

REMOVING LEAKAGE IN A QUANTUM BIT

BACKGROUND

[0001] Removing the parasitic occupation of a quantum bit is a task in quantum computing, as well as other applications.

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SUMMARY

[0002] This specification describes technologies relating to quantum hardware and methods for removing the parasitic occupation of higher levels, e.g., leakage, in a quantum bit (qubit) using a damped cavity mode, without requiring
10 prior knowledge of the state of the quantum bit. By moving the quantum bit in frequency close to the damped cavity frequency, parasitic occupation of higher levels will transfer to the cavity. The parasitic occupation may be damped in the cavity using the damped cavity mode.

[0002a] There is provided an apparatus, comprising:

15 one or more qubits, wherein each qubit facilitates occupation of at least one of a plurality of qubit levels, the qubit levels including a reset qubit level and one or more non-reset qubit levels that are each higher than the reset qubit level, and wherein the qubit facilitates transitions between qubit levels associated with a corresponding transition frequency;

20 a cavity, wherein the cavity defines a cavity frequency;

one or more couplers coupling each qubit to the cavity; and

one or more couplers coupling the cavity to an environment external to the one or more qubits and the cavity;

a frequency controller that controls the frequency of qubits such that, for each
25 qubit that the frequency controller controls, the qubit is reset by adjusting the frequency of the qubit relative to the cavity frequency such that a population of a non-reset level is transferred to the cavity.

[0002b] According to an aspect of the present invention, there is provided a method for
30 removing the occupation of higher qubit levels in one or more qubits of a quantum system, the method being performed by an apparatus comprising:

a quantum system comprising:

- one or more qubits, wherein each qubit has states corresponding to a plurality of qubit levels, the qubit levels including a reset qubit level and one or more non-reset qubit levels that are each higher than the reset qubit level, and wherein the qubit
- 5 transitions between qubit levels with corresponding transition frequencies;
- a cavity, wherein the cavity defines a cavity frequency;
- one or more couplers configured to couple each qubit to the cavity; and
- one or more couplers configured to couple the cavity to an environment external to the one or more qubits and the cavity such that the cavity is damped;
- 10 a frequency controller that controls the frequency of qubits such that, for each qubit that the frequency controller controls, the frequency of the qubit is adjusted relative to the cavity frequency such that a population of a non-reset level is transferred to the cavity; and
- the method comprising:
- controlling the frequency of each qubit using the frequency controller such that, for
- 15 each qubit, the frequency of the qubit is adjusted relative to the cavity frequency such that a population of a non-reset qubit level and at least one further qubit level is transferred to the cavity, wherein the adjusting comprises:
- for each of the non-reset qubit level and the at least one further qubit level, tuning the transition frequency corresponding to the qubit level to be aligned with
- 20 or swept past the cavity frequency.

[0002c] There is provided a method, comprising:

- in response to performing a computation in a quantum system that comprises:
- one or more qubits, wherein each qubit facilitates occupation of at least one
- of a plurality of qubit levels, the qubit levels including a reset qubit level and one or more
- 25 non-reset qubit levels that are each higher than the reset qubit levels, and wherein the qubit facilitates transitions between qubit levels associated with a corresponding transition frequency;
- a cavity, wherein the cavity defines a cavity frequency; and
- a frequency controller that controls the frequency of qubits such that, for
- 30 each qubit that the frequency controller controls, the qubit is reset by adjusting the frequency of the qubit relative to the cavity frequency such that a population of a non-reset level is transferred to the cavity;

controlling the frequency of each qubit that the frequency controller controls without prior knowledge of the population of the qubit levels such that, for each qubit that the frequency controller controls, the qubit is reset by adjusting the frequency of the qubit relative to the cavity frequency such that a population of the non-reset level is
5 transferred to the cavity.

