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(54) **QUANTUM CIRCUIT FOR IMPLEMENTING A MULTI-CONTROLLED NOT GATE**

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H03K 19/20 (2006.01)

(52) **U.S. Cl.**
CPC ***H03K 19/195*** (2013.01); ***G06N 10/20*** (2022.01); ***H03K 19/20*** (2013.01)

(57) **ABSTRACT**

Disclosed is a quantum circuit for implementing multi-controlled NOT gates with N control qubits. A quantum circuit for implementing multi-controlled NOT gates with N control qubits according to one embodiment of the present disclosure may include a first auxiliary circuit that corresponds to one or more initial layers of a plurality of layers and performs a controlled NOT operation on a target qubit based on an Nth control qubit from among the N control qubits and a first auxiliary qubit initialized to a |+> state, a quantum gate group that corresponds to the plurality of layers and performs controlled NOT operation on the first auxiliary qubit based on first to (N−1)th control qubits, and a second auxiliary circuit that corresponds one or more last layers of the plurality of layers and performs controlled NOT operation on the target qubit based on the Nth control qubit and the first auxiliary qubit.

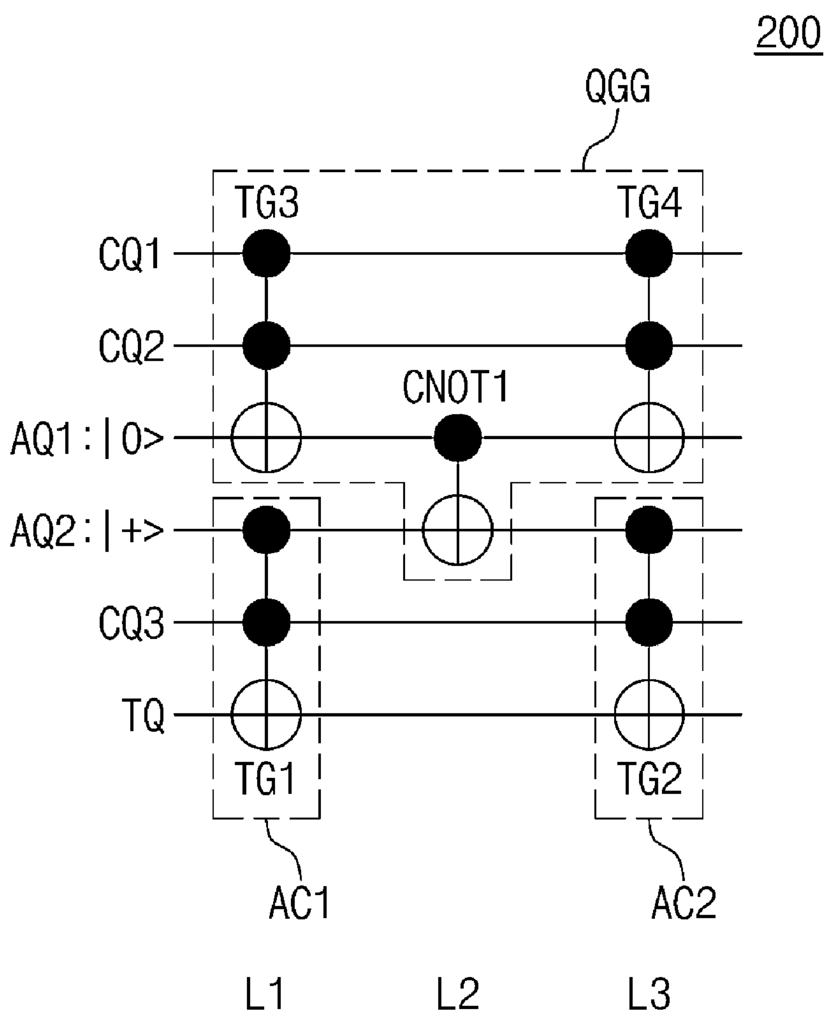


FIG. 1

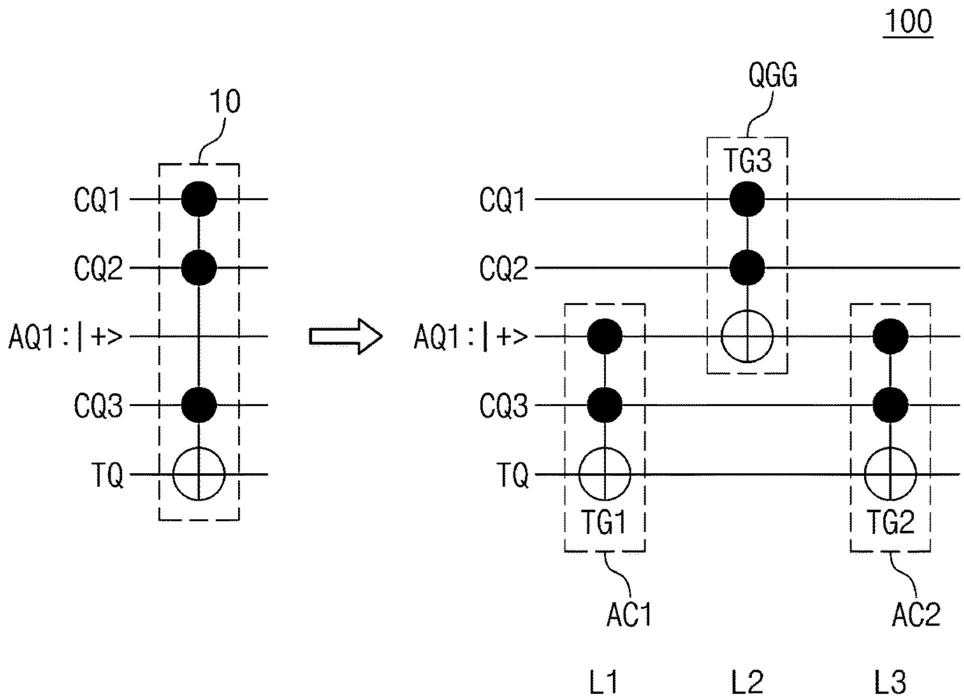

100
10
QGG
TG3
CQ1
CQ2
AQ1:|+>
CQ3
TQ
TG1
TG2
AC1
AC2
L1
L2
L3

FIG. 2

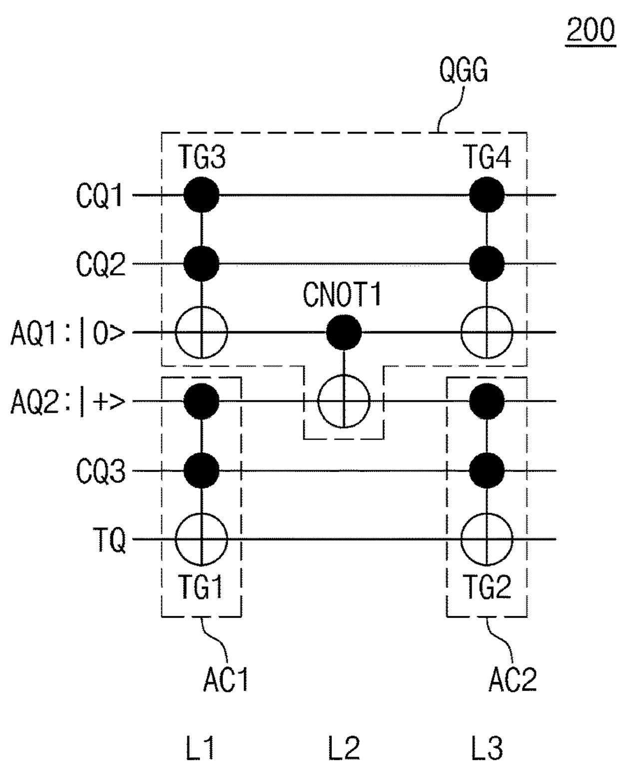

200
QGG
TG3
TG4
CQ1
CQ2
CNOT1
AQ1:|0>
AQ2:|+>
CQ3
TQ
TG1
TG2
AC1
AC2
L1
L2
L3

FIG. 3

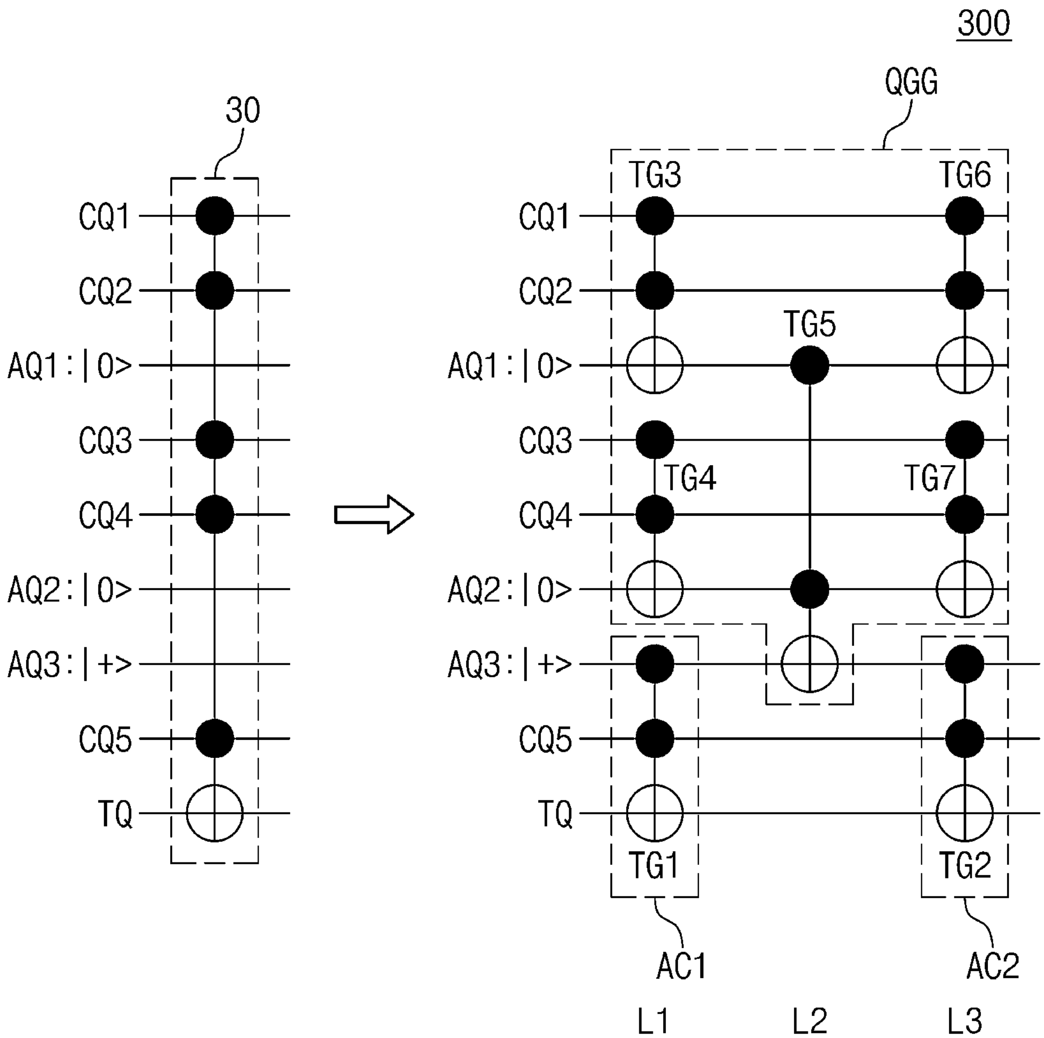

300
30
CQ1
CQ2
AQ1 : |0>
CQ3
CQ4
AQ2 : |0>
AQ3 : |+>
CQ5
TQ
QGG
TG3
TG6
TG5
TG4
TG7
TG1
TG2
AC1
AC2
L1
L2
L3

FIG. 4

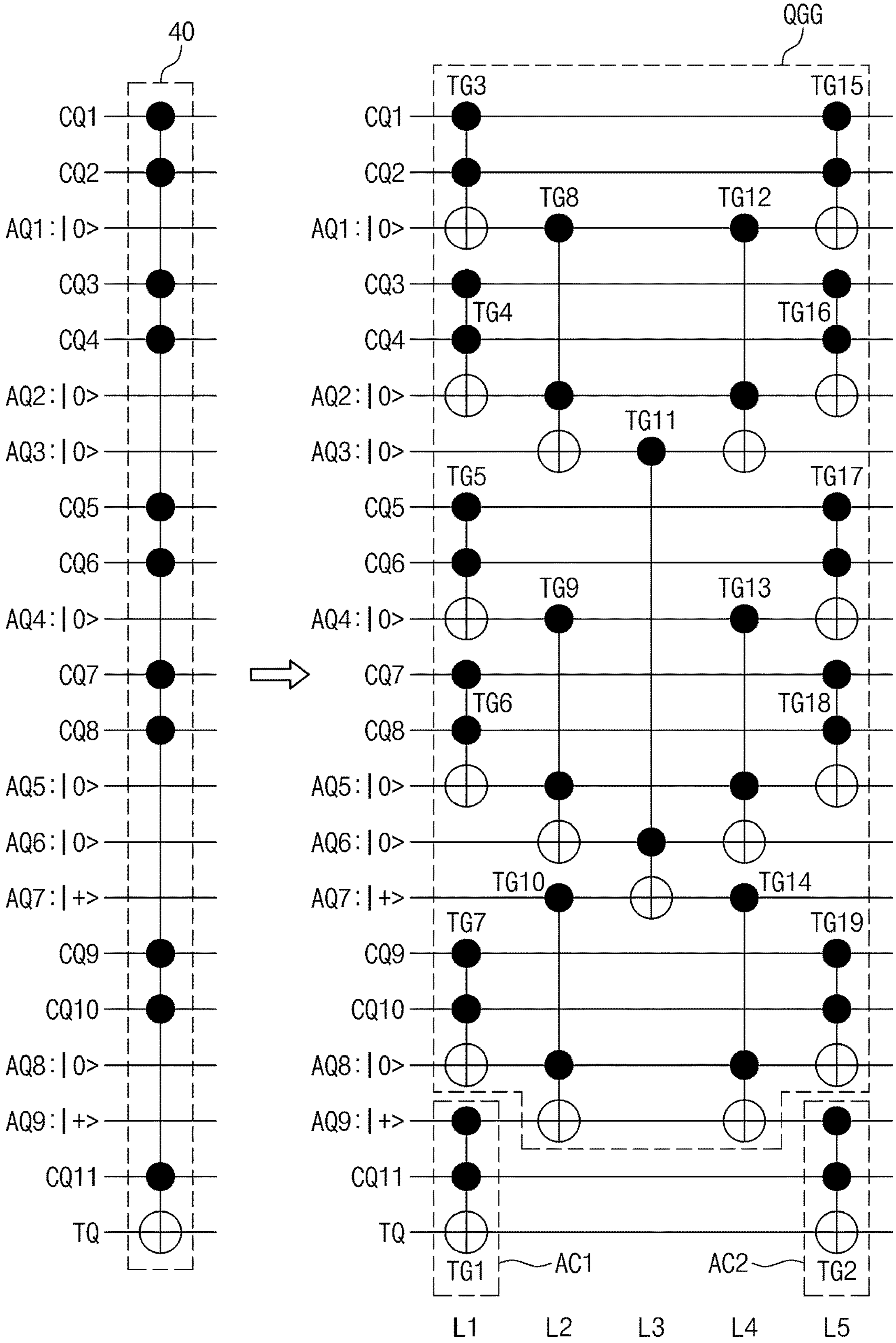

40
CQ1
CQ2
AQ1 : |0>
CQ3
CQ4
AQ2 : |0>
AQ3 : |0>
CQ5
CQ6
AQ4 : |0>
CQ7
CQ8
AQ5 : |0>
AQ6 : |0>
AQ7 : |+>
CQ9
CQ10
AQ8 : |0>
AQ9 : |+>
CQ11
TQ
QGG
TG3
TG15
TG8
TG12
TG4
TG16
TG11
TG5
TG17
TG9
TG13
TG6
TG18
TG10
TG14
TG7
TG19
TG1
AC1
AC2
TG2
L1
L2
L3
L4
L5

FIG. 5

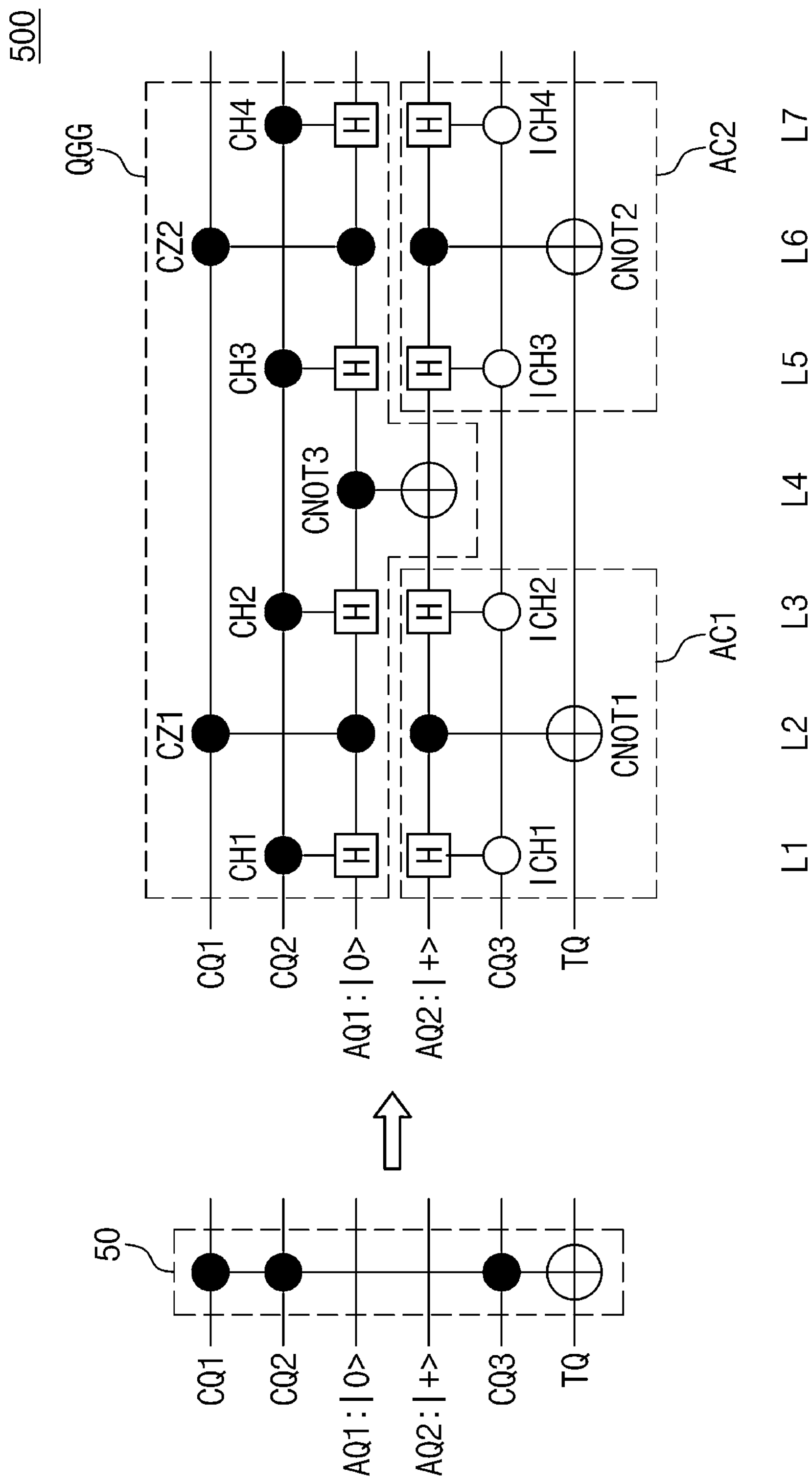

500
QGG
CZ1
CZ2
CH1
CH2
CH3
CH4
CNOT3
ICH1
ICH2
ICH3
ICH4
CNOT1
CNOT2
AC1
AC2
L1
L2
L3
L4
L5
L6
L7
CQ1
CQ2
AQ1 : |0>
AQ2 : |+>
CQ3
TQ
50
CQ1
CQ2
AQ1 : |0>
AQ2 : |+>
CQ3
TQ

FIG. 6

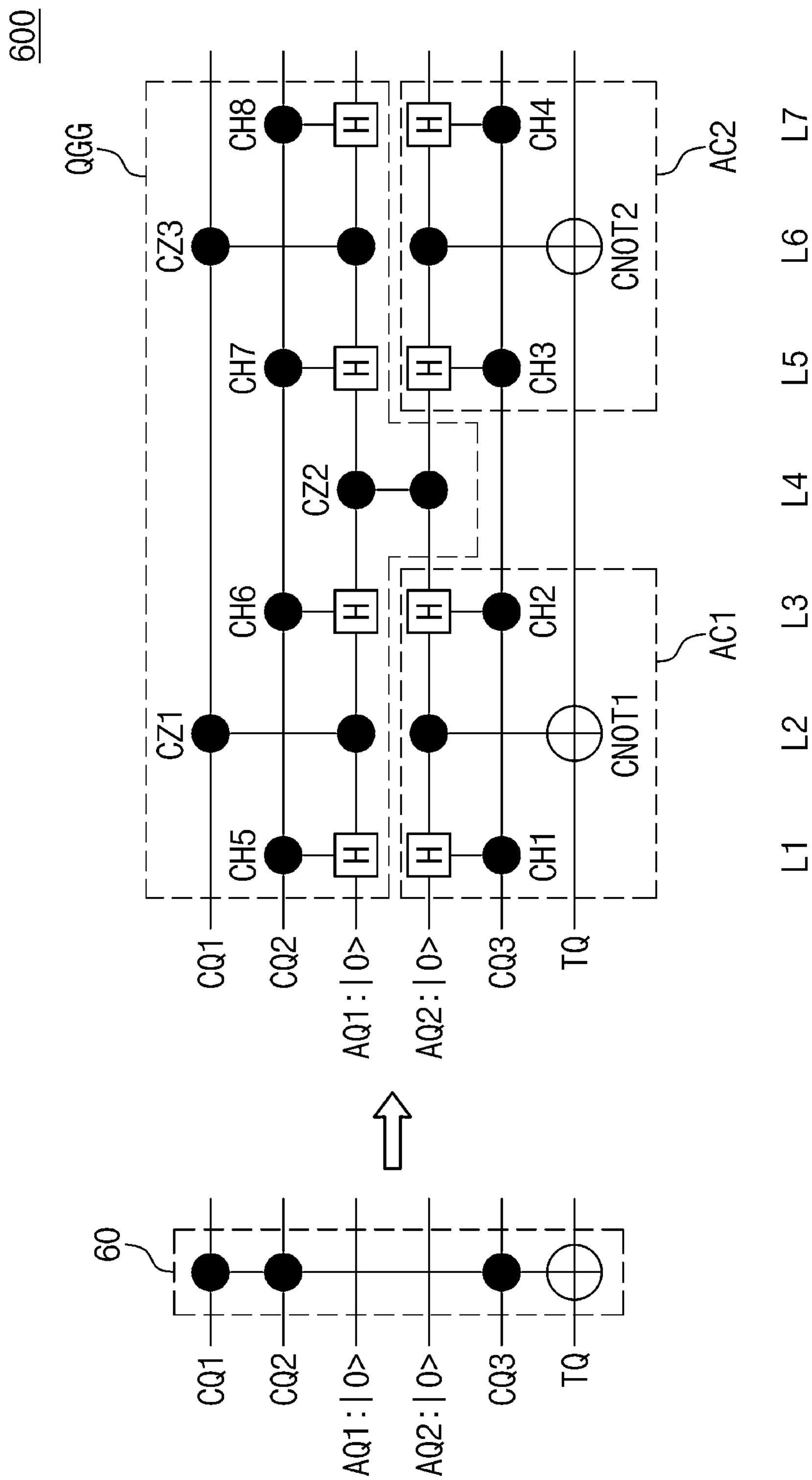

600
QGG
CZ3
CH8
CH7
CZ2
CH6
CZ1
CH5
AC2
CH4
CNOT2
CH3
AC1
CH2
CNOT1
CH1
L7
L6
L5
L4
L3
L2
L1
CQ1
CQ2
AQ1 : |0>
AQ2 : |0>
CQ3
TQ
60
CQ1
CQ2
AQ1 : |0>
AQ2 : |0>
CQ3
TQ
H

FIG. 7

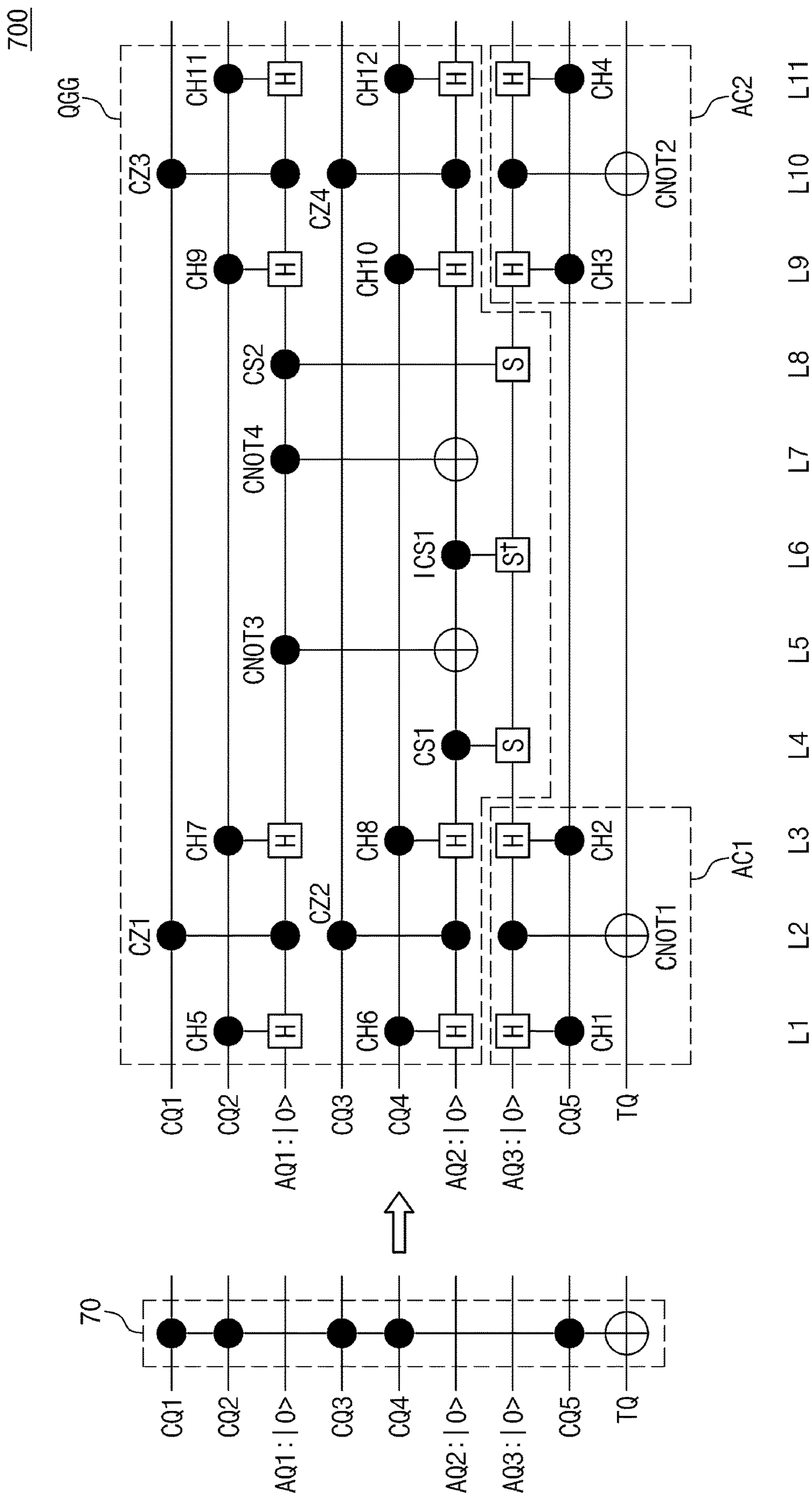

700
QGG
AC1
AC2
70
CQ1
CQ2
AQ1 : |0>
CQ3
CQ4
AQ2 : |0>
AQ3 : |0>
CQ5
TQ
CH1
CH2
CH3
CH4
CH5
CH6
CH7
CH8
CH9
CH10
CH11
CH12
CZ1
CZ2
CZ3
CZ4
CNOT1
CNOT2
CNOT3
CNOT4
CS1
CS2
ICS1
H
S
S†
L1
L2
L3
L4
L5
L6
L7
L8
L9
L10
L11

