Frequency Bins for Quantum Information Processing

Joseph M. Lukens

Oak Ridge National Laboratory

Photons offer a myriad of bases for encoding quantum information, including such popular choices as polarization, spatial modes, and time bins. And due to frequency's inherent stability and compatibility with optical fiber, spectral modes provide a particularly attractive Hilbert space for quantum computation. Yet control and processing of such modes can prove quite challenging, typically requiring complicated operations and strong classical pump fields. In this talk, I will describe our paradigm for universal quantum computation based on frequency-bin qubits and standard lightwave technology: electro-optic phase modulators and Fourier-transform pulse shapers. Our approach offers excellent resource scaling, parallelizability, and compatibility with fiber-optic technology. I will discuss experiments so far, including frequency-bin Hadamard and tritter gates, both with ultrahigh fidelity and broad bandwidth; quantum interference and independent spectral control of two photons in the same optical fiber; and a frequency-bin controlled-NOT, the first of its kind. Such experiments are augmented by Bayesian machine learning techniques, allowing for more detailed gate analysis than possible with conventional approaches. Finally, I will conclude with an outlook on future work, highlighting opportunities to address current challenges and summarizing the potential for our technique, not only in quantum computation proper, but also quantum interconnects, frequency-multiplexed networks, and on-chip integration.