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(54) RECONFIGURABLE MEMORY MODULE
AND METHOD

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(76) Inventors: **Terry R. Lee**, Boise, ID (US); **Joseph M. Jeddeloh**, Shoreview, MN (US)

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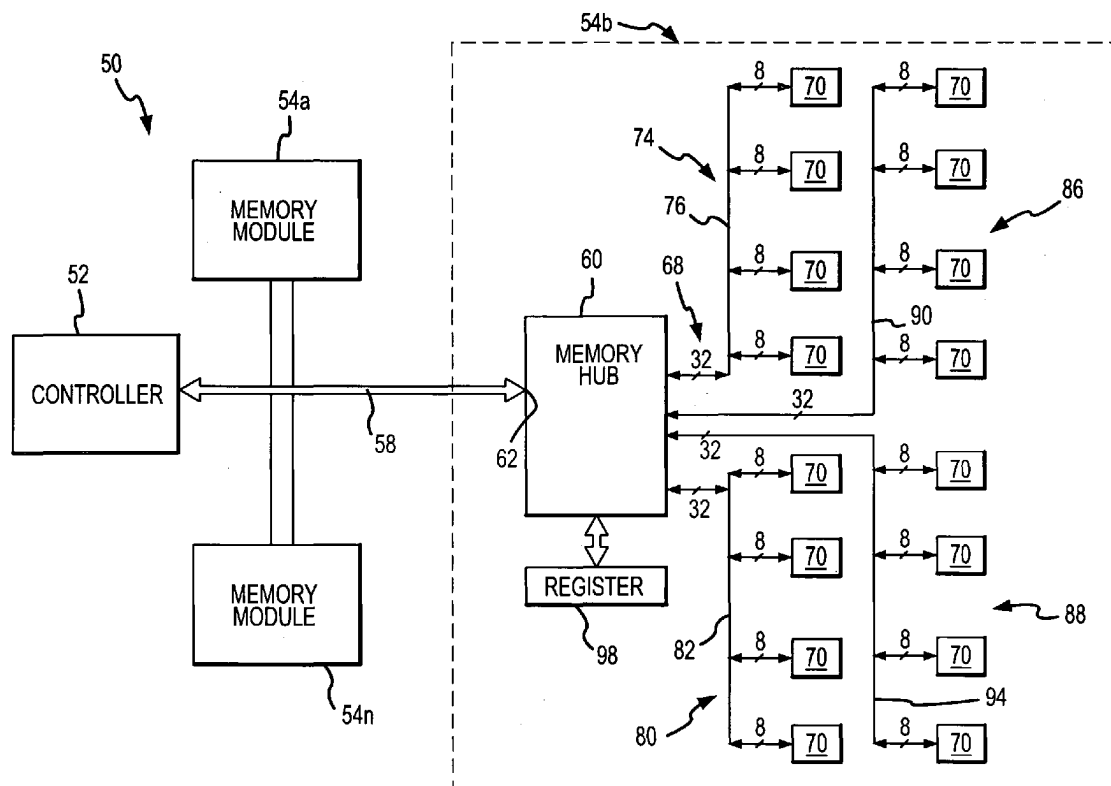
Correspondence Address:
Edward W. Bulchis, Esq.
DORSEY & WHITNEY LLP
Suite 3400
1420 Fifth Avenue
Seattle, WA 98101 (US)

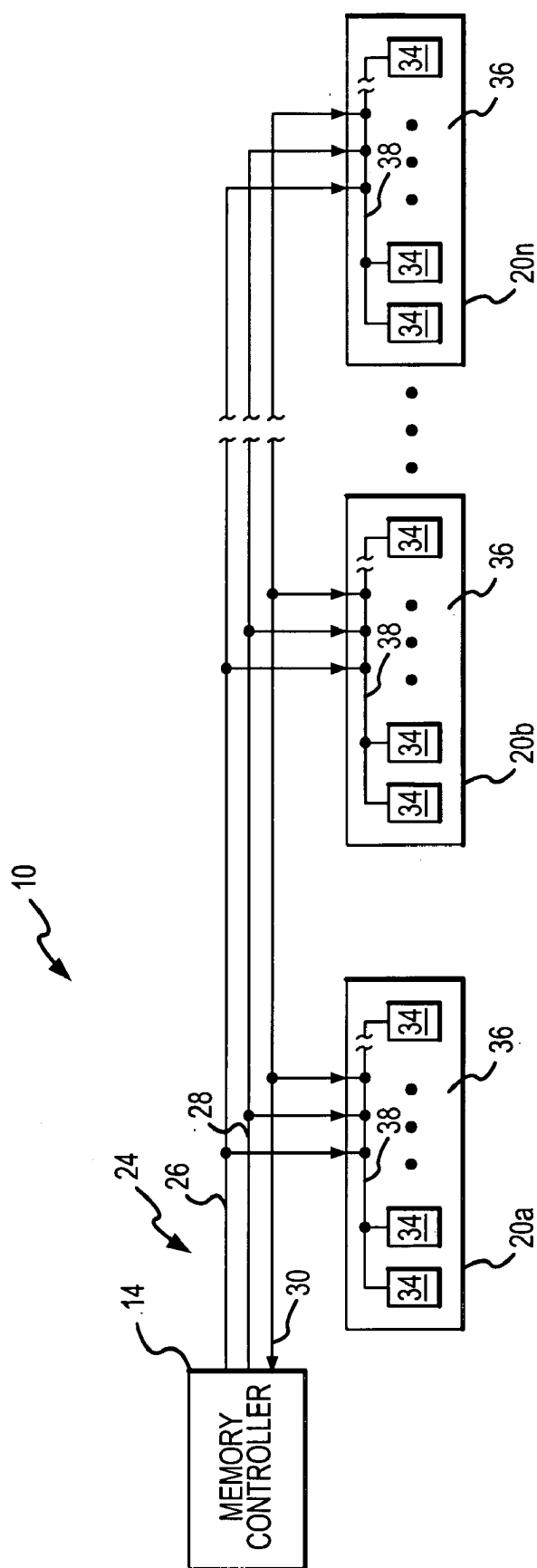
(57) **ABSTRACT**

A computer system includes a controller coupled to a plurality of memory modules each of which includes a memory hub and a plurality of memory devices divided into a plurality of ranks. The memory hub is operable to configure the memory module to simultaneously address any number of ranks to operate in a high bandwidth mode, a high memory depth mode, or any combination of such modes.

