

Frontiers in Petahertz Electronics

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Despite tremendous advances in semiconductor technology, the clock rate of modern electronics has plateaued at a few gigahertz. Fundamental limitations associated with pulsed voltage operation hinder further scaling of electronic switching speeds. To break through this gigahertz barrier, alternative methods for controlling the flow of charge carriers are being sought.

Petahertz electronics, also known as lightwave electronics, introduces a new concept: Instead of pulsed voltages, it uses tailored optical waveforms to control charge carriers in an electronic circuit at petahertz frequencies. A sizeable body of research has demonstrated such petahertz-scale currents driven by optical fields within and around solid-state systems and nanoscale structures. The analog age of petahertz electronics is underway, with several proof-of-principle demonstrations of sub-optical-cycle current generation, carrier-envelope-phase-sensitive readout, and optical-field-resolved waveform detection (field sampling) at the sub- to few-femtosecond scale. Beyond metrology, these strong-field currents provide a powerful spectroscopy platform: the field-driven response encodes band-structure and coherence on the natural time scale of Bloch electron motion and enables access to geometric and topological properties such as Berry curvature. Recent work has taken the first steps toward digital and quantum operation by demonstrating optical-field-driven switching, coherent logic-gate functionality, and memory concepts. Here, we review the progress toward petahertz electronics, highlighting key theoretical concepts, experimental milestones, and questions remaining as we push toward realizing digital petahertz electronics for potential ultrafast optical waveform analysis, communications, and quantum computation.