FIG. 8

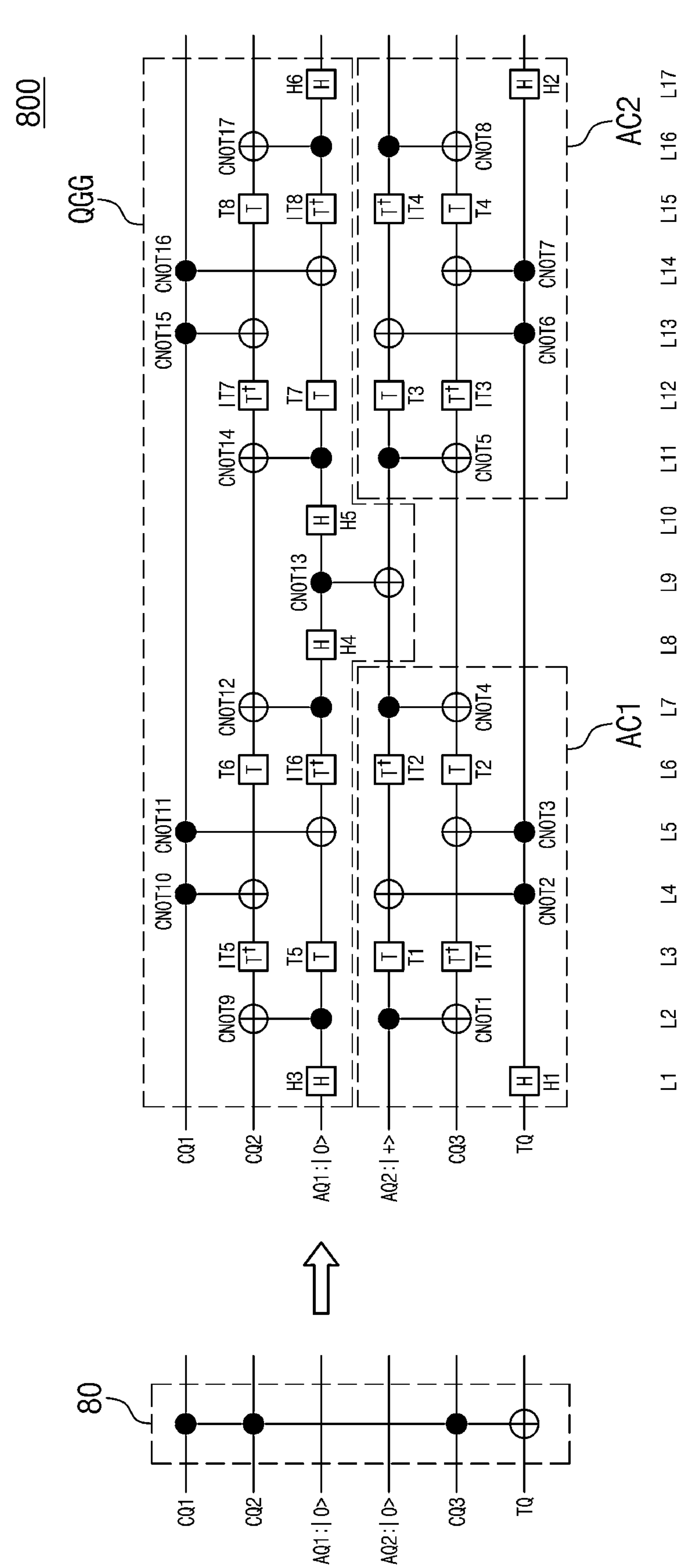

800
QGG
AC1
AC2
80
CQ1
CQ2
AQ1 : | 0>
AQ2 : | +>
AQ2 : | 0>
CQ3
TQ
H1
H2
H3
H4
H5
H6
T1
T2
T3
T4
T5
T6
T7
T8
IT1
IT2
IT3
IT4
IT5
IT6
IT7
IT8
CNOT1
CNOT2
CNOT3
CNOT4
CNOT5
CNOT6
CNOT7
CNOT8
CNOT9
CNOT10
CNOT11
CNOT12
CNOT13
CNOT14
CNOT15
CNOT16
CNOT17
L1
L2
L3
L4
L5
L6
L7
L8
L9
L10
L11
L12
L13
L14
L15
L16
L17

FIG. 9

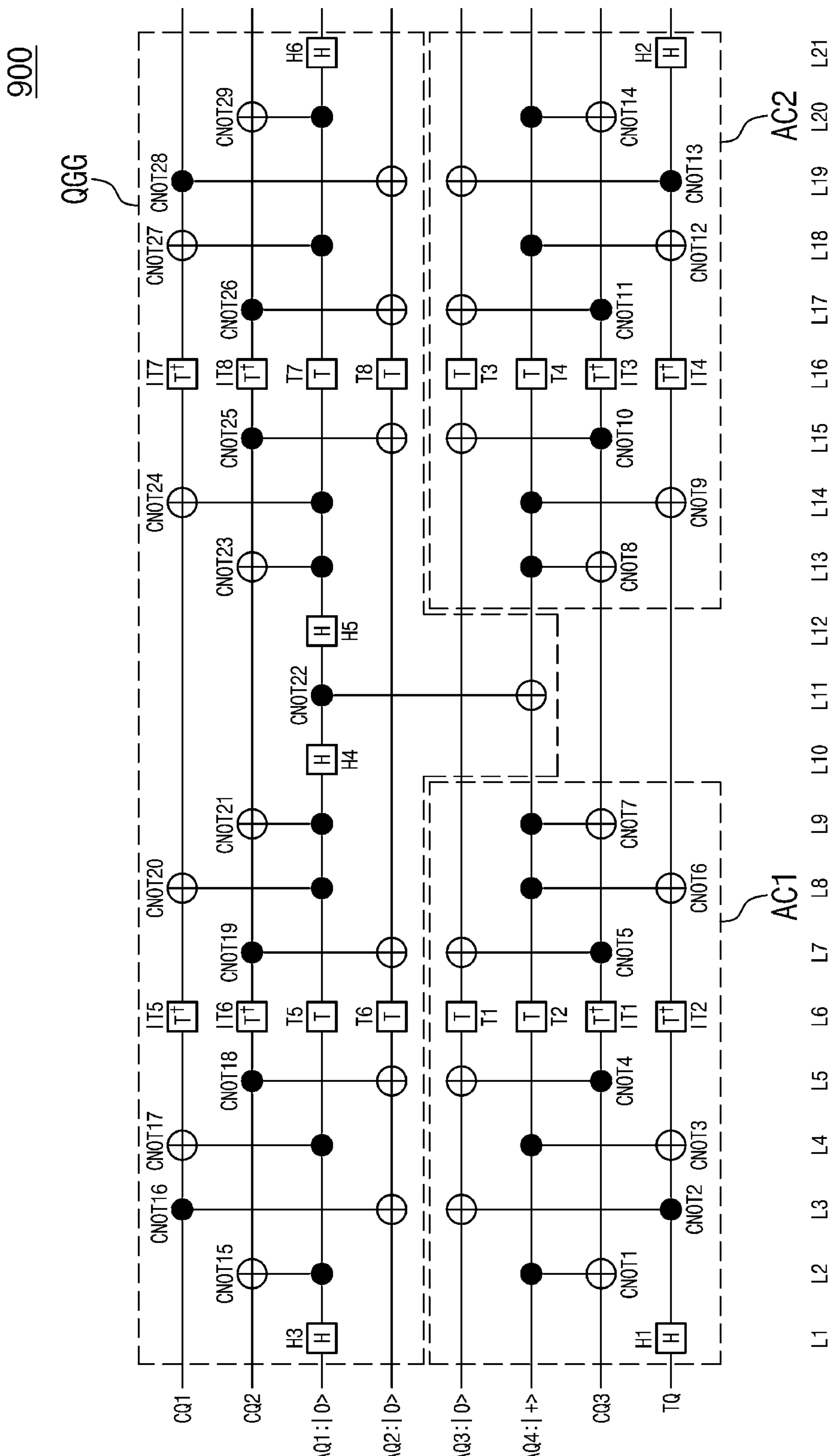

900
QGG
AC1
AC2
CQ1
CQ2
AQ1:|0>
AQ2:|0>
AQ3:|0>
AQ4:|+>
CQ3
TQ
H1
H2
H3
H4
H5
H6
T1
T2
T5
T6
T3
T4
T7
T8
IT1
IT2
IT3
IT4
IT5
IT6
IT7
IT8
CNOT1
CNOT2
CNOT3
CNOT4
CNOT5
CNOT6
CNOT7
CNOT8
CNOT9
CNOT10
CNOT11
CNOT12
CNOT13
CNOT14
CNOT15
CNOT16
CNOT17
CNOT18
CNOT19
CNOT20
CNOT21
CNOT22
CNOT23
CNOT24
CNOT25
CNOT26
CNOT27
CNOT28
CNOT29
L1
L2
L3
L4
L5
L6
L7
L8
L9
L10
L11
L12
L13
L14
L15
L16
L17
L18
L19
L20
L21

FIG. 10

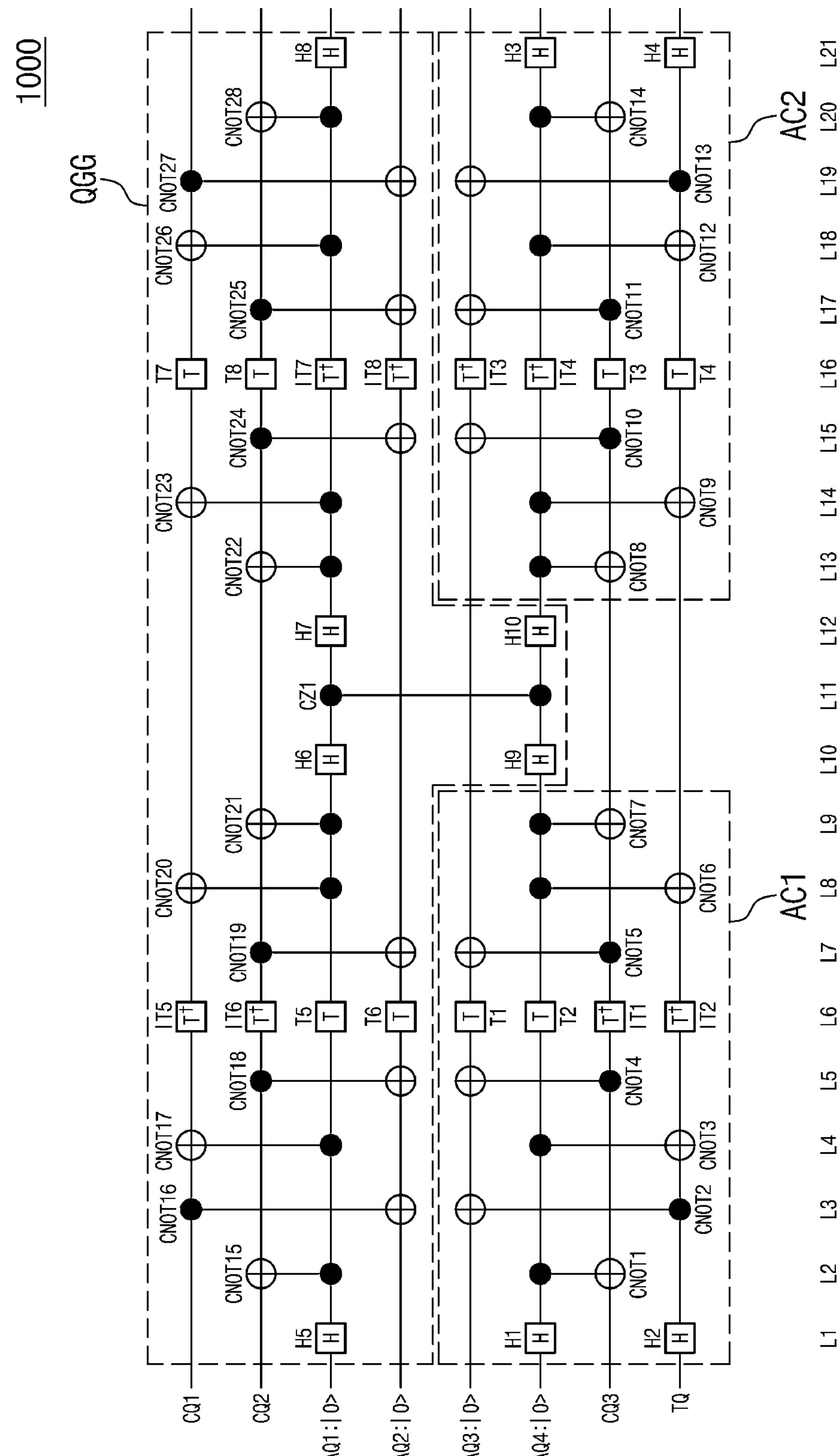

1000
QGG
AC1
AC2
CQ1
CQ2
AQ1:|0>
AQ2:|0>
AQ3:|0>
AQ4:|0>
CQ3
TQ
L1
L2
L3
L4
L5
L6
L7
L8
L9
L10
L11
L12
L13
L14
L15
L16
L17
L18
L19
L20
L21
H1
H2
H3
H4
H5
H6
H7
H8
H9
H10
CZ1
T1
T2
T3
T4
T5
T6
T7
T8
IT1
IT2
IT3
IT4
IT5
IT6
IT7
IT8
CNOT1
CNOT2
CNOT3
CNOT4
CNOT5
CNOT6
CNOT7
CNOT8
CNOT9
CNOT10
CNOT11
CNOT12
CNOT13
CNOT14
CNOT15
CNOT16
CNOT17
CNOT18
CNOT19
CNOT20
CNOT21
CNOT22
CNOT23
CNOT24
CNOT25
CNOT26
CNOT27
CNOT28

FIG. 11

1100

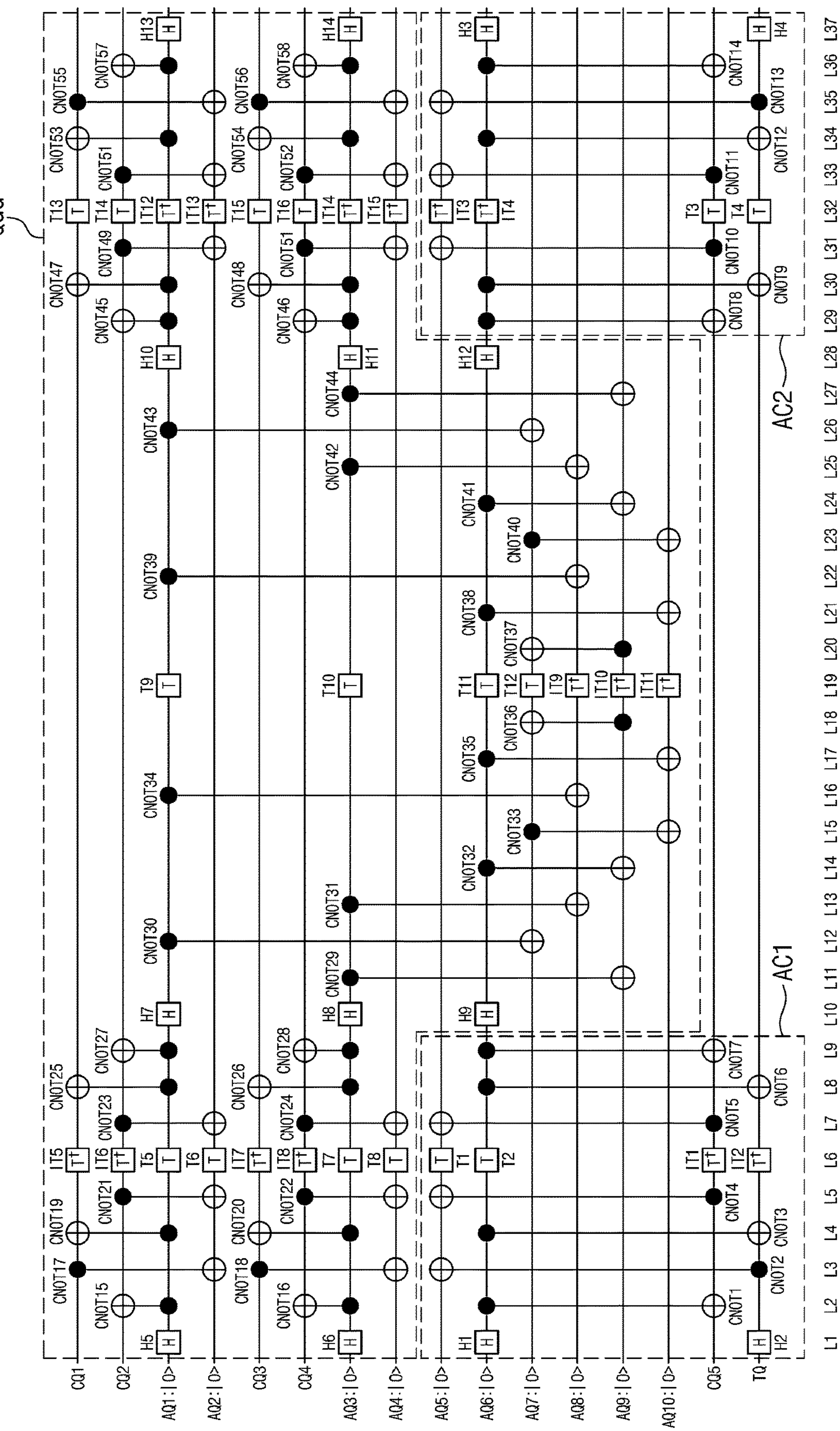

QGG
AC1
AC2
CQ1
CQ2
AQ1:|0>
AQ2:|0>
CQ3
CQ4
AQ3:|0>
AQ4:|0>
AQ5:|0>
AQ6:|0>
AQ7:|0>
AQ8:|0>
AQ9:|0>
AQ10:|0>
CQ5
TQ
L1 L2 L3 L4 L5 L6 L7 L8 L9 L10 L11 L12 L13 L14 L15 L16 L17 L18 L19 L20 L21 L22 L23 L24 L25 L26 L27 L28 L29 L30 L31 L32 L33 L34 L35 L36 L37

FIG. 12

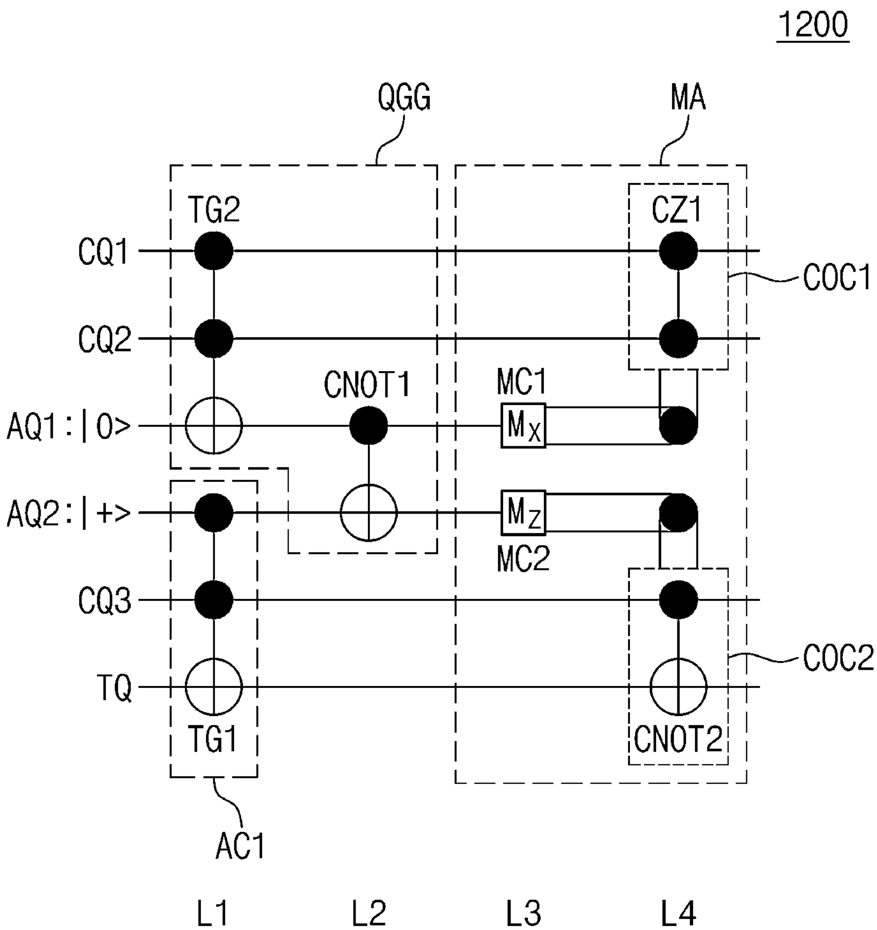

1200
QGG
MA
TG2
CZ1
CQ1
COC1
CQ2
CNOT1
MC1
AQ1:|0>
M_X
AQ2:|+>
M_Z
MC2
CQ3
COC2
TQ
TG1
CNOT2
AC1
L1
L2
L3
L4

FIG. 13

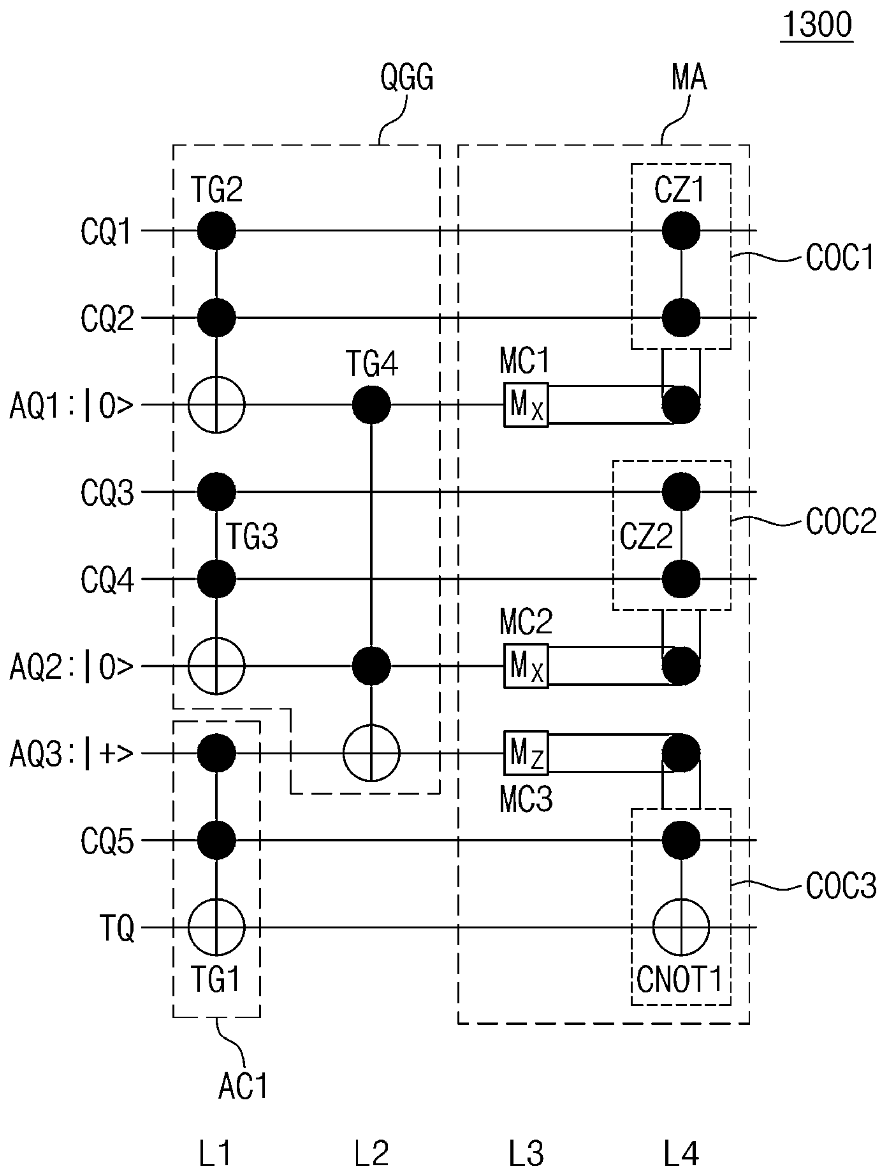
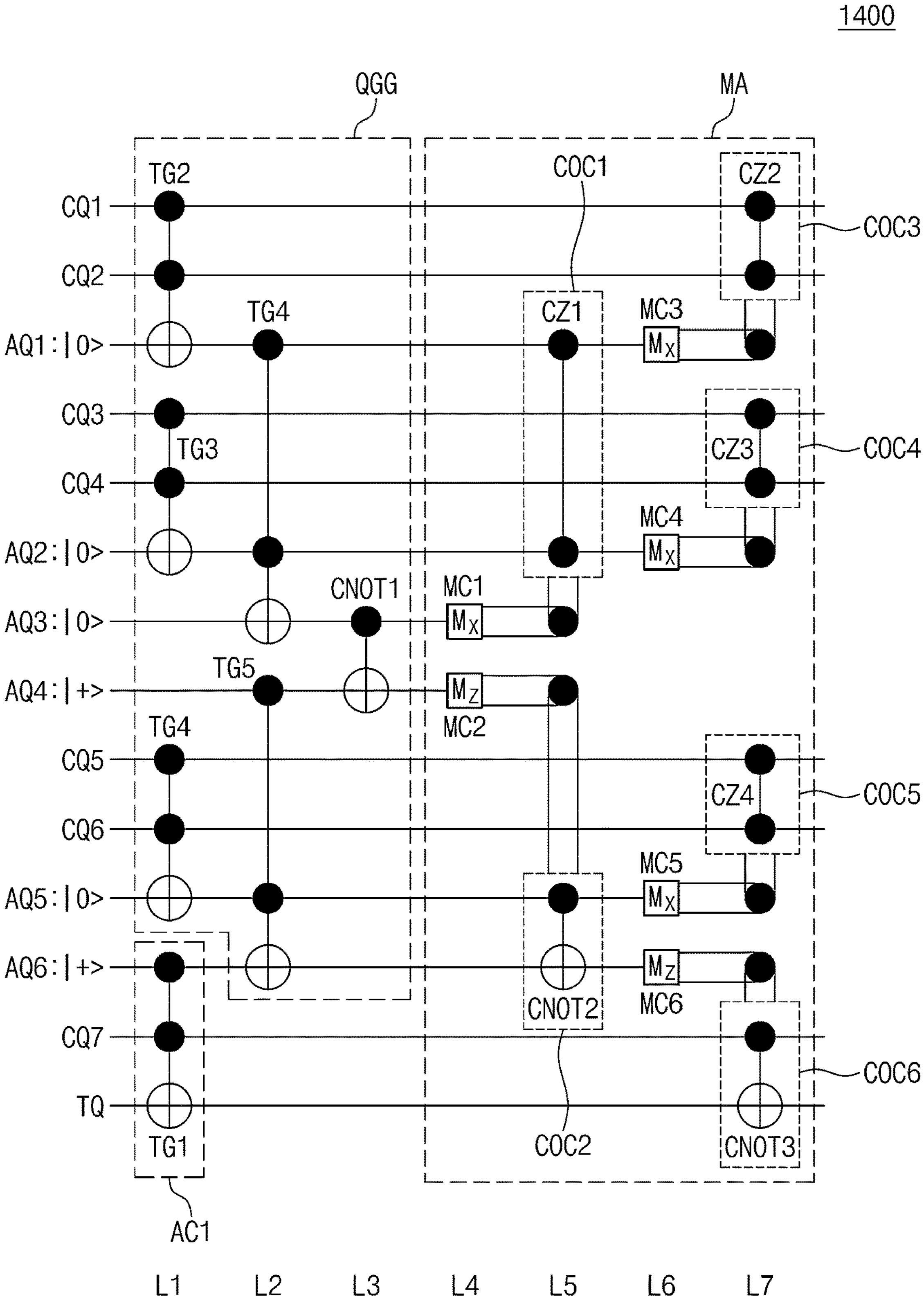

1300
QGG
MA
TG2
CZ1
CQ1
COC1
CQ2
TG4
MC1
AQ1 : |0>
M_X
CQ3
TG3
COC2
CZ2
CQ4
MC2
AQ2 : |0>
M_X
AQ3 : |+>
M_Z
MC3
CQ5
COC3
TQ
TG1
CNOT1
AC1
L1
L2
L3
L4

FIG. 14



1400
QGG
MA
TG2
COC1
CZ2
COC3
CQ1
CQ2
TG4
CZ1
MC3
AQ1:|0>
M_X
CQ3
COC4
TG3
CZ3
CQ4
MC4
AQ2:|0>
M_X
MC1
CNOT1
AQ3:|0>
M_X
TG5
AQ4:|+>
M_Z
MC2
TG4
CQ5
CZ4
COC5
CQ6
MC5
AQ5:|0>
M_X
AQ6:|+>
M_Z
CNOT2
MC6
CQ7
COC6
TQ
TG1
COC2
CNOT3
AC1
L1
L2
L3
L4
L5
L6
L7

FIG. 15

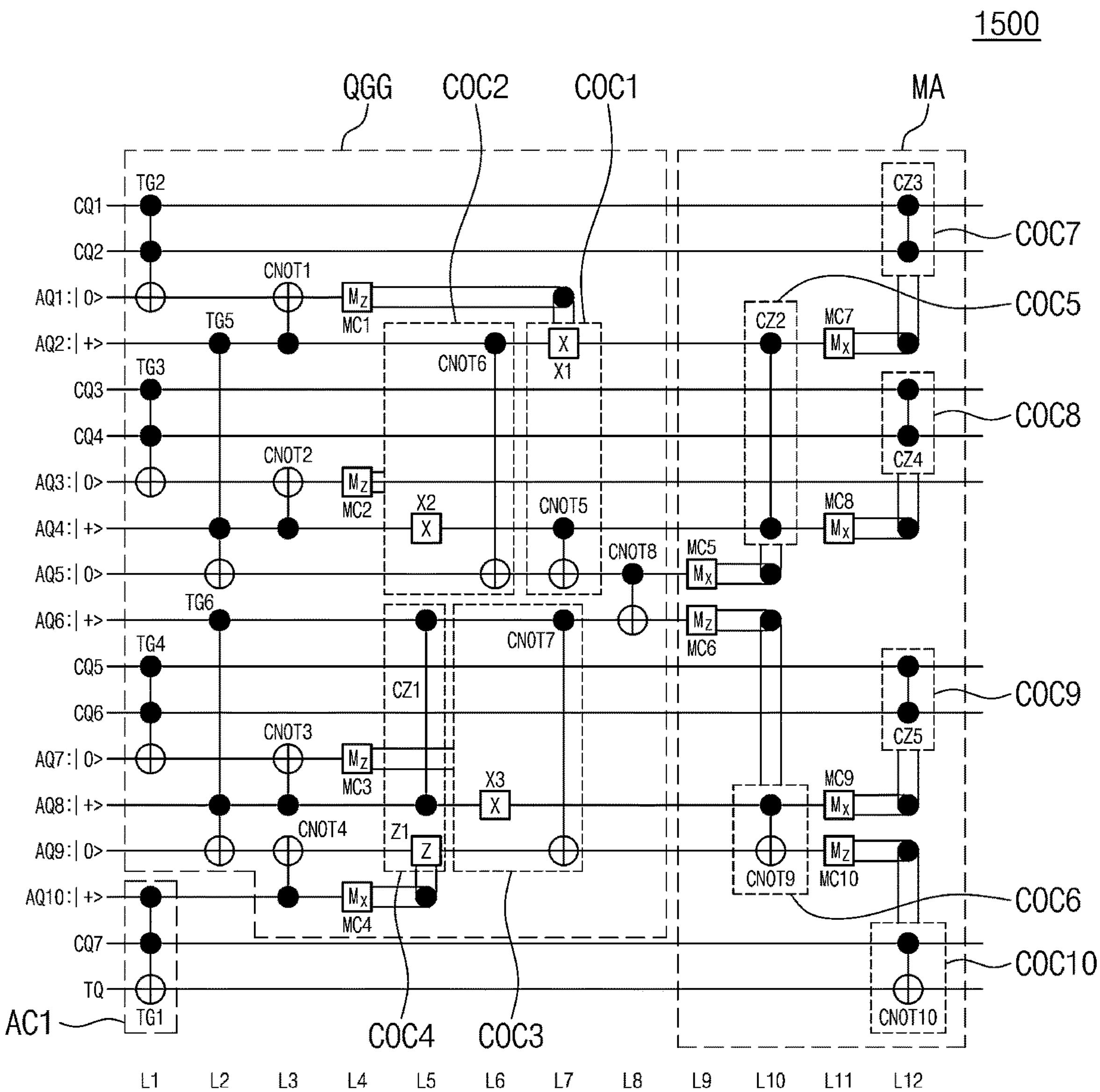

1500
QGG
COC2
COC1
MA
CQ1
CQ2
AQ1:|0>
AQ2:|+>
CQ3
CQ4
AQ3:|0>
AQ4:|+>
AQ5:|0>
AQ6:|+>
CQ5
CQ6
AQ7:|0>
AQ8:|+>
AQ9:|0>
AQ10:|+>
CQ7
TQ
TG1
TG2
TG3
TG4
TG5
TG6
CNOT1
CNOT2
CNOT3
CNOT4
CNOT5
CNOT6
CNOT7
CNOT8
CNOT9
CNOT10
MC1
MC2
MC3
MC4
MC5
MC6
MC7
MC8
MC9
MC10
X1
X2
X3
Z1
CZ1
CZ2
CZ3
CZ4
CZ5
COC3
COC4
COC5
COC6
COC7
COC8
COC9
COC10
AC1
L1 L2 L3 L4 L5 L6 L7 L8 L9 L10 L11 L12

FIG. 16

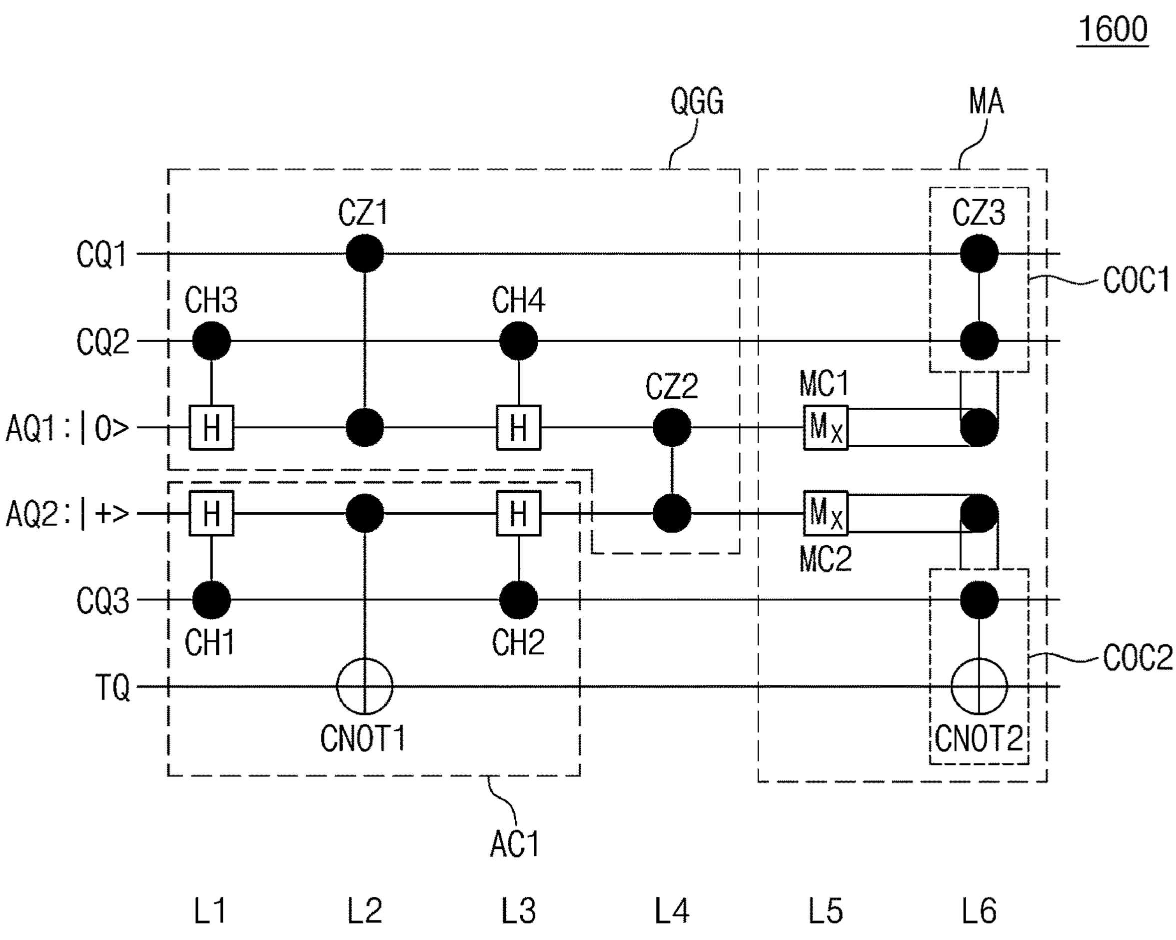

1600
QGG
MA
CZ1
CZ3
CQ1
COC1
CH3
CH4
CQ2
CZ2
MC1
AQ1:|0>
H
H
M_X
AQ2:|+>
H
H
M_X
MC2
CQ3
CH1
CH2
COC2
TQ
CNOT1
CNOT2
AC1
L1
L2
L3
L4
L5
L6

FIG. 17

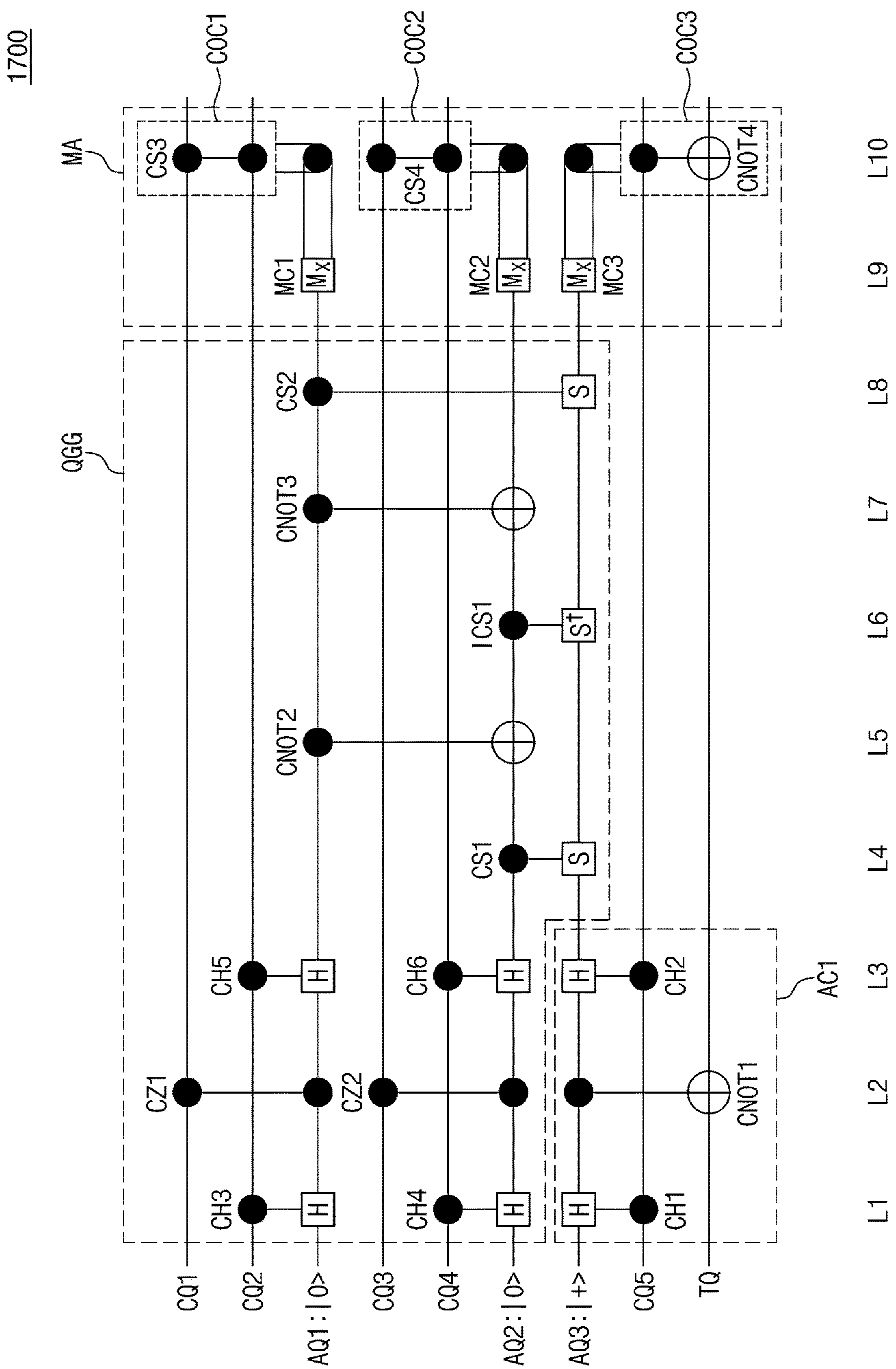

1700
MA
QGG
COC1
COC2
COC3
CS3
CS4
CNOT4
MC1
MC2
MC3
CS2
CNOT3
ICS1
CNOT2
CS1
CH5
CH6
CH2
AC1
CZ1
CZ2
CNOT1
CH3
CH4
CH1
CQ1
CQ2
AQ1 : |0>
CQ3
CQ4
AQ2 : |0>
AQ3 : |+>
CQ5
TQ
L1
L2
L3
L4
L5
L6
L7
L8
L9
L10

FIG. 18

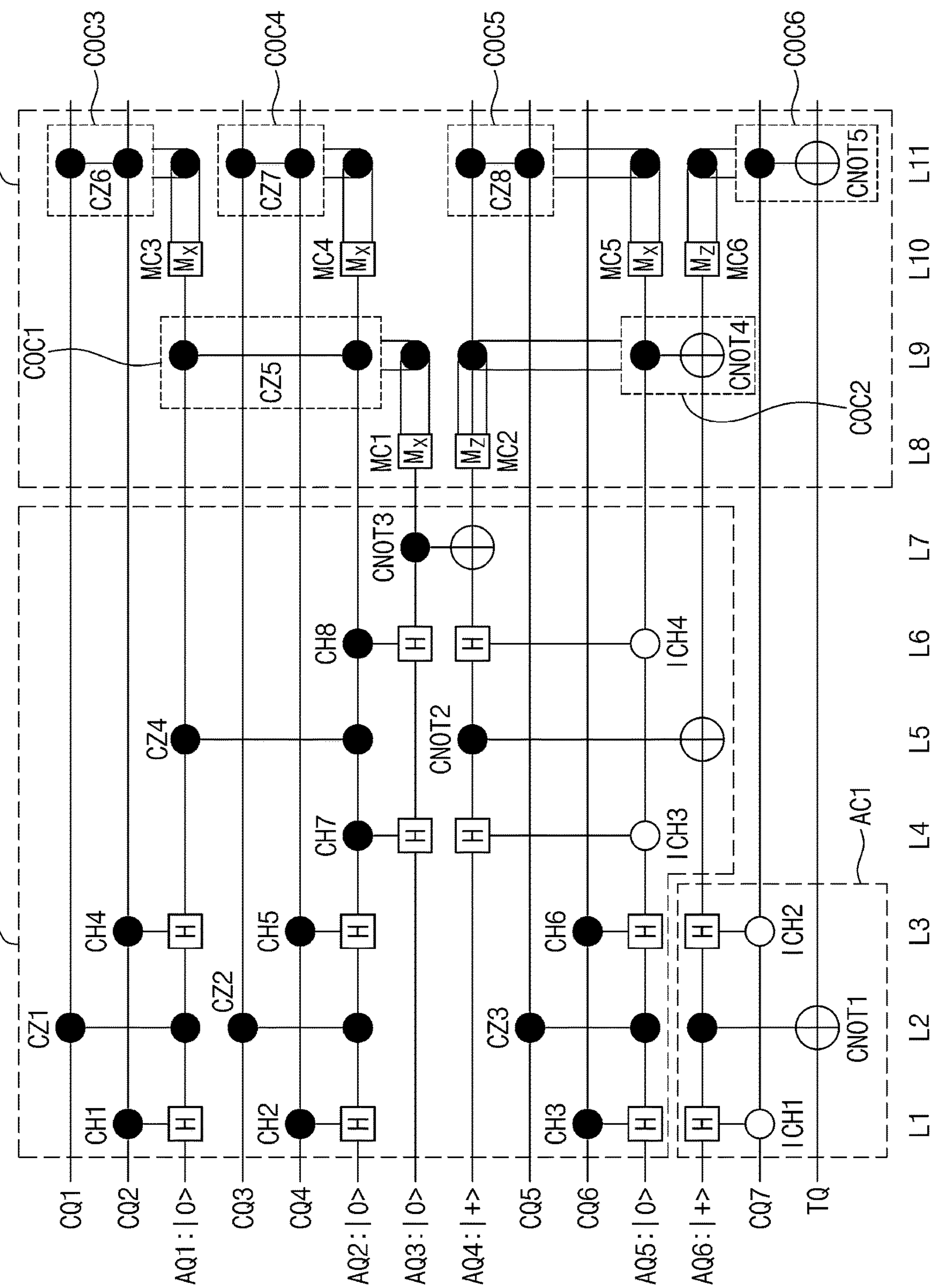

1800
MA
QGG
AC1
COC1
COC2
COC3
COC4
COC5
COC6
CQ1
CQ2
AQ1 : |0>
CQ3
CQ4
AQ2 : |0>
AQ3 : |0>
AQ4 : |+>
CQ5
CQ6
AQ5 : |0>
AQ6 : |+>
CQ7
TQ
CH1
CH2
CH3
CH4
CH5
CH6
CH7
CH8
ICH1
ICH2
ICH3
ICH4
CZ1
CZ2
CZ3
CZ4
CZ5
CZ6
CZ7
CZ8
CNOT1
CNOT2
CNOT3
CNOT4
CNOT5
MC1
MC2
MC3
MC4
MC5
MC6
H
Mx
Mz
L1
L2
L3
L4
L5
L6
L7
L8
L9
L10
L11

FIG. 19

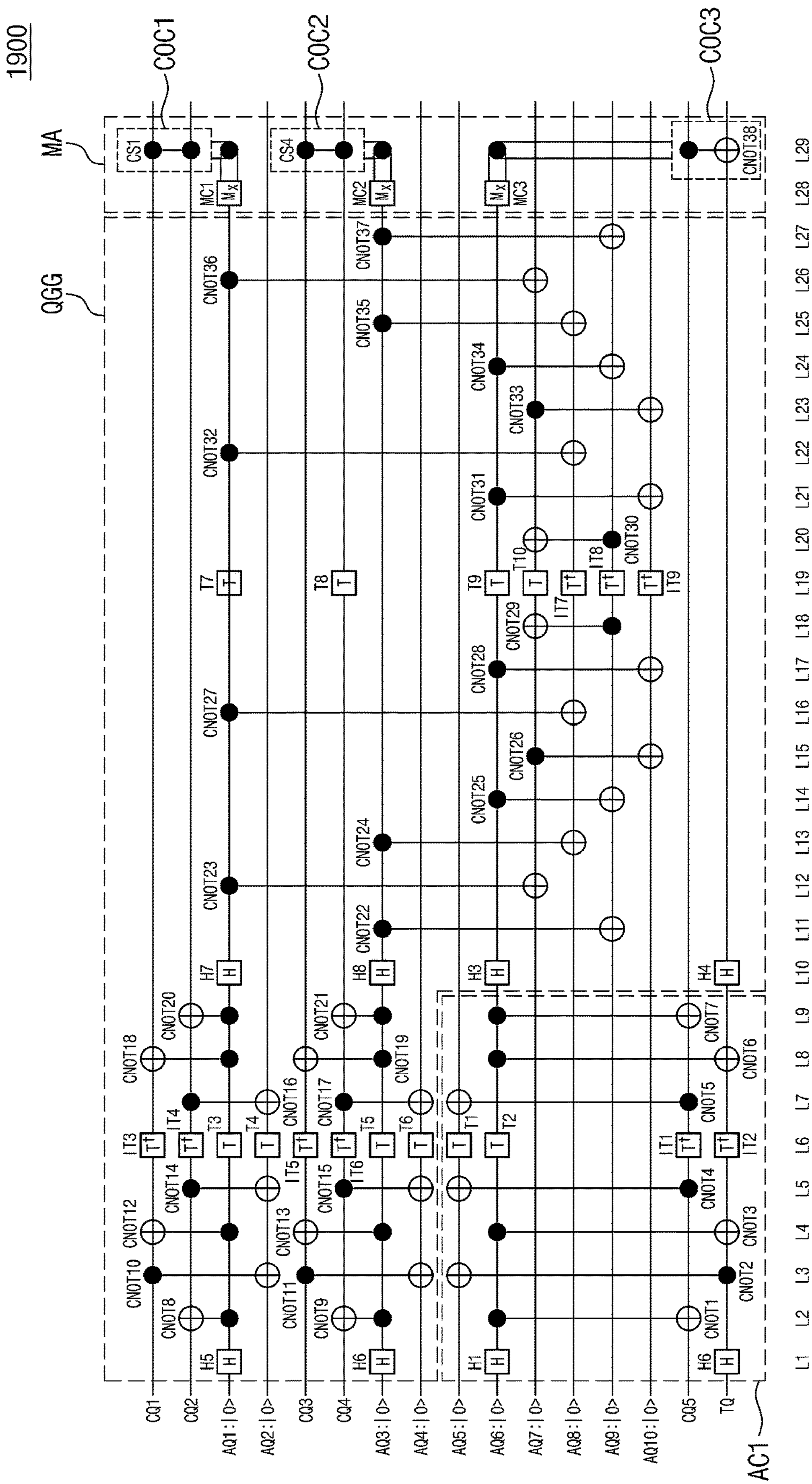

1900
MA
QGG
COC1
COC2
COC3
AC1
CS1
CS4
MC1
MC2
MC3
CNOT38
CQ1
CQ2
AQ1 : | 0>
AQ2 : | 0>
CQ3
CQ4
AQ3 : | 0>
AQ4 : | 0>
AQ5 : | 0>
AQ6 : | 0>
AQ7 : | 0>
AQ8 : | 0>
AQ9 : | 0>
AQ10 : | 0>
CQ5
TQ
L1 L2 L3 L4 L5 L6 L7 L8 L9 L10 L11 L12 L13 L14 L15 L16 L17 L18 L19 L20 L21 L22 L23 L24 L25 L26 L27 L28 L29

FIG. 20

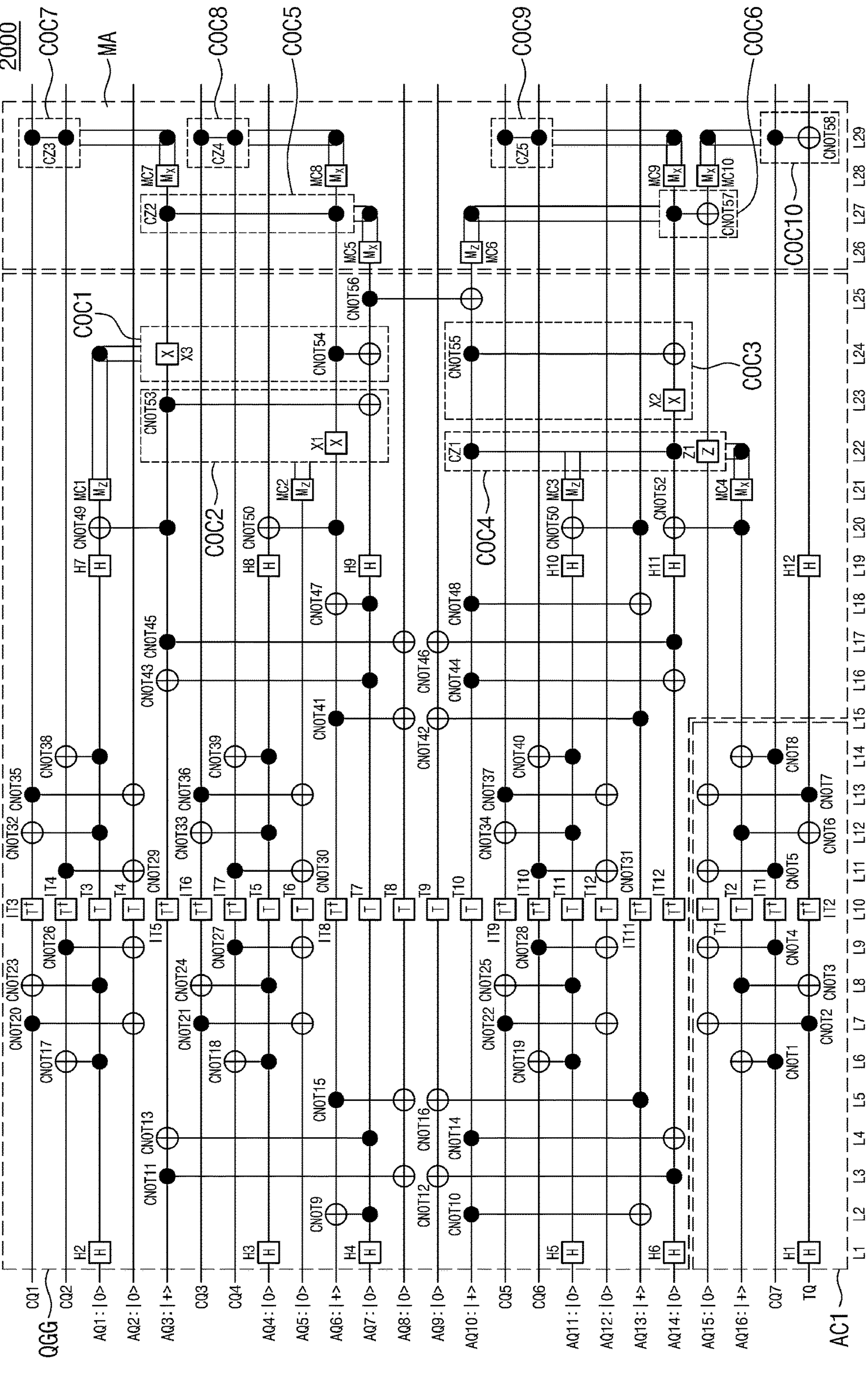
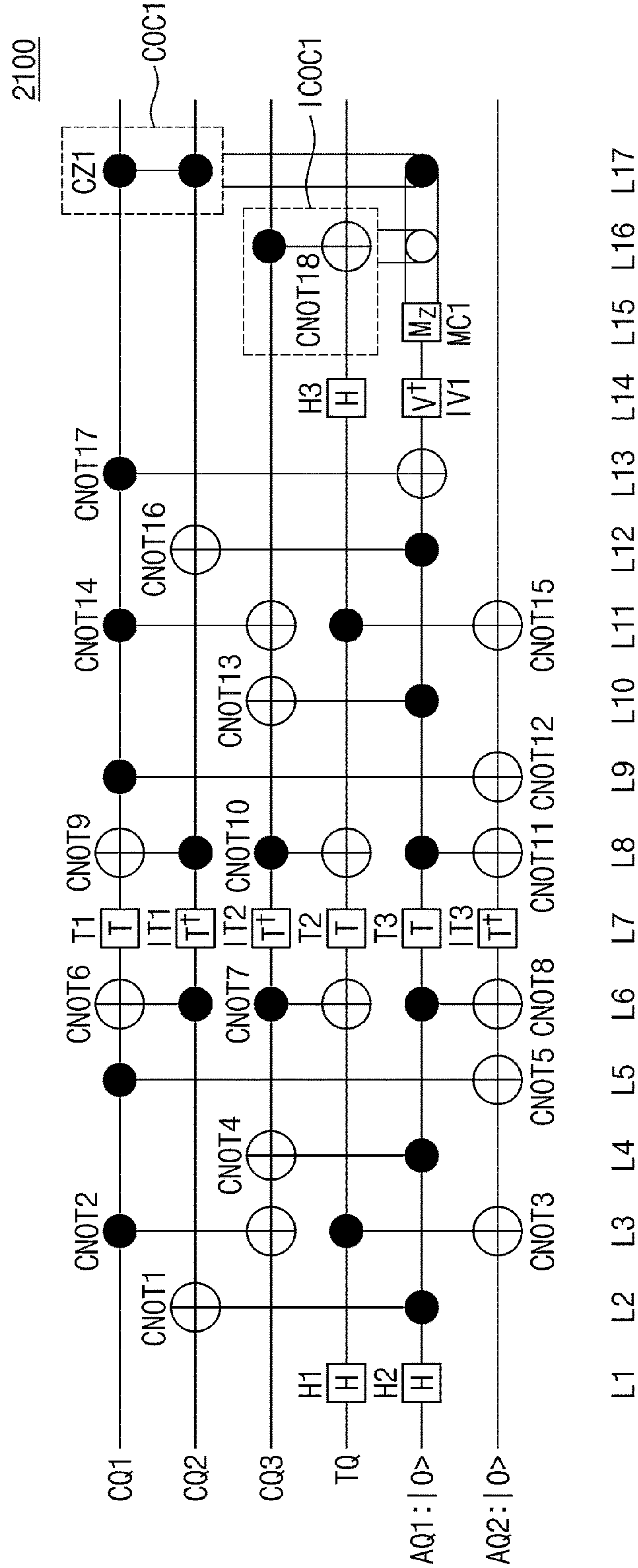

2000
MA
QGG
AC1
COC1
COC2
COC3
COC4
COC5
COC6
COC7
COC8
COC9
COC10
CQ1
CQ2
AQ1 : |0>
AQ2 : |0>
AQ3 : |+>
CQ3
CQ4
AQ4 : |0>
AQ5 : |0>
AQ6 : |+>
AQ7 : |0>
AQ8 : |0>
AQ9 : |0>
AQ10 : |+>
CQ5
CQ6
AQ11 : |0>
AQ12 : |0>
AQ13 : |+>
AQ14 : |0>
AQ15 : |0>
AQ16 : |+>
CQ7
TQ
L1
L2
L3
L4
L5
L6
L7
L8
L9
L10
L11
L12
L13
L14
L15
L16
L17
L18
L19
L20
L21
L22
L23
L24
L25
L26
L27
L28
L29

FIG. 21


2100
COC1
ICOC1
CZ1
CNOT1
CNOT2
CNOT3
CNOT4
CNOT5
CNOT6
CNOT7
CNOT8
CNOT9
CNOT10
CNOT11
CNOT12
CNOT13
CNOT14
CNOT15
CNOT16
CNOT17
CNOT18
H1
H2
H3
T1
T2
T3
IT1
IT2
IT3
IV1
MC1
CQ1
CQ2
CQ3
TQ
AQ1 : |0>
AQ2 : |0>
L1
L2
L3
L4
L5
L6
L7
L8
L9
L10
L11
L12
L13
L14
L15
L16
L17

QUANTUM CIRCUIT FOR IMPLEMENTING A MULTI-CONTROLLED NOT GATE

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority under 35 U.S.C. § 119 to Korean Patent Application No. 10-2024-0023465 filed on Feb. 19, 2024 and No. 10-2025-0016046 filed on Feb. 7, 2025, in the Korean Intellectual Property Office, the disclosures of which are incorporated by reference herein in their entireties.

BACKGROUND

[0002] Embodiments of the present disclosure described herein relate to a quantum circuit, and more particularly, to a quantum circuit for implementing a multi-controlled NOT gate.

[0003] A quantum computer may perform an operation based on a qubit represented by a superposition of '0' and '1' by using the principle of quantum mechanics, and thus may have a much faster operation speed than a digital computer using bits that can be represented only by '0' or '1'.

[0004] The multi-controlled conditional gate is a quantum logic gate that performs a conditional operation on a target qubit based on a plurality of control qubits. Multi-controlled conditional gates are applied to implement system software or specific algorithms related to quantum computation in various applications of quantum computing. For example, the multi-controlled NOT gate is a quantum logic gate of a quantum circuit relating to a plurality of control qubits and one target qubit. The multi-controlled NOT gate inverts the state of the target qubit when the state of all control qubits is $|1\rangle$.

[0005] The multi-controlled conditional gate may be implemented as elementary gates supported by a hardware platform of the quantum computer. However, in implementing a multi-controlled conditional gate by using basic gates, a circuit depth, which affects the speed of quantum computation, may be different according to arrangement of auxiliary qubits and basic gates. When the circuit depth of the quantum circuit is large, a relatively long computation time is required.

[0006] In order to implement a fast and efficient multi-controlled conditional gate, a quantum circuit with a minimum circuit depth is required using relatively simple gates.

SUMMARY

[0007] Embodiments of the present disclosure provide a quantum circuit for a multi-controlled NOT gate that can perform efficient and fast quantum computation.

[0008] Embodiments of the present disclosure provide a quantum circuit for a multi-controlled NOT gate that can minimize circuit depth in an environment where a type of operation is limited according to a hardware platform.

[0009] A quantum circuit for implementing multi-controlled NOT gates with N control qubits (N is an integer greater than or equal to 3) according to an embodiment of the present disclosure includes a first auxiliary circuit that corresponds to one or more initial layers of a plurality of layers and performs a controlled NOT operation on a target qubit based on an Nth control qubit from among the N control qubits and a first auxiliary qubit initialized to a $|+\rangle$ state, a quantum gate group that corresponds to the plurality of layers and performs controlled NOT operation on the first auxiliary qubit based on first to (N−1)th control qubits, and a second auxiliary circuit that corresponds one or more last layers of the plurality of layers, and performs controlled NOT operation on the target qubit based on the Nth control qubit and the first auxiliary qubit.

[0010] A quantum circuit for implementing multi-controlled NOT gates with N control qubits (N is an integer greater than or equal to 3) according to an embodiment of the present disclosure includes a first auxiliary circuit that corresponds to one or more initial layers of a plurality of layers and performs a controlled NOT operation on a target qubit based on an Nth control qubit from among the N control qubits and a first auxiliary qubit initialized to a $|+\rangle$ state, a quantum gate group that corresponds to the plurality of layers and perform controlled NOT operation on the first auxiliary qubit based on first to (N−1)th control qubits, one or more measurement circuits that correspond to one or more last layers of the plurality of layers, and measure a state of the one or more auxiliary qubits, and one or more conditional operation circuits that perform a conditional operation based on a measurement result of the one or more measurement circuits.

BRIEF DESCRIPTION OF THE FIGURES

[0011] The above and other objects and features of the present disclosure will become apparent by describing in detail embodiments thereof with reference to the accompanying drawings.

[0012] FIG. **1** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 3 control qubits according to an embodiment of the present disclosure.

[0013] FIG. **2** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 3 control qubits according to an embodiment of the present disclosure.

[0014] FIG. **3** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 5 control qubits according to an embodiment of the present disclosure.

[0015] FIG. **4** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 11 control qubits according to an embodiment of the present disclosure.

[0016] FIG. **5** is a circuit diagram illustrating another example of a quantum circuit for implementing a multi-controlled NOT gate with 3 control qubits according to an embodiment of the present disclosure.

[0017] FIG. **6** is a circuit diagram illustrating another example of a quantum circuit for implementing a multi-controlled NOT gate with 3 control qubits according to an embodiment of the present disclosure.

[0018] FIG. **7** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 5 control qubits according to an embodiment of the present disclosure.

[0019] FIG. **8** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 3 control qubits according to an embodiment of the present disclosure.

[0020] FIG. **9** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 3 control qubits according to an embodiment of the present disclosure.

[0021] FIG. **10** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 3 control qubits according to an embodiment of the present disclosure.

[0022] FIG. **11** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 5 control qubits according to an embodiment of the present disclosure.

[0023] FIG. **12** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 3 control qubits according to an embodiment of the present disclosure.

[0024] FIG. **13** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 5 control qubits according to an embodiment of the present disclosure.

[0025] FIG. **14** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 7 control qubits according to an embodiment of the present disclosure.

[0026] FIG. **15** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 7 control qubits according to an embodiment of the present disclosure.

[0027] FIG. **16** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 3 control qubits according to an embodiment of the present disclosure.

[0028] FIG. **17** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 5 control qubits according to an embodiment of the present disclosure.

[0029] FIG. **18** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 7 control qubits according to an embodiment of the present disclosure.

[0030] FIG. **19** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 5 control qubits according to an embodiment of the present disclosure.

[0031] FIG. **20** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 7 control qubits according to an embodiment of the present disclosure.

[0032] FIG. **21** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 3 control qubits according to an embodiment of the present disclosure.

DETAILED DESCRIPTION

[0033] Hereinafter, embodiments of the present disclosure will be described in detail and clearly to such an extent that an ordinary one in the art easily implements the present disclosure.

[0034] The components described with reference to the terms "unit", "module", "block", "or", "er", and the like used in the detailed description and the functional blocks shown in the drawings may be implemented in the form of software, hardware, or a combination thereof. Exemplarily, the software may be machine code, firmware, embedded code, and application software. For example, the hardware may include an electrical circuit, an electronic circuit, a processor, a computer, an integrated circuit, integrated circuit cores, a pressure sensor, an inertial sensor, a microelectromechanical system (MEMS), a passive device, or a combination thereof.

[0035] A multi-controlled NOT gate with N control qubits is a quantum logic gate that inverts the state of a target qubit based on the state of N control qubits being |1>. Relatively simpler gates and auxiliary qubits may be used to implement a multi-controlled NOT gate with N control qubits. When decomposing a multi-controlled NOT gate with N control qubits into simpler gates, the circuit depth may vary depending on the placement of the auxiliary qubits and gates. The following describes how the circuit depth can be minimized when disassembling a multi-controlled NOT gate.

[0036] FIG. **1** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 3 control qubits according to an embodiment of the present disclosure.

[0037] Referring to FIG. **1**, the multi-controlled NOT gate with 3 control qubits **10** may be implemented through a quantum circuit **100** including a first auxiliary circuit AC**1**, a quantum gate group QGG, and a second auxiliary circuit AC**2**.

[0038] A Toffoli gate is referred to as a CCNOT gate or a CCX gate, and is a conditional gate that inverts the state of a target qubit based on two control qubits. The Toffoli gate may invert the state of the target qubit TQ based on the state of the two control qubits being |1>.

[0039] The Pauli-X gate inverts the state of the qubit. Inverting of the qubit state refers to a π(i.e., 180°) rotation in the Bloch sphere about the X axis of the sphere. A qubit that is a state of |1> becomes a state of 0> through state inverting, and a qubit that of |0> can become |1> through state inverting. The CNOT gate corresponds to a conditional Pauli-X gate according to the control qubit. The Pauli-X operation refers rotating the qubit by π about the X axis.

[0040] The quantum circuit **100** may use an auxiliary qubit AQ**1**. The auxiliary qubit AQ**1** may be a qubit initialized to the |+> state.

[0041] In implementing the multi-controlled NOT gate with N control qubits, the first auxiliary circuit AC**1** may correspond to one or more initial layers among the plurality of layers and may perform a controlled NOT operation on the target qubit based on the Nth control qubit and the first auxiliary qubit initialized to the |+> state among the plurality of auxiliary qubits.

[0042] The quantum gate group QGG may perform controlled NOT operation on the first auxiliary qubit based on the first to N-lth control qubits.

[0043] The second auxiliary circuit AC**2** may correspond to one or more last layers of the plurality of layers and may perform controlled NOT operation on the target qubit based on the Nth control qubit and the first auxiliary qubit. The second auxiliary circuit AC**2** may be configured symmetrically with the first auxiliary circuit AC**1**.

[0044] Hereinafter, in FIGS. **1** to **4**, the first auxiliary circuit AC**1** may include a first Toffoli gate TG**1**, and the second auxiliary circuit AC**2** may include a second Toffoli gate TG**2**.

[0045] The first Toffoli gate TG**1** may correspond to the layer **1** (L**1**). The first Toffoli gate TG**1** may rotate the target qubit TQ by π about the X axis based on the auxiliary qubit AQ**1** initialized to the |+> state and the control qubit CQ**3**.

[0046] The quantum gate group QGG may correspond to the layer **2** (L**2**). The quantum gate group QGG may rotate the auxiliary qubit AQ**1** by π about the X axis based on the control qubit CQ**1** and the control qubit CQ**2**.

[0047] The second Toffoli gate TG**2** may correspond to the layer **3** (L**3**). The second Toffoli gate TG**2** may rotate the target qubit TQ by π about the X axis based on the auxiliary qubit AQ**1** and the control qubit CQ**3**.

[0048] The layers L**1** to L**3** may correspond to positions for describing arrangement of gates or circuits included in the quantum circuit **100**. One or more layers may correspond to one circuit depth. According to a relationship between gates corresponding to each of the layers, even when the gates correspond to different layers, the gates may correspond to one circuit depth when the gates are operable in parallel.

[0049] The quantum gate group QGG may include a third Toffoli gate TG**3**. The third Toffoli gate TG**3** may rotate the auxiliary qubit AQ**1** by **71** around the X axis based on the control qubit CQ**1** and the control qubit CQ**2**.

[0050] As a result, the multi-controlled NOT gate with 3 control qubits **10** may be decomposed into three Toffoli gates—a first Toffoli gate TG**1**, a second Toffoli gate TG**2**, and a third Toffoli gate GT**3**.

[0051] The quantum circuit **100** may parallelize the operation of the gates by using an auxiliary qubit AQ**1** of |+> which is in a uniform superposition state. Parallelization of quantum computation utilizing auxiliary qubits may reduce the depth of the decomposed circuit.

[0052] FIG. **2** is a circuit diagram illustrating another example of a quantum circuit implementing a multi-controlled NOT gate with 3 control qubits according to an embodiment of the present disclosure.

[0053] Referring to FIG. **2**, the quantum circuit **200** may include a first Toffoli gate TG**1**, a quantum gate group QGG, and a second Toffoli gate TG**2**.

[0054] The CNOT gate is a quantum logic gate in which the state of the target qubit does not change when the state of the control qubit is |0>, and the CNOT gate rotates the target qubit by π about the X axis when the state of control qubits is |1>.

[0055] The first Toffoli gate TG**1** may rotate the target qubit TQ by π about the X axis based on the auxiliary qubit AQ**2** initialized to the |+> state and the control qubit CQ**3**.

[0056] The quantum gate group QGG may include a third Toffoli gate TG**3** that rotates the auxiliary qubit AQ**1** initialized to the |0> state by π about the X axis based on the control qubit CQ**1** and the control qubit CQ**2**. The quantum gate group QGG may include a first CNOT gate CNOT**1** that rotates the auxiliary qubit AQ**2** by π about the X axis based on the auxiliary qubit AQ**1**. The quantum gate group QGG may include a fourth Toffoli gate TG**4** that rotates the auxiliary qubit AQ**1** by π about the X axis based on the control qubit CQ**1** and the control qubit CQ**2**. The quantum gate group QGG may apply a result calculated based on the control qubit CQ**1** and the control qubit CQ**2** on the auxiliary qubit AQ**2** through the third Toffoli gate TG**3**, the first CNOT gate CNOT**1**, and the fourth Toffoli gate TG**4**.

[0057] The second Toffoli gate TG**2** may rotate the target qubit TQ**3** by π about the X axis based on the auxiliary qubit AQ**2** and the control qubit CQ**3**.

[0058] In this case, the first Toffoli gate TG**1** and the third Toffoli gate TG**3** may correspond to the layer **1** (L**1**), the first CNOT gate CNOT**1** may correspond to the layer **2** (L**2**), and the second Toffoli gates TG**2** and TG**4** may correspond to the layer **2** (L**2**). That is, in the layer **1** (L**1**), the operation of the first Toffoli gate TG**1** and the third Toffoli gates TG**3** may be performed in parallel. In addition, the operation of the second Toffoli gate TG**2** and the third Toffoli gates TG**4** may be performed in parallel. Parallel operation of the Toffoli gates can reduce circuit depth.

[0059] FIG. **3** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 5 control qubits according to an embodiment of the present disclosure.

[0060] Referring to FIG. **3**, the multi-controlled NOT gate with 5 control qubits **30** may be implemented through a quantum circuit **300** including a first Toffoli gate TG**1**, a quantum gate group QGG, and a second Toffoli gate TG**2**.

[0061] The first Toffoli gate TG**1** may correspond to the layer **1** (L**1**), and may rotate the target qubit TQ by π about the X axis based on the auxiliary qubit AQ**3** initialized to the |+> state and the control qubit CQ**5**.

[0062] The quantum gate group QGG may correspond to the layers L**1** to L**3**. The quantum gate group QGG may rotate the auxiliary qubit AQ**3** by π about the X axis based on the control qubits CQ**1** to CQ**4**.

[0063] The quantum gate group QGG may include a third Toffoli gate TG**3** that rotates the auxiliary qubit AQ**1** that is initialized to the |0> state by π about the X axis based on the control qubit CQ**1** and the control qubit CQ**2**, a fourth Toffoli gate TG**4** that rotates the auxiliary qubit AQ**2** that is initialized in the |0> state by π about the X axis based on the control qubit CQ**3** and the control qubit CQ**4**. The quantum gate group QGG may include a fifth Toffoli gate TG**5** that rotates an auxiliary qubit AQ**3** by π about the X axis based on the auxiliary qubits AQ**1** and AQ**2**. The quantum gate group QGG may include a sixth Toffoli gate TG**6** that rotates the auxiliary qubit AQ**1** by π about the X axis based on the control qubit CQ**1** and the control qubit CQ**2**, and a seventh Toffoli gate TG**7** that rotates the auxiliary qubit AQ**2** by π about the X axis based on the control qubits CQ**3** and CQ**4**. In this case, the third Toffoli gate TG**3** and the fourth Toffoli gate TG**4** may correspond to the layer **1** (L**1**). The fifth Toffoli gate TG**5** may correspond to the layer **2** (L**2**). The sixth Toffoli gate TG**6** and the seventh Toffoli gate TG**7** may correspond to the layer **3** (L**3**).

[0064] The second Toffoli gate TG**2** corresponds to the layer **3** (L**3**) and may rotate the target qubit TQ by π about the X axis based on the auxiliary qubit AQ**3** and the control qubit CQ**5**.

[0065] Through the above-described parallelization, when the layer **1** (L**1**) is performed, the first Toffoli gate TG**1**, the third Toffoli gate TG**3**, and the fourth Toffoli gates TG**4** may be operated in parallel, when the layer **2** (L**2**) is performed, the fifth Toffoli gate is operated, and when the layer **3** (L**3**) is performed, the second Toffoli gate TG**2**, the Toffoli gate **6** TG**6**, and the Toffoli gate **7** TG**7** may be operated in parallel.

[0066] The quantum circuit **300** may implement a multi-controlled NOT gate with 5 control qubits having a circuit depth of 3 by using only a single type of Toffoli gate.

[0067] FIG. **4** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled

NOT gate with 11 control qubits according to an embodiment of the present disclosure.

[0068] Referring to FIG. **4**, the multi-controlled NOT gate with 11 control qubits **40** may be implemented by a quantum circuit **400** including a first Toffoli gate TG**1**, a quantum gate group QGG, and a second Toffoli gate TG**2**.

[0069] The first Toffoli gate TG**1** may correspond to the layer L**1**, and may rotate the target qubit TQ by π about the X axis based on the auxiliary qubit AQ**9** initialized to the |+1> state and the control qubit CQ**11**.

[0070] The quantum gate group QGG may correspond to the layer **1** (L**1**) to the layer **5** (L**5**), and may rotate the auxiliary qubit AQ**9** by π about the X axis based on the control qubits CQ**1** to CQ**10**.

[0071] The quantum gate group QGG may include a third Toffoli gate TG**3** that rotates the auxiliary qubit AQ**1** initialized to the |0> state by π about the X-axis based on the control qubit CQ**1** and the control qubit CQ**2**, a fourth Toffoli gate TG**4** that rotates the auxiliary qubit AQ**2** initialized to the |0> state by r about the X-axis based on the control qubit CQ**3** and the control qubit CQ**4**, a fifth Toffoli gate TG**5** that rotates the auxiliary qubit AQ**4** initialized to the |0> state by r about the X axis based on the control qubit CQ**5** and the control qubit CQ**6**, a sixth Toffoli gate AQ**6** that rotates the auxiliary qubit AQ**5** initialized to the |0> state by r about the X axis based on the control qubit CQ**7** and the control qubit CQ**8**, and a seventh Toffoli gate TG**7** that rotates the auxiliary qubit AQ**8** initialized to the |0> state by r about the X axis based on the control qubit CQ**9** and the control qubit CQ**10**. The third to seventh Toffoli gates TG**3**-TG**7** may correspond to the layer **1** (L**1**).

[0072] The quantum gate group QGG may include an eighth Toffoli gate TG**8** that rotates an auxiliary qubit AQ**3** initialized to the |0> state by π about the X axis based on the auxiliary qubits AQ**1** and AQ**2**, a ninth Toffoli gates TG**9** that rotates the auxiliary qubit AQ**6** initialized to |0> states by π about the X axis based on an auxiliary qubits AQ**4** and AQ**5**, and a tenth Toffoli gate TG**10** that rotates the auxiliary qubit AQ**9** by π about the X axis based on the auxiliary qubit AQ**8** and the auxiliary qubit AQ**7** initialized to |+> state. The eighth to tenth gates TG**8**-TG**10** may correspond to the layer **2** (L**2**).

[0073] The quantum gate group QGG may include an eleventh Toffoli gate TG**11** that rotates the auxiliary qubit AQ**7** by π about the X axis based on the auxiliary qubits AQ**3** and AQ**6**. The eleventh Toffoli gate TG**11** may correspond to the layer **3** (L**3**).

[0074] The quantum gate group QGG may include a twelfth Toffoli gate TG**12** that rotates an auxiliary qubit AQ**3** by π about the X axis based on the auxiliary qubit AQ**1** and the auxiliary qubit AQ**2**, a thirteenth Toffoli gate TG**13** that rotates the auxiliary qubit AQ**6** by π about the X axis based on the auxiliary qubit AQ**4** and the auxiliary qubit AQ**5**, and a fourteenth Toffoli gate TG**14** that rotates the auxiliary qubit AQ**9** by π about the X axis based on the auxiliary qubit AQ**7** and the auxiliary qubit AQ**8**. The twelfth to fourteenth gates TG**12**-TG**14** may correspond to the layer **4** (L**4**).

[0075] The quantum gate group QGG may include a fifteenth Toffoli gate TG**15** that rotates the auxiliary qubit AQ**1** by π about the X axis based on the control qubit CQ**1** and the control qubit CQ**2**, a sixteenth Toffoli gateway TG**16** that rotates the auxiliary qubit AQ**2** by π about the X axis based on the control qubit CQ**3** and control qubit CQ**4**, a seventeenth Toffoli gate TG**17** that rotates the auxiliary qubit AQ**4** by π about the X axis based on the controls qubit CQ**5** and control qubit CQ**6**, an eighteenth Toffoli gate TG**18** that rotates the auxiliary qubit AQ**5** by π about the X axis based on the control qubit CQ**7** and control qubit CQ**8**, and a nineteenth Toffoli gate TG**19** that rotates the auxiliary qubit AQ**8** by π about the X axis based on the control qubit CQ**9** and control qubit CQ**10**. The fifteenth to nineteenth Toffoli gates TG**15**-TG**19** may correspond to the layer **5** (L**5**).

[0076] The second Toffoli gate TG**2** corresponds to the layer **5** (L**5**) and may rotate the target qubit TQ by π about the X axis based on the auxiliary qubit AQ**9** and the control qubit CQ**11**.

[0077] Based on the decomposition described above in FIG. **1**, N−2 auxiliary qubits are required when implementing a multi-controlled NOT gate with N control qubits using Toffoli gates. When the multi-controlled NOT gate with N control qubits is implemented by using single type of Toffoli gate, the circuit depth of the quantum circuit may be represented by Equation 1.

$$K = 2\lceil \log_2(N+1)/3 \rceil + 1 \quad \text{[Equation 1]}$$

[0078] K is the circuit depth and N is the number of control qubits of the multi-controlled NOT gate.

[0079] When a multi-controlled NOT gate with N control qubits is implemented using only an auxiliary qubit of a |0> state conventionally, the circuit depth of the quantum circuit can be represented by Equation 2.

$$K = 2\lceil \log_2 N \rceil - 1 \quad \text{[Equation 2]}$$

[0080] In implementing a multi-controlled NOT gate with N control qubits, the quantum circuit according to an embodiment of the present disclosure may apply about 1.5 times control qubits compared to a conventional implementation. For example, when the circuit depth is 19, the number of control qubits may be 1024 according to a conventional implementation. At this time, a multi-controlled NOT gate with 1024 control qubits may be implemented. On the other hand, a quantum circuit according to an embodiment of the present disclosure may implement a multi-controlled NOT gate with 1535 control qubits in which the number of control qubits is 1535. It is possible to implement a multi-controlled NOT gate that operates based on more control qubits even if it corresponds to the same circuit depth. In another aspect, when rotating by π about the X axis based on the same number of control qubits, the quantum circuit according to an embodiment of the present disclosure may have a reduced circuit depth.

[0081] FIG. **5** is a circuit diagram illustrating another example of a quantum circuit for implementing a multi-controlled NOT gate with 3 control qubits according to an embodiment of the present disclosure.

[0082] Referring to FIG. **5**, the multi-controlled NOT gate with 3 control qubits **50** may be implemented by a quantum circuit **500** including a first auxiliary circuit AC**1**, a quantum gate group QGG, and a second auxiliary circuit AC**2**.

[0083] The quantum circuit **500** is obtained by implementing each of the Toffoli gates constituting the quantum circuit **200** described in FIG. **2** using a CH gate, a CZ gate, and inverted CH gates. The first auxiliary circuit AC1 may correspond to the first Toffoli gate TG1 of the quantum circuit 200 of FIG. 2. The quantum gate group QGG of the quantum circuit 500 may correspond to the quantum gate group QG of the quantum circuit 200. The second auxiliary circuit AC2 may correspond to the second Toffoli gate TG2 of the quantum circuit 200.

[0084] A Controlled-Hadamard (CH) gate is a quantum logic gate that maintains the state of a target qubit when the state of the control qubit is |0>, and performs Hadamard transformation on the target qubit when the state of the control qubit is |1>.

[0085] An Inverted-Controlled Hadamard Gate (Inverted CH Gate) is a quantum logic gate that performs Hadamard transformation on a target qubit when a state of a control qubit is |0>, and maintains the state of the target qubit when the state of the control qubits is |1>.

[0086] The controlled-Z gate (CZ gate) has no change in the state of the target qubit when the state of the control qubit is |0>, and inverts the phase of the target qubit when the state of the control qubit is |1>. The Pauli-Z gate rotates the qubit by π about the Z axis. The CZ gate has symmetry between the control qubit and the target qubit.

[0087] The first auxiliary circuit AC1 may include a first inverted CH gate ICH1 that corresponds to the layer 1 (L1) and performs inverted-controlled Hadamard transformation on the auxiliary qubit AQ2 initialized to the |+> state based on the control qubit CQ3, a first CNOT gate CNOT1 that corresponds to the layer 2 (L2) and rotates the target qubit TQ by π about X axis based on the auxiliary qubit AQ2, and a second inverted CH Gate ICH2 that corresponds to a layers 3 (L3) and performs inverted-controlled Hadamard transformation on the auxiliary qubit AQ2 based on the control qubit CQ3.

[0088] The quantum gate set QGG may include a first CH gate CH1 that corresponds to the layer 1 (L1) and performs controlled Hadamard transformation on the auxiliary qubit AQ1 initialized to |0> based on the control qubit CQ2, a first CZ gate CZ1 that corresponds to a layer 2 (L2) and rotates the auxiliary qubit AQ1 by π about the Z axis based on the control qubit CQ1, a second CH gate CH2 that corresponds to layer 3 (L3) and performs controlled Hadamard transformation on the auxiliary qubit AQ1 based on the control qubit CQ2; a third CNOT gate CNOT3 that corresponds to layer 4 (L4) and rotates the auxiliary qubit AQ2 by π about the X axis based on the auxiliary qubit AQ1; a third CH gate CH3 that corresponds to a layers 5 (L5) and performs controlled Hadamard transformation on an auxiliary qubit AQ1 based upon the control qubit CQ2; the second CZ gate CZ2 that corresponds to the layers 6 (L6) and rotates the auxiliary qubit AQ1 by π about the Z axis, based upon the control qubit CQ1; and a fourth CH gate CH4 that corresponds to layer 6 (L6) and performs controlled Hadamard transformation on the auxiliary qubit AQ1 based on the control qubit CQ2.

[0089] The second auxiliary circuit AC2 may include a third inverted CH gate ICH3 that corresponds to the layer 5 (L5) and performs inverted controlled Hadamard transformation on the auxiliary qubit AQ2 based on the control qubit CQ3, a second CNOT gate CNOT2 that corresponds to the layer 5 (L5) and rotates the target qubit TQ by π about the X axis based on the auxiliary qubit AQ2, and a fourth inverted CH gate ICH4 that corresponds to the layer 6 (L6) and performs inverted controlled Hadamard transformation on the auxiliary qubit AQ2 based on the control qubit CQ3.

[0090] Through this, it is possible to implement the multi-controlled NOT gate with 3 control qubits using the CH gate, the CZ gate, and the inverted CZ gates performing operation based on single control qubit.

[0091] FIG. 6 is a circuit diagram illustrating another example of a quantum circuit for implementing a multi-controlled NOT gate with 3 control qubits according to an embodiment of the present disclosure.

[0092] Referring to FIG. 6, the multi-controlled NOT gate with 3 control qubits 60 may be implemented by a quantum circuit 600 including a first auxiliary circuit AC1, a quantum gate group QGG, and a second auxiliary circuit AC2.

[0093] The first auxiliary circuit AC1 may include a first CH gate CH1 that corresponds to the layer 1 (L1) and performs controlled Hadamard transformation on a auxiliary qubit AQ2 initialized to the |0> state based on a control qubit CQ3, a first CNOT gate CNOT1 that corresponds to a layer 2 (L2) and rotates a target qubit TQ by π about the X axis based on the auxiliary qubit AQ2, and a second CH gate CH2 that corresponds to a layers 3 (L3) and performs controlled Hadamard transformation on an auxiliary qubit AQ2 based on the control qubit CQ3.

[0094] The quantum gate set QGG may include a fifth CH gate CH5 corresponding to the layer 1 (L1) and performs controlled Hadamard transformation on a auxiliary qubit AQ1 initialized to |0> based on a control qubit CQ2, a first CZ gate CZ1 corresponding to the layer 2 (L2) and rotating the auxiliary qubit AQ1 by π about the Z axis based on the control qubit CQ1, a sixth CH gate CH6 corresponding to the layer 3 (L3) and performing controlled Hadamard transformation on the auxiliary qubit AQ1 based on the control qubit CQ2, a second CZ gate CZ2 corresponding to a layer 4 (L4) and rotating the auxiliary qubit AQ2 by π about the Z axis based on the auxiliary qubit AQ1; a third CH gate CH3 corresponding to a layer 5 (L5) and performing controlled Hadamard transformation on an auxiliary qubit AQ1 based on a control qubit CQ2; a third CZ gate CZ3 corresponding to the layers 5 (L5), and rotating the auxiliary qubit AQ1 by π about the Z axis based on a control qubit CQ1; and an eighth CH gate CH8 corresponding to a layer 6 (L6) and performing controlled Hadamard transformation on the auxiliary qubit AQ1 based on the control CQ2.

[0095] The second auxiliary circuit AC2 may include a third CH gate CH3 corresponding to the layer 5 (L5) and performing controlled Hadamard transformation on the auxiliary qubit AQ2 based on the control qubit CQ3, a second CNOT gate CNOT2 corresponding to the layer 5 (L5) and rotating the target qubit TQ by π about the X axis based on the auxiliary qubit AQ2, and a fourth CH gate CH4 corresponding to a layer 6 (L6) and performing controlled Hadamard transformation on the auxiliary qubit AQ2 based on the control qubit CQ3.

[0096] Compared with the quantum circuit 500 in FIG. 5, the auxiliary qubit AQ2 of the quantum circuit 600 in FIG. 6 is initialized to the |0> state. The inverted CH gates included in the quantum circuit 500 of FIG. 5 are changed to CH gates in the quantum circuit 600 of FIG. 6. The third CNOT gate CNOT3 included in the quantum circuit 500 of FIG. 5 is changed to the second CZ gate CZ2 in the quantum circuit 600 of FIG. 6.

[0097] On the other hand, when configuring a quantum circuit with quantum logic gates (CH, CZ, CNOT, or inverted CH, etc.) having two gates (or terminals), N−1 auxiliary qubits are needed to implement a multi-controlled NOT gate with N control qubits. At this time, the depth M of the circuit can be expressed by Equation 3.

$$M = 6\lceil \log_2(N+1) \rceil - 5 \qquad \text{[Equation 3]}$$

[0098] With reference to FIG. **5** and FIG. **6**, the quantum logic gate with three gates in FIG. **2** can be represented by quantum logic gates with two gates. This enables a multi-controlled NOT gate with N control qubits to be implemented using a relatively simpler quantum logic gate.

[0099] FIG. **7** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 5 control qubits according to an embodiment of the present disclosure.

[0100] Referring to FIG. **7**, the multi-controlled NOT gate with 5 control qubits **70** may be implemented by a quantum circuit **700** including a first auxiliary circuit AC**1**, a quantum gate group QGG, and a second auxiliary circuit AC**2**.

[0101] A Controlled S gate (CS gate) is a quantum logic gate in which the state of a target qubit is maintained when the state of the control qubit is |0>, and the state of the target qubit changes in phase by π/2 when the state of control qubits is |1>. That is, when the state of the control qubit is |1>, the S gate is applied. An S gate is a quantum logic gate that rotates the state of a qubit in a Bloch sphere about the Z axis by π/2.

[0102] An Inverse Controlled-S gate (inverse CS gate) is a quantum logic gate in which the state of a target qubit is maintained when the state of the qubit is |0>, and the state of the target qubit changes by −π/2 when the state of a control qubit is |1>. That is, when the state of the control qubit is |1>, the inverse S gate is applied. An Inverse S gate is a quantum logic gate that rotates the state of a qubit in the Bloch sphere about the Z axis by −π/2.

[0103] The first auxiliary circuit AC**1** may include a first CH gate CH**1** that corresponds to the layer **1** (L**1**) and performs controlled Hadamard transformation on the auxiliary qubit AQ**3** initialized to the |0> state based on a control qubit CQ**5**, a first CNOT gate CNOT**1** that corresponds to layer **2** (L**2**) and rotates a target qubit TQ by π about the X axis based on the auxiliary qubit AQ**3**, and a second CH gate CH**2** that corresponds to layer **3** (L**3**) and performs controlled Hadamard transformation on the auxiliary qubit AQ**3** based on the control qubit CQ**5**.

[0104] The quantum gate group QGG may further include, corresponding to the layer **1** (L**1**), a fifth CH gate CH**5** that performs controlled Hadamard transformation on the auxiliary qubit AQ**1** initialized to the |0> state based on the control qubit CQ**2** and a sixth CH gate CH**6** that performs controlled Hadamard transformation on the auxiliary qubit AQ**2** initialized to the state |0> based on the control qubit CQ**4**.

[0105] The quantum gate group QGG may include, corresponding to the layer **2** (L**2**), a first CZ gate CZ**1** that rotates the auxiliary qubit AQ**1** by π about the Z axis based on the control qubit CQ**1** and a second CZ gate CZ**2** that rotates the auxiliary qubit AQ**2** by π about the Z axis based on the control qubit CQ**3**.

[0106] The quantum gate group QGG may further include, corresponding to the layer **3** (L**3**), a seventh CH gate CH**7** that performs controlled Hadamard transformation on the auxiliary qubit AQ**1** based on the control qubit CQ**2** and an eighth CH gate CH**8** that performs controlled Hadamard transformation on the auxiliary qubit AQ**2** based on the control qubit CQ**4**.

[0107] The quantum gate group QGG may further include, corresponding to a layer **4** (L**4**), a first CS gate CS**1** that rotates the auxiliary qubit AQ**3** by π/2 about the Z axis based on the auxiliary qubit AQ**2**.

[0108] The quantum gate group QGG may further include, corresponding to a layer **5** (L**5**) a third CNOT gate CNOT**3** that rotates the auxiliary qubit AQ**2** by π about the X axis based on the auxiliary qubit AQ**1**.

[0109] The quantum gate group QGG may further include, corresponding to a layer **6** (L**6**), a first inverse CS gate ICS**1** that rotates the auxiliary qubit AQ**3** by −π/2 about the Z axis based on the auxiliary qubit AQ**2**.

[0110] The quantum gate group QGG may further include, corresponding to a layer **7** (L**7**), may include a fourth CNOT gate CNOT**4** that rotates the auxiliary qubit AQ**2** by π about the X axis based on the auxiliary qubit AQ**1**.

[0111] The quantum gate group QGG may further include, corresponding to a layer **8** (L**8**), a second CS gate CS**2** that rotates the auxiliary qubit AQ**3** by −π/2 about the Z axis based on the auxiliary qubit AQ**1**.

[0112] The quantum gate group QGG may further include, corresponding to a layer **9** (L**9**), a ninth CH gate CH**9** that performs controlled Hadamard transformation on the auxiliary qubit AQ**1** based on the control qubit CQ**2**, and a tenth CH gate CH**10** that performs controlled Hadamard transformation on the auxiliary qubit AQ**2** based on the control qubit CQ**4**.

