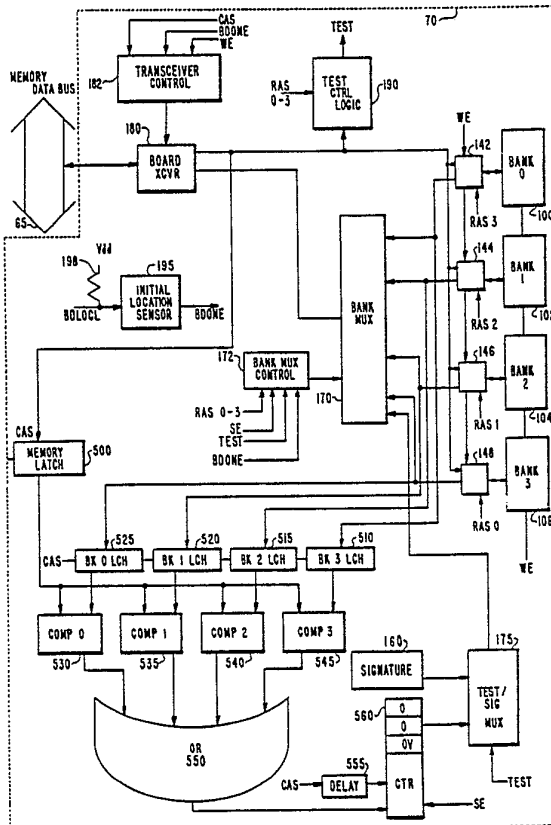




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(54) Title: AUTOMATIC SIZING MEMORY SYSTEM



(57) Abstract

In a memory module (70), signature data (160) identifying the configuration of memory in that module is multiplexed onto a general memory data bus (65) along with memory data normally transferred during memory access operations.

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AUTOMATIC SIZING MEMORY SYSTEMI. BACKGROUND OF THE INVENTION

This invention is related to the field of memories generally and specifically to memories with the capability for automatic configuration.

When power is first applied to a computer, or when the computer is first activated from some inactive state, it must be initialized. This is typically done using a "bootstrap" program which sets the computer into an initialization state, obtains information needed for operation, and performs other "housekeeping functions, such as automatic testing. One item of information which a computer needs for proper operation is the size and configuration of its memory, i.e., how much total memory is available and how is it distributed. For example, in a memory with 512K words, all of the memory can be on one board or it can be dispersed over several boards, such as four boards each with 128K of memory. It is important for the circuitry in the computer which controls the memory to know the memory configuration so that such memory control circuitry can activate the appropriate address control lines when the memory is accessed.

In modern computer systems, memory components are typically placed on several memory boards, each of which includes one or more individual banks of memory. The different banks of memory are then assigned different memory address locations. Then, during a read or write operation, only the bank containing the desired address location is accessed. To assign memory address locations to the different banks of memory cells, the control logic in the memory must know how many banks there are, where those banks are located, and how big each of the banks are.

One method of obtaining this information is to have an operator enter it either through switches or through a console. This method, however, requires that the operator both be able to determine the size and configuration of the memory and be accurate in entry of this information. In many applications, this requirement is difficult to implement.

More recently, processors have adopted one or more of automatic methods determining the size and configuration of the memory. A very basic automatic method is described in U.S.

-2-

Patent No. 4,330,825 to Girard which automatically counts the number of modules. Since the memory modules in that method have the same memory size, the number of modules sets both the size of the memory and its configuration. This method, however, cannot be used if the modules have different memory sizes.

Another approach is shown in U.S. Patent No. 4,025,903 to Kaufman et al. In Kaufman et al., each memory module knows its own size and uses its own range calculator to determine its address space. The memory modules are sequentially ordered and the first module determines its address space is beginning at the first memory location and ending at a location equal to the address of that first location plus the memory size of that module. That first module passes its final address to the next memory module, which calculates its initial address from the previous module's final address information and its final address from its own size information. That final address is passed to the next memory module and this process continues until each memory module computes its beginning and ending addresses. Memory is accessed in these systems by sending memory addresses to all the memory modules and letting the modules decide for themselves whether they contain the locations corresponding to those memory addresses. Although this system is very flexible, it requires intensive use of scarce backplane resources because the control circuitry is not centralized.

Another approach which has been employed is shown in U.S. Patent No. 4,468,729 to Schwartz et al. In this memory system, specialized circuitry pools each memory module using special lines to determine the module's size. That information is then sent back over special lines so that special circuitry can calculate the total size of the memory and the starting and ending addresses for each of the modules. This approach uses centralized control, but still requires special circuitry on each module, special memory configuration circuitry, and additional control lines to effect the polling.

Because of the increased capabilities of computers, space on memory board modules and wires on backplanes of

**SUBSTITUTE SHEET**

-3-

computers are often at a premium. Thus, it would be preferable to use as few of these resources as possible for bootstrap and automatic configuration operations.

