# Photonic True-time Delay Unit for Broadband Adaptive Nulling in Antenna Arrays

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***Abstract*— This paper describes an Opto-VLSI-based tunable true-time delay generation unit used for adaptive null steering in phased array antennas. Arbitrary single or multiple true-time delays can simultaneously be synthesized for each antenna element to generate multiple broadband nulls. Simulated azimuth gain patterns for a 4-elements antenna arrays are presented. Experimental results, which demonstrate the principle of the true-time delay unit are also presented.**

***Keywords*— Phased arrays, delay effects, beam steering, integrated optoelectronics, liquid crystal devices.**

## I. Introduction

The ability of electronically programmable phased-array antennas to adaptively scan radiated beams in three-dimensional space without mechanically moving the antenna structure makes it suitable for attaining higher signal-to-noise ratio, improved reliability and lower transmission power.

However, most of the research on phased-array antenna has been focused on broadband beam steering and less attention has been given to null beamforming, which is the ability to maintain nulls at chosen angular coordinates for broad frequency range [1]. Broadband null steering requires a beamformer that can generate variable and frequency independent true time-delays (TTD). This TTD requirement is difficult to be achieved using conventional electronic phase-shifter circuits or Digital Signal Processors (DSP), but more straightforward if it implemented using photonic-based signal processing devices [2].

In this paper, we present the design, simulation and a proof-of-concept demonstration of a wideband null-steering photonic-based beamformer, using Opto-VLSI processor and high dispersion fibers to synthesize multiple arbitrary time delays for TTD generation.

## II. Principle of Phased Array Antennas

Fig. 1 shows a typical N-element phased-array antenna architecture, whose array factor (or directional response) is given by [1]:

$$AF_N(\theta) = \prod_{n=1}^{N-1}(x - x_n) = \sum_{m=0}^{N-1} W_m x^m \qquad (1)$$

Where $x = \exp[jkd\sin(\theta)]$, $d$ is the antenna element spacing, $k$ = wave number = $\omega/c$, and $x_n = x\ (\theta_n)$ is a zero of the polynomial $AF_N$ corresponding to an antenna null at the angular coordinate $\theta_n$. Note that a change of even one zero (or null) affects all the weights, $W_m$. Note also that with N antenna elements, the phased-array antenna can synthesize only (N–1) nulls, as evident from Equation (1).

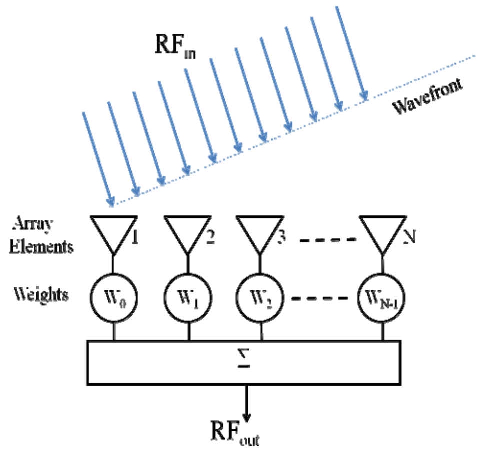


**Fig. 1.** Generic N-element antenna array structure.

Generally, for an N-element broadband phased array, the synthesis of (N–1) broadband nulls can be achieved if the beamformer of the antenna can adaptively generate and combine ($2^{N-1}$–1) delayed versions of the RF signals received by the antenna elements, as illustrated in Fig. 2.

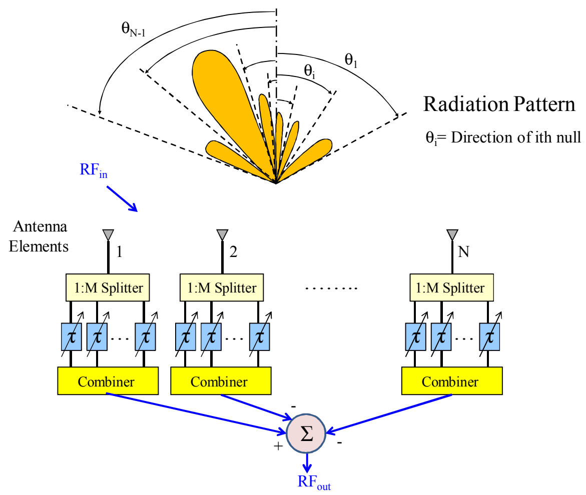


**Fig. 2.** Phased-array antenna structure for broadband null steering.

### III. PROPOSED PHOTONIC TRUE TIME DELAY STRUCTURE

Fig. 3 shows the proposed photonic phased-array antenna structure for broadband null steering [3]. An amplified spontaneous emission (ASE) source is split into N parts. Each ASE signal is modulated by the received RF signal via an Electro-optics Modulator (EOM). The RF-modulated optical signal from each is routed into an Erbium Doped Fiber Amplifier (EDFA) for amplification, and then collimated and launched into a diffractive grating plate. The latter demultiplexes the collimated ASE signal into different wavebands and maps them onto the surface of a 2-D Opto-VLSI processor as illustrated in Fig. 3.

