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Mitchell, Arnan

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LiNbO₃ devices for Microwave Photonics

Arnan Mitchell, *Member*, IEEE

Centre for Ultrabroadband Devices and Optical Systems (CUDOS)
School of Electrical and Computer Engineering, RMIT University
Melbourne, GPO Box 2476V, VIC 3001.

Abstract — A selection of microwave photonic systems using lithium niobate devices are presented. Systems include duplexers, variable phase shifters, filters and quadrature hybrids. Opportunities for monolithic integration are discussed.

I. INTRODUCTION

High speed modulators based on the electro-optic material LiNbO₃ can be found at the core of many microwave photonic systems. Although electro-optic modulators based on the Mach-Zehnder interferometer offer only moderate efficiency and linearity, due to their passive electro-optic behaviour, they introduce practically no noise during the modulation process and can be driven with very large optical power levels. This enables practical realization of systems with sensitivity limited by laser random intensity noise (RIN) [1]. LiNbO₃ electro-optic modulators thus enable exceptionally low noise analogue photonic transmission systems.

Along with its electro-optic coefficient, LiNbO₃ possesses a number of other useful characteristics derived from its ferroelectric crystal structure. These include strong birefringence, piezoelectric and piezo-optic effects and off-diagonal electro-optic effects. These characteristics combined enable LiNbO₃ to be used as a highly flexible platform for the manipulation of optical polarization.

An overview of three types of microwave photonic system that utilize LiNbO₃ modulators and polarization manipulation to achieve a range of signal processing functions is presented. The discussion will place particular emphasis on opportunities for monolithic integration, where the end user can be shielded from system complexity through monolithic optical integration and packaging with hybrid integrated electronic control.

II. PHOTONICALLY DIPLEXED ULTRA-BROADBAND ANTENNA

The first example is the most conceptually straightforward. An ultra-broadband patch antenna, covering 1-4GHz can be formed by combining two broadband patch antennas using an RF diplexer [2]. This configuration has been demonstrated with excellent performance; however, this relies on the quality of the diplexer element used.

The design and realization of this diplexer is complex due to the reactive loading of each element on the diplexer, even when the elements are out of band. The diplexer must thus be custom trimmed to match the specific patch antennas to be combined.

An alternate approach using photonics has been demonstrated in [3]. Here the signals from the two antennas are transferred to optical carriers using LiNbO₃ modulators (Fig 1). The same wavelength is used for both elements and polarization diversity is used to combine the two signals incoherently onto a single transmission fiber. This photonic approach does not require a customized diplexer and can be trivially reconfigured to accommodate a variety of radiating elements.

Indeed recent experiments with more than two radiating elements have shown promising results. Splitting of the single optical channel, independent modulation of two paths, polarization rotation and orthogonal combination onto a single fiber could be achieved by a single LiNbO₃ device.

III. PHOTONICALLY PHASED ARRAY ANTENNA

A related example is the photonic phased array antenna [4]. As in the previous example, a photonic system is used to combine the signals from multiple antenna elements; however, in this instance each of the elements is identical and by applying a true time delay phase shift to each arm, it is possible to direct the angle of a focused beam.

When transmitting light through polarization maintaining fiber, it is possible to obtain two different time delays by selecting the input polarization of the optical carrier. By adjusting the optical polarization to an intermediate state, one can obtain a continuous range of phase shifts through vector summation of the two time delays. Recently, we have shown that using an acousto-optic tunable filter (AOTF) the input polarization of up to eight wavelengths can be controlled simultaneously and hence the time delays of eight optical channels can be set with a single LiNbO₃ device (Fig 2) [5].

Progress on the development of a photonic phased array antenna with eight radiating elements, with each element independently phased using a single LiNbO₃ chip will be presented. It is our aim that the entire 4 bit phasing network could be realized on a single LiNbO₃ substrate to enable a compact interface for complex electronic control.

IV. PHOTONIC TRANSVERSAL FILTERING

The final example is transversal filtering. If it is possible to control the time delay and amplitude of independent optical channels, then it is possible to realize a dynamically reconfigurable transversal filter. Each optical channel (or tap), with a distinct delay, represents a time sample. By carefully controlling the amplitudes of these time samples, it is possible to generate a Fourier transform frequency response.

A transversal filter where the tap weights are controlled using an AOTF has been demonstrated [6]. Sophisticated filtering functions are possible including pass and stop band, notches and even quadrature hybrid functionality (Fig. 3) [7].

We have recently conceived a technique where a polarization controller and high-speed optical modulator can be realized on a single LiNbO₃ platform. In this way, it is possible to realize a monolithic transversal filter, with both positive and negative coefficients, that is dynamically reconfigurable, but has the complex multi-channel control encapsulated within a single device. Our current progress on demonstrating this transversal filtering device will be presented.

V. ACKNOWLEDGMENTS

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REFERENCES

- [1] A.J. Seeds, K.J. Williams, "Microwave Photonics", IEEE Journal of Lightwave Technology, vol. 24, no. 1, pp. 4628-4641 (2006)
- [2] K. Ghorbani and R.B. Waterhouse, "Ultrabroadband printed (UBP) antenna" IEEE Trans. Antennas and Propagation, vol. 50 pp. 1697 - 1705 (2002)
- [3] E. R. Lopez, L. A. Bui, K. Ghorbani, W. S. Rowe, A. Mitchell "Ultra-broadband Photonic Patch Antenna" IEEE International Microwave Symposium (IMS2006), pp. 1939-1942 (2006)
- [4] L. A. Bui, A. Mitchell, K. Ghorbani, T.-H. Chio, S. Mansoori, E. R. Lopez "Wide-band photonic phased array antenna using vector sum phase shifting approach" IEEE Trans. Antennas and Propagation, vol. 31, pp. 2248-2250 (2006)
- [5] L. A. Bui, K. Ghorbani, and A. Mitchell, "Multichannel vector sum phase shifter," Opt. Lett. 31, 577-579 (2006).
- [6] S. Mansoori, A. Mitchell, "RF transversal filter using an AOTF," IEEE Phot. Tech. Lett., vol. 16, pp 879-881, (2004)
- [7] , H. Emami, L. A. Bui, A. Mitchell "Broadband 90 degree hybrid coupler using photonic transversal approach" IEEE Asia-Pacific Microwave Photonics Conference , AP-MWP, p. 173-176, (2006)

Fig. 1. Gain response of microwave photonic combined antennas. Independent responses (MP ASP1 & 2) and various phases of combination (M1,2,3 and Matched) are shown.[3]

Fig. 2. Phase shift as a function of applied acoustic power for two independent optical channels within the multi-channel vector sum phase shifter. [5]

Fig. 3. Tap weights in time (wavelength) domain to enable 2-20GHz hybrid with 1dB ripple [7].