SAND2017-10082C

Photonic Integrated Circuits for RF Electronic Systems

Andrew Stark, Chris Ward, Kyle Davis, Benjamin Yang, Tim Brothers
Georgia Tech Research Institute
Atlanta USA
andy.stark@gtri.gatech.edu

Jerrod Langston, Christian Bottenfield, Gareeyasee Saha, Justin Lavrencik, Stephen E. Ralph
Georgia Institute of Technology
Atlanta USA

Arthur Paollela, Charles Middleton, Richard DeSalvo
Harris Corporation
Melbourne USA

Michael Gehl, Chris DeRose, Anthony Lentine
Sandia National Lab
Albuquerque USA

***Abstract*—We summarize several years of work to apply photonics to RF electronics systems via analog remoting, frequency conversion, and channelization. High-performance discrete component system (DCS) demonstrators have been constructed at relatively high TRL levels. Efforts are underway to further reduce size, weight, and power (SWaP) with photonic integrated circuit technology.**

***Keywords*—RF photonics; photonic integrated circuits; RF systems; frequency conversion; channelization**

I. RF Electronic Systems

A typical radio frequency (RF) electronic system must transmit and receive multiple RF signals from many antennas. These RF signals may be comprised of communication, radar, EW, or other waveforms. While the signal performance requirements are different between communication, radar, and EW systems, the functional requirements are nearly identical. These systems must receive a complex waveform, transport the waveform to a specific location, switch it properly, convert the received RF to an intermediate frequency (IF), digitize, process, convert back to an analog signal, up-convert, switch, transport, and transmit, Figure 1. Legacy systems may employ analog processing at IF in place of digital processing.

On larger platforms (e.g. airplanes), these signals are all routed to a central equipment bay for processing and then re-routed back to the antenna for transmission. The processing hardware, antennas, amplifiers, and cabling for the disparate signals may or may not be shared between the disparate sub-systems. The design constraints for aerial platforms are typically specified to achieve the required RF performance while minimizing size, weight, and power (SWaP) and meeting environmental specifications.

II. Photonics for RF Electronic Systems

Photonics technologies and fiber can provide many advantages to these RF systems: low, frequency-independent loss, large bandwidth, reduced SWaP, EMI immunity, and novel functions. GTRI, GT-ECE, Harris Corp, and Sandia National Labs have collaborated to develop photonics technology specifically for insertion into large wideband RF systems. Here we summarize three functions for RF systems implemented in discrete component photonics: (1) analog remoting, (2) frequency conversion, and (3) channelization. For each we have also launched efforts to miniaturize the technology by fabricating photonic integrated circuits (PICs) to transition to ultra-low SWaP systems.

Analog remoting is the most direct translation of photonic technology from telecommunications to RF electronic systems. Remoting leverages the low-loss and EMI-immunity characteristics of fiber optics along with high-BW photonic components to move signals from one physical location to another. Analog signal transport via fiber is well-understood [1] and employed extensively by the telecom industry in RF over glass (RFoG) systems. GTRI has constructed a pair of DCS demonstrators for 40 GHz remoting, Figure 2 (top left). While seemingly mundane, wideband remoting has experienced increased performance and deployments proven to be an integral part of the photonics value proposition. The advent of photonic integrated circuits has promise to shrink the required remoting hardware to SFP-style packages further increasing deployment opportunities. This technology is still in the concept stage at GT, Figure 2 (bottom left). The DCS remoting link demonstrates superior performance when compared to traditional coaxial cabling and metal waveguides for frequencies above a few hundred MHz and distances beyond a few hundred meters, Figure 3 (left), even with dispersive fading at high frequencies.

Frequency conversion describes the process of receiving one RF frequency band and shifting it to another (usually lower) intermediate frequency (IF) for digitization and/or processing. After processing, the frequency converter must also translate the signal back to RF for transmission. Harris Corp has developed a photonic frequency transceiver technology [2], Figure 2 (top middle) and provided GTRI with a system capable of 4-40 GHz, 4 GHZ IBW, and 45-55 dB dynamic range in 1G BW, Figure 3 (middle). This converter has been demonstrated with a wide variety of signal types [3]. GT-ECE in collaboration with Harris has launched a project to design, fabricate and validate a PIC with all the functionality of the downconverter transceiver. A variety of foundries, including

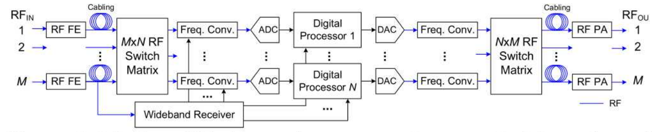

Figure 1. Modern RF electronic systems. In general, M number of physical antennas or bands are switched into N number of digital processing elements. A wideband receiver subsystem is often employed to guide frequency conversion and digital processors since the instantaneous bandwidth (IBW) of digitizers is limited.

