US00RE49467E

(19) **United States**
(12) **Reissued Patent**
Kim et al.

(10) **Patent Number: US RE49,467 E**
(45) **Date of Reissued Patent: Mar. 21, 2023**

(54) **SEMICONDUCTOR MEMORY DEVICES, MEMORY SYSTEMS INCLUDING SEMICONDUCTOR MEMORY DEVICES, AND OPERATING METHODS OF SEMICONDUCTOR MEMORY DEVICES**

(71) Applicant: **Samsung Electronics Co., Ltd.**, Suwon-si (KR)

(72) Inventors: **Young-Hun Kim**, Seoul (KR); **Sihong Kim**, Hwaseong-si (KR)

(73) Assignee: **Samsung Electronics Co., Ltd.**

(21) Appl. No.: **17/131,149**

(22) Filed: **Dec. 22, 2020**

Related U.S. Patent Documents

Reissue of:

(64) Patent No.: **10,347,323**
Issued: **Jul. 9, 2019**
Appl. No.: **15/985,200**
Filed: **May 21, 2018**

(30) **Foreign Application Priority Data**

Oct. 26, 2017 (KR) 10-2017-0140363

(51) **Int. Cl.**
G11C 11/40 (2006.01)
G11C 11/4093 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***G11C 11/4093*** (2013.01); ***G11C 5/025*** (2013.01); ***G11C 7/106*** (2013.01);
(Continued)

(58) **Field of Classification Search**
CPC ... G11C 11/4093; G11C 7/1066; G11C 7/222; G11C 11/4091
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,095,485 A * 3/1992 Sato G06F 11/10 712/42
5,367,526 A * 11/1994 Kong G06F 11/1032 714/801

(Continued)

FOREIGN PATENT DOCUMENTS

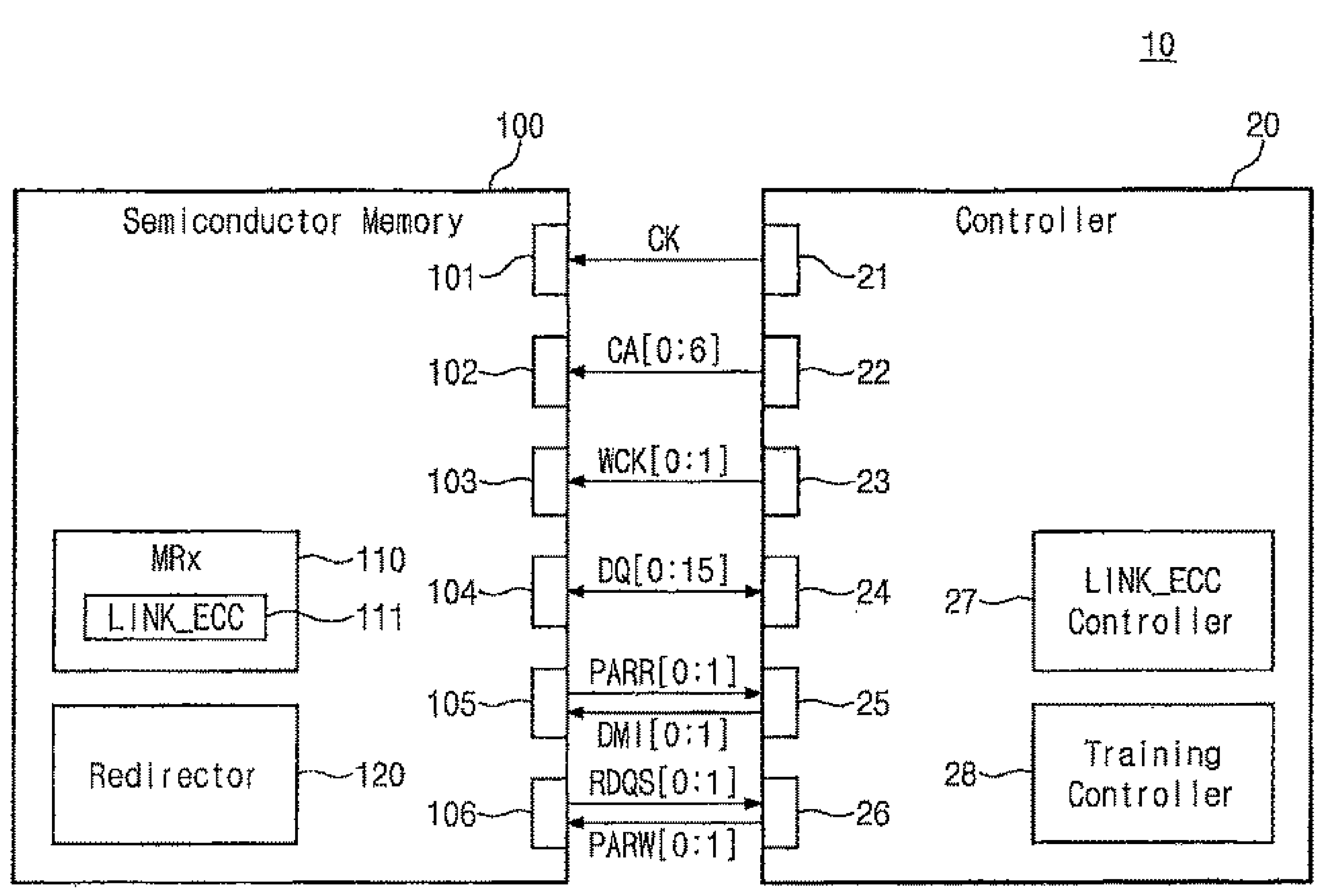
CN	1542852	11/2004
CN	1627441	6/2005
CN	103150273	6/2013

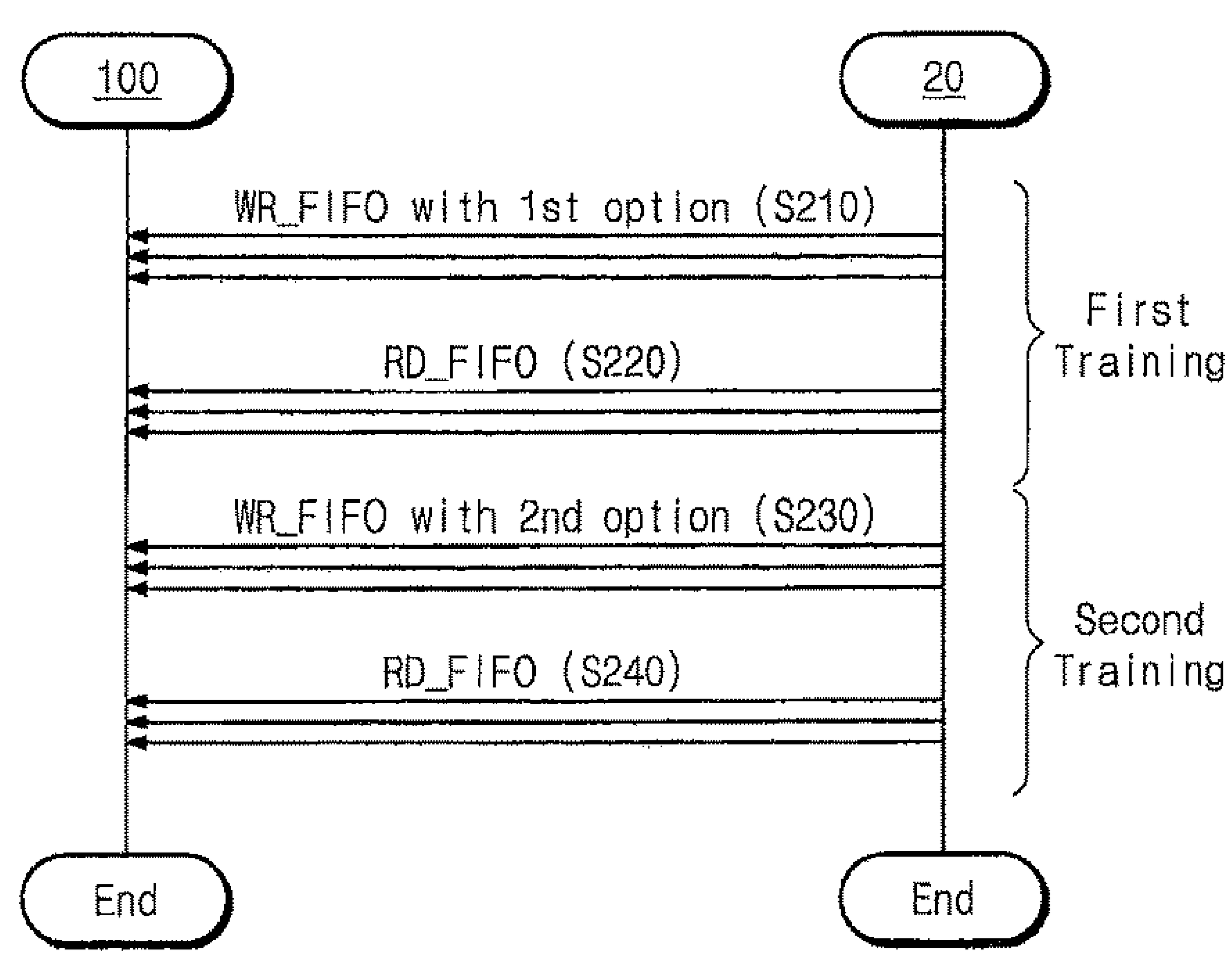
Primary Examiner — Woo H Choi
(74) *Attorney, Agent, or Firm* — Myers Bigel, P.A.

(57) **ABSTRACT**

A semiconductor memory device includes a memory core that performs reading and writing of data, data delivery and training blocks that are connected between first pads and the memory core, and at least one data delivery, clock generation and training block that is connected between at least one second pad and the memory core. In a first training operation, the data delivery and training blocks output first training data, received through the first pads, through the first pads as second training data. In a second training operation, at least one of the data delivery and training blocks outputs third training data, received through the at least one second pad, through at least one of the first pads as fourth training data. The second training data and the fourth training data are output in synchronization with read data strobe signals output through the at least one second pad.

69 Claims, 35 Drawing Sheets





(51) **Int. Cl.**
G11C 7/10 (2006.01)
G11C 11/4091 (2006.01)
G11C 7/22 (2006.01)
G11C 5/02 (2006.01)
G11C 29/02 (2006.01)
G11C 11/4076 (2006.01)

(52) **U.S. Cl.**
CPC ***G11C 7/1066*** (2013.01); ***G11C 7/1087*** (2013.01); ***G11C 7/1093*** (2013.01); ***G11C 7/222*** (2013.01); ***G11C 11/4091*** (2013.01); ***G11C 29/028*** (2013.01); *G11C 11/4076* (2013.01); *G11C 2207/105* (2013.01); *G11C 2207/107* (2013.01); *G11C 2207/2254* (2013.01)

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,052,818 A * 4/2000 Dell G06F 11/10 714/763
7,123,456 B2 10/2006 Kamata et al.
7,373,564 B2 * 5/2008 Kikutake G11C 29/10 365/201
7,415,569 B2 8/2008 Dietrich et al.
8,055,930 B2 * 11/2011 Bae G06F 1/12 327/144
8,207,976 B2 * 6/2012 Hein G11C 7/1051 327/158
8,248,873 B2 8/2012 Bae et al.
8,437,216 B2 * 5/2013 Oh G11C 7/1087 365/185.28
9,069,719 B2 6/2015 Ong
9,208,330 B2 12/2015 Srinivasan et al.
9,646,675 B1 5/2017 Lee
9,767,920 B2 * 9/2017 Kim G11C 29/42
10,163,485 B2 * 12/2018 Chen G11C 11/406
2004/0213073 A1 10/2004 Yoon et al.
2005/0141333 A1 6/2005 Fujisawa
2008/0068904 A1 3/2008 Hughes
2011/0314190 A1 12/2011 Tanaka
2013/0151752 A1 6/2013 Hsiao et al.
2015/0255147 A1 9/2015 Lin et al.
2016/0026436 A1 1/2016 Shen
2017/0331493 A1 * 11/2017 Yu H03M 13/098

* cited by examiner

FIG. 1

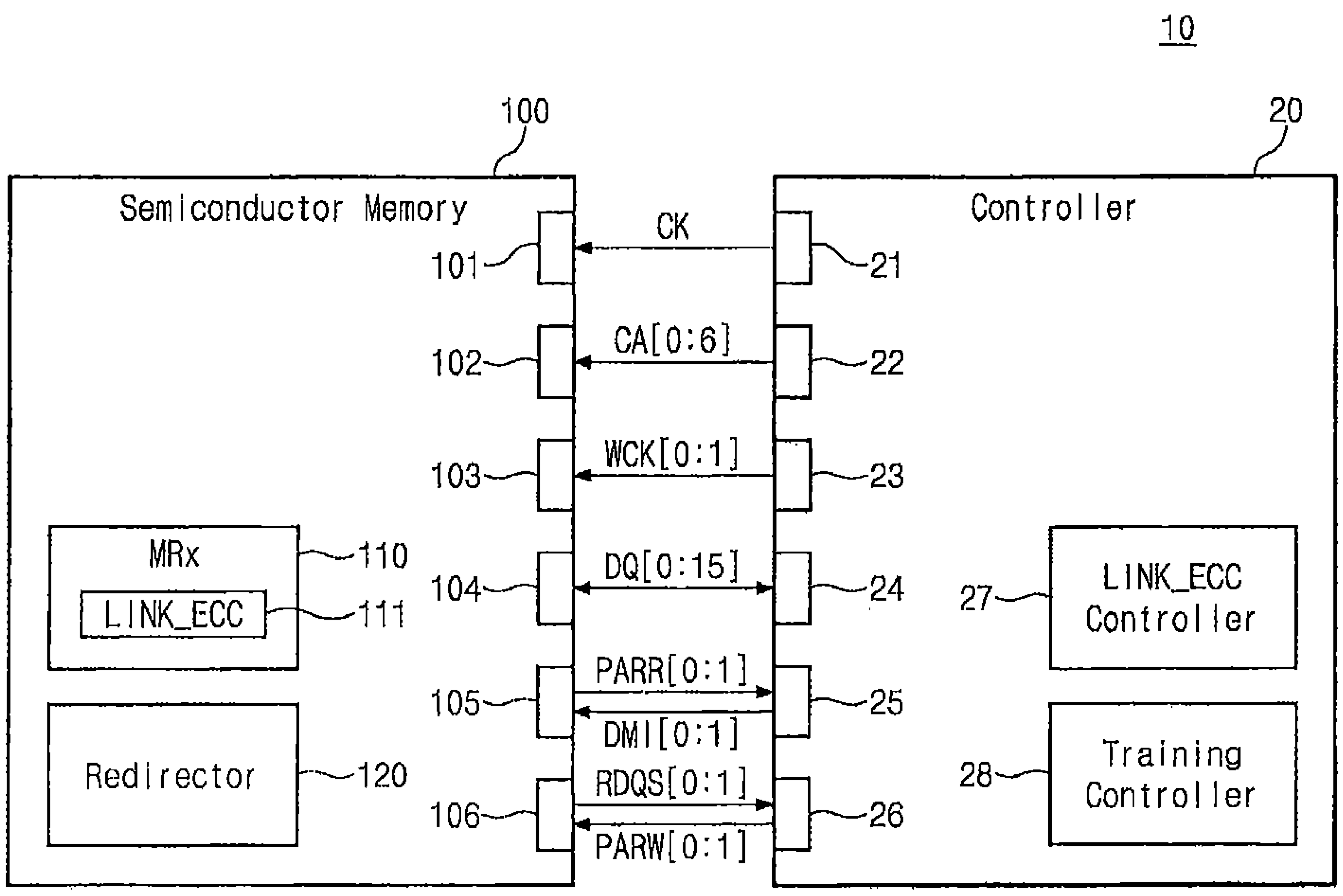

10
100
20
Semiconductor Memory
Controller
CK
CA[0:6]
WCK[0:1]
DQ[0:15]
PARR[0:1]
DMI[0:1]
RDQS[0:1]
PARW[0:1]
101
102
103
104
105
106
21
22
23
24
25
26
MRx
110
LINK_ECC
111
Redirector
120
LINK_ECC Controller
27
Training Controller
28

FIG. 2

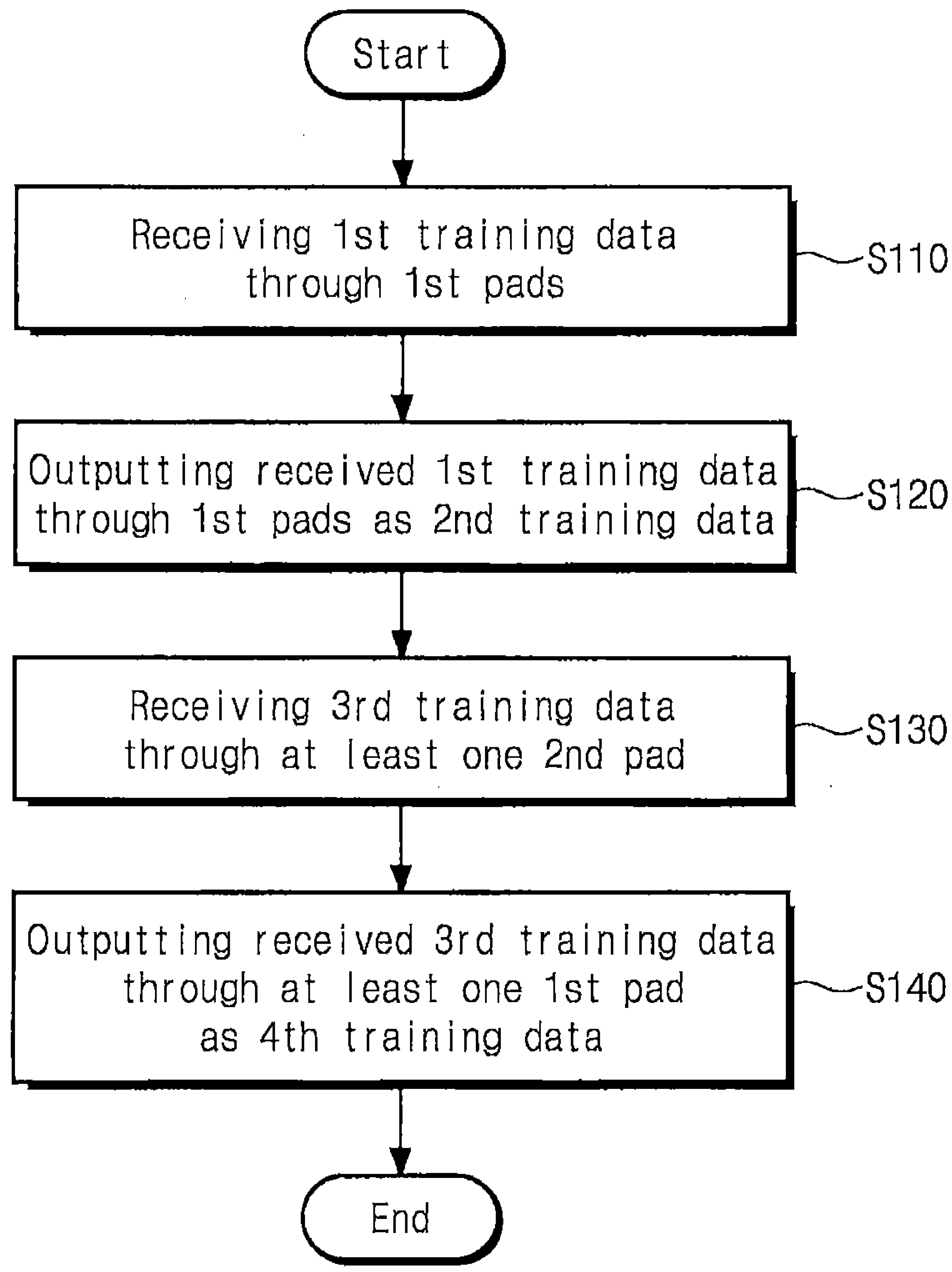

Start
Receiving 1st training data through 1st pads
S110
Outputting received 1st training data through 1st pads as 2nd training data
S120
Receiving 3rd training data through at least one 2nd pad
S130
Outputting received 3rd training data through at least one 1st pad as 4th training data
S140
End

FIG. 3

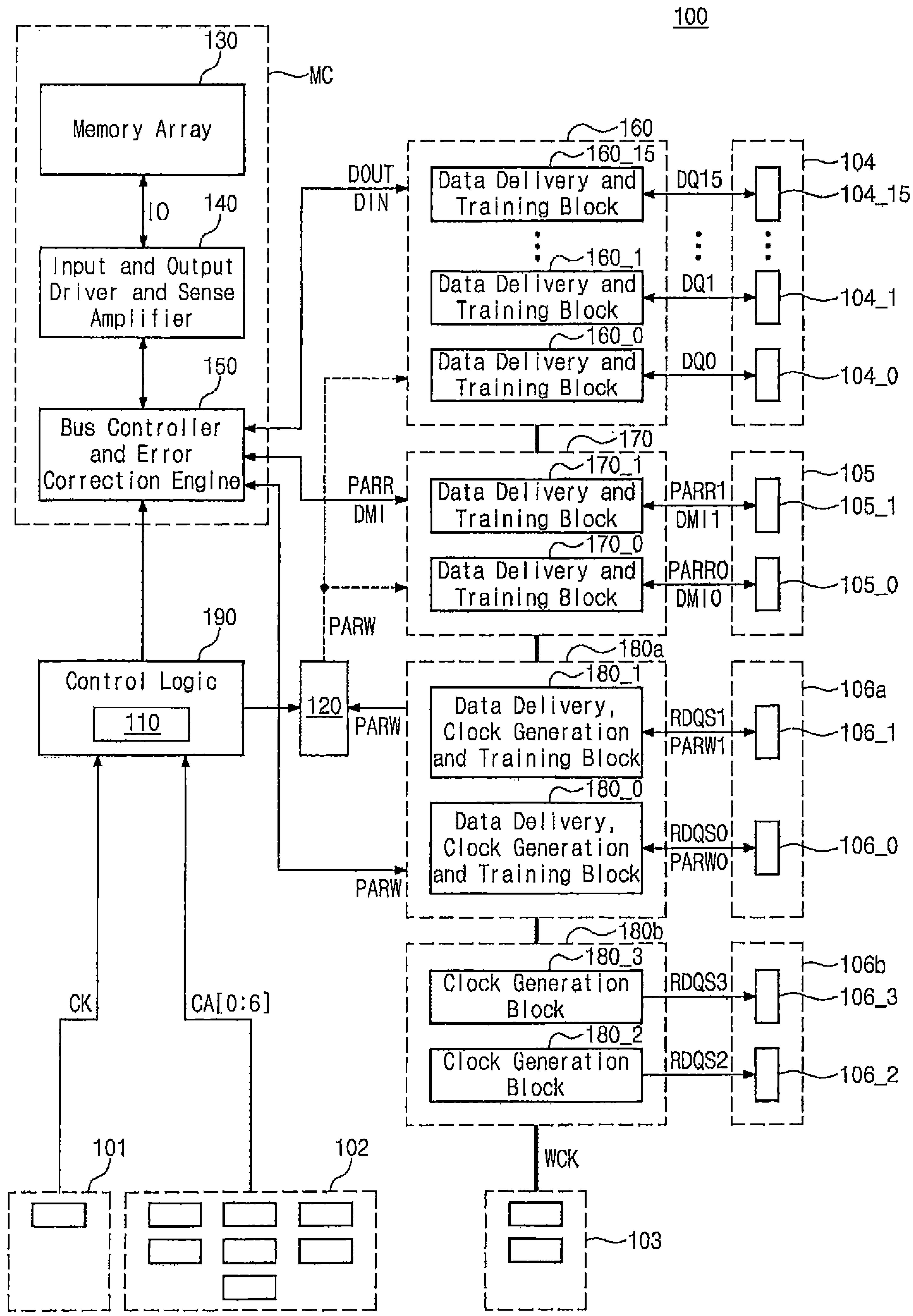
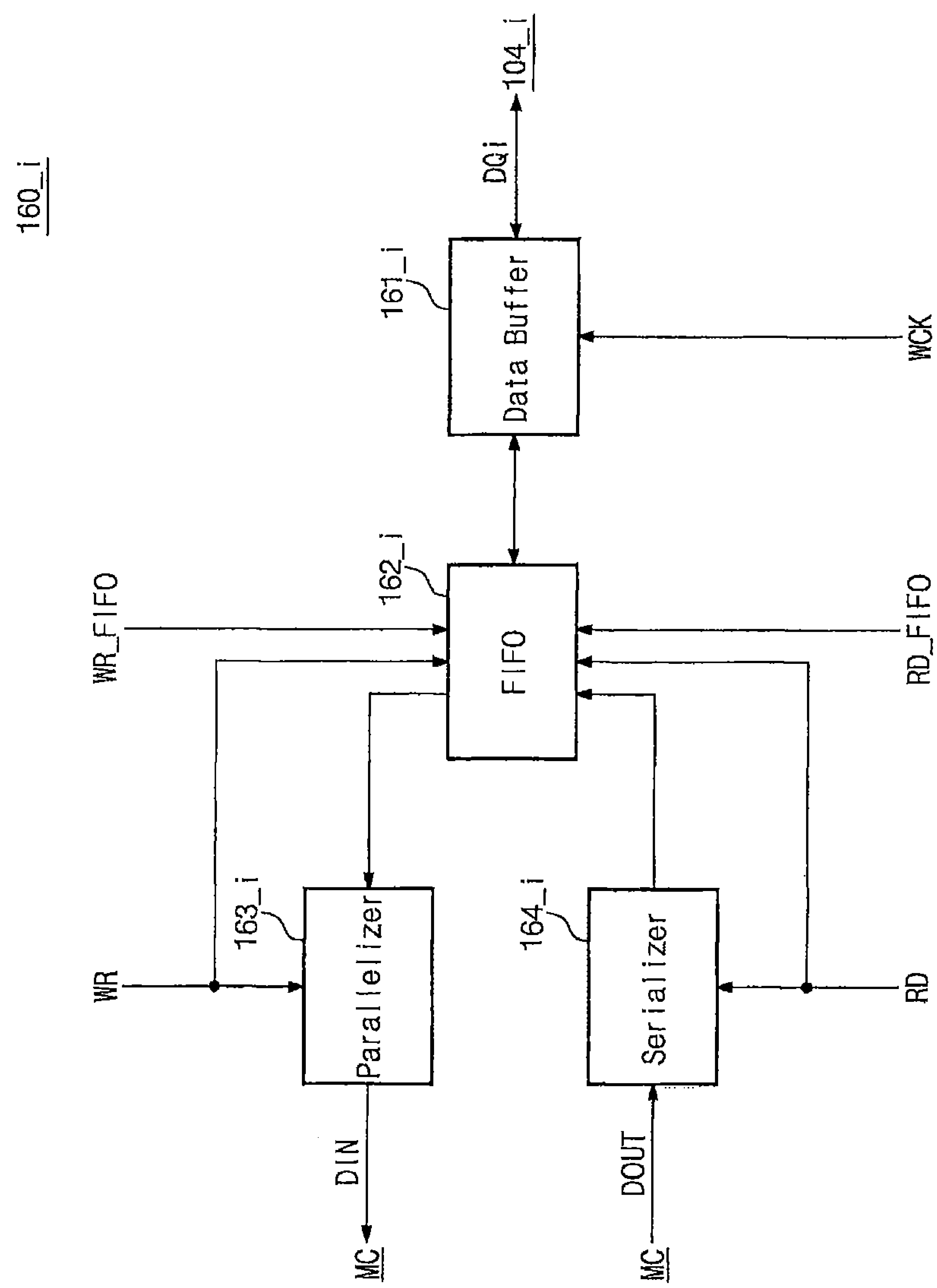

100
130
MC
Memory Array
IO
140
Input and Output Driver and Sense Amplifier
150
Bus Controller and Error Correction Engine
190
Control Logic
110
120
DOUT
DIN
PARR
DMI
PARW
PARW
PARW
160
160_15
Data Delivery and Training Block
160_1
Data Delivery and Training Block
160_0
Data Delivery and Training Block
170
170_1
Data Delivery and Training Block
170_0
Data Delivery and Training Block
180a
180_1
Data Delivery, Clock Generation and Training Block
180_0
Data Delivery, Clock Generation and Training Block
180b
180_3
Clock Generation Block
180_2
Clock Generation Block
DQ15
DQ1
DQ0
PARR1
DMI1
PARR0
DMI0
RDQS1
PARW1
RDQS0
PARW0
RDQS3
RDQS2
104
104_15
104_1
104_0
105
105_1
105_0
106a
106_1
106_0
106b
106_3
106_2
CK
CA[0:6]
WCK
101
102
103

FIG. 4A



160_i
104_i
DQi
161_i
Data Buffer
WCK
162_i
FIFO
WR_FIFO
RD_FIFO
163_i
Parallelizer
164_i
Serializer
WR
RD
DIN
DOUT
MC
MC

FIG. 4B

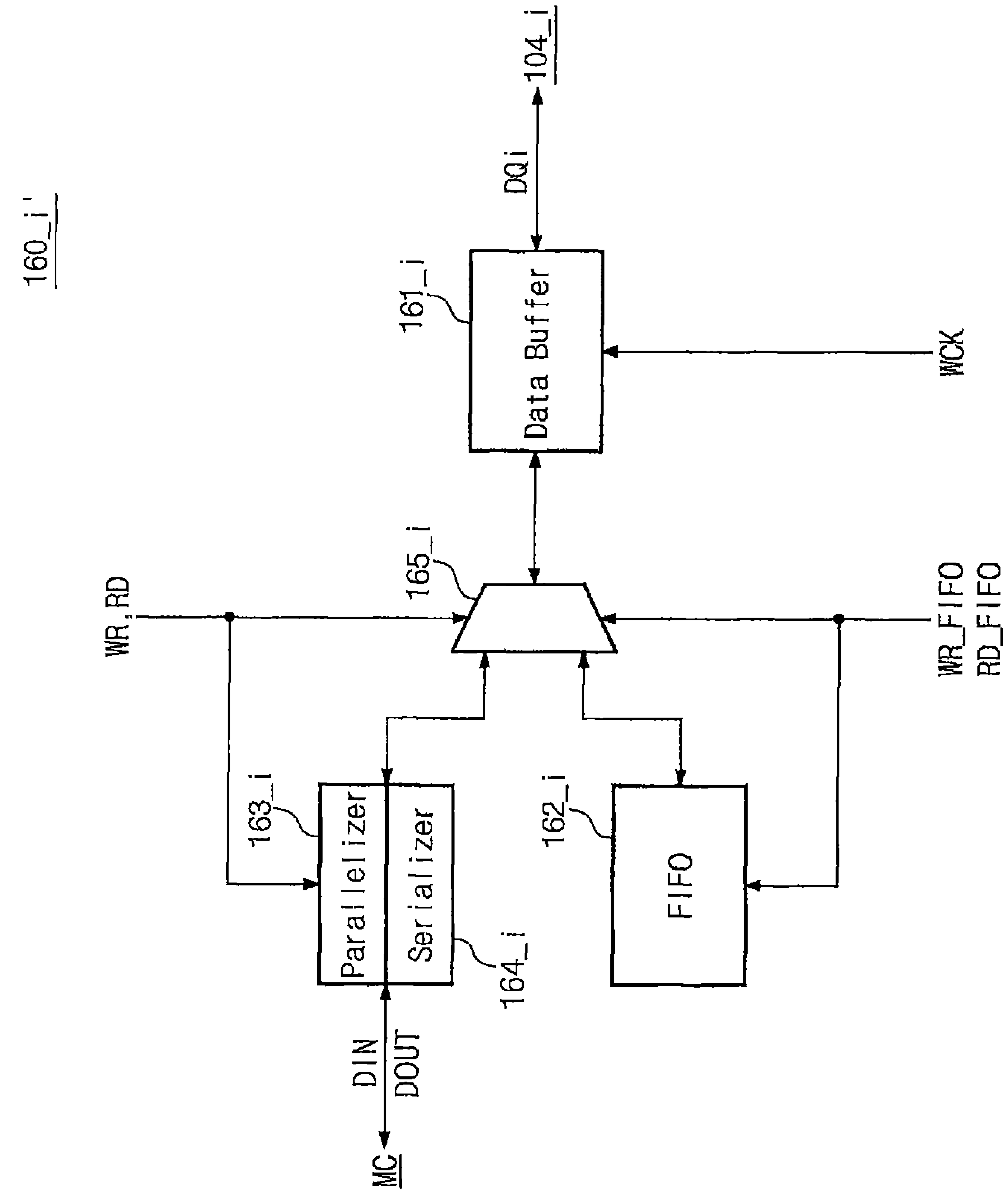

160_i'
104_i
DQi
161_i
Data Buffer
WCK
165_i
WR,RD
WR_FIFO
RD_FIFO
163_i
Parallelizer
Serializer
164_i
162_i
FIFO
DIN
DOUT
MC

