AFRL-RY-WP-TP-2013-0209

ADVANCEMENTS IN RADIO FREQUENCY (RF) PHOTONICS FOR SIGNAL PROCESSING APPLICATIONS ON AVIONIC PLATFORMS (PREPRINT)

Preetpaul Devgan

RF/EO Subsystems Branch
Aerospace Components and Subsystems Division

OCTOBER 2013
Interim

Approved for public release; distribution unlimited.

See additional restrictions described on inside pages

STINFO COPY

AIR FORCE RESEARCH LABORATORY
SENSORS DIRECTORATE
WRIGHT-PATTERSON AIR FORCE BASE, OH 45433-7320
AIR FORCE MATERIEL COMMAND
UNITED STATES AIR FORCE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE ***(DD-MM-YY)***
October 2013

2. REPORT TYPE
Conference Paper Preprint

3. DATES COVERED ***(From - To)***
1 October 2011 – 1 October 2013

4. TITLE AND SUBTITLE
ADVANCEMENTS IN RADIO FREQUENCY (RF) PHOTONICS FOR SIGNAL PROCESSING APPLICATIONS ON AVIONIC PLATFORMS (PREPRINT)

5a. CONTRACT NUMBER
In-house

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER
62204F

5d. PROJECT NUMBER
2002

5e. TASK NUMBER
IH

5f. WORK UNIT NUMBER
Y058

6. AUTHOR(S)
Preetpaul Devgan

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
RF/EO Subsystems Branch
Aerospace Components and Subsystems Division
Air Force Research Laboratory, Sensors Directorate
Wright-Patterson Air Force Base, OH 45433-7320
Air Force Materiel Command, United States Air Force

8. PERFORMING ORGANIZATION REPORT NUMBER
AFRL-RY-WP-TP-2013-0209

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory
Sensors Directorate
Wright-Patterson Air Force Base, OH 45433-7320
Air Force Materiel Command
United States Air Force

10. SPONSORING/MONITORING AGENCY ACRONYM(S)
AFRL/RYDR

11. SPONSORING/MONITORING AGENCY REPORT NUMBER(S)
AFRL-RY-WP-TP-2013-0209

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES
PAO Case Number 88ABW-2013-2265, Clearance Date 9 May 2013. To be presented at the IEEE Avionics, Fiber Optics, and Photonics (AVFOP) Conf., San Diego, CA, Oct. 2, 2013. This is a work of the U.S. Government and is not subject to copyright protection. Paper contains color

14. ABSTRACT
This paper summarizes some of the Transformational Element Level Arrays (TELA) Light Implemented Transitional Elements (LITE) in-house research program activity conducted from October 2011 to October 2013 by the Air Force Research Laboratory Sensors Directorate Radio Frequency/Electro-Optical (RF/EO) Subsystems Branch (AFRL/RYDR). The invited paper was presented at the Institute of Electrical and Electronics Engineers (IEEE) Avionics, Fiber Optics and Photonics (AVFOP) conference in San Diego, California on October 2, 2013.

15. SUBJECT TERMS
radio frequency, arrays, in-house, photonics

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT:	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON (Monitor)
Unclassified	Unclassified	Unclassified	SAR	6	Dale Stevens **19b. TELEPHONE NUMBER** *(Include Area Code)* N/A

ADVANCEMENTS IN RF PHOTONICS FOR SIGNAL PROCESSING APPLICATIONS ON AVIONIC PLATFORMS

Preetpaul Devgan
Air Force Research Laboratory
WPAFB, OH

This paper summarizes some of the Transformational Element Level Arrays (TELA) Light Implemented Transitional Elements (LITE) in-house research program activity conducted from October 2011 to October 2013 by the Air Force Research Laboratory Sensors Directorate Radio Frequency/Electro-Optical (RF/EO) Subsystems Branch (AFRL/RYDR). The invited paper was presented at the Institute of Electrical and Electronics Engineers (IEEE) Avionics, Fiber Optics and Photonics (AVFOP) conference in San Diego, California on October 2, 2013.

Introduction

The maturity of RF photonic components has reached the point where fiber optic links are being system tested to replace traditional copper coax links on avionic platforms. Many demonstrations of RF photonic links have been made with traditional and non-traditional modulation formats [1-4] to improve the RF performance of the link. While the advantages of RF photonic links in regard to size and weight are indeed important, the large instantaneous bandwidth of the fiber optic links is a key driver for the use of this technology in the airframe. As signals of interest evolve to higher frequencies, the use of RF photonics provides a path to identify and catalog these new signals. With the acceptance of the fiber optic link as a replacement to coax, the next step is to move the photonic technology to provide signal processing capability in the optical domain before converting back to an electrical signal. The current challenges are to continue to explore new photonic technologies for improved RF performance at the receive end of the link. This paper will focus on advancements in RF photonic solutions for signal processing.

Photonic Signal Processing Applications

Starting with a traditional RF photonic link shown in Figure 1, the RF signal is received at the antenna and then modulated onto an optical carrier provided by the laser. The RF modulated light is then passed down a fiber optic link to a photodetector, which then recovers the RF electrical signal. The RF signal would then be passed through a tuner to frequency down convert it to an intermediate frequency (IF) chosen by the local oscillator (LO). The IF signal is then digitized at an analog to digital converter (ADC) and processed. Since the RF signal is already in the optical domain, the photodetector and electronic tuner can be replaced with an optical tuner which can down convert the signal to an electrical IF. Work has already been shown that an optical tuner can reduce mixing spurs in RF frequency down conversion [5]. Such a system is important as it can provide better spur free performance than current electronic tuners and over a larger bandwidth. In addition, work continues on photonic ADCs that can digitize 10 GHz of instantaneous bandwidth with a resolution greater than 8 effective number of bits [6]. A combination of these technologies can provide an RF-to-bits architecture without an optical to electronic conversion in the middle.

