FREQUENCY-MODULATED MICROWAVE PHOTONIC LINKS FOR HIGH DYNAMIC-RANGE ANTENNA REMOTING SYSTEMS

John M. Wyrwas and Ming C. Wu
Department of Electrical Engineering and Computer Sciences, University of California
Berkeley, CA

Introduction

To support the need to distribute analog signals from microwave antennas dispersed throughout military aircraft, much research has been devoted to developing microwave photonic links (MPLs) with very high linearity and low noise figures. Frequency-modulated (FM) photonic links are a promising technology to provide high dynamic-range signal transmission for these airborne antenna remoting systems. FM lasers, where a phase modulator in the optical cavity varies the optical frequency with applied RF power, have been demonstrated with very high modulation efficiency [1, 2]. Demodulation performed using an optical filter based frequency discriminator and direct detection (FM-DD) (also called slope or interferometric detection) can be engineered for low nonlinearities by optimizing the transfer function of the filter [3]. The combination of a high efficiency FM laser with a discriminator filter for low-distortion demodulation leads to a MPL with signal gain, low noise figure and large dynamic range.

Link Architecture

The transmitter of the photonic link consists of an FM laser, and the receiver consists of two complementary optical filters and balanced photodetectors. The laser modulates the analog signal onto the optical carrier, where variations in the instantaneous frequency of the light are proportional to the analog signal. The frequency modulation is converted to amplitude modulation by the filters and then detected. In our experiments, our transmitter is a multi-section distributed Bragg reflector (DBR) laser, which is optimized for high modulation efficiency and low linewidth. The phase noise of the laser and modulation are in-phase and are indistinguishable in the demodulation process. The combination of the link's modulation efficiency, η, and the laser's phase noise, as signified by its linewidth, $\Delta\nu$, place a fundamental limit on the noise figure of the link, which for high optical powers is given by $NF = 1 + R_{load}\Delta\nu/\eta^2 k_B T\pi$. Common-mode intensity noise is cancelled by the balanced detection, so optimizing laser frequency noise is a priority for low noise figure MPLs.

A pair of complementary filters and a balanced detector demodulate the FM at the receiver. We use filters fabricated in a silica-on-silicon, planar lightwave circuit (PLC) process. PLC filters are compact, temperature stable and dynamically tunable, which motivate their use over other optical filter technologies, such as fiber Bragg gratings. PLC can implement both poles-and zeroes in the filter response, which is important in instantiating the desired filter transfer functions for linear demodulation.

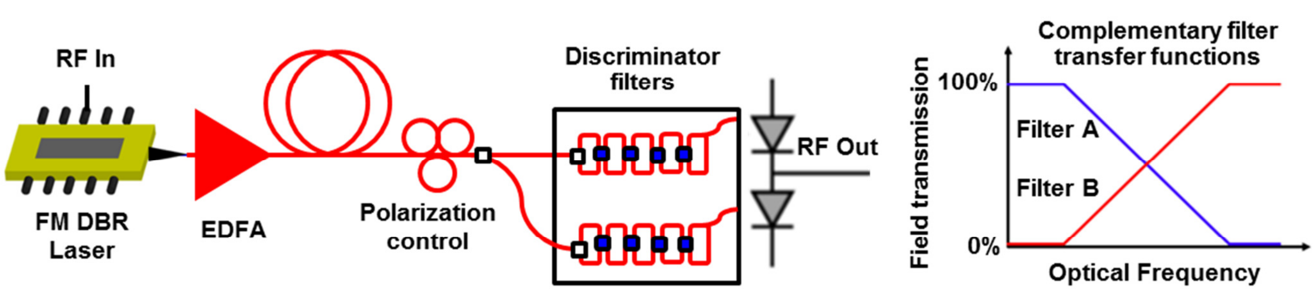

Figure 1. Link architecture for FM-DD link with integrated balanced frequency discriminators