[0002d] There is provided an apparatus, comprising:

one or more qubits, wherein each qubit facilitates occupation of at least one of a plurality of qubit levels, the qubit levels including two computational qubit levels and one or more non-computational qubit levels that are each higher than the computational
10 qubit levels, and wherein the qubit facilitates transitions between qubit levels associated with a corresponding transition frequency;

a cavity, wherein the cavity defines a cavity frequency;

one or more couplers coupling each qubit to the cavity; and

one or more couplers coupling the cavity to an environment external to the one
15 or more qubits and the cavity;

a frequency controller that controls the frequency of qubits, wherein for each qubit that the frequency controller controls, the frequency controller is configured to continuously sweep the qubit frequency past the cavity frequency such that a population of a non-computational level is transferred to the cavity.

20 [0002e] There is provided a method, comprising:

accessing a quantum system that comprises:

one or more qubits, wherein each qubit facilitates occupation of at least one of a plurality of qubit levels, the qubit levels including two computational qubit levels and one or more non-computational qubit levels that are each higher than the
25 computational qubit levels, and wherein the qubit facilitates transitions between qubit levels associated with a corresponding transition frequency;

a cavity, wherein the cavity defines a cavity frequency;

one or more couplers coupling each qubit to the cavity; and

one or more couplers coupling the cavity to an environment external to
30 the one or more qubits and the cavity;

a frequency controller that controls the frequency of qubits, wherein for each qubit that the frequency controller controls, the frequency controller is configured to continuously sweep the qubit frequency past the cavity frequency such that a population of a non-computational level is transferred to the cavity; and

5 controlling the frequency of each qubit such that, for each qubit, the frequency of the qubit is swept past the cavity frequency such that a population of a non-computational level is transferred to the cavity.

[0002f] There is provided an apparatus, comprising:

10 one or more qubits, wherein each qubit facilitates occupation of at least one of a plurality of qubit levels, the qubit levels including two computational qubit levels and one or more non-computational qubit levels that are each higher than the computational qubit levels, and wherein the qubit facilitates transitions between qubit levels associated with a corresponding transition frequency;

15 a cavity, wherein the cavity defines a cavity frequency;
 one or more couplers coupling each qubit to the cavity; and
 one or more couplers coupling the cavity to an environment external to the one or more qubits and the cavity;

 a frequency controller that controls the frequency of qubits, wherein for
20 each qubit that the frequency controller controls, the frequency controller is configured to iteratively perform downward qubit level transitions until a population of a non-computational level is transferred to the cavity.

[0002g] There is provided a method, comprising:

25 accessing a quantum system that comprises:
 one or more qubits, wherein each qubit facilitates occupation of at least one of a plurality of qubit levels, the qubit levels including two computational qubit levels and one or more non-computational qubit levels that are each higher than the computational qubit levels, and wherein the qubit facilitates transitions between qubit
30 levels associated with a corresponding transition frequency;

a cavity, wherein the cavity defines a cavity frequency;
one or more couplers coupling each qubit to the cavity; and
one or more couplers coupling the cavity to an environment external to
the one or more qubits and the cavity;

5 a frequency controller that controls the frequency of qubits, wherein for
each qubit that the frequency controller controls, the frequency controller is configured
to iteratively perform downward qubit level transitions until a population of a non-
computational level is transferred to the cavity; and

controlling the frequency of each qubit such that, for each qubit, downward
10 qubit level transitions are iteratively performed such that a population of a non-
computational level is transferred to the cavity.

[0003] There are disclosed methods that include the actions of accessing a
quantum system that comprises one or more qubits, wherein each qubit facilitates
15 occupation of at least one of a plurality of qubit levels, the qubit levels including
two computational qubit levels and one or more non-computational qubit levels that
are each higher than the computational qubit levels, and wherein the qubit
facilitates transitions between qubit levels associated with a corresponding
transition frequency; a cavity, wherein the cavity defines a cavity frequency; one or
20 more couplers coupling each qubit to the cavity; and one or more couplers coupling
the cavity to an environment external to the one or more qubits and the cavity; a
frequency controller that controls the frequency of qubits such that, for each qubit
that the frequency controller controls, the frequency of the qubit is adjusted relative
to the cavity frequency such that a population of a non-computational level may be
25 transferred to the cavity; and controlling the frequency of each qubit such that, for
each qubit, the frequency of the qubit may be adjusted relative to the cavity
frequency such that a population of a non-computational level may be transferred to
the cavity.

