# PHOTONIC METHODS FOR RF PHASE SHIFTING

*Ross T. Schermer and Frank Bucholtz*
*Naval Research Laboratory, Washington, DC*

*(Invited Paper)*

## Introduction

Optical-domain, radio-frequency (RF) true-time-delay (TTD) lines with programmable time delays, wide bandwidth and low optical loss are key components of microwave photonic signal processing systems [1-2]. Their unique advantages, including low loss (independent of RF frequency), large instantaneous bandwidth, immunity to electromagnetic interference, and parallel signal processing capability, have led to the realization of high-performance, tunable microwave filters, phased array be/amformers, fast analog-to-digital converters, arbitrary waveform generators, signal correlators, and frequency converters and mixers [1-2]. For such applications, it is critical that the delay lines exhibit low loss, wide RF bandwidth, minimal frequency-dependent loss, and achievable time delays at least on the order of the RF period. Rapid tuning speed and fine delay resolution are also of interest for enabling higher-performance, more agile photonic systems. In this presentation we will review various photonic methods for active RF phase control. We also report the demonstration of a rapidly-tunable, broadband RF TTD line which is capable of continuous tuning over a 150 ps range with switching time of approximately 2 μs.

## Beam-Scanned Grating Delay Line

A schematic diagram of the beam-scanned grating (BSG) delay line presented in this work is shown in Fig. 1(a). This configuration differs from that reported previously (and described in detail in [3]) in that an acousto-optic beam deflector was utilized for rapid beam deflection, and a focusing mirror was used to reduce device length. In its operation, the output of a single-mode optical fiber was imaged into an acousto-optic (AO) beam deflector cell, which allowed the beam deflection angle to be controlled via a tuning voltage $V_T$. The deflected beam was then reflected off a spherical collimating mirror, and subsequently retro-reflected back along its original path (into the fiber) by a diffraction grating aligned in Littrow configuration. At the end of the device a fiber-optic circulator was used to separate the input and output optical beams. A half-wave plate was also included to compensate for polarization dependences of the particular AO deflector and diffraction grating used. Due to the inclination of the grating, changes in the AO deflection angle altered the round-trip optical path length through the system. When the delay line was incorporated as part of a RF

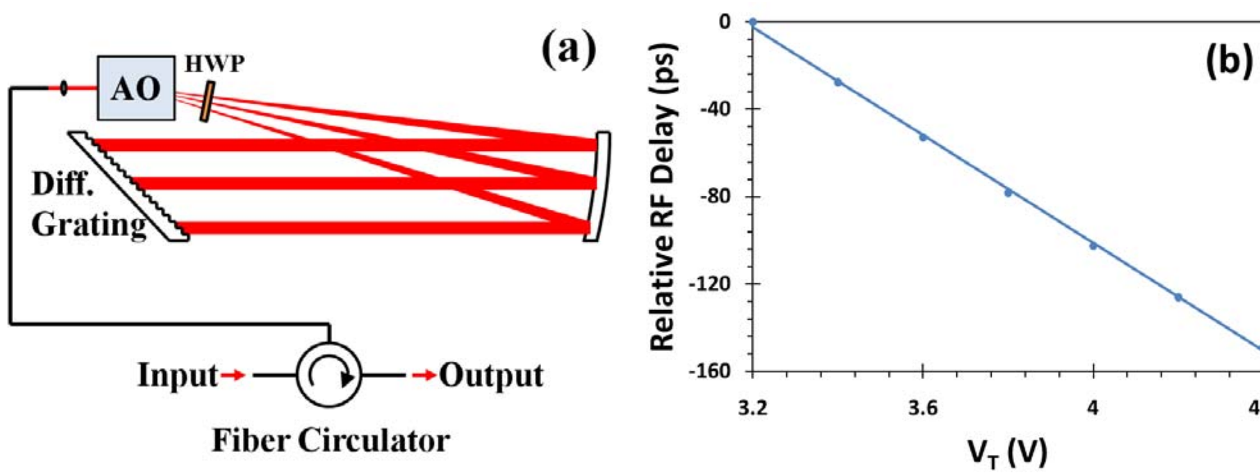


**Fig. 1. (a) BSG delay line schematic and (b) measured RF TTD vs. AO deflector tuning voltage.**

photonic link, this change in optical path length produced an identical change in RF path length. This resulted in the voltage-controlled RF TTD plotted in Fig. 1(b), as measured using a network analyzer over the range 6-18 GHz. The measured 150 ps delay was sufficient to provide RF phase tuning over at least a full RF period at 6.7 GHz and above.

