Novel space/time integrating acousto-optic architectures for radar signal processing

Riza, Nabeel

Nabeel A. Riza, "Novel space/time integrating acousto-optic architectures for radar signal processing," Proc. SPIE 2155, Optoelectronic Signal Processing for Phased-Array Antennas IV, (10 June 1994); doi: 10.1117/12.177424

Event: OE/LASE '94, 1994, Los Angeles, CA, United States

Novel Space/ Time Integrating Acoustooptic Architectures for Radar Signal Processing

Nabeel A. Riza
General Electric Corporate Research and Development Center
P. O. Box 8, KWB 617, Schenectady, N.Y. 12301

ABSTRACT

Novel space integrating acoustooptic correlators and convolvers are introduced that are based on the in-line AO interferometer. A new notch filter architecture is introduced with a potential of > 36 dB rf null depths.

2. INTRODUCTION

Recently, we introduced an inherently stable in-line additive acousto-optic (AO) interferometer based on a cascaded design of two Bragg cells [1]. In this design, unlike the Mach-Zehnder interferometer, the Bragg cells also act as beam splitters and beam combiners in a compact, in-line design. We have shown that with the proper orientation of the Bragg cells, the optical system can be used to control phased array antennas [2]. In this system, the output of the optical system is a set of radio frequency or microwave signals with an appropriate signal phase distribution generated by electrically controlling the deflection angle of the two interfering beams. Fig.1 shows this architecture.

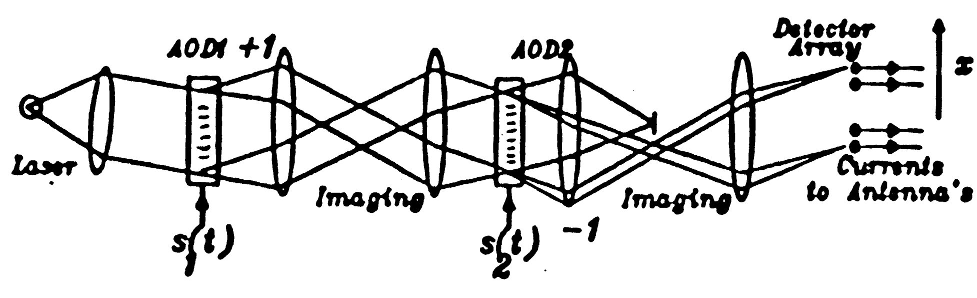

Fig.1 The in-line AO interferometer used for one dimensional phased array control.

It is also possible to use the AO in-line interferometer to form a wide instantaneous bandwidth space integrating optical spectrum analyzer that can be used as a microwave receiver [3]. This design is shown in Fig.2.