Accordingly, it is an object of the present invention to provide an automatic sizing memory system which requires few extra components and signal lines.

It is another object of the present invention to provide such automatic memory sizing in a system which is consistent with the architecture of the computer.

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Additional objects and advantages of the present invention will be set forth in part in the description that follows and in part will be obvious from that description or may be learned from the practice of the invention.

## II. SUMMARY OF THE INVENTION

The present invention achieves its objects and attains its advantages by multiplexing signature data identifying the configuration a memory onto the same memory bus over which data is transferred during normal memory access operations.

More particularly, to achieve the objects in accordance with the purpose of this invention, as embodied and as broadly described herein, a memory subsystem in a memory module coupled to a processor by way of a memory bus and coupled to storage means having one of a plurality of configurations comprises signature means for storing configuration data identifying the configuration of the storage means; multiplexer means, coupled to the storage means and the signature means, for placing, when activated, either the memory data or the configuration data onto the memory bus in response to multiplexing control signals; and control means, coupled to the multiplexer means and the memory bus, for generating the multiplex control signals from the memory addresses on the memory bus, thereby causing the multiplexer means, when activated, to transfer the memory data or the configuration data onto the memory bus.

-4-

The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate an embodiment of this invention, and together with the description, serve to explain the principles of the invention.

### III. BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a block diagram of a data processing system incorporating a preferred embodiment of this invention;

Fig. 2 is a block diagram of a preferred embodiment of a configuration status register 40 shown in Fig. 1;

Fig. 3 is a diagram showing the format of data stored in a configuration register 202 shown in Fig. 1;

Fig. 4 is a block diagram of a preferred embodiment of certain circuitry on Board 1 in Fig. 1;

Fig. 5 is a block diagram of a preferred embodiment of certain circuitry on Board 1 in Fig. 1;

Fig. 6 is a preferred embodiment of memory bank 100 shown in Fig. 5 and of associated buffer circuitry;

Fig. 7A is a timing diagram for performing a read operation in the data processing system of Fig. 1;

Fig. 7B is a timing diagram for a write operation using the data processing system shown in Fig. 1;

Fig. 7C is a timing diagram for a signature read operation;

Fig. 7D is a timing diagram for a fast diagnostic testing operation;

Fig. 8 is a flow diagram explaining the steps of a signature read operation; and

Fig. 9 is a flow diagram for the fast diagnostic test operation.

### IV. DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Reference will now be made in detail to a preferred embodiment of the present invention, an example of which is shown in the accompanying drawings.

#### General System and Automatic Memory Sizing Apparatus

Fig. 1 shows a data processing system 10 which provides automatic memory sizing and fast memory testing. As Fig. 1 shows, in its preferred embodiment, data processing system 10 includes a CPU board 15 and memory boards 70, 72, 74, and 76.

-5-

The specific arrangement of boards shown in Fig. 1, however, is incidental to the present invention.

Data processing system 10 includes a central processing unit, such as CPU 20 located on CPU board 15. CPU 20 is capable of executing instructions to carry out the present invention. A CPU bus 22 carries commands, address, and data from CPU 20 and also delivers data to CPU 20.

The data processing system of the present invention also includes booting means, coupled to the central processing unit, for causing the central processing unit to institute memory initialization procedures, including the generation of commands and addresses. In the preferred embodiment of the present invention, data processing system 10 includes Boot ROM 25 on CPU board 15. Boot ROM 25 is a read only memory containing programs for bootstrap or initialization procedures. Among the programs stored in Boot ROM 25 are programs for initialization, such as programs to control the operations necessary for the automatic memory sizing and fast memory test procedures. Of course, Boot ROM 25 can also include other programs and procedures.

The present invention can also include means for sensing an initialization condition to cause the central processing unit to begin the initialization program. As shown in the preferred embodiment of the invention in Fig. 1, a power sensor 28 detects when electrical power is provided to data processing system 10 in order to initiate bootstrap operations. The output of circuit 28 after passing through synchronization circuitry not important to an understanding of the present invention, generates a reset (RST) signal for various components of data processing system 10 which take specific actions at times of initialization. For example, in the preferred embodiment, CPU 20 sends a starting address to Boot ROM 25 in response to the RST signal. That starting address begins an initialization program stored in Boot ROM 25 which causes CPU 20 to carry out procedures for automatic memory sizing. The RST signal can also be generated from the detection of other conditions.

**SUBSTITUTE SHEET**

-6-

The data processing system of the present invention also includes a memory system, coupled to the central processing unit, which is responsive to the initialization procedures carried out by the central processing unit. Such a system in Fig. 1 includes memory controller 30 and memory boards 70, 72, 74, and 76.

The memory system in accordance with the present invention includes memory controller means for constructing a configuration table representing the arrangement of storage locations in the memory system and for forming memory addresses and memory select signals from the addresses and commands received from the central processing unit. In the preferred embodiment of the present invention shown in Fig. 1., memory controller 30 on CPU board 15 performs the functions of the memory controller means. Memory controller 30 includes a latch 34, a configuration status register 40, memory control logic 50, and an error detection and correction unit 45. Memory controller 30 receives addresses and commands from CPU 20 over CPU bus 22. In particular, an AS signal controls latch 34 to transfer an address from CPU bus 22 to a memory controller bus 32 in memory controller 30. Memory controller 30 then processes those addresses and commands and forms memory addresses and memory select signals (e.g., signals 310, 320, 330, 340, and 350-353 shown in Fig. 1).

Further in accordance with the present invention, the memory controller means also includes configuration register means for forming a configuration structure according to configuration data which is descriptive of the configuration of the memory system. An example of such configuration register means is configuration status register (CSR) 40 which is part of memory controller 30. Configuration data, which is also called "signature data," is described in more detail below. Generally, such data describes certain characteristics of a memory module such as or number banks.

Fig. 2 shows the preferred embodiment of configuration status register 40 in greater detail. CSR 40 includes several bank status register circuits 200, an OR GATE 220, and a RAS and CAS Decoder 230. In the preferred embodiment of the

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-7-

present invention, each memory board includes a number of individual banks of memory, and CSR 40 includes a separate bank status register circuit 200 for each bank of memory.

Bank status register circuits 200 each include a configuration register 202, a multiplexer 205, and a comparator 210. Each configuration register 202 contains configuration data about the memory bank corresponding to the bank status register circuit containing that configuration register. Bank status register circuits 200 cumulatively represent the configuration structure of the entire memory.

Fig. 3 shows an example of the contents of one configuration register 202, with the numerals across the top of Fig. 3 indicating bit position numbers. The information stored in each configuration register 202 is received either from a memory data bus 65 or from the CPU 20 by way of memory controller bus 32, latch 34, and CPU bus 22. Control signals from memory control logic 50 cause register 202 to store the received information. As shown in Fig. 3, the contents of each configuration register 202 include a number of fields. One of the fields is the base memory address for the corresponding memory bank. The base memory address of a memory bank is the address and size information of the other memory banks. The specific process used by CPU 20 in the preferred embodiment is explained in more detail below.

After computing a base memory address, CPU 20 then stores it in the appropriate configuration register 202 by way of CPU bus 22, latch 34, and memory controller bus 32. When the CPU 20 stores a base memory address into a corresponding configuration register 202, it also sets a validity bit for that register, as shown in Fig. 3, to indicate that the corresponding base memory address is valid.

Another field in configuration register 202 is a lock bit. Although the function of this bit is not directly relevant to the present invention, it is described briefly for purposes of completeness. The lock bit is set during an exclusive read-modified-write operation to a memory bank to preserve data integrity.

-8-

The next field is a signature read bit. CPU 20 sets this bit to cause memory controller 30 and memory boards 70, 72, 74, and 76 to initiate certain procedures necessary for storing the signature or configuration data of the corresponding memory bank into the remaining field of configuration register 202.

That remaining field is the signature or configuration data for the corresponding memory bank. That signature data, which comprises five bits of information, is obtained from the low order five lines of memory data bus 65 during a configuration data read operation. The configuration data field shown in Fig. 3 includes three subfields: an error subfield, a size subfield, and a use subfield. For the reasons discussed below, the configuration data in the preferred embodiment is the same for all the memory banks on a memory board.

The error subfield is two bits wide and identifies the type of error correction or detection which is being performed for the corresponding bank. In the preferred embodiment, error correction and detection can be absent or, if present, can be either single bit parity or a seven bit error correcting code. Of course, there is no limitation on the type of error correction that can be used in accordance with the present invention, nor is there any requirement that error correction be used at all. The error correction in the preferred embodiment is the same for each bank on a board, thus the configuration register 202 for all the banks on each board will have the same values in the error subfield.

The size subfield is one bit wide and identifies the size of the corresponding bank as either 1M words or 256K words in the preferred embodiment. In the preferred embodiment, words are four bytes long. In the preferred embodiment, all of the banks on each board have the same size, so each configuration register 202 for the memory banks on the same board has the same values for the size subfield. Identically-sized banks on a board, however, is not a requirement for all embodiments of the present invention.

-9-

The bank use subfield is a two-bit subfield specifying the number of memory banks on the board containing the corresponding memory bank. The two-bit subfield in the preferred embodiment identifies the size as either zero banks (absent board), one bank, two banks or four banks.

Preferably, bank status register circuits 200 in configuration status register 40 are each identical, as shown in Fig. 2, but they need not be. For example, they can differ if needed to reflect different bank requirements.

In addition to bank status register circuits 200, configuration status register 40 can have additional status register circuits, such as status register circuit 225 containing status register 228, to perform operational management. For example, in the preferred embodiment, CPU 20 performs fast diagnostic tests by setting a bit in status register circuit 225, as explained in detail below.

