



Reflectionless Programmable Signal Routers

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We introduce an approach to signal routing that enables reflectionless in-coupling of signals as well as programmability of the routing functionality. Our unconventional device concept leverages the high modal overlap of a wave chaotic system in combination with the hundreds of degrees of freedom of a programmable metasurface. We also report preliminary experiments that implement our concept “over-the-air” inside a 3D disordered metallic box in the microwave domain.

Reflectionless signal routers can be understood as a special case of systems with reflectionless scattering modes (RSMs) [1]. RSMs occur when a zero of the R-matrix lies on the real frequency axis, where the R-matrix is the part of the system’s full scattering matrix that only involves the channels desired for reflectionless in-coupling. A reflectionless signal router, such as a wavelength demultiplexer, involves multiple simultaneous RSMs at distinct frequencies in combination with additional constraints on (un)desired transmission between ports. RSMs are a non-trivial generalization of the well-known critical-coupling condition from single-input-port single-resonance systems to multiple-input systems with potentially strongly overlapping resonances. Coherent perfect absorption (CPA) [2] is an instance of an RSM in which all channels serve as input channels. RSM and CPA are linear processes based on complex interference of input signals and hence obey the superposition principle, allowing simultaneous control of multiple frequencies without crosstalk.

Imposing an RSM with high-fidelity (i.e., the zero is extremely close to the real frequency axis) and at a desired frequency is a challenging task because the system is extremely sensitive, being operated at a scattering anomaly associated with a diverging dwell time. Minute inaccuracies in fabrication or environmental perturbations can move the zero away from the real frequency axis. Endowing RSMs with programmability is yet more challenging because upon tuning the system, in principle there is no guarantee that the zero does not drift away from the real frequency axis (except for special \mathcal{PT} -symmetric systems [1]). Recently, these challenges were mastered by purposefully perturbing an overmoded random scattering system with hundreds of degrees of freedom offered by a programmable metasurface, targeting applications in secure communication [3] and analog differentiation [4].

In this presentation, we tackle the yet more challenging problem of programmable reflectionless signal routing which involves additional constraints regarding transmission from the input channels to the remaining channels not included in the R-matrix. We will present preliminary experimental results on a 3-port device acting as programmable reflectionless wavelength demultiplexers: a desired pair of frequencies f_1 and f_2 is coupled without reflection into the system through Port 1, and f_1 (f_2) is preferentially transmitted to Port 2 (Port 3). We inject *in situ* signals into Port 1 and measure the outputs on all three ports. We also consider variations of this problem in which each frequency is incident on a different port, and in which each frequency is incident on multiple ports. Moreover, we demonstrate our ability to toggle with ease between different choices of f_1 and f_2 and/or signal routing functionality simply by modifying the metasurface configuration. Our results introduce a new perspective on signal routing which is an essential functionality across wave engineering disciplines, including nanophotonic and RF transmission lines.

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