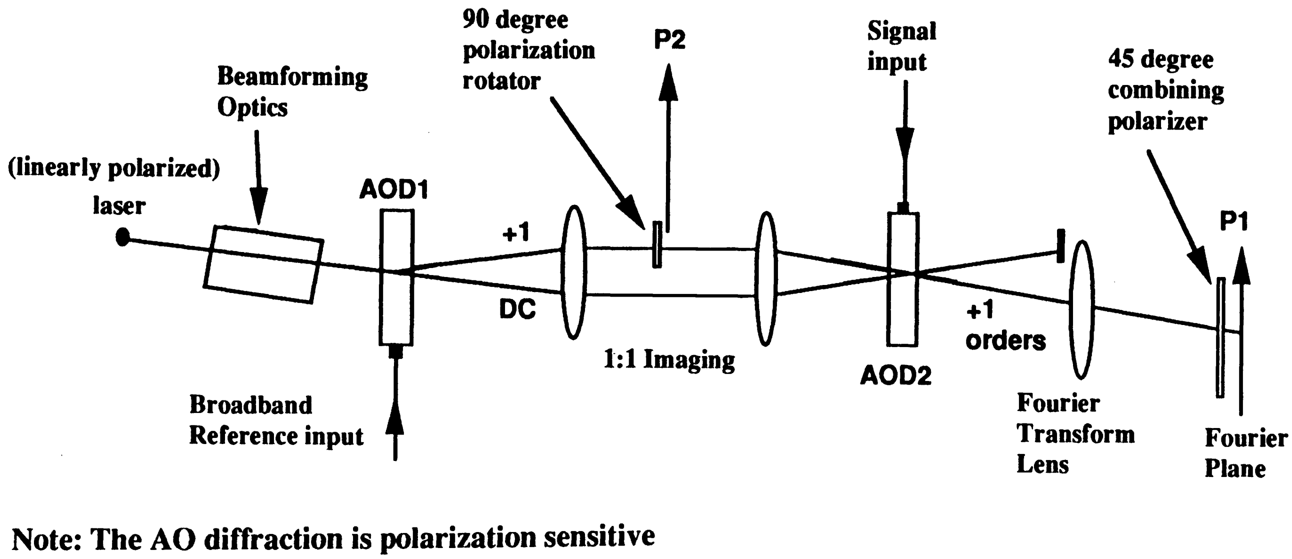

Fig.2 The in-line AO interferometer used as a wideband spectrum analyzer.

In addition, the AO in-line interferometer has also been combined with a pair of two dimensional (2-D) nematic liquid crystal (NLC) arrays for forming an analog beamformer for microwave phased array antennas with full analog signal amplitude and phase control capabilities [4-5]. This design is shown in Fig.3.

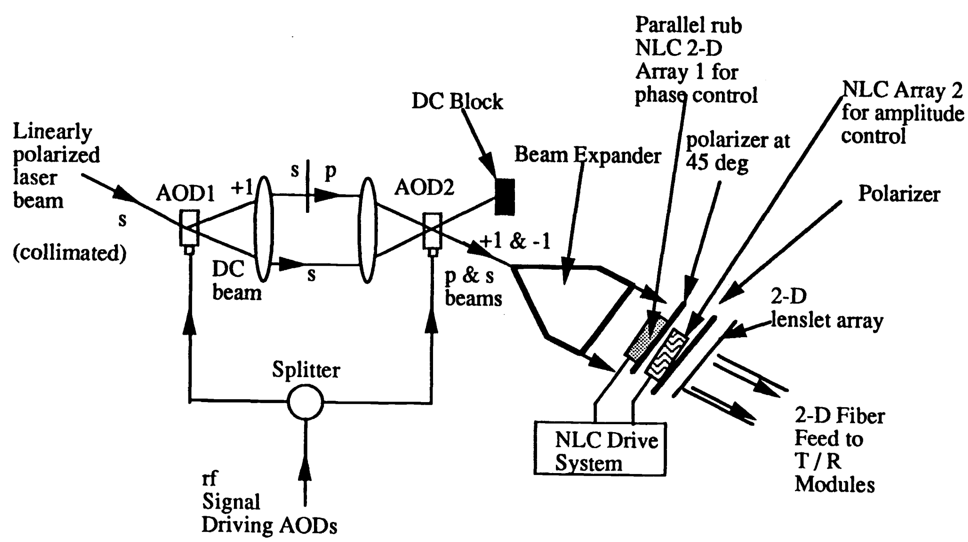

Fig.3 The in-line AO interferometer used in a nematic liquid crystal-based system for two dimensional phased array amtenna control.

Recently, we have also shown and experimentally verified how the AO in-line interferometer can also be modified to implement the time integrated one dimensional correlation function [6-7]. This design is shown in Fig.4. Researchers at Rome Labs (NY) have further extended this work to show excellent experimental results [8].