[0113] The quantum gate group QGG may further include, corresponding to the layer **10** (L**10**), a third CZ gate CZ**3** that rotates the auxiliary qubit AQ**1** by π about the Z axis based on the control qubit CQ**1**, and a fourth CZ gate CZ**4** that rotates the auxiliary qubit AQ**2** by π about the Z axis based on the control qubit CQ**3**.

[0114] The quantum gate group QGG may further include, corresponding to the layer **11** (L**11**), an eleventh CH gate CH**11** that performs controlled Hadamard transformation on the auxiliary qubit AQ**1** based on the control qubit CQ**2**, and a twelfth CH gate CH**12** that performs controlled Hadamard transformation on the auxiliary qubit AQ**2** based on the control qubit CQ**4**.

[0115] The second auxiliary circuit AC**2** may include a third CH gate CH**3** corresponding to the layer **9** (L**9**) and configured to perform controlled Hadamard transformation on the auxiliary qubit AQ**3** based on the control qubit CQ**5**, a second CNOT gate CNOT**2** corresponding to the layer **10** (L**10**) and configured to rotate the target qubit TQ by π about the X axis based on the auxiliary qubit AQ**3**, and a fourth CH gate CH**4** corresponding to the layer **11** (L**11**) and configured to perform controlled Hadamard transformation on the auxiliary qubit AQ**3** based on the control qubit CQ**5**.

[0116] According to Equation 3, when implementing a multi-controlled NOT gate with 5 control qubit using quantum logic gates having two gates, the circuit depth is 13. The quantum circuit **700** can reduce the circuit depth to 11 by using a CS gate and an inverse CS gate. As a result, the quantum circuit **700** can implement a multi-controlled NOT gate with a smaller circuit depth.

[0117] FIG. **8** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 3 control qubits according to an embodiment of the present disclosure.

[0118] Referring to FIG. **8**, the multi-controlled NOT gate with 3 control qubits **80** may be implemented through a quantum circuit **800** including a first auxiliary circuit AC**1**, a quantum gate group QGG, and a second auxiliary circuit AC**2**.

[0119] An H gate is a quantum logic gate that performs Hadamard transformation on a qubit.

[0120] A T gate is a quantum logic gate that rotates the state of a qubit by π/4 about the Z axis in a Bloch sphere.

[0121] An inverse T gate is a quantum logic gate that rotates the state of a qubit by −π/4 about the Z axis in a Bloch sphere.

[0122] The first auxiliary circuit AC**1** may include a first H gate H**1** that corresponds to layer **1** (L**1**) and performs Hadamard transformation on the target qubit TQ, a first CNOT gate CNOT**1** that corresponds to a layer **2** (L**2**) and performs Pauli-X operation on the control qubit CQ**3** based on the auxiliary qubit AQ**2** initialized to a |+> state, a first T gate T**1** that corresponds to layer **3** (L**3**) and performs π/4 phase transformation on the auxiliary qubit AQ**2**, a first inverse T gate IT**1** that corresponds to layer **3** (L**3**) and performs −π/4 phase transformation on the control qubit CQ**3**, a second CNOT gate CNOT**2** that corresponds to layer **4** (L**4**) and performs Pauli-X operation on the auxiliary qubit AQ**2** based on the target qubit TQ, a third CNOT gate CNOT**3** that corresponds to layer **5** (L**5**) and performs Pauli-X operation of the control qubit CQ**3** based on the target qubit TQ, a second inverse T gate (IT**2**) that corresponds to layer **6** (L**6**) and performs a −π/4 phase conversion on the auxiliary qubit AQ**2**, a second T gate T**2** that corresponds to layer **6** (L**6**) and performs π/4 phase transformation of the control qubit CQ**3**, and a fourth CNOT gates CNOT**4** that corresponds to layer **7** (L**7**) and performs the Pauli-X operation on the control qubit CQ**3** based on the auxiliary qubit AQ**2**.

[0123] The quantum gate group QGG may includes: corresponding to the layer **1** (L**1**), a third H gate H**3** that performs Hadamard transformation on the auxiliary qubit AQ**1** initialized to the |0> state; corresponding to the layer **2** (L**2**), a ninth CNOT gate CNOT**9** performs Pauli-X operation on the control qubit CQ**2** based on the auxiliary qubit AQ**1**; corresponding to layer **3** (L**3**), a fifth inverse T gate IT**5** that performs −π/4 phase transformation on the control qubit CQ**2** and a fifth T gate T**5** that performs π/4 phase transformation on the auxiliary qubit AQ**1**; corresponding to layer **4** (L**4**), a tenth CNOT gate CNOT**10** that performs Pauli-X operation on the control qubit CQ**2** based on the control qubit CQ**1**; corresponding to layer **5** (L**5**), an eleventh CNOT gate CNOT**11** that performs Pauli-X operation on the auxiliary qubit AQ**1** based on the control qubit CQ**1**; corresponding to the layer **6** (L**6**), a sixth T gate T**6** that performs π/4 phase transformation on the control qubit CQ**2** and a sixth inverse T gate (IT**6**) that performs −π/4 phase transformation on the auxiliary qubit AQ**1**; corresponding to the layer **7** (L**7**), a twelfth CNOT gate CNOT**12** that performs Pauli-X operation on the control qubit CQ**2** based on the auxiliary qubit AQ**1**; corresponding to a layer **8** (L**8**), a fourth H gate H**4** that performs Hadamard transformation on the auxiliary qubit AQ**1**; and, corresponding to a layer **9** (L**9**), a thirteenth CNOT gate CNOT**13** that performs Pauli-X operation on the auxiliary qubit AQ**2** based on the auxiliary qubit AQ**1**. The quantum gate group QGG may further includes: corresponding to a layer **10** (L**10**), a fifth H gate H**5** that performs Hadamard transformation on the auxiliary qubit AQ**1**; corresponding to a layer **11** (L**11**), a fourteenth CNOT gate CNOT**14** that performs Pauli-X operation on the control qubit CQ**2** based on the auxiliary qubit AQ**1**; corresponding to a layer **12** (L**12**), a seventh inverse T gate IT**7** that performs −π/4 phase transformation on the control qubit CQ**2** and a seventh T gate T**5** that performs π/4 phase transformation on the auxiliary qubit AQ**1**; corresponding to a layer **13** (L**13**), a fifteenth CNOT gate CNOT**15** that performs Pauli-X operation on the control qubit CQ**2** based on the control qubit CQ**1**; corresponding to a layer **14** (L**14**), an sixteenth CNOT gate CNOT**16** that performs Pauli-X operation on the auxiliary qubit AQ**1** based on the control qubit CQ**1**; corresponding to a layer **15** (L**15**), a eighth T gate T**8** that performs π/4 phase transformation on the control qubit CQ**2** and a eighth inverse T gate (IT**8**) that is perform −π/4 phase transformation on the auxiliary qubit AQ**1**; corresponding to a layer **16** (L**16**), a seventeenth CNOT gate CNOT**17** performs Pauli-X operation on the control qubit CQ**2** based on the auxiliary qubit AQ**1**; and, corresponding to a layer **17** (L**17**) a sixth H gate H**6** that performs Hadamard transformation on the auxiliary qubit AQ**1**.

[0124] The second auxiliary circuit AC**2** may include, corresponding to the layer **11** (L**11**), a fifth CNOT gate CNOT**5** that performs Pauli-X operation on the control qubit CQ**3** based on the auxiliary qubit AQ**2**, corresponding to the layer **12** (L**12**), a third T gate T**3** that performs π/4 phase transformation on the auxiliary qubit AQ**2** and a third inverse T gate IT**3** that performs a −π/4 phase transformation on the control qubit CQ**3**, corresponding to the layer **13** (L**13**), a sixth CNOT gate CNOT**6** that performs Pauli-X operation on the auxiliary qubit AQ**2** based on the target qubit TQ, corresponding to the layer **14** (L**14**), a seventh CNOT gate TNOT**7** that performs Pauli-X operation on the control qubit CQ**3** based on the target qubit TQ, corresponding to a layer **15** (L**15**), a fourth inverse T gate (IT**4**) that performs −π/4 phase transformation on the auxiliary qubit AQ**2** and a fourth T gate T**4** that performs a π/4 phase transformation of the control qubit CQ**3**, corresponding to the layer **16** (L**16**), an eighth CNOT gate CNOT**8** that performs a Pauli-X operation on the control qubit CQ**3** based on an auxiliary qubit AQ**2**, and, corresponding to the layer **17** (L**17**), a second H gate H**2** that performs Hadamard transformation on the target qubit TQ.

[0125] When implementing a quantum circuit with quantum logic gates having a CNOT gate or single qubit gates (H gate, T gate inverse T gate, etc.), N−1 auxiliary qubits are needed to implement a multi-controlled NOT gate with N control qubits. In this case, a circuit depth P of layers corresponding to the T gate or the inverse T gate (hereinafter, T-circuit depth) may be expressed by Equation 4.

$$P = 4(\lceil \log_2(N+1) \rceil - 1) \quad \text{[Equation 4]}$$

[0126] For example, for the quantum circuit **800**, it is a multi-controlled NOT gate with 3 control qubits, and the

T-circuit depth is 4. T-circuit depth can be used as an important indicator to dictate the speed of coupling tolerant quantum computing.

[0127] Referring to FIG. **8**, a quantum logic gate (i.e., a Toffoli gate) having three gates of FIG. **2** may be expressed as a CNOT gate or quantum logic gates having single qubit gates (H gate, T gate inverse T gate, etc.). This may enable a multi-controlled NOT gate with N control qubits to be implemented using a relatively simpler quantum logic gate.

[0128] FIG. **9** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 3 control qubits according to an embodiment of the present disclosure.

[0129] Referring to FIG. **9**, the quantum circuit **900** may include a first auxiliary circuit AC**1**, a quantum gate group QGG, and a second auxiliary circuit AC**2**.

[0130] The first auxiliary circuit AC**1** may include: corresponding to a layer **1** (L**1**), a first H gate H**1** configured to perform Hadamard transformation on a target qubit TQ; corresponding to a layer **2** (L**2**), a first CNOT gate CNOT**1** configured to rotate a control qubit CQ**3** by π about the X axis based on a auxiliary qubit AQ**4** initialized to the |+> state; corresponding to a layer **3** (L**3**), a second CNOT gate CNOT**2** configured to rotate the auxiliary qubit AQ**3** initialized to the state |0> by π about an X axis based on a target qubit TQ; corresponding to a layer **4** (L**4**), a third CNOT gate CNOT**3** configured to rotate the target qubit TQ by π about a X axis based on the auxiliary qubit AQ**4**; corresponding to a layer **5** (L**5**), a fourth CNOT gate CNOT**4** configured to rotate the auxiliary qubit AQ**3** by π about the X axis based on the control qubit CQ**3**; corresponding to a layer **6** (L**6**), a first T gate T**1** configured to perform π/4 phase transformation on the auxiliary qubit AQ**3**, a second T gate T**2** configured to perform π/4 phase transformation on the auxiliary qubit AQ**4**, a first inverse T gate IT**1** configured to perform −π/4 phase transformation on the control qubit CQ**3**, and a second inverse T gate IT**2** configured to perform −π/4 phase transformation on the target qubit TQ; configured to a layer **7** (L**7**), a fifth CNOT gate CNOT**5** configured to rotate auxiliary qubit AQ**3** by π about the X axis based on the control qubit CQ**3**; corresponding to a layer **8** (L**8**), a sixth CNOT gate CNOT**6** configured to rotate the target qubit TQ by π about the X axis based on the auxiliary qubit AQ**4**; and, corresponding to a layer **9** (L**9**), a seventh CNOT gate CNOT**7** configured to rotate the control qubit CQ**3** by π about the X axis based on the auxiliary qubit AQ**4**.

[0131] The quantum gate group QGG may include: corresponding to the layer **1** (L**1**), a third H gate H**3** that performs Hadamard transformation on the auxiliary qubit AQ**1** initialized to the |0> state; corresponding to the layer **2** (L**2**), a 15th CNOT gate CNOT**15** that rotates the control qubit CQ**2** by π about the X axis based the auxiliary qubit AQ**1**; corresponding to the layer **3** (L**3**), a 16th CNOT gate CNOT**16** that rotates the auxiliary qubit AQ**2** initialized to the 0> state by π about an X axis based on a control qubit CQ**1**; corresponding to the layer **4** (L**4**), a 17th CNOT gate CNOT**17** that rotates the control qubit CQ**1** by π about X axis based on the auxiliary qubit AQ**1**; corresponding to the layer **5** (L**5**), an 18th CNOT Gate CNOT**18** that rotates the auxiliary qubit AQ**2** by π about the X axis based on the control qubit CQ**2**; corresponding to the layer **6** (L**6**), a fifth inverse T gate IT**5** that performs −π/4 phase transformation on the control qubit CQ**1**, a sixth inverse T gate T**6** that performs −π/4 phase transformation on the control qubit CQ**2**, a fifth T gate T**5** that performs π/4 phase transformation on the auxiliary qubit AQ**1**, and a sixth T gate T**6** that performs π/4 phase transformation on the auxiliary qubit AQ**2**; corresponding to the layer **7** (L**7**), nineteenth CNOT gate CNOT**19** that rotates the auxiliary qubit AQ**2** by π about the X axis based on the control qubit CQ**2**; corresponding to the layer **8** (L**8**), twentieth CNOT gate CNOT**20** that rotates the control qubit CQ**1** by π about the X axis based on the auxiliary qubit AQ**1**; corresponding to the layer **9** (L**9**), 21st CNOT Gate that rotates the control qubit CQ**2** by π about the X axis based on the auxiliary qubit AQ**1**; corresponding to a layer **10** (L**10**), a fourth H gate H**4** that performs Hadamard transformation on the auxiliary qubit AQ**1**; and, corresponding to a layer **11** (L**11**), 22nd CNOT gate CNOT**22** that rotates the auxiliary qubit AQ**4** by π about the X axis based on the auxiliary qubit AQ**1**. The quantum gate group QGG may further include: corresponding to a layer **12** (L**12**), a fifth H gate H**5** that performs Hadamard transformation on the auxiliary qubit A**1**; corresponding to a layer **13** (L**13**), a 23th CNOT gate CNOT**23** that rotates the control qubit CQ**2** by π about the X axis based on the auxiliary qubit AQ**1**; corresponding to a layer **14** (L**14**), a 24th CNOT gate CNOT**24** that rotates the control qubit CQ**1** by π about the X axis based on the auxiliary qubit AQ**1**; corresponding to a layer **15** (L**15**), a 25th CNOT gate CNOT**25** that rotates the auxiliary qubit AQ**2** by π about the X axis based on the control qubit CQ**2**; corresponding to a layer **16** (L**16**), a seventh inverse T gate IT**7** that performs −π/4 phase transformation on the control qubit CQ**1**, a eighth inverse T gate T**8** that performs −π/4 phase transformation on the control qubit CQ**2**, a seventh T gate T**7** that performs π/4 phase transformation on the auxiliary qubit AQ**1**, and a eighth T gate T**8** that performs π/4 phase transformation on the auxiliary qubit AQ**2**; corresponding to a layer **17** (L**17**), a 26th CNOT gate CNOT**26** that rotates the auxiliary qubit AQ**2** by π about the X axis based on the control qubit CQ**2**; a 27th CNOT gate CNOT**27** that rotates the control qubit CQ**1** by π about the X axis based on the auxiliary qubit AQ**1**; corresponding to a layer **19** (L**19**), a 28th CNOT gate CNOT**28** that rotates the auxiliary qubit AQ**2** by π about the X axis based on the control qubit CQ**1**; corresponding to a layer **20** (L**20**), a 29th CNOT gate CNOT**29** that rotates the control qubit CQ**2** by π about the X axis based on the auxiliary qubit AQ**1**; and, corresponding to a layer **21** (L**21**), a sixth H gate H**6** that performs Hadamard transformation on the auxiliary qubit AQ**1**.

[0132] The second auxiliary circuit AC**2** may includes: corresponding to the layer **13** (L**13**), an eighth CNOT gate CNOT**8** that rotates the control qubit CQ**3** by π about the X axis based on the auxiliary qubit AQ**4**; corresponding to the layer **24** (L**24**), a ninth CNOT gate CNOT**9** that rotates the target qubit TQ by π about the X axis based on the auxiliary qubit AQ**4**; corresponding to the layer **15** (L**15**), a tenth CNOT gate CNOT**10** that rotates the auxiliary qubit AQ**3** by π about the X axis based on the control qubit CQ**3**; corresponding to the layer **16** (L**16**), a third T gate T**3** that performs π/4 phase transformation on the auxiliary qubit AQ**3**, a fourth T gate T**4** that performs π/4 phase transformation on the auxiliary qubit AQ**4**, a third inverse T gate IT**3** that performs −π/4 phase transformation on the control qubit CQ**3**, and a fourth inverse T gate IT**4** that performs −π/4 phase transformation on the target qubit TQ; corresponding to the layer **17** (L**17**), an eleventh CNOT gate CNOT**11** that rotates the auxiliary qubit AQ**3** by π about the X axis based on the control qubit CQ**3**; corresponding to the layer **18** (L**18**), a twelfth CNOT gate CNOT**12** that rotates the target qubit TQ by π about the X axis based on the auxiliary qubit AQ**4**; corresponding to the layer **19** (L**19**), a thirteenth CNOT gate CNOT**13** that rotates the auxiliary qubit AQ**3** by π about the X axis based on the target qubit TQ; corresponding to the layer **20** (L**20**), fourteenth CNOT gate CNOT**14** that rotates control qubit CQ**3** by π about the X axis based on the auxiliary qubit AQ**3**; and, corresponding to the layer **21** (L**21**), a second H gate H**2** that perform Hadamard transformation on the target qubit TQ.

[0133] The layer **2** (L**2**) and the layer **3** (L**3**) of the quantum circuit **900** may correspond to the same circuit depth. The layer **4** (L**4**) and the layer **5** (L**5**) of the quantum circuit **900** may correspond to the same circuit depth. The layer **7** (L**7**) and the layer **8** (L**8**) of the quantum circuit **900** may correspond to the same circuit depth. The layer **14** (L**14**) and the layer **15** (L**15**) of the quantum circuit **900** may correspond to the same circuit depth. The layer **17** (L**17**) and the layer **18** (L**18**) of the quantum circuit **900** may correspond to the same circuit depth. The layer **19** (L**19**) and the layer **20** (L**20**) of the quantum circuit **900** may correspond to the same circuit depth.

[0134] When a multi-controlled NOT gate with N control qubits is implemented based on the quantum circuit **900**, 2(N−1) auxiliary qubits are required. In this case, the T-circuit depth Q may be expressed by Equation 5.

$$Q = 2(\lceil \log_2(N+1) \rceil - 1) \qquad \text{[Equation 5]}$$

[0135] The quantum circuit **900** has a similar aspect to the quantum circuit **800** described in FIG. **8**, but the T-circuit depth can be reduced by half while using double auxiliary qubits. As a result, the quantum circuit **900** can have a smaller T-circuit depth.

[0136] FIG. **10** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 3 control qubits according to an embodiment of the present disclosure.

[0137] Referring to FIG. **10**, the quantum circuit **1000** may include a first auxiliary circuit AC**1**, a quantum gate group QGG, and a second auxiliary circuit AC**2**.

[0138] The first auxiliary circuit AC**1** includes: corresponding to a layer a (L**1**), a first H gate H**1** configured to perform Hadamard transformation on an auxiliary qubit AQ**4** initialized to the |0> state and a second H gate H**2** configured to perform Hadamard transformation on a target qubit TQ; corresponding to a layer **2** (L**2**), a first CNOT gate CNOT**1** configured to rotate a control qubit CQ**3** by π about the X axis based on the auxiliary qubit AQ**4**; corresponding to a layer **3** (L**3**), a second CNOT gate CNOT**2** configured to rotate an auxiliary qubit AQ**3** initialized to the |0> state by r about the X axis based on a target qubit TQ; corresponding to a layer **4** (L**4**), a third CNOT gate CNOT**3** configured to rotate the target qubit TQ by r about the X axis based on the auxiliary qubit AQ**4**; corresponding to a layer **5** (L**6**), a fourth CNOT gate CNOT**4** configured to rotate the auxiliary qubit AQ**3** by π about the X axis based on the control qubit CQ**3**; corresponding to a layer **6** (L**6**), a first T gate T**1** configured to perform π/4 phase transformation on the auxiliary qubit AQ**3**, a second T gate T**2** configured to perform π/4 phase transformation on the auxiliary qubit AQ**4**, a first inverse T gate IT**1** configured to perform −π/4 phase transformation on the control qubit CQ**3** and a second inverse T gate IT**2** configured to perform −λ/4 phase transformation on the target qubit TQ; corresponding to a layer **7** (L**7**), a fifth CNOT gate CNOT**5** configured to rotate the auxiliary qubit AQ**3** by r about the X axis based on the control qubit CQ**3**; corresponding to a layer **8** (L**8**), a sixth CNOT gate CNOT**6** configured to rotate the target qubit TQ by π about the X axis based on the auxiliary qubit AQ**4**; and, corresponding to a layer **9** (L**9**), a seventh CNOT gate CNOT**7** configured to rotate the control qubit CQ**3** by r about X axis based on the auxiliary qubit AQ**4**.

[0139] The quantum gate group QGG may include: corresponding to the layer **1** (L**1**), a fifth H gate H**5** that performs Hadamard transformation on the auxiliary qubit AQ**1** initialized to the |0> state; corresponding to the layer **2** (L**2**), a fifteenth CNOT gate CNOT**15** that rotates the control qubit CQ**2** by π about the X axis based on the auxiliary qubit AQ**1**; corresponding to the layer **3** (L**3**), a sixteenth CNOT gate CNOT**16** that rotates the auxiliary qubit AQ**2** initialized to the 0> state by r about the X axis based on the control qubit CQ**1**; corresponding to the layer **4** (L**4**), a seventeenth CNOT gate CNOT**17** that rotates the control qubit CQ**1** by π about the X axis based on the auxiliary qubit AQ**1**; corresponding to the layer **5** (L**5**), an eighteenth CNOT Gate CNOT**18** that rotates the auxiliary qubit AQ**2** by π about the X axis based on the control qubit CQ**2**; corresponding to the layer **6** (L**6**), a fifth inverse T gate IT**5** that performs −π/4 phase transformation on the control qubit CQ**1**, a sixth inverse T gate T**6** that performs −1/4 phase transformation on the control qubit CQ**2**, a fifth T gate T**5** that performs π/4 phase transformation on the auxiliary qubit AQ**1**, and a sixth T gate T**6** which performs π/4 phase transformation on the auxiliary qubit AQ**2**; corresponding to the layer **7** (L**7**), a nineteenth CNOT gate CNOT**19** that rotates the auxiliary qubit AQ**2** by π about the X axis based on the control qubit CQ**2**; corresponding to the layer **8** (L**8**), a 20th CNOT gate CNOT**20** that rotates the control qubit CQ**1** by π about the X axis based on the auxiliary qubit AQ**1**; corresponding to the layer **9** (L**9**), a 21st CNOT gate CNOT**21** that rotates the control qubit CQ**2** by π about the X axis based on the auxiliary qubit AQ**1**; corresponding to a layer **10** (L**10**), a sixth H gate H**6** that performs Hadamard transformation on the auxiliary qubit AQ**1** and ninth H gate H**9** that performs Hadamard transformation on the auxiliary qubit AQ**4**; corresponding to a layer **11** (L**11**), a first CZ gate CZ**1** that rotates the auxiliary qubit AQ**4** by π about the Z axis based on the auxiliary qubit AQ**1**; and, corresponding to a layer **12** (L**12**), a seventh H gate H**7** that performs Hadamard transformation on the auxiliary qubit AQ**1** and tenth H gate H**10** that performs Hadamard transformation on the auxiliary qubit AQ**4**. The quantum gate group QGG may further include: corresponding to a layer **13** (L**13**), a 22nd CNOT gate CNOT**22** that rotates the control qubit CQ**2** by π about the X axis based on the auxiliary qubit AQ**1**; corresponding to a layer **14** (L**14**), a 23rd CNOT gate CNOT**23** that rotates the control qubit CQ**1** by π about the X axis based on the auxiliary qubit AQ**1**; corresponding to a layer **15** (L**15**), a 24th CNOT gate CNOT**24** that rotates the auxiliary qubit AQ**2** by π about the X axis based on the control qubit CQ**2**; corresponding to a layer **16** (L**16**), a seventh T gate T**7** that performs π/4 phase transformation on the control qubit CQ**1**, a eighth T gate T**8** that performs π/4 phase transformation on the control qubit CQ**2**, a seventh inverse T gate IT**7** that performs $-\pi/4$ phase transformation on the auxiliary qubit AQ**1**, and a eighth inverse T gate IT**8** which performs $-\pi/4$ phase transformation on the auxiliary qubit AQ**2**; corresponding to a layer **17** (L**17**), a 25th CNOT gate CNOT**25** that rotates the auxiliary qubit AQ**2** by π about the X axis based on the control qubit CQ**2**; corresponding to a layer **18** (L**18**), a 26th CNOT gate CNOT**26** that rotates the control qubit CQ**1** by π about the X axis based on the auxiliary qubit AQ**1**; corresponding to a layer **19** (L**19**), a 27th CNOT gate CNOT**27** that rotates the auxiliary qubit AQ**2** by π about the X axis based on the control qubit CQ**1**; corresponding to a layer **20** (L**20**), a 28th CNOT gate CNOT**28** that rotates the control qubit CQ**2** by π about the X axis based on the auxiliary qubit AQ**1**; corresponding to a layer **21** (L**21**), an eight H gate H**8** that performs Hadamard transformation on the auxiliary qubit AQ**1**.

[0140] The second auxiliary circuit AC**2** may includes: corresponding to the layer **13** (L**13**), an eighth CNOT gate CNOT**8** that rotates the control qubit CQ**3** by π about the X axis based on the auxiliary qubit AQ**4**; corresponding to the layer **14** (L**14**), a ninth CNOT gate CNOT**9** that rotates the target qubit TQ by π about the X axis based on the auxiliary qubit AQ**4**; corresponding to the layer **15** (L**15**), a tenth CNOT gate TNOT**10** that rotates the auxiliary qubit AQ**3** by π about the X axis based on the control qubit CQ**3**; corresponding to the layer **16** (L**16**), a third inverse T gate IT**3** that performs $-\pi/4$ phase transformation on the auxiliary qubit AQ**3**, a fourth inverse T gate IT**4** that performs $-\pi/4$ phase transformation on the auxiliary qubit AQ**4**, a third T gate T**3** that performs $\pi/4$ phase transformation on the control qubit CQ**3**, and a fourth T gate T**4** that performs $\pi/4$ phase transformation on the target qubit TQ; corresponding to the layer **17** (L**17**), an eleventh CNOT gate CNOT**11** that rotates the auxiliary qubit AQ**3** by π about the X axis based on the control qubit CQ**3**; corresponding to the layer **18** (L**18**), a twelfth CNOT gate CNOT**12** that rotates the targets qubit T Q by π about the X axis based on auxiliary qubits AQ**4**; corresponding to the layer **19** (L**19**) a thirteenth CNOT gate CNOT**13** that rotate the auxiliary qubit AQ**3** by π the X axis based on the target qubit TQ; corresponding to the layer **20** (L**20**), a fourteenth CNOT gate CNOT**14** that rotates the control qubit CQ**3** by π about the X axis based on the auxiliary qubit AQ**4**; and, corresponding to the layer **21** (L**21**), a third H gate that performs Hadamard transformation on the auxiliary qubit AQ**4** and a fourth H gate that performs Hadamard transformation on the target qubit TQ.

[0141] The layer **2** (L**2**) and the layer **3** (L**3**) of the quantum circuit **1000** may correspond to the same circuit depth. The layer **4** (L**4**) and the layer **5** (L**5**) of the quantum circuit **1000** may correspond to the same circuit depth. The layer **7** (L**7**) and the layer **8** (L**8**) of the quantum circuit **1000** may correspond to the same circuit depth. The layer **14** (L**14**) and the layer **15** (L**15**) of the quantum circuit **1000** may correspond to the same circuit depth. The layer **17** (L**17**) and the layer **18** (L**18**) of the quantum circuit **1000** may correspond to the same circuit depth. The layer **19** (L**19**) and the layer **20** (L**20**) of the quantum circuit **1000** may correspond to the same circuit depth.

[0142] The quantum circuit **1000** is similar to the quantum circuit **900** of FIG. **9**, but the auxiliary qubit AQ**4** is initialized to |0>. In addition, in the quantum circuit **1000**, the first CZ gate CZ**1** is disposed at a position of the 22nd CNOT gate CNOT**22** included in the quantum circuit **900** of FIG. **9**. In the quantum circuit **1000**, the inverse T gates IT**3** and IT**4** are disposed at the third T gate T**3** and the fourth T gate T**4** of the quantum circuit **900** in FIG. **9**, and the T gates T**3** and T**4** are disposed at a third inverse T gate IT**3** and a fourth inverse T gate T**4** in the quantum circuit **900**. In the quantum circuit **1000**, T gates T**7** and T**8** are disposed at positions of the seventh inverted T gate IT**7** and the eighth inverted T gate IT**8** of the quantum circuit **900** of FIG. **9**, respectively, and the inverted T gates IT**7** and IT**8** are disposed at the positions of the seventh T gate T**7** and the eighth T gate T**8** of the quantum Circuit **900** of FIG. **9**.

[0143] FIG. **11** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 5 control qubits according to an embodiment of the present disclosure.

[0144] Referring to FIG. **11**, the quantum circuit **1100** may include a first auxiliary circuit AC**1**, a quantum gate group QGG, and a second auxiliary circuit AC**2**.

[0145] The first auxiliary circuit AC**1** may include: corresponding to a layer **1** (L**1**), a first H gate H**1** configured to perform Hadamard transformation on the auxiliary qubit AQ**6** initialized to the |0> state and a second H gate H**2** configured to perform a Hadamard transformation on a target qubit TQ; corresponding to a layer **2** (L**2**), a first CNOT gate CNOT**1** configured to rotate the control qubit CQ**5** by π about the X axis based on the auxiliary qubit AQ**6**; a second CNOT gate CNOT**2** configured to rotate the auxiliary qubit AQ**5** initialized to the 0> state based on the target qubit TQ by π about to the X axis; corresponding to a layer **3** (L**3**), a third CNOT gate CNOT**3** configured to rotate the target qubit TQ by π about the X axis based on the auxiliary qubit AQ**6**; corresponding to a layer **5** (L**5**), a fourth CNOT gate CNOT**4** configured to rotate the auxiliary qubit AQ**5** by π about the X axis based on the control qubit CQ**5**; corresponding to a layer **6** (L**6**), a first T gate T**1** configured to perform $\pi/4$ phase transformation on the auxiliary qubit AQ**5**, a second T gate T**2** configured to perform r/4 phase transformation on the auxiliary qubit AQ**6**, a first inverse T gate IT**1** configured to perform $-\pi/4$ phase transformation on the control qubit CQ**5**, and a second inverse T gate IT**2** configured to perform $-\pi/4$ phase transformation on the target qubit TQ; corresponding to a layer **7**, a fifth CNOT gate CNOT**5** configured to rotate the auxiliary qubit AQ**5** by r about the X axis based on the control qubit CQ**5**; corresponding to a layer **8** (L**8**), a sixth CNOT gate CNOT**6** configured to rotate the target qubit TQ by π about the X axis based on the auxiliary qubit AQ**6**; and, corresponding to a layer **9** (L**9**), a seventh CNOT gate CNOT**7** configured to rotate the control qubit CQ**5** by r about the X axis based on the auxiliary qubit AQ**6**.

