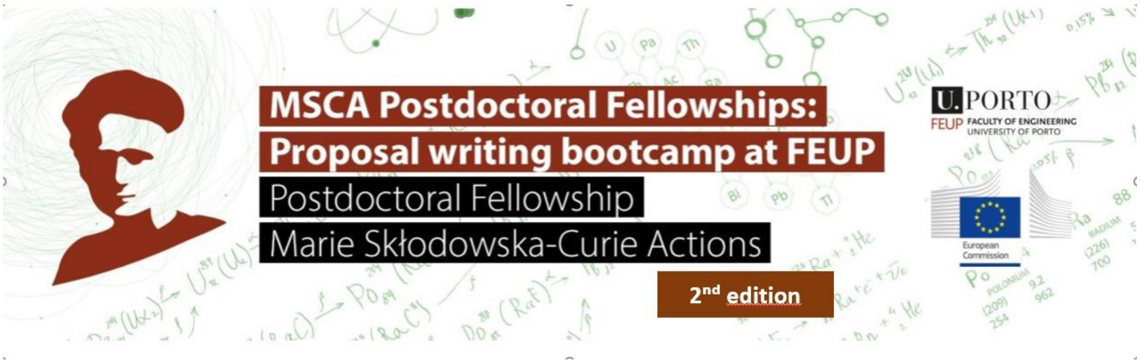

SUPERVISOR INFORMATION	
First and Last name	Henrique Salgado
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Department	Electrical and Computer Engineering
Field(s) of research	Underwater optical communications; Optical phase arrays
PROJECT PROPOSAL	
Title (optional)	Breakthrough Technologies for Next-Generation Underwater Optical Communication Systems Using Optical Phased Arrays
Brief project description	This research aims to develop a pioneering **Visible-Region Optical Phased Array (OPA)** system for **Underwater Wireless Optical Communication (UWOC)**. The project will focus on the design, simulation, and optimization of an integrated optical phased antenna array on a flexible Silicon Nitride (SiN) platform, utilizing VCSELs in the visible spectrum (blue and green wavelengths). The study targets challenges such as beam steering, energy efficiency, low loss, and environmental impact while addressing novel Internet of Things (IoT) underwater applications. Additional focus will be placed on investigating the phase tuning range and the relationship between SOI grating structures and beam shape, using advanced 3D electromagnetic simulations. This one-year PhD research aims to establish robust and high-speed underwater data connectivity, paving the way for a sustainable and resilient IoT-enabled underwater ecosystem.

Introduction

In an increasingly interconnected world, the demand for secure, resilient, and high-capacity communication networks has grown exponentially. While terrestrial communication systems have seen significant advancements, underwater environments remain a largely unexplored frontier. The development of robust underwater communication technologies is essential for enabling critical applications such as ocean exploration, environmental monitoring, border security, defense operations, and offshore energy resource management. These applications are vital not only for technological progress but also for addressing global challenges such as climate change, resource sustainability, and maritime security.

The Internet of Things (IoT) has transformed modern communication by enabling connectivity between physical objects, sensors, and systems. While the Internet of Terrestrial Things (IoTT) dominates current IoT applications, emerging domains such as the Internet of Underwater Things (IoWT) hold immense potential for advancing underwater connectivity. Conventional underwater communication technologies, such as acoustic systems, face limitations in terms of low bandwidth, high latency, and interference. In contrast, Underwater Wireless Optical Communication (UWOC) systems provide a promising alternative by offering high-speed, low-latency, and energy-efficient data transmission, making them ideal for dense underwater networks.

However, existing UWOC technologies primarily focus on static beam-steering mechanisms, which limit their adaptability to dynamic underwater environments. Additionally, conventional optical phased arrays (OPA) operating in the infrared spectrum are unsuitable for underwater applications due to the high absorption and scattering of infrared light. Instead, visible wavelengths, particularly blue (475 nm) and green (550 nm) light, experience minimal attenuation in water, making them the optimal choice for underwater communications.