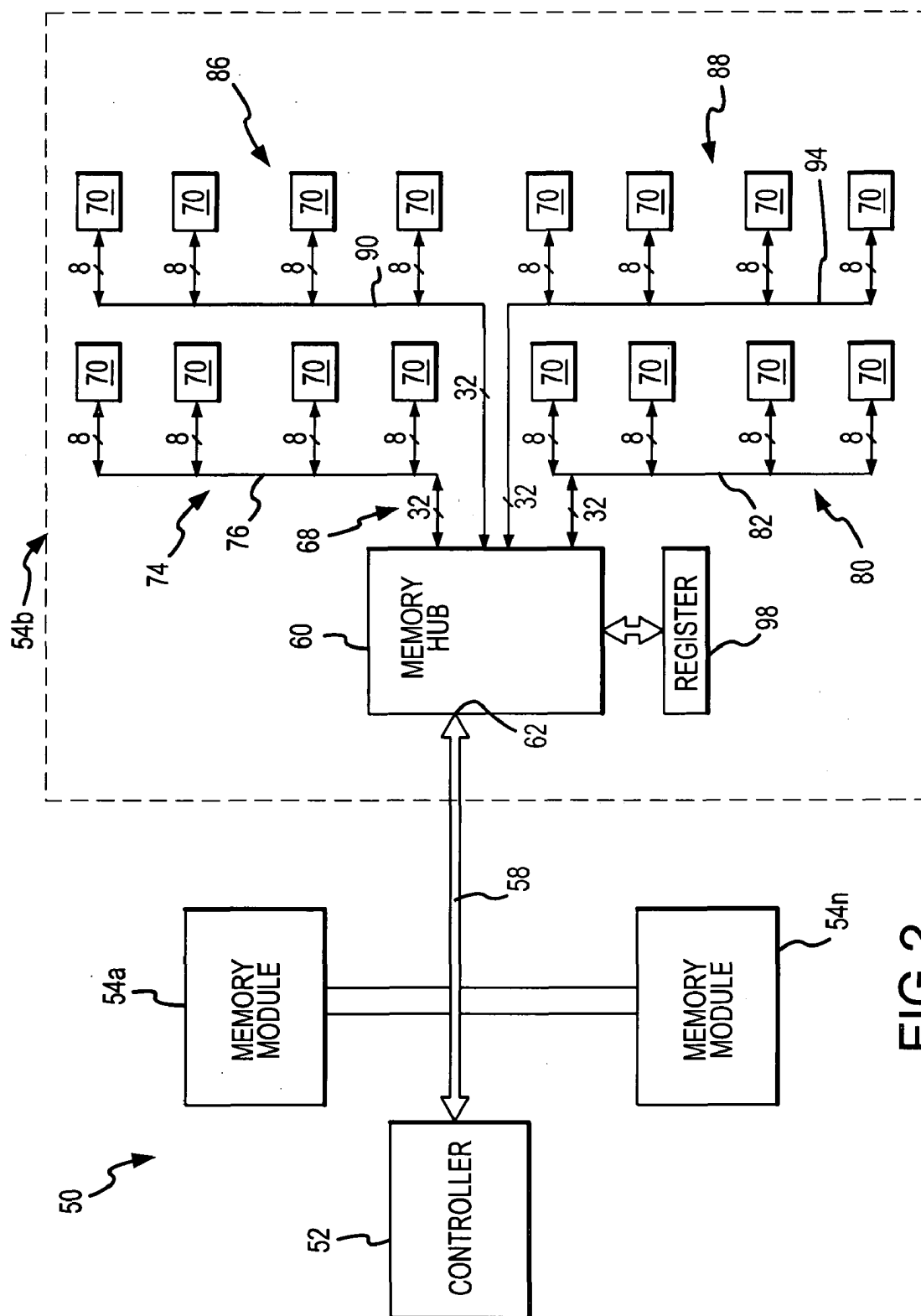
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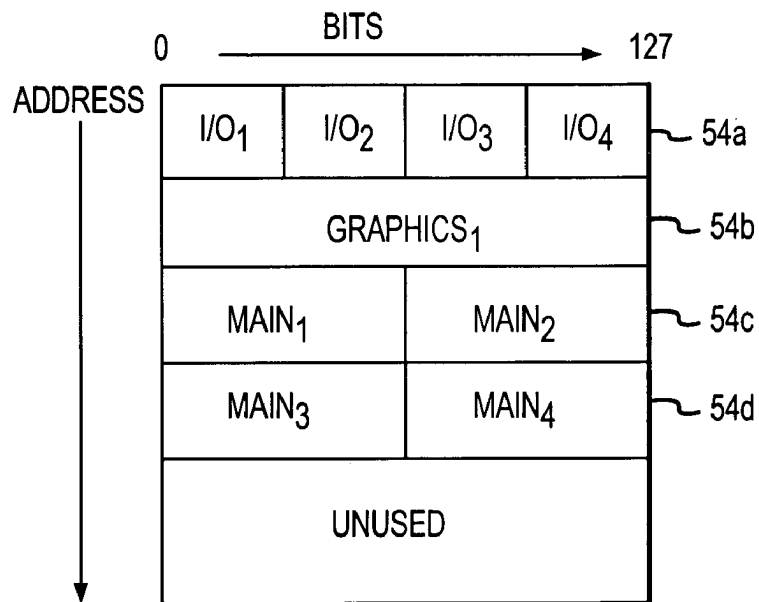
(22) Filed: **Jun. 19, 2003**





(PRIOR ART)
FIG. 1





PHYSICAL MEMORY MAP

FIG.3

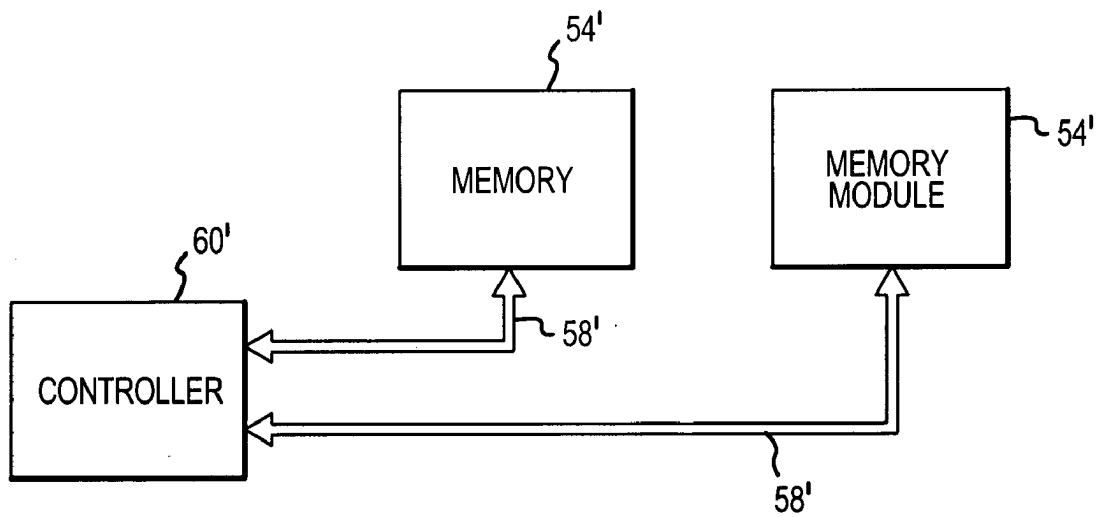


FIG.4

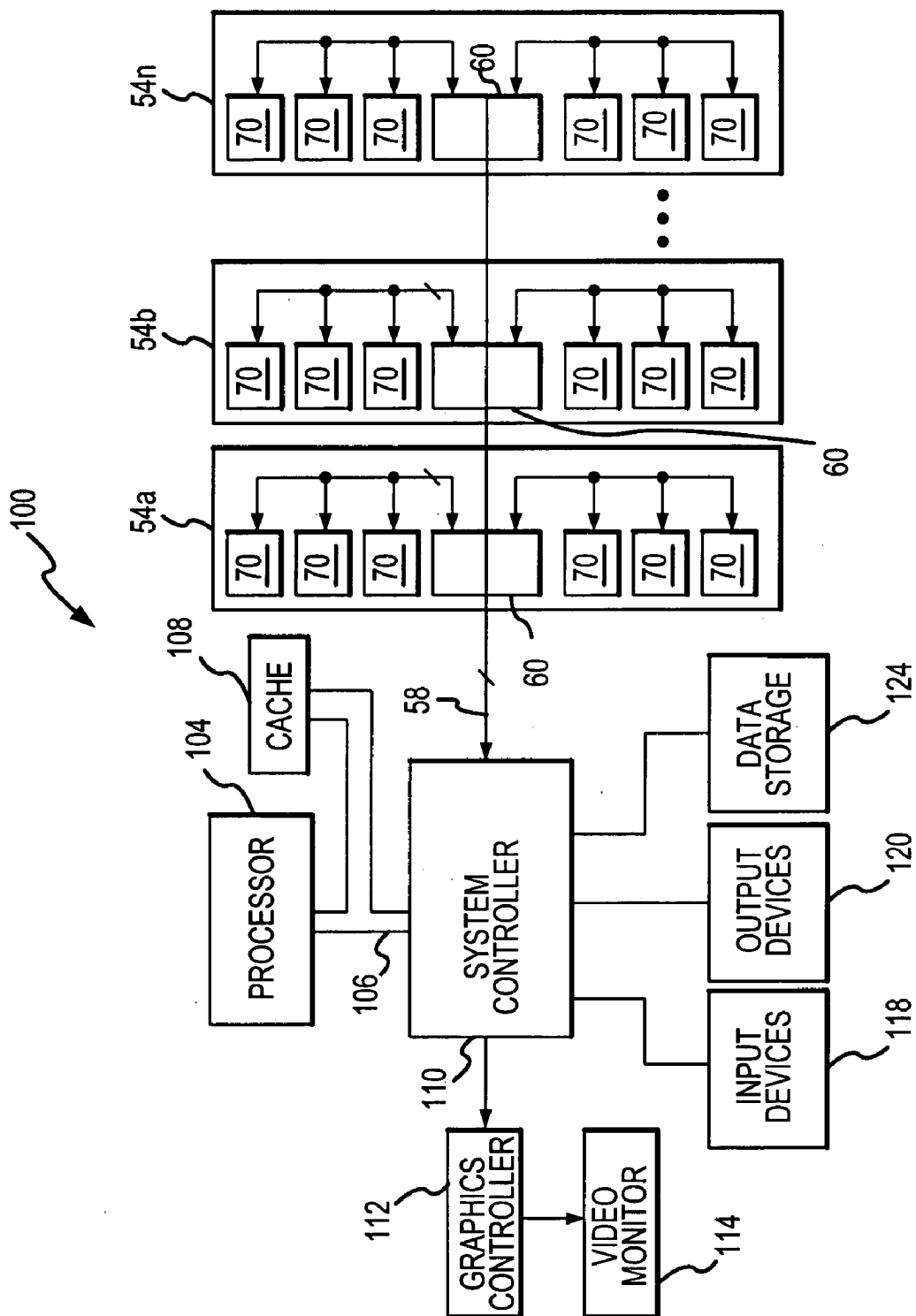


FIG.5

RECONFIGURABLE MEMORY MODULE AND METHOD

TECHNICAL FIELD

[0001] This invention relates to memory systems, and, more particularly, to a memory module that may be configured to a variety of data formats.

BACKGROUND OF THE INVENTION

[0002] Computer systems use memory devices, such as dynamic random access memory ("DRAM") devices, to store instructions and data that are accessed by a processor. These memory devices are normally used as system memory in a computer system. In a typical computer system, the processor communicates with the system memory through a processor bus and a memory controller. The processor issues a memory request, which includes a memory command, such as a read command, and an address designating the location from which data or instructions are to be read. The memory controller uses the command and address to generate appropriate command signals as well as row and column addresses, which are applied to the system memory. In response to the commands and addresses, data are transferred between the system memory and the processor. The memory controller is often part of a system controller, which also includes bus bridge circuitry for coupling the processor bus to an expansion bus, such as a PCI bus.