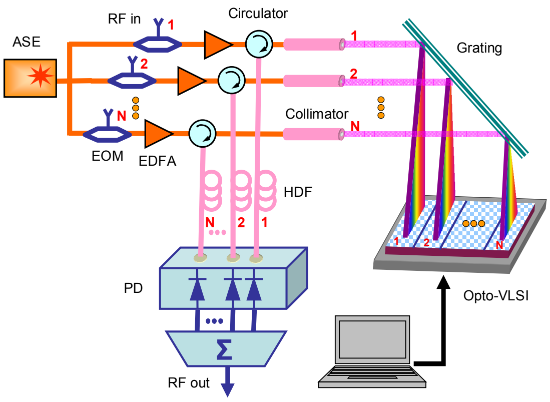


**Fig. 3.** Opto-VLSI-based True-time delay structure for broadband null steering in antenna array [3].

By driving the Opto-VLSI processor with an appropriate phase hologram, the RF-modulated waveband can be selected and steered back into its corresponding fiber collimator. The selected wavebands are then routed via optical circulators to high dispersion optical fibers (HDFs) with dispersion coefficient of 382.5 ps/nm, where they experience true-time delays that depend on their center wavelengths. The delayed RF-modulated wavebands in the HDFs are finally detected by a photo-receiver array, and combined with appropriate polarities to synthesize the required nulls.

### IV. SIMULATION AND EXPERIMENTAL RESULT

Fig. 4 shows the simulated azimuth gain pattern for a 4-element antenna array. The spacing between the antenna elements is half the RF wavelength. The Minimum Mean-Square Error (MMSE) algorithm was used to generate null objectives at -60°, -20° and 45°, and desired beam directions at 10°. Figure 5 shows the simulated field pattern polar plot for a 4-element antenna when the desired signal is at -15°, and the nulls are imposed at 60° , 10° and –45° . Figure 6 shows the spectra of RF-modulated wavebands and the corresponding RF response when these wavebands are delayed by the HDF and detected by the photodetector (Fig. 3), for small and large waveband spacing scenarios. The free-spectral range of the RF response is inversely proportional to the true-time delay between adjacent wavebands [3] and the experimental results shown in Fig. 6 demonstrate the simultaneous generation of 5 wavebands with 6.84nm separation, corresponding to an arbitrary inter-waveband true-time delay of up to 2.5 ns.

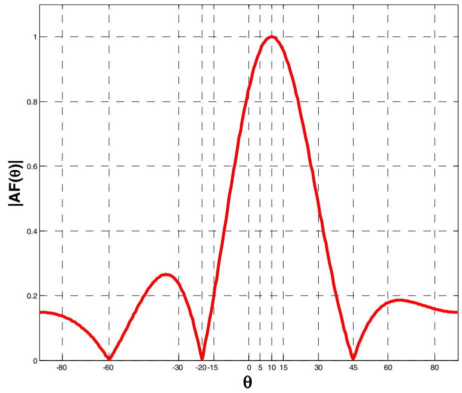


**Fig. 4.** The simulated azimuth gain patter of 4-element Array Factor for the proposed photonic null steering antenna array.

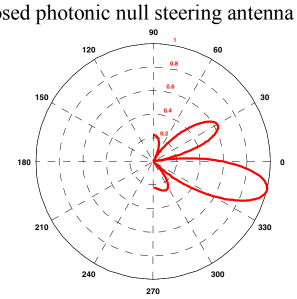

**Fig. 5.** Polar plot of 4-element antenna pattern with desired signal (main lobe) at -15° and interfering signals (nulls) at -60°, -20° and 80°.

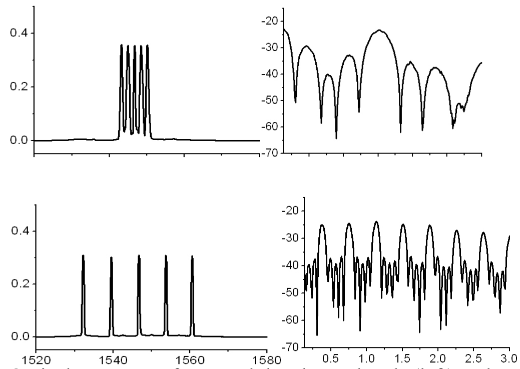

**Fig. 6.** Optical spectrum of RF-modulated wavebands (left) and measured RF responses for different waveband spacing scenarios.

### V. CONCLUSIONS

A photonic true-time-delay (TTD) unit capable of generating multiple arbitrary true-time delays of up to 2.5 ns has been simulated and experimentally demonstrated. The TTD unit can be applied for null steering in arrayed antennas.

### REFERENCES

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