CLAIMS

What is claimed is:

1. A system for implementing entangling gates that operate on two logical qubits, the system 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;

a readout resonator coupled to the ancilla qubit; and

at least one controller configured to:

perform an entangling gate between logical states of the first quantum oscillator and the second quantum oscillator by operating the at least one energy source to direct energy to the coupling element and/or to the ancilla qubit one or more times;

measure a state of the ancilla qubit measured subsequent to performing the entangling gate; and

determine whether the entangling gate produced an error based on the measured state of the ancilla qubit.

2. The system 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.

3. The system of any of claims 1-2, wherein operating the at least one energy source to direct energy to the coupling element and/or to the ancilla qubit one or more times comprises operating the at least one energy source to direct microwave tones to the coupling element and/or to the ancilla qubit one or more times.

4. The system of any of claims 1-3, wherein the ancilla qubit is not coupled to the second quantum oscillator.

5. The system of any of claims 1-4, wherein the at least one controller is configured to measure the state of the ancilla qubit subsequent to performing the entangling gate by operating the at least one energy source to direct energy to the readout resonator.

6. The system of any of claims 1-5, wherein the at least one controller is further configured to operate the at least one energy source to arrange the ancilla qubit in a ground state prior to performing the entangling gate.

7. The system of any of claims 1-6, wherein performing the entangling gate between logical states of the first quantum oscillator and the second quantum oscillator comprises operating the at least one energy source to:

direct energy to the ancilla qubit to perform a first rotation of the state of the ancilla qubit;

direct energy to the coupling element to perform a beamsplitter operation on the first quantum oscillator and the second quantum oscillator; and

direct energy to the ancilla qubit to perform a second rotation of the state of the ancilla qubit.

8. The system of claim 7, wherein the ancilla qubit exhibits a ground state $|g\rangle$, a first excited state $|e\rangle$ and a second excited state $|f\rangle$, and wherein the first and second rotations of the state of the ancilla qubit are rotations between the ground state $|g\rangle$ and the second excited state $|f\rangle$ of the ancilla qubit.

9. The system of any of claims 1-8, wherein performing the entangling gate between logical states of the first quantum oscillator and the second quantum oscillator further comprises operating the at least one energy source to direct energy to the coupling element for a length of time that is half the length of time that would be required to swap excitations of the first and second quantum oscillators.

10. The system of any of claims 1-9, wherein the ancilla qubit is a transmon qubit.

11. A system for implementing entangling gates that operate on two dual-rail qubits, the system comprising:

a first dual-rail qubit comprising:

a first quantum oscillator;

a second quantum oscillator;

a first coupling element coupled to the first quantum oscillator and to the second quantum oscillator; and

an ancilla qubit coupled to the second quantum oscillator;

a second dual-rail qubit comprising:

a third quantum oscillator;

a fourth quantum oscillator; and

a second coupling element coupled to the third quantum oscillator and to the fourth quantum oscillator;

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

at least one energy source; and

at least one controller configured to:

perform an entangling gate between a dual-rail state of the first dual-rail qubit and a dual-rail state of the second dual-rail qubit by operating the at least one energy source to direct energy to the third coupling element and/or to the ancilla qubit one or more times;

measure a state of the ancilla qubit measured subsequent to performing the entangling gate; and

determine whether the entangling gate produced an error based on the measured state of the ancilla qubit.

12. The system of claim 11, wherein the at least one controller is further configured to operate the at least one energy source to arrange the first dual-rail qubit in a 0 or 1 logical state by:

when the first 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 first 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.

13. The system of claim 12, wherein the at least one controller is further configured to operate the at least one energy source to arrange the second dual-rail qubit in a 0 or 1 logical state by:

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

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

14. The system of any of claims 11-13, wherein operating the at least one energy source to direct energy to the third coupling element and/or to the ancilla qubit one or more times comprises operating the at least one energy source to direct microwave tones to the third coupling element and/or to the ancilla qubit one or more times.

15. The system of any of claims 11-14, wherein the ancilla qubit is not coupled to the first quantum oscillator.

16. The system of any of claims 11-15, wherein the at least one controller is configured to measure the state of the ancilla qubit subsequent to performing the entangling gate by operating the at least one energy source to direct energy to a readout resonator coupled to the ancilla qubit.

17. The system of any of claims 11-16, wherein the ancilla qubit is a transmon qubit.