[0003] A memory system **10** typically used in a computer system is shown in **FIG. 1**. The memory system **10** includes a memory controller **14** coupled to several memory modules **20a, b . . . n** through a bus system **24**. The bus system **24** typically includes an address bus **26**, a command bus **28**, and a bi-directional data bus **30**. However, other conventional memory systems may use bus systems **24** having other configurations, such as a combined address bus **26** and command bus **28**. In any case, each of the memory modules **20** includes several memory devices **34**, such as DRAM devices, mounted on an insulative substrate **36**. Conductive leads **38** are fabricated on the substrate **36** to couple the memory devices **34** to the buses **26-30**. The conductive leads **38** typically couple the memory devices **34** to all of the buses **26-30** in parallel, although some of the lines in the command bus **28**, such as chip select lines, may be coupled to the memory devices **34** in fewer than all of the memory modules **20**.

[0004] In operation, the memory controller **14** applies row and column addresses through the address bus **26** and command signals to the command bus **28** to read data from or write data to the memory devices **34**. In the event of a write memory access, there are also coupled from the memory controller **14** to the memory devices **34**. In the event of a read memory access, data are coupled from the memory devices **34** to the memory controller **14**. Although address, command and write data signals are applied to the memory devices **34** and all of the memory modules **20**, a chip select signal or other similar signal selects the memory devices **34** on only one of the memory modules **20** for the memory access.

[0005] The memory modules **20** shown in **FIG. 1** are normally configured for a particular data format. For example, sixteen memory devices **34** may be included in the memory module **20**, and each memory device **34** may couple

a single bit of data to and from the memory controller **14**. In such case, each of the memory modules **20** will input and output data in 16-bit words. Alternatively, the memory devices **34** may be divided into two groups or "ranks" each of which are individually accessed by, for example, being enabled by separate chip select signals. In such case, if each memory device **34** couples a single bit of data to and from the memory controller **14**, the memory module **20** will output data in 8-bit bytes. By way of further example, the memory devices **34** on each memory module may be individually accessed, and each memory device **34** may couple 8 bits of data to and from the memory controller **14**. In such case, each memory module **20** will output data in 8-bit bytes. Other data formats used in conventional memory systems will be apparent to one skilled in the art.

[0006] The selection of a data format controls not only the size of the data word coupled to and from each memory module **20**, but it also controls the effective size of the memory that may be addressed in each module **20**. More specifically, assume each memory module **20** includes eight memory devices **34** each of which has an 8-bit data bus and one million addressable locations. Each memory device **34** thus has a capacity of 1 MB so that the total size of the memory module **20** is 8 MB. Each of the memory devices **34** may be individually addressed to interface with an 8-bit data bus so that there are 8 million addresses in the address space. Alternatively, all of the memory devices **34** may be simultaneously addressed to interface with a 64-bit data bus so that there are 1 million addresses in the address space. The memory devices **34** may also be operated in two ranks to interface with a 32-bit data bus with an address space of 4 million addresses. In all of these cases, the total memory capacity of the memory module **20** is 8 MB. However, in each of these cases the data bandwidth, i.e., the rate at which data bits are coupled through the data bus, and the number of memory addresses, i.e., the depth of the memory module **20**, vary. The memory bandwidth and memory depth are thus trade-offs of each other.

[0007] In conventional memory systems, the memory bandwidth and memory depth are selected based the bandwidth and depth desired for a specific application. For example, a first data format may be used for a system in which maximizing bandwidth is important, such as a memory system used in a video graphics card. However, a second data format may be used in a system in which maximizing memory depth is important, such as in a database system. Unfortunately, the memory system must be optimized for either high memory bandwidth, high memory depth or a combination of bandwidth and depth. The memory system is optimized by selecting appropriate memory devices **34** for inclusion in the memory module **20** and selecting a configuration for the bus structure **24** and conductive leads **38** formed on the substrate **36**. Insofar as the data format selected is determined by the hardware design, is not possible to easily alter the data format. Instead, different memory modules must be used, a different motherboard in which the memory modules are normally inserted must be used, and a different memory controller must be used. Therefore, the data format is normally a fixed data format optimized for a particular application, even though the memory system may be called upon to operate in another application in which a different data format would be optimal. In such cases, the memory system cannot provide optimum performance.

[0008] There is therefore a need for a memory system that can have a variety of data formats each of which can be optimized to a specific application.

SUMMARY OF THE INVENTION

[0009] A memory system that can be used in a computer system includes a controller operable to receive a memory request and to transmit a corresponding memory request to an input/output port. The memory system also includes a plurality of memory modules, each which includes a memory hub and a plurality of memory devices arranged in a plurality of ranks. The memory hub in each memory module is programmable to configure the memory module in a plurality of data formats each corresponding to a respective number of ranks of memory devices that are simultaneously accessed. The memory hubs in each of the memory modules may be programmed for the same or for different data formats. The memory hub in each memory module receives a memory request at an input/output port and couples a corresponding memory request to the memory device in each of the ranks that the memory hub has been programmed to access. When programmed for a high bandwidth, the memory hub simultaneously accesses the memory devices in all of the ranks. When programmed for a high memory depth, the memory hub accesses the memory devices in only one of the ranks at a time.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. 1 is a block diagram of a conventional memory system containing several memory modules.

[0011] FIG. 2 is a block diagram of a memory system according to one example of the invention in which a controller is coupled to several memory modules each of which contains a reconfigurable memory hub coupled to several memory devices.

[0012] FIG. 3 is a memory map showing the use of the address space provided by the memory system of FIG. 2.

[0013] FIG. 4 is a block diagram of a memory system according to another example of the invention.

[0014] FIG. 5 is a block diagram of a computer system using the memory system of FIG. 2.

