



## **Master in Photonics – “PHOTONICS BCN” Master ERASMUS Mundus “EuroPhotonics”**

### **MASTER THESIS PROPOSAL**

**Full time from April 2026** (it can start part time from February 2026)  
**Presentation date to be chosen: end of July or beginning of September 2026**

**Note:** The main Master Thesis supervisor has to be a professor of the Master in Photonics program. One co-supervisor (internal or external) can be defined. Main Supervisor is responsible for the subject of the proposal and has to give continuous support to the student (research development, Report writing and presentation preparation). For external proposals a co-supervisor from the Master program and a collaboration agreement with UPC are needed. You can find all information about the Master Thesis process in [our webpage](#).

**Laboratory:** Optoelectronics group (led by Prof. Dr. Valerio Pruneri)

**Institution:** ICFO - The Institute of Photonic Sciences

**City, Country:** Castelldefels (Barcelona), Spain

**Title of the master thesis:** Design Limitations and Scalability of Multi-Output Multimode Interference Couplers in Thin-Film Lithium Niobate

**Name and affiliation of the master thesis supervisor:** Prof. Dr. Valerio Pruneri (supervisor), ICFO

**Name and affiliation of the co-supervisor** (if any): Dr. Raquel Fernández de Cabo (for external proposals a co-supervisor chose among the Master Program professors and a collaboration agreement with UPC is needed)

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**Keywords:** integrated photonic circuits, fan-in/fan-out, power splitting and combining, multimode interference.

### **1. Summary of the subject (maximum 1 page):**

Deep neural networks (DNNs) have driven significant advancements in the field of artificial intelligence. However, the increasing size and bandwidth requirements of these networks are placing increasing strain on electronic hardware, as the energy and delay associated with data movement increasingly become the principal bottlenecks to performance and efficiency.



Photonic integrated circuits (PICs) offer a promising alternative to overcome these constraints by encoding information onto optical carriers that propagate with low loss over broad bandwidths, leveraging the intrinsic parallelism of optics for signal processing. To effectively translate these advantages into scalable, complex photonic systems, PICs require the fundamental capability to simultaneously distribute signals across numerous parallel paths (fan-out) and subsequently recombine them (fan-in) for continued processing or readout. This critical fan-in/fan-out functionality, implemented on-chip via multiport power splitters and combiners, thus constitutes an essential building block in optical signal-processing and photonic computing systems.

The material platform for PIC development is a critical design consideration since it determines achievable loss, bandwidth, integration density, and functionality. Thin-film lithium niobate (TFLN), typically realized as lithium niobate on insulator (LNOI), is particularly attractive platform because its properties that enable tight mode confinement, wide transparency window, and strong second-order nonlinearity with a large electro-optic response, allowing for low-loss light propagation as well as high-speed modulation. These properties make TFLN especially suitable for advanced photonic signal-processing and computing architectures, which intrinsically demand low-loss, broadband multiport splitters and combiners to implement on-chip fan-in/fan-out.

A common approach to realize  $1 \times N$  splitting or  $N \times 1$  combining is to cascade multiple  $1 \times 2$  building blocks (e.g., Y-junctions or directional couplers), but this increases footprint and leads to the accumulation of imbalance and phase errors as  $N$  grows. Multimode interference (MMI) couplers provide a compact and scalable alternative: they exploit the self-imaging effect in a multimode section to reproduce the input field into multiple replicas at the output plane, thereby enabling uniform multi-output splitting and, by reciprocity, combining. Owing to their relaxed fabrication tolerances and potential for scaling with port count, MMIs are considered promising candidates for multiport fan-in/fan-out functionality in complex photonic circuits.

The performance and integration potential of these components depend strongly on the underlying material platform. In this context, multi-output MMIs in TFLN constitute key passive primitives that can be co-integrated with high-speed electro-optic elements in complex optical systems. However, MMI devices are intrinsically highly wavelength-dependent and their performance is constrained as the number of ports  $N$  grows. This project aims to investigate the design limitations of multi-output MMIs in lithium, with particular emphasis on their spectral sensitivity and scalability with port count. This project integrates photonic design with state-of-the-art software, and the technology developed is oriented towards real-world applications, and may lead to novel intellectual property and/or scientific journal publication.

## 2. Objectives (maximum 1 page):

- Establish the theoretical framework for multimode interference in integrated waveguides.
- Develop and validate a design methodology for  $1 \times N$  and  $N \times 1$  multi-output MMIs in TFLN, using numerical tools (e.g. eigenmode solvers, finite-difference-time-domain).
- Derive design guidelines and figures of merit for multi-output MMIs in thin-film lithium niobate.
- Quantitatively characterize the spectral response of TFLN MMIs as a function of port count, extracting key performance metrics such as insertion loss, splitting uniformity, phase error, and crosstalk.



- Evaluation of scalability with port count is achieved through analysis of the evolution of device footprint, modal content, wavelength sensitivity, and tolerance to geometrical variations as port count increases.

### 3. References

[1] S. Sun, et al. (2025). Highly efficient photonic convolver via lossless mode-division fan-in. *Nature Communications*, 16(1), 7513.

[2] Y. Hu, et al. (2025). Integrated lithium niobate photonic computing circuit based on efficient and high-speed electro-optic conversion. *Nature communications*, 16(1), 8178.

[3] P. Yousefi, et al. (2025). Design of thin-film lithium niobate power splitters and combiners based on multimode interference. *Optical and Quantum Electronics*, 57(3), 198.

#### **Additional information (if needed):**

\* Required skills:

\* Miscellaneous: