New approach beyond Floquet to tunneling current under external periodic drive of arbitrary shape

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We present a novel approach to analyze the electron tunneling current through a time-dependent barrier under external periodic drive. We derive simple and exact analytic expressions for the current generated by periodic pulses of any shape, going beyond the conventional Floquet expansion. These results remain valid in both the adiabatic and non-adiabatic limits. Our findings explicitly reveal that, in the case of Markovian leads, the tunneling current through the barrier mirrors the oscillations of the barrier with no time delay, indicating zero tunneling time. However, a time delay emerges in the case of non-Markovian leads, although it is not directly associated with the concept of tunneling time. We also apply our method to analyze the time-dependent current in various quantum systems driven by ultra-short (femtosecond and attosecond) pulses. The obtained analytical results proved to be highly relevant to recent experimental developments investigating currents in laser-driven junctions.