DETAILED DESCRIPTION OF THE INVENTION

[0015] A memory system 50 according to one example of the invention is shown in FIG. 2. The memory system 50 includes a controller 52 coupled to several memory modules 54a, b . . . n through a high-speed link 58. The controller 52 may be coupled to a memory access device, such as a processor (not shown), or it may be, for example, itself a processor. The high-speed link 58 may be a bus formed by multiple conductors, an optical communication link, and RF communication link, or some other type of high-speed communication link. Typically, the high-speed link 58 will have a capacity for coupling data having a predetermined bus width between the controller 52 and each memory module 54. In the example shown in FIG. 2, the link 58 couples a 32-bit data word. The high-speed link 58 also couples address and command signals from the controller 52 to the memory modules 54. Although the high-speed link 58 is shown in FIG. 2 as having a multi-drop topology in which

the link 58 is coupled to several memory modules 54a, b . . . n, other topologies may be used, including a point-to-point topology in which each of several links is coupled to a respective one of the memory modules 54a, b . . . n. A switching topology in which the high-speed bus 58 is selectively switched to each of the memory modules 54a, b . . . n or some other topology may also be used.

[0016] Each of the memory modules 54 includes a memory hub 60 having an input/output port 62 coupled to the high-speed link 58 and a bus system 68 coupled to several memory devices 70. The memory devices 70 may be, for example, dynamic random access memory devices ("DRAMs") or some other type of memory devices. In the example shown in FIG. 2, the memory devices 70 are divided into four groups or "ranks" coupled to the memory hub 60 through a respective bus system. More particularly, a first rank 74 includes four memory devices 70 coupled to the memory hub 60 through a first bus system 76 having a 32-bit data bus. A second rank 80 containing four memory devices 70 are coupled to the memory hub 60 through a second bus system 82 having a 32-bit data bus. Similarly, third and fourth ranks 86, 88 are each coupled to the memory hub 60 through respective bus systems 90, 94 each having a 32-bit data bus. In the example shown in FIG. 2, each of the memory devices 70 have an 8-bit data bus so that the four memory devices 70 together provide 32 bits for the 32-bit data buses of the bus systems 76, 82, 90, 94. The bus systems 76, 82, 90, 94 also includes address and command buses coupling the memory hub 60 to the memory devices 70.

[0017] In operation, a non-volatile register 98 in the memory module 54 is programmed to configure the memory hub 60 depending upon whether a high memory bandwidth or a high memory depth is desired. For example, for a high memory bandwidth, the memory hub 60 addresses all of the memory devices 70 simultaneously so that 128 bits of data are written to or read from the memory devices 70 each memory access. If each memory device 70 stores 8 MB of data, for example, there will only be 1 million addresses in the memory system 50 in the high bandwidth mode. The 128 bits of data can be coupled through the high-speed link 58 by either increasing the speed of the link 58 or the size of the data word coupled through the link 58. For example, in the high-speed mode, a 128-bit data word may be coupled through the link 58. Therefore, for every memory access, 128 data bits will be coupled through the link 58. Alternatively, the link 58 may transfer only a 32-bit data word, but it may operate at four times the speed of the memory devices 70. Thus, for example, if the memory devices 70 operate at a rate of 500 MB/sec, the high-speed link 58 may couple data at a rate of 2 GB/sec. Other alternatives are also possible. For example, the high-speed link 58 may couple 64-bit data words at a rate of 1 GB/sec.

[0018] In the high memory depth mode, only one rank 74, 80, 86, 88 may be addressed at a time. In this mode, only 32 bits of data will be coupled to or from the memory module 54 with each memory access in contrast to the 128 bits of data coupled in the high bandwidth mode. However, since only one rank 74, 80, 86, 88 is addressed at a time, there will be 4 million addresses in the memory system 50, assuming that each memory device 70 stores 8 MB of data. Thus, in this mode, the address space is 4 times deeper than the address space in the high bandwidth mode. In the high

memory depth mode, the high-speed link **58** can operate at a slower data rate than in the high bandwidth mode.

[0019] The memory hub **60** can also configure the memory module **54** to operate in a medium bandwidth, medium depth mode in which one pair of ranks **74, 80** are simultaneously accessed and the other pair of ranks **86, 88** are simultaneously accessed. In this mode, 64 bits of data are coupled through the high-speed link **58** with each memory access.

[0020] By allowing the memory hub **60** to configure the data format of the memory module **54**, the data format can be optimized for a particular application being executed in a computer system or other electronic system containing the memory system **50**. For example, when executing a graphics intensive application like a video game, the memory system **50** can be configured in the high bandwidth mode. When a computer system is executing a database application, for example, the memory system **50** can be configured in the high memory depth mode. The data format is therefore not fixed as in conventional memory systems.

[0021] Although all of the memory modules **54a, b . . . n** may be configured to operate using the same data format, different memory modules **54a, b . . . n** may be configured to operate using different data formats at the same time. For example, with reference to the memory map shown in **FIG. 3**, the first memory module **54a** is configured in the high memory depth mode optimized for performing input/output functions. In this mode, 32 data bits are coupled through the high-speed link **58** with each memory access. Therefore, the first memory module **54a** would be used for input/output functions by the application being executed in a computer system containing the memory system **50**. The second memory module **54b** is configured in the high bandwidth mode so that it can handle graphics processing in an optimum manner. In this mode, 128 data bits are coupled through the high-speed link **58** with each memory access. An application being executed by a computer system containing the memory system **50** might therefore access the second memory module **54b** with a graphics processor (not shown). The third and fourth memory modules **54c, d** are configured in the medium bandwidth mode optimized to serve as system main memory for a computer system. In this mode, 64 data bits are coupled through the high-speed link **58** with each memory access. By configuring each memory module **54** with a different data format, an application being executed can operate in an optimum manner even though it requires different data formats to do so. Furthermore, the manner in which the different memory modules **54** are configured can change depending upon the nature of the application being executed by a computer system containing the memory system **50**. For example, the memory system **50** may be configured from using its address space as shown in the memory map shown in **FIG. 3** to a configuration in which the first two memory modules **54a, b** are configured for the high bandwidth mode and the second two memory modules **54c, d** are configured for the high memory depth mode.

