CLAIMS

1. A dual-rail qubit comprising:

a first quantum oscillator;

a second quantum oscillator;

a coupling element coupled to the first quantum oscillator and to the second quantum oscillator, wherein the coupling element is a superconducting nonlinear asymmetric inductive element (SNAIL) or a superconducting quantum interface device (SQUID);

an ancilla qubit coupled to the first quantum oscillator;

at least one energy source; and

at least one controller configured to operate the at least one energy source to initialize the dual-rail qubit in a 0 or 1 logical state by:

when the dual-rail qubit is to be initialized in the 0 logical state, operating the at least one energy source to arrange the first quantum oscillator in a single photon state and the second quantum oscillator in its ground state; or

when the dual-rail qubit is to be initialized in the 1 logical state, operating the at least one energy source to arrange the first quantum oscillator in its ground state and the second quantum oscillator in a single photon state.

2. The dual-rail qubit of claim 1, wherein arranging the first quantum oscillator or the second quantum oscillator in a single photon state comprises operating the at least one energy source to perform a plurality of optimal control pulses and/or cavity-ancilla sideband drives.

3. The dual-rail qubit of claim 1, wherein arranging the first quantum oscillator in the single photon state comprises operating the at least one energy source to arrange the first quantum oscillator in a $|1\rangle$ Fock state.

4. The dual-rail qubit of claim 1, wherein:

the coupling element is dispersively coupled to the first quantum oscillator and to the second quantum oscillator; and

the ancilla qubit is dispersively coupled to the first quantum oscillator.

5. The dual-rail qubit of claim 1, wherein the coupling element is a transmon qubit or a superconducting nonlinear asymmetric inductive element (SNAIL).

6. The dual-rail qubit of claim 1, wherein the ancilla qubit is not coupled to the second quantum oscillator.

7. The dual-rail qubit of claim 1, wherein the ancilla qubit is a transmon qubit.

8. The dual-rail qubit of claim 1, wherein the first quantum oscillator is a first microwave cavity, and wherein the second quantum oscillator is a second microwave cavity.

9. The dual-rail qubit of claim 1, wherein:

the at least one controller is further configured to operate the at least one energy source to perform a single-qubit rotation of a logical state of the dual-rail qubit by operating the at least one energy source to direct energy to the coupling element one or more times.

10. The dual-rail qubit of claim 9, wherein the at least one controller is further configured to drive the coupling element at a frequency equal to a difference between a resonant frequency of the first quantum oscillator and a resonant frequency of the second quantum oscillator.

11. The dual-rail qubit of claim 9, wherein the at least one controller is further configured to select an amplitude, duration and phase for said operation of the at least one energy source based on rotation angles of the single-qubit rotation.

12. The dual-rail qubit of claim 11, wherein the amplitude and duration are selected based on a polar angle of the single-qubit rotation, and wherein the phase is selected based on an angle of rotation about the Bloch sphere Z axis in the single-qubit rotation.

13. The dual-rail qubit of claim 9, wherein:

the coupling element is dispersively coupled to the first quantum oscillator and to the second quantum oscillator; and

the ancilla qubit is dispersively coupled to the first quantum oscillator.

14. The dual-rail qubit of claim 9, wherein the ancilla qubit is not coupled to the second quantum oscillator.

15. The dual-rail qubit of claim 9, wherein the ancilla qubit is a transmon qubit.

16. The dual-rail qubit of claim 9, wherein the first quantum oscillator is a first microwave cavity, and wherein the second quantum oscillator is a second microwave cavity.

17. The dual-rail qubit of claim 1, wherein:

the at least one controller is further configured to:

operate the at least one energy source to measure a parity state of the first quantum oscillator;

operate the at least one energy source to measure a parity state of the second quantum oscillator; and

determine a logical state of the dual-rail qubit based on the measured parity states of the first and second quantum oscillators.

18. The dual-rail qubit of claim 17, wherein, when the parity state of the first quantum oscillator is measured to be opposite to the parity state of the second quantum oscillator, the determined logical state of the dual-rail qubit is the 0 logical state or the 1 logical state.

19. The dual-rail qubit of claim 17, wherein the at least one controller is further configured to identify an erasure error when the parity states of the first and second quantum oscillators are both measured to be even.

20. The dual-rail qubit of claim 17, wherein the at least one controller is configured to operate the at least one energy source to measure the parity state of the first quantum oscillator a plurality of times, to operate the at least one energy source to measure the parity state of the second quantum oscillator a plurality of times, thereby producing a plurality of parity state measurements for each of the first and second quantum oscillators.

21. The dual-rail qubit of claim 17, wherein the at least one controller is configured to determine the logical state of the dual-rail qubit based on a majority result of a plurality of parity state measurements for the first quantum oscillator and based on a majority result of the plurality of parity state measurements for the second quantum oscillator.

22. The dual-rail qubit of claim 17, wherein operating the at least one energy source to measure the parity state of the first quantum oscillator comprises operating the at least one energy source to measure a state of the ancilla qubit and identifying the parity state of the first quantum oscillator based on the measured state of the ancilla qubit.

23. The dual-rail qubit of claim 17, wherein the at least one controller is further configured to direct energy to the coupling element to perform a beamsplitter operation on the first quantum oscillator and the second quantum oscillator subsequent to operating the at least one energy source to measure the parity state of the first quantum oscillator and prior to operating the at least one energy source to measure the parity state of the second quantum oscillator.

24. The dual-rail qubit of claim 17, wherein:

the coupling element is dispersively coupled to the first quantum oscillator and to the second quantum oscillator; and

the ancilla qubit is dispersively coupled to the first quantum oscillator.

25. The dual-rail qubit of claim 17, wherein the ancilla qubit is not coupled to the second quantum oscillator.

26. The dual-rail qubit of claim 17, wherein the ancilla qubit is a transmon qubit.

27. The dual-rail qubit of claim 17, wherein the first quantum oscillator is a first microwave cavity, and wherein the second quantum oscillator is a second microwave cavity.