FIG. 5A

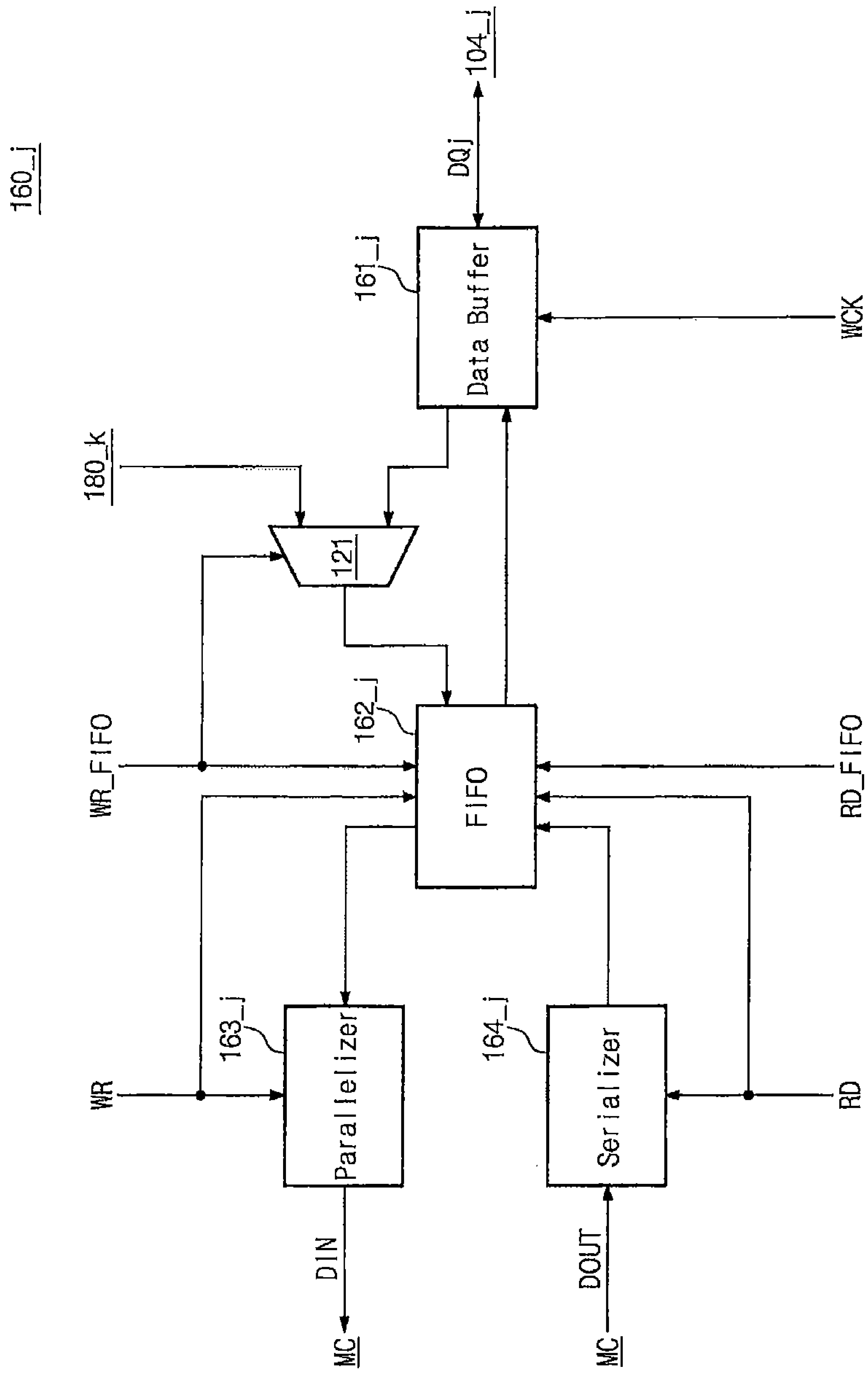

160_j
104_j
DQj
161_j
Data Buffer
WCK
180_k
121
162_j
FIFO
WR_FIFO
RD_FIFO
163_j
Parallelizer
164_j
Serializer
WR
RD
DIN
DOUT
MC
MC

FIG. 5B

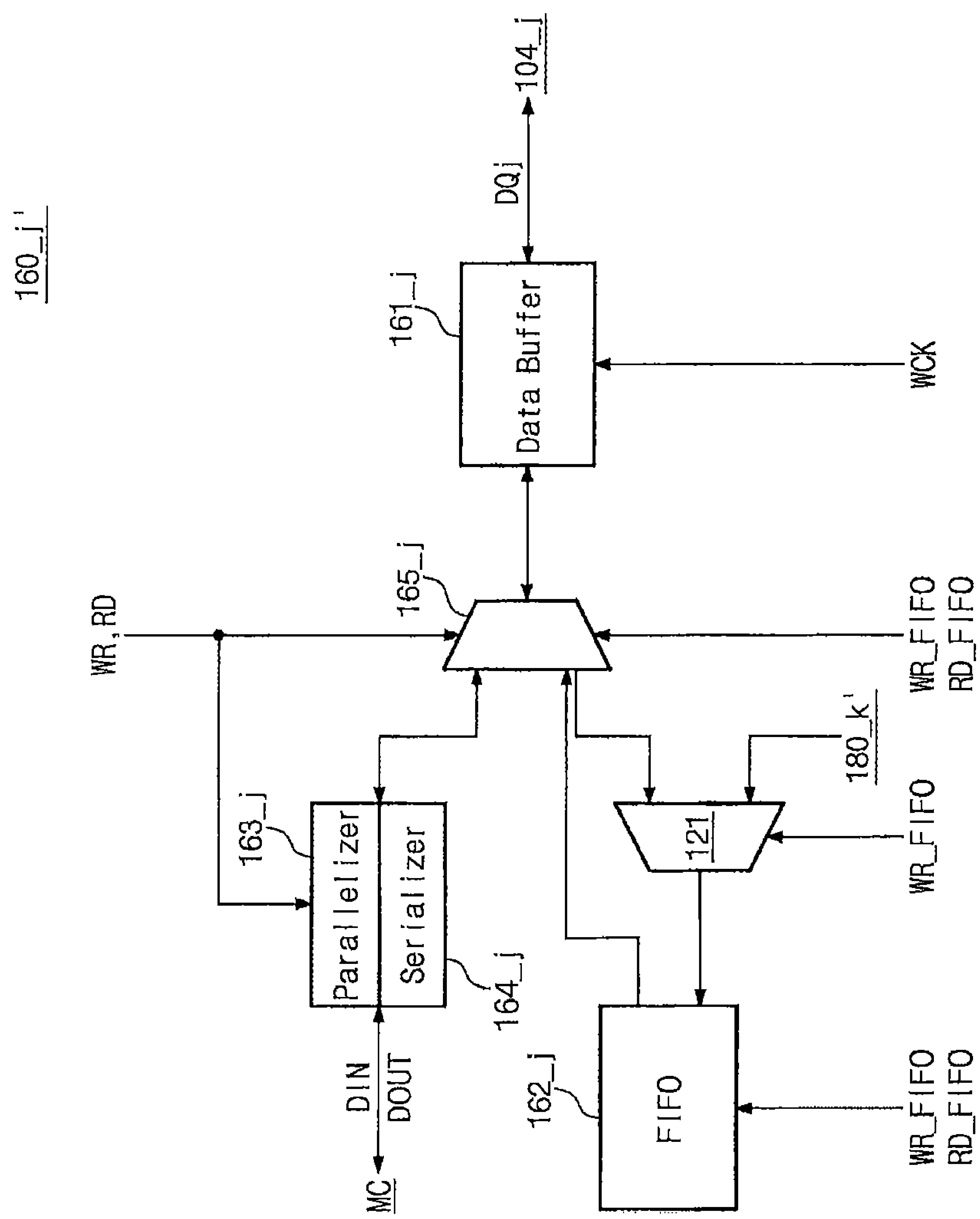

160_j'
104_j
DQj
161_j
Data Buffer
WCK
165_j
WR,RD
WR_FIFO
RD_FIFO
180_k'
163_j
Parallelizer
Serializer
121
WR_FIFO
164_j
DIN
DOUT
MC
162_j
FIFO
WR_FIFO
RD_FIFO

FIG. 6A

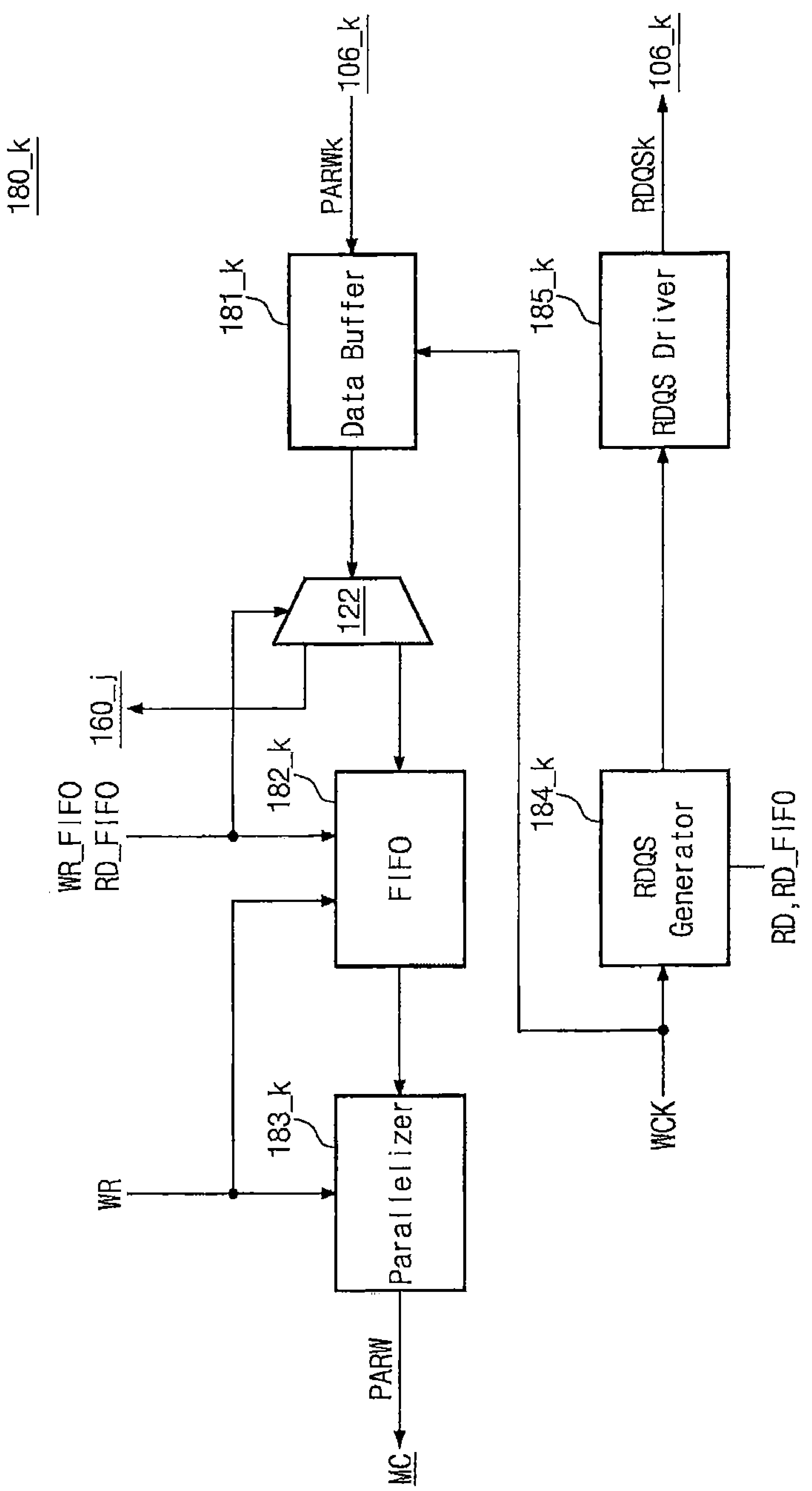

180_k
PARWk
106_k
181_k
Data Buffer
RDQSk
106_k
185_k
RDQS Driver
122
160_j
182_k
FIFO
WR_FIFO
RD_FIFO
184_k
RDQS
Generator
RD,RD_FIFO
183_k
Parallelizer
WR
WCK
PARW
MC

FIG. 6B

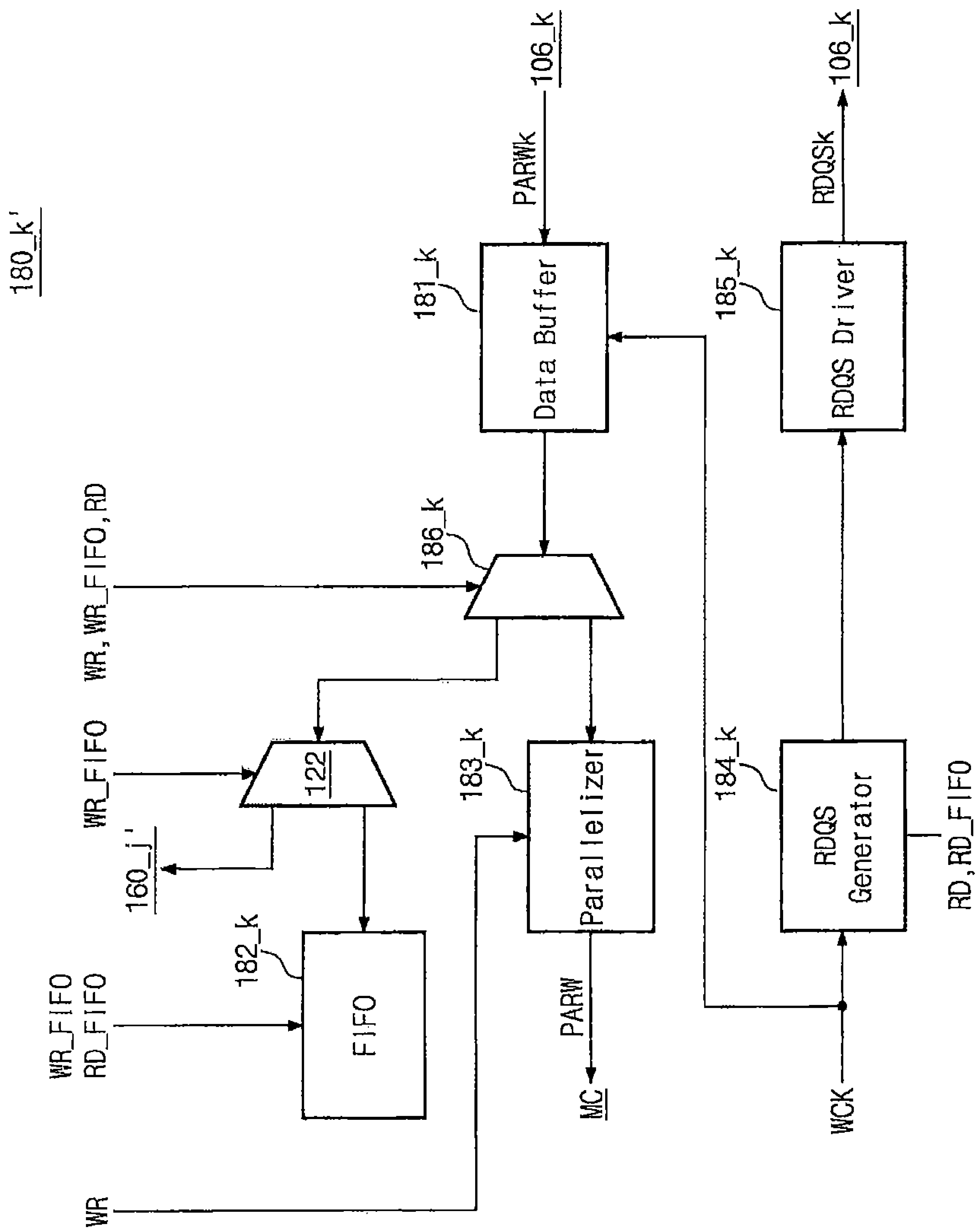

180_k'
PARWk
106_k
181_k
Data Buffer
185_k
RDQS Driver
RDQSk
106_k
WR, WR_FIFO,RD
186_k
WR_FIFO
122
160_j'
183_k
Parallelizer
184_k
RDQS Generator
RD,RD_FIFO
WR_FIFO
RD_FIFO
182_k
FIFO
PARW
MC
WCK
WR

FIG. 7

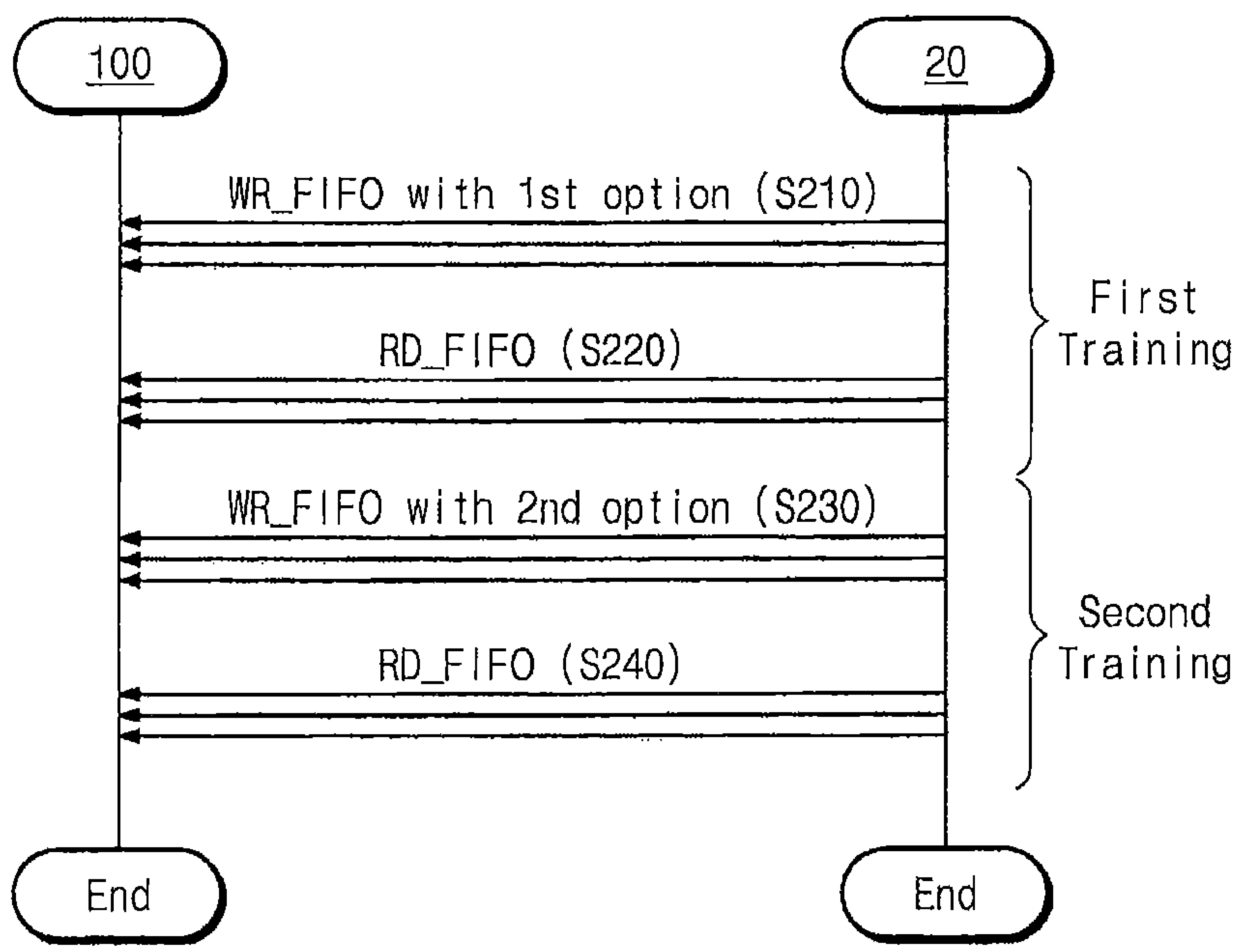

100
20
WR_FIFO with 1st option (S210)
RD_FIFO (S220)
WR_FIFO with 2nd option (S230)
RD_FIFO (S240)
First Training
Second Training
End
End

FIG. 8

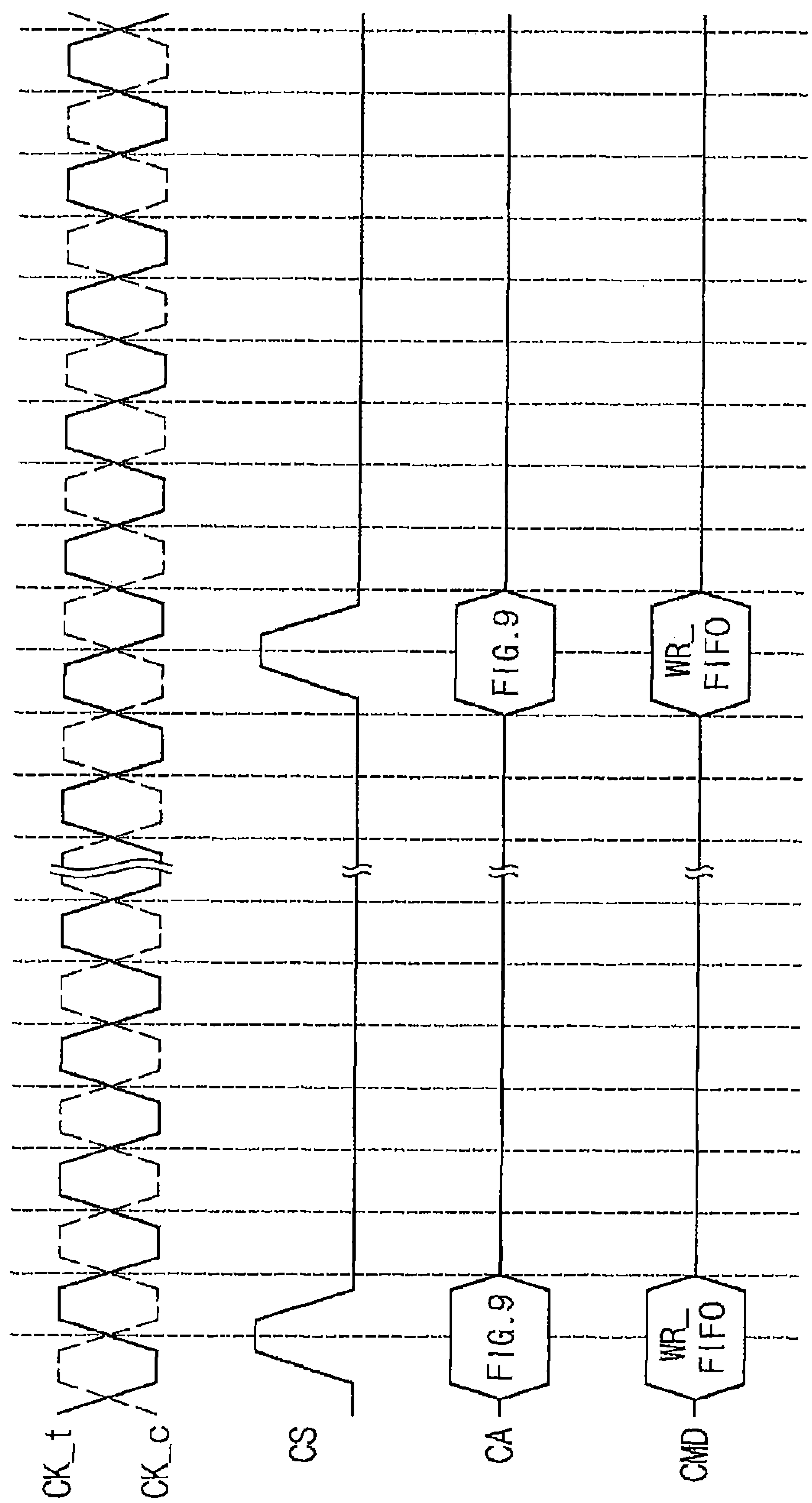


FIG. 9

Command	CK_t	CS	CA0	CA1	CA2	CA3	CA4	CA5	CA6
WR_FIFO with 1st option	R	H	L	L	L	L	L	H	H
	F	X	L	V	V	V	V	V	V
WR_FIFO with 2nd option	R	H	L	L	L	L	L	H	H
	F	X	H	V	V	V	V	V	V