[0022] As previously mentioned, the controller **60** is coupled to the memory modules **54** through the high-speed link **58** using a multi-drop topology. However, a controller **60'** may be coupled to several memory modules **54'** using the topology shown in **FIG. 4** in which a separate high-speed link **58'** is coupled to each memory module **54'**. This topology further increases the memory bandwidth

because data may be coupled to the controller **60'** through each of the high-speed links **58'** in the maximum memory bandwidth format.

[0023] A computer system **100** using the memory system **50** shown in **FIG. 2** is shown in **FIG. 5**. The computer system **100** includes a processor **104** for performing various computing functions, such as executing specific software to perform specific calculations or tasks. The processor **104** includes a processor bus **106** that normally includes an address bus, a control bus, and a data bus. The processor bus **106** is typically coupled to cache memory **108**, which is usually static random access memory ("SRAM"). Finally, the processor bus **106** is coupled to a system controller **110**, which is also sometimes referred to as a "North Bridge" or "memory controller."

[0024] The system controller **110** serves as a communications path to the processor **104** for a variety of other components. More specifically, the system controller **110** includes a graphics port that is typically coupled to a graphics controller **112**, which is, in turn, coupled to a video monitor **114**. The system controller **110** is also coupled to one or more input devices **118**, such as a keyboard or a mouse, to allow an operator to interface with the computer system **100**. Typically, the computer system **100** also includes one or more output devices **120**, such as a printer, coupled to the processor **104** through the system controller **110**. One or more data storage devices **124** are also typically coupled to the processor **104** through the system controller **110** to allow the processor **104** to store data or retrieve data from internal or external storage media (not shown). Examples of typical storage devices **124** include hard and floppy disks, tape cassettes, and compact disk read-only memories (CD-ROMs).

[0025] The system controller **110** is coupled to several of the memory modules **54a, b . . . n** through the high-speed link **58**. The processor **194** accesses some of the memory modules **54** in the computer system **100** in a data format optimized for use as main memory. One of the memory modules **54** is directly accessed by the graphics controller **112**, and this memory module is configured in the high bandwidth mode, as previously explained.

[0026] Although the computer system **100** uses the system controller **110** to generate memory requests that are coupled to the memory modules **54**, other components that are either part of or separate from the system controller **110** may instead be used.

[0027] From the foregoing it will be appreciated that, although specific embodiments of the invention have been described herein for purposes of illustration, various modifications may be made without deviating from the spirit and scope of the invention. Accordingly, the invention is not limited except as by the appended claims.

1. A memory module, comprising:

- a plurality of memory devices arranged in a plurality of ranks; and
- a memory hub coupled to the memory devices in each of the ranks, the memory hub being programmable to configure the memory module in a plurality of data

formats each corresponding to a respective number of ranks of memory devices that are simultaneously accessed.

2. The memory module of claim 1 wherein the memory hub is coupled to the memory devices in each of the ranks through respective busses.

3. The memory module of claim 1 wherein the memory hub is operable to either address all of the ranks of memory devices in a first mode to simultaneously couple data to or from all of the memory devices in the memory module, or address less than all of the ranks of memory devices in a second mode to couple data to or from less than all of the memory devices in the memory module.

4. The memory module of claim 1 wherein the memory module comprises four ranks of memory devices, and wherein the memory hub is operable to simultaneously address all of four ranks of memory devices in a first mode to simultaneously couple data to or from all of the memory devices in the memory module, to simultaneously address two ranks of memory devices in a second mode to simultaneously couple data to or from the memory devices in the two addressed ranks, or to address one rank of memory devices in a third mode to couple data to or from the memory devices in the addressed rank.

5. The memory module of claim 1, further comprising a programmable storage device coupled to the memory hub, the programmable storage device being programmed to control the operating mode of the memory hub.

6. The memory module of claim 1 wherein the memory devices in each rank are collectively operable to read or write N-bit data words, and wherein the memory hub further comprises an input/output port that is operable to receive or transmit $M \times N$ -bit data words, where M is the number of ranks of memory devices in the memory module.

7. The memory module of claim 1 wherein the memory devices in each rank are collectively operable to read or write N-bit data words in a first period of time, and wherein the memory hub further comprises an input/output port that is operable to receive or transmit $M \times N$ data bits in the first period of time, where M is the number of ranks of memory devices in the memory module.

8. The memory module of claim 7 wherein the memory devices are operable to read or write data at a rate of X bits per second, and wherein the input/output port comprises an N-bit input/output port that is operable to transmit or receive N-bit data words at a rate of $M \times X$ data words per second.

9. The memory module of claim 7 wherein the memory devices are operable to read or write data at a rate of X bits per second, and wherein the input/output port comprises a $2 \times N$ -bit input/output port that is operable to transmit or receive $2 \times N$ -bit data words at a rate of $M \times X/2$ data words per second.

10. The memory module of claim 7 wherein the memory devices are operable to read or write data at a rate of X bits per second, and wherein the input/output port comprises a $M \times N$ -bit input/output port that is operable to transmit or receive $M \times N$ -bit data words at a rate of X data words per second.

11. The memory module of claim 1 wherein the memory devices comprise dynamic random access memory devices.

12. The memory module of claim 11 wherein the dynamic random access memory devices comprise synchronous dynamic random access memory devices.

13. A memory system, comprising:

a controller operable to receive a memory request and to transmit a corresponding memory request to an input/output port;

a plurality of memory modules, each of the memory modules comprising:

a plurality of memory devices arranged in a plurality of ranks; and

a memory hub operable to receive a memory request at an input/output port, the memory hub being coupled to the memory devices in each of the ranks, the memory hub being programmable to configure the memory module in a plurality of data formats each corresponding to a respective number of ranks of memory devices that are simultaneously accessed; and

a communications link coupling the input/output port of the controller to the input/output ports of the memory hubs in the respective memory modules.

14. The memory system of claim 13 wherein the memory hub in each of the memory modules is coupled to the memory devices in each of the ranks through respective busses.

15. The memory system of claim 13 wherein the memory hub is operable to either address all of the ranks of memory devices in a first mode to simultaneously couple data to or from all of the memory devices in the memory module, or address less than all of the ranks of memory devices in a second mode to couple data to or from less than all of the memory devices in the memory module.

