Enabling Microwave Photonic Technologies for Antenna Remoting

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The low-loss, electromagnetic interference free, and wide bandwidth microwave signal transport over lightweight and non-conducting photonic links offers the potential for providing new capabilities, significant performance improvements, and design flexibility to a diverse range of microwave systems [1,2]. In this article we describe some enabling microwave photonic technologies for fiber-optic antenna remoting in RF sensor systems and wireless communication networks.

Adaptive Feedforward Linearization for High Dynamic Range RF Photonic Links

A major hurdle to fully realizing the benefits of photonic signal remoting in microwave systems is the high dynamic range requirement of many applications, limited by the inherent nonlinearity of the electrical-to-optical (E/O) conversion process. Several linearization schemes suitable for correcting microwave photonic link nonlinearities have been demonstrated, most derived from common RF amplifier design techniques such as predistortion [3,4] and feedforward [5,6] architectures. Novel electro-optical modulator designs [7] have also been proposed and demonstrated. The majority of these implementations, however, have been characterized by limited operational and/or instantaneous bandwidths, as well as the achievable Spurious Free Dynamic Range (SFDR).

Recently, in collaboration with researchers at Johns Hopkins University Applied Physics Laboratory, we developed a linearized high SFDR RF photonic link with multi-octave operational bandwidth and an instantaneous bandwidth approaching 1 GHz [8]. Our approach for correcting the performance-limiting E/O nonlinear distortion was based on the use of feedforward (FF) linearization. Figure 1 shows the high level architecture of the linearized circuit which is based on an intensity modulation direct detection link and also incorporates adaptive functionality. As shown in the diagram, an electro-optic modulator (EOM) encodes the input RF signal(s) onto an optical carrier. Distortion due to this nonlinear transfer function is dominated by third-order intermodulation distortion products (IMD3) which are important to suppress since they typically lie within the frequency band of interest. The adaptive FF linearization architecture incorporates three main parts: a signal cancellation circuit (SCC), an error cancellation circuit (ECC), and a control circuit (CC). Control loops are also utilized to provide real-time adaptive capability whereby the RF photonic link can maintain system performance during changing operating conditions. As their names imply, the SCC and ECC cancel the signal and error respectively, forming the foundation of a conventional FF linearization system.

As highlighted in Figure 1, the input RF signal to the FF linearized RF photonic circuit is split into three paths. In the SCC, the amplitude and phase of one of the copies of the input signal (represented by the 'ΔA, $\Delta\varphi$' block) is adjusted for maximum signal cancellation when it is combined with a portion of the main optical path after optical-to-electrical (O/E) conversion in a high-speed photodetector (PD). The main optical signal and the input RF replica are arranged to have equal amplitudes and

