Fully tunable and switchable coupler for photonic routing in quantum detection and modulation

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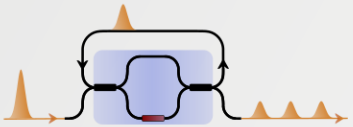


We report on 2×2 photonic coupler with arbitrary splitting ratio switchable by a low-voltage electronic signal with 10 GHz bandwidth and 60 ns latency. The coupler is based on a dual-wavelength Mach-Zehnder interferometer allowing real-time phase lock with sub-degree stability. We show full tunability and sub-nanosecond switching performance with the extinction of 26 dB. Using the coupler, we demonstrate the perfectly balanced loop-based time multiplexing that is suitable for photon-number resolving detection and qudit state preparation.

Related publication:

V. Švarc *et al*, Opt. Lett. 44, 5844-5847 (2019)

Palacký University Olomouc

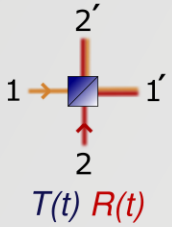
GAČR Czech Science Foundation 17-26143S

QuantERA project HYPER-U-P-S No 8C180023S

POM Photonics Online Meetup

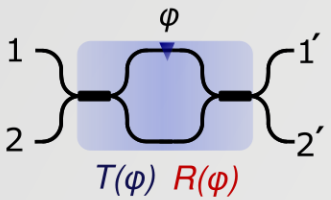
Motivation, challenge, and approach

There is a need for...



a device acting as a real-time tunable beam splitter that operates at the single-photon level. Such a beam splitter is a crucial element in many demanding applications such as quantum simulations, entanglement synthetizing, single-photon generation, and photon-number resolving detection.

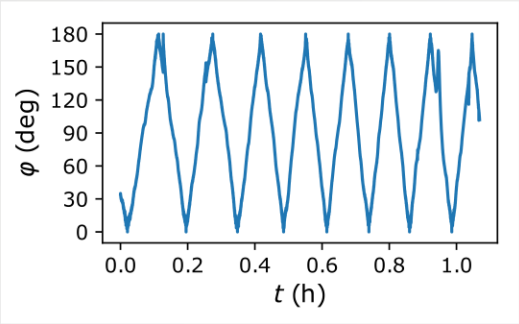
How to implement?



An efficient way to reach such a device is to control the phase in a Mach-Zehnder interferometer. To provide high speed and low-latency performance, it is beneficial to employ integrated electro-optic modulators (EOMs).

Tasks to solve:

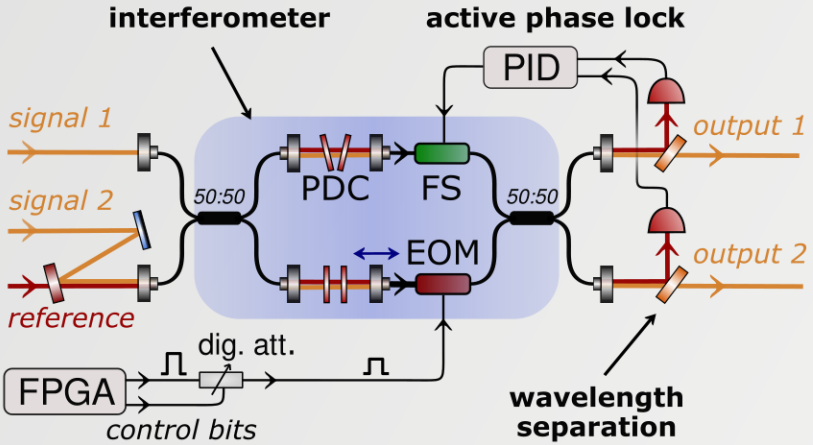
- visibility optimization → perfect overlap in all possible degrees of freedom
- environmentally-induced phase noise → need for high-precision active phase locking → challenging at single-photon level