16. The memory system of claim 13 wherein the memory module comprises four ranks of memory devices, and wherein the memory hub is operable to simultaneously address all of four ranks of memory devices in a first mode to simultaneously couple data to or from all of the memory devices in the memory module, to simultaneously address two ranks of memory devices in a second mode to simultaneously couple data to or from the memory devices in the two addressed ranks, or to address one rank of memory devices in a third mode to couple data to or from the memory devices in the addressed rank.

17. The memory system of claim 13, further comprising a programmable storage device coupled to the memory hub, the programmable storage device being programmed to control the operating mode of the memory hub.

18. The memory system of claim 13 wherein the memory devices in each rank are collectively operable to read or write N-bit data words, and wherein the memory hub further comprises an input/output port that is operable to receive or transmit $M \times N$ -bit data words, where M is the number of ranks of memory devices in the memory module.

19. The memory system of claim 13 wherein the memory devices in each rank are collectively operable to read or write N-bit data words in a first period of time, and wherein the memory hub further comprises an input/output port that is operable to receive or transmit $M \times N$ data bits in the first period of time, where M is the number of ranks of memory devices in the memory module.

20. The memory system of claim 19 wherein the memory devices are operable to read or write data at a rate of X bits per second, and wherein the input/output port comprises an

N-bit input/output port that is operable to transmit or receive N-bit data words at a rate of $M \times X$ data words per second.

21. The memory system of claim 19 wherein the memory devices are operable to read or write data at a rate of X bits per second, and wherein the input/output port comprises a $2 \times N$ -bit input/output port that is operable to transmit or receive $2 \times N$ -bit data words at a rate of $M \times X/2$ data words per second.

22. The memory system of claim 19 wherein the memory devices are operable to read or write data at a rate of X bits per second, and wherein the input/output port comprises a $M \times N$ -bit input/output port that is operable to transmit or receive $M \times N$ -bit data words at a rate of X data words per second.

23. The memory system of claim 13 wherein the memory devices comprise dynamic random access memory devices.

24. The memory system of claim 23 wherein the dynamic random access memory devices comprise synchronous dynamic random access memory devices.

25. The memory system of claim 13 wherein the memory hubs in at least two of the memory modules are programmed to configure the memory module in different data formats.

26. The memory system of claim 25 wherein the memory hub in a first of the memory modules is programmed to configure the first memory module so that all of the ranks of memory devices in the first memory module are simultaneously addressed, the memory hub in a second of the memory modules is programmed to configure the second memory module so that half of the ranks of memory devices in the second memory module are simultaneously addressed, and the memory hub in a third of the memory modules is programmed to configure the third memory module so that each of the ranks of memory devices in the third memory module are individually addressed.

27. The memory system of claim 13 wherein the input/output port of the controller and the input/output port of each of the memory hubs comprises an optical input/output port, and wherein the communications link comprises an optical communications link.

28. A computer system, comprising:

a central processing unit ("CPU");

a system controller coupled to the CPU, the system controller being operable to receive a memory request from the central processing unit and to transmit a corresponding memory request to an input/output port;

an input device coupled to the CPU through the system controller;

an output device coupled to the CPU through the system controller;

a storage device coupled to the CPU through the system controller;

a plurality of memory modules, each of the memory modules comprising:

a plurality of memory devices arranged in a plurality of ranks; and

a memory hub operable to receive a memory request at an input/output port, the memory hub being coupled to the memory devices in each of the ranks, the memory hub being programmable to configure the memory module in a plurality of data formats each

corresponding to a respective number of ranks of memory devices that are simultaneously accessed; and

a communications link coupling the input/output port of the system controller to the input/output ports of the memory hubs in the respective memory modules.

29. The computer system of claim 28 wherein the memory hub in each of the memory modules is coupled to the memory devices in each of the ranks through respective busses.

30. The computer system of claim 28 wherein the memory hub is operable to either address all of the ranks of memory devices in a first mode to simultaneously couple data to or from all of the memory devices in the memory module, or address less than all of the ranks of memory devices in a second mode to couple data to or from less than all of the memory devices in the memory module.

31. The computer system of claim 28 wherein the memory module comprises four ranks of memory devices, and wherein the memory hub is operable to simultaneously address all of four ranks of memory devices in a first mode to simultaneously couple data to or from all of the memory devices in the memory module, to simultaneously address two ranks of memory devices in a second mode to simultaneously couple data to or from the memory devices in the two addressed ranks, or to address one rank of memory devices in a third mode to couple data to or from the memory devices in the addressed rank.

32. The computer system of claim 28, further comprising a programmable storage device coupled to the memory hub, the programmable storage device being programmed to control the operating mode of the memory hub.

33. The computer system of claim 28 wherein the memory devices in each rank are collectively operable to read or write N-bit data words, and wherein the memory hub further comprises an input/output port that is operable to receive or transmit $M \times N$ -bit data words, where M is the number of ranks of memory devices in the memory module.

34. The computer system of claim 28 wherein the memory devices in each rank are collectively operable to read or write N-bit data words in a first period of time, and wherein the memory hub further comprises an input/output port that is operable to receive or transmit $M \times N$ data bits in the first period of time, where M is the number of ranks of memory devices in the memory module.

35. The computer system of claim 34 wherein the memory devices are operable to read or write data at a rate of X bits per second, and wherein the input/output port comprises an N-bit input/output port that is operable to transmit or receive N-bit data words at a rate of $M \times X$ data words per second.

36. The computer system of claim 34 wherein the memory devices are operable to read or write data at a rate of X bits per second, and wherein the input/output port comprises a $2 \times N$ -bit input/output port that is operable to transmit or receive $2 \times N$ -bit data words at a rate of $M \times X/2$ data words per second.

37. The computer system of claim 34 wherein the memory devices are operable to read or write data at a rate of X bits per second, and wherein the input/output port comprises a $M \times N$ -bit input/output port that is operable to transmit or receive $M \times N$ -bit data words at a rate of X data words per second.

38. The computer system of claim 28 wherein the memory devices comprise dynamic random access memory devices.

39. The computer system of claim 38 wherein the dynamic random access memory devices comprise synchronous dynamic random access memory devices.

40. The computer system of claim 28 wherein the memory hubs in at least two of the memory modules are programmed to configure the memory module in different data formats.

