on the vortices enacting potentially arbitrary unitary transformations (computational gates) on the full system. Coupling between this topological phase and the SC computational state ideally will yield a composite qubit which is topologically protected in some respects.

This hybrid systems approach aims to generate some form of quality gain over the traditional SC qubit without needing a fully realized topological qubit, avoiding the pitfalls of realizing a scalable topological qubit during its technological infancy. Regardless of method, any system able to read a SC state into a topologically protected state, even one without the ability to enact gates, will be able to act as a quantum memory device, allowing decoherence free quantum information storage as one possible boon of the hybrid design. Many possible implementations of this topological Josephson junction setup can be envisioned, each relying on different topological material properties and different SC basis systems in unique ways. This provides a richness of research in exploring different hybrid computational systems and the benefits provided to quantum computation.

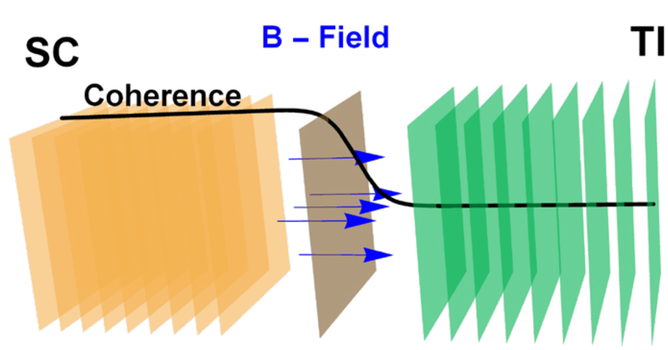


Figure 1) Surface of a Topological Insulator becoming superconducting through the proximity effect.

AFIT Alum Selected to be First Turkish Citizen in Space

Turkish Presidency via AP

Turkey's President Recep Tayyip Erdogan, right, holds a Turkish flag with Turkish air force pilot Alper Gezeravci (M.S. Operations Research, 2008) at Teknofest military fair in Istanbul, Turkey, April 29, 2023. Erdogan says his country's first astronaut will travel to the International Space Station by the end of the year.

ISTANBUL (AP) — Turkey's first astronaut will travel to the International Space Station by the end of the year, President Recep Tayyip Erdogan said after an illness forced him to cancel several days of appearances.

Air force pilot Alper Gezeravci (M.S. Operations Research, 2008), 43, was selected to be the first Turkish citizen in space. His backup is Tuva Cihangir Atasever, 30, an aviation systems engineer at Turkish defense contractor Roketsan.

Erdogan made the announcement at the Teknofest aviation and space fair in Istanbul. He appeared alongside Azerbaijan's president, Ilham Aliyev, and Libya's interim prime minister, Abdul Hamid Dbeibeh.

"Our friend, who will go on Turkey's first manned space mission, will stay on the International Space Station for 14 days," Erdogan said. "Our astronaut will perform 13 different experiments prepared by our country's esteemed universities and research institutions during this mission."

Erdogan described Gezeravci as a "heroic Turkish pilot who has achieved significant success in our Air Force Command."

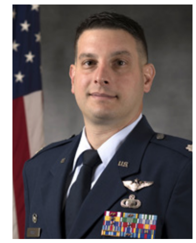
The Turkish Space Agency website describes Gezeravci as a 21-year air force veteran and F-16 pilot who attended the U.S. Air Force Institute of Technology.

Turkey is dealing with a prolonged economic downturn, and the government received criticism after a February earthquake killed more than 50,000 in the country. Experts blamed the high death toll in part on shoddy construction and law enforcement of building codes.

While campaigning for reelection, Erdogan unveiled a number of prestigious projects, such as Turkey's first nuclear power plant and the delivery of natural gas from Black Sea reserves.

AFIT ALUMNI NEWS BRIEFS

AF Outstanding Scientist/ Engineer, Senior Military Category Award



Lt. Col. Paul Dolce

The Air Force Outstanding Scientist/Engineer Awards recognize the efforts and achievements of the top U.S. Air Force scientists or engineers who make noteworthy and/or significant contributions to technology, engineering and/or solving technical problems in development, sustainment, testing, training, or advancement of Air Force systems.

AFIT alum **Lt. Col. Paul Dolce** (M.S. Electrical Engineering, 2011) received the AF Outstanding Scientist/Engineer, Senior Military Category award.

Buzz Aldrin Promoted to Brigadier General

Brig. Gen. Buzz Aldrin

Congratulations to Buzz Aldrin on his honorary rank promotion to Brigadier General. **Brig. Gen. Aldrin** earned his PhD from Massachusetts Institute of Technology (MIT) through the Air Force Institute of Technology's Civilian Institution Program.

Space pioneer, legend, and now official United States Space Force Guardian, Buzz Aldrin was officially promoted to Brigadier General by SSC Commander Lt. Gen. Michael Guetlein during a ceremony at Los Angeles Air Force Base.

READ MORE ONLINE:
https://e.AFIT.edu/TrZZc8

CALENDAR EVENTS

JUNE 2023

AFIT Graduate School Spring Graduation (Degree conferral only)
15 Jun 2023 I AFIT Campus, WPAFB, OH

AETC Commander Visit
20-21 Jun 2023 I AFIT Campus, WPAFB, OH

AFIT Graduate School Summer Quarter Classes Begin
26 Jun 2023 I AFIT Campus, WPAFB, OH

JULY 2023

AFIT ROTC Immersive Cyber Education Course (ICE)
11 Jul-4 Aug 2023 I AFIT Campus, WPAFB, OH

AFIT Graduate School Fall Quarter Registration Begins
31 Jul 2023 I AFIT Campus, WPAFB, OH

AFLCMC Life Cycle Industry Days
31 Jul-2 Aug 2023 I Dayton Convention Center

AUGUST 2023

AFIT Graduate School Summer Quarter Classes End
31 Aug 2023 I AFIT Campus, WPAFB, OH

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