

MEMORY CONTROLLER WITH PROGRAMMABLE ADDRESS CONFIGURATION

Background of the Invention

1. Field of the Invention

5 The invention is related to the field of memory controllers, and in particular, to a memory controller that can be programmed with various address configurations for different memory devices.

2. Statement of the Problem

10 A memory controller provides a system with access to memory devices. For example, a memory controller provides the interface between a computer processor and a Dynamic Random Access Memory (DRAM). The memory controller translates control signals and addresses that pass between the system and the memory devices. Memory controllers also buffer data during data transfers between the
15 system and the memory devices.

 The memory controller uses an address configuration and a memory configuration to translate system addresses into memory addresses and memory device selections. Unfortunately, different memory devices have different address configurations, and different memory systems have different memory configurations.

20 Thus, the memory controller must be designed to use the same address configuration and the same memory configuration as the memory devices. This requires that the specific memory devices for a memory system be selected during system design when it is difficult to predict the future availability and price of specific memory devices.

In addition, many different types of memory controllers are needed to service the many different types of memory devices. Multiple different memory controllers add complexity to memory system design. The current situation also prevents the efficient mass production of a single type of memory controller.

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Summary of the Solution

The invention solves the above problems with a memory controller that uses a programmable address configuration and memory configuration to convert system addresses into memory addresses and memory device selections. Advantageously, the memory controller does not need to be designed specifically for a given memory device or system because the memory controller can be subsequently programmed with the address configuration of the selected memory devices and with the memory configuration of the selected memory system. Address configuration and memory configuration programming occurs after the memory controller is designed and manufactured.

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The memory controller comprises a programmable interface coupled to address circuitry. The programmable interface is configured to receive configuration signals into the memory controller indicating a selected address configuration. The address circuitry is configured to process system addresses based on the selected address configuration to generate memory addresses. In some examples of the invention, the configuration signals also indicate a selected memory configuration, and the address circuitry is configured to process the system addresses based on the selected memory configuration to generate memory device selections.

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Description of the Drawings

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FIG. 1 is a block diagram that illustrates a memory controller in an example of the invention.

FIG. 2 is a flow diagram that illustrates memory controller configuration in an example of the invention.

5 FIG. 3 is a flow diagram that illustrates memory controller operation in an example of the invention.

FIG. 4 is a flow diagram that illustrates memory system manufacturing in an example of the invention.

10 FIG. 5 is a block diagram that illustrates DRAM memory controller circuitry in an example of the invention.

FIG. 6 is a block diagram that illustrates device selection circuitry of a DRAM memory controller in an example of the invention.

Detailed Description of the Invention

Memory Controller – FIGS. 1-4

15 FIGS. 1-4 depict a specific example of a memory controller and system in accord with the present invention. Those skilled in the art will appreciate numerous variations from this example that do not depart from the scope of the invention. Those skilled in the art will also appreciate that various features described below
20 could be combined with other embodiments to form multiple variations of the invention.

FIG. 1 is a block diagram that illustrates memory controller 110 in an example of the invention. Memory system 105 comprises the memory controller 110 and memory devices 121-123 that are coupled together in a conventional manner.

25 Memory controller 110 comprises data circuitry 111, control circuitry 112, address

circuitry 113, and programmable interface 114. Memory controller 110 exchanges data 101 between system 100 and memory devices 121-123. Those skilled in the art will appreciate that some conventional aspects of memory system 105 and memory controller 110 have been simplified or omitted for clarity.

5 To write data, system 100 transfers data 101, system control signals 102, and system address 103 to memory controller 110. System control signals 102 indicate the write operation. System address 103 indicates the desired location within memory devices 121-123 to write data 101.

10 Control circuitry 112 receives system control signals 102, and in response, generates memory control signals 115. Control circuitry 112 transfers memory control signals 115 to memory devices 121-123. Address circuitry 113 receives system address 103, and in response, generates memory address 116 and memory device selection signals 117 according to settings in programmable interface 114. Address circuitry 113 transfers memory address 116 and memory device selection
15 signals 117 to memory devices 121-123. Data circuitry 111 receives and transfers data 101 from system 100 to memory devices 121-123.

20 Memory control signals 115 indicate the write operation. Memory address 116 indicates the desired location for data 101 within a selected one of the memory devices 121-123. Memory device selection signals 117 indicate the selected one of memory devices 121-123 to write data 101. Memory devices 121-123 write data 101 to internal memory in response to memory control signals 115, memory address 116, and memory device selection signals 117.

 To read data, system 100 transfers system control signals 102 and system address 103 to memory controller 110. System control signals 102 now indicate the

read operation. System address 103 indicates the location within memory devices 121-123 to read data 101.