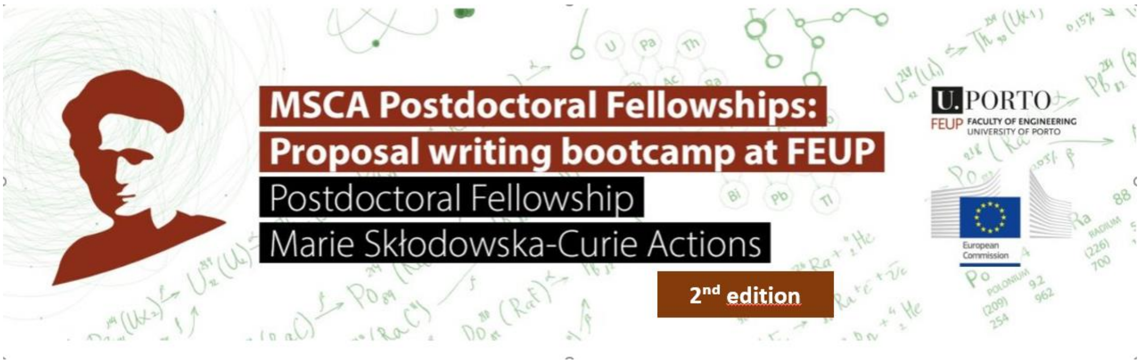
This project aims to bridge these gaps by developing an innovative visible-spectrum Optical Phased Array (OPA) system tailored for underwater environments. The research will leverage Silicon Nitride (SiN) platforms and advanced beam-steering techniques to achieve high-performance data connectivity. A particular focus will be placed on optimizing the phase tuning range of the system through 3D electromagnetic simulations of SOI grating structures. By addressing these challenges, the project seeks to deliver a groundbreaking UWOC solution that is not only energy-efficient and scalable but also aligned with the goals of building resilient and sustainable communication networks, as outlined in the United Nations' 2030 Sustainable Development Agenda.

Objectives

The research aims to:

- Design and develop an integrated optical phased antenna array (OPA) operating in the visible spectrum (blue/green wavelengths).
- Investigate and optimize beam steering capabilities (transversal and longitudinal) through phase shifters and wavelength tuning.
- Analyze phase tuning range and SOI grating structures using 3D electromagnetic simulations to optimize beam performance.
- Simulate and validate the OPA circuit using Fabless Aided Circuit Design Software.
- Contribute to UWOC advancements to enable high-capacity, sustainable underwater IoT applications.

Tasks:



Task 1: Literature Review and State-of-the-Art Analysis

The first task focuses on conducting a comprehensive review of the current state-of-the-art technologies in optical phased arrays (OPA), beam-steering methods, and underwater wireless optical communication (UWOC) systems. This phase will identify the strengths and limitations of existing approaches, particularly in conventional acoustic and optical communication systems. Special attention will be given to beam-steering techniques operating in the visible spectrum, analyzing their applicability to underwater environments, and understanding the challenges associated with attenuation, energy efficiency, and system scalability.

Task 2: Design of Optical Phased Array (OPA)