In the preferred embodiment of control status register 40, additional elements are associated with each of the bank status register circuits 200. These elements, which are shown in Fig. 2, include multiplexer 205 and comparator 210. Although only one set of these elements is shown, it should be understood that in the preferred embodiment, each bank status register circuit 200 would have its own multiplexer 205 and comparator 210.

In the preferred embodiment of bank status register circuit 200, a comparator 210 compares the base address information for that bank status register, which is received via multiplexer 205, with addresses on memory controller bus 32 which have been received from CPU 20. If banks on a board each have 1M words, and assuming that the base addresses for those banks are multiples of 1M, memory addresses for locations in that bank share the same high order bits. The same holds true if a bank has 256K words. The difference in situations is that for an address of a given number of bits, there is a greater number of common bits for the smaller size banks than for the larger size. Thus, to ensure that comparator 210 is comparing the correct number of address bits for each memory size, multiplexer 205 has inputs both the higher order address bits for 1M

**SUBSTITUTE SHEET**

-10-

word memories and high order address bits for 265K word memories. Multiplexer 205 selects one of those inputs in response to the size subfield.

Comparator 210 compares the selected portions of the base memory address for that bank and the addresses on memory controller bus 32, and enables a corresponding bank hit signal 215 when the address portions on controller bus 32 equal the base memory address portion in status register 202. When the bank bit signal is enabled, it means that the memory addresses are within the address space for the corresponding bank. The comparators 210 in each of the bank status register circuits 200 perform similar comparisons simultaneously and enable their own bank hit signals when the addresses from CPU 20 are within the address space of the corresponding bank. As is apparent, at most one bank hit signal is enabled for a single address.

All the bank hit signals 215 are inputs both to OR GATE 220 and to RAS and CAS Decoder 230. OR GATE 220 produces an address hit signal if any of the bank hit signals 215 is enabled. An enabled address hit signal indicates that the address from the CPU 20 is within the address space of the associated memory. Sometimes addresses will be outside of that address space, such as to access one of the status register circuits. In this case, none of the bank hit signals will be enabled.

The bank hit signals are also used by RAS and CAS Decoder 230 to enable the appropriate RAS EN and CAS EN signals. When enabled, the RAS EN signals and CAS EN signals assume a level which is then used to generate the row address strobe (RAS) and column address strobe (CAS) that activate a corresponding bank of the memory. Each bank of the memory is selected by a different combination of one RAS and one CAS. The RAS EN and CAS EN signals are outputs of configuration status register 40, as is the address hit signal and other signals which are either discussed below or are not relevant to an understanding of the present invention.

The memory controller means of the invention also includes control logic for forming the memory addresses and memory select signals from the addresses and commands received from

-11-

the central processing unit and from the configuration structure in the configuration register means. An example of such control logic is shown in Fig. 1 as control logic circuit 50. Control logic circuit 50 is shown in greater detail in Fig. 4.

Control logic circuit 50 receives several signals from configuration status register 40, including the address hit signal, the RAS EN signals, and the CAS EN signals. In addition, control logic 50 receives clock signals, the AS signal, and the RST signal, and is coupled to memory controller bus 32. Memory control logic 50 also produces the signals constituting memory address interconnect 62.

As shown in Figs. 1 and 4, memory address interconnect 62 includes: 10-bit memory address lines 310, which specify one of the address locations within each bank; signals CASO-CAS3 (350-353), which are formed from the corresponding CAS signals and clock signals; signals RASO-3 (340), which are formed from the corresponding RAS signals and clock signals; the SE (signature enable) signal; and the WE (write enable) signal.

Generally, CASO-CAS3 are mutually exclusive, as are RASO-3, except as described below for testing. CASO-CAS3 each correspond to a different memory board, and RASO-3 each correspond to one of the banks on each memory board. The SE signal causes a read of the signature or configuration data, and the WE signal causes the memory bank designated by RASO-3 and the board designated by CASO-CAS3 to write data from memory data bus 65 into a location specified by the memory address lines 310. Memory address lines 310 also specify a location in a bank from which data is transferred to memory data bus 65 during a read operation.

As shown in Fig. 4, memory control logic 50 includes a microsequencer 52, memory address interconnect control 54, clock logic 56, and precharge circuitry 66. Other elements, such as buffering circuits, are omitted from the description of preferred embodiments for simplicity and because the implementation of these elements is within the level of ordinary skill. Clock logic 56 receives system clock signals (CLK) and provides internal clock signals to microsequencer 52 and to

**SUBSTITUTE SHEET**

-12-

memory address interconnect control 54. Preferably, such internal clock signals, designated in Fig. 4 as P1-P4, correspond to subcycles of the main cycles of data processing system 10. Memory address interconnect control 54 uses the internal clock signals to add the appropriate timing to the RAS EN and CAS EN signals to form the RASO-3 and the CASO-CAS3 signals. The RASO-3 signals are four separate signals, as are CASO-CAS3. Memory address interconnect control 54 adds such timing in response to control signals from microsequencer 52.