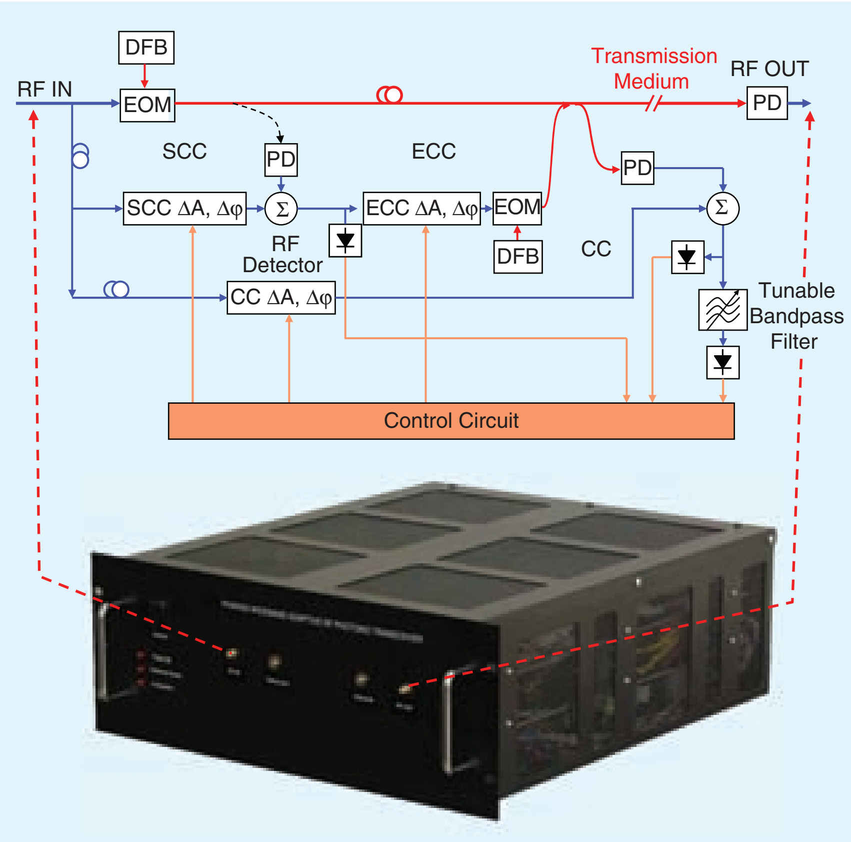

Figure 1. Top: Block diagram of the wideband adaptive FF linearization transmission circuit architecture; Bottom: Photograph of the RF photonic transceiver module.

opposite phase when combined; the signal component is then cancelled leaving only the error. The error signal is then prepared by amplitude and phase adjustment and encoded with a second EOM in the ECC before being optically coupled back into the main transmission path. Proper error cancellation occurs when these two signals are equal in amplitude and opposite in phase and ideally, an undistorted copy of the input RF signal through the transmission medium at the final O/E conversion will result. The CC in the adaptive FF linearized RF photonic link is effectively a signal cancellation loop that monitors the performance of the circuit. It operates in a similar way to the SCC; combining the amplitude and phase adjusted section of the undistorted input RF signal and a fraction of the transmitter output to isolate the remaining distortion component of the output signal.

The operating bandwidth of the circuit shown in Figure 1 is dependent only on the frequency response of the components and the path length difference of the delay lines at the signal and error combination points. Commercial-off-the-shelf devices were used to realize a multi-octave operational bandwidth. Each control loop in the adaptive FF circuit includes amplitude and phase tuning hardware as well as a wideband RF detector to provide feedback on the loop performance. The detectors provide a voltage proportional to the RF signal strength at their specific locations. A control circuit interfaces between the various components in the control loops and also executes the control algorithms. Further information regarding the adaptive algorithms can be found in [7].

The linearity performance of the adaptive FF linearized RF photonic circuit was measured over the RF component limited operational bandwidth of 1–20 GHz using the test configuration shown in Figure 2 with an input test signal comprising a two-tone RF signal centered at 15 GHz. Fundamental and IMD3 levels were measured using a high frequency RF spectrum analyzer. Figure 2 shows an example of the measured IMD3 suppression performance and presents the measured RF spectra of the detected optical output signal with and without adaptive FF linearization implemented. IMD3 suppression of third order intermodulation distortion products by 20–25 dB in a 30 MHz instantaneous bandwidth (IBW) was achieved with the adaptive FF linearized circuit. The SFDR of the multi-octave adaptive FF linearized RF photonic link was determined from the IMD3 suppression measurements and the measured noise floor of the system. Table I summarizes the measured linearity performance of the link at instantaneous bandwidths of 30 MHz and 300 MHz, highlighting the SFDR. Table II presents the measured SFDR at a center frequency of 10 GHz

