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Low-Level Radio Frequency Control System for HUST-UED

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ABSTRACT
Ultrafast electron diffraction (UED) is a crucial technique for investigating ultrafast microscopic dynamical processes in matter. In MeV-UED facilities based on radio-frequency (RF) electron guns, space-charge effects can be effectively suppressed. However, amplitude fluctuations of the microwave field and deviations in beam–wave phase synchronization inside the electron gun introduce energy and time-of-flight jitter, thereby limiting the spatiotemporal resolution of the system. To ensure the stable generation and acceleration of femtosecond electron bunches, it is therefore essential to achieve real-time monitoring and high-precision control of the RF signal amplitude and phase. This paper presents the design and implementation of the Low-Level Radio Frequency (LLRF) system for the Huazhong University of Science and Technology Ultrafast Electron Diffraction (HUST-UED) facility. The system features high-speed real-time signal processing, precise measurement and calibration of power parameters, and closed-loop feedback control based on a proportional–integral (PI) algorithm. This configuration effectively suppresses the adverse effects of microwave field amplitude and phase fluctuations on the energy stability of the electron beam. Experimental results demonstrate that the proposed system improves the root-mean-square (RMS) amplitude stability of the RF power injected into the electron gun to 0.0895%, while the RMS phase stability reaches 0.1349°. These results highlight that the developed LLRF system significantly enhances the stability of the RF field, providing a key guarantee for achieving and maintaining high spatiotemporal resolution in UED applications.
Keywords: ultrafast electron diffraction, LLRF, RF stability, digital signal processing, closed-loop control

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