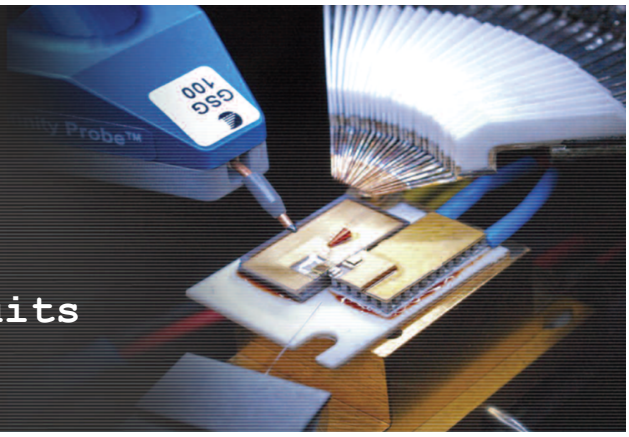


Photonic Integrated Circuits for Tunable Delay Lines

A delay line is a device that allows controlling the propagation delay of signals in a continuous mode, ensuring a true-time-delay operation on large operative bandwidths.

Induce a temporal delay on a signal it is not an easy task. Apart digital electronics that can take advantage of shift registers for a discrete arbitrary delay, in analog electronics, microwave and photonics a continuously variable delay without moving parts is difficult to achieve. However, integrated photonic circuits offer a number of solutions to achieve true-time-delay in very compact, flexible and potentially low cost devices.

A typical application of a delay line is shown in Fig. 1 where an absolute delay on an optical signal or a relative delay between two signals for synchronization purposes is achieved. The delay Δt should be continuously controllable, induce negligible attenuation and have sufficient bandwidth to let the pulses go through undistorted.

There are a large number of applications where delay lines play a key role: optical Beam Forming Networks for antenna arrays, imaging processing units, radio-on-fiber links and devices, interferometry, sensing units, etc. In case the signal is electrical, it could be convenient to modulate the light generated by a laser with the RF signal, delay in the optical domain and convert back to electrical by means of a photodiode.

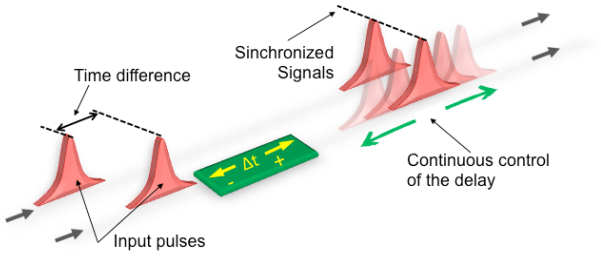


Figure 1- Typical use of a delay line: synchronization of two signals

Using a proper technology (Indium Phosphide), the laser, modulator and photodiode can be integrated on the same photonic integrated circuit (PIC), providing a very compact, electrically terminated, robust device. This is a classical expedient that goes under the generic name of microwave photonics.

Photonic Delay Lines

Fig. 2 shows three examples of photonics delay lines integrated on chip. The coil a) induces a fixed delay and it is the integrated version of the classical coils of optical fibers or coaxial cables used in many bulk applications. This is the basic element to realize, in combination with integrated 2x2 switches, delay lines providing a discrete numbers of fixed delays. It has a very small footprint, low losses, huge bandwidth and does not require any external control. Fig. 2 shows in b) a coupled Ring Resonators based delay line and in c) a Mach-Zehnder based single stage delay line. Both solutions provide a continuously tunable delay and can be electrically controllable thanks to proper thermal controllers placed above the waveguides.

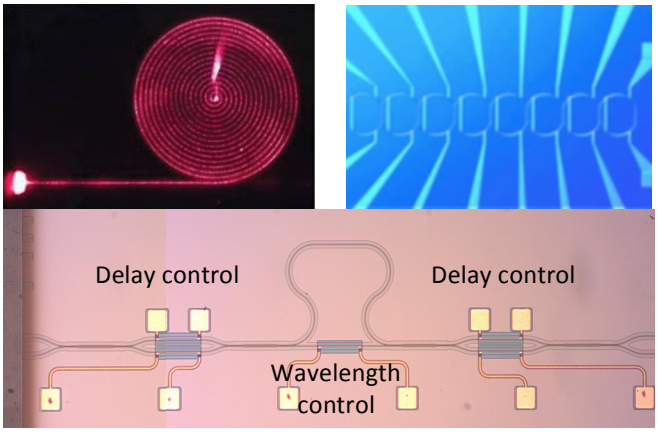


Figure 2 – a) Fixed delay line; b) Coupled Ring Resonator based tunable delay line; c) Mach-Zehnder based single stage tunable delay line.