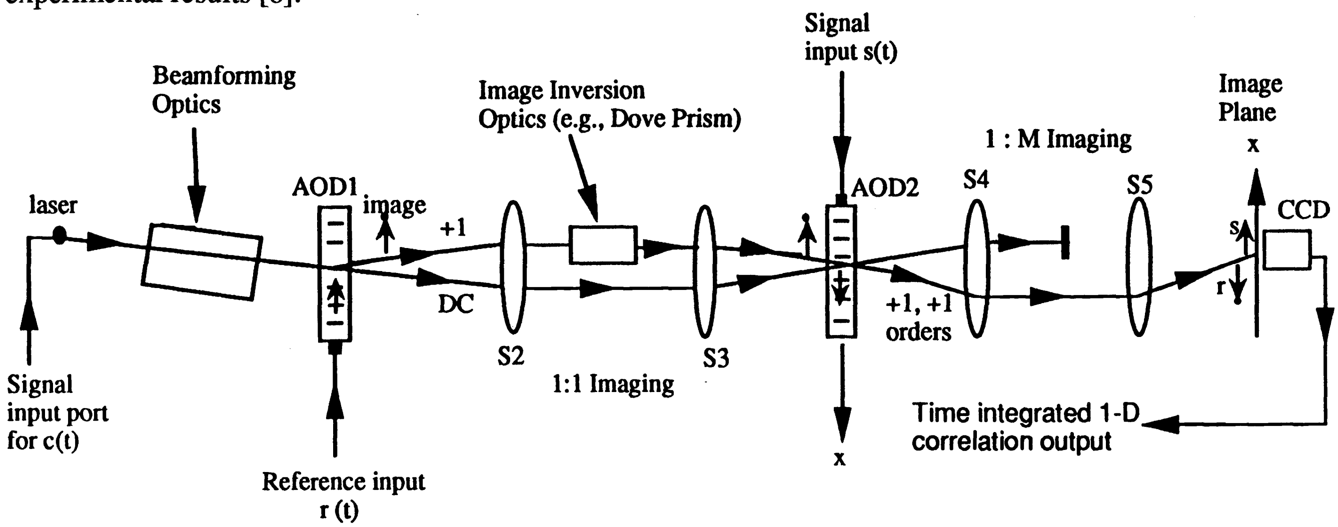

Fig.4 The in-line AO interferometer as a time integrating correlator.

In this paper, we will describe how the in-line AO interferometer can be used to form novel space integrating architectures to perform important correlation and convolution transformations required in radar signal processing. In addition, a notch filter architecture based on the in-line AO interferometer and NLCs will also be highlighted.

3. CONVOLUTION AND CORRELATION

The equations to follow describe the mathematical frame work for the convolution and correlation operations. The convolution integral where the integration is performed in time can be expressed as:

$$g(x) = \int_{-\infty}^{+\infty} f(t)h(x-t)dt$$

while the convolution integral where the integration is performed in space can be expressed as:

$$g(t) = \int_{-\infty}^{+\infty} f(x)h(t-x)dx$$

The cross-correlation function where the integration is performed in time can be expressed as:

$$g_{fh}(x) = \int_{-\infty}^{+\infty} f(t)h^*(t+x)dt$$

while the cross-correlation function where the integration is performed in space can be expressed as:

$$g_{fh}(t) = \int_{-\infty}^{+\infty} f(x)h^*(x+t)dx$$

Applications of these transformations occur in signal filtering operations in radar and communication systems, with specific applications as matched filters, range/doppler filters, and spectrum analyzers.

4. THE NOVEL SPACE INTEGRATING ARCHITECTURES

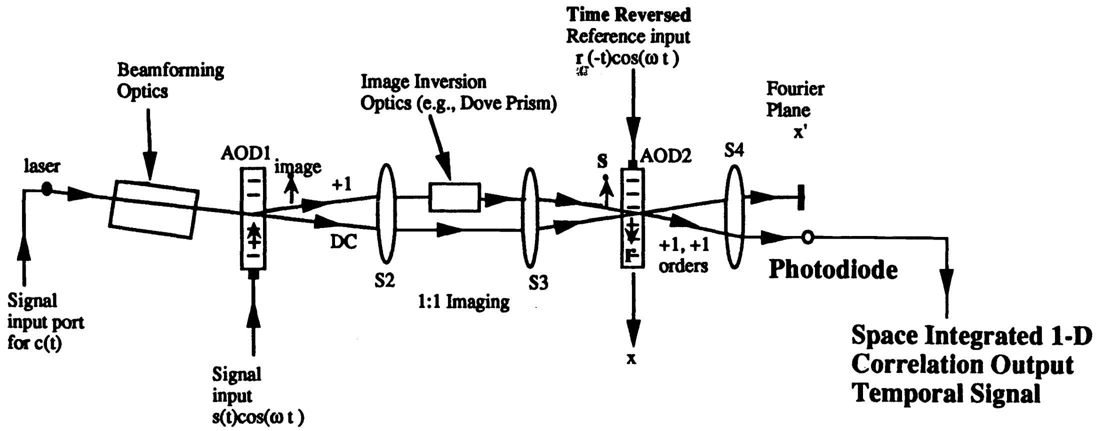

Fig.5 The in-line AO interferometer used as a space integrating correlator.

