Discrete Space Optical Signal Processing with Metamaterials

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Digital circuits have played a crucial role in information processing during the past half centure, but as transistors are approaching the limits predicted by Moore's law, there is a pressing need for devising alternative computing approaches. In this context, the old concept of optical signal processing (OSP) has received renewed attention, revisited in the light of metamaterials and nano-photonics. Taking advantage of inherent nonlocal effects in metamaterials, this approach has been successful in realizing basic mathematical operations, such as derivatives and integrals, but it may be difficult to be applied to ones with significantly different characteristics than the nonlocal responses that can be obtained through metamaterials.

Here, we present a radically new approach to OSP, with the ability to implement arbitrary linear or nonlinear mathematical operations. Our approach is inspired by digital filters, where a desired operation is implemented in the discrete time domain, after a signal is discretized in time through a sampling circuit, like a switch. Following this paradigm, we introduce a system where an optical signal is first sampled in space through an array of antennas, the output of which is supplied to a nano-scale network with a discrete number of input and output ports that performs a desired mathematical operation. The output of this network is a discrete signal in space and can be directly supplied to an array of photodetectors, if the periodicity of the antenna array is selected to be the same as the one of the photodetector array. Similar to digital filters, our system offers great versatility for implementing general operations, since its design reduces to the design of a discrete port network with a given scattering matrix. We demonstrate this approach for the case of edge detection, by designing a structure that performs a discrete derivative in space. The proposed structure is based on an array of lens antennas for sampling the signal in space and a waveguide with periodic arrays of input and output apertures for implementing the desired mathematical operation. Our approach is characteristic for its generality and offers the exciting opportunity for the development of a new type of cameras with embedded OSP capabilities.