FIG. 10

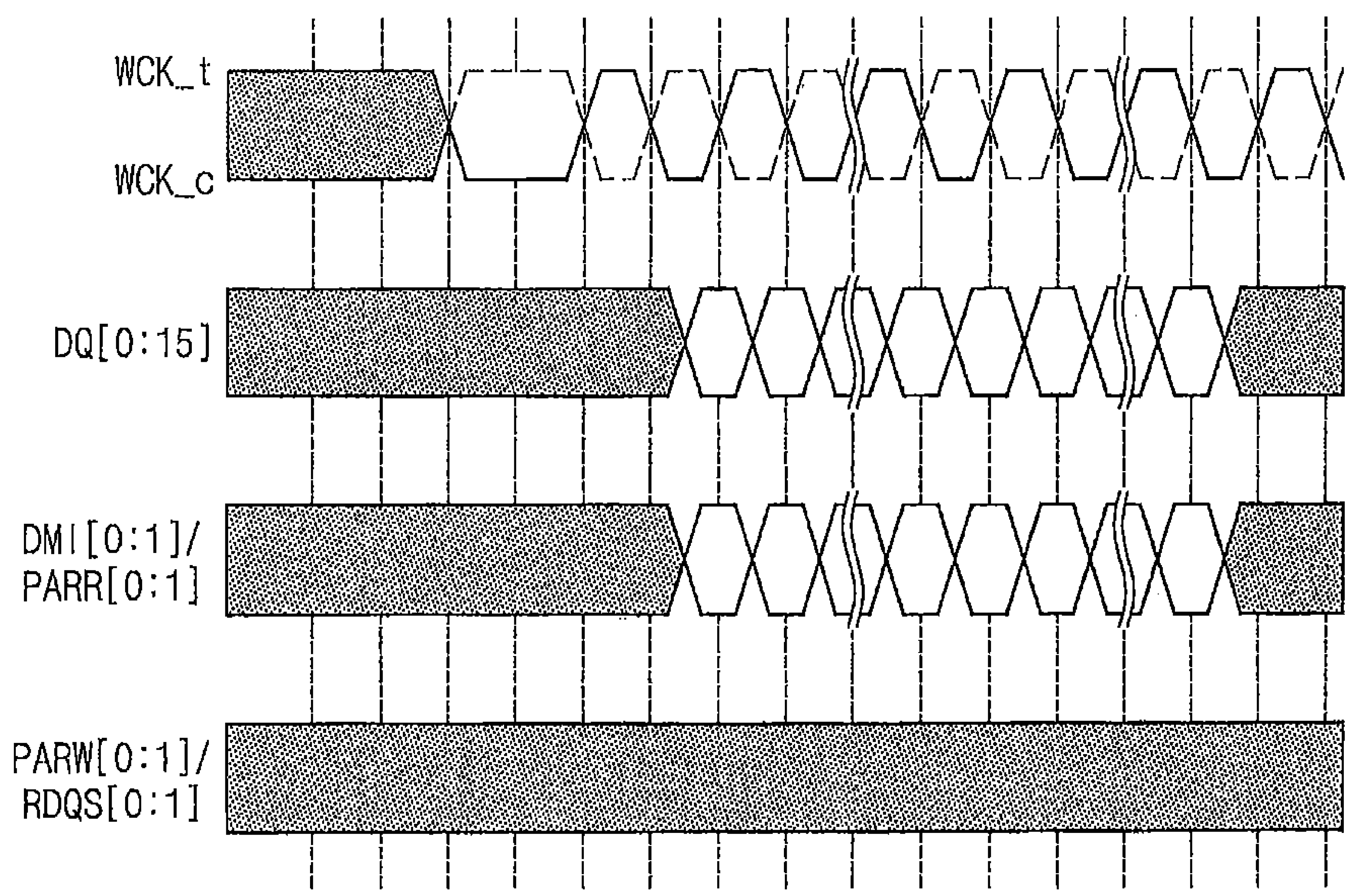


FIG. 11

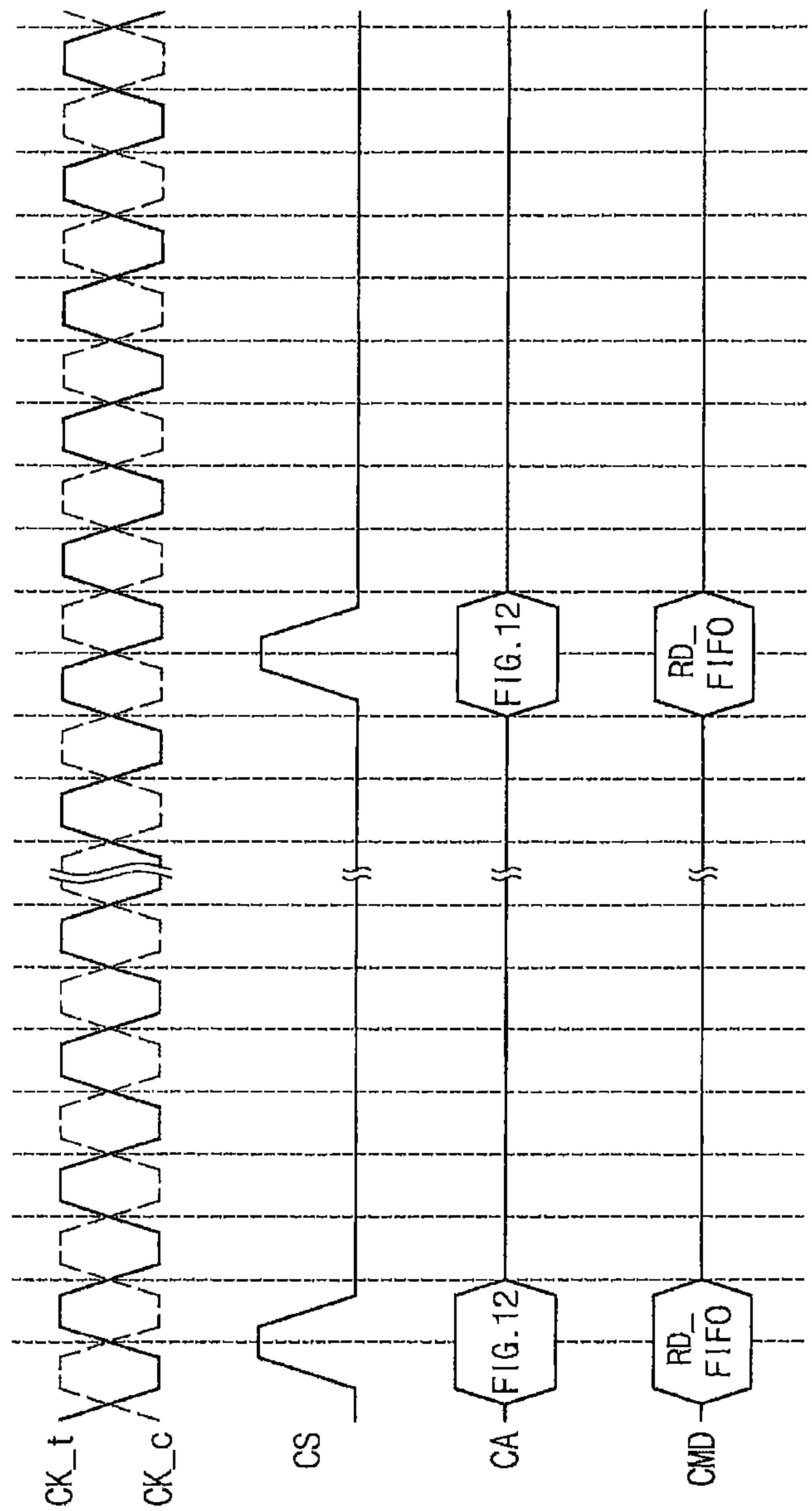


FIG. 12

CK_t	CS	CA0	CA1	CA2	CA3	CA4	CA5	CA6
R	H	L	L	L	L	L	H	L
F	X	V	V	V	V	V	V	V

FIG. 13

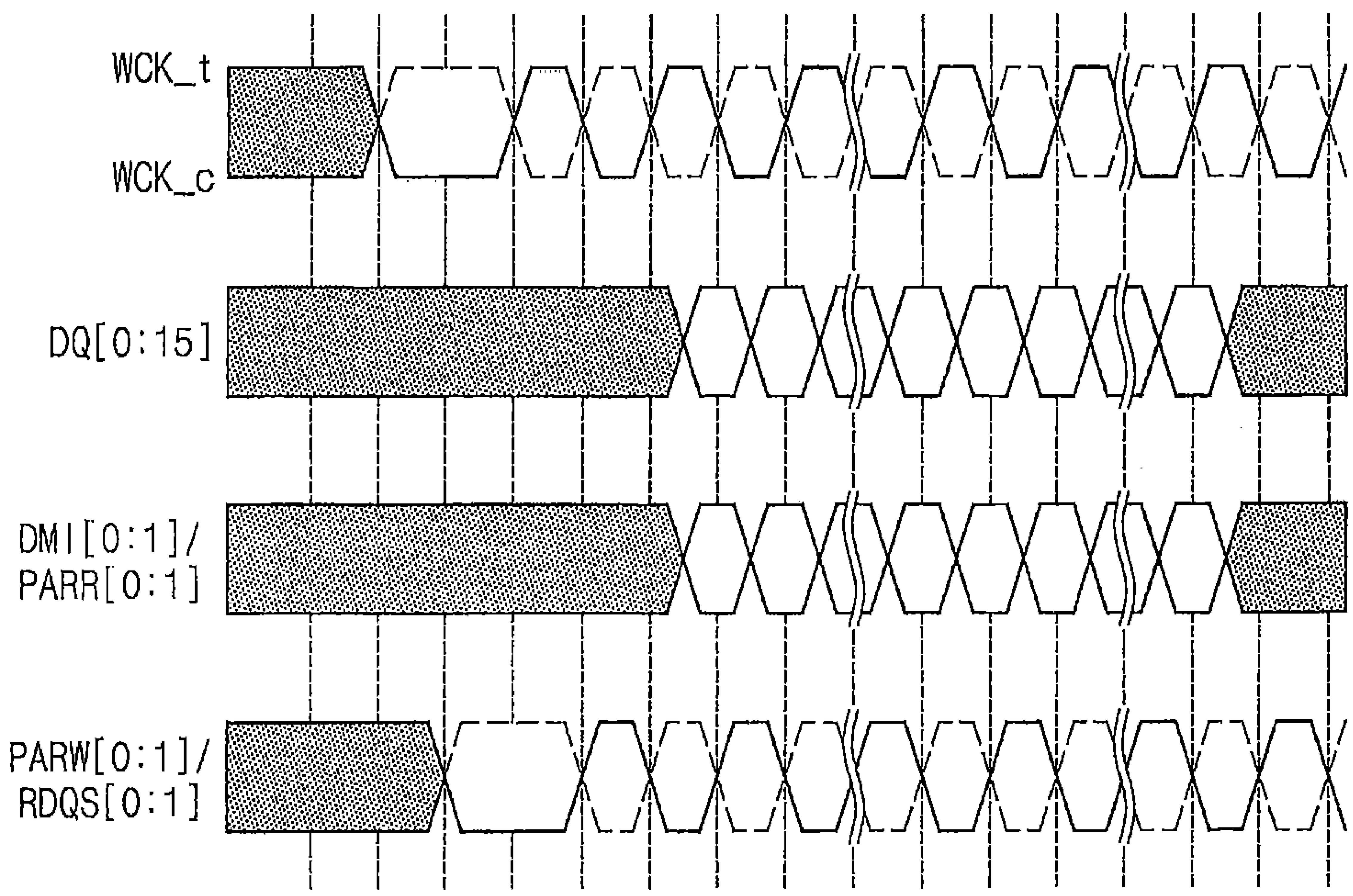


FIG. 14

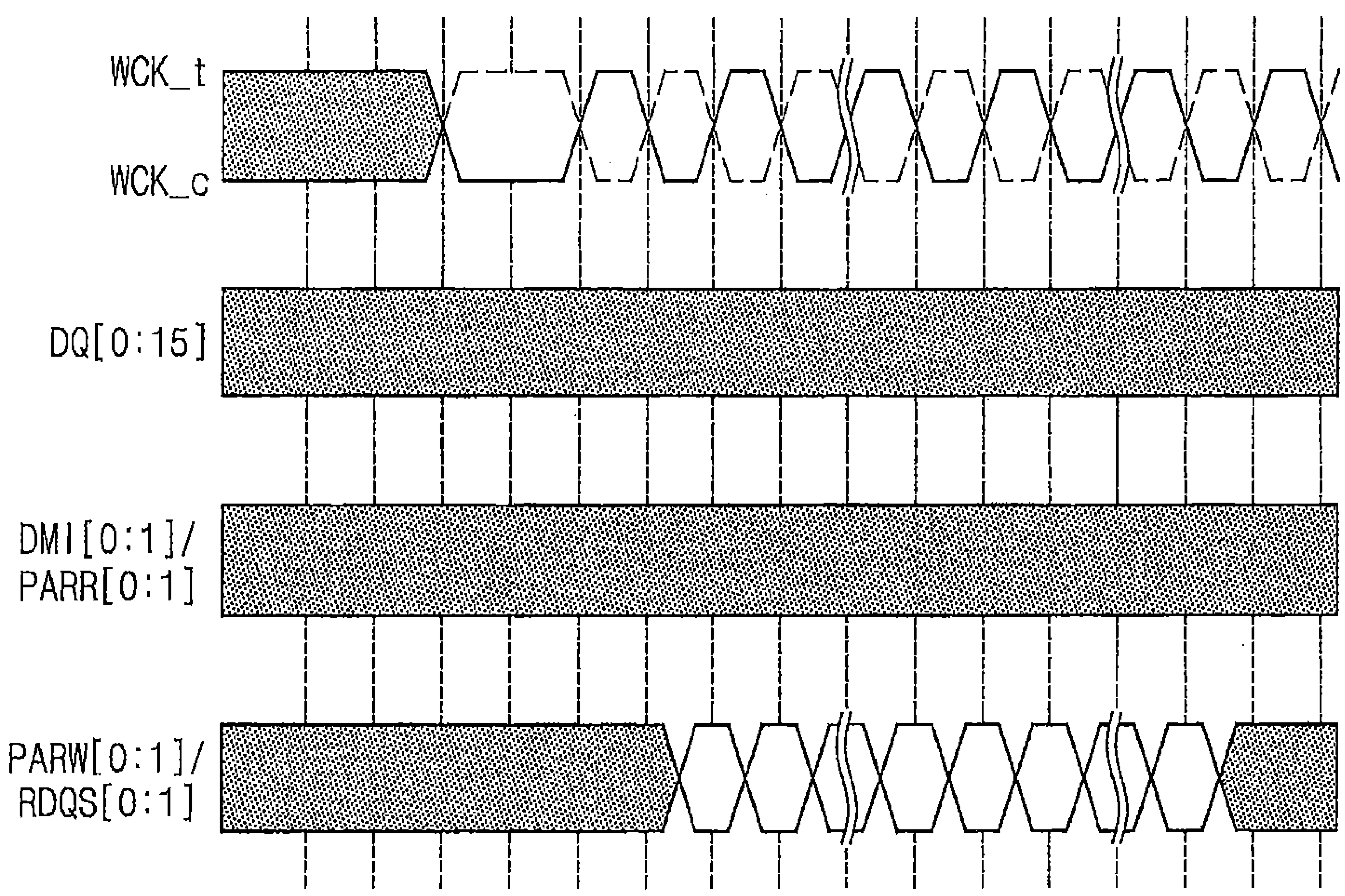


FIG. 15

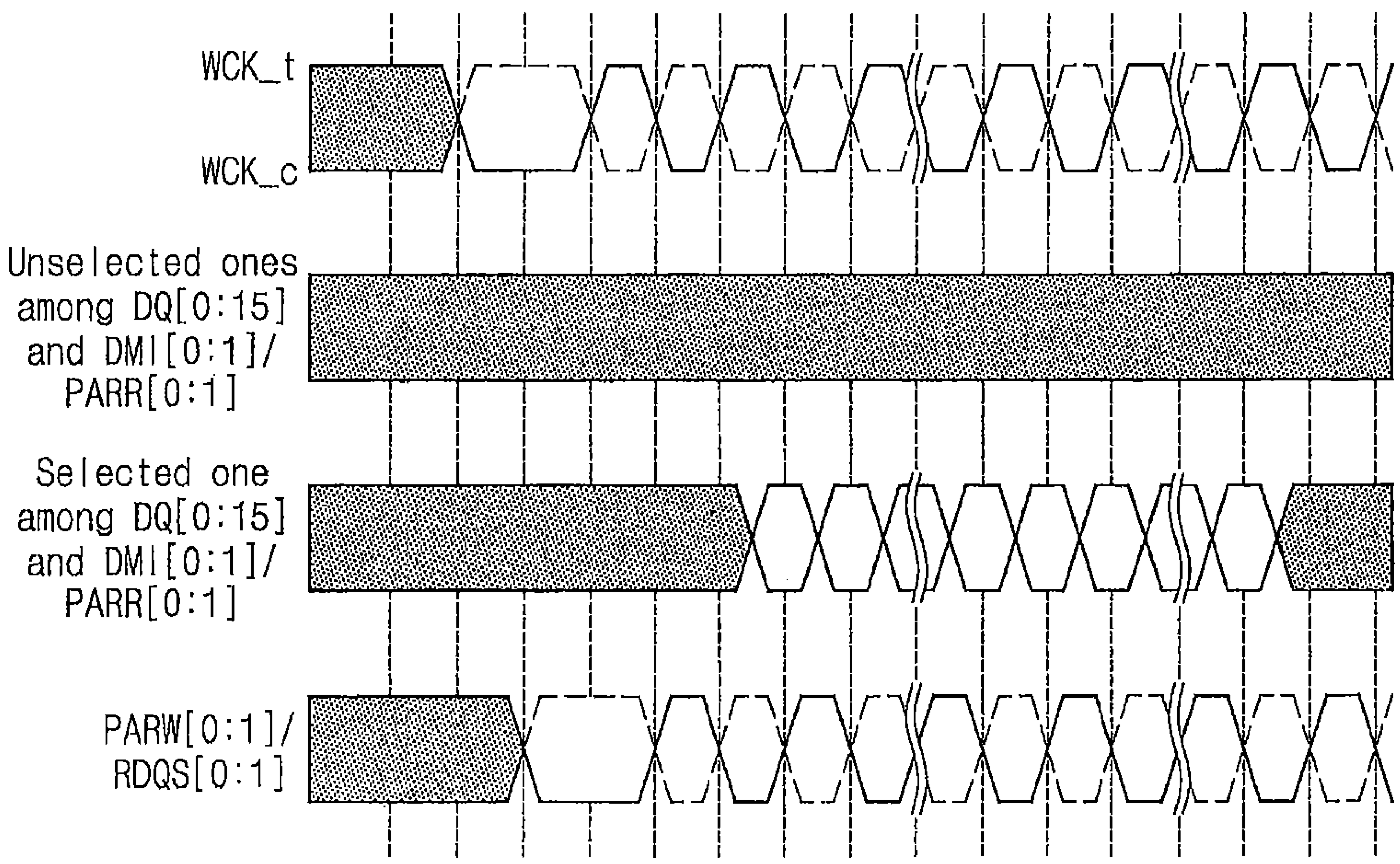

WCK_t
WCK_c
Unselected ones among DQ[0:15] and DMI[0:1]/ PARR[0:1]
Selected one among DQ[0:15] and DMI[0:1]/ PARR[0:1]
PARW[0:1]/ RDQS[0:1]

FIG. 16A

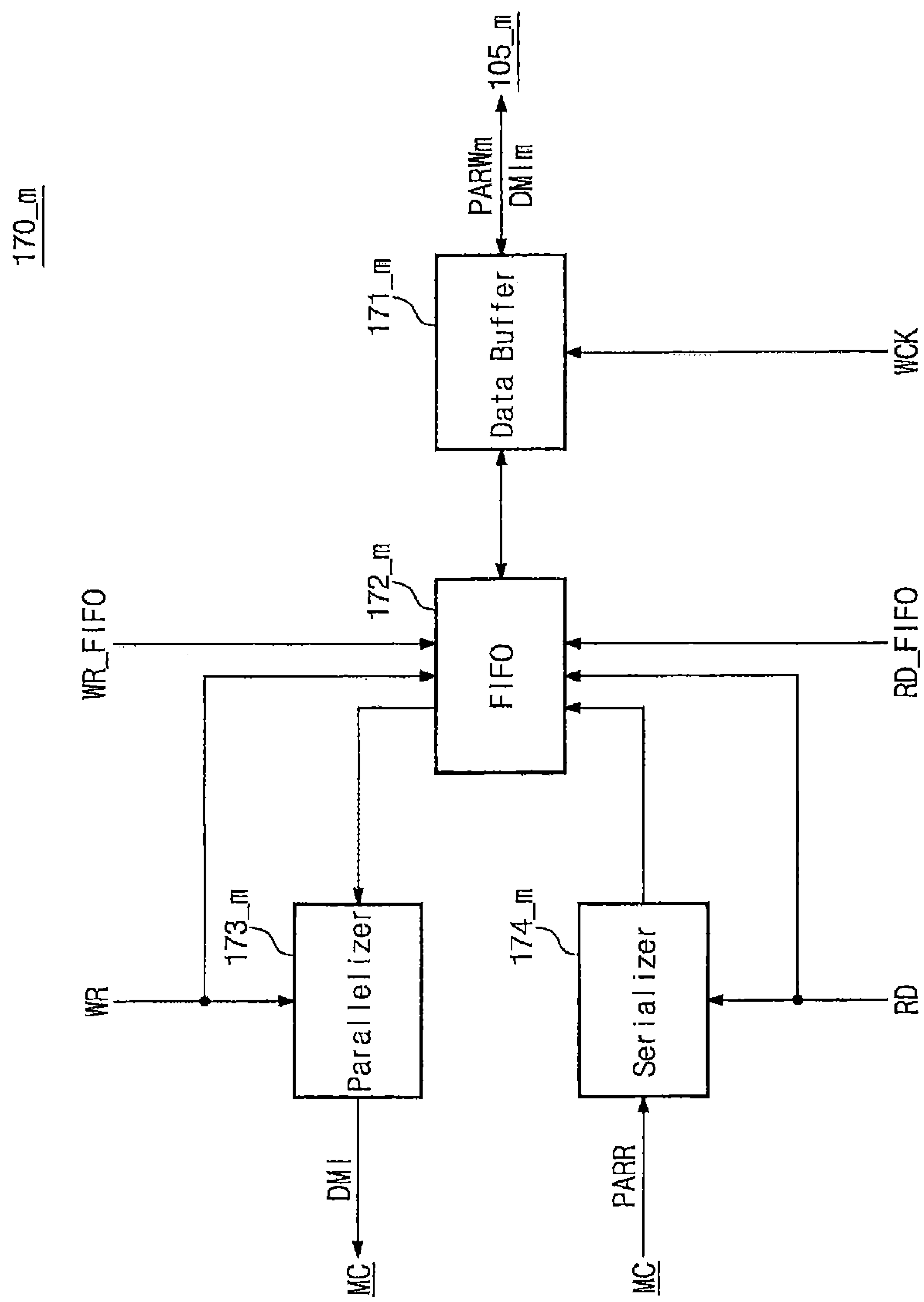

170_m
105_m
PARWm
DMIm
171_m
Data Buffer
WCK
172_m
FIFO
WR_FIFO
RD_FIFO
173_m
Parallelizer
174_m
Serializer
WR
RD
DMI
MC
PARR
MC

FIG. 16B

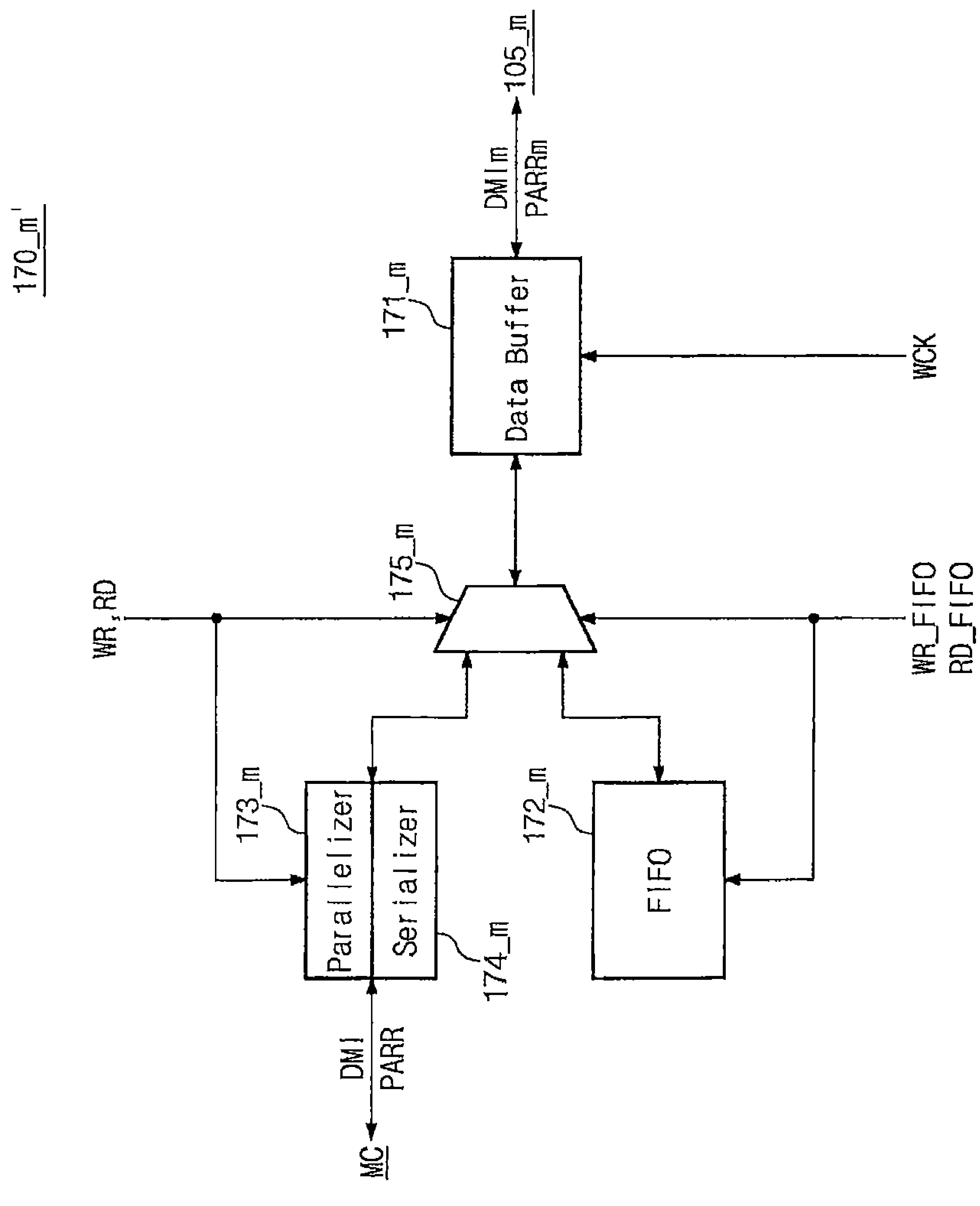

170_m'
105_m
DMIm
PARRm
171_m
Data Buffer
WCK
175_m
WR, RD
WR_FIFO
RD_FIFO
173_m
Parallelizer
Serializer
174_m
172_m
FIFO
DMI
PARR
MC

FIG. 17A

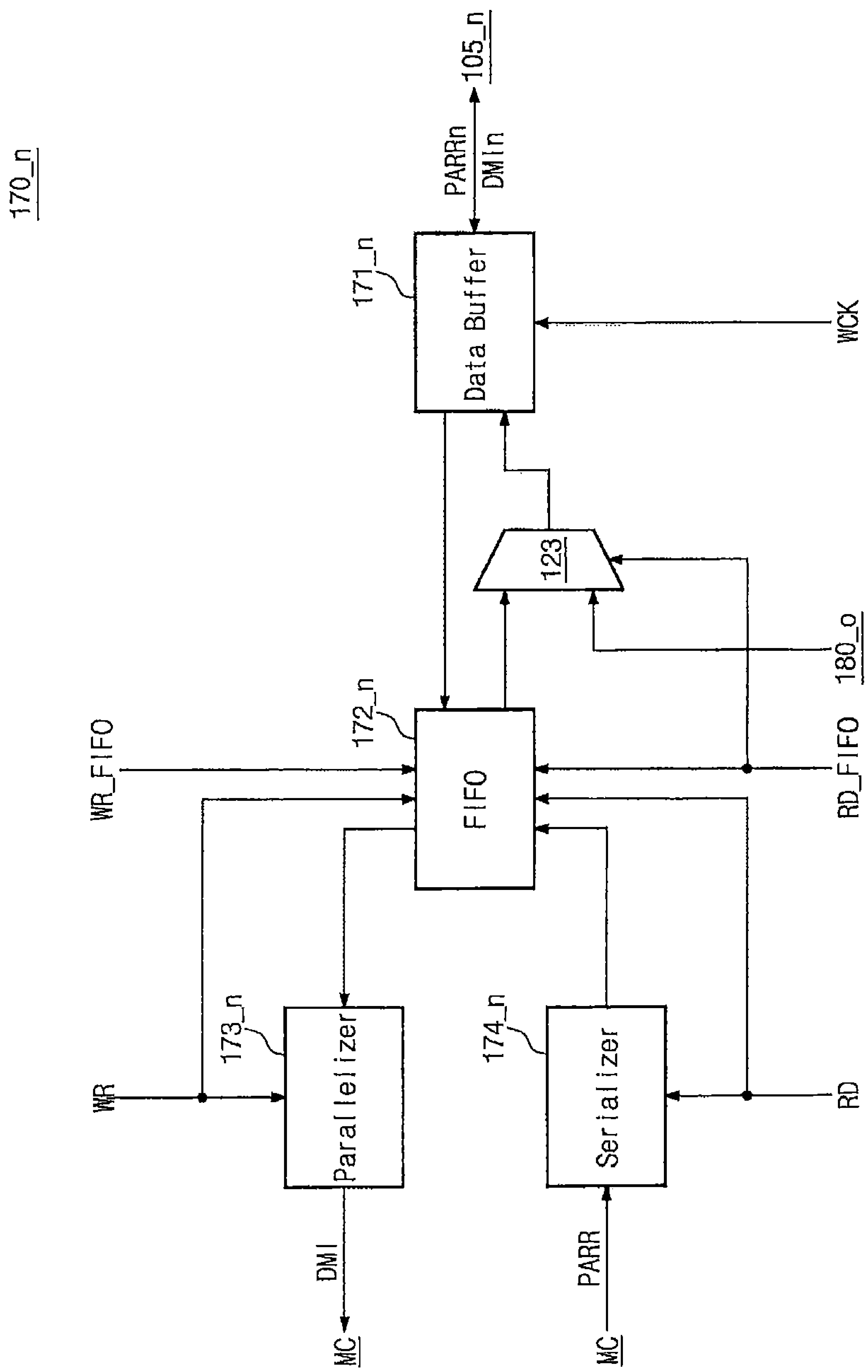

170_n
105_n
PARRn
DMIn
171_n
Data Buffer
WCK
123
180_o
172_n
FIFO
WR_FIFO
RD_FIFO
173_n
Parallelizer
174_n
Serializer
WR
RD
DMI
MC
PARR
MC

FIG. 17B

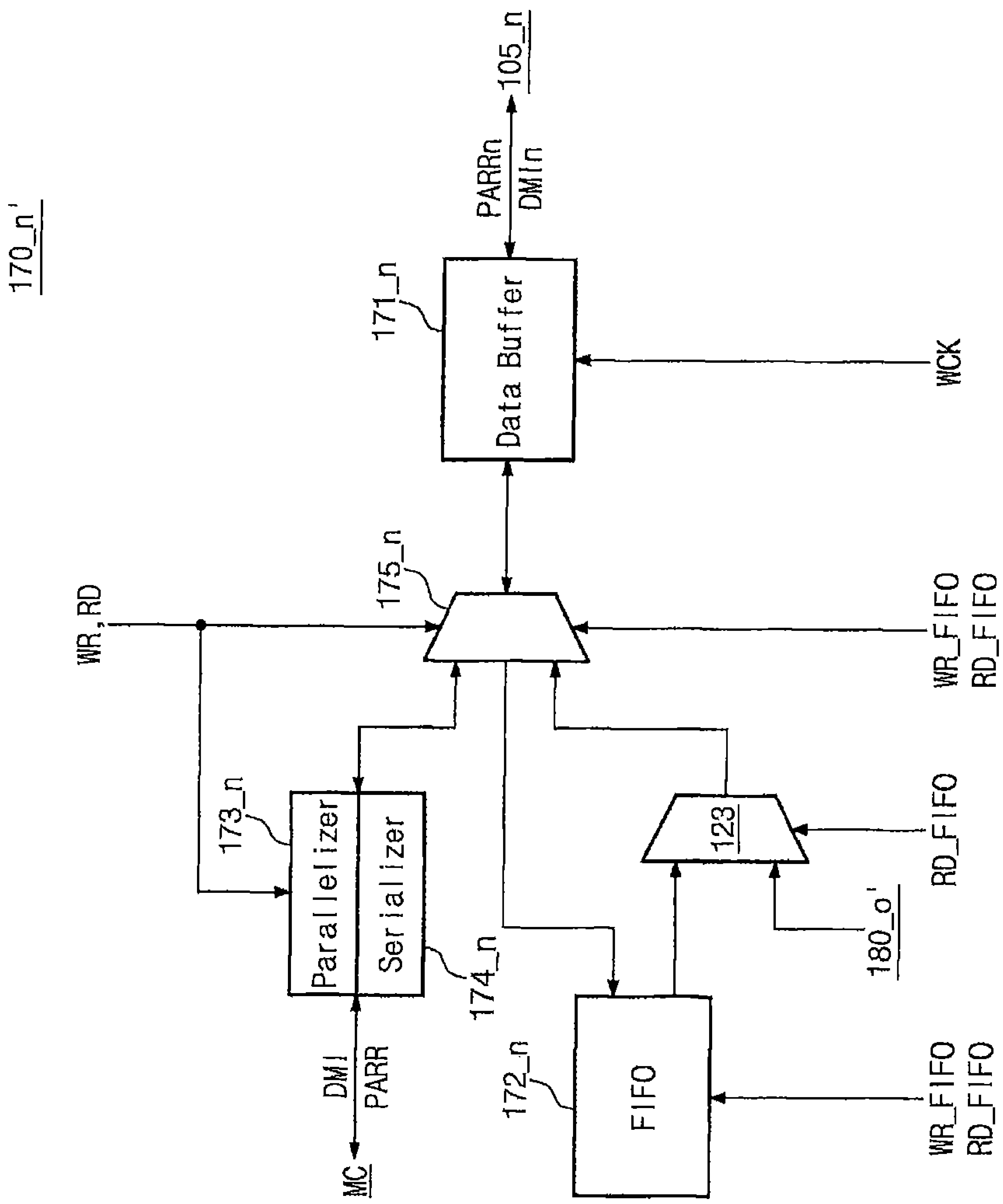
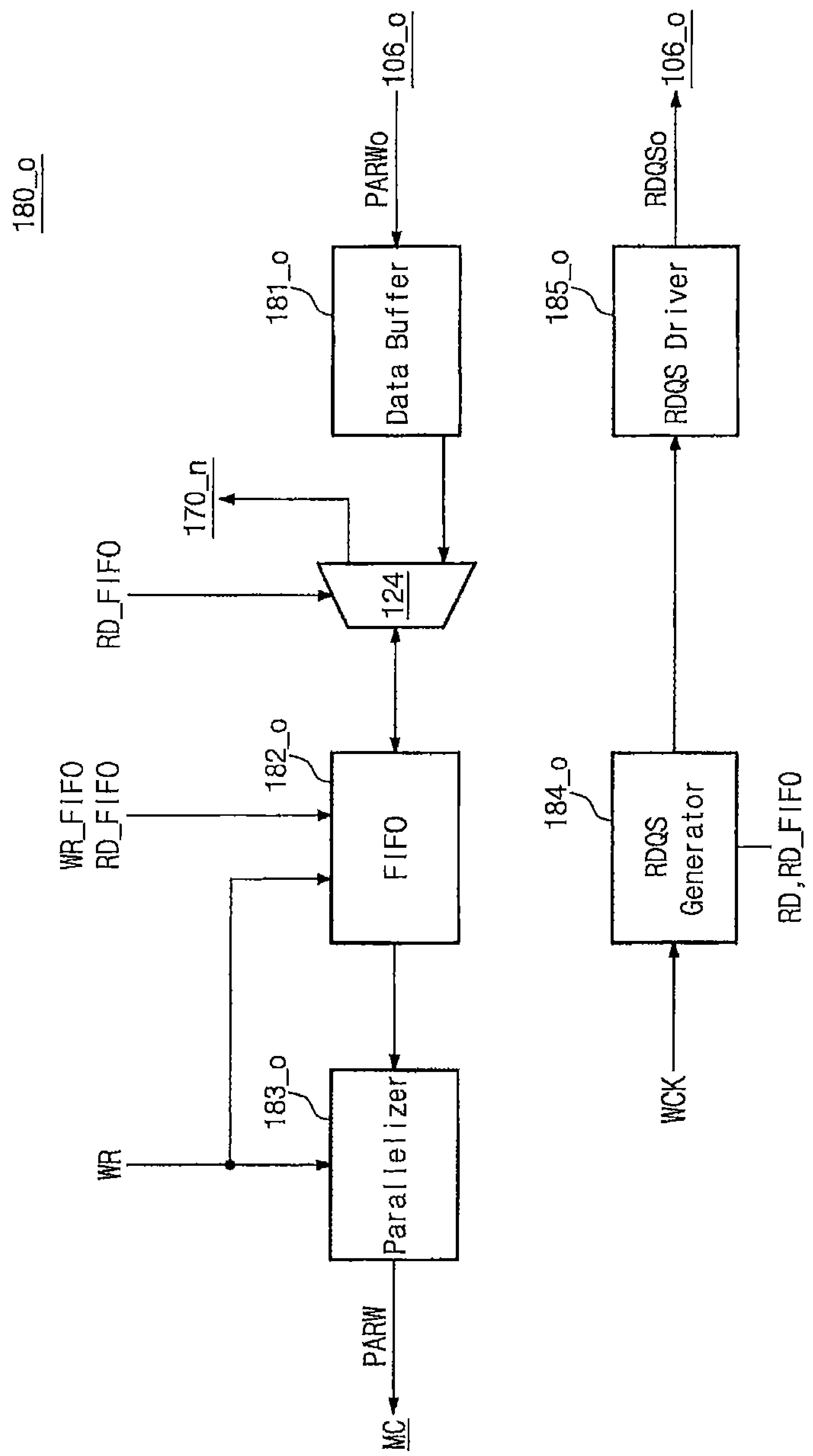