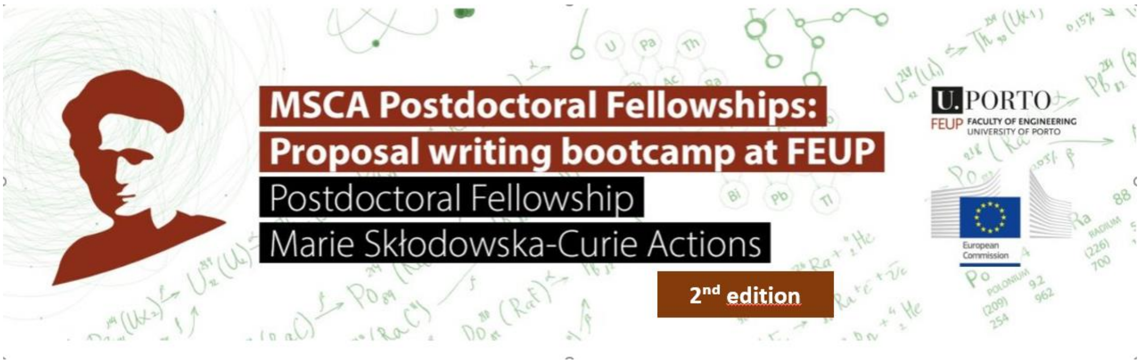
This task involves designing a visible-spectrum optical phased array system integrated on a flexible Silicon Nitride (SiN)/Triplex platform, using Fabless Aided Circuit Design software. The design will include the integration of gratings for beam steering, phase shifters for dynamic control of beam directionality, and wavelength-tuned for transversal and longitudinal beam-steering capabilities. Although advanced techniques, such as MEMS-based tuned VCSELs, have shown promising results, this project will focus on thermal wavelength tuning, which has demonstrated a broader tuning range (7-8 cm^{-1}) compared to other methods. The OPA system will be structured to ensure narrow beam formation, minimal loss, and large field-of-view, addressing critical underwater communication requirements.

Task 3: Simulation of SOI Grating Structures and Phase Tuning

The performance of the OPA will be evaluated by analyzing the phase tuning range and its relationship to the SOI grating structure design. This task will employ advanced 3D electromagnetic simulation software to model and optimize the grating structure for desired performance characteristics. The study will focus on minimizing beam divergence, improving steering efficiency, and ensuring stability under underwater conditions, thereby enhancing the range and quality of data transmission and beam performance (narrowness, range, and directionality).

Task 4: Validation and Benchmarking

In the final task, the simulated OPA system's performance will be benchmarked against existing beam-steering techniques and conventional underwater communication solutions. Key metrics such as beam quality, energy consumption, latency, and environmental impact will be assessed to validate the effectiveness of the proposed system. The outcomes will provide a comprehensive comparison, highlighting the advantages and potential real-world applications of the developed technology.



Task 5: Documentation and Dissemination

The final phase involves documenting the research findings in detailed reports and preparing scientific publications for dissemination. Results will be presented at relevant international conferences and workshops to contribute to the global advancement of UWOC systems and visible-spectrum optical phased array technologies. This task will ensure the knowledge gained throughout the project reaches the broader research community and stakeholders interested in underwater IoT applications.

Research Outcomes

- **Innovative Optical Phased Array Design:** A fully simulated and optimized OPA system operating in the visible spectrum (green/blue) for UWOC applications.
- **High-Performance Beam Steering:** Transversal and longitudinal beam-steering achieved via phase shifters and wavelength tuning.
- **Advanced SOI Grating Performance:** Optimized SOI grating structures simulated using 3D electromagnetic software to enhance phase tuning and beam control.
- **Energy-Efficient, Low-Loss Solution:** Demonstration of a simulated energy-efficient and environmentally sustainable underwater communication system.
- **Publications and Future Research Directions:** Peer-reviewed publications in high-impact journals and the identification of future research avenues for next-generation UWOC systems.

Conclusion

This research presents an innovative approach to advancing Underwater Wireless Optical Communication (UWOC) systems by developing a visible-spectrum Optical Phased Array (OPA). Through the integration of phase shifters, wavelength-tuned VCSELs, and optimized SOI grating structures on a flexible Silicon Nitride (SiN)/Triplex platform, the project will achieve precise beam steering, energy efficiency, and enhanced underwater data connectivity.

By focusing on simulation, optimization, and performance validation, this work will lay the foundation for a robust and sustainable Internet of Underwater Things (IoWT) ecosystem, unlocking applications in ocean exploration, environmental monitoring, and maritime security. The outcomes will significantly contribute to the development of resilient, high-speed communication networks, supporting global initiatives like the United Nations' 2030 Sustainable Development Goals for a more inclusive and sustainable future.