Control circuitry 112 receives system control signals 102, and in response, generates memory control signals 115. Control circuitry 112 transfers memory control signals 115 to memory devices 121-123. Address circuitry 113 receives system address 103, and in response, generates memory address 116 and memory device selection signals 117 according to settings in programmable interface 114. Address circuitry 113 transfers memory address 116 and memory device selection signals 117 to memory devices 121-123. Data circuitry 111 receives and transfers data 101 from memory devices 121-123 to system 100.

Memory control signals 115 indicate the read operation. Memory address 116 indicates the location of data 101 within the selected one of the memory devices 121-123. Memory device selection signals 117 indicate the selected one of the memory devices 121-123 to read data 101. Memory devices 121-123 read data 101 from internal memory in response to memory control signals 115, memory address 116, and memory device selection signals 117.

The addresses for memory devices 121-123 have a format that is referred to as an address configuration. Thus, memory controller 110 converts system address 103 into memory address 116 based on the address configuration of memory devices 121-123. In a distinct advance in the art, memory controller 110 uses a programmable address configuration for this conversion. Advantageously, memory controller 110 does not need to be designed specifically for memory devices 121-123 because memory controller 110 can be subsequently programmed with the address configuration for memory devices 121-123. Address configuration programming may

occur after memory controller 110 is designed and manufactured, and after memory devices 121-123 are selected.

A memory configuration is used to select a memory device when multiple memory devices 121-123 are connected to memory controller 110. Memory controller converts system address 103 into memory device selection signals 117 based on the memory configuration of memory devices 121-123 and conventional device select control signal 118. In a distinct advance in the art, memory controller 110 uses a programmable memory configuration for this conversion.

Advantageously, memory controller 110 does not need to be created specifically for memory devices 121-123 because memory controller 110 can be subsequently programmed with the memory configuration for memory devices 121-123. Memory configuration programming may occur after memory controller 110 is designed and after memory devices 121-123 are selected.

To program memory controller 110, programmable interface 114 receives configuration signal 119 that indicates the selected address configuration and memory configuration for memory devices 121-123. Address circuitry 113 is coupled to programmable interface 114. Address circuitry 113 processes system address 103 based on the selected address configuration to generate memory address 116. If programmable interface 114 receives a new configuration signal 119 indicating a new address configuration, then address circuitry 113 processes system address 103 based on the new address configuration to generate new memory address 116. Address circuitry 113 also processes system address 103 and control signal 118 based on the selected memory configuration to generate memory device selection signals 117. If programmable interface 114 receives a new configuration signal 119 indicating a new memory configuration, then address circuitry 113 processes system

address 103 and control signal 118 based on the new memory configuration to generate new memory device selection signals 117.

FIG. 2 is a flow diagram that illustrates memory controller 110 configuration in an example of the invention. For initial configuration, memory controller 110 receives and stores a configuration signal indicating a selected address configuration and a selected memory configuration. Memory controller 110 can be re-configured at any time with a new configuration signal that it stores. If memory controller 110 receives and stores a new configuration signal indicating a new address configuration, then memory controller 110 processes the system addresses based on the new address configuration to generate new memory addresses. If memory controller 110 receives a new configuration signal indicating a new memory configuration, then memory controller 110 processes the system addresses based on the new memory configuration to generate new memory device selections.

FIG. 3 is a flow diagram that illustrates memory controller 110 operation in an example of the invention. Memory controller 110 receives system addresses. Memory controller 110 processes the system addresses based on the selected address configuration to generate memory addresses. Memory controller 110 processes the system addresses based on the selected memory configuration to generate memory device selections. Memory controller 110 transfers the memory addresses and the memory device selections to the memory devices.

FIG. 4 is a flow diagram that illustrates memory system 105 manufacturing in an example of the invention. First, select a programmable memory controller and memory devices to form a selected memory system. Second, integrate the selected programmable memory controller and the selected memory devices within circuitry to form the selected memory system. The programmable memory controller can

process system addresses based on various address configurations to generate memory addresses. The programmable memory controller can also process the system addresses based on various memory configurations to generate memory device selections. The selected memory devices use one of the various address configurations, and the selected memory system uses one of the various memory configurations. Third, program the selected programmable memory controller to use the address configuration of the selected memory devices and the memory configuration of the selected memory system.

DRAM Memory Controller Circuitry – FIGS. 5-6

FIGS. 5-6 depict a specific example of circuitry for a DRAM controller in accord with the present invention. Those skilled in the art will appreciate numerous variations from this example that do not depart from the scope of the invention. Those skilled in the art will also appreciate that various features described below could be combined with other embodiments to form multiple variations of the invention.