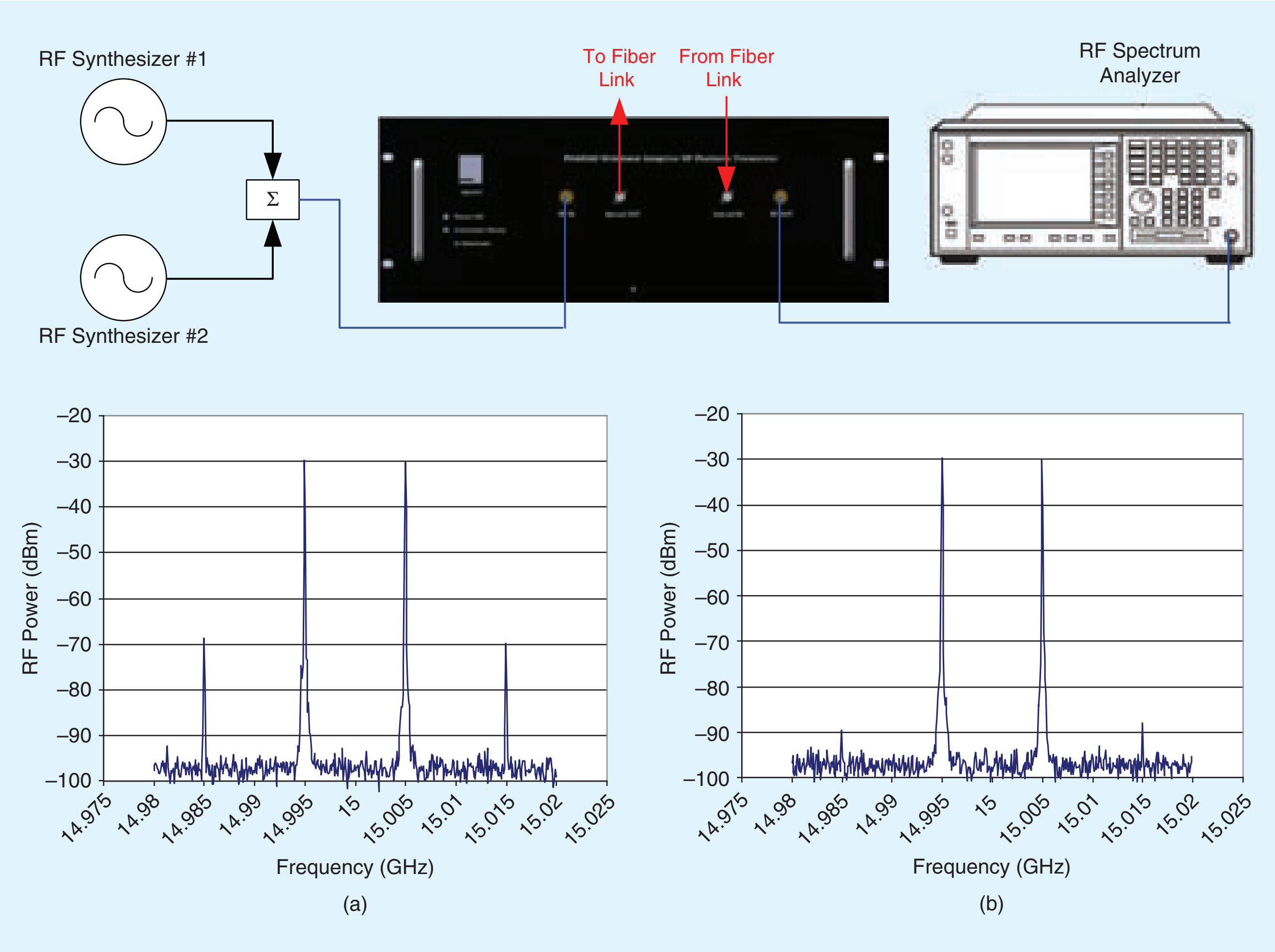

Figure 2. Top: Test configuration used to measure the linearity performance of the wideband adaptive FF linearized RF photonic transceiver; Below: Measured IMD3 suppression of the wideband RF photonic link at 15 GHz with a 10 MHz two-tone spacing: (a) without and (b) with adaptive FF linearization.

Band	Center Frequency (GHz)	SFDR (dB-Hz$^{2/3}$)	
		30 MHz IBW	300 MHz IBW
S-band	3	112.97	111.86
C-band	6.5	111.76	111.90
X-band	10	114.03	111.16
Ku-band	15	115.24	111.07

Table I. Measured SFDR of the multi-octave adaptive FF linearized RF photonic link at 30 MHz and 300 MHz instantaneous bandwidth.

Instantaneous Bandwidth (MHz)	SFDR (dB-Hz$^{2/3}$)
3	113.91
30	114.03
150	113.81
300	111.16
600	113.10
900	111.40

Table II. Measured SFDR of the multi-octave adaptive FF linearized RF photonic link at 10 GHz for different instantaneous bandwidths.

for increasing instantaneous bandwidths. SFDR values in excess of 111 dB-Hz$^{2/3}$ were achieved for instantaneous bandwidths approaching 1 GHz.

Antenna Technologies for Fiber Optic Antenna Remoting Links

High performance RF photonic links are not the only requirement for fiber optic antenna remoting applications. Efficient, low loss interfaces between the guided optical medium and the free-space microwave link are also necessary for maximizing overall system performance. To address this challenge, Pharad is developing unique antenna technologies that are compatible with efficient integration with common photonic materials such as lithium niobate and indium phosphide. In order to support wideband fiber optic antenna remoting links, we are also focusing on broadband antenna structures that can be directly integrated with optical transmitters and receivers. The challenge lies in not compromising either the overall antenna bandwidth or the efficiency of the RF photonic link, since conventional antennas developed on high dielectric constant materials typically feature poor efficiency and limited bandwidth.