The functions of microsequencer 52 include advising interconnect control 54 of the cycle during which the CASO-CAS3, RASO-3, memory address lines 310, SE, and WE should be enabled. In response, control 54 enables and disables those signals during the proper subcycles. Microsequencer 52 also receives commands and data from CPU 20 via memory controller bus 32, as well as the AS signal, indicating that CPU 20 has sent such commands and addresses, and receives the address hit signal from CSR 40, indicating that the address from CPU 20 is within the memory's address space. In addition, microsequencer 52 sends control signals to CSR 40, for example to cause the storage of data into registers 202. Other functions of microsequencer 52 will become apparent from a description of the methods of this invention.

The memory system of the present invention also includes a memory bus coupled to the memory controller means, and carrying memory data, memory addresses, and memory select signals. Such a memory bus can, in the preferred embodiment, include both address interconnect 62 and memory data bus 65. Preferably, memory data bus 65 is on a backplane of a computer structure and memory boards 70, 72, 74, and 76, as well as CPU board 15, plug into that backplane by way of connectors. Connectors 71, 73, 75, and 77, corresponding respectively to boards 70, 72, 74, and 76, are shown in Fig. 1.

The memory system of the present invention also includes memory modules coupled to the memory bus. Memory boards 70, 72, 74, and 76 are such memory modules in the preferred embodiment.

**SUBSTITUTE SHEET**

-13-

In accordance with the present invention, the memory modules include storage means, coupled to the memory bus and having one of several configurations, for storing memory data to and for retrieving stored memory data from different locations corresponding to the memory addresses on the memory bus. In the preferred embodiment shown in Fig. 1, memory banks 99, which can be organized into as many as four banks per board, perform and functions of such a storage means.

Fig. 5 shows a system diagram with certain elements of memory board 70, including elements of control logic 95 and interface circuitry 93 (shown in Fig. 1). Memory board 70 preferably includes four memory banks, 100, 102, 104, and 106, which are collectively equivalent to memory banks 99 in Fig. 1. The connections between bank 100 and other elements of memory board 70 are shown in greater detail in Fig. 6.

As shown in Fig. 6, bank 100 includes a memory array of 256K or 1M words which act as a storage means in accordance with the present invention. In the preferred embodiment, bank 100 provides storage of 32 bit words and an error detection and correction code of up to 7 bits. Preferably, as illustrated in Fig. 6, bank 100 is organized either as 39 parallel 1 bit by 256K memories or as 39 parallel 1 bit by 1M memories.

Memory bank 100 is coupled to a column address buffer 120, which is shared by all the banks on memory board 70, and a row address buffer 130, which is unique to bank 100. Prior to being latched into buffers 120 and 130, the memory address lines pass through buffers 97, shown in Fig. 1. The RAS and CAS for bank 100 pass through buffers 120 and 130 is capable of holding 10 address bits. The 20 total address bits are sufficient for addressing each location in up to 1M words of memory. Up to ten-bits of memory addresses from memory address lines 310 are latched into row address buffer 130 during assertion of the corresponding RAS signal, and up to ten-bits of memory addresses are latched into column address buffer 120 during assertion of the corresponding CAS signal.

The timing of the RAS and CAS in relationship to the memory address lines and memory data bus is shown in Fig. 7A for a single transfer read operation (no errors), and is shown

-14-

in Fig. 7B for a single transfer write operation (no errors). Multiple transfer read and write operations are similar but involve toggling the CAS signal as the column address changes.

As Fig. 7A shows, consistent with the description just provided for read operations, the row address signals are valid on memory address lines 310 during assertion of the RAS and the column address signals are valid on memory address lines 310 during assertion of the CAS. Data from the read operation is available on memory data bus 65 for part of the time that the CAS is asserted and when the CAS is deasserted.

As Fig. 7B shows, the timing of the assertion of the RAS and CAS is the same for read and write operations, but the durations of those signals are different. The WE signal is asserted before the data on memory data bus 65 becomes valid and is deasserted after that data is no longer invalid. Data is written when the appropriate CAS is asserted.

As shown in Fig. 5, associated with each bank is a bank transceiver. Thus bank transceivers 142, 144, 146, and 148 correspond respectively to memory banks 100, 102, 104, and 106. The direction of data flow through transceivers 142, 144, 146, and 148 is controlled by the WE signal.

