Tunable True Time Delay Engine for UWB mm-Wave Beamforming

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We present a photonic true time delay device based on the control of group delay in 3-way coupled Silicon ridge waveguides. The wave slow-down is achieved as a consequence of a stationary inflection point (SIP) with vanishing group velocity in the dispersion diagram of the coupled 6-port structure (G. Mumcu, K. Sertel and J. L. Volakis, "Partially coupled microstrip lines for printed antenna miniaturization," *2009 IEEE International Workshop on Antenna Technology*, Santa Monica, CA, 2009). The conventional Silicon ridge waveguide topology is used with periodic circular holes etched into the ridge to induce bandgaps in the propagation. Subsequently, 3 such guides were brought together to allow for mode coupling, leading to unprecedented mode diversity. The structure is then tuned to exhibit a SIP within the propagation band. The number of periodic unit cells of the resulting 6-port device is chosen to enable effective excitation of the frozen mode using a single fiber coupled ridge waveguide port. Likewise, the output signal is designed to be strong at a single output port, where the delayed light is coupled out. In addition, a thin liquid crystal cladding layer incorporated into the ridge waveguide geometry enables some voltage tuning of the dispersion, this allowing for group delay control. The design of the multi-coupled photonic guide is presented for the industry standard 1550nm operation, and allows for dispersion-free delay of modulation bandwidths well in excess of 50GHz. As an example to demonstrate the potential benefits of this novel phenomenon, a 10 micrometer long device consisting of 30 unit cells is presented that provides 385-times slower group velocity as compared to free space. This true time delay device can be used for UWB beamforming at 60GHz by incorporating a tunable delay device with each antenna element. This topology provides $\pm 60^{o}$ beam scanning over extremely large bandwidths and the extremely-small footprint and continuous beam scanning afforded by voltage tuning of the delay makes it ideal for 5G and automotive radar applications.