170_n'
105_n
PARRn
DMIn
171_n
Data Buffer
WCK
175_n
WR,RD
WR_FIFO
RD_FIFO
173_n
Parallelizer
Serializer
174_n
123
RD_FIFO
180_o'
DMI
PARR
MC
172_n
FIFO
WR_FIFO
RD_FIFO

FIG. 18A


180_o
106_o
PARWo
181_o
Data Buffer
170_n
RD_FIFO
124
185_o
RDQS Driver
RDQSo
106_o
182_o
FIFO
WR_FIFO
RD_FIFO
184_o
RDQS
Generator
RD,RD_FIFO
183_o
Parallelizer
WR
PARW
MC
WCK

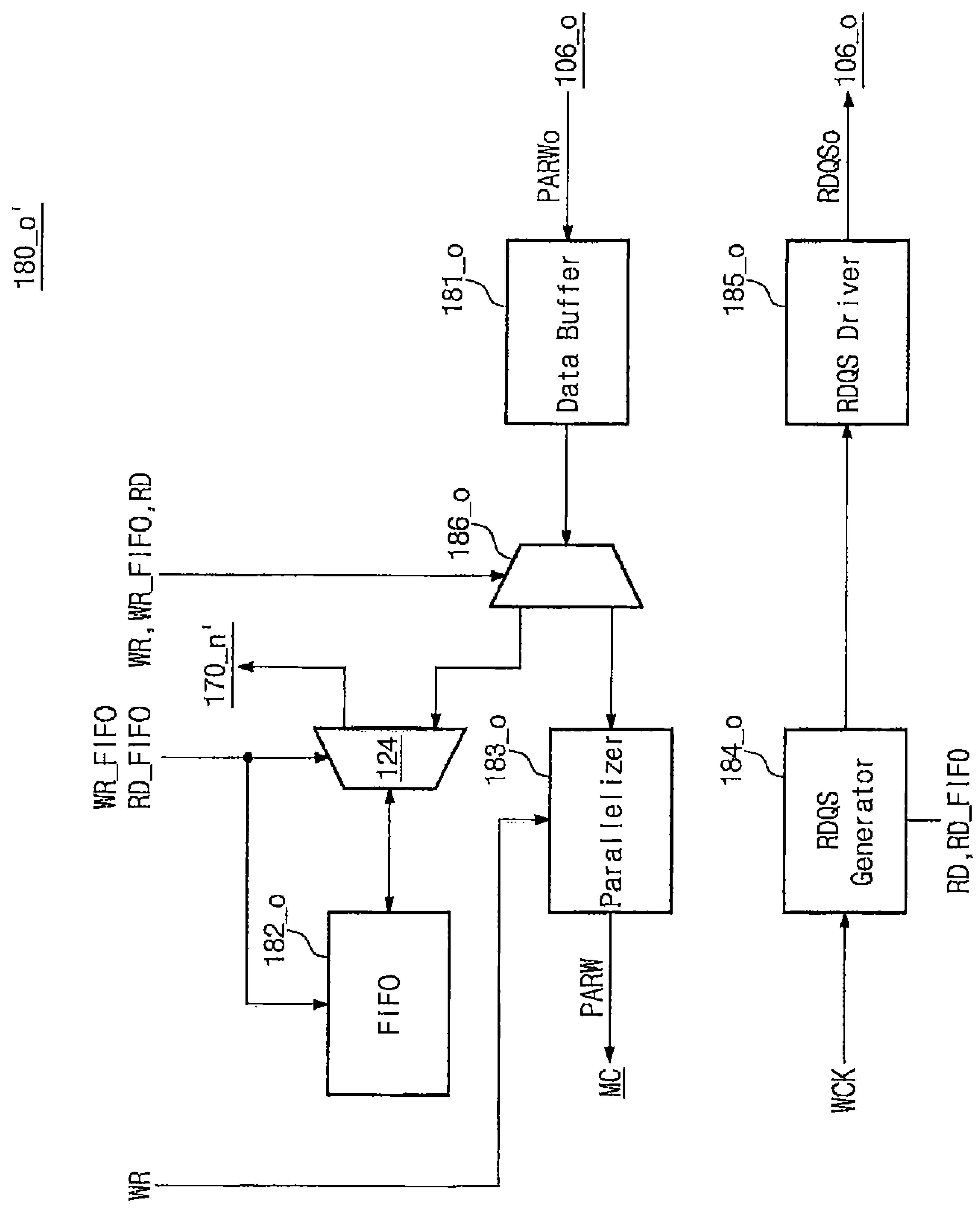

180_o'
106_o
PARWo
181_o
Data Buffer
106_o
RDQSo
185_o
RDQS Driver
WR,WR_FIFO,RD
186_o
170_n'
WR_FIFO
RD_FIFO
124
183_o
Parallelizer
184_o
RDQS Generator
RD,RD_FIFO
182_o
FIFO
PARW
MC
WCK
WR

FIG. 18B

FIG. 19

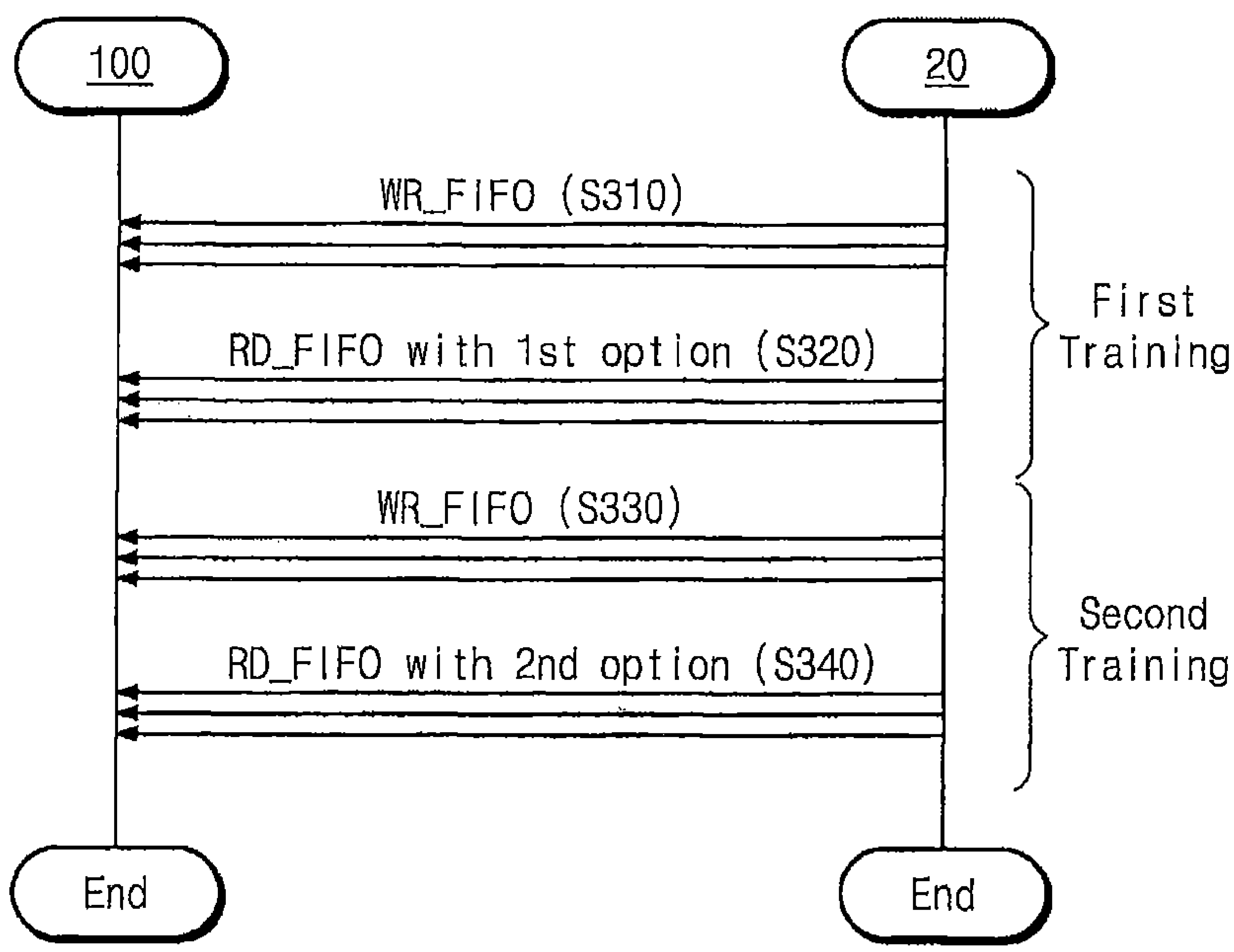

100
20
WR_FIFO (S310)
RD_FIFO with 1st option (S320)
WR_FIFO (S330)
RD_FIFO with 2nd option (S340)
First Training
Second Training
End
End

FIG. 20

CK_t	CS	CA0	CA1	CA2	CA3	CA4	CA5	CA6
R	H	L	L	L	L	L	H	L
F	X	V	V	V	V	V	V	V

FIG. 21

Command	CK_t	CS	CA0	CA1	CA2	CA3	CA4	CA5	CA6
RD_FIFO with 1st option	R	H	L	L	L	L	L	H	H
	F	X	L	V	V	V	V	V	V
RD_FIFO with 2nd option	R	H	L	L	L	L	L	H	L
	F	X	H	V	V	V	V	V	V

FIG. 22

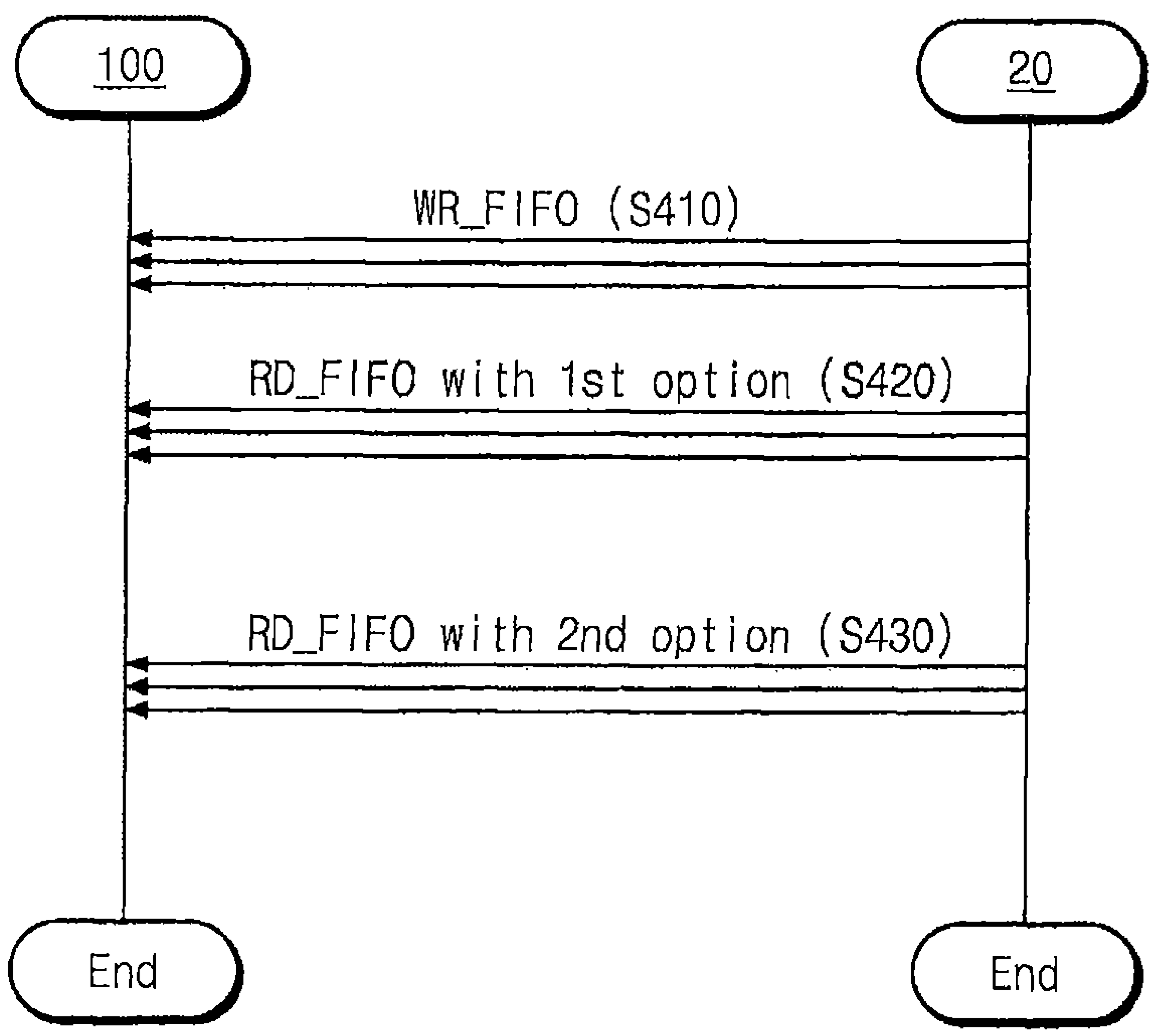

100
20
WR_FIFO (S410)
RD_FIFO with 1st option (S420)
RD_FIFO with 2nd option (S430)
End
End

FIG. 23

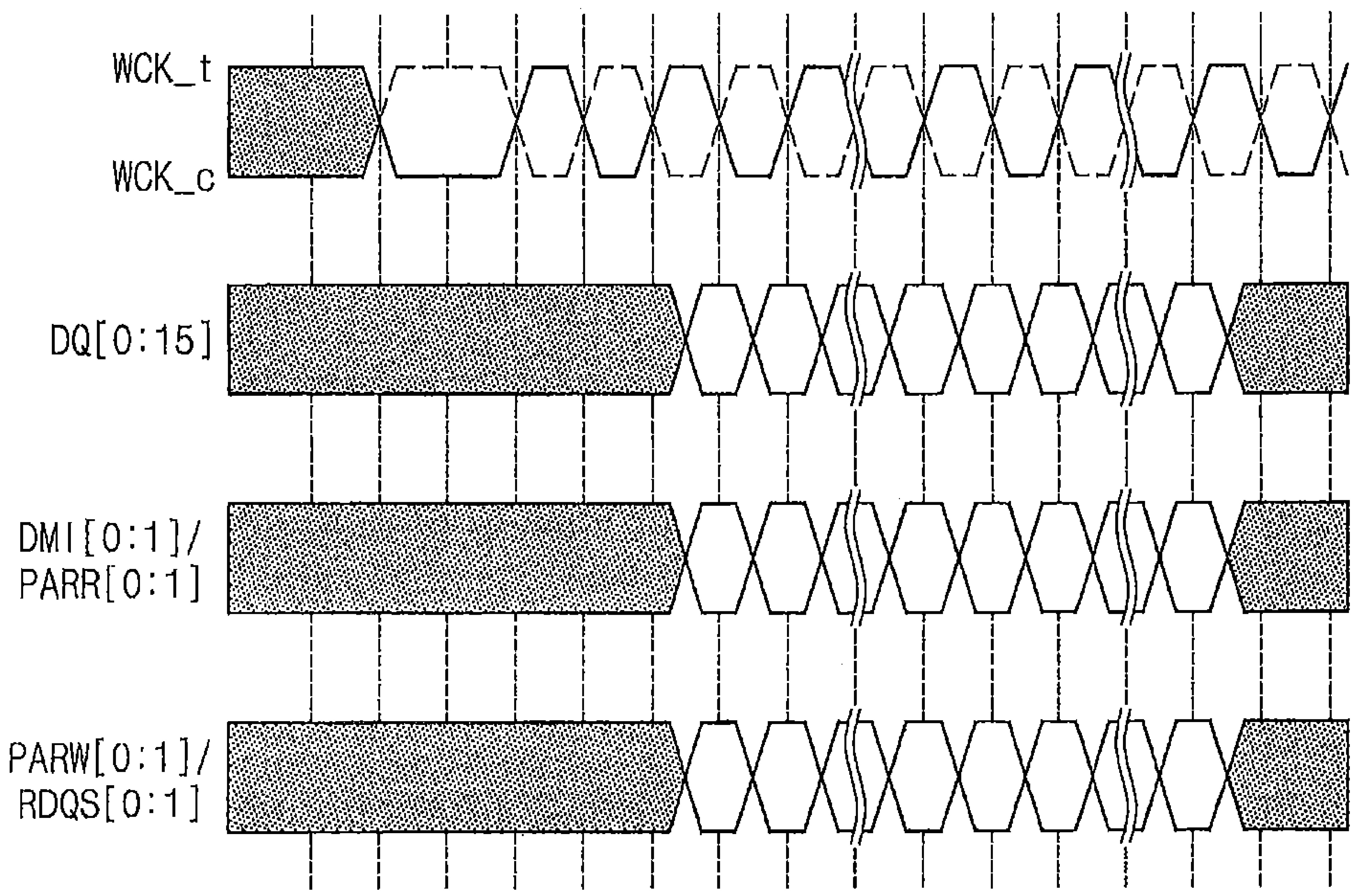


FIG. 24

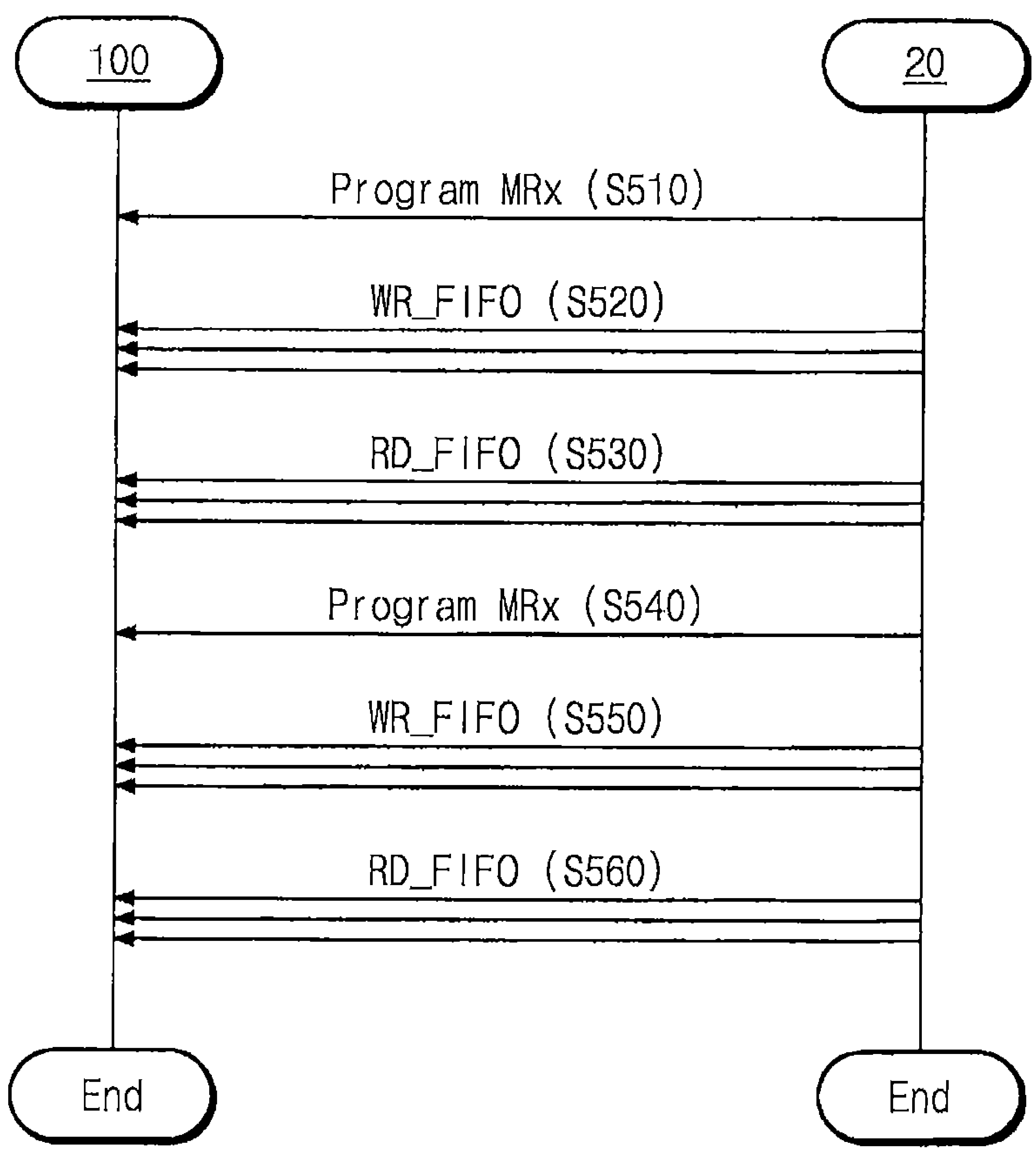

100
20
Program MRx (S510)
WR_FIFO (S520)
RD_FIFO (S530)
Program MRx (S540)
WR_FIFO (S550)
RD_FIFO (S560)
End
End

FIG. 25

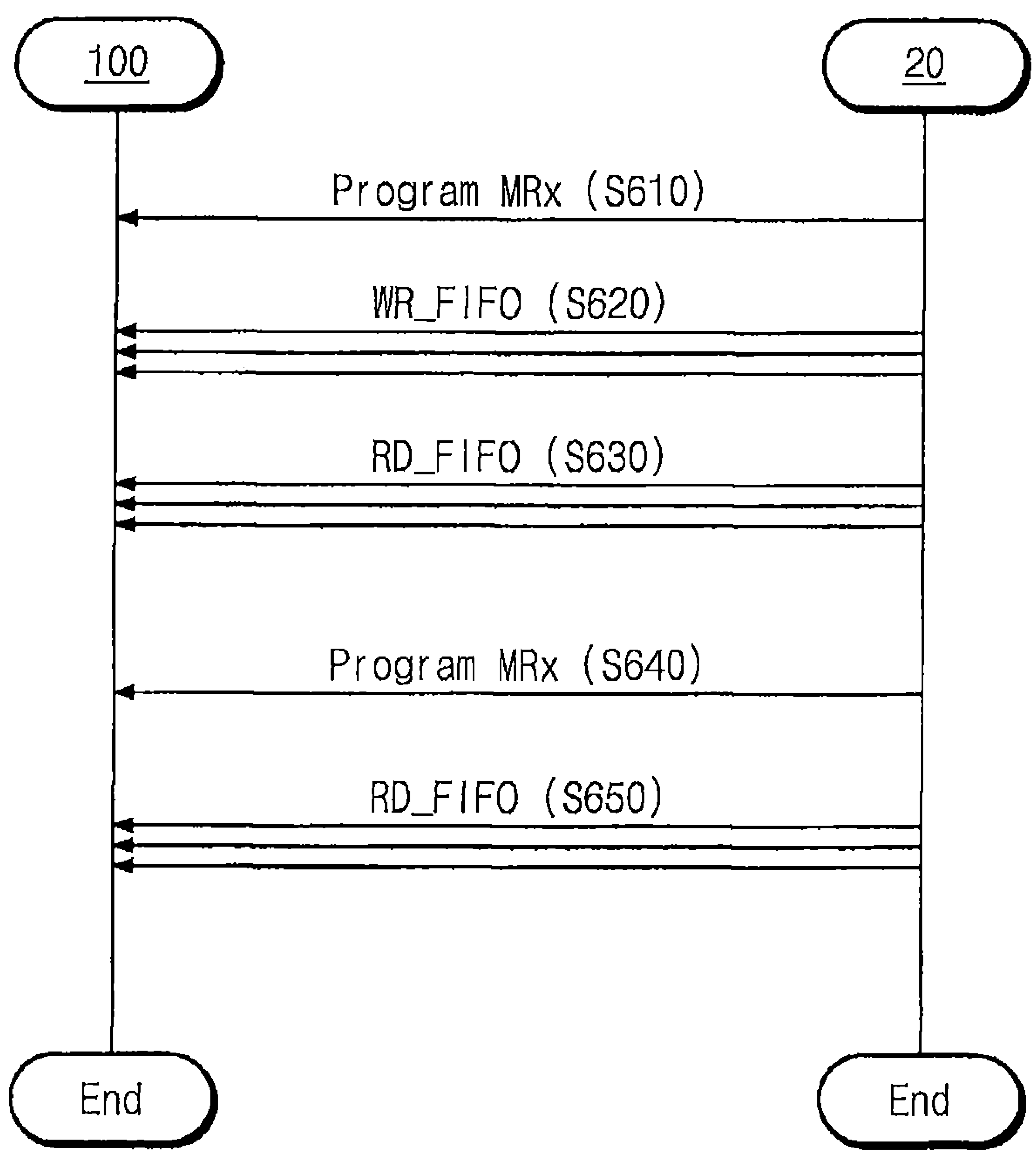

100
20
Program MRx (S610)
WR_FIFO (S620)
RD_FIFO (S630)
Program MRx (S640)
RD_FIFO (S650)
End
End

FIG. 26A

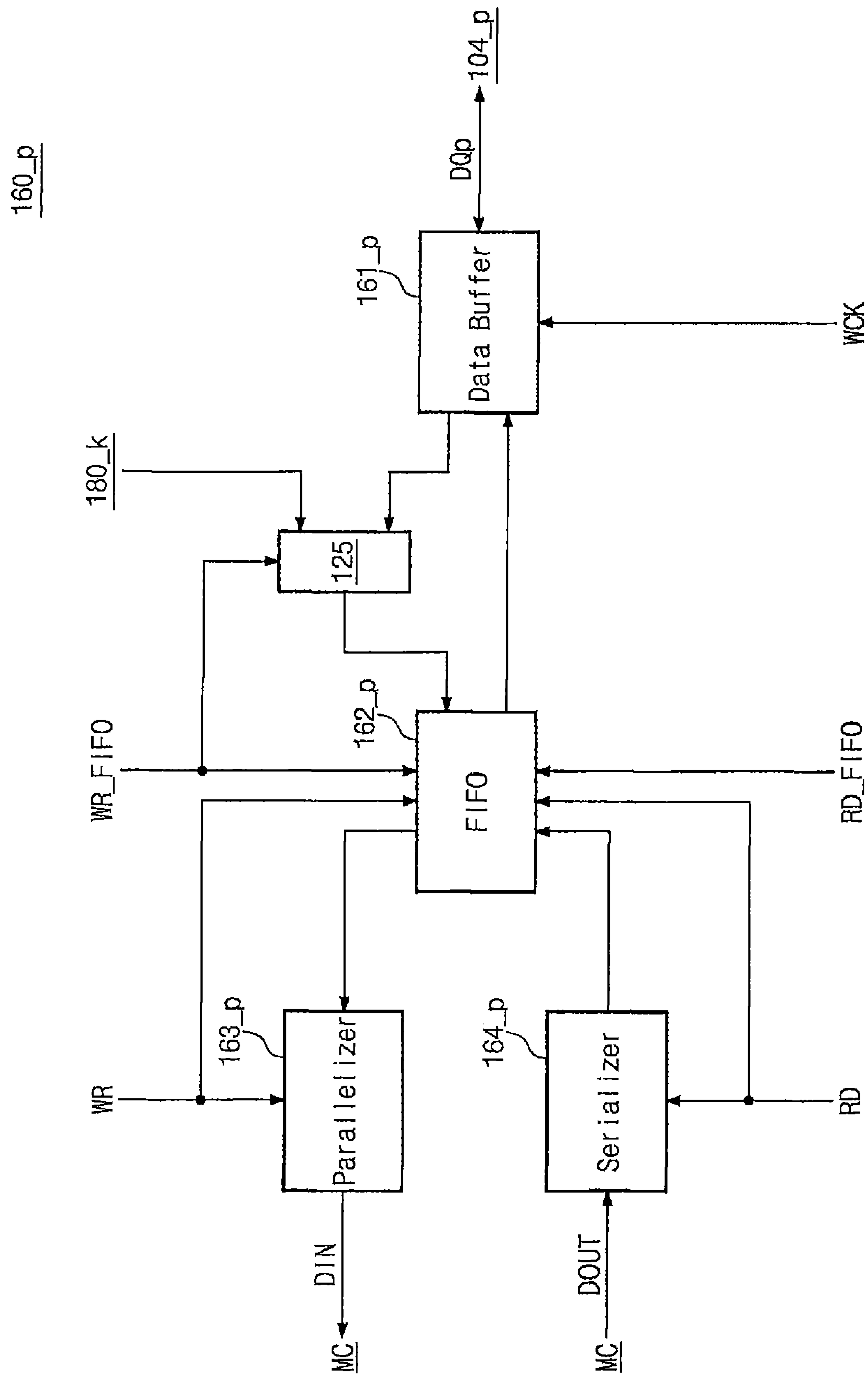

160_p
104_p
DQp
161_p
Data Buffer
WCK
180_k
125
162_p
FIFO
WR_FIFO
RD_FIFO
163_p
Parallelizer
164_p
Serializer
WR
RD
DIN
DOUT
MC
MC

