Claims:

1. A multi-frequency laser system comprising:

a master oscillator configured to generate a master beam;

an arm splitter configured to split the master beam into a first beam and a second beam, the first beam provided to a primary mode arm for generation of a primary mode beam and the second beam provided to a sideband mode arm for generation of a sideband mode beam; and

the sideband beam arm comprising:

a modulator configured to modulate the second beam to generate a beam comprising sidebands;

a filter configured to select a particular sideband mode from the beam comprising sidebands to generate a selected sideband beam;

an amplifier cavity configured to amplify the particular sideband mode and suppress other residual modes present in the selected sideband beam; and

an acousto-optical modulator configured to shift the frequency of each mode of an amplified selected sideband beam to generate a sideband mode beam,

wherein the primary mode beam and sideband mode beam are provided in a coordinated manner to one or more atomic objects to enact a quantum gate, wherein the primary mode beam and the sideband mode beam have a non-zero relative frequency difference and the relative energy difference between the primary mode beam and the sideband mode beam is determined based on an energy difference between two states of a qubit space defined for a quantum computer comprising the multi-frequency laser system.

2. The multi-frequency laser system of claim 1, wherein the filter is an etalon.

3. The multi-frequency laser system of claim 2, wherein the etalon is maintained at a constant temperature by a temperature controlled oven.

4. The multi-frequency laser system of claim 1, wherein the primary mode arm and the sideband mode arm each comprise a set of nonlinear optical elements.

5. The multi-frequency laser system of claim 4, wherein the set of nonlinear optical elements comprises a second harmonics generation cavity.

6. The multi-frequency laser system of claim 4, wherein, when the primary mode beam and the sideband mode beam are provided as non-copropagating beams, the primary mode beam and the sideband mode beam are phase-locked to a local oscillator via actuation of a double-pass acousto-optical modulator.

7. The multi-frequency laser system of claim 6, wherein the double-pass acousto-optical modulator is located in an optical path of the primary mode arm and an optical path of the sideband mode arm upstream of the set of nonlinear optical elements.

8. The multi-frequency laser system of claim 4, wherein a relative difference between the frequency of the primary mode beam and the sideband mode beam is measured downstream of the set of nonlinear optical elements.

9. The multi-frequency laser system of claim 8, further comprising an acousto-optical modulator located upstream of the set of nonlinear optical elements of the primary mode arm and the set of nonlinear optical elements of the sideband mode arm configured to phase lock the primary mode beam and the sideband mode beam based on a measurement of the relative difference.

10. The multi-frequency laser system of claim 1, wherein, when the primary mode beam and the sideband mode beam are copropagating beams, a relative phase difference between the primary mode beam and the sideband mode beam is stabilized using a radio frequency oscillator.

11. The multi-frequency laser system of claim 1, further comprising a servo system configured to stabilize a relative phase difference and/or a relative frequency difference between the primary mode beam and the sideband mode beam.

12. The multi-frequency laser system of claim 11, wherein the servo system receives as input at least one local oscillator signal and a direct digital synthesizer (DDS) signal.

13. The multi-frequency laser system of claim 12, wherein the DDS signal is provided as part of an input arm of the servo system and provided to an output arm of the servo system.

14. The multi-frequency laser system of claim 13, wherein the DDS signal is provided to the output arm of the servo system via a delay line.

15. The multi-frequency laser system of claim 13, wherein the application of the DDS signal to the output arm of the servo system enables discontinuous phase changes in at least one of the primary mode beam and the sideband mode beam.

16. A servo system coupled to the multi-frequency laser system of claim 1, the servo system configured to stabilize a relative phase difference and/or a relative frequency difference between a primary mode beam and a sideband mode beam generated by the multi-frequency laser system, the servo system comprising:

an input arm configured to provide an input signal to a servo, the input arm configured to receive a local oscillator signal and a direct digital synthesizer (DDS) signal as input; and

an output arm configured to receive an output signal from the servo and a DDS signal.

17. The servo system of claim 16, wherein the DDS signal is provided to the output arm of the servo system via a delay line configured to compensate for a time delay for changes in the DDS signal to propagate through the servo system.

18. The servo system of claim 16, wherein the application of the DDS signal to the output arm of the servo system enables discontinuous phase changes in at least one of the primary mode beam and the sideband mode beam.

19. The servo system of claim 16, wherein the input arm further receives a beat frequency signal corresponding to a relative frequency difference between the primary mode beam and the sideband mode beam.