Fig.5 shows the space integrating (SI) AO correlator. The second AOD (called AOD2) is fed with a time reversed reference input that is modulated by the AOD carrier frequency. At the AOD2 plane x, the two signals are counterpropagating and have similar positive doppler shifts. The photodiode at the Fourier plane x' produces a temporal signal that is the space integrated correlation function. This signal can be expressed as

$$i(t, x' = 0) = Cons\tan t\ Bias + 2\,\mathrm{Re}\left\{\int \tilde{s}(u)\tilde{r}^{*}(u - 2t)du\right\}$$

where u=t+x/v, and the second term gives the real value of the complex correlation. If the correlation is desired on a temporal carrier, a slight difference between the carriers for the two AODs can be used to modulate their respective input waveforms. This carrier difference should be small enough so that both the signal and reference signal Fourier transforms fall on the same photodiode.

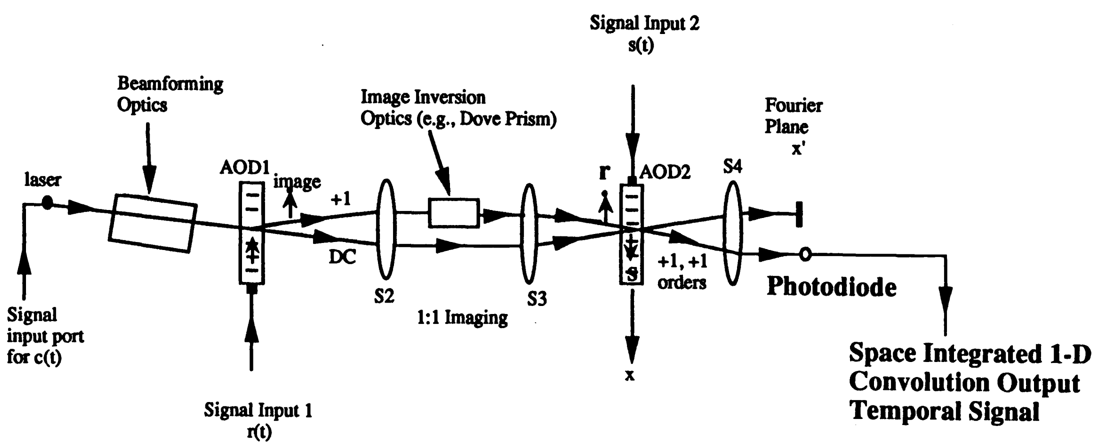

Fig.6 The in-line AO interferometer used as a space integrating convolver.

Fig.6 shows the SI AO convolver. In this case, the signal input to AOD2 is not time reversed. The space integrated output of the photodiode can be expressed as:

$$i(t, x' = 0) = Constant\ Bias + 2\,\mathrm{Re}\left\{\int \tilde{r}(u)\tilde{s}^*(2t - u)du\right\}$$

where u=t+x/v, and the second term gives the real value of the complex convolution. Once again, this convolution can be generated on temporal carrier, if desired, using a difference in the AOD carrier signals.

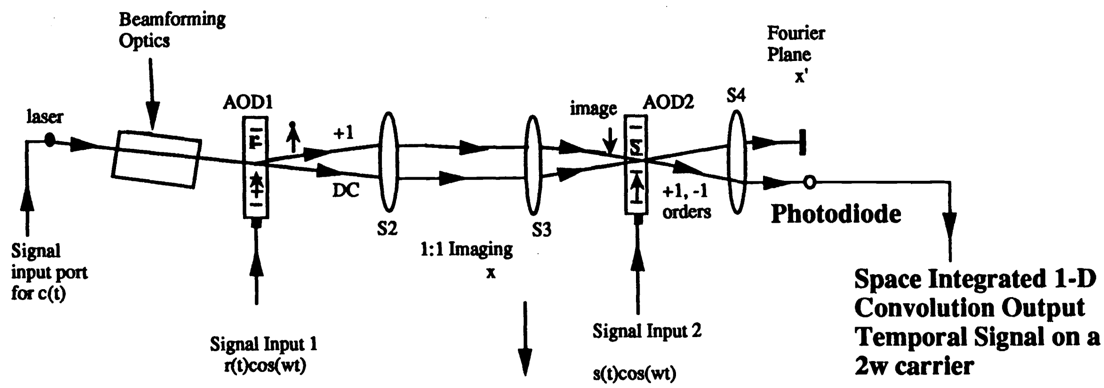

Fig.7 The in-line AO interferometer used as a space integrating convolver that generates the output on a fast temporal carrier.