FIG. 26B

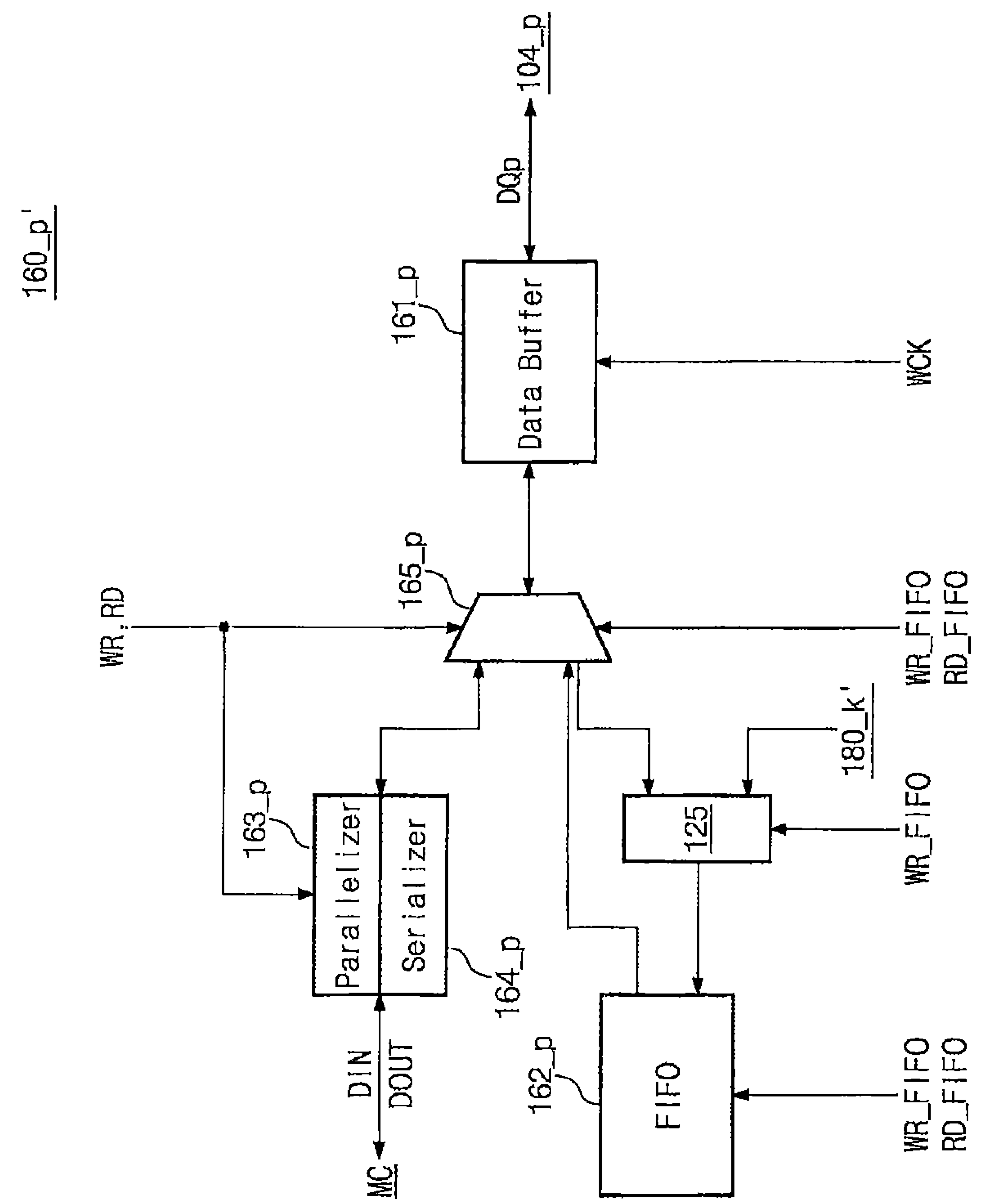

160_p'
104_p
DQp
161_p
Data Buffer
WCK
165_p
WR, RD
WR_FIFO
RD_FIFO
180_k'
163_p
Parallelizer
Serializer
125
WR_FIFO
164_p
DIN
DOUT
MC
162_p
FIFO
WR_FIFO
RD_FIFO

FIG. 27A

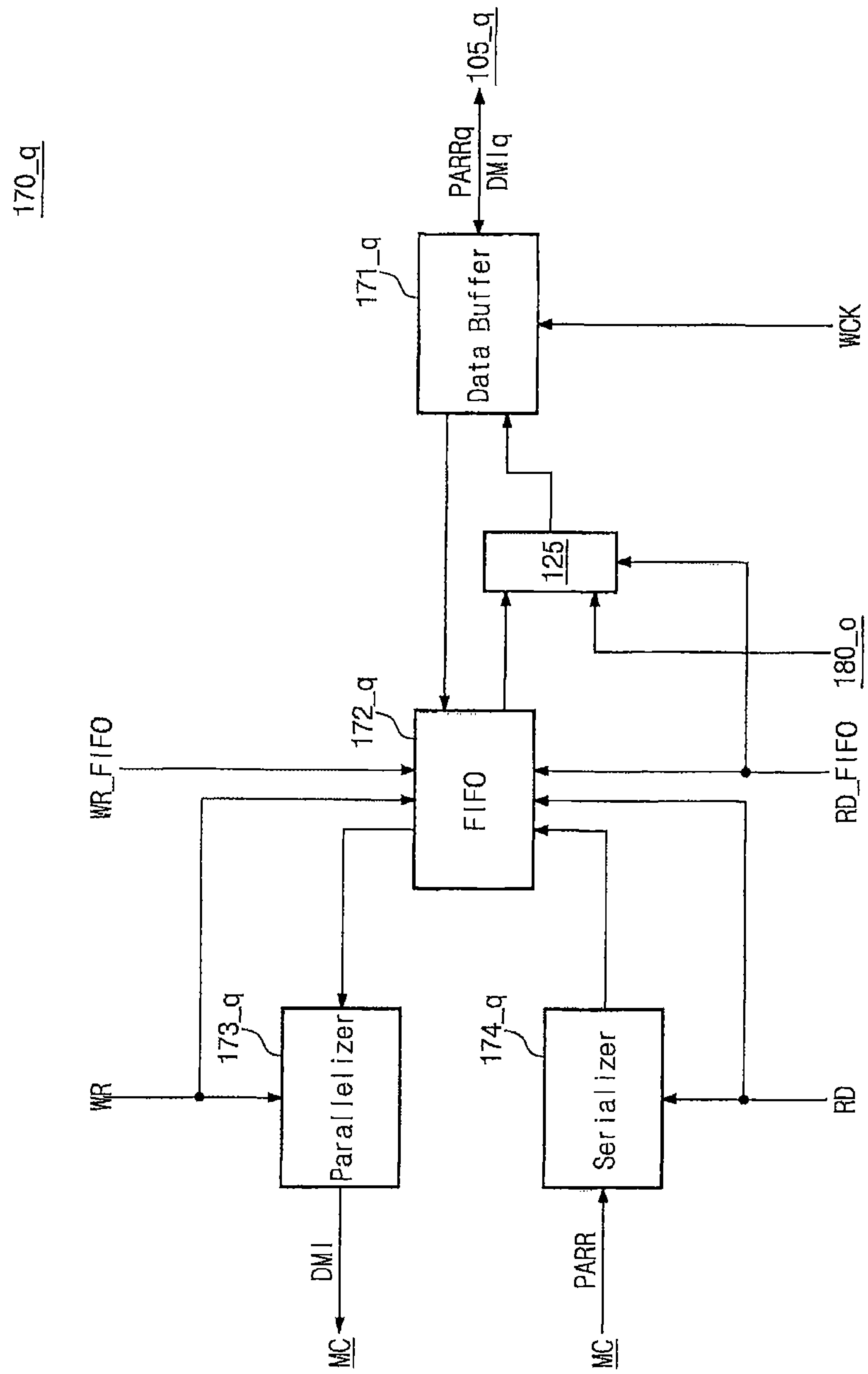
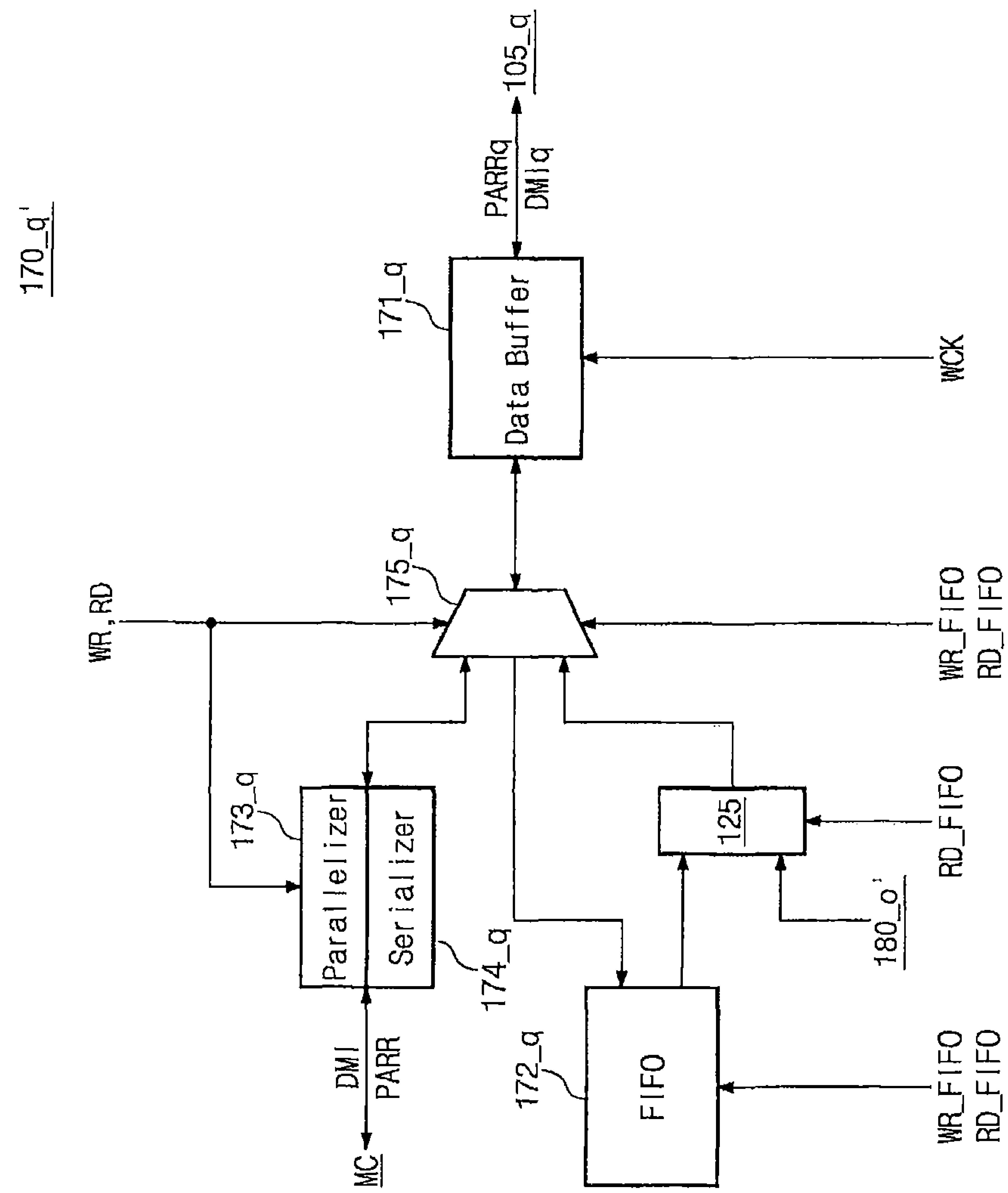

170_q
105_q
PARRq
DMIq
171_q
Data Buffer
WCK
125
180_o
172_q
FIFO
WR_FIFO
RD_FIFO
173_q
Parallelizer
174_q
Serializer
WR
RD
DMI
MC
PARR
MC

FIG. 27B


170_q'
105_q
PARRq
DMIq
171_q
Data Buffer
WCK
175_q
WR,RD
WR_FIFO
RD_FIFO
173_q
Parallelizer
Serializer
174_q
125
RD_FIFO
180_o'
172_q
FIFO
WR_FIFO
RD_FIFO
DMI
PARR
MC

SEMICONDUCTOR MEMORY DEVICES, MEMORY SYSTEMS INCLUDING SEMICONDUCTOR MEMORY DEVICES, AND OPERATING METHODS OF SEMICONDUCTOR MEMORY DEVICES

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue; a claim printed with strikethrough indicates that the claim was canceled, disclaimed, or held invalid by a prior post-patent action or proceeding.

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority under 35 U.S.C. § 119 to Korean Patent Application No. 10-2017-0140363 filed Oct. 26, 2017, in the Korean Intellectual Property Office, the entire contents of which are incorporated by reference herein.

BACKGROUND

Embodiments of the inventive concepts described herein relate to semiconductor memory devices, also referred to herein as semiconductor memory, and more particularly, relate to semiconductor memory, memory systems including the semiconductor memory, and operating methods of the semiconductor memory.

Semiconductor memory devices are used in various electronic devices. The semiconductor memory devices may be used to store data used for the electronic devices to operate. Also, the semiconductor memory may be used to load codes, which the electronic devices may execute, such as an operating system, firmware, software, and the like.

As the quality of content used in the electronic devices is improved, there is an increasing demand for the performance of the semiconductor memory. For example, there is an increasing demand for an increase in the speed and reliability of the semiconductor memory. To satisfy the demand, a variety of new functions for the semiconductor memory have been developed and adopted.

Some of the new functions may use one or more pads that may be used for the semiconductor memory to communicate with a controller. If new pads are used for some functions, the number of pads to be used for the semiconductor memory may increase. If the number of pads increases, the size of the semiconductor memory may increase, and thus, manufacturing costs of the semiconductor memory may increase.

SUMMARY

Embodiments of the inventive concepts provide semiconductor memory with improved reliability without an increase in the number of pads, memory systems including the semiconductor memory, and operating methods of the semiconductor memory.

According to an example embodiment of the inventive concepts, a semiconductor memory device includes a memory core that performs reading and writing of data, data delivery and training blocks that are connected between first pads and the memory core, and at least one data delivery, clock generation and training block that is connected between at least one second pad and the memory core. In a first training operation, the data delivery and training blocks output first training data, which are received through the first pads, through the first pads as second training data. In a second training operation, at least one of the data delivery and training blocks outputs third training data, which are received through the at least one second pad, through at least one of the first pads as fourth training data. The second training data and the fourth training data are output in synchronization with read data strobe signals output through the at least one second pad.

According to an example embodiment of the inventive concepts, a memory system includes a semiconductor memory, and a controller configured to control the semiconductor memory. The semiconductor memory and the controller communicate with each other through data input and output lines, data mask inversion lines, and read data strobe lines. In a first training operation, the controller transmits first data to the semiconductor memory through the data input and output lines and the data mask inversion lines, and reads the first data from the semiconductor memory through the data input and output lines and the data mask inversion lines. In a second training operation, the controller transmits second data to the semiconductor memory through the read data strobe lines and reads the second data from the semiconductor memory through at least two of the data input and output lines and the data mask inversion lines.

According to an example embodiment of the inventive concepts, a semiconductor memory device includes a memory core that performs reading and writing of data, a first data delivery and training block that are connected between a first pad and the memory core, a second data delivery and training block that are connected between a second pad and the memory core, and a data delivery, clock generation and training block that is connected between a third pad and the memory core. In a training input operation, the first and second data delivery and training blocks receive first and second training data through the first pad and the second pad, respectively, and the data delivery, clock generation and training block receives third training data through the third pad. In a training output operation, the first data delivery and training block outputs the first training data through the first pad, and the second data delivery and training block combines the second and third training data to generate fourth training data and outputs the fourth training data through the second pad.

BRIEF DESCRIPTION OF THE FIGURES

The above and other objects and features of the inventive concepts will become apparent by describing in detail example embodiments thereof with reference to the accompanying drawings.

FIG. **1** is a block diagram illustrating a memory system according to embodiments of the inventive concepts.

FIG. **2** is a flowchart illustrating an operating method of a semiconductor memory according to embodiments of the inventive concepts.

FIG. **3** is a block diagram illustrating a semiconductor memory device according to embodiments of the inventive concepts.

FIG. **4**A illustrates an example of one of first data delivery and training blocks according to embodiments of the inventive concepts.

FIG. **4**B illustrates an application of one of the first data delivery and training blocks, which is illustrated in FIG. **4**A.

FIG. **5**A illustrates another example of one of the first data delivery and training blocks according to embodiments of the inventive concepts.

FIG. **5**B illustrates an application of another of the first data delivery and training blocks, which is illustrated in FIG. **5**A.

FIG. **6**A illustrates an example of one of a data delivery, clock generation, and training blocks according to embodiments of the inventive concepts.

FIG. **6**B illustrates an application of one of the data delivery, clock generation, and training blocks.

FIG. **7** is a flowchart illustrating a write training method according to embodiments of the inventive concepts.

FIG. **8** illustrates an example in which a controller transmits a FIFO register write command to the semiconductor memory.

FIG. **9** illustrates an example of command and address signals of a FIFO register write command.

FIG. **10** illustrates an example in which the controller transmits first training data to the semiconductor memory depending on a FIFO register write command.

FIG. **11** illustrates an example in which the controller transmits the FIFO register read command to the semiconductor memory.

FIG. **12** illustrates an example of command and address signals of a FIFO register read command.

FIG. **13** illustrates an example in which the semiconductor memory transmits second training data to the controller depending on the FIFO register read command.

FIG. **14** illustrates an example in which the controller transmits third training data to the semiconductor memory depending on a FIFO register write command.

FIG. **15** illustrates an example in which the semiconductor memory transmits fourth training data to the controller depending on a FIFO register read command.

FIG. **16**A illustrates an example of one of second data delivery and training blocks according to embodiments of the inventive concepts.

FIG. **16**B illustrates another example of one of the second data delivery and training blocks according to embodiments of the inventive concepts.

FIG. **17**A illustrates an example of another of the second data delivery and training blocks according to embodiments of the inventive concepts.

FIG. **17**B illustrates an application of one of the second data delivery and training blocks according to embodiments of the inventive concepts.

FIG. **18**A illustrates another example of one of data delivery, clock generation, and training blocks according to embodiments of the inventive concepts.

FIG. **18**B illustrates an application of one of the data delivery, clock generation, and training blocks according to embodiments of the inventive concepts.

FIG. **19** is a flowchart illustrating a write training method according to embodiments of the inventive concepts.

FIG. **20** illustrates an example of command and address signals of a FIFO register write command.

FIG. **21** illustrates an example of command and address signals of a FIFO register read command.

FIG. **22** is a flowchart illustrating a write training method according to embodiments of the inventive concepts.

FIG. **23** illustrates an example in which first training data and third training data are transmitted to the semiconductor memory depending on a FIFO register write command.

FIG. **24** is a flowchart illustrating a write training method according to embodiments of the inventive concepts.

FIG. **25** is a flowchart illustrating a write training method according to embodiments of the inventive concepts.

FIG. **26**A illustrates another example of one of the first data delivery and training blocks according to embodiments of the inventive concepts.

FIG. **26**B illustrates an application of another of the first data delivery and training blocks, which is illustrated in FIG. **25**A.

FIG. **27**A illustrates an example of one of the second data delivery and training blocks according to embodiments of the inventive concepts.

FIG. **27**B illustrates an example of one of the second data delivery and training blocks according to embodiments of the inventive concepts.

DETAILED DESCRIPTION

Below, embodiments of the inventive concepts may be described in detail and clearly to such an extent that one of ordinary skill in the art may implement embodiments of the inventive concepts.

FIG. **1** is a block diagram illustrating a memory system **10** according to embodiments of the inventive concepts. Referring to FIG. **1**, the memory system **10** may include a controller **20** and a semiconductor memory device **100**, also referred to herein as semiconductor memory **100**. For example, the semiconductor memory **100** may include a dynamic random access memory (DRAM), a synchronous DRAM (SDRAM), a double date rate SDRAM (DDR SDRAM), and low power DDR SDRAM (LPDDR SDRAM).

The controller **20** may communicate with the semiconductor memory **100** through first to sixth controller pads **21** to **26**. The semiconductor memory **100** may communicate with the controller **20** through first to sixth memory pads **101** to **106**. As described herein, individual ones of the second to sixth controller pads **22** to **26** and the second to sixth memory pads **102** to **106** may respectively include more than one pad (e.g., a pad of FIG. **1** may represent a collection of pads). The first controller pad **21** may be connected with the first memory pad **101**. The controller **20** may supply a clock signal CK to the semiconductor memory **100** through the first controller pad **21**. The clock signal CK may be toggled periodically between a low level and a high level. In some embodiments, a pad (e.g., first to sixth controller pads **21** to **26** and/or first to sixth memory pads **101** to **106**) may refer to a conductive region of the semiconductor memory **100** that may be used for attaching signal-transmitting elements of the semiconductor memory **100**.

The second controller pad **22** may be connected with the second memory pad **102**. For example, the second controller pad **22** may include 7 controller pads. The second memory pad **102** may include 7 memory pads respectively connected to the 7 controller pads. The controller **20** may provide a command and address signals CA[**0**:**6**] to the semiconductor memory **100** through the second controller pad **22**.

The third controller pad **23** may be connected with the third memory pad **103**. For example, the third controller pad **23** may include 2 controller pads. The third memory pad **103** may include 2 memory pads respectively connected to the 2 controller pads. The controller **20** may provide write clock signals WCK[**0**:**1**] to the semiconductor memory **100** through the third controller pad **23**.

The write clock signals WCK[**0**:**1**] may be toggled periodically between the high level and the low level. The controller **20** may supply the write clock signals WCK[**0**:**1**] to the semiconductor memory **100** upon reading data from the semiconductor memory **100** or writing data in the semiconductor memory **100**.

The fourth controller pad **24** may be connected with the fourth memory pad **104**. For example, the fourth controller pad **24** may include 16 controller pads. The fourth memory pad **104** may include 16 memory pads respectively connected to the 16 controller pads. The controller **20** and the semiconductor memory **100** may exchange data signals DQ[**0**:**15**] with each other through the fourth controller pad **24** and the fourth memory pad **104**.

The fifth controller pad **25** may be connected with the fifth memory pad **105**. For example, the fifth controller pad **25** may include 2 controller pads. The fifth memory pad **105** may include 2 memory pads respectively connected to the 2 controller pads. The controller **20** may provide data mask to inversion signals DMI[**0**:**1**] to the semiconductor memory **100** through the fifth controller pad **25**. The semiconductor memory **100** may provide read parity signals PARR[**0**:**1**] to the controller **20** through the fifth controller pad **25**.

The sixth controller pad **26** may be connected with the sixth memory pad **106**. For example, the sixth controller pad **26** may include 2 controller pads. The sixth memory pad **106** may include 2 memory pads respectively connected to the 2 controller pads. The controller **20** may provide write parity signals PARW[**0**:**1**] to the semiconductor memory **100** through the sixth controller pad **26**. The semiconductor memory **100** may provide read data strobe signals RDQS [**0**:**1**] to the controller **20** through the sixth controller pad **26**.

The semiconductor memory **100** includes a mode register (MRx) **110** and a redirector **120**. The mode register **110** may store various information used in the operation of the semiconductor memory **100**. The mode register **110** may be programmed by the controller **20**.

The redirector **120** may operate under control of the controller **20** in training. For example, in training, the redirector **120** may output a signal received through at least one pad through at least another pad. An example in which the redirector **120** redirects the input and output of signals will be more fully described below.

The controller **20** includes a link error correction code (ECC) controller **27**. The link error correction code controller **27** may determine whether to apply an error correction code to communication between the controller **20** and the semiconductor memory **100**. In the case of applying the error correction code, the controller **20** may transmit the write parity signals PARW[**0**:**1**] to the semiconductor memory **100** through the sixth controller pad **26** during a write operation.

The link error correction code controller **27** may generate the write parity signals PARW[**0**:**1**] by applying one of various error correction codes such as a cyclic redundancy code (CRC), a hamming code, and Bose-Chaudhri-Hocquenghem (BCH) code to the data signals DQ[**0**:**15**].

The write parity signals PARW[**0**:**1**] may be generated from the data signals DQ[**0**:**15**]. For example, each of the write parity signals PARW[**0**:**1**] may correspond to 8 data signals. The semiconductor memory **100** may correct an error of the data signals DQ[**0**:**15**] based on the write parity signals PARW[**0**:**1**] and the data signals DQ[**0**:**15**].

In the case of applying the error correction code, the semiconductor memory **100** may transmit the read parity signals PARR[**0**:**1**] to the controller **20** through the fifth controller pad **25** during a read operation. The read parity signals PARR[**0**:**1**] may be generated by applying an error correction code to the data signals DQ[**0**:**15**]. The controller **20** may correct an error of the data signals DQ[**0**:**15**] based on the read parity signals PARR[**0**:**1**] and the data signals DQ[**0**:**15**].

In the case of not applying the error correction code, the controller **20** may not transmit the write parity signals PARW[**0**:**1**] during a write operation. Also, the semiconductor memory **100** may not transmit the read parity signals PARR[**0**:**1**] during a read operation. For example, the link error correction code controller **27** may adjust whether to apply an error correction code by adjusting a link error correction code configuration (LINK_ECC) **111** of the mode register **110** in the semiconductor memory **100**.

In some embodiments, the read parity signals PARR[**0**:**1**] and the write parity signals PARW[**0**:**1**] may be for correcting an error occurring during communication between the controller **20** and the semiconductor memory **100**. The read parity signals PARR[**0**:**1**] and the write parity signals PARW [**0**:**1**] may be distinguished from a storage parity in that they are not stored in a memory array **130** (refer to FIG. **3**) of the semiconductor memory **100**.

The write parity signals PARW[**0**:**1**] may be for correcting an error occurring when the controller **20** transmits the data signals DQ[**0**:**15**] to the semiconductor memory **100**. The read parity signals PARR[**0**:**1**] may be for correcting an error occurring when the semiconductor memory **100** transmits the data signals DQ[**0**:**15**] to the controller **20**.

In contrast, the storage parity may be for correcting an error occurring while the data signals DQ[**0**:**15**] are stored in the semiconductor memory **100**. The storage parity that is included as a part of the data signals DQ[**0**:**15**] may be written in the memory array **130** of the semiconductor memory **100** and may be read from the memory array **130** of the semiconductor memory **100**.

A training controller **28** may control training between the controller **20** and the semiconductor memory **100**. For example, the training may include write training to adjust timings between the write clock signals WCK[**0**:**1**] and the data signals DQ[**0**:**15**] during a write operation, and read training to adjust timings between the read data strobe signals RDQS[**0**:**1**] and the data signals DQ[**0**:**15**] during a read operation.

The write training may be performed by transmitting preset pattern signals to the semiconductor memory **100** and again receiving the transmitted signals from the semiconductor memory **100**. For example, the write training may be performed with respect to signals exchanged between the controller **20** and the semiconductor memory **100** in synchronization with the write clock signals WCK[**0**:**1**] or the read data strobe signals RDQS[**0**:**1**].

For example, the controller **20** may transmit pattern signals to the semiconductor memory **100** through the fourth and fifth controller pads **24** and **25** connected to the fourth and fifth memory pads **104** and **105** in synchronization with the write clock signals WCK[**0**:**1**]. For example, the pattern signals may be transmitted as the data signals DQ[**0**:**15**] and the data mask inversion signals DMI[**0**:**1**].

The controller **20** may receive pattern signals from the semiconductor memory **100** through the fourth and fifth controller pads **24** and **25** connected to the fourth and fifth memory pads **104** and **105** in synchronization with the read data strobe signals RDQS[**0**:**1**]. For example, the pattern signals may be received as the data signals DQ[**0**:**15**] and the read parity signals PARR[**0**:**1**] from the semiconductor memory **100**.

Write training may be performed on signals exchanged through the fourth and fifth controller pads **24** and **25** by writing and reading pattern signals through the fourth and fifth controller pads **24** and **25**. For example, write training may be performed on transmission timings of the data signals DQ[**0**:**15**], the data mask inversion signals DMI[**0**:**1**], and/or the read parity signals PARR[**0**:**1**].

In the case where the link error correction code controller **27** activates application of an error correction code, the controller **20** may further transmit the write parity signals PARW[**0**:**1**] to the semiconductor memory **100** in synchronization with the write clock signals WCK[**0**:**1**]. Accordingly, in the case where the application of the error correction code is activated, there is a need to perform write training on the sixth controller pad **26** connected to the sixth memory pad **106** through which the controller **20** and the semiconductor memory **100** exchange the write parity signals PARW[**0**:**1**].

For write training associated with the write parity signals PARW[**0**:**1**], the controller **20** may transmit pattern signals to the semiconductor memory **100** through the sixth controller pad **26** connected to the sixth memory pad **106**. For example, the pattern signals may be transmitted to the semiconductor memory **100** as the write parity signals PARW[**0**:**1**].

However, even though the controller **20** intends to read pattern signals from the semiconductor memory **100** through the sixth controller pad **26** connected to the sixth memory pad **106**, the semiconductor memory **100** may be specified to transmit the read data strobe signals RDQS[**0**:**1**] through the sixth memory pad **106** connected to the sixth controller pad **26**. Accordingly, the controller **20** cannot receive pattern signals from the semiconductor memory **100** through the sixth controller pad **26** connected to the sixth memory pad **106**.

The semiconductor memory **100** includes the redirector **120** for the purpose of performing write training on the sixth controller pad **26** connected to the sixth memory pad **106**. The training controller **28** may control the redirector **120** to receive pattern signals, which are transmitted to the semiconductor memory **100** through the sixth controller pad **26** connected to the sixth memory pad **106**, through a different memory pad or controller pad. Accordingly, write training may be performed on the write parity signals PARW[**0**:**1**] in addition to the data signals DQ[**0**:**15**] and the data mask inversion signals DMI[**0**:**1**].

Kinds of pads and the number of pads are described concretely in FIG. **1**. However, kinds of pads and the number of pads described in FIG. **1** are examples and do not limit the technical ideas of the inventive concepts. Pads that are not illustrated in FIG. **1** may be included in the memory system **10**, and a part of pads illustrated in FIG. **1** may be removed from the memory system **10**. Also, the number of pads illustrated in FIG. **1** may be variously changed.

FIG. **2** is a flowchart illustrating an operating method of the semiconductor memory **100** according to embodiments of the inventive concepts. For example, an example of an operating method of the semiconductor memory **100** in write training is illustrated in FIG. **2**. Referring to FIGS. **1** and **2**, in operation **S110**, the semiconductor memory **100** may receive first training data from the controller **20** through first pads. For example, the first pads may include the fourth memory pad **104** and the fifth memory pad **105**.

For example, the first training data may be received as the data signals DQ[**0**:**15**] and the data mask inversion signals DMI[**0**:**1**]. The first training data may include pattern signals having a pattern for write training. The controller **20** may output preset pattern signals as the first training data to the semiconductor memory **100**.

The first training data may be received in synchronization with the write clock signals WCK[**0**:**1**]. If a difference between toggle timings of the write clock signals WCK[**0**:**1**] and transmission timings of training data received through one pad of the first pads is within a threshold value (e.g., belongs to a normal receive range), training data transmitted through the corresponding pad may be received normally in the semiconductor memory **100**.

If a difference between the toggle timings of the write clock signals WCK[**0**:**1**] and transmission timings of training data received through another pad of the first pads is out of the threshold value (e.g., does not belong to the normal receive range), training data transmitted through the corresponding pad may not be received normally in the semiconductor memory **100**. For example, the training data may be received as erroneous values.

In operation **S120**, the semiconductor memory **100** may output the received first training data to the controller **20** through the first pads as second training data. The second training data may include values that are the same as and different from the first training data depending on transmission timings of the first training data and toggle timings of the write clock signals WCK[**0**:**1**] that the controller **20** transmits.

The first pads may include the fourth memory pad **104** and the fifth memory pad **105**: The second training data may be output in synchronization with the read data strobe signals RDQS[**0**:**1**]. For example, it is assumed that read training is completed before write training. That is, it is assumed that a difference between toggle timings of the read data strobe signals RDQS[**0**:**1**] output from the semiconductor memory **100** and transmission timings of the first training data is within a threshold value.