What is claimed is:

1. A method for removing the occupation of higher qubit levels in one or more
5 qubits of a quantum system, the method being performed by an apparatus comprising:
a quantum system comprising:
one or more qubits, wherein each qubit has states corresponding to a
plurality of qubit levels, the qubit levels including a reset qubit level and one or
more non-reset qubit levels that are each higher than the reset qubit level, and
10 wherein the qubit transitions between qubit levels with corresponding transition
frequencies;
a cavity, wherein the cavity defines a cavity frequency;
one or more couplers configured to couple each qubit to the cavity; and
one or more couplers configured to couple the cavity to an environment
15 external to the one or more qubits and the cavity such that the cavity is damped;
a frequency controller that controls the frequency of qubits such that, for each
qubit that the frequency controller controls, the frequency of the qubit is adjusted
relative to the cavity frequency such that a population of a non-reset level is transferred
to the cavity; and
20 the method comprising:
controlling the frequency of each qubit using the frequency controller such that,
for each qubit, the frequency of the qubit is adjusted relative to the cavity frequency
such that a population of a non-reset qubit level and at least one further qubit level is
transferred to the cavity, wherein the adjusting comprises:
25 for each of the non-reset qubit level and the at least one further qubit
level, tuning the transition frequency corresponding to the qubit level to be
aligned with or swept past the cavity frequency.
2. The method of claim 1, wherein the method comprises, for each qubit:
30 iteratively performing downward qubit level transitions until the reset qubit
level is reached, wherein performing a downward qubit level transition comprises:
aligning the relevant qubit transition frequency to the cavity frequency;
and

waiting for a predetermined amount of time.

3. The method of claim 2, wherein iteratively performing downward qubit level transitions until the reset qubit level is reached for each qubit is performed in parallel
5 for similar qubits.
4. The method of claim 2 or 3, wherein the predetermined amount of time is optimized to enable effective leakage removal.
- 10 5. The method of claim 1, wherein the method comprises, for each qubit: sweeping the qubit frequency past the cavity frequency.
6. The method of claim 5, wherein sweeping the qubit frequency past the cavity frequency performs downward qubit level transitions for qubits that are at or below a
15 relevant qubit level and optionally wherein the downward qubit level transitions are sequentially performed until the reset qubit level is reached.
7. The method of claim 6, wherein sweeping the qubit frequency past the cavity frequency is performed in parallel for similar qubits.
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8. The method of claim 6 or 7, wherein sweeping the qubit comprises:
determining a qubit frequency trajectory relative to the cavity frequency;
moving the qubit frequency according to the qubit frequency trajectory.
- 25 9. The method of claim 8, wherein moving the qubit frequency according to the qubit frequency trajectory causes qubit transition frequencies to sequentially become aligned with the cavity frequency for population transfer to the cavity, and wherein the downward qubit level transitions are sequentially performed until the reset qubit level is reached.
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10. The method of any one of the preceding claims, wherein the quantum system is provided for use in a quantum computation, preferably wherein the method is repeatedly performed after one or more computation operations in the quantum

computation, wherein the final step of the computation operation is a measurement operation.

11. The method of any one of the preceding claims, wherein the method is
5 repeatedly performed immediately before a measurement operation associated with one or more computation operations in the quantum computation.

12. The apparatus according to claim 1 configured to perform the method of any one of the preceding claims.

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13. The apparatus of claim 12, wherein the quantum system further comprises the environment, the environment is formed by a wire, preferably a readout line, which connects to a load, wherein the cavity is optionally a readout resonator.

15 14. The apparatus of claim 12 or 13, wherein the coupler coupling the cavity to the environment is strong and/or where the one or more qubits exhibit weak non-linearity.

15. A non-transitory storage medium comprising instructions for execution by the apparatus of any one of claims 12 to 14 to implement the method of any one of claims 1
20 to 11.