Linear FM Demodulation

Complementary “linear-field” transfer functions for the discriminator filters are necessary for low distortion demodulation. Experiments have demonstrated FM-DD links using integrated filters based on micro-ring resonators [4]. However, normalized to the same received photocurrent, the third-order and second-order nonlinearities measured by [4] were significantly worse than just a simple asymmetrical Mach Zehnder interferometer (A-MZI) [5], while the link had much added complexity. Theoretical frequency-domain analyses of FM-DD MPLs [6, 3] give insight on this problem. While many authors have explored using filters with a linear power transmission-versus-frequency curve, this transfer function does not result in ideal linear discrimination. Instead, filtering should be done coherently with a linear electric-field transmission-versus-frequency curve, and the phase of the filter’s transfer function also should be linear. This results in linear FM to amplitude modulation (AM) discrimination, rather than IM. A pair of complementary filters and balanced detection cancel second harmonics produced when directly detecting the AM.

Link Measurements

We report on our link measurements of FM-DD MPLs. The discriminators are tuned to closely approximate the desired complementary linear-field transfer functions. We tune the wavelength of the transmitter to find the optimal operating point on the filters. It is important to correct balance the optical power between the two filters and match the second-order distortion produced on each end of the receiver in order to have cancellation of the second-harmonic and wideband operation. Careful control of the polarization into the filters also affects the linearization.

Two-tone RF measurements are used to characterize the distortion performance. Two radio-frequency synthesizers generate closely-spaced tones at frequencies over a 100 MHz to 10 GHz band, and they are combined with a microwave coupler. We perform experiments both using an external phase modulator and the phase-section of a multisection DBR laser in order to separately measure contributions to the distortion from the laser and from the demodulation. At the receiver, we measure the signal gain and distortion products at the second-harmonic and intermodulation distortion at difference frequencies $2f_1 - f_2$ and $2f_2 - f_1$. We demonstrate linearity improvement with both approaches and simultaneous achievement of low third-order and second-order distortion.

Acknowledgements

This material is based upon work funded by DARPA’s TROPHY program, under AFRL Contract No. FA8650-10-C-7003. Any opinions, findings and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of DARPA or the United States Air Force.

References

[1] Q. S. Xiang, Y. Zhao, and F.-S. Choa, “A high-performance RF-light-wave transmitter for analog fiber links,” in Proc. LEOS 2000, 13th Annu. Meeting, vol. 1, pp. 138–139.

[2] X. Xie, J. Khurgin, F. S. Choa, X. Yu, J. Cai, J. Yan, X. Ji, Y. Gu, Y. Fang, Y. Sun, G. Ru, and Z. Chen, "A model for optimization of the performance of frequency-Modulated DFB semiconductor laser," IEEE J Quantum Electron, 2005, 41, 473-482.

[3] J. M. Wyrwas and M. C. Wu, “Dynamic Range of Frequency Modulated Direct-Detection Analog Fiber Optic Links,” J. Lightw. Technol., vol. 27, no. 24, pp. 5552–5562, Dec. 2009.

[4] D. Marpaung, C. Roeloffzen, A. Leinse, and M. Hoekman, “A photonic chip based frequency discriminator for a high performance microwave photonic link,” Opt. Express, vol. 18, no. 26, pp. 27359–27370, Dec. 13, 2010.

[5] V. J. Urick, F. Bucholtz, P. S. Devgan, J. D. McKinney, and K. J. Williams, “Phase Modulation With Interferometric Detection as an Alternative to Intensity Modulation With Direct Detection for Analog-Photonic Links,” Microwave Theory and Techniques, IEEE Transactions on , vol. 55, no. 9, pp. 1978–1985, Sep. 2007.

[6] P. Driessen, T. Darcie, and J. Zhang, “Analysis of a class-B microwave-photonic link using optical frequency modulation,” J. Lightw. Technol., vol. 26, no. 15, pp. 2740–2747, Aug. 1, 2008.