The tuning speed of the BSG delay line was tested by incorporating the device into a photonic link, and in turn placing the photonic link within one arm of a balanced RF Mach-Zehnder (MZ) interferometer. A continuous-wave, 10.24 GHz signal was applied to the interferometer, and the RF output power was measured as a function of $V_T$ using a Schottky diode detector and oscilloscope. Figure 2(a) plots the measured interference signal for a 50 kHz saw-tooth tuning voltage input, determined from the relation

$$A \cdot \cos\phi_{RF} = \left(P_{tot} - P_1 - P_2\right) / \left(2\sqrt{P_1 P_2}\right),$$

where $P_1$ and $P_2$ are the RF powers in each arm of the interferometer, $P_{tot}$ is the output power, and $A$ accounts for residual amplitude modulation in the delay line. Despite some amplitude modulation, the RF phase in Fig. 2(a) tuned continuously over a range of approximately 1.5 RF periods within 10 μs. Figure 2(b) plots the measured interference signal for a 50 kHz square wave tuning voltage input. This shows that the RF phase was discretely switchable, with could be switched discretely with rise and fall times of 1.8 μs and 2.1 μs, respectively.

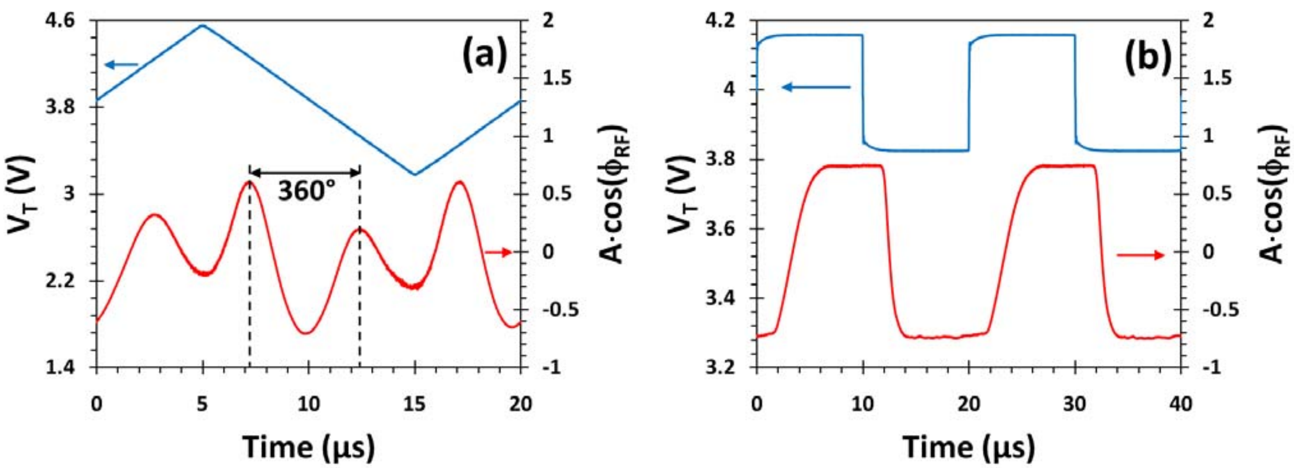


**Fig. 2. (a) Continuous and (b) discrete RF phase tuning at 10.24 GHz using a BSG delay line.**

## Conclusion

This paper demonstrates a delay line capable of near-MHz switching of continuously-tunable, optical-domain RF TTD. The rapid tuning speed offers advantages for high-performance, agile photonic systems.


## Acknowledgment

The authors would like to thank Fredrik Fatemi and Marc Currie for providing the AO deflector and diffraction grating used for this work.


## References


[1] A. J. Seeds and K. J. Williams, "Microwave photonics," *J. Lightwave Tech*., vol. 24, pp. 4628-4642, 2006.

[2] R. A. Minasian, "Photonic signal processing of microwave signals," *IEEE Trans. Microwave Theory and Techniques*, vol. 54, pp. 832-846, 2006.

[3] R. T. Schermer et al, "Continuously-tunable microwave photonic true-time-delay based on a fiber-coupled beam deflector and diffraction grating," *Optics Express*, vol. 19, pp. 5371-5378, 2011.