Simulating relativistic motion in superconducting circuits: Dynamic Casimir effect and the twin paradox

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Relativistic motion is hard to achieve for massive objects. However, it is possible to simulate a relativistically moving mirror in a superconducting circuit. With microwave frequencies around 5GHz and at temperatures below 50mK, we can study relativistic physics on a microchip with a quantized electromagnetic field.

A Superconducting Quantum Interference Device (SQUID) can act as a parametric inductance and if it is placed at the end of a transmission line, a flux tuned SQUID can modulate the electrical length of that transmission line. This has precisely the same effect as a movable mirror. When the SQUID is being pumped with a rapidly oscillating flux, the electrical length changes very fast. The electromagnetic field inside the transmission line experiences a boundary condition which is moving at relativistic speeds. In experiments we obtained speeds up to 25\% of the speed of light. This relativistic motion parametrically generates microwave photons out of quantum vacuum fluctuations (Fig.1). We have used this to demonstrate the Dynamical Casimir Effect (DCE).\textsuperscript{1}

Placing one SQUID at each end of a 1D microwave transmission-line resonator (Fig. 2), we can dynamically control the boundary conditions for the electromagnetic field in the cavity. By ultrafast modulation of the individual magnetic field of each SQUID, it is possible to simulate arbitrary mirror trajectories at relativistic velocities. In particular, we propose\textsuperscript{2} to realize the trajectories of the twin paradox. Initializing the field inside the cavity in a coherent state, the phase of this state can be used as the pointer of a clock, which can be compared with a clock at rest. Preliminary estimates show that the difference in measured time due to time dilation should be measurable.