Further in accordance with the present invention, the memory boards also include signature means for storing configuration data identifying the configuration of the storage means. In the preferred embodiment of memory board 70 shown in Fig. 5, signature register 160 holds configuration data for the corresponding memory banks on memory board 70. Preferably, the signature register is a set of pins which are connected to voltage sources representing either "1" or a "0" levels. As explained above, the memory banks on one memory board of this embodiment share the same five bits of configuration data because the sizes of the memory banks on each board must be the same, and all memory banks must use the same error correction and detection scheme. Thus, a single signature register can suffice to provide configuration data for each memory bank on memory board 70. The present invention, however, is not limited to this embodiment and it is also possible to provide a signature register for each bank if the configuration data for each bank can be different.



-15-

Signature register 160 is preferably a five bit words. The first two bits specify the error detection scheme (1 bit parity, 7 bit error correction, or no error detection at all), the second two bits specify whether the banks are 256K words or 1M words.

The memory boards of the present invention also include multiplexer means, coupled to the storage means and signature means, for placing, when activated, either the memory data or the configuration data onto the memory bus in response to multiplex control signals. In the preferred embodiment of the invention, interface circuitry 93, shown in Fig. 1, provide such means. Certain of the elements of interface circuitry 93 are shown more completely in Fig. 5 as a bank multiplexer 170 and a test/sig multiplexer 175. Other elements in Fig. 5 are part of control logic 95 or represent the other elements of board 70 shown in Fig. 1.

Bank multiplexer 170 has inputs coupled to the outputs of bank transceivers 142, 144, 146, and 148, and can select one of those outputs as an input to board transceiver 180. Bank multiplexer 170 also has an input coupled to the output of test/sig multiplexer 175 and can instead select that output as an input to board transceiver 180. One of the inputs to test/sig multiplexer 175 is signature register 160. Test/sig multiplexer 175 gates the contents of signature register 160 as an input to bank multiplexer 170 when the TEST signal is disabled. The generation of the TEST signal is described in detailed below.

Bank multiplexer 170 is controlled by bank multiplexer control circuit 172, which has as inputs RAS0-RAS3, the SE signal, the TEST signal, and a BDONE signal also described in more detail below. In response to bank multiplexer control circuit 172, bank multiplexer 170 selects either the outputs of one of the bank transceivers 142, 144, 146 and 148, or the output of test/sig multiplexer 175. The selected output is then sent onto memory data bus 65 through board transceiver 180.

Board transceiver 180, as shown in Fig. 5, not only controls the transfer of data onto memory data bus 65 from bank multiplexer 170, it also controls the transfer of information

-16-

from memory data bus 65 to the banks 100, 102, 104, and 106 by way of the corresponding bank transceivers. Board transceiver 180 is responsive to board transceiver control circuit 182 from the corresponding CAS, as well as the BDONE and WE signals.

Each of the bank transceivers is enabled by a different one of RAS0-RAS3, and the direction of data flow through the transceiver is determined by the WE signal. The control is generally the same for each memory board.

The present invention also contains the capability for automatic memory sizing even if a full complement of memory boards is not available. Each of the memory boards plugs into a corresponding memory board connector in the backplane, but each of the memory board connectors need not contain a memory board.

The memory controller means of this invention can include means for obtaining configuration data for memory connectors that do not contain boards. In the preferred embodiment of this invention, the lines of memory data bus 65 are precharged by precharge circuit device 66 in memory control logic 50 shown in Fig. 4. Preferably, precharge circuit is a transistor which pulls up to supply voltage  $V_{dd}$  the five lines of memory data bus 65 which transfer the signature data to memory controller 30. If there is no board in one of the connectors when configuration status register 40 attempts to read signature data from an empty connector, it will read in values at the precharged or default condition for memory data bus 65. Those default values correspond to the indication that the memory board has no memory banks.

Fig. 7C shows the timing for signature operations. The corresponding CAS is asserted simultaneously with the SE signal and memory data bus 65 is precharged before the CAS is asserted. When the corresponding CAS and SE signal are asserted, the signature data are gated to memory data bus 65.

In addition, the memory system of this invention can also include error detecting means, coupled to the memory bus, for detecting errors in a memory data. An example of such error detecting means is shown in Fig. 1 as ECC unit 45. ECC unit 45 can perform parity error detection or a Hamming code

**SUBSTITUTE SHEET**

-17-

type of error detection correction. Other types of error detection and correction are also possible.

#### B. Operation of Automatic Sizing

With an understanding of the functions performed by the different elements shown in Figs. 1-6, the method of automatic sizing of this invention can now be readily understood. Prior to an explanation of that method, however, it would be helpful to under the general memory access operations of data processing system 10 in more detail.

Generally, CPU 20 makes a read or write request over CPU bus 22 which includes addresses or data. A memory address supplied by CPU 20 in such a memory access operation is sent through latch 34 onto memory controller bus 32, and is an input comparators 210 of each bank status register circuit. If that memory address is within the address space of the memory on boards 70, 72, 74 and 76, then one of the comparators 210 will enable its bank hit signal indicating that the address is for a location in the address space of the bank corresponding to that comparator. The enabled bank hit signal then causes RAS and CAS Decoder 230 to assert the one RAS and the one CAS corresponding to that bank. Memory control logic 50, specifically memory address interconnect control 54, then adds clock (phase) timing to form the corresponding RAS and CAS.

