

# A Fully Integrated Silicon Quantum Frequency Processor for Biphoton State Manipulation

Sara Congia<sup>1</sup>, Elena Rovetta<sup>1</sup>, Leopold Virost<sup>2</sup>, Antonio Fincato<sup>2</sup>, Frederic Boeuf<sup>2</sup>, Matteo Galli<sup>1</sup>,  
Daniele Bajoni<sup>3</sup>, Massimo Borghi<sup>1</sup>.

1. University of Pavia, Department of Physics, via Bassi 6, 27100 Pavia, Italy

2. STMicroelectronics, Crolles, France

3. University of Pavia, Department of Industrial and Information Engineering, via Ferrata 1, 27100 Pavia, Italy

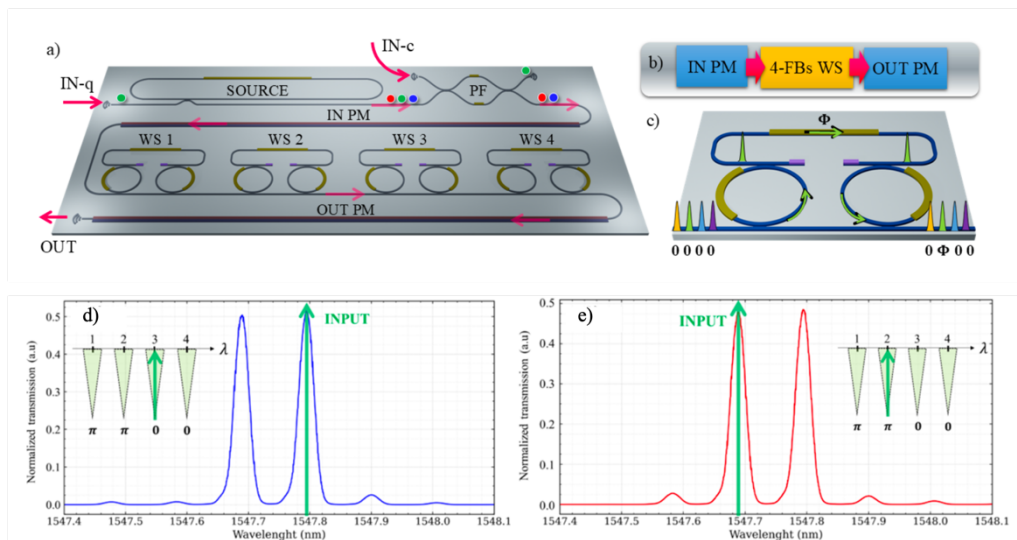
## Abstract:

We present a monolithic silicon photonic quantum frequency processor integrating photon-pair generation, fast modulation and wave-shaper functionality, showcasing a frequency beamsplitter with 94.7% success probability and the coherent control of biphoton frequency quantum-walks.

Biphoton quantum frequency comb (BQFC) sources generate high-dimensional entangled states in the frequency domain, which can be used for quantum information processing. Their coherent manipulation requires frequency-bin processors to perform reconfigurable unitary operations with high fidelity.

In this work, we present a fully integrated silicon photonic quantum frequency processor (QFP) fabricated on a silicon-on-insulator platform. The device integrates a micro-ring resonator (MRR) source, generating BQFCs via spontaneous four-wave mixing, followed by a pump rejection filter. The QFP architecture comprises an input high-speed phase modulator (IN PM), a four-channel wave-shaper (WS) realized by cascading pairs of add-drop MRRs, and an output phase modulator (OUT PM).

We demonstrate a 50/50 beam splitter (BS) on two target frequency modes without spurious light scattering into adjacent modes. The QFP achieved a fidelity of 99.3% and a success probability of 94.7%, significantly exceeding the 66.7% limit of single-modulator implementations. Furthermore, we demonstrate the coherent manipulation of BQFCs by reconfiguring a quantum walk. Using the WS, we compensated for the phase difference between idler and signal photons, avoiding energy transport outside the main diagonal of the correlation matrix. These results represent a key step toward fully integrated quantum frequency-processing platforms.



**Fig. 1** a) Scheme of the silicon photonic device. b) Building blocks of the on-chip QFP. c) Detail of each WS unit: a single FB from the input comb is first dropped by a MRR, de-phased by  $\Phi$ , and then loaded again into the bus WG. Experimental results of the QFP in the classical (a) and quantum (b) regimes. Panels d) and e) show the output spectra when injecting a laser into IN-c at the bins indicated by the green arrows, while applying with the WS the reported phase pattern on a total of 4 bins. The plots are normalized to the input intensity after compensating the WS losses ( $\sim 5$  dB).

## References

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