41. The computer system of claim 40 wherein the memory hub in a first of the memory modules is programmed to configure the first memory module so that all of the ranks of memory devices in the first memory module are simultaneously addressed, the memory hub in a second of the memory modules is programmed to configure the second memory module so that half of the ranks of memory devices in the second memory module are simultaneously addressed, and the memory hub in a third of the memory modules is programmed to configure the third memory module so that each of the ranks of memory devices in the third memory module are individually addressed.

42. The computer system of claim 28 wherein the input/output port of the system controller and the input/output port of each of the memory hubs comprises an optical input/output port, and wherein the communications link comprises an optical communications link.

43. A method of accessing data in a memory module containing a plurality of memory devices, the method comprising:

dividing the memory devices into a plurality of ranks;

configuring the memory module to access the data stored in the memory module in a first data format in which a first number of ranks of memory devices are simultaneously accessed; and

configuring the memory module to access the data stored in the memory module in a second data format in which a second number of ranks of memory devices are simultaneously accessed, the second number being different from the first.

44. The method of claim 43 wherein the act of configuring the memory module to access the data stored in the memory module in the first data format comprises configuring the memory module to simultaneously access all of the ranks of memory devices in the memory module so that data are simultaneously coupled to or from all of the memory devices in the memory module, and wherein the act of configuring the memory module to access the data stored in the memory module in the second data format comprises configuring the memory module to individually access each of the ranks of memory devices in the memory module so that data are simultaneously coupled to or from only the memory devices in a single rank of memory devices.

45. The method of claim 43, further comprising configuring the memory module to simultaneously access a plurality but less than all of the ranks of memory devices in the memory module so that data are simultaneously coupled to or from all of the memory devices in a plurality of ranks of memory devices but less than all of the memory devices in the memory module.

46. The method of claim 43 wherein the memory devices in each rank are collectively operable to read or write N-bit data words, and wherein the method further comprises receiving or transmitting $M \times N$ -bit data words from the memory module, where M is the number of ranks of memory devices in the memory module.

47. The method of claim 43 wherein the memory devices in each rank are collectively operable to read or write N-bit data words in a first period of time, and wherein the method further comprises receiving at the memory module or transmitting from the memory module M N-bit data bits in the first period of time, where M is the number of ranks of memory devices in the memory module.

48. The method of claim 47 wherein the memory devices in the memory module are operable to read or write data at a rate of X bits per second, and wherein the method further comprises receiving at the memory module or transmitting from the memory module N-bit data words data at a rate of $M \times X$ data words per second.

49. The method of claim 47 wherein the memory devices in the memory module are operable to read or write data at a rate of X bits per second, and wherein the method further comprises receiving at the memory module or transmitting from the memory module $2 \times N$ -bit data words data at a rate of $M \times X/2$ data words per second.

50. The method of claim 47 wherein the memory devices in the memory module are operable to read or write data at a rate of X bits per second, and wherein the method further comprises receiving at the memory module or transmitting from the memory module $M \times N$ -bit data words data at a rate of X data words per second.

51. In a computer system, a method of accessing data in a plurality of memory modules each of which contains a plurality of memory devices, the method comprising:

dividing the memory devices in each of the memory modules into a plurality of ranks;

configuring each of the memory modules to access the data stored in the memory module in one of a plurality of data formats each corresponding to a respective number of ranks of memory devices that are simultaneously accessed; and

accessing data in each of the memory modules in the configured data format.

52. The method of claim 51 wherein the act of configuring the memory modules to access the data stored in the memory modules in one of a plurality of data formats comprises configuring at least one of the memory modules to simultaneously access all of the ranks of memory devices in the memory module so that data are simultaneously coupled to or from all of the memory devices in the memory module.

53. The method of claim 51 wherein the act of configuring the memory modules to access the data stored in the memory modules in one of a plurality of data formats comprises configuring at least one of the memory modules to individually access each of the ranks of memory devices in the memory module so that data are simultaneously coupled to or from only the memory devices in a single rank of memory devices.

54. The method of claim 51 wherein the act of configuring the memory modules to access the data stored in the memory modules in one of a plurality of data formats comprises configuring at least one of the memory modules to simultaneously access a plurality but less than all of the ranks of memory devices in the memory module so that data are simultaneously coupled to or from all of the memory devices in a plurality of ranks of memory devices but less than all of the memory devices in the memory module.

55. The method of claim 51 wherein the memory devices in each rank are collectively operable to read or write N-bit

data words, and wherein the method further comprises receiving or transmitting $M*N$ -bit data words from each of the memory modules, where M is the number of ranks of memory devices in the memory module.

56. The method of claim 51 wherein the memory devices in each rank are collectively operable to read or write N -bit data words in a first period of time, and wherein the method further comprises receiving at each of the memory modules or transmitting from each of the memory modules M N -bit data bits in the first period of time, where M is the number of ranks of memory devices in the memory module.

57. The method of claim 56 wherein the memory devices in each of the memory modules are operable to read or write data at a rate of X bits per second, and wherein the method further comprises receiving at each of the memory modules or transmitting from each of the memory modules N -bit data words data at a rate of $M*X$ data words per second.

58. The method of claim 56 wherein the memory devices in each of the memory modules are operable to read or write data at a rate of X bits per second, and wherein the method further comprises receiving at each of the memory modules or transmitting from each of the memory modules $2*N$ -bit data words data at a rate of $M*X/2$ data words per second.

59. The method of claim 56 wherein the memory devices in each of the memory modules are operable to read or write data at a rate of X bits per second, and wherein the method further comprises receiving at each of the memory modules or transmitting from each of the memory modules $M*N$ -bit data words data at a rate of X data words per second.

60. The method of claim 51 wherein the act of configuring each of the memory modules comprises configuring at least two of the memory modules for different data formats.

61. The method of claim 60 wherein the act of configuring at least two of the memory modules for different data formats comprises configuring a first memory module so that all of the ranks of memory devices in the first memory module are simultaneously addressed, configuring a second memory module so that half of the ranks of memory devices in the second memory module are simultaneously addressed, and configuring a third memory module so that each of the ranks of memory devices in the third memory module are individually addressed.

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