Low profile patch-based antennas can provide efficient, broadband radiator solutions that can be either readily developed on photonic materials, or electromagnetically coupled to them. Figure 3 shows a variation of this type of radiator structure, known as a hi-lo stacked patch [8, 9], which can be integrated on photonic materials and still provide an inherently broadband, efficient solution. The patch antenna is created on the photonic device material where the RF electrode structure is developed (a microstrip transmission line is shown in Figure 3). Another patch antenna created on a separate combination of dielectric layers is then electromagnetically coupled to the driven antenna. This second radiator enhances the overall efficiency and bandwidth of the antenna.

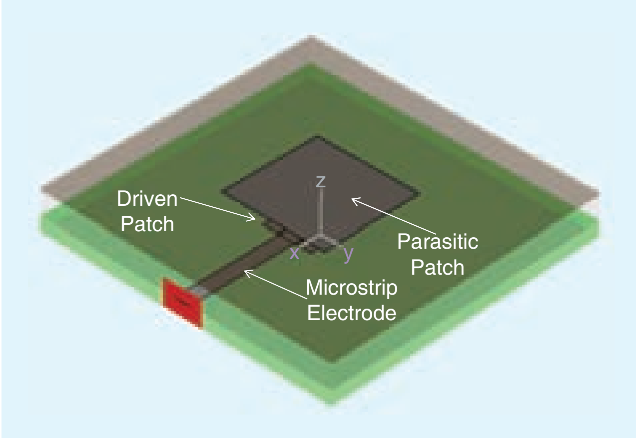

Figure 3. Schematic of a hi-lo stacked patch antenna that can be integrated with photonic materials.

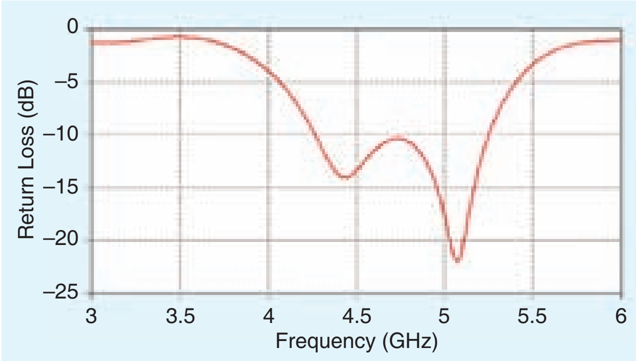

Figure 4. Return loss response of a hi-lo stacked patch antenna designed for operation at 5 GHz and to be integrated with InP.

Figure 4 shows the return loss performance of a hi-lo stacked patch antenna that was designed for operation at approximately 5 GHz and for integration with InP. As can be seen from the response, a –10 dB return loss bandwidth of approximately 20% was achieved using the radiator structure shown in Figure 3. Furthermore, the overall efficiency of the antenna was greater than 92%, even though the driven patch was developed on a high dielectric constant material ($\varepsilon_r > 11$).

Conclusion

The growing spectral demands of existing microwave systems, as well as new technology opportunities such as high data rate wireless communications, make photonic signal remoting capabilities likely to see increased insertion opportunities in the near as well as far future. High performance RF photonic link and antenna technologies are key to realizing these systems.

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Dalma Novak is a Vice-President at Pharad, LLC located in Glen Burnie, Maryland. She has over 16 years of experience in the microwave photonics and optical communications fields, with more than 250 publications in these areas. From 1992–2004 Dr. Novak was a faculty member in the Department of Electrical and Electronic Engineering at The University of Melbourne, Australia, where she is now a Professorial Fellow. From June 2001–December 2003 she was a Technical Section Lead at Dorsál Networks, Inc. and later at Corvis Corporation where she led cross-disciplinary R&D teams developing networking hardware for telecommunications applications. In 2007 Dr. Novak was elected to the grade of IEEE Fellow for contributions to enabling technologies for the implementation of fiber radio systems. She received the PhD degree in Electrical Engineering from the University of Queensland, Australia, in 1992.

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