Microwave photonics (MWP) is a mature discipline that brings together the worlds of microwave (MMW), radiofrequency (RF) engineering and optoelectronics by the manipulation of RF/MMW signals using photonic techniques and components. MWP allows the generation, distribution and processing of RF and MMW signals in the optical domain.

MWP systems and links have relied almost exclusively on the assembly of discrete devices resulting into bulky, not cost-effective, power-consuming systems, with limited reconfiguration. Hence, MWP was initially suited for defense applications. During the past two decades, the performance improvement of components such as semiconductor lasers and photodetectors, electro-optic modulators and optical amplifiers has led to an exponential growth of optical networks and communication systems to address a considerable number of civil applications such as cellular, wireless and satellite communications, distributed antenna systems, sensing, radio astronomy, medical imaging, among many other.

Despite the rapid evolution of cost-effective discrete optical devices and its cost reduction due to the huge demand for many applications in general, the assembly of MWP systems using discrete component aggregation is not suitable. In particular, for many emerging application scenarios such as 5G communications, smart cities, body area networks & wearable technologies and the internet of things, the requirements of Space, Weight and Power (SWaP) may not be met building systems by discrete aggregation.

The incorporation of MW photonic components and subsystems in photonic integrated circuits (PIC), termed Integrated Microwave Photonics (IMWP) is instrumental to achieve the foreseen evolution objectives in different. One proposal to building general purpose IMWP processing engines is the reconfigurable IMWP processor\(^1\), that can be implemented by using generic optoelectronic building blocks, currently offered by different photonics integration technology platforms. The building blocks include optical sources and detectors, electrooptic modulators, optical and electrical filters, optical couplers and RF switches.

The interface of this IMWP processor has several optical and electrical signal input/output ports, and several electrical control pads devised to reconfigure the processor to result into one of several functionalities: transmitter, receiver, optoelectronic oscillator and microwave photonic filter. The latter is central for all the applications, hence in this...
application note the microwave reconfigurable optical filter, is addressed.

**Integrated Microwave Photonics Filters**

Optical filters are widely used in almost every photonic application. They are passive devices which linearly process an optical signal so as to set the amplitude and phase of the different spectral components. Different integrated optical filter devices exist, such as arrayed waveguide gratings, microcavities and optical lattice filters, among many other. They exploit well-known phenomena such as resonance, coherent interference, multimodal dispersion and spatial diffraction effects. The optical lattice filter architecture is reconfigurable, allowing to design different filter responses, as well as to tune several of each properties, such as central frequency, bandwidth and response roll-off and rejection, which is very interesting for many broad band applications, in for MWP in scenarios where multiple RF/MMW bands need to be addressed by single system/device.

An integrated and reconfigurable optical lattice filter is a repetitive concatenation of integrated photonic structures, such as ring resonators and Mach-Zehnder Interferometers (MZIs) that are laid out via the interconnection of optical waveguides and couplers, including phase shifters (thermo-optic, electro-optic, current injection...) as well, that enable filter response tuning. These devices are known as Ring-Assisted MZIs (RAMZIs) filters. In Figure 2 a schematic representation of a RAMZI filter is shown. The response of the filter is determined by the values of the optical coupling constants between the rings (K) and the MZI arms, as well as the optical phase shifts in the rings (φ) and the MZI arms (β).

The response of a RAMZI filter is periodic in frequency, since it borrows many similitudes with digital filters and digital signal processing (DSP) theory. Thus, the same mathematical tools (Z transform) can be employed to analyze and synthesize their response. In particular the RAMZI filter is an Infinite Impulse Response (IIR), which as per DSP theory are known to meet a given filter specification with smaller number of elements (filter order) than their Finite Impulse Response (FIR) counterparts. Therefore, they result in devices with comparatively less power consumption, control complexity and footprint requirements. In addition, canonical filter designs are possible such as the commonly DSP known Butterworth, Chebyshev type I and II, Elliptic approximations, among other. The RAMZI design flow can in fact depart from the very same tools using in DSP. The selection of the filter response type (low-pass, high-pass, band-pass, stop-band), the design method (IIR filter type Chebyshev, Butterworth...), the filter mask specifications (bands and attenuations) result into the digital filter order and the digital filter coefficients. These are next translated into the optical architecture parameters for the implementation as a RAMZI, namely the coupling constants, Ks, and phase shifts, φs, by means of a synthesis algorithm.

![Figure 1. Reconfigurable IMWP processor](image)

![Figure 2. RAMZI filter architecture](image)

Figure 3 shows an example of such a RAMZI photonic chip filter, working as the main functional block of a fully integrated receiver for frequency modulated MWP links. The chip was designed and fabricated in an InP platform. It consisted of three RAMZI filters working together to act as band splitters and frequency discriminator, and a high-speed balanced photodetector integrated on the same substrate.
An additional example on the use of RAMZI filters in IMWP processors is given in Figure 4. The InP chip contains two DFB lasers, one photodetector, one electrooptic modulator, a 4th order Chebyshev-II RAMZI filter with phase shifters, and control pads for controlling the overall chip.

Figure 4. First prototype of a reconfigurable MWP processor.

Figure 5 shows a reconfigurable MWP filter with optical carrier re-injection containing a high-speed photodetector, a 4th order Chebyshev-II RAMZI filter, thermo-optic phase shifters with control pads to tune the filter frequency response.

Figure 5. MWP RAMZI filter with optical carrier re-injection

Discuss your application with us

If you want to learn more on the use of PIC technologies for the implementation of microwave optical filters, please contact the PICs4All consortium\(^3\). Our consortium can support you in the techno-economic evaluation of photonic integration geared towards your products and applications. Support may be given as well in the design and characterization.

In the framework of the EU H2020 PICs4All project the partners offer free-of-charge guidance to companies, research institutes and academia interested in development and implementation of their commercial products, using photonic devices.

The PICs4All consortium is funded under the EU Horizon 2020 programme and brings together expertise of nine European Application Support Centers (ASCs). The ASCs can guide you through the existing eco-system of design houses, foundries, packaging and test services.

References


3. http://www.pics4all.jeppix.eu

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