The controller **20** may compare the second training data received from the semiconductor memory **100** with the first training data that the controller **20** transmits. If the second training data and the first training data are matched, it may be determined that a difference between toggle timings of the write clock signals WCK[**0**:**1**] and transmission timings of the first training data is within the threshold value. If the second training data and the first training data are not matched, it may be determined that a difference between toggle timings of the write clock signals WCK[**0**:**1**] and transmission timings of at least a part of the first training data is out of the threshold value.

The controller **20** may detect a difference between toggle timings of the write clock signals WCK[**0**:**1**] and transmission timings of the first training data while sweeping toggle timings of the write clock signals WCK[**0**:**1**] and transmission timings of the first training data. The controller **20** may adjust transmission timings through the first pads, for example, transmission timings of the data signals DQ[**0**:**15**] and the data mask inversion signals DMI[**0**:**1**] depending on the detected difference.

In operation **S130**, the semiconductor memory **100** may receive third training data from the controller **20** through at least one second pad. For example, the at least one second pad may include the sixth memory pad **106**. The third training data may be received as the write parity signals PARW[**0**:**1**]. The third training data may be received in synchronization with the write clock signals WCK[**0**:**1**].

If a difference between toggle timings of the write clock signals WCK[**0**:**1**] and transmission timings of training data received through the at least one second pad is within the threshold value (e.g., belongs to a normal receive range), training data transmitted through the corresponding pad may be received normally in the semiconductor memory **100**.

If a difference between toggle timings of the write clock signals WCK[**0**:**1**] and transmission timings of training data received through the at least one second pad is out of the threshold value (e.g., does not belong to a normal receive range), training data transmitted through the corresponding pad may not be received normally in the semiconductor memory **100**. For example, the training data may be received as erroneous values.

In operation S**140**, the semiconductor memory **100** may output the received third training data to the controller **20** through the at least one first pad as fourth training data. The at least one first pad may be at least one of the first pads mentioned above. For example, the at least one first pad may include at least one of the fourth memory pad **104** and the fifth memory pad **105**.

The fourth training data may be output in synchronization with the read data strobe signals RDQS[**0**:**1**] transmitted through the at least one second pad. The controller **20** may compare the fourth training data received from the semiconductor memory **100** with the third training data that the controller **20** transmits.

The controller **20** may detect a difference between toggle timings of the write clock signals WCK[**0**:**1**] and transmission timings of the third training data while sweeping toggle timings of the write clock signals WCK[**0**:**1**] and transmission timings of the third training data. The controller **20** may adjust transmission timings through the at least one second pad, for example, transmission timings of the write parity signals PARW[**0**:**1**] depending on the detected difference.

As described above, the fourth memory pad **104** and the fifth memory pad **105** may be used for communication of data (or communication of additional information/data associated with the communication of data) between the semiconductor memory **100** and the controller **20** and are free from the input (or receive) and output of data. Accordingly, training of the fourth memory pad **104** and/or the fifth memory pad **105** may be performed by receiving (or input) (operation S**110**) and transmission (or output) (operation S**120**) of training data.

The sixth memory pad **106** may be used for communication of data (or communication of additional information/data associated with the communication of data) between the semiconductor memory **100** and the controller **20**, and is free to input (or receive) and output data but is not used to transmit (or output) data. Accordingly, training of the sixth memory pad **106** may be performed by receiving (or input) (operation S**130**) of training data and transmission (or output) (operation S**140**) of the training data through another pad (e.g., at least one of the first pads).

Write training associated with the sixth memory pad **106** which is not used to output data may be possible by outputting received (or input) data to another pad through redirecting. Accordingly, the reliability of the semiconductor memory **100** and the memory system **10** including the semiconductor memory **100** may be improved.

Also, as the read data strobe signals RDQS[**0**:**1**] and the write parity signals PARW[**0**:**1**] uses the sixth memory pad **106** in common, the number of pads of the semiconductor memory **100** may be prevented from increasing, and an increase in manufacturing costs of the semiconductor memory **100** may be reduced and/or suppressed.

FIG. **3** is a block diagram illustrating the semiconductor memory **100** according to embodiments of the inventive concepts. Referring to FIGS. **1** and **3**, the semiconductor memory **100** includes the redirector **120**, the memory array **130**, an input and output driver and sense amplifier **140**, a bus controller and error correction engine **150**, a first block **160**, a second block **170**, a third block **180**a, a fourth block **180**b, and control logic **190**.

The memory array **130** includes memory cells. The memory cells may be arranged in a matrix form or may be stacked in a three-dimensional structure. The memory array **130** is connected to the input and output driver and sense amplifier **140** through input and output lines IO. The input and output driver and sense amplifier **140** may perform read and write operations on the memory cells of the memory array **130**.

The bus controller and error correction engine **150** may be connected with the first block **160**, the second block **170**, and the third block **180**a. The bus controller and error correction engine **150** may receive input data DIN from the first block **160** and may transmit the received input data DIN to the input and output driver and sense amplifier **140**.

The bus controller and error correction engine **150** may receive output data DOUT from the input and output driver and sense amplifier **140** and may transmit the received output data DOUT to the first block **160**. The bus controller and error correction engine **150** may receive the data mask inversion signal DMI from the second block **170**.

The data mask inversion signal DMI may indicate whether an inversion of data or a write mask of data is to be used. The data mask inversion signal DMI may be set by programming the mode register **110**. When the data mask inversion signal DMI indicates data mask, the bus controller and error correction engine **150** may not transmit the input data DIN to the input and output driver and sense amplifier **140**.

When the data mask inversion signal DMI indicates inversion, the bus controller and error correction engine **150** may invert the input data DIN or may transmit the data mask inversion signal DMI to the input and output driver and sense amplifier **140** together with the input data DIN.

In a read operation, the bus controller and error correction engine **150** may generate a read parity PARR based on the output data DOUT. The bus controller and error correction engine **150** may transmit the read parity PARR to the second block **170**.

In a write operation, the bus controller and error correction engine **150** may receive a write parity PARW from the third block **180**a. The bus controller and error correction engine **150** may perform error correction based on the write parity PARW and the input data DIN. The memory array **130**, the input and output driver and sense amplifier **140**, and the bus controller and error correction engine **150** may constitute a memory core MC of the semiconductor memory **100**.

The control logic **190** may receive clock signals CK through the first memory pad **101**. The control logic **190** may receive the command and address signals CA[**0**:**6**] through the second memory pads **102**. For example, the control logic **190** may receive the command and address signals CA[**0**:**6**] in synchronization with the clock signals CK.

The control logic **190** may control operations of the memory core MC, the redirector **120**, the first and second blocks **160** and **170**, the third block **180**a, and the fourth block **180**b in response to the command and address signals CA[**0**:**6**].

In some embodiments, the mode register **110** is illustrated as being included in the control logic **190**. However, the mode register **110** is not limited as being included in the control logic **190**. The mode register **110** may be provided outside the control logic **190** or may be included inside any other component, not the control logic **190**.

The first block **160** may include first data delivery and training blocks **160_1** to **160_15** that operate in synchronization with the write clock signals WCK[**0**:**1**]. The first data delivery and training blocks **160_1** to **160_15** may be respectively connected to fourth memory pads **104_0** to **104_15**. The first data delivery and training blocks **160_1** to **160_15** may exchange the data signals DQ[**0**:**15**] with the fourth memory pads **104_0** to **104_15**, respectively.

In a write operation, the first block **160** may transmit the data signals DQ**0** to DQ**15** as the input data DIN to the memory core MC. In a read operation, the first block **160** may output the output data DOUT transmitted from the memory core MC as the data signals DQ**0** to DQ**15**.

In a write operation of write training, the first data delivery and training blocks **160_1** to **160_15** may receive and store training data from the fourth memory pads **104_0** to **104_15**, respectively. In a read operation of write training, the first data delivery and training blocks **160_1** to **160_15** may output the stored training data to the fourth memory pads **104_0** to **104_15**, respectively.

The second block **170** may include second data delivery and training blocks **170_0** and **170_1** that operate in synchronization with the write clock signals WCK[**0**:**1**]. The second data delivery and training blocks **170_0** and **170_1** may be respectively connected to fifth memory pads **105_0** and **105_1**.

The second data delivery and training blocks **170_0** and **170_1** may transmit the read parity signals PARR**0** and PARR**1** to the fifth memory pads **105_0** and **105_1** and may receive the data mask inversion signals DMI**0** and DMI**1** from the fifth memory pads **105_0** and **105_1**.

In a write operation, the second block **170** may transmit the data mask inversion signals DMI**0** and DMI**1** as the data mask inversion signal information DMI to the memory core MC. In a read operation, the second block **170** may output a read parity PARR transmitted from the memory core MC as the read parity signals PARR**0** and PARR**1**.

In a write operation of write training, the second data delivery and training blocks **170_0** and **170_1** may receive and store training data from the fifth memory pads **105_0** and **105_1**, respectively. In a read operation of write training, the second data delivery and training blocks **170_0** and **170_1** may output the stored training data to the fifth memory pads **105_0** and **105_1**, respectively.

The third block **180**a may include data delivery, clock generation and training blocks **180_0** and **180_1** that operate in synchronization with the write clock signals WCK[**0**:**1**]. The fourth block **180**b may include clock generation blocks **180_2** and **180_3** that operate in synchronization with the write clock signals WCK[**0**:**1**].

The blocks **180_0** to **180_3** may be respectively connected to sixth memory pads **106_0** to **106_3**. The data delivery, clock generation and training blocks **180_0** and **180_1** may receive the write parity signals PARW**0** and PARW**1** from the sixth memory pads **106_0** and **106_1** and may transmit the read data strobe signals RDQS**0** and RDQS**1** to the sixth memory pads **106_0** and **106_1**.

The clock generation blocks **180_2** and **180_3** may transmit the read data strobe signals RDQS**2** and RDQS**3** to the sixth memory pads **106_2** and **106_3**. Compared with FIG. **1**, the sixth memory pads **106_2** and **106_3** may be further included which do not transmit the write parity signals PARW**0** and PARW**1** and transmit only the read data strobe signals RDQS**2** and RDQS**3**.

In a write operation, the third block **180**a may transmit the write parity signals PARW**0** and PARW**1** as a write parity PARW to the memory core MC. In a read operation, the third block **180**a may generate and output the read data strobe signals RDQS**0** and RDQS**1** from the write clock signals WCK[**0**:**1**]. In a read operation, the fourth block **180**b may generate and output the read data strobe signals RDQS**2** and RDQS**3** from the write clock signals WCK[**0**:**1**].

The redirector **120** may support the data delivery, clock generation and training blocks **180_0** and **180_1** of the third block **180**a. For example, in a write operation of write training, the redirector **120** may allow training data received from the sixth memory pads **106_0** and **106_1** to be redirected to and stored in the first block **160** or the second block **170**.

As another example, in a read operation of write training, the redirector **120** may allow training data stored in the third block **180**a to be output through at least one pad of the fourth memory pads **104_0** to **104_15** or the fifth memory pads **105_0** and **105_1**. That is, the redirector **120** may allow training data received through the sixth memory pads **106_0** and **106_1** to be output to other memory pads, for example, the fourth memory pads **104_0** to **104_15** or the fifth memory pads **105_0** and **105_1**.

In FIG. **3**, for convenience of description, the redirector **120** is illustrated as a block existing outside the first, second, and third blocks **160**, **170**, and **180**a. However, the redirector **120** may be distributed to and positioned in the first, second, and/or third blocks **160**, **170**, and **180**a. That is, the redirector **120** may be included in at least one of the first, second, and third blocks **160**, **170**, and **180**a.

FIG. **4**A illustrates an example of one of the first data delivery and training blocks **160_0** to **160_15** according to embodiments of the inventive concepts. In some embodiments, an example of a first data delivery and training block **160**_i that is not associated with the redirector **120** is illustrated in FIG. **4**A. Referring to FIGS. **3** and **4**A, the first data delivery and training block **160**_i includes a data buffer **161**_i, a first-in first-out (FIFO) register **162**_i, a parallelizer **163**_i, and a serializer **164**_i.

The data buffer **161**_i may temporarily store data (e.g., a data signal DQi or training data) transmitted from the FIFO register **162**_i and may transmit the stored data to the fourth memory pad **104**_i. The data buffer **161**_i may temporarily store data (e.g., a data signal DQi or training data) received from the fourth memory pad **104**_i and may transmit the stored data to the FIFO register **162**_i. The data buffer **161**_i may operate in synchronization with one WCK of the write clock signals WCK[**0**:**1**].

The FIFO register **162**_i may compensate for a speed difference between a relatively high-speed data buffer **161**_i and a relatively low-speed memory core MC. In a data input or write operation, in response to a write command WR transmitted from the control logic **190**, the FIFO register **162**_i may store data transmitted from the data buffer **161**_i and may output the stored data to the parallelizer **163**_i in a FIFO manner.

Likewise, in a data output or read operation, in response to a read command RD transmitted from the control logic **190**, the FIFO register **162**_i may store data transmitted from the serializer **164**_i and may output the stored data to the data buffer **161**_i in a FIFO manner.

The FIFO register **162**_i may support write training. In response to a FIFO register write command WR_FIFO received from the control logic **190**, the FIFO register **162**_i may store data (e.g., training data) received from the data buffer **161**_i. The FIFO register **162**_i may not transmit the stored data to the parallelizer **163**_i.

In response to a FIFO register read command RD_FIFO received from the control logic **190**, the FIFO register **162**_i may output the stored data (e.g., training data) to the data buffer **161**_i. That is, in write training, training data may be transmitted to the FIFO register **162**_i and may not be transmitted to the memory core MC.

In response to the write command WR, the parallelizer **163**_i may parallelize data sequentially transmitted from the FIFO register **162**_i and may output the parallelized data as a part of the input data DIN to the memory core MC. In response to the read command RD, the serializer **164**_i may serialize a part of the output data DOUT received from the memory core MC and may transmit the serialized data to the FIFO register **162**_i.

In some embodiments, first data delivery and training blocks, which are not associated with the redirector **120**, from among the first data delivery and training blocks **160_0** to **160_15** may have the same structure as illustrated in FIG. **4**A and may operate in the same manner as described with reference to FIG. **4**A. Likewise, except for signals exchanged with the memory core MC and reference numerals of components, a second data delivery and training block, which is not associated with the redirector **120**, from among the second data delivery and training blocks **170_0** and **170_1** may have the same structure as illustrated in FIG. **4**A and may operate in the same manner as described with reference to FIG. **4**A.

FIG. **4**B illustrates an application of one of the first data delivery and training blocks **160_0** to **160_15**, which is illustrated in FIG. **4**A. In some embodiments, an example of a first data delivery and training block **160**_i' that is not associated with the redirector **120** is illustrated in FIG. **4**B. Referring to FIGS. **3** and **4**B, the first data delivery and training block **160**_i' includes the data buffer **161**_i, the FIFO register **162**_i, the parallelizer **163**_i, the serializer **164**_i, and an encoder **165**_i.

In response to a write command WR or a read command RD from the control logic **190**, the encoder **165**_i may connect the parallelizer **163**_i and the serializer **164**_i with the data buffer **161**_i. In response to a FIFO register write command WR_FIFO or a FIFO register read command RD_FIFO, the encoder **165**_i may connect the FIFO register **162**_i with the data buffer **161**_i.

The parallelizer **163**_i may parallelize the data signal DQi to the input data DIN depending on a write command WR. The serializer **164**_i may serialize the output data DOUT to the data signal DQi depending on a read command RD. The FIFO register **162**_i may store training data in response to the FIFO register write command WR_FIFO and may output the stored data as training data in response to the FIFO register read command RD_FIFO.

That is, in a write or read operation, the data signal DQi may be transmitted to the serializer **164**_i or the parallelizer **163**_i without passing through the FIFO register **162**_i. The FIFO register **162**_i may be a separate register provided for training. In some embodiments, and within the detailed description, the first data delivery and training block **160**_i of FIG. **4**A and the first data delivery and training block **160**_i' of FIG. **4**B may be interchangeably used.

FIG. **5**A illustrates another example of one of the first data delivery and training blocks **160_0** to **160_15** according to embodiments of the inventive concepts. In some embodiments, an example of a first data delivery and training block **160**_j that is associated with the redirector **120** is illustrated in FIG. **5**A. Referring to FIGS. **3** and **5**A, the first data delivery and training block **160**_j includes a data buffer **161**_j, a first-in first-out (FIFO) register **162**_j, a parallelizer **163**_j, and a serializer **164**_j.

In a normal operation (e.g., not training), the data buffer **161**_j may communicate a data signal DQj with a fourth memory pad **104**_j. In training, the data buffer **161**_j may communicate training data with the fourth memory pad **104**_j.

The data buffer **161**_j, the FIFO register **162**_j, the parallelizer **163**_j, and the serializer **164**_j may operate in the same manner as described with reference to FIG. **4**A, and thus, a description thereof will not be repeated here.

A first encoder. **121** of the redirector **120** may be positioned on a path through which the data buffer **161**_j transmits data to the FIFO register **162**_j. The first encoder **121** may operate in response to the FIFO register write command WR_FIFO. When the FIFO register write command WR_FIFO has a first option, the first encoder **121** may transmit an output of the data buffer **161**_j to the FIFO register **162**_j.

In training, when the FIFO register write command WR_FIFO has a second option, the first encoder **121** may store training data transmitted from a data delivery, clock generation and training block **180**_k(refer to FIG. **6**A) and may output the stored training data to the fourth memory pad **104**_j. Accordingly, write training associated with the fourth memory pad **104**_j may be performed.

In training, when the FIFO register write command WR_FIFO has the second option, the FIFO register **162**_i may store training data transmitted from the data delivery, clock generation and training block **180**_k and may output the stored training data through the fourth memory pad **104**_j. Write training may be performed on the sixth memory pad **106_0** or **106_1** by redirecting an output of training data.

In some embodiments, except for signals exchanged with the memory core MC and reference numerals of components, a second data delivery and training block, which is associated with the redirector **120**, from among the second data delivery and training blocks **170_0** and **170_1** may have the same structure as illustrated in FIG. **5**A and may operate in the same manner as described with reference to FIG. **5**A. That is, training data may be redirected to the first block **160** or the second block **170**.

FIG. **5**B illustrates an application of another of the first data delivery and training blocks **160_0** to **160_15**, which is illustrated in FIG. **5**A. In some embodiments, an example of a first data delivery and training block **160**_j' that is associated with the redirector **120** is illustrated in FIG. **5**B. Referring to FIGS. **3** and **5**B, the first data delivery and training block **160**_j' includes the data buffer **161**_j, the FIFO register **162**_j, the parallelizer **163**_j, the serializer **164**_j, and an encoder **165**_j.

In response to a write command WR or a read command RD from the control logic **190**, the encoder **165**_j may connect the parallelizer **163**_j and the serializer **164**_j with the data buffer **161**_j. In response to a FIFO register write command WR_FIFO or a FIFO register read command RD_FIFO, the encoder **165**_j may connect an output of the FIFO register **162**_j with the data buffer **161**_j and may connect an output of the data buffer **161**_j with the first encoder **121**.

The parallelizer **163**_j may parallelize a data signal DQj to the input data DIN depending on the write command WR. The serializer **164**_j may serialize the output data DOUT to the data signal DQj depending on the read command RD.

When the FIFO register write command WR_FIFO has a first option, the first encoder **121** may transmit training data transmitted through the encoder **165**_j from the data buffer **161**_j to the FIFO register **162**_j. When the FIFO register write command WR_FIFO has a second option, the first encoder **121** may transmit training data transmitted from a data delivery, clock generation and training block **180**_k' (refer to FIG. **6**B) to the FIFO register **162**_j.

The FIFO register **162**_j may store training data transmitted from the first encoder **121** in response to the FIFO register write command WR_FIFO and may output the stored data as training data to the encoder **165**_j in response to the FIFO register read command RD_FIFO.

In some embodiments, and within the detailed description, the first data delivery and training block **160**_j of FIG. **5**A and the first data delivery and training block **160**_j' of FIG. **5**B may be interchangeably used.

FIG. **6**A illustrates an example of one of the data delivery, clock generation and training blocks **180_0** and **180_1** according to embodiments of the inventive concepts. Referring to FIGS. **3** and **6**A, a data delivery, clock generation and training block **180**_k includes a data buffer **181**_k, a FIFO register **182**_k, a parallelizer **183**_k, a read data strobe signal generator **184**_k, and a read data strobe signal driver **185**_k.

A second encoder **122** of the redirector **120** may be positioned between the data buffer **181**_k and the FIFO register **182**_k. The data buffer **181**_k may temporarily store data (e.g., a write parity signal PARWk or training data) received from the sixth memory pad **106**_k and may transmit the stored data to the second encoder **122**. The data buffer **181**_k may operate in synchronization with one WCK of the write clock signals WCK[**0**:**1**].

The second encoder **122** may operate in response to the FIFO register write command WR_FIFO. When the FIFO register write command WR_FIFO has a first option or when the FIFO register write command WR_FIFO is absent, the second encoder **122** may transmit data output from the data buffer **181**_k to the FIFO register **182**_k.

When the FIFO register write command WR_FIFO has a second option, the second encoder **122** may transmit data output from the data buffer **181**_k to the first data delivery and training block **160**_j(refer to FIG. **5**A). As another example, the second encoder **122** may transmit data output from the data buffer **181**_k to the second data delivery and training block **170_0** or **170_1** associated with the redirector **120**.

The FIFO register **182**_k may compensate for a speed difference between a relatively high-speed data buffer **181**_k and a relatively low-speed memory core MC. In a data input or write operation, in response to a write command WR transmitted from the control logic **190**, the FIFO register **182**_k may store data (e.g., the write parity signal PARWk) transmitted from the data buffer **181**_k and may output the stored data to the parallelizer **183**_k in a FIFO manner.

In response to a FIFO register write command WR_FIFO received from the control logic **190**, the FIFO register **182**_k may store data (e.g., training data) received from the data buffer **181**_k. The FIFO register **182**_k may not transmit the stored data to the parallelizer **183**_k. In response to the write command WR, the parallelizer **183**_k may parallelize data sequentially transmitted from the FIFO register **182**_k and may output the parallelized data as a part of a write parity PARW to the memory core MC.

A read data strobe signal generator **184**_k may generate a read data strobe signal RDQSk in response to one write clock signal WCK of the write clock signals WCK[**0**:**1**]. In response to a read command RD or a FIFO register read command RD_FIFO from the control logic **190**, the read data strobe signal RDQSk is output to the sixth memory pad **106**_k through a read data strobe signal driver **185**_k.

In some embodiments, the data delivery, clock generation and training blocks **180_0** and **180_1** may have the structure described with reference to FIG. **6**A and may operate in the manner described with reference to FIG. **6**A. Clock generation blocks **180_2** and **180_3** associated with only read data strobe signals RDQS**2** and RDQS**3** may include the read data strobe signal generator **184**_k and the read data strobe signal driver **185**_k among components illustrated in FIG. **6**A.

FIG. **6**B illustrates an application of one of the data delivery, clock generation and training blocks **180_0** and **180_1**. Referring to FIGS. **3** and **6**B, a data delivery, clock generation and training block **180**_k' includes the data buffer **181**_k, the FIFO register **182**_k, the parallelizer **183**_k, the read data strobe signal generator **184**_k, the read data strobe signal driver **185**_k, and an encoder **186**_k.

In response to a write command WR or a read command RD from the control logic **190**, the encoder **186**_k may connect the data buffer **181**_k with the parallelizer **183**_k. In response to a FIFO register write command WR_FIFO, the encoder **186**_k may transmit an output of the data buffer **181**_k to the second encoder **122**. The parallelizer **183**_k may parallelize a write parity signal PARWk to a write parity PARW depending on the write command WR.

When the FIFO register write command WR_FIFO has a first option, the second encoder **122** may transmit training data transmitted through the encoder **186**_k from the data buffer **181**_k to the FIFO register **182**_k. When the FIFO register write command WR_FIFO has a second option, the second encoder **122** may transmit training data transmitted through the encoder **186**_k from the data buffer **181**_k to a data delivery and training block **160**_j' (refer to FIG. **5**B) of the first block **160** associated with the redirector **120** or a data delivery and training block of the second block **170**.

In some embodiments, and within the detailed description, the data delivery, clock generation and training block **180**_k of FIG. **6**A and the data delivery, clock generation and training block **180**_k' of FIG. **6**B may be interchangeably used.

As described with reference to FIGS. **4**A to **6**B, the third block **180**a may transmit training data received through the sixth memory pads **106_0** and **106_1** to the first block **160** or the second block **170** in response to the FIFO register write command WR_FIFO. A FIFO register of the first block **160** or the second block **170** may store training data.

The FIFO register of the first block **160** or the second block **170** may output the stored training data in response to a FIFO register read command RD_FIFO. That is, training data received in the third block **180**a through the sixth memory pads **106_0** and **106_1** may be output to the outside after being redirected to the first block **160** or the second block **170**. Accordingly, write training may be performed on the sixth memory pads **106_0** and **106_1**.

FIG. **7** is a flowchart illustrating a write training method according to a first example of the inventive concept. Referring to FIGS. **1**, **3**, and **4**A to **7**, in operation S**210**, the controller **20** may transmit the FIFO register write command WR_FIFO having a first option to the semiconductor memory **100**. The FIFO register write command WR_FIFO may be transmitted multiple times.

The controller **20** may transmit first training data to the semiconductor memory **100** together with the FIFO register write command WR_FIFO. For example, the first training data may be transmitted through the fourth memory pads **104_0** to **104_15** and the fifth memory pads **105_0** and **105_1**. The semiconductor memory **100** may store the first training data in the FIFO registers (e.g., **162**_i and/or **162**_j) in response to the FIFO register write command WR_FIFO.

In operation S**220**, the controller **20** may transmit the FIFO register read command RD_FIFO to the semiconductor memory **100**. In response to the FIFO register read command RD_FIFO, the semiconductor memory **100** may output the data stored in the FIFO registers (e.g., **162**_i and/or **162**_j) as second training data to the controller **20**. The second training data may be transmitted through the fourth memory pads **104_0** to **104_15** and the fifth memory pads **105_0** and **105_1**. The FIFO register read command RD_FIFO may be transmitted multiple times.

Operation S**210** and operation S**220** may constitute a first training operation targeted for pads that are not obstructed to output training data. Afterwards, in operation S**230** and operation S**240**, a second training operation may be performed on pads that are obstructed to output training data. The second training operation may be redirected training in which an input pad and an output pad of training data are redirected.

In operation S**230**, the controller **20** may transmit the FIFO register write command WR_FIFO having a second option to the semiconductor memory **100**. The controller **20** may transmit third training data to the semiconductor memory **100** together with the FIFO register write command WR_FIFO. For example, the third training data may be transmitted to the semiconductor memory **100** through the sixth memory pads **106_0** and **106_1**. The FIFO register write command WR_FIFO may be transmitted multiple times.

In response to the FIFO register write command WR_FIFO having the second option, the semiconductor memory **100** may store the third training data in the FIFO register **162**_j of at least one of the first data delivery and training blocks **160_0** to **160_15** of the first block **160** or at least one of the second data delivery and training blocks **170_0** and **170_1** of the second block **170**.

In operation S**240**, the controller **20** may transmit the FIFO register read command RD_FIFO to the semiconductor memory **100**. In response to the FIFO register read command RD_FIFO, at least one of the first data delivery and training blocks **160_0** to **160_15** or at least one of the second data delivery and training blocks **170_0** and **170_1** of the second block **170** may output the data stored in the FIFO register **162**_j to the controller **20** as fourth training data. The fourth training data may be transmitted output at least one of the fourth memory pads **104_0** to **104_15** or at least one of the fifth memory pads **105_0** and **105_1**. The FIFO register read command RD_FIFO may be transmitted multiple times.

FIG. **8** illustrates an example in which the controller **20** transmits the FIFO register write command WR_FIFO to the semiconductor memory **100**. In FIG. **8**, "CK_t" indicates the clock signal CK, and "CK_c" indicates an inverted version of the clock signal CK. "CS" refers to a chip select signal to select the semiconductor memory **100**. "CMD" shows command and address signals CA[**0**:**6**] conceptually and does not mean a signal that the controller **20** and the semiconductor memory **100** actually convey.

Referring to FIGS. **1**, **3**, and **8**, when the chip select signal CS transitions to a high level, the controller **20** may transmit the FIFO register write command WR_FIFO to the semiconductor memory **100**. The FIFO register write command WR_FIFO is transmitted through the command and address signals CA[**0**:**6**]. The FIFO register write command WR_FIFO may be transmitted during one cycle of the clock signal CK_t or CK_c. The FIFO register write command WR_FIFO will be more fully described with reference to FIG. **9**.

For write training, the controller **20** may transmit the FIFO register write command WR_FIFO multiple times. An example is illustrated in FIG. **8** as the controller **20** transmits the FIFO register write command WR_FIFO two times or more. However, the controller **20** may transmit the FIFO register write command WR_FIFO once to perform the first training operation or the second training operation.

FIG. **9** illustrates an example of command and address signals CA**0** to CA**6** of the FIFO register write command WR_FIFO. Referring to FIGS. **8** and **9**, an option of the FIFO register write command WR_FIFO may be determined according to whether the command and address signals CA**0** to CA**6** have any values at a falling edge "F" of the clock signal CK_t after the chip select signal CS has a high level "H".

For example, at a rising edge "R" of the clock signal CK_t when the chip select signal CS has the high level "H," the command and address signals CA**0** to CA**6** of the FIFO register write command WR_FIFO may sequentially have a low level "L," the low level "L," the low level "L," the low level "L," the low level "L," the high level "H," and the high level "H."

At the falling edge "F" of the clock signal CK_t regardless of a level of the chip select signal CS ("X"), the command and address signal CA**0** of the FIFO register write command WR_FIFO having a first option has the low level "L." The remaining command and address signals CA**1** to CA**6** may have a valid level "V" corresponding to any one of a high level and a low level.

At the falling edge "F" of the clock signal CK_t regardless of a level of the chip select signal CS ("X"), the command and address signal CA**0** of the FIFO register write command WR_FIFO having a second option has the high level "H." The remaining command and address signals CA**1** to CA**6** may have a valid level "V" corresponding to any one of a high level and a low level.

As described with reference to FIG. **9**, an option of the FIFO register write command WR_FIFO is selected according to whether the command and address signal CA**0** has the high level "H" or the low level "L" at the falling edge "F" of the clock signal CK_t. Since an additional cycle of the clock signal CK_t or an addition pad is unnecessary, the overhead due to options of the FIFO register write command WR_FIFO is suppressed.

FIG. **10** illustrates an example in which the controller **20** transmits first training data to the semiconductor memory **100** depending on the FIFO register write command WR_FIFO. In some embodiments, an example in which first training data are transmitted according to the FIFO register write command WR_FIFO having a first option is illustrated in FIG. **10**. In FIG. **10**, "WCK_t" indicates one of the write clock signals WCK[**0**:**1**], and "WCK c" indicates an inverted version of the write clock signal WCK_t.

Referring to FIGS. **1**, **3**, **8**, and **10**, the controller **20** may transmit pieces of first training data to the semiconductor memory **100** when a specific time elapses after transmitting the FIFO register write command WR_FIFO. The first training data may be transmitted to the semiconductor memory **100** in synchronization with the write clock signal WCK_t or WCK_c.