In data processing system 10, memory control logic 50 reformats the memory address received from CPU 20 via memory controller bus 32, and sends the reformatted memory address to the memory boards 70, 72, 74, and 76 through memory address interconnect control 54 and memory address lines 310 in ten-bit segments. The first segment contains the row address and the subsequent segment(s) contain(s) the column address. Memory control logic 50 controls the timing, as shown in Figs. 7A and 7B, so that the RAS occurs first and on its assertion causes the ten-bits on the memory address lines 310 of the row address to be read into the row address buffers 130 for the corresponding bank. The assertion of the subsequent CAS causes the next ten bits, which represent the column address on memory address lines 310, to be read into the column address buffer 120 for the designated board. If a multiple word read takes place,

**SUBSTITUTE SHEET**

-18-

then there will be multiple CAS's and multiple column addresses for a single row address.

For a read operation, the corresponding memory bank will produce data from the contents of the location specified by the addresses in row address buffer 130 and column address buffer 120. Those data will be sent through the corresponding bank transceiver (142, 144, 146, or 148) and board transceiver 180 to the memory data bus 65. The bank transceivers will be controlled by the corresponding RAS and the board transceiver will be controlled by the corresponding CAS.

For a write operation, the data to be written will be transferred to memory data bus 65 from CPU 20 via CPU bus 22, through latch 34, memory controller bus 32, and ECC block 45. From memory data bus 65, that data will be provided to the appropriate memory bank through the board transceiver, enabled by the CAS and WE signal, and through the bank transceiver controlled by the WE signal and the corresponding RAS. The CAS will then cause the data to be stored in the contents of the location specified by the addresses in the row and column addresses of the selected memory bank.

One of the advantages of the automatic memory sizing apparatus and method of the present invention is that it requires very little additional hardware and only one additional backplane signal to implement since it takes advantage of existing memory access hardware and control. In data processing system 10, the RST signal is sent both to CPU 20 and to memory control 30. CPU 20 uses the RST signal to send a starting address to Boot ROM 25 which contains initialization or bootstrapping procedures, including the automatic memory sizing procedures. In response to the RST signal, memory controller logic 50 deasserts the CAS, RAS, SE, and WE signals, and clears all the bank status register circuits 200, including lock bits in the status configuration registers of those circuits.

Fig. 8 is a flowchart showing the signature read operation of the present invention. The reset operation just described is shown as step 410 in that flowchart. To initiate the automatic memory sizing procedures, the CPU 20 sets the

**SUBSTITUTE SHEET**

-19-

signature read request bit in the status configuration register 202 for one of the banks (Step 420). Next, memory data bus lines 65 are precharged (Step 425).

Memory control logic 50, and specifically microsequencer 52, detects the signature read bit in the word sent to the status configuration register 220 and begins the read signature operations. In first, in the preferred embodiment, microsequencer 52 does not acknowledge completion of the CPU transfer to the status configuration register until the read signature operation is complete. This method of operation, however, is only one implementation and not the only method of operation possible within the scope of the present invention. Memory control logic 50 then asserts the CAS for the board containing that bank and also asserts the SE signal (Step 430). As can be seen from Fig. 5, the assertion of these signals causes the contents of signature signal register 160 in that board, which represent the signature data for that board, to be gated onto the memory data bus 65 through test/sig multiplexer 175, bank multiplexer 170, and board transceiver 180 (Step 440).

The signature data is then written from memory data bus 65 into the status configuration register 202 for each of the banks on the board from which the configuration data was just read (Step 450). CPU 20 then obtains that signature data from the status configuration register 202 and computes the base memory address for each of the banks on that same board according to procedures executed from Boot ROM 25 (Step 460). In general, such computation involves maintaining a "next base address" value (which can be initialized to zero) using this value as the base address for bank 0 of the board, and adding the size (1M or 256K) to get the base addresses for the remaining banks and then to set the "next base address" value.

Next, CPU 20 writes base addresses for each bank on that board into the configuration status register 202 corresponding to that bank (Step 470). Then, the CPU determines whether the signatures have been read from all the boards (Step 480). If so, the memory initialization procedure is finished. If not, the procedure is repeated again starting at step 420 for the next board.

**SUBSTITUTE SHEET**

-20-

The present invention provides the automatic memory sizing and thus does not require the addition of significant new hardware or signal lines, and is adapted to the existing memory hardware. By use of the memory data bus, the RAS's, and the CAS's, the signature or configuration data for each board is obtained with the addition of only a single additional signal, the SE signal. All the other signals used in the method just described are present because they are needed for other memory operations. Furthermore, the only additional function needed on each board to effect the method of this operation, besides some minor control circuitry, is signature register 160.

