Advances in high-speed electro-optic modulators: a computer-aided design perspective

Giovanni Ghione
Politecnico di Torino, Department of Electronics and Communications, Torino, Italy

During the last few years, advances in materials and fabrication methods have led to a renewed interest in research on high-speed electro-optic modulators, key elements in any high data rate optical transmission systems [1,2]. Integration with photonic platforms has been, in the last decade, the main research drive on electro-optic modulators (Mach-Zehnder or resonant ring) compatible with InP-based or Si-based photonic integrated platforms (PICs). Examples of innovative approaches are thin-film lithium niobate modulators, ITO- and graphene-based modulators, and, more recently, plasmonic modulators. Plasmonic-Organic-Hybrid (POH) modulators are a very high speed, extremely compact solution compatible with Si-based PICs, albeit at the price of a comparatively large ON-state insertion loss.

From a modelling perspective, electro-optic modulators present a real challenge when *physics-based* simulations are required to design and optimize the modulator structure. Despite the current availability of powerful simulation tools based on the finite-difference time-domain method (FDTD), capable to perform the optical simulation of comparatively large and complex structures, several issues make the *all-in-one* modulator simulation a difficult task. In fact, many modulators (like the InP-based) exhibit a large layout, with multiple heterostructures in the cross section, and often are based on a distributed coupling principle between the optical and electrical waves that no FDTD simulator can support at present; not to mention the problems arising when a self-consistent multi-physics simulation is needed exploiting a coupled semiconductor transport – optical model. Even POH modulators, whose structure is lumped, with micron-scale layout, require CPU times of the order of a few days to perform a full DC simulation of the input-output transfer curve, thus making a Design of Experiments (DOE)-based optimization strategy practically impossible.

On a different modelling level, computationally efficient, behavioral modulator models are indispensable for the simulation of optical transmission systems. Despite the progress made during the past years in terms of black-box, neural-network based approaches for the modelling of nonlinear dispersive systems at large, the application of such concepts to behavioral modulator modelling has only been sparsely considered.

In the presentation, after a review of the electro-optic modulator state of the art, physics-based modeling challenges will be discussed, and a different, much more efficient approach based on the structure segmentation (*divide-and-conquer* approach) will be described, with particular attention to the modeling of POH Mach-Zehnder modulators [3]. Finally, some examples of system-level neural-network based behavioral modulator modeling will be presented.

References

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