The controller **20** may transmit a part of the first training data to the semiconductor memory **100** through the fourth memory pads **104_0** to **104_15** as the data signals DQ[**0**:**15**] in synchronization with a rising edge and a falling edge of the write clock signal WCK_t. The controller **20** may transmit the remaining part of the first training data to the semiconductor memory **100** through the fifth memory pads **105_0** and **105_1** as the data mask inversion signals DMI

[**0**:**1**] in synchronization with the rising edge and the falling edge of the write clock signal WCK_t.

An embodiment is illustrated in FIG. **10** as the first training data are not transmitted to the semiconductor memory **100** through the sixth memory pads **106_0** and **106_1** or as the write parity signals PARW[**0**:**1**]. However, the controller **20** may be changed to transmit another part of the first training data or dummy data to the semiconductor memory **100** through the sixth memory pads **106_0** and **106_1** as the write parity signals PARW[**0**:**1**].

FIG. **11** illustrates an example in which the controller **20** transmits the FIFO register read command RD_FIFO to the semiconductor memory **100**. In FIG. **11**, "CK_t" indicates the clock signal CK, and "CK_c" indicates an inverted version of the clock signal CK. "CS" refers to a chip select signal to select the semiconductor memory **100**. "CMD" shows command and address signals CA[**0**:**6**] conceptually and does not mean a signal that the controller **20** and the semiconductor memory **100** actually convey.

Referring to FIGS. **1**, **3**, and **11**, when the chip select signal CS transitions to a high level, the controller **20** may transmit the FIFO register read command RD_FIFO to the semiconductor memory **100**. The FIFO register read command RD_FIFO is transmitted through the command and address signals CA[**0**:**6**]. The FIFO register read command RD_FIFO may be transmitted during one cycle of the clock signal CK_t or CK_c. The FIFO register read command RD_FIFO will be more fully described with reference to FIG. **12**.

For write training, the controller **20** may transmit the FIFO register read command RD_FIFO multiple times. An example is illustrated in FIG. **11** as the controller **20** transmits the FIFO register read command RD_FIFO two times or more. However, the controller **20** may transmit the FIFO register read command RD_FIFO once to perform the first training operation or the second training operation.

FIG. **12** illustrates an example of command and address signals CA**0** to CA**6** of the FIFO register read command RD_FIFO. Referring to FIGS. **11** and **12**, at a rising edge "R" of the clock signal CK_t when the chip select signal CS has the high level "H" the command and address signals CA**0** to CA**6** of the FIFO register read command RD_FIFO may sequentially have the low level "L," the low level "L", the low level "L," the low level "L," the low level "L," the high level "H," and the low level "L."

At a falling edge "F" of the clock signal CK_t regardless of a level of the chip select signal CS ("X"), the command and address signals CA**0** to CA**6** of the FIFO register read command RD_FIFO may have a valid value "V" corresponding to any one of a high level and a low level. For example, the FIFO register read command RD_FIFO that does not have an option may not be associated with a falling edge of the clock signal CK_t.

FIG. **13** illustrates an example in which the semiconductor memory **100** transmits second training data to the controller **20** depending on the FIFO register read command RD_FIFO. In some embodiments, an example in which second training data are transmitted according to the FIFO register read command RD_FIFO following the FIFO register write command WR_FIFO having a first option is illustrated in FIG. **13**. In FIG. **13**, "WCK_t" indicates one of the write clock signals WCK[**0**:**1**]; and "WCK_c" indicates an inverted version of the write clock signal WCK_t.

Referring to FIGS. **1**, **3**, **11**, and **13**, the semiconductor memory **100** may receive the FIFO register read command RD_FIFO and may transmit second training data to the controller **20** when a specific time elapses. The second training data may be transmitted in synchronization with the read data strobe signals RDQS[**0**:**1**] (or RDQS**0** and RDQS**1**) output through the sixth memory pads **106_0** and **106_1** or the read data strobe signals RDQS**2** and RDQS**3** output through the sixth memory pads **106_2** and **106_3**.

The semiconductor memory **100** may transmit a part of the second training data to the controller **20** through the fourth memory pads **104_0** to **104_15** as the data signals DQ[**0**:**15**] in synchronization with a rising edge and a falling edge of the read data strobe signals RDQS[**0**:**1**]. The semiconductor memory **100** may transmit the remaining part of the second training data to the controller **20** through the fifth memory pads **105_0** and **105_1** as the read parity signals PARR[**0**:**1**] in synchronization with a rising edge and a falling edge of the read data strobe signals RDQS[**0**:**1**].

FIG. **14** illustrates an example in which the controller **20** transmits third training data to the semiconductor memory **100** depending on the FIFO register write command WR_FIFO. In some embodiments, an example in which third training data are transmitted according to the FIFO register write command WR_FIFO having a second option is illustrated in FIG. **14**. In FIG. **14**, "WCK_t" indicates one of the write clock signals WCK[**0**:**1**], and "WCK_c" indicates an inverted version of the write clock signal WCK_t.

Referring to FIGS. **1**, **3**, **8**, and **14**, the controller **20** may transmit the FIFO register write command WR_FIFO and may transmit third training data to the semiconductor memory **100** when a specific time elapses. The third training data may be transmitted to the semiconductor memory **100** in synchronization with the write clock signal WCK_t or WCK_c.

The controller **20** may transmit the third training data to the semiconductor memory **100** through the sixth memory pads **106_0** and **106_1** as the write parity signals PARW[**0**:**1**] in synchronization with a rising edge and a falling edge of the write clock signal WCK_t. An embodiment is illustrated in FIG. **14** as the third training data are not transmitted to the semiconductor memory **100** through the fourth memory pads **104_0** to **104_15** and the fifth memory pads **105_0** and **105_1**. However, the controller **20** may be changed to transmit another part of the third training data or dummy data to the semiconductor memory **100** through the fourth memory pads **104_0** to **104_15** and the fifth memory pads **105_0** and **105_1**.

FIG. **15** illustrates an example in which the semiconductor memory **100** transmits fourth training data to the controller **20** depending on the FIFO register read command RD_FIFO. In some embodiments, an example in which fourth training data are transmitted according to the FIFO register read command RD_FIFO following the FIFO register write command WR_FIFO having a second option is illustrated in FIG. **15**. In FIG. **15**, "WCK_t" indicates one of the write clock signals WCK[**0**:**1**], and "WCK_c" indicates an inverted version of the write clock signal WCK_t.

Referring to FIGS. **1**, **3**, **11**, and **15**, the semiconductor memory **100** may receive the FIFO register read command RD_FIFO and may transmit fourth training data to the controller **20** when a specific time elapses. The fourth training data may be transmitted in synchronization with the read data strobe signals RDQS[**0**:**1**] (or RDQS**0** and RDQS**1**) output through the sixth memory pads **106_0** and **106_1** or the read data strobe signals RDQS**2** and RDQS**3** output through the sixth memory pads **106_2** and **106_3**.

The semiconductor memory **100** may transmit the fourth training data through at least one selected from the data signals DQ[**0**:**15**] and the read parity signals PARR[**0**:**1**] to the controller **20** in synchronization with a rising edge and a falling edge of the read data strobe signals RDQS[**0**:**1**]. Signals that are not selected from the data signals DQ[**0**:**15**] and the read parity signals PARR[**0**:**1**] may not be used to transmit the fourth training data.

In some embodiments, the third training data received through one sixth memory pad **106_0** or **106_1** may be output through two or more pads. For example, the fourth memory pads **104_0** to **104_15** and the fifth memory pads **105_0** and **105_1** may output the fourth training data (or a replica of the fourth training data) as the data signals DQ[**0**:**15**] and the read parity signals PARR[**0**:**1**].

FIG. **16**A illustrates an example of one of the second data delivery and training blocks **170_0** and **170_1** according to embodiments of the inventive concepts. In some embodiments, an example of a second data delivery and training block **170**_m that is not associated with the redirector **120** is illustrated in FIG. **16**A. Referring to FIGS. **3** and **16**A, the second data delivery and training block **170**_m includes a data buffer **171**_m, a first-in first-out (FIFO) register **172**_m, a parallelizer **173**_m, and a serializer **174**_m.

In a normal operation (e.g., not training), the data buffer **171**_m may communicate a write parity signal PARWm and a data mask inversion signal DMIm with a fifth memory pad **105**_m. In training, the data buffer **171**_m may communicate training data with the fifth memory pad **105**_m.

In some embodiments, the second data delivery and training block **170**_m may operate in the same manner as the first data delivery and training block **160**_i, which is described with reference to FIG. **4**A, and thus, a description thereof will not be repeated here.

In some embodiments, except for signals exchanged with the memory core MC and reference numerals of components. first data delivery and training blocks, which are not associated with the redirector **120**, from among the first data delivery and training blocks **160_0** to **160_15** may have the same structure as illustrated in FIG. **16**A and may operate in the same manner as described with reference to FIG. **16**A.

FIG. **16**B illustrates another example of one of the second data delivery and training blocks **170_0** and **170_1** according to embodiments of the inventive concept. In some embodiments, an example of a second data delivery and training block **170**_m' that is not associated with the redirector **120** is illustrated in FIG. **16**B. Referring to FIGS. **3** and **16**B, a second data delivery and training block **170**_m' includes the data buffer **171**_m, the FIFO register **172**_m, the parallelizer **173**_m, the serializer **174**_m, and an encoder **175**_m.

In some embodiments, the second data delivery and training block **170**_m' may operate in the same manner as the first data delivery and training block **160**_i', which is described with reference to FIG. **4**B, and thus, a description thereof will not be repeated here.

In some embodiments, except for signals exchanged with the memory core MC and reference numerals of components, first data delivery and training blocks, which are not associated with the redirector **120**, from among the first data delivery and training blocks **160_0** to **160_15** may have the same structure as illustrated in FIG. **16**B and may operate in the same manner as described with reference to FIG. **16**B.

In some embodiments, in the detailed description, the second data delivery and training block **170**_m of FIG. **16**A and the second data delivery and training block **170**_m' of FIG. **16**B may be interchangeably used.

FIG. **17**A illustrates an example of one of the second data delivery and training blocks **170_0** and **170_1** according to embodiments of the inventive concepts. In some embodiments, an example of a second data delivery and training block **170**_n that is associated with the redirector **120** is illustrated in FIG. **17**A. Referring to FIGS. **3** and **17**A, the second data delivery and training block **170**_n includes a data buffer **171**_n, a first-in first-out (FIFO) register **172**_n, a parallelizer **173**_n, and a serializer **174**_n.

In a normal operation, not training, the data buffer **171**_n may communicate a write parity signal PARRn and a data mask inversion signal DMIn with a fifth memory pad **105**_n. In training, the data buffer **171**_n may communicate training data with the fifth memory pad **105**_n.

The data buffer **171**_n, the FIFO register **172**_n, the parallelizer **173**_n, and the serializer **174**_n operate in the same manner as described with reference to FIG. **4**A, and thus, a description thereof will not be repeated here.

A third encoder **123** of the redirector **120** may be positioned on a path through which the FIFO register **172**_n transmits data to the data buffer **171**_n. The third encoder **123** may operate in response to the FIFO register read command RD_FIFO. When the FIFO register read command RD_FIFO has a first option, the third encoder **123** may transmit an output of the FIFO register **172**_n to the data buffer **171**_n.

When the FIFO register read command RD_FIFO has a second option, the third encoder **123** may transmit data (e.g., training data) transmitted from a data delivery, clock generation and training block **180**_o(refer to FIG. **18**B) to the data buffer **171**_n.

That is, if the FIFO register write command WR_FIFO is received following the FIFO register read command RD_FIFO having a first option, the data buffer **171**_n may output training data transmitted from the FIFO register **172**_n to the fifth memory pad **105**_n. Accordingly, write training associated with the fifth memory pad **105**_n is performed.

If the FIFO register write command WR_FIFO is received following the FIFO register read command RD_FIFO having a second option, the data buffer **171**_n may output training data transmitted from the data delivery, clock generation and training block **180**_o(refer to FIG. **18**A) to the fifth memory pad **105**_n. Write training may be performed on the sixth memory pad **106_0** or **106_1** by redirecting an output of training data.

In some embodiments, except for signals exchanged with the memory core MC and reference numerals of components, a first data delivery and training block, which is associated with the redirector **120**, from among the first data delivery and training blocks **160_0** to **160_15** may have the same structure as illustrated in FIG. **17**A and may operate in the same manner as described with reference to FIG. **17**A. That is, training data may be redirected to the first block **160** or the second block **170**.

FIG. **17**B illustrates an example of one of the second data delivery and training blocks **170_0** and **170_1** according to embodiments of the inventive concepts. In some embodiments, an example of a second data delivery and training block **170**_n' that is associated with the redirector **120** is illustrated in FIG. **17**B. Referring to FIGS. **3** and **17**B, a second data delivery and training block **170**_n' includes the data buffer **171**_n, the FIFO register **172**_n, the parallelizer **173**_n, the serializer **174**_n, and an encoder **175**_n.

In response to a write command WR or a read command RD from the control logic **190**, the encoder **175**_n may connect the parallelizer **173**_n or the serializer **174**_n with the data buffer **171**_n. In response to the FIFO register write command WR_FIFO or the FIFO register read command RD_FIFO, the encoder **175**_n may connect an output of the data buffer **171**_n with the FIFO register **172**_n and may transmit training data transmitted through the third encoder **123** to the data buffer **171**_n.

The parallelizer **173**_n may parallelize a data mask inversion signal DMIn to the data mask inversion signal DMI depending on the write command WR. The serializer **174**_n may serialize a read parity PARR to a read parity signal PARRn depending on the read command RD.

When the FIFO register read command RD_FIFO has a first option, the third encoder **123** may transmit training data transmitted from the FIFO register **172**_n to the data buffer **171**_n through the encoder **175**_n. When the FIFO register read command RD_FIFO has a second option, the third encoder **123** may transmit training data transmitted from a data delivery, clock generation and training block **180**_o' (refer to FIG. **18**B) to the data buffer **171**_n.

In some embodiments, and within the detailed description, the second data delivery and training block **170**_n of FIG. **17**A and the second data delivery and training block **170**_n' of FIG. **17**B may be interchangeably used.

FIG. **18**A illustrates an example of one of the data delivery, clock generation and training blocks **180_0** and **180_1** according to embodiments of the inventive concepts. Referring to FIGS. **3** and **18**A, a data delivery, clock generation and training block **180**_o includes a data buffer **181**_o, a FIFO register **182**_o, a parallelizer **183**_o, a read data strobe signal generator **184**_o, and a read data strobe signal driver **185**_o.

A fourth encoder **124** of the redirector **120** may be positioned between the data buffer **181**_o and the FIFO register **182**_o. The data buffer **181**_o may temporarily store data (e.g., a write parity signal PARWo or training data) received from the sixth memory pad **106**_o and may transmit the stored data to the fourth encoder **124**. The data buffer **181**_o may operate in synchronization with one WCK of the write clock signals WCK[**0**:**1**].

The fourth encoder **124** may operate in response to the FIFO register read command RD_FIFO. When the FIFO register read command RD_FIFO has a first option or when the FIFO register read command RD_FIFO is absent, the fourth encoder **124** may connect the data buffer **181**_o and the FIFO register **182**_o.

When the FIFO register read command RD_FIFO has a second option, the fourth encoder **124** may connect the FIFO register **182**_o and the second data delivery and training block **170**_n of FIG. **17**A. For example, the fourth encoder **124** may transmit data (e.g., training data) transmitted from the FIFO register **182**_o to the second data delivery and training block **170**_n associated with the redirector **120**.

As another example, the fourth encoder **124** may transmit data (e.g., training data) transmitted from the FIFO register **182**_o to a first data delivery and training block associated with the redirector **120** among the first data delivery and training blocks **160_0** to **160_15**.

In a normal operation (e.g., not training), the data buffer **181**_o may receive the write parity signal PARWo from the sixth memory pad **106**_o. In training, the data buffer **181**_o may receive training data from the sixth memory pad **106**_o. When data are output regardless of training, the read data strobe signal driver **185**_o may output a read data strobe signal RDQSo.

The FIFO register **182**_o, the parallelizer **183**_o, the read data strobe signal generator **184**_o, and the read data strobe signal driver **185**_o operate the same as described with reference to FIG. **6**A, and thus, a description thereof will not be repeated here.

In some embodiments, data delivery, clock generation and training blocks **180_0** and **180_1** may have the structure described with reference to FIG. **18**A and may operate in the manner described with reference to FIG. **18**A. Clock generation blocks **180_2** and **180_3** associated with read data strobe signals RDQS**2** and RDQS**3** may include the read data strobe signal generator **184**_o and the read data strobe signal driver **185**_o among components illustrated in FIG. **18**A.

FIG. **18**B illustrates an application of one of the data delivery, clock generation and training blocks **180_0** and **180_1** according to embodiments of the inventive concepts. Referring to FIGS. **3** and **18**B, a data delivery, clock generation and training block **180**_o' includes the data buffer **181**_o, the FIFO register **182**_o, the parallelizer **183**_o, the read data strobe signal generator **184**_o, the read data strobe signal driver **185**_o, and an encoder **186**_o.

In response to a write command WR from the control logic **190**, the encoder **186**_o may connect the data buffer **181**_o with the parallelizer **183**_o. In response to a FIFO register write command WR_FIFO, the encoder **186**_o may transmit an output of the data buffer **181**_o to the fourth encoder **124**. The parallelizer **183**_o may parallelize a write parity signal PARWo to a write parity PARW depending on the write command WR.

When the FIFO register read command RD_FIFO has a first option, the FIFO register **182**_o may not operate. As another example, the FIFO register **182**_o may output stored training data, and the fourth encoder **124** may block the training data output from the FIFO register **182**_o.

When the FIFO register read command RD_FIFO has a second option, the FIFO register **182**_o may output stored training data. The fourth encoder **124** may transmit training data output from the FIFO register **182**_o to a data delivery and training block of the first block **160** associated with the redirector **120** or the data delivery and training block **170**_n' of the second block **170**.

In some embodiments, in the detailed description, the data delivery, clock generation and training block **180**_o of FIG. **18**A and the data delivery, clock generation and training block **180**_o' of FIG. **18**B may be interchangeably used.

As described with reference to FIGS. **16**A to **18**B, the third block **180**a may store training data received through the sixth memory pads **106_0** and **106_1** in a FIFO register in response to the FIFO register write command WR_FIFO. The third block **180**a may transmit the stored training data to the first block **160** or the second block **170** depending on the FIFO register read command RD_FIFO.

The first block **160** or the second block **170** may output the training data transmitted from the third block **180**a. That is, training data received in the third block **180**a through the sixth memory pads **106_0** and **106_1** may be output to the outside after being redirected to the first block **160** or the second block **170**. Accordingly, write training may be performed on the sixth memory pads **106_0** and **106_1**.

FIG. **19** is a flowchart illustrating a write training method according to embodiments of the inventive concepts. Referring to FIGS. **1**, **3**, and **16**A to **19**, in operation S**310**, the controller **20** may transmit the FIFO register write command WR_FIFO to the semiconductor memory **100**. The controller **20** may transmit first training data to the semiconductor memory **100** together with the FIFO register write command WR_FIFO.

For example, the first training data may be transmitted through the fourth memory pads **104_0** to **104_15** and the fifth memory pads **105_0** and **105_1**. The semiconductor memory **100** may store the first training data in the FIFO registers **172**_m and **172**_n in response to the FIFO register write command WR_FIFO.

In operation S**320**, the controller **20** may transmit the FIFO register read command RD_FIFO having a first option to the semiconductor memory **100**. In response to the FIFO register read command RD_FIFO, the semiconductor memory **100** may output the data stored in the FIFO registers **172**_m and/or **172**_n as second training data to the controller **20**. The second training data may be transmitted through the fourth memory pads **104_0** to **104_15** and the fifth memory pads **105_0** and **105_1**.

Operation S**310** and operation S**320** may constitute a first training operation targeted for pads that are not obstructed to output training data. Afterwards, in operation S**330** and to operation S**340**, a second training operation may be performed on pads that are obstructed to output training data. The second training operation may be redirected training in which an input pad and an output pad of training data are redirected.

In operation S**330**, the controller **20** may transmit the FIFO register write command WR_FIFO to the semiconductor memory **100**. The controller **20** may transmit third training data to the semiconductor memory **100** together with the FIFO register write command WR_FIFO. For example, the third training data may be transmitted to the semiconductor memory **100** through the sixth memory pads **106_0** and **106_1**. The semiconductor memory **100** may store the third training data in the FIFO register **182**_o in response to the FIFO register write command WR_FIFO.

In operation S**340**, the controller **20** may transmit the FIFO register read command RD_FIFO having a second option to the semiconductor memory **100**. In response to the FIFO register read command RD_FIFO having the second option, at least one of the first data delivery and training blocks **160_0** to **160_15** or at least one of the second data delivery and training blocks **170_0** and **170_1** of the second block **170** may output the third training data stored in the FIFO register **182**_o of the third block **180**a to the controller **20** as fourth training data. The fourth training data may be output through at least one of the fourth memory pads **104_0** to **104_15** or at least one of the fifth memory pads **105_0** and **105_1**.

FIG. **20** illustrates an example of command and address signals CA**0** to CA**6** of the FIFO register write command WR_FIFO. Referring to FIGS. **11** and **20**, at a rising edge "R" of the clock signal CK_t when the chip select signal CS has the high level "H," the command and address signals CA**0** to CA**6** of the FIFO register write command WR_FIFO may sequentially have the low level "L," the low level "L," the low level "L," the low level "L," the low level "L," the high level "H," and the low level "L."

At a falling edge "F" of the clock signal CK_t regardless of a level of the chip select signal CS ("X"), the command and address signals CA**0** to CA**6** of the FIFO register write command WR_FIFO may have a valid value "V" corresponding to any one of a high level and a low level. For example, the FIFO register write command WR_FIFO that does not have an option may not be associated with a falling edge of the clock signal CK_t.

FIG. **21** illustrates an example of command and address signals CA**0** to CA**6** of the FIFO register read command RD_FIFO. Referring to FIGS. **8** and **21**, an option of the FIFO register read command RD_FIFO may be determined according to whether the command and address signals CA**0** to CA**6** have any values at a falling edge "F" of the clock signal CK_t after the chip select signal CS has a high level "H."

For example, at a rising edge "R" of the clock signal CK_t when the chip select signal CS has the high level "H," the command and address signals CA**0** to CA**6** of the FIFO register read command RD_FIFO may sequentially have the low level "L," the low level "L," the low level "L," the low level "L," the low level "L," the high level "H," and the high level "H."

At a falling edge "F" of the clock signal CK_t regardless of a level of the chip select signal CS ("X"), the command and address signal CA**0** of the FIFO register write command WR_FIFO having a first option has the low level "L." The remaining command and address signals CA**1** to CA**6** may have a valid level "V" corresponding to any one of a high level and a low level.

At the falling edge "F" of the clock signal CK_t regardless of a level of the chip select signal CS ("X"), the command and address signal CA**0** of the FIFO register read command RD_FIFO having a second option has the high level "H." The remaining command and address signals CA**1** to CA**6** may have a valid level "V" corresponding to any one of a high level and a low level.

As described with reference to FIG. **21**, an option of the FIFO register read command RD_FIFO is selected according to whether the command and address signal CA**0** has the high level "H" or the low level "L" at the falling edge "F" of the clock signal CK_t. Since an additional cycle of the clock signal CK_t or an additional pad is unnecessary, the overhead due to options of the FIFO register write command WR_FIFO is suppressed.

In some embodiments, a flow of first training data according to the FIFO register write command WR_FIFO may be the same as illustrated in FIG. **10**. A flow of second training data according to the FIFO register read command RD_FIFO having a first option may be the same as illustrated in FIG. **13**.

A flow of third training data according to the FIFO register write command WR_FIFO may be the same as illustrated in FIG. **14**. A flow of fourth training data according to the FIFO register read command RD_FIFO having a second option may be the same as illustrated in FIG. **15**.

FIG. **22** is a flowchart illustrating a write training method according to embodiments of the inventive concept. Referring to FIGS. **1**, **3**, **16**A to **18**b, and **22**, in operation S**410**, the controller **20** may transmit the FIFO register write command WR_FIFO to the semiconductor memory **100**. The controller **20** may transmit first training data to the semiconductor memory **100** together with the FIFO register write command WR_FIFO.

For example, the first training data may be transmitted through the fourth memory pads **104_0** to **104_15**, the fifth memory pads **105_0** and **105_1**, and the sixth memory pads **106_0** and **106_1**. The semiconductor memory **100** may store the first training data in the FIFO registers **172**_m, **172**_n, and/or **182**_o in response to the FIFO register write command WR_FIFO.

In operation S**420**, the controller **20** may transmit the FIFO register read command RD_FIFO having a first option to the semiconductor memory **100**. Depending on the FIFO register read command RD_FIFO, the semiconductor memory **100** may output partial data, which correspond to the fourth memory pads **104_0** to **104_15** and the fifth memory pads **105_0** and **105_1**, from among the stored first training data to the controller **20** as second training data. The second training data may be transmitted through the fourth memory pads **104_0** to **104_15** and the fifth memory pads **105_0** and **105_1**.

In operation S**430**, the controller **20** may transmit the FIFO register read command RD_FIFO having a second option to the semiconductor memory **100**. In response to the FIFO register read command RD_FIFO having the second option, at least one of the first data delivery and training blocks **160_0** to **160_15** or at least one of the second data delivery and training blocks **170_0** and **170_1** of the second block **170** may output the remaining partial data of the first training data stored in the FIFO register **182**_o of the third block **180**a to the controller **20** as fourth training data.

The fourth training data may be output through at least one of the fourth memory pads **104_0** to **104_15** or at least one of the fifth memory pads **105_0** and **105_1**. That is, according to a third embodiment illustrated in FIG. **22**, the first training data and the third training data may be transmitted to the semiconductor memory **100** at the same time.

FIG. **23** illustrates an example in which first training data and third training data are transmitted to the semiconductor memory **100** depending on the FIFO register write command WR_FIFO. In FIG. **23**, "WCK_t" indicates one of the write clock signals WCK[**0**:**1**], and "WCK_c" indicates an inverted version of the write clock signal WCK_t.

Referring to FIGS. **1**, **3**, **11**, and **23**, the controller **20** may transmit first and third training data to the semiconductor memory **100** when a specific time elapses after transmitting the FIFO register write command WR_FIFO. The controller **20** may transmit a part of the first training data to the semiconductor memory **100** through the fourth memory pads **104_0** to **104_15** as the data signals DQ[**0**:**15**] in synchronization with a rising edge and a falling edge of the write clock signal WCK_t.

The controller **20** may transmit the remaining part of the first training data to the semiconductor memory **100** through the fifth memory pads **105_0** and **105_1** as the data mask inversion signals DMI[**0**:**1**] in synchronization with the rising edge and the falling edge of the write clock signal WCK_t. The controller **20** may transmit the third training data to the semiconductor memory **100** through the sixth memory pads **106_0** and **106_1** as the write parity signals PARW[**0**:**1**] in synchronization with a rising edge and a falling edge of the write clock signal WCK_t.

In some embodiments, a flow of second training data according to the FIFO register read command RD_FIFO having a first option may be the same as illustrated in FIG. **13**. A flow of fourth training data according to the FIFO register read command RD_FIFO having a second option may be the same as illustrated in FIG. **15**.

FIG. **24** is a flowchart illustrating a write training method according to embodiments of the inventive concepts. Referring to FIGS. **1**, **3**, and **24**, in operation S**510**, the controller **20** may program the mode register **110** of the semiconductor memory **100**. For example, the controller **20** may program the mode register **110** such that an option of the FIFO register write command WR_FIFO or an option of the FIFO register read command RD_FIFO is set to a first option. Afterwards, training is performed according to the programmed option.

In operation S**520**, the controller **20** may transmit the FIFO register write command WR_FIFO to the semiconductor memory **100**. Depending on the FIFO register write command WR_FIFO, the controller **20** may transmit first training data to the semiconductor memory **100**. The first training data may be transmitted through the fourth memory pads **104_0** to **104_15** and the fifth memory pads **105_0** and **105_1** as described with reference to FIG. **10**.

In operation S**530**, the controller **20** may transmit the FIFO register read command RD_FIFO to the semiconductor memory **100**. Depending on the FIFO register read command RD_FIFO, the semiconductor memory **100** may transmit second training data to the controller **20**. The second training data may be transmitted through the fourth memory pads **104_0** to **104_15** and the fifth memory pads **105_0** and **105_1** as described with reference to FIG. **13**.

In operation S**540**, the controller **20** may program the mode register **110** of the semiconductor memory **100**. For example, the controller **20** may program the mode register **110** such that an option of the FIFO register write command WR_FIFO or an option of the FIFO register read command RD_FIFO is set to a second option. Afterwards, training continues depending on the programmed option.

In operation S**550**, the controller **20** may transmit the FIFO register write command WR_FIFO to the semiconductor memory **100**. Depending on the FIFO register write command WR_FIFO, the controller **20** may transmit third training data to the semiconductor memory **100**. The third training data may be transmitted through the sixth memory pads **106_0** and **106_1** as described with reference to FIG. **14**.

In operation S**560**, the controller **20** may transmit the FIFO register read command RD_FIFO to the semiconductor memory **100**. Depending on the FIFO register read command RD_FIFO, the semiconductor memory **100** may transmit fourth training data to the controller **20**. The fourth training data may be transmitted through at least one pad selected from the fourth memory pads **104_0** to **104_15** and the fifth memory pads **105_0** and **105_1** as described with reference to FIG. **15**.

FIG. **25** is a flowchart illustrating a write training method according to embodiments of the inventive concepts. Referring to FIGS. **1**, **3**, and **25**, in operation S**610**, the controller **20** may program the mode register **110** of the semiconductor memory **100**. For example, the controller **20** may program the mode register **110** such that an option of the FIFO register read command RD_FIFO is set to a first option.

In operation S**620**, the controller **20** may transmit the FIFO register write command WR_FIFO to the semiconductor memory **100**. Depending on the FIFO register write command WR_FIFO, the controller **20** may transmit first training data to the semiconductor memory **100**. The first training data may be transmitted through the fourth memory pads **104_0** to **104_15**, the fifth memory pads **105_0** and **105_1**, and the sixth memory pads **106_0** and **106_1** as described with reference to FIG. **23**.

In operation S**630**, the controller **20** may transmit the FIFO register read command RD_FIFO to the semiconductor memory **100**. Depending on the FIFO register read command RD_FIFO, the semiconductor memory **100** may transmit second training data to the controller **20**. The second training data may be transmitted through the fourth memory pads **104_0** to **104_15** and the fifth memory pads **105_0** and **105_1** as described with reference to FIG. **13**.

In operation S**640**, the controller **20** may program the mode register **110** of the semiconductor memory **100**. For example, the controller **20** may program the mode register **110** such that an option of the FIFO register read command RD_FIFO is set to a second option. Training continues depending on the programmed option.

In operation S**650**, the controller **20** may transmit the FIFO register read command RD_FIFO to the semiconductor memory **100**. Depending on the FIFO register read command RD_FIFO, the semiconductor memory **100** may transmit fourth training data to the controller **20**. The fourth training data may be transmitted through at least one pad selected from the fourth memory pads **104_0** to **104_15** and the fifth memory pads **105_0** and **105_1** as described with reference to FIG. **15**.

FIG. **26**A illustrates another example of one of the first data delivery and training blocks **160_0** to **160_15** according to embodiments of the inventive concepts. In some embodiments, an example of a first data delivery and training block **160**_p that is associated with the redirector **120** is illustrated in FIG. **26**A. Referring to FIGS. **3** and **26**A, the first data delivery and training block **160**_p includes a data buffer **161**_p, a first-in first-out (FIFO) register **162**_p, a parallelizer **163**_p, and a serializer **164**_p.

