CLAIMS

1. A tunable qubit device comprising:
a tunable qubit, the tunable qubit comprising a superconducting quantum interference device (SQUID) loop;
a superconducting loop inductively coupled to the SQUID loop; and
a flux bias line inductively coupled to the superconducting loop,
wherein the superconducting loop comprises a superconducting material having a critical temperature that is a lower temperature than a critical temperature of any superconducting material of the tunable qubit, and
wherein, in operation, the superconducting loop tunes a frequency of the tunable qubit by providing a persistent bias to the tunable qubit.

2. The tunable qubit device according to claim 1, wherein the superconducting loop creates a magnetic field that tunes a frequency of the tunable qubit.

3. The tunable qubit device according to claim 2, wherein the superconducting loop continues to create the magnetic field when no magnetic field is created by the flux bias line.

4. The tunable qubit device according to claim 1, wherein the superconducting loop has a radius that is greater than a radius of the SQUID loop.

5. The tunable qubit device according to claim 1, wherein the superconducting loop comprises one of titanium, zirconium, or hafnium.

6. The tunable qubit device according to claim 1, wherein the tunable qubit comprises one of niobium, aluminum, and titanium nitride, and wherein the superconducting loop comprises one of titanium, zirconium, or hafnium.

7. A tunable qubit device comprising:
a tunable qubit, the tunable qubit comprising a superconducting quantum interference device (SQUID) loop;
a superconducting loop inductively coupled to the SQUID loop;
a flux bias line inductively coupled to the superconducting loop; and
a substrate,
wherein the superconducting loop comprises a superconducting material having a critical temperature that is a lower temperature than a critical temperature of any superconducting material of the tunable qubit,
wherein, in operation, the superconducting loop provides a persistent bias to the tunable qubit, and
wherein the SQUID loop is formed on a first surface of the substrate, and the superconducting loop is formed on a second surface of the substrate opposing the first surface.

8. A tunable qubit device comprising:
a tunable qubit, the tunable qubit comprising a superconducting quantum interference device (SQUID) loop;
a superconducting loop inductively coupled to the SQUID loop; and
a flux bias line inductively coupled to the superconducting loop,
wherein the superconducting loop comprises a superconducting material having a critical temperature that is a lower temperature than a critical temperature of any superconducting material of the tunable qubit,
wherein, in operation, the superconducting loop provides a persistent bias to the tunable qubit,
wherein the SQUID loop is formed to be substantially in a first plane,
wherein the superconducting loop is formed to be substantially in a second plane, the second plane being spaced apart from and substantially parallel to the first plane, and
wherein the SQUID loop and the superconducting loop are aligned so as to maximize inductive coupling between the SQUID loop and the superconducting loop.

9. A tunable qubit device comprising:
a tunable qubit, the tunable qubit comprising a superconducting quantum interference device (SQUID) loop;
a superconducting loop inductively coupled to the SQUID loop; and
a flux bias line inductively coupled to the superconducting loop,
wherein the superconducting loop comprises a superconducting material having a critical temperature that is a lower temperature than a critical temperature of any superconducting material of the tunable qubit,
wherein, in operation, the superconducting loop provides a persistent bias to the tunable qubit,
wherein the SQUID loop is formed to be substantially in a first plane,
wherein the superconducting loop is formed to be substantially in a second plane, the second plane being spaced apart from and substantially parallel to the first plane, and
wherein the SQUID loop and the superconducting loop are aligned so as to be concentric.

10. A method of producing a tunable qubit device, comprising:
forming, on a first surface of a substrate, a tunable qubit comprising a superconducting quantum interference device (SQUID) loop;
forming, on a second surface of the substrate, the second surface opposing the first surface, a superconducting loop comprising a superconducting material having a critical temperature that is a lower temperature than a critical temperature of each superconducting material of the tunable qubit; and
forming, on the second surface of the substrate, a flux bias line inductively coupled to the superconducting loop,
wherein the superconducting loop is inductively coupled to the SQUID loop, and
wherein, in operation, the superconducting loop provides a persistent bias to the tunable qubit.

11. The method of claim 10, wherein forming the superconducting loop comprises aligning the superconducting loop with the SQUID loop so as to maximize inductive coupling between the SQUID loop and the superconducting loop.

12. The method of claim 10, further comprising:
tuning the tunable qubit using a persistent bias current in the superconducting loop, wherein the persistent bias current persists when flux from the flux bias line is removed.