[0146] The quantum gate group QGG may includes:

[0147] corresponding the layer **1** (L**1**), a fifth H gate H**5** configured to perform Hadamard transformation on a auxiliary qubit AQ**1** initialized to the |0> state, and a sixth H gate H**6** configured to perform Hadamard transformation on an auxiliary qubit AQ**3** initialized to the 0> state;

[0148] corresponding to the layer **2** (L**2**), a fifteenth CNOT gate CNOT**15** configured to rotate a control qubit CQ**2** by π about the X axis based on the auxiliary qubit AQ**1**, and a sixteenth CNOT gate CNOT**16** configured to rotate a control qubit CQ**4** by π about the X axis based on the auxiliary the qubit AQ**3**;

[0149] corresponding to the layer **3** (L**3**), a seventeenth CNOT gate CNOT**17** configured to rotate the auxiliary qubit AQ**2** initialized to the |0> state by π about the X axis based on the control qubit CQ**1**, and an eighteenth CNOT gateway CNOT**18** configured to rotate an auxiliary qubit AQ**4** initialized to the 0> state by π about the X axis based on a control qubit CQ**3**;

[0150] corresponding to the layer **4** (L**4**), a nineteenth CNOT gate CNOT**19** configured to rotate the control qubit CQ**1** by π about the X axis based on the auxiliary qubit AQ**1**, and a twentieth CNOT gate CNOT**20** configured to rotate the control qubit CQ**3** by π about the X axis based on the auxiliary qubit AQ**3**;

[0151] corresponding to the layer **5** (L**5**), a 21st CNOT gate CNOT**21** configured to rotate the auxiliary qubit AQ**2** by π about the X axis based on the control qubit CQ**2**, and a 22nd CNOT gate CNOT**22** configured to rotate the auxiliary qubit AQ**4** by π about the X axis based on the control CQ**4**;

[0152] corresponding to the layer **6** (L**6**), a fifth inverse T gate IT**5** configured to perform −π/4 phase transformation on the control qubit CQ**1**, a sixth inverse T gate IT**6** configured to perform −π/4 phase transformation on the control qubit CQ**2**, a fifth T gate T**5** configured to perform π/4 phase transformation on the auxiliary qubit AQ**1**, a sixth T gate T**6** configured to perform π/4 Phase Transformation on the auxiliary qubit AQ**2**, a seventh inverse T gate IT**7** configured to perform −π/4 Phase transformation on the control qubit CQ**3**, an eighth inverse T gate IT**8** configured to perform −π/4 phase transformation on the control qubit CQ**4**, a seventh T gate T**7** configured to perform π/4 phase transformation on the auxiliary qubit AQ**3**, and an eighth T gate T**8** configured to perform π/4 phase transformation on the auxiliary qubit AQ**4**;

[0153] corresponding to the layer **7**, a 23rd CNOT gate CNOT**23** configured to rotate the auxiliary qubit AQ**2** by π about the X axis based on the control qubit CQ**2** and a 24th CNOT gate CNOT**24** configured to rotate the auxiliary qubit AQ**4** by π about the X axis to correspond to the layer **7**;

[0154] corresponding to the layer **8** (L**8**), a 25th CNOT gate CNOT**25** configured to rotate the control qubit CQ**1** by π about the X axis based on the auxiliary qubit AQ**1**, and a 26th CNOT gate CNOT**26** configured to rotate the control qubit CQ**3** by π about the X axis based on the auxiliary qubit AQ**3**;

[0155] corresponding to the layer **9** (L**9**), a 27th CNOT gate CNOT**27** configured to rotate the control qubit CQ**2** by π about the X axis based on the auxiliary qubit AQ**1**, and a 28th CNOT gate CNOT**28** configured to rotate the control qubit CQ**4** by π about the X axis based on the auxiliary qubit AQ**3**;

[0156] corresponding to a layer **10** (L**10**), a seventh H gate H**7** configured to perform Hadamard transformation on the auxiliary qubit AQ**1**, an eighth H gate H**8** configured to perform Hadamard transformation on an auxiliary qubit AQ**3**, and a ninth H gate H**9** configured to perform Hadamard transformation on auxiliary qubits AQ**6**;

[0157] corresponding to a layer **11** (L**11**), a 29th CNOT gate CNOT**29** configured to rotate an auxiliary qubit AQ**9** initialized to the |0> state by π about the X axis based on the auxiliary qubit AQ**3**;

[0158] corresponding to a layer **12** (L**12**), a 30th CNOT gate CNOT**30** configured to rotate an auxiliary qubit AQ**7** initialized to the |0> state by π about the X axis based on the auxiliary qubit AQ**1**;

[0159] corresponding to a layer **13** (L**13**), a 31st CNOT gate CNOT**31** configured to rotate an auxiliary qubit AQ**8** initialized to the |0> state by π about the X axis based on the auxiliary qubit AQ**3**;

[0160] corresponding to a layer **14** (L**14**), a 32nd CNOT gate CNOT**32** configured to rotate the auxiliary qubit AQ**9** by π about the X axis based on the auxiliary qubit AQ**6**;

[0161] corresponding to a layer **15** (L**15**), a 33rd CNOT gate CNOT**33** configured to rotate an auxiliary qubit AQ**10** initialized to the |0> state by π about the X axis based on the auxiliary qubit AQ**7**;

[0162] corresponding to a layer **16** (L**16**), a 34th CNOT gate CNOT**34** configured to rotate the auxiliary qubit AQ**8** by π about the X axis based on the auxiliary qubit AQ**1**;

[0163] corresponding to a layer **17** (L**17**), a 35th CNOT gate CNOT**35** configured to rotate the auxiliary qubit AQ**10** by π about the X axis based on the auxiliary qubit AQ**6**;

[0164] corresponding to a layer **18** (L**18**), a 36th CNOT gate CNOT**36** configured to rotate the auxiliary qubit AQ**7** by π about the X axis based on the auxiliary qubit AQ**9**;

[0165] corresponding to a layer **19** (L**19**), a ninth T gate T**9** configured to perform π/4 phase transformation on the auxiliary qubit AQ**1**, a tenth T gate T**10** configured to perform π/4 phase transformation on the auxiliary qubit AQ**3**, an eleventh T gate T**11** configured to perform **7***r*/4 phase transformation on the auxiliary qubit AQ**6**, a twelfth T gate T**12** configured to perform π/4 phase transformation on the auxiliary qubit AQ**7**, a ninth inverse T gate IT**9** configured to perform −π/4 phase transformation on the auxiliary qubit AQ**8**, a tenth inverse T gate IT**10** configured to perform −π/4 Phase Transformation on the auxiliary qubit AQ**9**, and an eleventh inverse T gate IT**11** that performs −π/4 phase transformation on the auxiliary qubit AQ**10**;

[0166] corresponding to a layer **20** (L**20**), a 37th CNOT gate CNOT**37** configured to rotate the auxiliary qubit AQ**7** by π about the X axis based on the auxiliary qubit AQ**9**;

[0167] corresponding to a layer **21** (L**21**), a 38th CNOT gate CNOT**38** configured to rotate the auxiliary qubit AQ**10** by π about the X axis based on the auxiliary qubit AQ**6**;

[0168] corresponding to a layer **22** (L**22**), a 39th CNOT gate CNOT**39** configured to rotate the auxiliary qubit AQ**8** by π about the X axis based on the auxiliary qubit AQ**1**;

[0169] corresponding to a layer **23** (L**23**), a 40th CNOT gate CNOT**40** configured to rotate the auxiliary qubit AQ**10** by π about the X axis based on the auxiliary qubit AQ**7**;

[0170] corresponding to a layer **24** (L**24**), a 41st CNOT gate CNOT**41** configured to rotate the auxiliary qubit AQ**9** by π about the X axis based on the auxiliary qubit AQ**6**;

[0171] corresponding to a layer **25** (L**25**), a 42nd CNOT gate CNOT**42** configured to rotate the auxiliary qubit AQ**8** by π about the X axis based on the auxiliary qubit AQ**3**;

[0172] corresponding to a layer **26** (L**26**), a 43rd CNOT gate CNOT**43** configured to rotate the auxiliary qubit AQ**7** by π about the X axis based on the auxiliary qubit AQ**1**;

[0173] corresponding to a layer **27** (L**27**), a 44th CNOT gate CNOT**44** configured to rotate the auxiliary qubit AQ**9** by π about the X axis based on the auxiliary qubit AQ**3**;

[0174] corresponding to a layer **28** (L**28**), a tenth H gate H**10** configured to perform Hadamard transformation on the auxiliary qubit AQ**1**, an eleventh H gate H**11** configured to perform Hadamard transformation on the auxiliary qubit AQ**3**, and a twelfth H gate H**12** configured to perform Hadamard transformation on the auxiliary qubit AQ**6**;

[0175] corresponding to a layer **29** (L**29**), a 45h CNOT gate CNOT**45** configured to rotate the control qubit CQ**2** by π about the X axis based on the auxiliary qubit AQ**1** and a 46th CNOT gate CNOT**46** configured to rotate the control qubit CQ**4** by π about the X axis based on the auxiliary qubit AQ**3**;

[0176] corresponding to a layer **30** (L**30**), a 47h CNOT gate CNOT**47** configured to rotate the control qubit CQ**1** by π about the X axis based on the auxiliary qubit AQ**1**, and a 48th CNOT gate CNOT**48** configured to rotate the control qubit CQ**3** by π about the X axis based on the auxiliary qubit AQ**3**;

[0177] corresponding to a layer **31** (L**31**), a 49th CNOT gate CNOT**49** configured to rotate the auxiliary qubit AQ**2** by π about the X axis based on the control qubit CQ**2**, and a 50th CNOT gate CNOT**50** configured to rotate the auxiliary qubit AQ**4** by π about the X axis based on the control-qubit CQ**4**;

[0178] corresponding to a layer **32** (L**32**), a thirteenth T gate T**13** configured to perform π/4 phase transformation on the control qubit CQ**1**, a fourteenth T gate T**14** configured to perform π/4 phase transformation on the control qubit CQ**2**, a twelfth inverse T gate IT**12** configured to perform −π/4 phase transformation on the auxiliary qubit AQ**1**, a thirteenth inverse T gate IT**13** configured to perform −π/4 phase transformation on the auxiliary qubit AQ**2**, a fifteenth T gate T**15** configured to perform π/4 phase transformation on the control qubit CQ**3***a* sixteenth T gate T**16** configured to perform π/4 phase transformation on the control qubit CQ**4**, a fourteenth inverse T gate IT**14** configured to perform −π/4 phase transformation on the auxiliary qubit AQ**3**, and a fifteenth inverse T gate IT**15** configured to perform −π/4 phase transformation on the auxiliary qubit AQ**4**;

[0179] corresponding to a layer **33** (L**33**), a 51st CNOT gate CNOT**51** configured to rotate the auxiliary qubit AQ**2** by π about the X axis based on the control qubit CQ**2**, and a 52nd CNOT gate CNOT**52** configured to rotate the auxiliary qubit AQ**4** by π about the X axis based on the control qubit CQ**4**;

[0180] corresponding to a layer **34** (L**34**), a 53rd CNOT gate CNOT**53** configured to rotate the control qubit CQ**1** by π about the X axis based on the auxiliary qubit AQ**1**, and a 54th CNOT gate CNOT**54** configured to rotate the control qubit CQ**3** by π about the X axis based on the auxiliary qubit AQ**3**;

[0181] corresponding to a layer **35** (L**35**), a 55th CNOT gate CNOT**55** configured to rotate the auxiliary qubit AQ**2** by π about the X axis based on the control qubit CQ**1**, and a 56th CNOT gate CNOT**56** configured to rotate the auxiliary qubit AQ**4** by π about the X axis based on the control qubit CQ**3**;

[0182] corresponding to a layer **36** (L**36**), a 57th CNOT gate CNOT**57** configured to rotate the control qubit CQ**2** by π about the X axis based on the auxiliary qubit AQ**1**, and a 58th CNOT gate CNOT**58** configured to rotate the control qubit CQ**4** by π about the X axis based on the auxiliary-qubit AQ**3**;

[0183] corresponding to the layer **37** (L**37**), a thirteenth H gate H**13** configured to perform Hadamard transformation on the auxiliary qubit AQ**1** and a fourteenth H gate H**14** configured to perform Hadamard transformation on an auxiliary qubit AQ**3**.

[0184] The second auxiliary circuit AC**2** may include: corresponding to the layer **29** (L**29**), an eighth CNOT gate CNOT**8** configured to rotate the control qubit CQ**5** by π about the X axis based on the auxiliary qubit AQ**6**; corresponding to the layer **30** (L**30**), a ninth CNOT gate CNOT**9** configured to rotate the target qubit TQ by π about the X axis based on an auxiliary qubit AQ**6**; corresponding to the layer **31** (L**31**), a tenth CNOT gate CNOT**10** configured to rotate the auxiliary qubit AQ**5** by π about the X axis based on the control qubit CQ**5**; corresponding to the layer **32** (L**32**), a third inverse T gate IT**3** configured to perform −π/4 phase transformation on the auxiliary qubit AQ**5**, a fourth inverse T gate T**4** configured to perform −π/4 phase transformation on the auxiliary qubit AQ**6**, a third T gate T**3** configured to perform π/4 phase transformation on the control qubit CQ**5**, and a fourth T gate T**4** configured to perform π/4 phase transformation on the target qubit TQ; corresponding to the layer **33** (L**33**), an eleventh CNOT gate CNOT**11** configured to rotate the auxiliary qubit AQ**5** by π about the X axis based on the control qubit CQ**5**; corresponding to the layer **34** (L**34**), a twelfth CNOT gate CNOT**12** configured to rotate the target qubit TQ by π about the X axis based on the auxiliary qubit AQ**6**; corresponding the layer **35** (L**35**), a thirteenth CNOT gate CNOT**13** configured to rotate the auxiliary qubit AQ**5** by π about the X axis based on the target qubit TQ; corresponding to the layer **36** (L**36**), fourteenth CNOT gate CNOT**14** configured to rotate the control qubit CQ**5** by π about the X axis based on the auxiliary qubit AQ**6**; and, corresponding to the layer **37** (L**37**), a third H gate H**3** configured to perform Hadamard transformation on an auxiliary qubit AQ**6**, and a fourth H gate H**4** configured to perform Hadamard transformation on the target qubit TQ.

[0185] The layer **2** (L**2**) and the layer **3** (L**3**) may correspond to the same circuit depth. The layer **4** (L**4**) and the layer **5** (L**5**) may correspond to the same circuit depth. The layer **7** (L**7**) and the layer **8** (L**8**) may correspond to the same circuit depth. The layer **11** (L**11**) and the layer **12** (L**12**) may correspond to the same circuit depth. The layer **13** (L**13**), the layer **14** (L**14**), and the layer **15** (L**15**) may correspond to the same circuit depth. The layer **16** (L**16**), the layer **17** (L**17**), and the layer **18** (L**18**) may correspond to the same circuit depth. The layer **20** (L**20**), the layer **21** (L**21**), and the layer **22** (L**22**) may correspond to the same circuit depth. The layer **23** (L**23**), the layer **24** (L**24**), and the layer **25** (L**25**) may correspond to the same circuit depth. The layer **26**

(L**26**) and the layer **27** (L**27**) may correspond to the same circuit depth. The layer **30** (L**30**) and the layer **33** (L**31**) may correspond to the same circuit depth. The layer **33** (L**33**) and the layer **34** (L**34**) may correspond to the same circuit depth. The layer **35** (L**35**) and the layer **36** (L**36**) may correspond to the same circuit depth. Layers corresponding to the same circuit depth may be performed in parallel with each other.

[0186] In the quantum circuit **1100**, the layer **6** (L**6**), the layer **19** (L**19**), and the layer **32** (L**32**) are layers corresponding to T gates or inverse T gates. The quantum circuit **1100** may have 10 auxiliary qubits AQ**1**-AQ**10** and have a T-circuit depth of 3 while implementing a multi-controlled NOT gate with 5 control qubits.

[0187] FIG. **12** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 3 control qubits according to an embodiment of the present disclosure.

[0188] Referring to FIG. **12**, the quantum circuit **1200** may include a first auxiliary circuit AC**1**, a quantum gate group QGG, and a measurement area MA.

[0189] In implementing the multi-controlled NOT gate with N control qubits, the first auxiliary circuit AC**1** may correspond to one or more initial layers of the plurality of layers and may perform controlled NOT operation on the target qubit based on an Nth control qubit from among the N control qubits and a first auxiliary qubit initialized to a |+> state from among the plurality of auxiliary qubits.

[0190] The quantum gate group QGG may correspond to the plurality of layers and may perform controlled NOT operation on the first auxiliary qubit based on the first to (N−1)th control qubits.

[0191] The measurement area MA may correspond to the last one or more layers of the plurality of layers and may include one or more measurement circuits that measure the state of one or more auxiliary qubits, and one or more conditional operation circuits that perform a conditional operation based on a measurement result of the one or more measurement circuits.

[0192] Hereinafter, in FIGS. **12** to **15**, the first auxiliary circuit AC**1** may include a first Toffoli gate TG**1**.

[0193] The first Toffoli gate TG**1** corresponds to the layer **1** (L**1**), and may rotate the target qubit TQ by π about the X axis based on the auxiliary qubit AQ**2** initialized to the |+> state and the control qubit CQ**3**.

[0194] The quantum gate group QGG may include: corresponding to the first layer **1** (L**1**), a second Toffoli gate TG**2** configured to rotate a auxiliary qubit AQ**1** initialized to the |0> state by π about the X axis based on a control qubit CQ**1** and a control qubit CQ**2** corresponding to the layer **1** (L**1**); and, and, corresponding to a layer **2** (L**2**), a first CNOT gate CNOT**1** configured to rotate the auxiliary qubit AQ**2** by π about the X axis based on the auxiliary qubit AQ**1**.

[0195] The measurement area MA may include a first measurement circuit MC**1** that measures the auxiliary qubit AQ**1** on the X basis and a second measurement circuit MC**2** that measures the auxiliary qubit AQ**2** on the Z basis corresponding to the layer **3** (L**3**).

[0196] The measurement area MA may include a first conditional operation circuit COC**1** that performs an operation based on a measurement result of the first measurement circuit MC**1** and a second conditional operation circuit COC**2** that performs an operation based on a measurement result of the second measurement circuit MC**2** corresponding to the layer **4** (L**4**).

[0197] The first conditional operation circuit COC**1** may include a first CZ gate CZ**1** configured to rotate the control qubit CQ**2** by π about the Z axis based on the control qubit CQ**1**. When the measurement result of the first measurement circuit MC**1** is 0, the first conditional operation circuit COC**1** does not perform a predetermined operation. When the measurement result of the first measurement circuit MC**1** is 1, the first conditional operation circuit COC**1** performs the predetermined operation. In this case, the operation of the first CZ gate CZ**1** may be performed.

[0198] The second conditional operation circuit COC**2** may include a second CNOT gate CNOT**2** configured to rotate the target qubit TQ by π about to the X axis based on the control qubit CQ**3**. When the measurement result of the second measurement circuit MC**2** is 0, the second conditional operation circuit COC**2** does not perform a predetermined operation. When the measurement result of the second measurement circuit MC**2** is 1, the second conditional operation circuit COC**2** performs the predetermined operation. In this case, the operation of the second CNOT gate CNOT**2** may be performed.

[0199] When compared with the quantum circuit **200** of FIG. **2**, the quantum circuit **1200** may include the measurement area MA to reduce the circuit depth of the Toffoli gate from 3 to 1. At this time, the circuit depth of the measurement circuit is additionally required to be 1. The number of auxiliary qubits required in the quantum circuit **1200** is 2.

[0200] FIG. **13** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 5 control qubits according to an embodiment of the present disclosure.

[0201] Referring to FIG. **13**, the quantum circuit **1300** may include a first Toffoli gate TG**1**, a quantum gate group QGG, and a measurement region MA.

[0202] The first Toffoli gate TG**1** corresponds to the layer **1** (L**1**), and may rotate the target qubit TQ by π about the X axis based on the auxiliary qubit AQ**3** initialized to the |+> state and the control qubit CQ**5**.

[0203] The quantum gate group QGG may include, corresponding to the layer **1** (L**1**), a second Toffoli gate TG**2** configured to rotate the auxiliary qubit AQ**1** initialized to the |0> state by π about the X axis based on a control qubit CQ**1** and a control qubit CQ**2**, and a third Toffoli gates TG**3** configured to rotate the auxiliary qubit AQ**2** by π about the X axis based on control qubits CQ**3** and CQ**4**. The quantum gate group QGG may include, corresponding to a layer **2** (L**2**), a fourth Toffoli gate TG**4** configured to rotate the auxiliary qubit AQ**1** by π about the X axis based on the auxiliary qubit AQ**1** and the auxiliary qubit AQ**3**.

[0204] The measurement area MA may include a first measurement circuit MC**1** that measures the auxiliary qubit AQ**1** on the X basis, a second measurement circuit MC**2** that measures the auxiliary qubit AQ**2** on the X basis, and a third measurement circuit MC**3** that measures the auxiliary qubit AQ**3** on the Z basis, corresponding to a layer **3** (L**3**).

[0205] The measurement area MA may include a first conditional operation circuit COC**1** that performs an operation based on a measurement result of the first measurement circuit MC**1**, a second conditional operation circuit COC**2** that performs an operation based on a measurement result of a second measurement circuit MC**2**, and a third conditional operation circuit COC**3** that performs an operation based on the measurement result of the third measurement circuit MC**3**, corresponding to a layer **4** (L**4**).

[0206] The first conditional operation circuit COC**1** may include a first CZ gate CZ**1** configured to rotate the control qubit CQ**2** by π about the Z axis based on the control qubit CQ**1**. When the measurement result of the first measurement circuit MC**1** is 0, the first conditional operation circuit COC**1** does not perform a predetermined operation. When the measurement result of the first measurement circuit MC**1** is 1, the first conditional arithmetic circuit COC**1** performs the predetermined operation. In this case, the operation of the first CZ gate CZ**1** may be performed.

[0207] The second conditional arithmetic circuit COC**2** may include a second CZ gate CZ**2** configured to rotate the control qubit CQ**4** by π about the Z axis based on the control qubit CQ**3**. When the measurement result of the second measurement circuit MC**2** is 0, the second conditional operation circuit COC**2** does not perform a predetermined operation. When the measurement result of the second measurement circuit MC**2** is 1, the second conditional operation circuit COC**2** performs the predetermined operation. In this case, the operation of the second CZ gate CZ**2** may be performed.

[0208] The third conditional operation circuit COC**3** may include a first CNOT gate CNOT**1** configured to rotate the target qubit TQ by π about the X axis based on the control qubit CQ**5**. When the measurement result of the third measurement circuit MC**3** is 0, the third conditional operation circuit COC**3** does not perform a predetermined operation. When the measurement result of the third measurement circuit MC**3** is 1, the third conditional operation circuit COC**3** performs the predetermined operation. In this case, the operation of the first CNOT gate CNOT**1** may be performed.

[0209] When compared with the quantum circuit **200** of FIG. **2**, the quantum circuit **1200** may include the measurement area MA to reduce the circuit depth of the Toffoli gate from 3 to 1. At this time, the circuit depth of the measurement circuit is additionally required to be 1. The number of auxiliary qubits required in the quantum circuit **1200** is 2.

[0210] When compared with the quantum circuit **300** of FIG. **3**, the quantum circuit **1300** may include the measurement area MA to reduce the circuit depth of the Toffoli gate from 3 to 2. At this time, the circuit depth of the measurement circuit is additionally required to be 1. The number of auxiliary qubits required in the quantum circuit **1200** is 3.

[0211] FIG. **14** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 7 control qubits according to an embodiment of the present disclosure.

[0212] Referring to FIG. **14**, the quantum circuit **1400** may include a first Toffoli gate TG**1**, a quantum gate group QGG, and a measurement area MA.

[0213] The first Toffoli gate TG**1** corresponds to a layer **1** (L**1**), and may rotate the target qubit TQ by π about the X axis based on an auxiliary qubit AQ**6** initialized to the |+> state and a control qubit CQ**7**.

[0214] The quantum gate group QGG may include, corresponding to the layer a (L**1**), a second Toffoli gate TG**2** configured to rotate the auxiliary qubit AQ**1** initialized to the |0> state by π about the X axis based on a control qubit CQ**1** and a control qubit CQ**2**, a third Toffoli gate TG**3** configured to rotate the auxiliary qubit AQ**2** initialized to the 0> state by π about the Z axis based on a control qubit CQ**3** and a control qubit CQ**4**, and a fourth Toffoli gate TG**4** configured to rotate the auxiliary qubit A Q**5** initialized to the O> state by π about the X axis based on a control qubit CQ**5** and a controlling qubit CQ**6**.

[0215] The quantum gate group QGG may include corresponding to a layer **2** (L**2**), a fourth Toffoli gate TG**4** configured to rotate an auxiliary qubit AQ**3** initialized to a |0> state by π about the X axis based on the auxiliary qubits AQ**1** and AQ**2** and a fifth Toffoli gates TG**5** configured to rotate the auxiliary qubits AQ**6** initialized to |+> states by π about to the X axis based on the auxiliary qubit AQ**4** and the auxiliary qubit AQ**5**.

[0216] The quantum gate group QGG may include a first CNOT gate CNOT**1** configured to rotate the auxiliary qubit AQ**4** by π about the X axis based on the auxiliary qubit AQ**3** corresponding to a layer **3** (L**3**).

[0217] The measurement area MA may include a first measurement circuit MC**1** that measures the auxiliary qubit AQ**3** on the X basis and a second measurement circuit MC**2** that measures the auxiliary qubit AQ**4** on the Z basis corresponding to the layer **4** (L**4**).

[0218] The measurement area MA may include a first conditional operation circuit COC**1** that performs an operation based on a measurement result of the first measurement circuit MC**1** and a second conditional operation circuit COC**2** that performs an operation on the based on a measurement result of a second measurement circuit MC**2** corresponding to the layer **5** (L**5**).

[0219] The first conditional operation circuit COC**1** may include a first CZ gate CZ**1** that rotates the auxiliary qubit AQ**2** by π about the Z axis based on the auxiliary qubit AQ**1**. When the measurement result of the first measurement circuit MC**1** is 0, the first conditional operation circuit COC**1** does not perform a predetermined operation. When the measurement result of the first measurement circuit MC**1** is 1, the first conditional operation circuit COC**1** performs a predetermined operation. In this case, the operation of the first CZ gate CZ**1** may be performed.

[0220] The second conditional operation circuit COC**2** may include a second CNOT gate CNOT**2** configured to rotate the auxiliary qubit AQ**6** by π about the X axis based on the auxiliary qubit AQ**5**. When the measurement result of the second measurement circuit MC**2** is 0, the second conditional operation circuit COC**2** does not perform a predetermined operation. When the measurement result of the second measurement circuit MC**2** is 1, the second conditional operation circuit COC**2** performs the predetermined operation. In this case, the operation of the second CNOT gate CNOT**2** may be performed.

[0221] The measurement area MA may include, corresponding to a layer **6** (L**6**), a third measurement circuit MC**3** that measures the auxiliary qubit AQ**1** on the X basis, a fourth measurement circuit MC**4** that measures the auxiliary qubit AQ**2** on the X basis, a fifth measurement circuit MC**5** that measures the auxiliary qubit AQ**5** on the X basis, and a sixth measurement circuit MC**6** that measures the auxiliary qubit AQ**6** on the Z basis.

[0222] The measurement area MA may include a third conditional operation circuit COC**3** that performs an operation based on a measurement result of the third measurement circuit MC**3**, a fourth conditional operation circuit COC**4** that performs an operation according to a measurement result of a fourth measurement circuit MC**4**, a fifth conditional operation circuit CoC**5** that performs an operation based on the measurement result of the fifth measurement circuit MC**5**, and a sixth conditional operation circuit coC**6** that performs an operation of the sixth measurement circuit MC**6** corresponding to a layer **7** (L**7**).

[0223] The third conditional operation circuit COC**3** may include a second CZ gate CZ**2** configured to rotate the control qubit CQ**2** by π about the Z axis based on the control qubit CQ**1**. When the measurement result of the third measurement circuit MC**3** is 0, the third conditional operation circuit COC**3** does not perform a predetermined operation. When the measurement result of the third measurement circuit MC**3** is 1, the third conditional operation circuit COC**3** performs the predetermined operation. In this case, the operation of the second CZ gate CZ**2** may be performed.

[0224] The fourth conditional arithmetic circuit COC**4** may include a third CZ gate CZ**3** configured to rotate the control qubit CQ**4** by π about the Z axis based on the control qubit CQ**3**. When the measurement result of the fourth measurement circuit MC**4** is 0, the fourth conditional operation circuit COC**4** does not perform a predetermined operation. When the measurement result of the fourth measurement circuit MC**4** is 1, the fourth conditional operation circuit COC**4** performs the predetermined operation. In this case, the operation of the third CZ gate CZ**3** may be performed.

[0225] The fifth conditional computation circuit COC**5** may include a fourth CZ gate CZ**4** configured to rotate the control qubit CQ**6** by π about the Z axis based on the control qubit CQ**5**. When the measurement result of the fifth measurement circuit MC**5** is 0, the fifth conditional operation circuit COC**5** does not perform a predetermined operation. When the measurement result of the fifth measurement circuit MC**5** is 1, the fifth conditional operation circuit COC**5** performs predetermined operation. In this case, the operation of the fourth CZ gate CZ**4** may be performed.

[0226] The sixth conditional arithmetic circuit COC**6** may include a third CNOT gate CNOT**3** configured to rotate the target qubit TQ by π about the X axis based on the control qubit CQ**7**. When the measurement result of the sixth measurement circuit MC**6** is 0, the sixth conditional operation circuit COC**6** does not perform a predetermined operation. When the measurement result of the sixth measurement circuit MC**6** is 1, the sixth conditional operation circuit COC**6** performs the predetermined operation. In this case, the operation of the third CNOT gate CNOT**3** may be performed.