In a normal operation (e.g., not training), the data buffer **161**_p may communicate a data signal DQp with a fourth memory pad **104**_p. In training, the data buffer **161**_p may communicate training data with the fourth memory pad **104**_p.

The data buffer **161**_p, the FIFO register **162**_p, the parallelizer **163**_p, and the serializer **164**_p operate in the same manner as described with reference to FIG. **5**A, and thus, a description thereof will not be repeated here.

In some embodiments, the first data delivery and training block **160**_p may complete training together with the data delivery, clock generation and training block **180**_k(refer to FIG. **6**A) depending on one FIFO register write command WR_FIFO and one FIFO register read command RD_FIFO.

In training, when transmitting the FIFO register write command WR_FIFO, the controller **20** may transmit training data to the fourth memory pads **104_0** to **104_15**, the fifth memory pads **105_0** and **105_1**, and the sixth memory pads **106_0** to **106_3**. That is, the controller **20** may transmit training data to all pads used for training.

If the FIFO register write command WR_FIFO is received, the data delivery, clock generation and training block **180**_k may output training data (e.g., first combination training data) to a fifth encoder **125**. Also, the data buffer **161**_p may output training data (e.g., second combination training data) received through the fourth memory pad **104**_p to the fifth encoder **125**.

If the FIFO register write command WR_FIFO is received, the fifth encoder **125** may perform encoding on the pieces of first and second combination training data. For example, the fifth encoder **125** may perform an XOR operation on the pieces of first and second combination training data. The fifth encoder **125** may store the encoding result (e.g., third combination data) in the FIFO register **162**_p.

If the FIFO register read command RD_FIFO is received, the FIFO register **162**_p may output the stored data as fourth combination data to the data buffer **161**_p. The data buffer **161**_p may transmit the fourth combination data through the fourth memory pad **104**_p.

That is, the first data delivery and training blocks **160_0** to **160_15**, the second data delivery and training blocks **170_0** and **170_1**, and the data delivery, clock generation and training blocks **180_0** and **180_1** may perform (or complete) training depending on one FIFO register write command WR_FIFO free from an option (i.e., without, or regardless of, a first or second option as described herein) and one FIFO register read command RD_FIFO free from an option (i.e., without, or regardless of, a first or second option as described herein).

FIG. **26**B illustrates an application of another of the first data delivery and training blocks **160_0** to **160_15**, which is illustrated in FIG. **25**A. In some embodiments, an example of a first data delivery and training block **160**_p' that is associated with the redirector **120** is illustrated in FIG. **26**B. Referring to FIGS. **3** and **26**B, the first data delivery and training block **160**_p' includes the data buffer **161**_p, the FIFO register **162**_p, the parallelizer **163**_p, the serializer **164**_p, and an encoder **165**_p.

In response to a write command WR or a read command RD from the control logic **190**, the encoder **165**_p may connect the parallelizer **163**_p and the serializer **164**_p with the data buffer **161**_p. In response to the FIFO register write command WR_FIFO or the FIFO register read command RD_FIFO, the encoder **165**_p may connect an output of the FIFO register **162**_p with the data buffer **161**_p and may connect an output of the data buffer **161**_p with the fifth encoder **125**.

The parallelizer **163**_p may parallelize a data signal DQp to the input data DIN depending on the write command WR. The serializer **164**_p may serialize the output data DOUT to the data signal DQp depending on the read command RD.

If the FIFO register write command WR_FIFO is received, the data delivery, clock generation and training block **180**_k' (refer to FIG. **6**B) may output training data (e.g., first combination training data) to the fifth encoder **125**. Also, the data buffer **161**_p may output training data (e.g., second combination training data) received through the fourth memory pad **104**_p as the data signal DQp to the fifth encoder **125**.

If the FIFO register write command WR_FIFO is received, the fifth encoder **125** may perform encoding on the pieces of first and second combination training data. For example, the fifth encoder **125** may perform an XOR operation on the pieces of first and second combination training data. The fifth encoder **125** may store the encoding result (e.g., third combination data) in the FIFO register **162**_p.

If the FIFO register read command RD_FIFO is received, the FIFO register **162**_p may output the stored data as fourth combination data to the data buffer **161**_p. The data buffer **161**_p may transmit the fourth combination data as the data signal DQp through the fourth memory pad **104**_p.

FIG. **27**A illustrates an example of one of the second data delivery and training blocks **170_0** and **170_1** according to embodiments of the inventive concepts. In some embodiments, an example of a second data delivery and training block **170**_q that is associated with the redirector **120** is illustrated in FIG. **27**A. Referring to FIGS. **3** and **27**A, the second data delivery and training block **170**_q includes a data buffer **171**_q, a first-in first-out (FIFO) register **172**_q, a parallelizer **173**_q, and a serializer **174**_q.

In a normal operation (e.g., not training), the data buffer **171**_q may communicate a read parity signal PARRq and a data mask inversion signal DMIq with a fifth memory pad **105**_q. In training, the data buffer **171**_q may communicate training data with the fifth memory pad **105**_q.

The data buffer **171**_q, the FIFO register **172**_q, the parallelizer **173**_q, and the serializer **174**_q operate in the same manner as described with reference to FIG. **4**A, and thus, a description thereof will not be repeated here.

In some embodiments, the second data delivery and training block **170**_q may complete training together with the data delivery, clock generation and training block **180**_o (refer to FIG. **18**A) depending on one FIFO register write command WR_FIFO and one FIFO register read command RD_FIFO.

When transmitting the FIFO register write command WR_FIFO, the controller **20** may transmit training data to the fourth memory pads **104_0** to **104_15**, the fifth memory pads **105_0** and **105_1**, and the sixth memory pads **106_0** to **106_3**. That is, the controller **20** may transmit training data to all pads used for training.

If the FIFO register write command WR_FIFO is received, the data delivery, clock generation and training block **180**_o may store training data (e.g., first combination training data) in the FIFO register **182**_o. Also, the data buffer **171**_q may store training data (e.g., second combination training data) received through the fifth memory pad **105**_q in the FIFO register **172**_q.

If the FIFO register read command RD_FIFO is received, the data delivery, clock generation and training block **180**_o may output the first combination training data to the fifth encoder **125**. The FIFO register **172**_q may output second combination training data to the fifth encoder **125**.

The fifth encoder **125** may perform encoding on the pieces of first and second combination training data. For example, the fifth encoder **125** may perform an XOR operation on the pieces of first and second combination training data. The fifth encoder **125** may output the encoding result (e.g., third combination data) to the fifth memory pad **105**_q through the data buffer **171**_q.

That is, the first data delivery and training blocks **160_0** to **160_15**, the second data delivery and training blocks **170_0** and **170_1**, and the data delivery, clock generation and training blocks **180_0** and **180_1** may perform (or complete) training depending on one FIFO register write command WR_FIFO free from an option (i.e., without, or regardless of, a first or second option as described herein) and one FIFO register read command RD_FIFO free from an option (i.e., without, or regardless of, a first or second option as described herein).

FIG. **27**B illustrates an example of one of the second data delivery and training blocks **170_0** and **170_1** according to embodiments of the inventive concept. In some embodiments, an example of a second data delivery and training block **170**_q' that is associated with the redirector **120** is illustrated in FIG. **27**B. Referring to FIGS. **3** and **27**B, the second data delivery and training block **170**_q' includes the data buffer **171**_q, the FIFO register **172**_q, the parallelizer **173**_q, the serializer **174**_q, and an encoder **175**_q.

In response to a write command WR or a read command RD from the control logic **190**, the encoder **175**_q may connect the parallelizer **173**_q and the serializer **174**_q with the data buffer **171**_q. In response to the FIFO register write command WR_FIFO or the FIFO register read command RD_FIFO, the encoder **175**_q may connect an output of the data buffer **171**_q with the FIFO register **172**_q and may transmit training data transmitted through the fifth encoder **125** to the data buffer **171**_q.

The parallelizer **173**_q may parallelize a data mask inversion signal DMIq to the data mask inversion signal DMI depending on the write command WR. The serializer **174**_q may serialize a read parity PARR to a read parity signal PARRq depending on the read command RD.

If the FIFO register write command WR_FIFO is received, the data delivery, clock generation and training block **180**_o' (refer to FIG. **18**B) may store training data (e.g., first combination training data) in the FIFO register **182**_o. Also, the data buffer **171**_q may store training data (e.g., second combination training data) received through the fifth memory pad **105**_q in the FIFO register **172**_q.

If the FIFO register read command RD_FIFO is received, the data delivery, clock generation and training block **180**_o' may output the first combination training data to the fifth encoder **125**. The FIFO register **172**_q may output second combination training data to the fifth encoder **125**.

The fifth encoder **125** may perform encoding on the pieces of first and second combination training data. For example, the fifth encoder **125** may perform an XOR operation on the pieces of first and second combination training data. The fifth encoder **125** may output the encoding result (e.g., third combination data) to the fifth memory pad **105**_q through the data buffer **171**_q.

As described above, according to embodiments of the inventive concepts, it is possible to perform write training on a pad that is specified not to transmit data in reading and is specified to transmit data in writing. Accordingly, a semiconductor memory with improved reliability, a memory system including the semiconductor memory, and an operating method of the semiconductor memory are provided.

In the above-described embodiments, components according to embodiments of the inventive concept are referenced by using the terms "block," "engine," "logic," and the like. The "block," "engine," or "logic" may be implemented with various hardware devices, such as an integrated circuit (IC), an application specific IC (ASIC), a field programmable gate array (FPGA), and a complex programmable logic device (CPLD), firmware driven in hardware devices, software such as an application, or a combination of a hardware device and software. Also, "block," "engine," or "logic" may include circuits or intellectual property (IP) implemented with semiconductor devices.

According to the inventive concept, a read data strobe signal and write parity data are conveyed through the same pad, and training is performed on a write parity by using other pads. Accordingly, the reliability of a semiconductor memory is improved by apply a read data strobe signal and write parity data to the semiconductor memory without increasing the number of pads.

It will be understood that although the terms "first," "second," etc. are used herein to describe members, regions, layers, portions, sections, components, and/or elements in example embodiments of the inventive concepts, the members, regions, layers, portions, sections, components, and/or elements should not be limited by these terms. These terms are only used to distinguish one member, region, portion, section, component, or element from another member, region, portion, section, component, or element. Thus, a first member, region, portion, section, component, or element described below may also be referred to as a second member, region, portion, section, component, or element without departing from the scope of the inventive concepts. For example, a first element may also be referred to as a second element, and similarly, a second element may also be referred to as a first element, without departing from the scope of the inventive concepts.

The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of example embodiments. As used herein, the singular forms "a," "an," and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises," "comprising," "includes," and/or "including," if used herein, specify the presence of stated features, integers, steps, operations, elements and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components and/or groups thereof.

Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by those of ordinary skill in the art to which the inventive concepts pertain. It will also be understood that terms, such as those defined in commonly used dictionaries, should be interpreted as having a meaning that is consistent with their meaning in the context of this specification and the relevant art and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

When a certain example embodiment may be implemented differently, a specific process order may be performed differently from the described order. For example, two consecutively described processes may be performed substantially at the same time or performed in an order opposite to the described order.

As used herein, the term "and/or" includes any and all combinations of one or more of the associated listed items. Expressions such as "at least one of," when preceding a list of elements, modify the entire list of elements and do not modify the individual elements of the list.

It will be understood that when an element is referred to as being "connected" or "coupled" to another element, it can be directly connected or coupled to the other element or intervening elements may be present. In contrast, when an element is referred to as being "directly connected" or "directly coupled" to another element, there are no intervening elements present. Other words used to describe the relationship between elements or layers should be interpreted in a like fashion (e.g., "between" versus "directly between," "adjacent" versus "directly adjacent," "on" versus "directly on").

Like numbers refer to like elements throughout. Thus, the same or similar numbers may be described with reference to other drawings even if they are neither mentioned nor described in the corresponding drawing. Also, elements that are not denoted by reference numbers may be described with reference to other drawings.

While the inventive concepts have been described with reference to example embodiments thereof, it will be apparent to those of ordinary skill in the art that various changes and modifications may be made thereto without departing from the spirit and scope of the inventive concepts as set forth in the following claims.

What is claimed is:

1. A semiconductor memory device comprising:

a memory core configured to perform reading and writing of data;

data delivery and training blocks connected between first pads and the memory core; and

at least one data delivery, clock generation and training block connected between at least one second pad and the memory core,

wherein, in a first training operation, the data delivery and training blocks output first training data, which are received through the first pads, through the first pads as second training data,

wherein, in a second training operation, at least one of the data delivery and training blocks outputs third training data, which are received through the at least one second pad, through at least one of the first pads as fourth training data, and

wherein the second training data and the fourth training data are output in synchronization with read data strobe signals output through the at least one second pad.

2. The semiconductor memory device of claim **1**, wherein each of the data delivery and training blocks includes a first first-in first-out (FIFO) register,

wherein the at least one data delivery, clock generation and training block includes a second FIFO register, and

wherein the first training operation and the second training operation are performed according to a FIFO register write command and a FIFO register read command.

3. The semiconductor memory device of claim **2**, wherein, in the first training operation, the data delivery and training blocks store the first training data received from the first pads in respective first FIFO registers of the data delivery and training blocks responsive to the FIFO register write command, and

wherein, in the first training operation, the data delivery and training blocks output the first training data stored in the first FIFO registers through the first pads as the second training data responsive to the FIFO register read command.

4. The semiconductor memory device of claim **2**, wherein, in the second training operation, the at least one of the data delivery and training blocks stores the third training data received from the at least one second pad in at least one first FIFO register of the at least one of the data delivery and training blocks responsive to the FIFO register write command, and

wherein, in the second training operation, the at least one of the data delivery and training blocks outputs the third training data stored in the at least one first FIFO register through the at least one of the first pads as the fourth training data responsive to the FIFO register read command.

5. The semiconductor memory device of claim **2**, wherein the FIFO register write command comprises different respective options in the first training operation and the second training operation.

6. The semiconductor memory device of claim **2**, wherein, in the second training operation, the at least one data delivery, clock generation and training block stores the third training data received from the at least one second pad in the second FIFO register responsive to the FIFO register write command, and

wherein, in the second training operation, the at least one of the data delivery and training blocks outputs the third training data stored in the second FIFO register through the at least one of the first pads as the fourth training data responsive to the FIFO register read command.

7. The semiconductor memory device of claim **2**, wherein, in the first training operation, the at least one data delivery, clock generation and training block stores the third training data received from the at least one second pad in the second FIFO register responsive to the FIFO register write command, and

wherein, in the second training operation, the at least one of the data delivery and training blocks outputs the third training data stored in the second FIFO register through at least one of the first pads as the fourth training data responsive to the FIFO register read command.

8. The semiconductor memory device of claim **2**, wherein the FIFO register read command comprises different respective options in the first training operation and the second training operation.

9. The semiconductor memory device of claim **2**, wherein the memory core includes a mode register, and

wherein the first training operation is selected responsive to the mode register being programmed to have a first option and the second training operation is selected responsive to the mode register being programmed to have a second option.

10. The semiconductor memory device of claim **1**, wherein first data delivery and training blocks of the data delivery and training blocks transmit data bits, which are to be written in the memory core or are read from the memory core, between a first one of the first pads and the memory core.

11. The semiconductor memory device of claim **10**, wherein the data bits include a data portion and a parity portion for the data portion.

12. The semiconductor memory device of claim **10**, wherein the at least one data delivery, clock generation and training block transmits a write parity transmitted from the at least one second pad to the memory core and outputs at least one read data strobe signal through the at least one second pad.

13. The semiconductor memory device of claim **10**, wherein second data delivery and training blocks of the data delivery and training blocks transmit data mask inversion signals, which are transmitted from a second one of the first pads, to the memory core and output a read parity transmitted from the memory core to the second one of the first pads.

14. The semiconductor memory device of claim **1**, further comprising:

at least one clock generation block connected to at least one third pad,

wherein the second training data and the fourth training data are output in synchronization with a second read data strobe signal output through the at least one third pad.

15. A memory system comprising:

a semiconductor memory; and

a controller configured to control the semiconductor memory,

wherein the semiconductor memory and the controller communicate with each other through data input and output lines, data mask inversion lines, and read data strobe lines,

wherein, in a first training operation, the controller transmits first data to the semiconductor memory through the data input and output lines and the data mask inversion lines and reads the first data from the semiconductor memory through the data input and output lines and the data mask inversion lines, and

wherein, in a second training operation, the controller transmits second data to the semiconductor memory through the read data strobe lines and reads the second data from the semiconductor memory through at least two of the data input and output lines and the data mask inversion lines.

16. The memory system of claim **15**, wherein the semiconductor memory outputs read data strobe signals through the read data strobe lines and outputs the first data and the second data through the data input and output lines and the data mask inversion lines in synchronization with the read data strobe signals.

17. The memory system of claim **16**, wherein the controller transmits a clock signal to the semiconductor memory through a clock line and transmits a write clock signal to the semiconductor memory through a write clock line, and

wherein the semiconductor memory adjusts the write clock signal to output the read data strobe signals.

18. The memory system of claim **15**, wherein the controller selects one of the first training operation or the second training operation responsive to one of receiving a FIFO register write command, receiving a FIFO register read command, and a programming of a mode register.

19. A semiconductor memory device comprising:

a memory core configured to perform reading and writing of data;

a first data delivery and training block connected between a first pad and the memory core;

a second data delivery and training block connected between a second pad and the memory core; and

a data delivery, clock generation and training block connected between a third pad and the memory core,

wherein, in a training input operation, the first and second data delivery and training blocks receive first and second training data through the first pad and the second pad, respectively, and the data delivery, clock generation and training block receives third training data through the third pad,

wherein, in a training output operation, the first data delivery and training block outputs the first training data through the first pad, and the second data delivery and training block combines the second and third training data to generate fourth training data and outputs the fourth training data through the second pad.

20. The semiconductor memory device of claim **19**, wherein, in the training output operation, the data delivery, clock generation and training block outputs a read data strobe signal through the third pad, and

wherein the first and second data delivery and training blocks respectively output the first and fourth training data in synchronization with the read data strobe signal.

21. A semiconductor memory device that is configured to perform a write training operation which comprises a first training operation and a second training operation, the semiconductor memory device comprising:

a first data buffer coupled between a first pad and a first first-in first-out (FIFO) register, wherein the first data buffer, in response to a first FIFO register write command during the first training operation, is configured to receive a data mask inversion signal through the first pad and to store the received data mask inversion signal in the first FIFO register; and

a second data buffer coupled between a second pad and a second FIFO register, wherein the second data buffer, in response to a second FIFO register write command during the second training operation, is configured to receive a write parity signal through the second pad and to store the received write parity signal in the second FIFO register,

wherein the first data buffer, in response to a first FIFO register read command during the first training operation, is configured to output the data mask inversion signal stored in the first FIFO register through the first pad, and

wherein the first data buffer, in response to a second FIFO register read command during the second training operation, is configured to output the write parity signal stored in the second FIFO register through the first pad.

22. The semiconductor memory device of claim 21, wherein the second data buffer, in response to the first FIFO register read command during the first training operation, is configured to output a first read data strobe (RDQS) signal through the second pad, and

wherein the second data buffer, in response to the second FIFO register read command during the second training operation, is configured to output a second RDQS signal through the second pad.

23. The semiconductor memory device of claim 22, wherein the first data buffer, in response to the first FIFO register read command during the first training operation, is *configured to output the data mask inversion signal stored in the first FIFO register in synchronization with the first RDQS signal, and*

wherein the first data buffer, in response to the second FIFO register read command during the second training operation, is configured to output the write parity signal stored in the second FIFO register in synchronization with the second RDQS signal.

24. The semiconductor memory device of claim 23, further comprising a third data buffer coupled between a third pad and a third FIFO register, wherein the third data buffer, in response to the first FIFO register write command, is configured to receive a first data signal through the third pad and to store the received first data signal in the third FIFO register, and

wherein, the third data buffer, in response to the first FIFO register read command, is configured to output the first data signal stored in the third FIFO register through the third pad.

25. The semiconductor memory device of claim 24, wherein the third data buffer, in response to the second FIFO register write command, is configured to receive a second data signal through the third pad and to store the received second data signal in the third FIFO register, and

wherein, the third data buffer, in response to the second FIFO register read command, is configured to output the second data signal stored in the third FIFO register through the third pad.

26. The semiconductor memory device of claim 25, wherein each of the first to third data buffers, during the write training operation, is further configured to:

receive a write clock signal through a fourth pad;

latch one or more of the data mask inversion signal, the write parity signal, and the first and second data signals based on a toggling of the write clock signal; and

store the latched one or more of the data mask inversion signal, the write parity signal, and the first and second data signals in the first to third FIFO registers respectively.

27. The semiconductor memory device of claim 26, wherein the first to third data buffers are configured to repeat the write training operation with adjusted phase relationships between the write clock signal and each of the data mask inversion signal, the write parity signal, and the first and second data signals.

28. The semiconductor memory device of claim 21, further comprising a mode register, the mode register configured to set one of the first training operation and the second training operation of the semiconductor memory device.

29. The semiconductor memory device of claim 28, wherein the first and second FIFO register write commands comprise information that sets one of the first training operation and the second training operation of the semiconductor memory device.

30. The semiconductor memory device of claim 28, wherein the first and second FIFO register read commands comprise information that sets one of the first training operation and the second training operation of the semiconductor memory device.

31. The semiconductor memory device of claim 21, wherein the write parity signal is a cyclic redundancy code (CRC).

32. The semiconductor memory device of claim 31, wherein the CRC is configured to detect an error in communication with an external device.

33. A method for performing a write training operation in a semiconductor memory device, the method comprising:

receiving a first first-in first-out (FIFO) register write command;

receiving a data mask inversion signal associated with the first FIFO register write command through a first pad and storing the received data mask inversion signal in a first FIFO register coupled to the first pad;

receiving a first FIFO register read command;

outputting the data mask inversion signal stored in the first FIFO register through the first pad in response to the first FIFO register read command;

receiving a second FIFO register write command;

receiving a write parity signal associated with the second FIFO register write command through a second pad and storing the received write parity signal in a second FIFO register coupled to each of the first and second pads;

receiving a second FIFO register read command; and

outputting the write parity signal stored in the second FIFO register through the first pad in response to the second FIFO register read command.

34. The method of claim 33, further comprising outputting a first read data strobe (RDQS) signal through the second pad in response to the first FIFO register read command and outputting a second RDQS signal through the second pad in response to the second FIFO register read command.

35. The method of claim 34, wherein the semiconductor memory device is configured to output the data mask inversion signal stored in the first FIFO register in synchronization with the first RDQS signal in response to the first FIFO register read command, and to output the write parity signal stored in the second FIFO register in synchronization with the second RDQS signal in response to the second FIFO register read command.

36. The method of claim 35, further comprising:

receiving a first data signal through a third pad in response to the first FIFO register write command;

storing the received first data signal in a third FIFO register coupled to the third pad; and

outputting the first data signal stored in the third FIFO register through the third pad in response to the first FIFO register read command.

37. The method of claim 36, further comprising:

receiving a second data signal through the third pad in response to the second FIFO register write command;

storing the received second data signal in the third FIFO register; and

outputting the second data signal stored in the third FIFO register through the third pad in response to the second FIFO register read command.

38. The method of claim 37, further comprising:

receiving a write clock signal through a fourth pad;

latching the data mask inversion signal and the first data signal in response to the first FIFO register write command;

latching the write parity signal and the second data signal in response to the second FIFO register write command; and

storing the latched data mask inversion signal, the latched write parity signal and the latched first and second data signals in the first to third FIFO registers respectively.

39. The method of claim 38, further comprising repeating the write training operation with adjusted phase relation-

ships between the write clock signal and each of the data mask inversion signal, the write parity signal and the first and second data signals.

40. The method of claim 33, wherein the write parity signal is a cyclic redundancy code (CRC).

41. The method of claim 40, wherein the CRC is configured to detect an error in communication with an external device.

42. A memory system that is configured to perform a write training operation, the memory system comprising:

a semiconductor memory device comprising a plurality of first-in first-out (FIFO) registers; and

a memory controller coupled to the semiconductor memory device, the memory controller configured to perform a first training operation and a second training operation,

wherein the first training operation comprises:

transmitting a first FIFO register write command followed by transmitting a first write clock (WCK) through a write clock controller pad and transmitting a data mask inversion signal through a first controller pad, the data mask inversion signal being latched by the first WCK and stored in a first FIFO register of the semiconductor memory device;

transmitting a first FIFO register read command for receiving the stored data mask inversion signal through the first controller pad; and

comparing logic values of the transmitted data mask inversion signal and the received stored data mask inversion signal,

wherein the second training operation comprises:

transmitting a second FIFO register write command followed by transmitting a second WCK through the write clock controller pad and transmitting a write parity signal through a second controller pad, the write parity signal being latched by the second WCK and stored in a second FIFO register of the semiconductor memory device;

transmitting a second FIFO register read command for receiving the stored write parity signal through the first controller pad; and

comparing logic values of the transmitted write parity signal and the received stored write parity signal,

wherein the memory controller is further configured to repeat the first and second training operations after adjusting respective phase relationships between the first WCK and the data mask inversion signal and between the second WCK and the write parity signal.

43. The memory system of claim 42, wherein the memory controller is further configured to receive a first read data strobe (RDQS) signal through the second controller pad while receiving the stored data mask inversion signal through the first controller pad and to receive a second RDQS signal through the second controller pad while receiving the stored write parity signal through the first controller pad.

44. The memory system of claim 43, wherein the stored data mask inversion signal and the stored write parity signal are received in synchronization with the first and second RDQS signals respectively.

45. The memory system of claim 44, wherein the memory controller is further configured to transmit a first data signal through a third controller pad after transmitting the first FIFO register write command for storing the first data signal in a third FIFO register of the semiconductor memory device and to receive the stored first data signal through the third controller pad after transmitting the first FIFO register read command.

46. The memory system of claim 45, wherein the memory controller is further configured to transmit a second data signal through the third controller pad after transmitting the second FIFO register write command for storing the second data signal in the third FIFO register of the semiconductor memory device and to receive the stored second data signal through the third controller pad after transmitting the second FIFO register read command.

47. The memory system of claim 42, wherein the memory controller is further configured to program a mode register of the semiconductor memory device to set one of the first training operation and the second training operation.

48. The memory system of claim 42, wherein the first and second FIFO register write commands comprise information that sets one of the first training operation and the second training operation.

49. The memory system of claim 42, wherein the write parity signal is a cyclic redundancy code (CRC), and

wherein the CRC is configured to detect an error in communication between the memory controller and the semiconductor memory device.

50. A semiconductor memory device performing a write training operation which comprises a first training operation and a second training operation, the semiconductor memory device comprising:

a first pad;

a first data buffer coupled to the first pad and configured to receive a data mask inversion signal through the first pad in response to a first first-in first-out (FIFO) register write command and output the received data mask inversion signal through the first pad in response to a first FIFO register read command during the first training operation;

a second pad; and

a second data buffer coupled to the second pad and configured to receive a write parity signal through the second pad in response to a second FIFO register write command and output a read data strobe (RDQS) signal through the second pad during the second training operation,

wherein the first data buffer is further configured to output the received write parity signal through the first pad in response to the second FIFO register read command during the second training operation.

51. The semiconductor memory device of claim 50, wherein the first data buffer, during the first training operation, stores the data mask inversion signal in a first FIFO register in response to the first FIFO register write command and outputs the stored data mask inversion signal through the first pad in response to the first FIFO register read command, and the second data buffer, during the second training operation, stores the write parity signal in a second FIFO register in response to the second FIFO register write command and outputs the stored write parity signal through the first pad in response to the second FIFO register read command.

52. The semiconductor memory device of claim 50, wherein the first data buffer, during the first training operation, stores the data mask inversion signal in a FIFO register in response to the first FIFO register write command and outputs the stored data mask inversion signal through the first pad in response to the first FIFO register read command, and the second data buffer, during the second training operation, stores the write parity signal in the FIFO register *in response to the second FIFO register write command and outputs the stored write parity signal through the first pad in response to the second FIFO register read command.*

53. The semiconductor memory device of claim 50, wherein the first data buffer, during the first training operation, outputs the received data mask inversion signal through the first pad in synchronization with a second RDQS signal output through the second pad, and the first data buffer, during the second training operation, outputs the received write parity signal through the first pad in synchronization with the RDQS signal output through the second pad.

54. The semiconductor memory device of claim 50, further comprising a third data buffer coupled to a third pad, wherein the third data buffer receives a first data signal through the third pad in response to the first FIFO register write command and outputs the received first data signal through the third pad in response to the first FIFO register read command.

55. The semiconductor memory device of claim 54, wherein the third data buffer stores the received first data signal in a third FIFO register.

56. The semiconductor memory device of claim 54, wherein, during the write training operation, each of the first to third data buffers receives a write clock signal through a fourth pad and latches each of the data mask inversion signal, write parity signal, and the first data signal by toggling the write clock signal and stores each latched signal in corresponding FIFO register respectively.

57. The semiconductor memory device of claim 50, wherein the semiconductor memory device repeats the write training operation with adjusted phase relationships between the write clock signal and each of the data mask inversion signal, write parity signal and the first data signal.

58. The semiconductor memory device of claim 50, further comprising a mode register, the mode register being programmed to set one of the first training operation and the second training operation of the semiconductor memory device.

59. The semiconductor memory device of claim 50, wherein the first and second FIFO register write commands include first information setting one of the first training operation and the second training operation of the semiconductor memory device, and the first and second FIFO register read commands include second information setting one of the first training operation and the second training operation of the semiconductor memory device.

60. The semiconductor memory device of claim 50, wherein the write parity signal is a cyclic redundancy code (CRC).

61. The semiconductor memory device of claim 60, wherein the CRC is used for detecting an error occurred while communicating with an external device.

62. A method for performing a write training operation in a semiconductor memory device, the method comprising:

receiving a first first-in first-out (FIFO) register write command;

receiving a data mask inversion signal associated with the first FIFO register write command through a first pad;

receiving a first FIFO register read command;

outputting the received data mask inversion signal through the first pad in response to the first FIFO register read command;

receiving a second FIFO register write command;

receiving a write parity signal associated with the second FIFO register write command through a second pad;

receiving a second FIFO register read command; and

outputting the received write parity signal through the first pad in response to the second FIFO register read command,

wherein the received write parity signal is output through the first pad in synchronization with a read data strobe (RDQS) signal which is output through the second pad.

63. The method of claim 62, wherein the received data mask inversion signal is output through the first pad in synchronization with a second RDQS signal which is output through the second pad.

64. The method of claim 63, wherein the received data mask inversion signal is stored in a first FIFO register and the received write parity signal is stored in a second FIFO register.

65. The method of claim 64, further receiving a first data signal through a third pad in response to the first FIFO register write command and outputting the received first data signal stored through the third pad in response to the first FIFO register read command.

66. The method of claim 65, further receiving a second data signal through the third pad in response to the second FIFO register write command and outputting the received second data signal through the third pad in response to the second FIFO register read command.

67. The method of claim 66, further receiving a write clock signal through a fourth pad and latching the data mask inversion signal and the write parity signal respectively.

68. The method of claim 67, further repeating the whole steps with adjusted phase relationships between the write clock signal and each of the data mask inversion signal and the write parity signal.

69. The method of claim 62, wherein the received data mask inversion signal and the received write parity signal are stored in a FIFO register before outputting through the first pad.

* * * * *