In support of the frequency down converter and ADC technologies, work continues on the optical clock that is used either for the LO or the sampler in these architectures, respectively. Optoelectronic oscillators continue to be investigated for improved performance [7,8]. However the limited frequency tunability is still a drawback to these types of low phase noise clock sources. New methods have been shown to make tunable RF sources using the injection locking of two lasers [9,10]. These sources continue to be further explored in order to determine their noise performance over their tunable range.

Other signal processing applications include signal discrimination in cluttered RF environments. Once the RF signals have been modulated onto the optical carrier, a portion of the light can be split off for spectrum analysis. Demonstrations have already been made with a rare-earth doped crystal in a spectrum analyzer with an RF instantaneous bandwidth of 10 GHz [11] with the potential for even higher bandwidths. Another demonstration has been made with a multimode optoelectronic oscillator for selective amplification of RF signals with an input sensitivity less than 15 dB above the thermal noise limit [12]. These systems are sensitive to frequency agile signals and can be used to cue a narrowband receiver to analyze the signal.

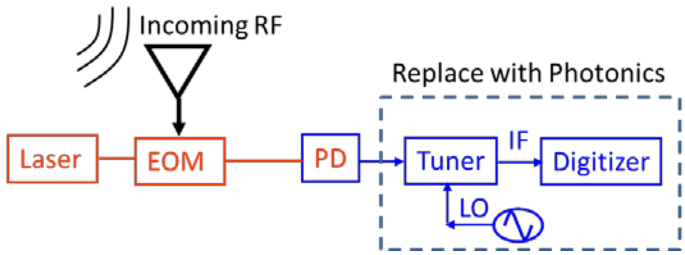

Figure 1: RF photonic link with electronic tuner and digitizer. EOM: Electro-optic modulator, PD: Photodetector, LO: Local oscillator, IF: Intermediate frequency

Conclusion

Work continues on using RF photonic solutions for signal processing at the receive end of the fiber optic link on an avionic platform. Multiple applications exist that can benefit from the large instantaneous bandwidth of photonic systems. However to compete with electronic solutions, integrating photonic solutions into small form factors will continue to be emphasized. The ability to heterogeneously integrate photonic components onto silicon waveguides will address many issues in meeting form factor limitations. AFRL continues to seek solutions to these problems.

Acknowledgements

This research was funded through Defense Advanced Research Projects Agency (DARPA), Air Force Office of Scientific Research (AFOSR), Office of Naval Research (ONR), and AFRL.

References

[1] C. Cox, E. Ackerman, G. Betts, and J. Prince, “Limits on the performance of RF-over-fiber links and their impact on device design,” IEEE Trans. Microwave Theory and Tech., **54**, pp. 906-920, 2006.
[2] V. Urick, F. Bucholtz, P. Devgan, J. McKinney, and K. Williams, “Phase modulation with interferometric detection as an alternative to intensity modulation with direct detection for analog-photonic links,” IEEE Trans. Microwave Theory and Tech., **55**, pp. 1978-1985, 2007.
[3] P. Devgan, J. Diehl, V. Urick, C. Sunderman, and K. Williams, "Even-order harmonic cancellation for off-quadrature biased Mach-Zehnder modulator with improved RF metrics using dual wavelength inputs and dual outputs," Opt. Express, **17**, pp. 9028-9039, 2009.
[4] P. Devgan, A. Hastings, V. Urick, and K. Williams, "Cancellation of photodiode-induced second harmonic distortion using single side band modulation from a dual parallel Mach-Zehnder," Opt. Express, **20**, pp. 27163-27173, 2012.
[5] C. Middleton, A. Mast, and R. DeSalvo, “Mixing spur reduction through photonic-assisted frequency conversion,” *IEEE Avionics Fiber-Optics and Photonics Conference*, TuC3, 2012.
[6] R. Zanoni, K. Jepsen, O. King, T. Cullen, M. Laliberte, G. Fish, A. Fang, and J. Clark, “High frequency, high resolution analog to digital converter,” *GOMACTech*, 2.2, 2012.
[7] P. Devgan, V. Urick, J. Diehl, and K. Williams, “Improvement in the phase noise of a 10 GHz optoelectronic oscillator using all-photonic gain,” IEEE Jour. of Light. Technol., **27**, pp. 3189-3193, 2009.
[8] M. Bagnell, J. Davila-Rodriguez, and P. Delfyett, “Highly stable optoelectronic oscillator with a 10^5 finesse etalon as a photonic filter,” *IEEE Avionics Fiber-Optics and Photonics Conference*, TuC5, 2012.
[9] D. Grund, G. Ejzak, G. Schneider, J. Murakowski, S. Shi, and D. Prather, “ Toward a widely tunable narrow linewidth RF source utilizing an integrated heterogeneous silicon photonic module,” *Proc. SPIE 8624*, 86240K, 2013.

[10] T. Simpson, J. Liu, M. AlMulla, N. Usechak, and V. Kovanis, "Tunable photonic microwave oscillator self-locked by polarization-rotated optical feedback," *IEEE Freq. Control Symp.*, 2012.
[11] G. Gorju, V. Crozatier, I. Lorgere, J.-L. Le Gouet, and F. Bretenaker, "10-GHz bandwidth RF spectral analyzer with MHz resolution based on spectral hole burning in Tm^{3+}:YAG," IEEE Photon. Technol. Lett., **17**, pp.2385-2387, 2005.
[12] P. Devgan, V. Urick and K. Williams, "Detection of low-power RF signals using a two laser multimode optoelectronic oscillator," IEEE Photon. Technol. Lett., **24**, pp. 857-859, 2012.