[0227] The quantum circuit **1400** may include the measurement area MA to reduce the circuit depth of the Toffoli gate from 5 to 2. At this time, the circuit depth of the measurement circuit is 2. The quantum circuit **1400** requires six auxiliary qubits.

[0228] FIG. **15** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 7 control qubits according to an embodiment of the present disclosure.

[0229] Referring to FIG. **15**, the quantum circuit **1500** may include a first Toffoli gate TG**1**, a quantum gate group QGG, and a measurement area MA.

[0230] The first Toffoli gate TG**1** corresponds to the layer **1** (L**1**), and may rotate the target qubit TQ by π about the X axis based on an auxiliary qubit AQ**6** initialized to the |+> state and a control qubit CQ**7**.

[0231] The quantum gate group QGG may include, corresponding to a layer **1** (L**1**), a second Toffoli gate TG**2** configured to rotate the auxiliary qubit AQ**1** initialized to the |0> state by π about the X axis based on the control qubit CQ**1** and the control qubit CQ**2**, a third Toffoli gate TG**3** configured to rotate a auxiliary qubit AQ**3** initialized to the 0> state by π about the X axis based on a control qubit CQ**3** and a control qubit CQ**4**, and a fourth Toffoli gate TG**4** configured to rotate an auxiliary qubit AQ**7** initialized to the O> state by π about the X axis based on a control qubit CQ**5** and a control qubit CQ**6**.

[0232] The quantum gate group QGG may further include, corresponding to a layer **2** (L**2**), a fifth Toffoli gate TG**5** configured to rotate an auxiliary qubit AQ**5** initialized to the |0> state by π about the X axis based on an auxiliary qubits AQ**2** initialized to |+> states and an auxiliary qubit AQ**4** initialized to |+> states, and a sixth Toffoli gates TG**6** configured to rotate an auxiliary qubits AQ**9** initialized to the 0> by a π about the X axis w based on an auxiliary qubit AQ**6** initialized to the +> state and an auxiliary qubit AQ**8** initialized to the +> state.

[0233] The quantum gate group QGG may further include, corresponding to a layer **3** (L**3**), a first CNOT gate CNOT**1** configured to rotate the auxiliary qubit AQ**1** by π about the X axis based on the auxiliary qubit AQ**2**, a second CNOT gate CNOT**2** configured to rotate the auxiliary qubit AQ**3** by π about the X axis based on the auxiliary qubit AQ**4**, a third CNOT gate CNOT**3** configured to rotate the auxiliary qubit AQ**7** by π about the X axis based on the auxiliary qubit AQ**8**, and a fourth CNOT gates CNOT**4** configured to rotate the auxiliary qubits AQ**9** by π about the X axis based on the auxiliary qubits AQ**10**.

[0234] The quantum gate group QGG may further include, corresponding to a layer **4** (L**4**), a first measurement circuit MC**1** that measures an auxiliary qubit AQ**1** on the Z basis, a second measurement circuit MC**2** that measures an auxiliary qubit AQ**3** on the Z basis, a third measurement circuit MC**3** that measures an auxiliary qubit AQ**7** on the Z basis, and a fourth measurement circuit MC**4** that measures an auxiliary qubit AQ**10** on the X basis.

[0235] The quantum gate group QGG may further include, corresponding to a layer **5** (L**5**), a layer **6** (L**6**), and a layer **7** (L**7**), a first conditional operation circuit COC**1** that performs an operation based on a measurement result of the first measurement circuit MC**1**, a second conditional operation circuit COC**2** that performs an operation based on a measurement result of a second measurement circuit MC**2**, a third conditional operation circuit COC**3** that performs an operation based on a measurement result of the third measurement circuit MC**3**, and a fourth conditional operation circuit COC**4** that performs an operation based on a measurement result of the fourth measurement circuit MC**4**.

[0236] The first conditional operation circuit COC**1** may include, corresponding to the layer **7** (L**7**), a first X gate X**1** configured to rotate the auxiliary qubit AQ**2** by π about the X axis and a fifth CNOT gate CNOT**5** configured to rotate the auxiliary qubit AQ**5** by π about the X axis based on the auxiliary qubit AQ**4**. When the measurement result of the first measurement circuit MC**1** is 0, the first conditional operation circuit COC**1** does not perform a predetermined operation. When the measurement result of the first measurement circuit MC**1** is 1, the first conditional operation circuit COC**1** performs the predetermined operation.

[0237] The second conditional operation circuit COC**2** may include a second X gate X**2** configured to rotate the auxiliary qubit AQ**4** by π about the X axis corresponding to the layer **5** (L**5**) and a sixth CNOT gate CNOT**6** configured to rotate the auxiliary qubit AQ**5** by π about the X axis based on the auxiliary qubit AQ**2** corresponding to the layer **6** (L**6**). When the measurement result of the second measurement circuit MC**2** is 0, the second conditional operation circuit COC**2** does not perform a predetermined operation. When the measurement result of the second measurement circuit MC**2** is 1, the second conditional operation circuit COC**2** performs the predetermined operation.

[0238] The third conditional operation circuit COC**3** may include a third X gate X**3** configured to rotate the auxiliary qubit AQ**8** by π about the X axis corresponding to the layer **6** (L**6**) and a seventh CNOT gate CNOT**7** configured to rotate the auxiliary qubit AQ**9** by π about the X axis based on the auxiliary qubit AQ**6** corresponding to the layer **7** (L**7**). When the measurement result of the third measurement circuit MC**3** is 0, the third conditional operation circuit COC**3** does not perform a predetermined operation. When the measurement result of the third measurement circuit MC**3** is 1, the third conditional operation circuit COC**3** performs the predetermined operation.

[0239] The fourth conditional operation circuit COC**4** may include a first CZ gate CZ**1** configured to rotate the auxiliary qubit AQ**8** by π about the Z axis based on the auxiliary qubit AQ**6** corresponding to the layer **5** (L**5**) and a first Z gate XZ configured to rotate the auxiliary qubit AQ**9** by π about the Z axis. When the measurement result of the fourth measurement circuit MC**4** is 0, the fourth conditional operation circuit COC**4** does not perform a predetermined operation. When the measurement result of the fourth measurement circuit MC**4** is 1, the fourth conditional operation circuit COC**4** performs the predetermined operation.

[0240] The quantum gate group QGG may further include an eighth CNOT gate CNOT**8** configured to rotate the auxiliary qubit AQ**6** by π about the X axis based on the auxiliary qubit AQ**5** corresponding to the layer **8** (L**8**).

[0241] The measurement area MA may include, corresponding to a layer **9** (L**9**), a fifth measurement circuit MC**5** that measures the auxiliary qubit AQ**5** on the X basis and a sixth measurement circuit MC**6** that measures the auxiliary qubit AQ**6** on the Z basis.

[0242] The measurement area MA may include, corresponding to a layer **10** (L**10**), a fifth conditional operation circuit COC**5** that performs an operation based on a measurement result of the fifth measurement circuit MC**5** and a sixth conditional operation circuit COC**6** that performs an operation based on a measurement result of a sixth measurement circuit MC**6**.

[0243] The fifth conditional operation circuit COC**5** may include a second CZ gate CZ**2** configured to rotate the auxiliary qubit AQ**4** by π about the Z axis based on the auxiliary qubit AQ**2**. When the measurement result of the fifth measurement circuit MC**5** is 0, the fifth conditional circuit COC**5** does not perform a predetermined operation. When the measurement result of the fifth measurement circuit MC**5** is 1, the fifth conditional operation circuit COC**5** performs the predetermined operation. In this case, the operation of the second CZ gate CZ**2** may be performed.

[0244] The sixth conditional computation circuit COC**6** may include a ninth CNOT gate CNOT**9** configured to rotate the auxiliary qubit AQ**9** by π about the X axis based on the auxiliary qubit AQ**8**. When the measurement result of the sixth measurement circuit MC**6** is 0, the sixth conditional operation circuit COC**6** does not perform a predetermined operation. When the measurement result of the sixth measurement circuit MC**6** is 1, the sixth conditional operation circuit COC**6** performs the predetermined operation. In this case, the operation of the ninth CNOT gate CNOT**9** may be performed.

[0245] The measurement area MA may include, corresponding to a layer **11** (L**11**) a seventh measurement circuit MC**7** that measures the auxiliary qubit AQ**2** on the X basis, an eighth measurement circuit MC**8** that measures the auxiliary qubit AQ**4** on the X basis, a ninth measurement circuit MC**9** that measures the auxiliary qubit AQ**8** on the X basis, and a tenth measurement circuit MC**10** that measures the auxiliary qubit AQ**9** on the Z basis.

[0246] The measurement area MA may include, corresponding to a layer **12** (L**12**), a seventh conditional operation circuit COC**7** that performs an operation based on a measurement result of the seventh measurement circuit MC**7**, an eighth conditional operation circuit COC**8** that performs an operation based on a measurement result of an eighth measurement circuit MC**8**, a fifth conditional operation circuit COC**9** that performs an operation based on a measurement result of a ninth measurement circuit MC**9**, and a tenth conditional operation circuit COC**10** that performs an operation based on a measurement result of the tenth measurement circuit MC**10**.

[0247] The seventh conditional arithmetic circuit COC**7** may include a third CZ gate CZ**3** configured to rotate the control qubit CQ**2** by π about the Z axis based on the control qubit CQ**1**. When the measurement result of the seventh measurement circuit MC**7** is 0, the seventh conditional operation circuit COC**7** does not perform a predetermined operation. When the measurement result of the seventh measurement circuit MC**7** is 1, the seventh operation arithmetic circuit COC**7** performs the predetermined operation. In this case, the operation of the third CZ gate CZ**3** may be performed.

[0248] The eighth conditional computation circuit COC**8** may include a fourth CZ gate CZ**4** configured to rotate the control qubit CQ**4** by π about the Z axis based on the control qubit CQ**3**. When the measurement result of the eighth measurement circuit MC**8** is 0, the eighth conditional operation circuit COC**8** does not perform a predetermined operation. When the measurement result of the eighth measurement circuit MC**8** is 1, the eighth conditional operation circuit COC**8** performs the predetermined operation. In this case, the operation of the fourth CZ gate CZ**4** may be performed.

[0249] The ninth conditional computation circuit COC**9** may include a fifth CZ gate CZ**5** configured to rotate the control qubit CQ**6** by π about the Z axis based on the control qubit CQ**5**. When the measurement result of the ninth measurement circuit MC**9** is 0, the ninth conditional operation circuit COC**9** does not perform a predetermined operation. When the measurement result of the ninth measurement circuit MC**9** is 1, the ninth conditional operation circuit COC**9** performs the predetermined operation. In this case, the operation of the fifth CZ gate CZ**5** may be performed.

[0250] The tenth conditional operation circuit COC**10** may include a tenth CNOT gate CNOT**10** configured to rotate the target qubit TQ by π about the X axis based on the control qubit CQ**7**. When the measurement result of the tenth measurement circuit MC**10** is 0, the tenth conditional operation circuit COC**10** does not perform a predetermined operation. When the measurement result of the tenth measurement circuit MC**10** is 1, the tenth conditional operation circuit COC**10** performs the predetermined operation. In this case, the operation of the tenth CNOT gate CNOT**10** may be performed.

[0251] The layer **1** (L**1**) and the layer **2** (L**2**) may correspond to the same circuit depth. The quantum circuit **1500** may reduce a circuit depth of a Toffoli gate to 1 by using gate teleportation. At this time, the measurement circuit depth is 3, and 10 auxiliary qubits are required.

[0252] Extending the quantum circuit **1500** may implement a multi-controlled NOT gate with N control qubits where the circuit depth of the Toffoli gate is 1. At this time, 2(N−2) or smaller auxiliary qubits are required. The measurement circuit depth R can be represented by Equation 6.

$$R = 2(\lceil \log_2(N+1) \rceil - 3) \quad \text{[Equation 6]}$$

[0253] FIG. **16** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT with 3 control qubits gate according to an embodiment of the present disclosure.

[0254] Referring to FIG. **16**, the quantum circuit **1600** may include a first auxiliary circuit AC**1**, a quantum gate group QGG, and a measurement area MA.

[0255] The first auxiliary circuit AC**1** may include: corresponding to a layer (L**1**), a first CH gate **CH1** configured to perform controlled Hadamard transformation on a auxiliary qubit AQ**2** initialized to the |+> state based on a control qubit CQ**3**; corresponding to a layer **2** (L**2**), a first CNOT gate CNOT**1** configured to rotate a target qubit TQ by π about the X axis based on the auxiliary qubit AQ**2**; and, corresponding to a layer **3** (L**3**), a second CH gate CH**2** configured to perform controlled Hadamard transformation on the auxiliary qubit AQ**2** based on the control qubit CQ**3**.

[0256] The quantum gate set QGG may include: corresponding to the layer **1** (L**1**), a third CH gate CH**3** configured to perform controlled Hadamard transformation on a auxiliary qubit AQ**1** initialized to |0> based on a control qubit CQ**2**; corresponding to the layer **2** (L**2**), a first CZ gate **CZ1** configured to rotate the auxiliary qubit AQ**1** by π about the Z axis based on a control qubit CQ**1**; corresponding to a fourth CH gate **CH4** configured to perform controlled Hadamard transformation on the auxiliary qubit AQ**1** based on the control qubit CQ**2**; and, corresponding to a layer **4** (L**4**), a second CZ gate C Z**2** configured to rotate the auxiliary qubit AQ**2** by π about the Z axis based on the auxiliary qubit AQ**1**.

[0257] The measurement area MA may include a first measurement circuit MC**1** that measures the auxiliary qubit AQ**1** on the X basis and a second measurement circuit MC**2** that measures the auxiliary qubit AQ**2** on the Z basis corresponding to a layer **5** (L**5**).

[0258] The measurement area MA may include a first conditional operation circuit COC**1** that performs an operation based on a measurement result of the first measurement circuit MC**1** and a second conditional operation circuit COC**2** that performs an operation based on a measurement result of a second measurement circuit MC**2** corresponding to a layer **6** (L**6**).

[0259] The first conditional arithmetic circuit COC**1** may include a third CZ gate CZ**3** configured to rotate the control qubit CQ**2** by π about the Z axis based on the control qubit CQ**1**. When the measurement result of the first measurement circuit MC**1** is 0, the first conditional operation circuit COC**1** does not perform a predetermined operation. When the measurement result of the first measurement circuit MC**1** is 1, the first conditional operation circuit COC**1** performs the predetermined operation. In this case, the operation of the third CZ gate CZ**3** may be performed.

[0260] The second conditional operation circuit COC**2** may include a second CNOT gate CNOT**2** configured to rotate the target qubit TQ by π about the X axis based on the control qubit CQ**3**. When the measurement result of the second measurement circuit MC**2** is 0, the second conditional operation circuit COC**2** does not perform a predetermined operation. When the measurement result of the second measurement circuit MC**2** is 1, the second conditional operation circuit COC**2** performs the predetermined operation. In this case, the operation of the second CNOT gate CNOT**2** may be performed.

[0261] FIG. **17** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 5 control qubits according to an embodiment of the present disclosure.

[0262] Referring to FIG. **17**, the quantum circuit **1700** may include a first auxiliary circuit AC**1**, a quantum gate group QGG, and a measurement region MA.

[0263] The first auxiliary circuit AC**1** may include: corresponding to a layer (L**1**), a first CH gate CH**1** configured to perform controlled Hadamard transformation on a auxiliary qubit AQ**3** initialized to the +> state based on a control qubit CQ**5**; corresponding to a layer **2** (L**2**), a first CNOT gate CNOT**1** configured to rotate a target qubit TQ by π about the X axis based on the auxiliary qubit AQ**3**; and, corresponding to a layer **3** (L**3**), a second CH gate CH**2** configured to perform controlled Hadamard transformation on the auxiliary qubit AQ**3** based on the control qubit CQ**5**.

[0264] The quantum gate group QGG may include: corresponding to the layer **1** (L**1**), a third CH gate CH**3** configured to perform a controlled Hadamard transformation on a auxiliary qubit AQ**1** initialized to the |0> state based on a control qubit CQ**2**, and a fourth CH gate CH**4** configured to perform controlled Hadamard transformation on a auxiliary qubit AQ**2** initialized to the state |0> based on a control qubit CQ**4**.

[0265] The quantum gate group QGG may further include, corresponding to the layer **2** (L**2**), a first CZ gate **CZ1** configured to rotate the auxiliary qubit AQ**1** by π about the Z axis based on a control qubit CQ**1**, and a second CZ gate CZ**2** configured to rotate the auxiliary qubit AQ**2** by π about the Z axis based on a control qubit CQ**3**.

[0266] The quantum gate group QGG may further include, corresponding to the layer **3** (L**3**), a fifth CH gate CH**5** configured to perform controlled Hadamard transformation on the auxiliary qubit AQ**1** based on the control qubit CQ**2**, and a sixth CH gate CH**6** configured to perform controlled Hadamard transformation on the auxiliary qubit AQ**2** based on the control qubit CQ**4**.

[0267] The quantum gate group QGG may further include, corresponding to a layer **4** (L**4**), a first CS gate CS**1** configured to rotate the auxiliary qubit AQ**3** by n/2 about the Z axis based on the auxiliary qubit AQ**2**.

[0268] The quantum gate group QGG may further include, corresponding to a layer **5** (L**5**), a second CNOT gate CNOT**2** configured to rotate the auxiliary qubit AQ**2** by π about the X axis based on the auxiliary qubit AQ**1**.

[0269] The quantum gate group QGG may further include, corresponding to a layer **6** (L**6**), a first inverse CS gate ICS**1** configured to rotate the auxiliary qubit AQ**3** by $-\pi/2$ about the Z axis based on the auxiliary qubit AQ**2**.

[0270] The quantum gate group QGG may further include, corresponding to a layer **7** (L**7**), a third CNOT gate CNOT**3** configured to rotate the auxiliary qubit AQ**2** by π about the X axis based on the auxiliary qubit AQ**1**.

[0271] The quantum gate group QGG may further include, corresponding to a layer **8** (L**8**), a second CS gate CS**2** configured to rotate the auxiliary qubit AQ**3** by $-\pi/2$ abut the Z axis based on the auxiliary qubit AQ**1**.

[0272] The measurement area MA may include, corresponding to a layer **9** (L**9**), a first measurement circuit MC**1** that measures the auxiliary qubit AQ**1** on the X basis, a second measurement circuit MC**2** that measures the auxiliary qubit AQ**2** on the X basis, and a third measurement circuit MC**3** that measures the auxiliary qubit AQ**3** on the Z basis.

[0273] The measurement area MA may include, corresponding to a layer **10** (L**10**), a first conditional operation circuit COC**1** that performs an operation based on a measurement result of the first measurement circuit MC**1**, a second conditional operation circuit COC**2** that performs an operation based on a measurement result of the second measurement circuit MC**2**, and a third conditional operation circuit COC**3** that performs an operation based on a measurement result of the third measurement circuit MC**3**.

[0274] The first conditional arithmetic circuit COC**1** may include a third CZ gate CZ**3** configured to rotate the control qubit CQ**2** by π about the Z axis based on the control qubit CQ**1**. When the measurement result of the first measurement circuit MC**1** is 0, the first conditional operation circuit COC**1** does not perform a predetermined operation. When the measurement result of the first measurement circuit MC**1** is 1, the first conditional operation circuit COC**1** performs the predetermined operation. In this case, the operation of the third CZ gate CZ**3** may be performed.

[0275] The second conditional arithmetic circuit COC**2** may include a fourth CZ gate CZ**4** configured to rotate the control qubit CQ**4** by π about the Z axis based on the control qubit CQ**3**. When the measurement result of the second measurement circuit MC**2** is 0, the second conditional operation circuit COC**2** does not perform a predetermined operation. When the measurement result of the second measurement circuit MC**2** is 1, the second conditional operation circuit COC**2** performs the predetermined operation. In this case, the operation of the fourth CZ gate CZ**4** may be performed.

[0276] The third conditional operation circuit COC**3** may include a first CNOT gate CNOT**1** configured to rotate the target qubit TQ by π about the X axis based on the control qubit CQ**5**. When the measurement result of the third measurement circuit MC**3** is 0, the third conditional operation circuit COC**3** does not perform a predetermined operation. When the measurement result of the third measurement circuit MC**3** is 1, the third conditional operation circuit COC**3** performs the predetermined operation. In this case, the operation of the fourth CNOT gate CNOT**4** may be performed.

[0277] FIG. **18** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 7 control qubits according to an embodiment of the present disclosure.

[0278] Referring to FIG. **18**, the quantum circuit **1700** may include a first auxiliary circuit AC**1**, a quantum gate group QGG, and a measurement area MA.

[0279] The first auxiliary circuit AC**1** may include: corresponds to a layer **1** (L**1**), a first inverted CH gate ICH**1** configured to perform inverted-controlled Hadamard transformation on a auxiliary qubit AQ**8** initialized to the |+> state based on the control qubit CQ**7**; corresponding to a layer **2** (L**2**), a first CNOT gate CNOT**1** configured to rotate a target qubit TQ by π about the X axis based on the auxiliary qubit AQ**6**; and, corresponding to a layer **3** (L**3**), a second inverted CH gate ICH**2** configured to perform inverted-controlled Hadamard transformation on the auxiliary qubit AQ**6** based on the control qubit CQ**7**.

[0280] The quantum gate group QGG may include, corresponding to the layer **1** (L**1**), a first CH gate CH**1** configured to perform controlled Hadamard transformation on a auxiliary qubit AQ**1** initialized to the |0> state based on a control qubit CQ**2**, a second CH gate CH**2** configured to perform controlled Hadamard transformation on a auxiliary qubit AQ**2** initialized to the state |0> based on a control qubit CQ**4**, and a third CH gate CH**3** configured to perform controlled Hadamard transformation on an auxiliary qubit AQ**5** initialized to the states 10> based on a control qubit CQ**6**.

[0281] The quantum gate group QGG may further include, corresponding to the layer **2** (L**2**), a first CZ gate CZ**1** configured to rotate the auxiliary qubit AQ**1** by π about the Z axis based on a control qubit CQ**1**, a second CZ gate CZ**2** configured to rotate the auxiliary qubit AQ**2** by π about the Z axis based on a control qubit CQ**3**, and a third CZ gate CZ**3** configured to rotate the auxiliary qubit AQ**5** by π about the Z axis based on a control qubit CQ**5**.

[0282] The quantum gate group QGG may further include, corresponding to the layer **3** (L**3**), a fourth CH gate CH**4** configured to perform controlled Hadamard transformation on the auxiliary qubit AQ**1** based on the control qubit CQ**2**, a fifth CH gate CH**5** configured to perform controlled Hadamard transformation on the auxiliary qubit AQ**2** based on the control qubit CQ**4**, and a sixth CH gate CH**6** configured to perform controlled Hadamard transformation on an auxiliary qubit AQ**5** based on the control qubit CQ**6**.

[0283] The quantum gate group QGG may further include, corresponding to a layer **4** (L**4**) a seventh CH gate CH**7** configured to perform controlled Hadamard transformation on the auxiliary qubit AQ**3** based on the auxiliary qubit AQ**2**, and a third inverted CH gate ICH**3** that configured to perform inverted-controlled Hadamard transformation on the auxiliary Qubit AQ**4** based on the auxiliary qubit AQ**5**.

[0284] The quantum gate group QGG may further include, corresponding to a layer **5** (L**5**), a fourth CZ gate CZ**4** configured to rotate the auxiliary qubit AQ**2** by π about the Z axis based on the auxiliary qubit AQ**1**, and a second CNOT gate CNOT**2** configured to rotate the auxiliary qubit AQ**6** by π about the X axis based on the auxiliary qubit AQ**4**.

[0285] The quantum gate group QGG may further include, corresponding to a layer **6** (L**6**) an eighth CH gate CH**8** configured to perform controlled Hadamard transformation on the auxiliary qubit AQ**3** based on the auxiliary qubit AQ**2**, and a fourth inverted CH gate ICH**4** configured to perform inverted-controlled Hadamard transformation on the auxiliary Qubit AQ**4** based on the auxiliary qubit AQ**5**.

[0286] The quantum gate group QGG may further include a third CNOT gate CNOT**3** configured to rotate the auxiliary qubit AQ**4** by π about the X axis based on the auxiliary qubit AQ**3**.

[0287] The measurement area MA may include, corresponding to a layer **8** (L**8**), a first measurement circuit MC**1** that measures the auxiliary qubit AQ**5** on the X basis and a second measurement circuit MC**2** that measures the auxiliary qubit AQ**6** on the Z basis.

[0288] The measurement area MA may further include, corresponding to a layer **9** (L**9**), a first conditional operation circuit COC**1** that performs an operation based on a measurement result of the first measurement circuit MC**1** and a second conditional operation circuit COC**2** that performs an operation based on a measurement result of a second measurement circuit MC**2** corresponding to the layer **9L9**.

[0289] The first conditional operation circuit COC**1** may include a fifth CZ gate CZ**5** configured to rotate the auxiliary qubit AQ**3** by **7**t about the Z axis based on the auxiliary qubit AQ**1**. When the measurement result of the first measurement circuit MC**1** is 0, the first conditional operation circuit COC**1** does not perform a predetermined operation. When the measurement result of the first measurement circuit MC**1** is 1, the first conditional operation circuit COC**1** performs the predetermined operation. In this case, the operation of the fifth CZ gate CZ**5** may be performed.

[0290] The second conditional operation circuit COC**2** may include a fourth CNOT gate CNOT**4** configured to rotate the auxiliary qubit AQ**6** by π about the X axis based on the auxiliary qubit AQ**5**. When the measurement result of the second measurement circuit MC**2** is 0, the second conditional operation circuit COC**2** does not perform a predetermined operation. When the measurement result of the second measurement circuit MC**2** is 1, the second conditional operation circuit COC**2** performs the predetermined operation. In this case, the operation of the fourth CNOT gate CNOT**4** may be performed.

[0291] The measurement area MA may further include, corresponding to a layer **10** (L**10**), a third measurement circuit MC**3** that measures the auxiliary qubit AQ**1** on the X basis, a fourth measurement circuit MC**4** that measures the auxiliary qubit AQ**2** on the X basis, a fifth measurement circuit MC**5** that measures the auxiliary qubit AQ**5** on the X basis, and a sixth measurement circuit MC**6** that measures the auxiliary qubit AQ**6** on the Z basis.

[0292] The measurement area MA may further include, corresponding to the layer **11** (L**11**) a third conditional operation circuit COC**3** that performs an operation based on a measurement result of the third measurement circuit MC**3**, a fourth conditional operation circuit COC**4** that performs an operation based on a measurement result of a fourth measurement circuit MC**4**, a fifth conditional operation circuit COC**5** that performs an operation based on a measurement result of the fifth measurement circuit MC**5**, and a sixth conditional operation circuit COC**6** that performs an operation based on a measurement result of a sixth measurement circuit MC**6**.

[0293] The third conditional arithmetic circuit COC**3** may include a sixth CZ gate CZ**6** that rotates the control qubit CQ**2** by π about the Z axis based on the control qubit CQ**1**. When the measurement result of the third measurement circuit MC**3** is 0, the third conditional operation circuit COC**3** does not perform a predetermined operation. When the measurement result of the third measurement circuit MC**3** is 1, the third conditional operation circuit COC**3** performs the predetermined operation. In this case, the operation of the sixth CZ gate CZ**6** may be performed.

[0294] The fourth conditional arithmetic circuit COC**4** may include a seventh CZ gate CZ**7** that rotates the control qubit CQ**4** by π about the Z axis based on the control qubit CQ**3**. When the measurement result of the fourth measurement circuit MC**4** is 0, the fourth conditional operation circuit COC**4** does not perform a predetermined operation. When the measurement result of the fourth measurement circuit MC**4** is 1, the fourth conditional operation circuit COC**4** performs the predetermined operation. In this case, the operation of the seventh CZ gate CZ**7** may be performed.

[0295] The ninth conditional computation circuit COC**9** may include an eighth CZ gate CZ**8** that rotates the control qubit CQ**6** by π about the Z axis based on the control qubit CQ**5**. When the measurement result of the fifth measurement circuit MC**5** is 0, the ninth conditional operation circuit COC**9** does not perform a predetermined operation. When the measurement result of the fifth measurement circuit MC**5** is 1, the ninth conditional operation circuit COC**9** performs the predetermined operation. In this case, the operation of the eighth CZ gate CZ**8** may be performed.

[0296] The tenth conditional operation circuit COC**10** may include a fifth CNOT gate CNOT**5** that rotates the target qubit TQ by π about the X axis based on the control qubit CQ**7**. When the measurement result of the sixth measurement circuit MC**6** is 0, the tenth conditional operation circuit COC**10** does not perform a predetermined operation. When the measurement result of the sixth measurement circuit MC**6** is 1, the tenth conditional operation circuit COC**10** performs the predetermined operation. In this case, the operation of the fifth CNOT gate CNOT**5** may be performed.

[0297] The quantum circuit **1800** has a 2 qubit circuit depth of 9 and a measurement circuit depth of 2. The number of auxiliary qubits used in the quantum circuit **1800** is 6.

[0298] Generalizing the configuration of the quantum circuit **1800**, N−1 auxiliary qubits are needed when implementing a multi-controlled NOT gate with N control qubits. When a multi-controlled NOT gate with N control qubits is implemented based on the structure of the quantum circuit **1800**, the 2 qubit circuit depth S and the measurement circuit depth T can be expressed by Equations (7) and (8), respectively.

$$S = 4\lceil \log_2(N+1) \rceil - 3 \quad \text{[Equation 7]}$$

$$T = \lceil \log_2(N+1) \rceil - 1 \quad \text{[Equation 8]}$$

[0299] FIG. **19** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 5 control qubits according to an embodiment of the present disclosure.

[0300] Referring to FIG. **19**, the quantum circuit **1900** may include a first auxiliary circuit AC**1**, a quantum gate group QGG, and a measurement region MA.

[0301] The first auxiliary circuit AC**1** of the quantum circuit **1900** corresponds to the first auxiliary circuit AC**1** of the quantum circuit **1100** described with reference to FIG. **11**. The quantum gate group QGG of the quantum circuit **1900** corresponds to the quantum gate group QGG of the quantum circuit **1100** described in FIG. **11**. However, the quantum gate group QGG of the quantum circuit **1900** corresponds to only a configuration included in the layer **1** (L**1**) to the layer **27** (L**27**) in the quantum circuit **1100**. The quantum gate group QGG of the quantum circuit **1900** may further include a fourth H gate H**4** configured to perform Hadamard transformation on the target qubit TQ corresponding to a layer **10** (L**10**). The fourth H gate H**4** corresponds to the fourth H gate H**4** of the quantum circuit **1100**.