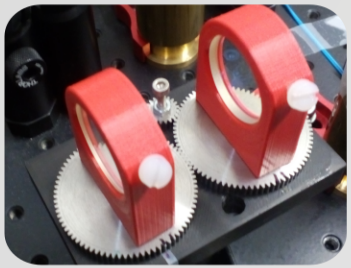


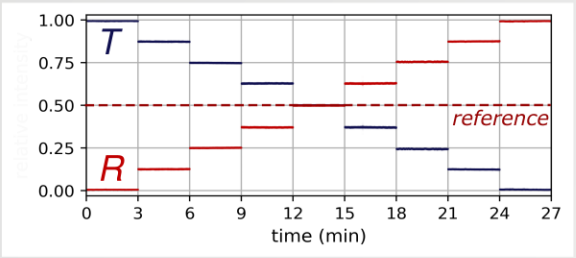
Spontaneous phase drift in a Mach-Zehnder interferometer.

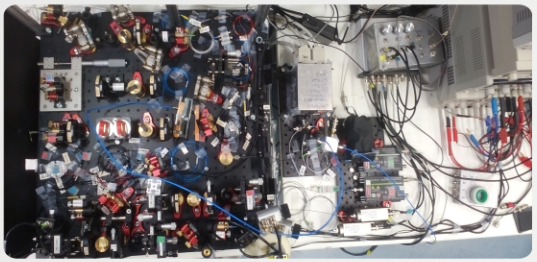
Experimental methods

- combined bulk-fiber architecture → visibility 99.55%
- broadband operation → 3 nm around 810 nm
- sub-degree phase stability → active phase locking using strong reference light at 830 nm
- crosstalk from reference to signal <10 photons/s





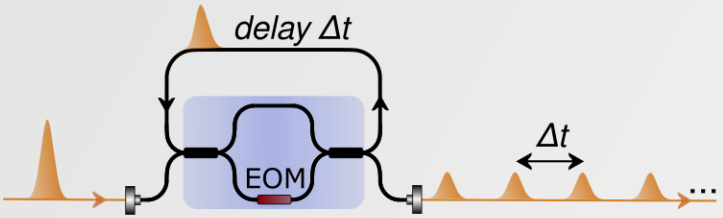




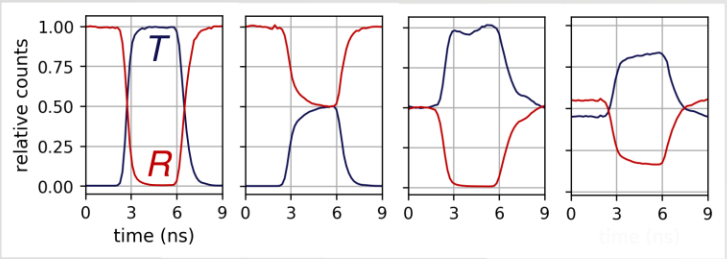
PDC enables for full tunability of the coupler while the reference is locked at π/2.

Fast switching and temporal multiplexing

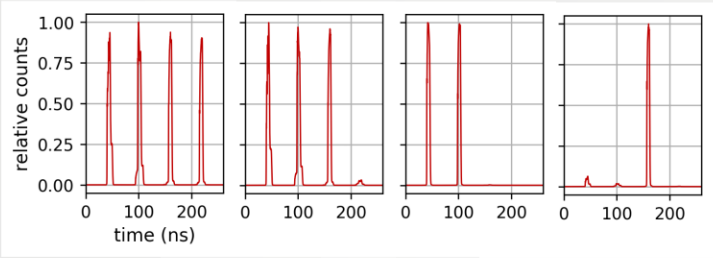
The core of the coupler is $LiNbO_3$ EOM providing optical switching up to 10 GHz. Since the arbitrary splitting ratio is adjustable with electronic pulses up to 3 V, low-latency operation is possible. These properties, together with the precise phase control, allows for a demanding application of loop-based time multiplexing which we demonstrate for four-level time-bin sequences. Our results show a way how to generate qudits.



- incident pulse is trapped in the loop
- after each roundtrip, a certain fraction is sent out
- precise control of *T:R* allows for an arbitrary pattern



Sub-nanosecond switching between arbitrary splitting ratios



Four-level time multiplexing using loop-based configuration