A DRAM has banks of arrays that are comprised of columns and rows. The DRAM address must indicate the proper bank, row, and column for accurate read and write operations. Different DRAMs have different address configurations. For example, DRAM "A" might require 13 bits to identify a column and DRAM "B" might require 15 bits to identify a column. Thus, the DRAM controller must use the specific address configuration of the specific DRAM to function effectively.

FIG. 5 is a block diagram that illustrates address circuitry 513 and programmable interface 514 for a DRAM controller in an example of the invention. Programmable interface 514 receives configuration signal 519. Address circuitry

513 receives system address 503 and chip selection signal 518. Chip selection signal 518 is a conventional signal in memory controller circuitry. Address circuitry 513 processes system address 503 based on configuration signal 519 to generate DRAM address 516. Address circuitry 513 also processes system address 503 based on configuration signal 519 and chip selection signal 518 to generate DRAM selection signals 517.

Configuration signal 519 indicates the address configuration for the selected DRAMs and the memory configuration for the selected memory system. The address configuration identifies the number of bits that specify the column (# COL), row (# ROW), and bank (#BANK) in the DRAM address. The memory configuration identifies the total number of address bits used in DRAM memory device selection (# DEVICE). The number of column address bits is the selection input to a row address mux. The number of column address bits is added to the number of row address bits and is the selection input to a bank address mux.

The sum of column and row address bits is added to the number of bank address bits and is the selection input to a device selection mux. The device selection mux provides resulting device address bits 521 to device selection circuitry 530. Device selection circuitry 530 combines chip selection signal 518 with device address bits 521 based on the number of device bits 520 to produce device selection signals 517. An example of device selection circuitry 530 is described further below with respect to FIG. 6.

System address 503 is logically parsed into bit groups that form inputs to the muxes. To select the particular bit groups that will generate DRAM address 516, the row mux uses the number of column bits from configuration signal 519, and the bank mux uses the number of column and row bits from configuration signal 519. The

device mux uses the number of bank, column, and row bits from configuration signal 519 to select the particular bit group that will generate device selection signals 517.

The number and size of the bit groups can vary based on the given memory controller design goal, and FIG. 5 is only an illustrative example of one such design.

5 In this example, each mux receives three bit groups from system address 503 that cover a range of address configurations for various DRAMs. All possible bit groups from system address 503 could be used as inputs to the muxes to provide maximum programmability, but this implementation is typically inefficient. The number of mux inputs and the number of bits in each bit group depend on the desired range of

10 DRAM address configurations to support. To illustrate the principle further, consider the following DRAM address configurations.

DRAM "A" ADDRESS CONFIGURATION (TOTAL BITS)			
COLUMN BITS (15)	ROW BITS (14)	BANK BITS (2)	DEVICE BITS (1)
14-0	28-15	30-29	31

For DRAM "A", system address 503 would include bits 31-0, and configuration

15 signal 519 would indicate 15, 14, and 2 as the respective number of column, row, and bank bits, and 1 as the device bits (indicating two memory devices). Bits 14-0 from system address 503 become bits 14-0 of the column address in DRAM address 516. Note that system address bit 15 becomes column address bit 15, but this is not a problem because the DRAM ignores column address bit 15. The row address mux

20 uses the number of column bits (15) to select system address bits 28-15 to become bits 13-0 of the row address in DRAM address 516. Note that system address bits 30-29 become row address bits 15-14, but this is not a problem because the DRAM

ignores row address bits 15-14. The bank address mux uses the sum of column bits and row bits ($15+14=29$) to select the system address bits 30-29 to become bits 1-0 of the bank address in DRAM address 516. The device selection mux uses the sum of column bits, row bits, and bank bits ($15+14+2=31$) to select the system address bit 31 for combination with chip selection signal 518 to provide bits 1-0 of device selection signals 517.

DRAM "B" ADDRESS CONFIGURATION (TOTAL BITS)			
COLUMN BITS (21)	ROW BITS (21)	BANK BITS (3)	DEVICE BITS (3)
20-0	41-21	44-42	47-45

For DRAM "B", system address 503 would include bits 47-0 in this address configuration, and configuration signal 519 would indicate 21, 21, and 3 as the respective number of column, row, and bank bits, and 3 as the device bits (indicating eight memory devices). Bits 20-0 from system address 503 become bits 20-0 of the column address in DRAM address 516. The row address mux uses the number of column bits (21) to select system address bits 41-21 to become bits 20-0 of the row address in DRAM address 516. The bank address mux uses the sum of column bits and row bits ($21+21=42$) to select the system address bits 44-42 to become bits 2-0 of the bank address in DRAM address 516. The device selection mux uses the sum of column bits, row bits, and bank bits ($21+21+3=45$) to select the system address bits 47-45 for combination with chip selection signal 518 to provide bits 7-0 of device selection signals 517.