13. The method of claim 10, wherein tuning the tunable qubit using a persistent bias current in the superconducting loop comprises:
raising the temperature of the tunable qubit device from a temperature suitable for operation of the tunable qubit to a temperature above the critical temperature of the superconducting loop but below the critical temperature of each superconducting material of the tunable qubit;
applying a magnetic field to the superconducting loop using the flux bias line;
reducing the temperature of the tunable qubit device to a temperature below the critical temperature of the superconducting loop, thereby trapping a flux in the superconducting loop; and
removing the magnetic field applied by the flux bias line while maintaining the persistent bias current in the superconducting loop,
wherein the magnetic field created by the persistent bias current in the superconducting loop penetrates the SQUID loop, tuning a frequency of the tunable qubit.

14. The method of claim 13, further comprising:
further tuning the frequency of the tunable qubit by:
raising the temperature of the tunable qubit device to a temperature above the critical temperature of the superconducting loop but below the critical temperature of each superconducting material of the tunable qubit;
applying a magnetic field to the superconducting loop that is weaker or stronger than a previously applied magnetic field using the flux bias line;
reducing the temperature of the tunable qubit device to a temperature below the critical temperature of the superconducting loop; and
removing the magnetic field applied by the flux bias line.

15. A method of tuning a tunable qubit device comprising a superconducting quantum interference device (SQUID) loop and a bias superconducting loop, comprising:

raising the temperature of the tunable qubit device from a temperature suitable for operation of the tunable qubit to a temperature above a critical temperature of the bias superconducting loop but below a critical temperature of each superconducting material of the SQUID loop;
applying a magnetic field to the bias superconducting loop using a flux bias line;
reducing the temperature of the tunable qubit device to a temperature below the critical temperature of the bias superconducting loop, thereby trapping a flux in the bias superconducting loop;
removing the magnetic field applied by the flux bias line while maintaining the persistent bias current in the bias superconducting loop; and
wherein the magnetic field created by the persistent bias current in the superconducting loop penetrates the SQUID loop, tuning a frequency of the tunable qubit.

16. A method of tuning a tunable qubit device comprising a superconducting quantum interference device (SQUID) loop and a bias superconducting loop, comprising:
raising the temperature of the tunable qubit device from a temperature suitable for operation of the tunable qubit to a temperature above a critical temperature of the bias superconducting loop but below a critical temperature of each superconducting material of the SQUID loop;
applying a magnetic field to the bias superconducting loop using a flux bias line;
reducing the temperature of the tunable qubit device to a temperature below the critical temperature of the bias superconducting loop, thereby trapping a flux in the bias superconducting loop;
removing the magnetic field applied by the flux bias line while maintaining the persistent bias current in the bias superconducting loop; and
further tuning the frequency of the tunable qubit by:
raising the temperature of the tunable qubit device to a temperature above the critical temperature of the superconducting loop but below the critical temperature of each superconducting material of the tunable qubit;
applying a magnetic field to the superconducting loop that is weaker or stronger than a previously applied magnetic field using the flux bias line;
reducing the temperature of the tunable qubit device to a temperature below the critical temperature of the superconducting loop; and
removing the magnetic field applied by the flux bias line,
wherein the magnetic field created by the persistent bias current in the superconducting loop penetrates the SQUID loop, tuning a frequency of the tunable qubit.

17. A quantum computer, comprising:
a refrigeration system under vacuum comprising a containment vessel;

a qubit chip contained within a refrigerated vacuum environment defined by the containment vessel, wherein the qubit chip comprises a plurality of tunable qubit devices; and

a plurality of electromagnetic waveguides arranged within the refrigerated vacuum environment so as to direct electromagnetic energy to and receive electromagnetic energy from at least a selected one of the plurality of tunable qubit devices;

wherein each of the plurality of tunable qubit devices comprises:

a tunable qubit, the tunable qubit comprising a SQUID loop;

a superconducting loop inductively coupled to the SQUID loop; and

a flux bias line inductively coupled to the superconducting loop,

wherein the superconducting loop comprises a superconducting material having a critical temperature that is a lower temperature than a critical temperature of any superconducting material of the tunable qubit, and

wherein, in operation, the superconducting loop provides a persistent bias to the tunable qubit.

18. The quantum computer according to claim 17, wherein the superconducting loop of each tunable qubit device creates a magnetic field that tunes a frequency of the tunable qubit of the tunable qubit device.

19. The quantum computer according to claim 18, wherein the superconducting loop of each tunable qubit device continues to create the magnetic field when no magnetic field is created by the flux bias line of the tunable qubit device.

20. The quantum computer according to claim 17, wherein the superconducting loop comprises one of titanium, zirconium, or hafnium.