[0302] The measurement area MA may include a first measurement circuit MC**1** that measures the auxiliary qubit AQ**1** on the X basis, a second measurement circuit MC**2** that measures the auxiliary qubit AQ**3** on the X basis, and a third measurement circuit MC**3** that measures the auxiliary qubit AQ**6** on the X basis corresponding to a layer **28** (L**28**).

[0303] The measurement area MA may further include a first conditional operation circuit COC**1** that performs an operation based on a measurement result of the first measurement circuit MC**1**, a second conditional operation circuit CoC**2** that performs an operation based on a measurement result of a second measurement circuit MC**2**, and a third conditional operation circuit COC**3** that performs an operation based on a measurement result of the third measurement circuit MC**3** corresponding to a layer **29** (L**29**).

[0304] The first conditional arithmetic circuit COC**1** may include a first CZ gate CZ**1** configured to rotate the control qubit CQ**2** by π about the Z axis based on the control qubit CQ**1**. When the measurement result of the first measurement circuit MC**1** is 0, the first conditional operation circuit COC**1** does not perform a predetermined operation. When the measurement result of the first measurement circuit MC**1** is 1, the first conditional operation circuit COC**1** performs the predetermined operation. In this case, the operation of the first CZ gate CZ**1** may be performed.

[0305] The second conditional arithmetic circuit COC**2** may include a second CZ gate CZ**2** configured to rotate the control qubit CQ**4** by π about the Z axis based on the control qubit CQ**3**. When the measurement result of the second measurement circuit MC**2** is 0, the second conditional operation circuit COC**2** does not perform a predetermined operation. When the measurement result of the second measurement circuit MC**2** is 1, the second conditional operation circuit COC**2** performs the predetermined operation. In this case, the operation of the second CZ gate CZ**2** may be performed.

[0306] The third conditional operation circuit COC**3** may include a first CNOT gate CNOT**1** configured to rotate the target qubit TQ by π about the X axis based on the control qubit CQ**5**. When the measurement result of the third measurement circuit MC**3** is 0, the third conditional operation circuit COC**3** does not perform a predetermined operation. When the measurement result of the third measurement circuit MC**3** is 1, the third conditional operation circuit COC**3** performs the predetermined operation. In this case, the operation of the first CNOT gate CNOT**1** may be performed.

[0307] FIG. **20** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 7 control qubits according to an embodiment of the present disclosure.

[0308] Referring to FIG. **20**, the quantum circuit **2000** may include a first auxiliary circuit AC**1**, a quantum gate group QGG, and a measurement area MA.

[0309] The first auxiliary circuit AC**1** may include a first H gate H**1**, first to eighth CNOT gates CNOT**1**-CNOT**8**, first to second T gates T**1** and T**2**, and first to second inverse T gates IT**1** and IT**2**.

[0310] The quantum gate group QGG may include second to twelfth H gates H**2**-H**12**, ninth to 56th CNOT gates CNOT**9**-CNOT**56**, third to 12th T gates T**3**-T**12**, third to 12th inverse T gates IT**3**-IT**12**, first to fourth measurement circuits MC**1**-MC**4**, first to third X gates X**1**-X**3**, a first CZ gate CZ**1**, and a first Z gate Z**1**.

[0311] The quantum gate group QGG may include first to fourth conditional arithmetic circuits COC**1**-COC**4**. The first conditional operation circuit COC**1** performs an operation based on the measurement result of the first measurement circuit MC**1**, and may include a third X gate X**3** and a 54th CNOT gate CNOT**54**. The second conditional operation circuit COC**2** performs an operation based on the measurement result of the second measurement circuit MC**2**, and may include a first X gate X**1** and a 53rd CNOT gate CNOT**53**. The third conditional operation circuit COC**3** performs an operation based on the measurement result of the third measurement circuit MC**3**, and may include a second X gate X**2** and a 54th CNOT gate CNOT**54**. The fourth conditional operation circuit COC**4** performs an operation based on the measurement result of the fourth measurement circuit MC**4**, and may include a first Z gate Z**1** and a first CZ gate CZ**1**.

[0312] The measurement area MA may include fifth to tenth measurement circuits MC**5**-MC**10** and fifth to tenth conditional operation circuits COC**5**-COC**10**. The fifth conditional arithmetic circuit COC**5** may include a second CZ gate CZ**2**. The sixth conditional arithmetic circuit COC**6** may include a 57th CNOT gate CNOT**57**. The seventh conditional arithmetic circuit COC**7** may include a third CZ gate CZ**3**. The eighth conditional arithmetic circuit COC**8** may include a fourth CZ gate CZ**4**. The ninth conditional arithmetic circuit COC**9** may include a fifth CZ gate CZ**5**. The tenth conditional computation circuit COC**10** may include a 58th CNOT gate CNOT**58**.

[0313] The quantum circuit **2000** may have a T-circuit depth of 1 due to the application of gate teleportation. The measurement circuit depth of the quantum circuit **2000** is 3. When a configuration method of the quantum circuit **2000** is generalized, 3(N−1) or less auxiliary qubits are required, and the measurement circuit depth V may be expressed by Equation 9.

$$V = 2\lceil \log_2(N+1) \rceil - 3 \quad \text{[Equation 9]}$$

[0314] FIG. **21** is a circuit diagram illustrating an example of a quantum circuit for implementing a multi-controlled NOT gate with 3 control qubits according to an embodiment of the present disclosure.

[0315] Referring to FIG. **21**, the quantum circuit **2100** may include a plurality of quantum logic gates corresponding to a plurality of layers L**1**-L**17**.

[0316] The quantum circuit **2100** may include, corresponding to a layer **1** (L**1**), a first H gate H**1** configured to perform Hadamard transformation on a target qubit TQ and a second H gate H**2** configured to perform Hadamard transformation on an auxiliary qubit AQ**1** initialized to the |0> state.

[0317] The quantum circuit **2100** may further include, corresponding to a layer **2** (L**2**), a first CNOT gate CNOT**1** configured to rotate a control qubit CQ**2** by π about the X axis based on the auxiliary qubit AQ**1**.

[0318] The quantum circuit **2100** may further include, corresponding to a layer **3** (L**3**), a second CNOT gate CNOT**2** configured to rotate a control qubit CQ**3** by π about the X axis based on a control qubit CQ**1** and a third CNOT gate CNOT**3** configured to rotate a auxiliary qubit AQ**2** initialized to the |0> state by π about the X axis based on the target qubit TQ.

[0319] The quantum circuit **2100** may further include, corresponding to a layer **4** (L**4**), a fourth CNOT gate CNOT**4** configured to rotate the control qubit CQ**3** by π about the X axis based on the auxiliary qubit AQ**1**.

[0320] The quantum circuit **2100** may further include corresponding to a layer **5** (L**5**), a fifth CNOT gate CNOT**5** configured to rotate the auxiliary qubit AQ**2** by π about the X axis based on the control qubit CQ**1**.

[0321] The quantum circuit **2100** may further include, corresponding to a layer **6** (L**6**), a sixth CNOT gate CNOT**6** configured to rotate the control qubit C**1** by π about the X axis based on the control qubit C**2**, a seventh CNOT gate CNOT**7** configured to rotate the target qubit TQ by π about the X axis based on a control qubit CQ**3**, and an eighth CNOT gate CNOT**8** configured to rotate the auxiliary qubit AQ**2** by π about the X axis based on the auxiliary qubit AQ**1**.

[0322] The quantum circuit **2100** may further include, corresponding to a layer **7** (L**7**), a first T gate T**1** configured to perform π/4 phase transformation on the control qubit CQ**1**, a first inverse T gate IT**1** configured to perform −π/4 phase transformation on the control qubit CQ**2**, a second inverse T gate IT**2** configured to perform −π/4 phase transformation of the control qubit CQ**3**, a second T gate T**2** configured to perform π/4 phase transformation of the target qubit TQ, a third T gate T**3** configured to perform π/4 phase transformation on the auxiliary qubit AQ**1**, and a third inverse T gate IT**3** configured to perform −π/4 phase transformation on the auxiliary qubit AQ**2**.

[0323] The quantum circuit **2100** may further include, corresponding to a layer **8** (L**8**), a ninth CNOT gate CNOT**9** configured to rotate the control qubit C**1** by π about the X axis based on the control qubit C**2**, a tenth CNOT gate CNOT**10** configured to rotate the target qubit TQ by π about the X axis based on a control qubit CQ**3**, and an eleventh CNOT gate CNOT**11** configured to rotate the auxiliary qubit AQ**2** by π about the X axis based on an auxiliary qubit AQ**1**.

[0324] The quantum circuit **2100** may further include, corresponding to a layer **9** (L**9**), a twelfth CNOT gate CNOT**12** configured to rotate the auxiliary qubit AQ**2** by π about the X axis based on the control qubit CQ**1**.

[0325] The quantum circuit **2100** may further include, corresponding to a layer **10** (L**10**), a thirteenth CNOT gate CNOT**13** configured to rotate the control qubit CQ**3** by π about the X axis based on the auxiliary qubit AQ**1**.

[0326] The quantum circuit **2100** may further include, corresponding to a layer **11** (L**11**), a fourteenth CNOT gate CNOT**14** configured to rotate the control qubit CQ**3** by π about the X axis based on the control qubit CQ**1**, and a fifteenth CNOT gate CNOT**15** configured to rotate the auxiliary qubit AQ**2** by π about the X axis based on a target qubit TQ.

[0327] The quantum circuit **2100** may further include, corresponding to a layer **12** (L**12**), a sixteenth CNOT gate CNOT**16** configured to rotate the control qubit CQ**2** by π about the X axis based on the auxiliary qubit AQ**1**.

[0328] The quantum circuit **2100** may further include, corresponding to a layer **13** (L**13**), a seventeenth CNOT gate CNOT**17** configured to rotate the auxiliary qubit AQ**2** by π about the X axis based on the control qubit CQ**1**.

[0329] The quantum circuit **2100** may further include, corresponding to a layer **14** (L**14**), a third H gate H**3** configured to perform Hadamard transformation on the target qubit TQ, and a first inverse V gate IV**1** configured to rotate the auxiliary qubit AQ**1** by −π/2 about the X axis.

[0330] The quantum circuit **2100** may further include a first measurement circuit MC**1** that measures the auxiliary qubit AQ**1** on a Z basis corresponding to a layer **15** (L**15**).

[0331] The quantum circuit **2100** may further include a first inverted conditional operation circuit ICOC**1** that performs a conditional operation based on a measurement result of the first measurement circuit MC**1** corresponding to the layer **16** (L**16**).

[0332] The first inverted conditional operation circuit ICOC**1** may include a seventeenth CNOT gate CNOT**17** configured to rotate the target qubit TQ by π about the X axis based on the control qubit CQ**3**. The first inverted conditional operation circuit ICOC**1** does not perform a predetermined operation when the measurement result of the first measurement circuit MC**1** is 1. When the measurement result of the first measurement circuit MC**1** is 0, the first inverted conditional operation circuit ICOC**1** performs the predetermined operation. In this case, the operation of the seventeenth CNOT gate CNOT**17** may performed.

[0333] The quantum circuit **2100** may include a first conditional operation circuit COC**1** that performs a conditional operation based on the measurement result of the first measurement circuit MC**1** corresponding to the layer **17** (L**17**).

[0334] The first conditional operation circuit COC**1** may include a first CZ gate CZ**1** configured to rotate the control qubit CQ**2** by π about the Z axis based on the control qubit CQ**1**. When the measurement result of the first measurement circuit MC**1** is 0, the first conditional operation circuit COC**1** does not perform a predetermined operation. When the measurement result of the first measurement circuit MC**1** is 1, the first conditional operation circuit COC**1** performs the predetermined operation. At this time, the operation of the first CZ gate CZ**1** may be performed.

[0335] The quantum circuit **2100** may implement a multi-controlled NOT gate with 3 control qubits by using only two auxiliary qubits.

[0336] In accordance with the embodiments described above, the quantum circuit may implement a multi-controlled NOT gate with N control qubits with minimal circuit depth. This enables fast and efficient quantum computation. In addition, even when a type of operation directly provided by a hardware platform is limited, a quantum circuit having a minimum circuit depth can be provided by using the limited type of operation.

[0337] A quantum computer on which a quantum circuit is implemented may be composed of a plurality of components that perform various functions. For example, a quantum computer in which the above-described quantum circuit is implemented may include a CPU that processes quantum information, a memory that stores quantum information, and a bus that transfers information between the CPU and the memory.

[0338] The CPU may perform a function as a central processing unit of the quantum computer. The CPU may operate by utilizing a computation space of the memory, and the quantum circuit may perform, under control of the CPU, an operation of a control-rotation gate by using a control qubit, a target qubit, and an auxiliary qubit. The quantum circuit may generate a control qubit, a target qubit, and an auxiliary qubit under control of the CPU, and perform an operation according to a gate operation on the target qubit based on a state of the control qubit. By using the quantum circuit according to the embodiment of the present invention, the processing speed of quantum information will be improved, and resources for processing quantum information will be reduced.

[0339] The foregoing are specific embodiments for practicing the present disclosure. The present disclosure will include not only the above-described embodiments, but also embodiments that can be simply changed in design or easily changed. In addition, the present disclosure will include techniques that can be easily modified and implemented by using the embodiments. Therefore, the scope of the present disclosure should not be limited to the above-described embodiments, but should be defined by the following claims as well as equivalents to the claims of the present disclosure.

[0340] A quantum circuit according to an embodiment of the present disclosure may implement a multi-controlled NOT gate that may reduce circuit depth by effectively decomposing the gates using auxiliary qubits.

[0341] A quantum circuit according to an embodiment of the present disclosure may implement a multi-controlled NOT gate capable of reducing a circuit depth through a measurement circuit.

What is claimed is:

1. A quantum circuit for implementing multi-controlled NOT gates with N control qubits, where N is an integer greater than or equal to 3, the quantum circuit comprising:

a first auxiliary circuit corresponding to one or more initial layers of the plurality of layers and configured to performing controlled NOT operation on a target qubit based on an Nth control qubit from among the N control qubits and a first auxiliary qubit initialized to a |+> state;

a quantum gate group corresponding to a plurality of layers and configured to perform controlled NOT operation on the first auxiliary qubit based on first to (N−1)th control qubits; and

a second auxiliary circuit corresponding to one or more last layers of the plurality of layers and configured to performing controlled NOT operation on the target qubit based on the Nth control qubit and the first auxiliary qubit.

2. The quantum circuit of claim **1**, wherein the first auxiliary circuit includes a first Toffoli gate configured to rotate the target qubit by π about X axis based on the Nth control qubit and the first auxiliary qubit, and

wherein the second auxiliary circuit includes a second Toffoli gate configured to rotate the target qubit by π about the X axis based on the Nth control qubit and the first auxiliary qubit.

3. The quantum circuit of claim **2**, wherein N is 3, and wherein the quantum gate group includes:

a third Toffoli gate corresponding to a second layer and configured to rotate the first auxiliary qubit by π about the X axis based on a first control qubit and a second control qubit.

4. The quantum circuit of claim **2**, wherein N is 5, and wherein the quantum gate group includes:

a third Toffoli gate corresponding to a first layer of the plurality of layers and configured to rotate a second auxiliary qubit initialized to a |0> state by π about the X axis based on a first control qubit and a second control qubit;

a fourth Toffoli gate corresponding to the first layer and configured to rotate a third auxiliary qubit initialized to a |0> state by π about the X axis based on a third control qubit and a fourth control qubit;

a fifth Toffoli gate corresponding to a second layer and configured to rotate the first auxiliary qubit by π about the X axis based on the first auxiliary qubit and the second auxiliary qubit;

a sixth Toffoli gate corresponding to a third layer and configured to rotate the second auxiliary qubit by π about the X axis based on the first control qubit and the second control qubit; and

a seventh Toffoli gate that corresponds to the third layer and configured to rotate the third auxiliary qubit by π about the X axis based on the third control qubit and the fourth control qubit.

5. The quantum circuit of claim **2**, wherein a circuit depth of the plurality of layers is $K=2\lceil \log_2(N+1)/3\rceil+1$.

6. The quantum circuit of claim **1**, wherein the first auxiliary circuit includes:

a first inverted CH gate corresponding to a first layer of the plurality of layers and configured to perform inverted Hadamard transformation on the first auxiliary qubit based on the Nth control qubit;

a first CNOT gate corresponding to a second layer and configured to rotate the target qubit by π about X axis based on the first auxiliary qubit; and

a second inverted CH gate corresponding to a third layer and configured to perform inverted Hadamard transformation on the first auxiliary qubit based on the Nth control qubit; and

wherein the second auxiliary circuit is configured symmetrically with the first auxiliary circuit.

7. The quantum circuit of claim **6**, wherein a circuit depth of the plurality of layers is $6\lceil \log_2(N+1)\rceil 5$.

8. The quantum circuit of claim **1**, wherein the first auxiliary qubit is initialized to |0>, and

wherein the first auxiliary circuit includes:

a first CH gate corresponding to a first layer of the plurality of layers and configured to perform Hadamard transformation on the first auxiliary qubit based on the Nth control qubit;

a first CNOT gate corresponding to a second layer and configured to rotate the target qubit by π about X axis based on the first auxiliary qubit; and

a second CH gate corresponding to a third layer and configured to perform Hadamard transformation on the first auxiliary qubit based on the Nth control qubit;

wherein the second auxiliary circuit is configured symmetrically with the first auxiliary circuit.

9. The quantum circuit of claim **1**, wherein the first auxiliary circuit includes:

a first H gate corresponding to a first layer of the plurality of layers and configured to perform Hadamard transformation on the target qubit;

a first CNOT gate corresponding to a second layer and configured to rotate the Nth control qubit by π about X axis based on the first auxiliary qubit;

a first T gate corresponding to a third layer and configured to perform π/4 phase transformation on the first auxiliary qubit;

a first inverse T gate corresponding to the third layer and configured to perform −π/4 phase transformation on the Nth control qubit;

a second CNOT gate corresponding to a fourth layer and configured to rotate the first auxiliary qubit by π about the X axis based on the target qubit;

a third CNOT gate corresponding to a fifth layer and configured to rotate the Nth control qubit by π about the X axis based on the target qubit;

a second inverse T gate corresponding to a sixth layer and configured to perform −π/4 phase transformation on the first auxiliary qubit;

a second T gate corresponding to the sixth layer and configured to perform π/4 phase transformation on the Nth control qubit;

a fourth CNOT gate corresponding to a seventh layer and configured to rotate the Nth control qubit by π about the X axis based on the first auxiliary qubit; and

wherein the second auxiliary circuit is configured symmetrically with the first auxiliary circuit.

10. The quantum circuit of claim **9**, wherein the T-circuit depth is $4(\log_2(N+1)-1)$.

11. The quantum circuit of claim **1**, wherein the first auxiliary circuit includes:

a first H gate corresponding to a first layer of the plurality of layers and configured to perform Hadamard transformation on the target qubit;

a first CNOT gate corresponding to a second layer and configured to rotate the Nth control qubit by π about X axis based on the first auxiliary qubit;

a second CNOT gate corresponding to a third layer and configured to rotate by π about the X axis based on a second auxiliary qubit initialized to a |0> state based on the target qubit;

a third CNOT gate corresponding to a fourth layer and configured to rotate the target qubit by π about the X axis based on the first auxiliary qubit;

a fourth CNOT gate corresponding to a fifth layer and configured to rotate the second auxiliary qubit by π about the X axis based on the Nth control qubit;

a first T gate corresponding to a sixth layer and configured to perform π/4 phase transformation on the second auxiliary qubit;

a second T gate corresponding to the sixth layer and configured to perform π/4 phase transformation on the first auxiliary qubit;

a first inverse T gate, corresponding to the sixth layer and configured to perform −π/4 phase transformation on the Nth control qubit;

a second inverse T-gate corresponding to the sixth layer and configured to perform −π/4 phase transformation on the second auxiliary qubit;

a fifth CNOT gate corresponding to a seventh layer and configured to rotate the second auxiliary qubit by π about the X axis based on the Nth control qubit;

a sixth CNOT gate corresponding to a eighth layer and configured to rotate the target qubit by π about the X axis based on the first auxiliary qubit; and

a seventh CNOT gate corresponding to a ninth layer and configured to rotate the Nth control qubit by π about the X axis based on the first auxiliary qubit; and

wherein the second auxiliary circuit is configured symmetrically with the first auxiliary circuit.

12. The quantum circuit of claim **11**, wherein the T-circuit depth is $2(\lceil\log_2(N+1)\rceil-1)$.

13. The quantum circuit of claim **1**, wherein the first auxiliary qubit is initialized to a |0> state, and

wherein the first auxiliary circuit includes:

a first H gate corresponding to a first layer of the plurality of layers and configured to perform Hadamard transformation on the first auxiliary qubit;

a second H gate corresponding to the first layer and configured to perform Hadamard transformation on the target qubit;

a first CNOT gate corresponding to a second layer and configured to rotate the Nth control qubit by π about the X axis based on the first auxiliary qubit;

a second CNOT gate corresponding to a third layer and configured to rotate by π about the X axis based on a second auxiliary qubit that is initialized to a |0> state;

a third CNOT gate corresponding to a fourth layer and configured to rotate the target qubit by π about the X axis based on the first auxiliary qubit;

a fourth CNOT gate corresponding to a fifth layer and configured to rotate the second auxiliary qubit by π about the X axis based on the Nth control qubit;

a first T gate corresponding to a sixth layer and configured to perform π/4 phase transformation on the second auxiliary qubit;

a second T gate corresponding to the sixth layer and configured to perform π/4 phase transformation on the first auxiliary qubit;

a first inverse T gate corresponding to the sixth layer and configured to perform −π/4 phase transformation on the Nth control qubit;

a second inverse T-gate corresponding to the sixth layer and configured to perform −π/4 phase transformation on the second auxiliary qubit;

a fifth CNOT gate corresponding to a seventh layer and configured to rotate the second auxiliary qubit by π about the X axis based on the Nth control qubit;

a sixth CNOT gate corresponding to the eighth layer and configured to rotate the target qubit by π about the X axis based on the first auxiliary qubit; and

a seventh CNOT gate corresponding to a ninth layer and configured to rotate the Nth control qubit by π about the X axis based on the first auxiliary qubit; and

wherein the second auxiliary circuit is configured symmetrically with the first auxiliary circuit.

14. A quantum circuit for implementing multi-controlled NOT gates with N control qubits, where N is an integer greater than or equal to 3, the quantum circuit comprising:

a first auxiliary circuit corresponding to one or more initial layers in the plurality of layers and configured to perform controlled NOT operation on a target qubit based on an Nth control qubit from among the N control qubits and a first auxiliary qubit initialized to a |+> state in the plurality of auxiliary qubits;

a quantum gate group corresponding to a plurality of layers and configured to perform controlled NOT operation on the first auxiliary qubit based on first to (N−1)th control qubits; and

a measurement area corresponding to a last one or more layers of the plurality of layers and including one or more measurement circuits that measure a state of one or more auxiliary qubits, and one or more conditional operation circuits that perform a conditional operation based on a measurement result of the one or more measurement circuits.

15. The quantum circuit of claim **14**, wherein N is 3, and

wherein the first auxiliary circuit includes a first Toffoli gate corresponding to a first layer and configured to rotate the target qubit by π about X axis based on the first auxiliary qubit and a third control qubit, and

wherein the quantum gate group includes a second Toffoli gate corresponding to the first layer and configured to rotate a second auxiliary qubit initialized to a |0> state by π about the X axis based on the first control qubit and the second control qubit, and a first CNOT gate corresponding to a second layer and configured to rotate the first auxiliary qubit by π about an X axis based on the second auxiliary qubit, and

wherein the measurement area includes a first measurement circuit corresponding to a third layer and configured to measure the second auxiliary qubit on X basis, a second measurement circuit corresponding to a fourth layer and configured to measure the first auxiliary qubit on Z basis, a first conditional operation circuit corresponding to a fourth layer and configured to rotate the second control qubit by π about Z axis based on the first control qubit, in response to a measurement result of the first measurement circuit, and a second conditional operation circuit corresponding to the fourth layer and configured to rotate the target qubit by the π about the X axis based on the third control qubit, in response to the measurement result of the second measurement circuit.

16. The quantum circuit of claim **14**, wherein the first auxiliary circuit includes:

a first inverted CH gate corresponding to a first layer of the plurality of layers and configured to perform an inverted Hadamard transformation on the first auxiliary qubit based on the Nth control qubit;

a first CNOT gate corresponding to a second layer and configured to rotate the target qubit by π about X axis based on the first auxiliary qubit; and

a second inverted CH gate corresponding to a third layer and performing an inverted Hadamard transformation on the first auxiliary qubit based on the Nth control qubit.

17. The quantum circuit of claim **14**, wherein the first auxiliary qubit is initialized to |0>, and

wherein the first auxiliary circuit includes:

a first CH gate corresponding to a first layer of the plurality of layers and configured to perform Hadamard transformation on the first auxiliary qubit based on the Nth control qubit;

a first CNOT gate corresponding to a second layer and configured to rotate the target qubit by π about X axis based on the first auxiliary qubit; and

a second CH gate that performs a Hadamard transformation on the first auxiliary qubit based on the Nth control qubit corresponding to a third layer.

18. The quantum circuit of claim **14**, wherein the first auxiliary qubit is initialized to a |0> state, and

wherein the first auxiliary circuit includes:

a first H gate corresponding to a first layer of the plurality of the layers and configured to perform Hadamard transformation on the first auxiliary qubit;

a second H gate corresponding to the first layer and configured to perform Hadamard transformation on the target qubit;

a first CNOT gate corresponding to a second layer and configured to rotate the Nth control qubit by π about the X axis based on the first auxiliary qubit;

a second CNOT gate corresponding to a third layer and configured to rotate a second auxiliary qubit initialized to a |0> state by π about the X axis based on the target qubit;

a third CNOT gate corresponding to a fourth layer and configured to rotate the target qubit by π about the X axis based on the first auxiliary qubit;

a fourth CNOT gate corresponding to a fifth layer and configured to rotate the second auxiliary qubit by π about the X axis based on the Nth control qubit;

a first T gate corresponding to a sixth layer and configured to perform π/4 phase transformation on the second auxiliary qubit;

a second T gate corresponding to the sixth layer and configured to perform π/4 phase transformation on the first auxiliary qubit;

a first inverse T gate corresponding to the sixth layer and configured to perform −π/4 phase transformation on the Nth control qubit;

a second inverse T gate corresponding to the sixth layer and configured to perform −π/4 phase transformation on the second auxiliary qubit;

a fifth CNOT gate corresponding to a seventh layer and configured to rotate the second auxiliary qubit by π about the X axis based on the Nth control qubit;

a sixth CNOT gate corresponding to an eighth layer and configured to rotate the target qubit by π about the X axis based on the first auxiliary qubit; and

a seventh CNOT gate corresponding to a ninth layer and configured to rotate Nth control qubit by π about the X axis based on the first auxiliary qubit.

19. The quantum circuit of claim **14**, wherein the quantum gate group includes at least one measurement circuit for gate teleportation and at least one conditional operation circuit that performs a conditional operation in response to a measurement result of the at least one measurement circuit.

20. A quantum circuit comprising:

corresponding to a first layer, a first H gate configured to perform Hadamard transformation on a target qubit, and a second H gate configured to perform Hadamard transformation on a first auxiliary qubit initialized to the |0> state;

corresponding to a second layer, a first CNOT gate and configured to rotate a second control qubit by π about X axis based on the first auxiliary qubit;

corresponding to a third layer, a second CNOT gate and configured to rotate a third control qubit by π about the X-axis based on a first control qubit, and a third CNOT gate configured to rotate a second auxiliary qubit initialized to a |0> state by π about the X axis based on the target qubit;

corresponding to a fourth layer, a fourth CNOT gate configured to rotate the third control qubit by π about the X axis based on the first auxiliary qubit;

corresponding to a fifth layer, a fifth CNOT gate configured to rotate the second auxiliary qubit by π about the X axis based on the first control qubit;

corresponding to a sixth layer, a sixth CNOT gate configured to rotate the first control qubit by π about the X axis based on the second control qubit, a seventh CNOT gate configured to rotate the target qubit by π about the X axis based on the third control qubit, and an eighth CNOT gate configured to rotate the second auxiliary qubit by π based on the first auxiliary qubit;

corresponding to a seventh layer, a first T gate configured to perform π/4 phase transformation on the first control qubit, a first inverse T gate configured to perform −π/4 phase transformation on the second control qubit, a second inverse T gate configured to perform −π/4 phase transformation on the third control qubit, a second T gate configured to perform the π/4 phase transformation on the target qubit, a third T gate configured to perform π/4 phase transformation on the first auxiliary qubit, and a third inverse T gate configured to perform −π/4 phase transformation on the second auxiliary qubit;

corresponding to an eighth layer, a ninth CNOT gate configured to rotate the first control qubit by π about the X axis based on the second control qubit, a tenth CNOT gate configured to rotate the target qubit by the π about the X axis based on the third control qubit, and an eleventh CNOT gate configured to rotate the second auxiliary qubit by π about the X axis based on the first auxiliary qubit;

corresponding to a ninth layer, a twelfth CNOT gate configured to rotate the second auxiliary qubit by π about the X axis based on the first control qubit;

corresponding to a tenth layer, a thirteenth CNOT gate configured to rotate the third control qubit by π about the X axis based on the first auxiliary qubit;

corresponding to an eleventh layer; a fourteenth CNOT gate configured to rotate the third control qubit by π about an X axis based on the first control qubit, and a fifteenth CNOT gate configured to rotate the second auxiliary qubit by π about the X axis based on the target qubit;

corresponding to a twelfth layer, a sixteenth CNOT gate configured to rotate the second control qubit by π about the X axis based on the first auxiliary qubit;

corresponding to a thirteenth layer, a seventeenth CNOT gate configured to rotate the first auxiliary qubit by π about the X axis based on the first control qubit;

corresponding to a fourteenth layer, a third H gate configured to perform Hadamard transformation on the target qubit, and a first inverse V gate configured to rotate the first auxiliary qubit by −π/2 about the X axis;

corresponding to a fifteenth layer a first measurement circuit configured to measure the first auxiliary qubit on Z basis;

corresponding to a sixteenth layer, a first inverted conditional operation circuit configured to not perform an operation in response to a measurement result being 1, and to rotate the target qubit by π about the X axis based on the third control qubit in response to the measurement result being 0; and

corresponding to a seventeenth layer, a first conditional operation circuit configured to do not perform an operation in response to the measurement being 0, and to rotate the second control qubit by π about Z axis based on the first control qubit in response to the measurement result being 1.

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