FIG. 6 is a block diagram that illustrates device selection circuitry 530 in an example of the invention. Device selection circuitry 530 combines chip selection

signal 518 with device address bits 521 based on device bits 520 to produce device selection signals 517. A different one of the device selection signals 517 is provided to each of the memory devices. In this example, there could be from 1-4 memory devices, so all of the device selection signals 517 may not be needed.

5 Chip selection signal 518 and device address bits 521 are provided to various AND gates. Device address bits 521 are inverted prior some AND gate inputs. The AND gates produce a 1 only if chip selection signal 518 is also a 1. The following table illustrates the values of device address bits 521 that are required to produce a 1 from the AND gates.

AND GATE	1A	2A	1B	2B	3B	4B
BIT 1	--	--	0	0	1	1
BIT 0	0	1	0	1	0	1
GATE OUTPUT	1	1	1	1	1	1

The muxes select their respective inputs to become device selection signals 517 based on device bits 520 which indicates the number of bits in the system address that are used for memory device selection. If device bits 520 are zero, then there is only one memory device in the system, and chip selection signal 518 is passed directly to this memory device. If device bits 520 are one, then there are two memory devices in the system, and outputs from AND gates 1A and 2A are respectively passed to memory devices 1 and 2. If device bits 520 are two, then there four memory devices in the system, and outputs from AND gates 1B, 2B, 3B, and 4B are respectively passed to memory devices 1, 2, 3, and 4.

Chip selection signal 518 and device address bits 521 are manipulated to provide a 1 to the selected memory device and a 0 to the other memory devices. Device bits 520 allow a choice of selection signals 517 based on the memory configuration being used by the memory system.

5 Those skilled in the art will appreciate variations of the above-described embodiments that fall within the scope of the invention. As a result, the invention is not limited to the specific examples and illustrations discussed above, but only by the following claims and their equivalents.



WHAT IS CLAIMED IS:

1. A memory controller comprising:

a programmable interface configured to receive a configuration signal into the memory controller indicating a selected address configuration; and

5 address circuitry coupled to the programmable interface and configured to process system addresses based on the selected address configuration to generate memory addresses.

2. A memory controller as claimed in claim 1, wherein the address circuitry is
10 configured to select bit groups from the system addresses based on the selected memory configuration to generate the memory addresses.

3. A memory controller as claimed in claim 1 or claim 2, wherein the configuration
15 signal also indicates a selected memory configuration and the address circuitry is further configured to process the system addresses based on the selected memory configuration to generate memory device selections.

4. A memory controller as claimed in claim 1, claim 2 or claim 3, wherein the
20 address circuitry is further configured to receive the system addresses into the memory controller and transfer the memory addresses from the memory controller and further comprising:

control circuitry configured to receive system control signals into the memory controller, generate memory control signals in response to the system control signals, and transfer the memory control signals from the memory controller; and

25 data circuitry configured to receive data into the memory controller and transfer the data from the memory controller.



5. A memory controller as claimed in any of the preceding claims, wherein the address circuitry is configured to generate the memory addresses for a dynamic random access memory.

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6. A method of operating a memory controller, the method comprising:
receiving a configuration signal into the memory controller indicating a selected address configuration; and
processing system addresses based on the selected address configuration to
10 generate memory addresses.

7. A method as claimed in claim 6, wherein processing the system addresses to generate the memory addresses comprises selecting bit groups from the system addresses based on the selected memory configuration.

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8. A method as claimed in claim 6 or claim 7, wherein the configuration signal also indicates a selected memory configuration and further comprising processing the system addresses based on the selected memory configuration to generate memory device selections.

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9. A method as claimed in claim 6, claim 7 or claim 8, further comprising:
receiving system control signals and the system addresses into the memory controller;



generating memory control signals in response to the system control signals;
transferring the memory control signals and the memory addresses from the
memory controller; and
receiving data into the memory controller and transferring the data from the
5 memory controller.

10. A method as claimed in any one of claims 6 to 9, wherein processing the system
addresses to generate the memory addresses comprises generating the memory
addresses for a dynamic random access memory.

10 11. A memory controller as described herein with reference to Figures 1, 5 and 6.

12. A memory system as described herein with reference to Figure 1.

15 13. A method of operating a memory controller as described herein with reference to
Figures 2 and 3.

14. A method of manufacturing a memory system as described herein with reference
to Figure 4.