Fast Nonadiabatic Gates for Quantum Signal Processing via Landau-Zener-Stückelberg-Majorana interferometry

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Fast and accurate implementation of elementary quantum operations is a central requirement for scalable quantum computation. Most gate protocols rely on resonant driving, where rotations are produced by weak or moderately strong periodic fields. An alternative route is offered by nonadiabatic Landau-Zener-Stückelberg-Majorana (LZSM) transitions, where strong driving through an avoided crossing generates controllable population transfer through interference. Such dynamics can be used to construct fast quantum gates in small-gap two-level systems [1,2].

This work establishes a connection between LZSM-based gates and quantum signal processing (QSP). QSP implements polynomial transformations through sequences of elementary single-qubit operations, typically written as alternating fixed rotations and adjustable phase shifts [3,4]. A similar sequence structure naturally appears in the adiabatic-impulse model (AIM): adiabatic evolution produces phase accumulation, while nonadiabatic transitions act as population-changing operations. This correspondence allows AIM dynamics to reproduce the elementary structure required for QSP [5].

We show that suitable driving parameters can realize QSP sequences using double LZSM transitions. Within this formulation, the interferometric phase and transition probability determine the effective gate parameters, allowing QSP operations to be implemented through fast nonadiabatic passages rather than conventional resonant pulses. This connection provides a new interpretation of LZSM interferometry as a resource for quantum information processing and suggests possible high-speed implementations of QSP in strongly driven small-gap systems.

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