Devices inducing a variable time delay up to few nanoseconds have been realized and successfully tested. These devices require a suitable electronic and software to achieve the control and stabilization against thermal and other fluctuations and be adaptive to the variations of the input signals.

Potentials and Limits

The ring-based delay line is a popular solution because of the very small footprint. Tunability is achieved by changing the resonant frequency and the combination of various rings provides shaping of the spectral region in which the delay is achieved. The bandwidth, instead, is usually narrow and the achieved bandwidth - delay product is rather small.

The Mach-Zehnder based delay line has a much larger bandwidth-delay product and induces a very small distortion on the delayed signals. Several stages can be cascaded to achieve a longer delay, still maintaining a large bandwidth as shown in Fig. 3 for a double stage device. Only one electrical control is required to change the coupling coefficient K of the directional couplers. Further, being a 2x2 circuit, it can provide a differential delay between two input signals.

The photonic integrated delay line is perfectly suitable for the combination with other functionality, active devices as lasers, modulators and photodetectors and packaged in a single case with electrical or optical input and output. This solution, without moving parts is perfectly suitable for applications where speed, number of delays, reliability and costs are key factors.

For any solution shown in Fig. 2, the induced attenuation is proportional to the total time delay and hence the choice of the most suitable technology (Silicon Photonics, Indium Phosphide or Silicon Nitride) is of key importance.

The Mach-Zehnder based delay line is patented[1] by Politecnico di Milano and it is available for exclusive and non-exclusive licensing.

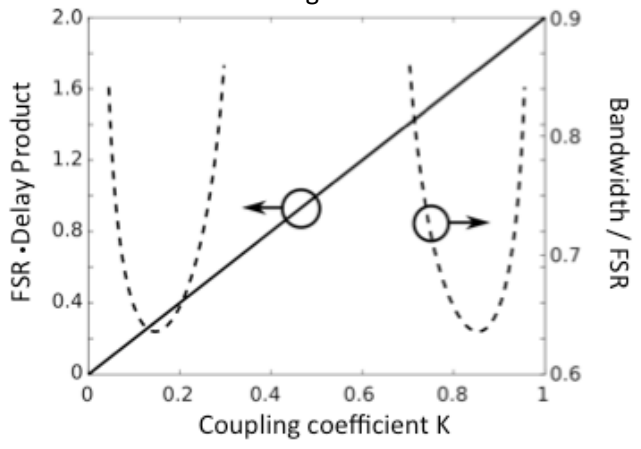
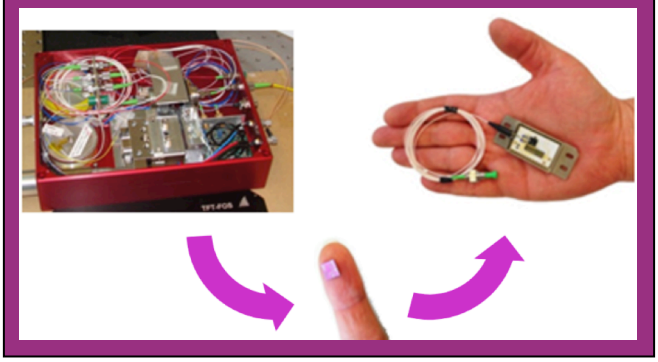


Figure 3 - Characteristics of a two-stages Mach-Zehnder based tunable delay line.

[1] Patent IT- 102017000053579.
[2] http://pics4all.jeppix.eu/

Photonic Integrated Circuits (PICs)

Also known as optical chips, PICs can contain tens to hundreds of optical components. While electronic ICs consist of transistors, capacitors and resistors, a PIC consists of, for example, lasers, modulators, photodetectors and filters, all integrated on a single substrate. These PICs are nowadays extensively used commercially, mainly in datacom and telecom, becoming popular also in sensing. PIC technology has now become accessible to users without a cleanroom, through so-called multi-project wafer runs and open foundries. Indium phosphide based technology is commercially available through SMART Photonics and Heinrich Hertz Institute. Access is coordinated by the JePPIX platform: http://www.jeppix.eu/.



Discuss your application with us

Each specific application requires a careful evaluation of the requested requirements in terms of maximum delay, delay resolution, attenuation, bandwidth, speed and control technique. A preliminary analysis permits to identify the most suitable technology.

Please contact the PICs4All consortium[2] to know more about the use of PIC technology. The PICs4All is funded under the Horizon 2020 framework and brings together expertise to support end-users with PIC technology. We help you connecting to the ecosystem of designers, foundries, packaging and test services.

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[2] http://pics4all.jeppix.eu/