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

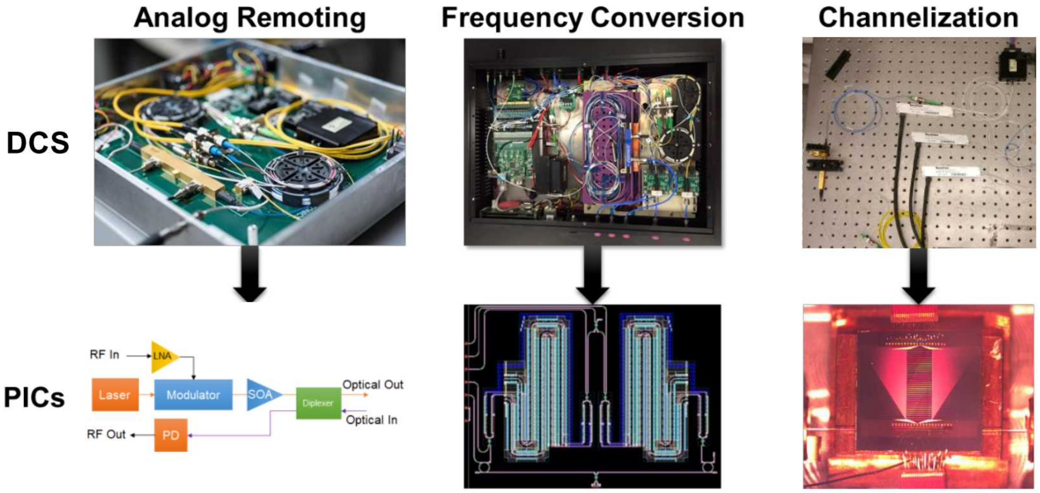

Figure 2. Three applications of photonics to RF electronic systems: analog remoting, frequency conversion, and channelization. GTRI has worked with collaborators in the GT ECE departments, at Harris Corporation, and at Sandia National Labs to take DCS versions of each of the photonic sub-systems and developed prototype PICs. The analog link PIC is still in the concept phase.

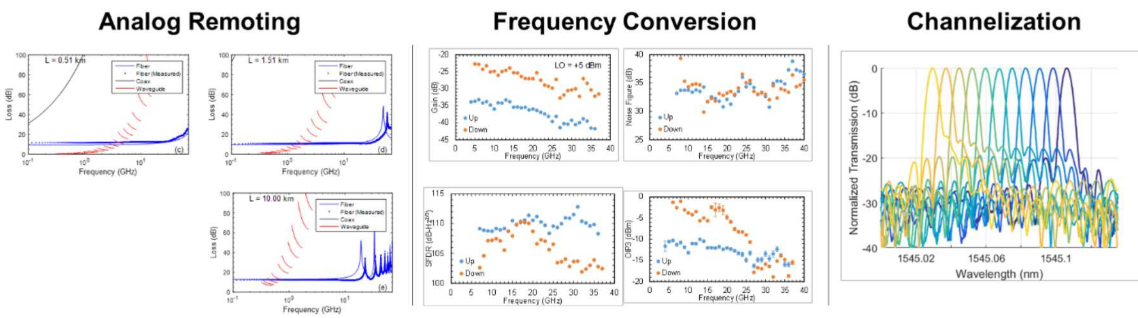

Figure 3. Selected results demonstrating DCS RF performance of the photonic subsystems.

the AIM photonics manufacturing institute [5], are establishing a complete PIC infrastructure analogous to that of the electronics industry. First reports of these efforts are expected in late December, Figure 2 (bottom middle).

Wideband channelization is another RF electronic sub-system. Channelized receivers are typically employed to provide continuous situational awareness and to enable dynamic allocation of available RF resources (detection, digitization and inspection) and thereby maximize sensitivity and signal intelligence. GTRI has constructed a discrete component channelizer based on fiber Bragg Grating (FBG) filters and high-speed modulators (70G+), Figure 2 (top right) and has also partnered with Sandia National Labs to leverage PICs and build an arrayed-waveguide grating (AWG) filter bank to dramatically reduce the SWaP of this channelized receiver, Figure 2 (bottom right). Initial demonstrations of AWGs for RF channelization have shown 1 GHz bins **Error! Reference source not found.**, Figure 3 (right). GTRI expects to receive the next version of the AWG PICs during Fall 2017 which will comprise 20 channels of 2 GHz bins.

III. CONCLUSIONS

We have summarized years of effort to exploity photonics technology to improve various attributes of RF electronics systems use for analog remoting, frequency conversion, and channelization. High-performance DCS demonstrators have been constructed at relatively high technology readiness level (TRL). Efforts are underway to further SWaP-reduce with photonic integrated circuit technology.

ACKNOWLEDGMENT

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

REFERENCES

[1] V. J. Urick et al., "Long-Haul Analog Photonics," in Journal of Lightwave Technology, vol. 29, no. 8, pp. 1182-1205, April15, 2011.

[2] A. Mast, C. Middleton, S. Meredith, and R. DeSalvo, "Extending Frequency and Bandwidth Through the Use of Agile, High Dynamic Range Photonic Converters," IEEE Aerospace Conference, 2012.

[3] A. J. Stark, M. D. Merritt, J. Langston, C. Middleton, R. DeSalvo and S. E. Ralph, "Photonic frequency conversion for dynamic spectral access and signal remoting," 2016 IEEE Photonics Conference (IPC), Waikoloa, HI, 2016, pp. 279-280.

[4] M. Gehl, D. Trotter, A. Starbuck, A. Pomerene, A. L. Lentine, and C. DeRose, "Active phase correction of high resolution silicon photonic arrayed waveguide gratings," Opt. Express 25, 6320-6334 (2017).

[5] http://www.aimphotonics.com/