Fig.7 shows another SI AO convolver. In this case, the convolution integral is generated on a fast temporal carrier that is twice the AOD carrier frequency that is being used to drive both AOD1 and AOD2. In this case, the photodiode output can be written as:

$$i(t, x' = 0) = Constant\ Bias + 2\,\mathrm{Re}\left\{\exp(-j2\omega t)\int s(u)r(2t - u)du\right\}$$

In this case, a photodiode with a wide bandwidth is required, particularly when using GHz band Bragg cells with 3 GHz carrier frequencies.

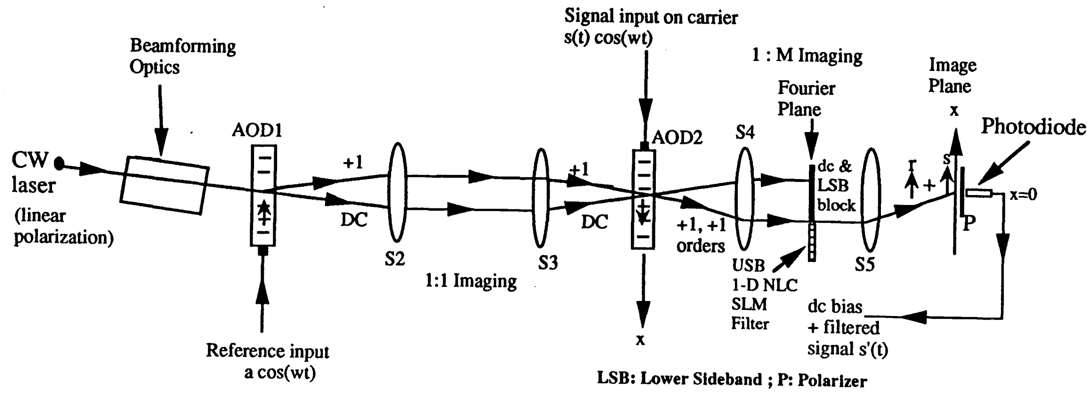

Fig.8 The in-line AO interferometer used as a notch filter.

Another application of the in-line AO interferometer is the novel interferometric AO signal excisor/notch filter shown in Fig.8. Here, the output of the photodiode is proportional to the amplitude of the filtered signal, a result of the coherent detection process. The output signal contains only the filtered signal riding on a bias term, with the bias possibly being removed using an electrical dc-block circuit. Note that the use of the polarization-based high optical extinction ratio (e.g., > 3500 : 1) NLC spatial light modulator (SLM) can result in > 36 dB electrical notch filtering. Because wideband Bragg cells can be used in this optical design, direct notch filtering of very wide (e.g. , 1 GHz) instantaneous bandwidth signals is achieveable, without a need for large or possibly any frequency down conversion from the antenna receive band. Recall that our previous experiments have shown that indeed NLCs can form very high isolation optical switches [9,5].

Future work relates to the experimental verification of these novel optical architectures.

5. REFERENCES

[1] N. A. Riza, `` Novel acousto-optic systems for spectrum analysis and phased array radar signal processing," Ph.D dissertation, (California Institute of Technology, Pasadena, Calif., 1989) in *University Micofilms*, Ann Arbor, MI.

[2] N. A. Riza and D. Psaltis, ``Acousto-optic signal processors for transmission and reception of phased array antenna signals," *Applied Optics*, vol.30, no.23, pp.3294-3303, 1991.

[3] N. A. Riza, ``Optically efficient interferometric acousto-optic architecture for spectrum analysis," *Applied Optics*, Vol.31, No.17, pp.3194-3196, June 10, 1992.

[4] N. A. Riza, `` Compact electrooptic controller for microwave phased array antennas,'' SPIE Proc. 2026, pp.286-296, 1993.

[5] N. A. Riza, `` Liquid crystal-based optical controllers for phased array antennas,'' SPIE Proc. 2155-20, O-E LASE, Jan., Los Angeles, 1994.

[6] N. A. Riza, `` In-line acoustooptic interferometer as a correlator and spectrum analyzer,'' SPIE Proc. 2026, pp.130-141, 1993.

[7] N. A. Riza, `` In-line interferometric time integrating acoustooptic correlator,'' to appear in *Applied Optics*, 1994.
[8] C. W. Keefer and M. J. Ward, `` Modified interferometric in-line time integrating correlator,'' SPIE Proc. 2026, pp.177-184, 1993.
[9] N. A. Riza, `` Three dimensional optical time delay units for radar ,'' SPIE Proc. 2026, pp.227-237, 1993.