### C. Fast Memory Diagnostics

The present embodiment also speeds up memory diagnostics through simultaneous data comparison of all memory banks with a reference bank. This allows memory testing to proceed more quickly since it takes place in parallel. In general, the testing begins by "broadcast writing," which involves simultaneously writing the same patterns into corresponding locations and all the memory banks. Then the fast memory diagnostic method continues by comparing the contents of a reference memory bank against the contents of corresponding locations in the other memory banks.

The self-testing memory includes circuitry for simultaneously writing the same test patterns into each of a plurality of memory banks. This function is embodied as the broadcast write operation which simultaneously writes a pattern, represented by the data on memory data bus 65, into corresponding locations of all the banks 0-3 on each memory board. In general, this is accomplished by simultaneously asserting the RAS0-RAS3 as well as the CAS0-CAS3.

In normal memory write operations, only one RAS and one CAS are asserted because the desired memory location resides in only one bank. In the preferred embodiment of the fast memory diagnostic procedure, however, asserting all the RAS stores the pattern on memory data bus 65 simultaneously in response to the CAS and WE signal.

**SUBSTITUTE SHEET**

-21-

The simultaneous assertion of the RAS line is effected by circuitry in memory controller 30. Specifically, CPU 20 begins fast memory diagnostics by setting a bit, called the fast diagnostic flag 229, in status register 228 of status register circuit 225 to begin such diagnostics. In response to the setting of this flag, RAS and CAS Decoder 230 (Fig. 2) enables the RAS0-RAS3 EN and CAS0-CAS3 EN signals to implement the broadcast write function. As shown in Fig. 2, RAS and CAS decoder 230 receives the fast diagnostic flag 229 directly, although other implementations are also possible.

Control logic 50 asserts all RAS's simultaneously and all CAS's simultaneously in response to the simultaneous enabling of RAS EN and CAS EN signals. Memory address interconnect control 54 then adds the appropriate timing, as described above. Then, in response to instructions from Boot ROM 25, CPU 20 issues consecutive write commands to consecutive memory locations causing the same patterns to be written into each location of every bank. The time required to write to every bank, however, is the same as would be required to write to a single bank.

When CPU 20 sets the fast diagnostic flag 229, test set logic 232, shown in Fig. 2, sets certain lines on the memory data bus 65 in response to that flag. In the preferred embodiment, the lines which are set include lines 0, 10, 20, and 30. The reason for choosing such lines is that they correspond to the preferred memory architecture. In that architecture, memory data bus 65 is 39 bits wide to accommodate a simultaneous transfer of all 39 memory bits. In the preferred implementation, each memory board 70, 72, 74 and 76 comprises four ten-bit wide slices, so memory data bus 65 comprises four sets of ten (the last is actually nine) conductors, each set being connected to a different "slice." For every ten-bit slice, the lowest order bit (i.e., bits 0, 10, 20 and 30) is used to indicate a test. When these lines are asserted, the memory board is in a test mode. Memory board control logic circuit 190 senses the assertion of these lines and forms the TEST signal mentioned above. This TEST signal is then used by memory board 70 to implement fast memory diagnostic procedures.

**SUBSTITUTE SHEET**

-22-

The self-testing memory also includes circuitry for simultaneously comparing the contents at locations at one of the memory banks with contents at corresponding locations of the other memory banks. Such circuitry can include circuitry for reading out the contents of a selected one of the memory banks. In the preferred embodiment, the selected memory bank is bank 0 on board 1. Board 1 is determined using a signal BDLOCLI on the backplane. BDLOCLI is generated at CPU board 15. The first memory board 70 (i.e., the one closest to CPU board 15) receives the BDLOCLI signal as an input of an initial location sensor 195 (Fig. 5). That input is pulled up to Vdd by resistor 198. If initial location sensor 195 determines that the BDLOCLI is at the Vss level, it asserts a BDONE or "board one" signal which identifies that board as being the closest memory board to CPU board 15. The closest memory board to CPU 20 also stops the BDLOCLI signal from propagating further. Thus, the BDLOCLI signal to all but the closest memory board to CPU 20 is floating. The resistors 198 on those other memory boards will pull the BDLOCLI signal up to Vdd and their initial location sensor will not assert their BDONE signals.

The circuitry for reading a selected one of the memory banks includes bank multiplexer control circuit 172. When board 70 senses from control logic 190's enabling of the TEST signal that board 70 is in the test mode, bank multiplexer control circuit 172 enables bank multiplexer 170 to select the designated contents of bank 0 during a memory read, and transceiver control circuit 182 causes board transceiver 180 to gate these contents onto the memory data bus 65. The designated contents are determined by the memory address lines 310 according to the addresses from CPU 20.

The simultaneous comparing circuitry can include circuitry for storing the contents of the one memory board into a first latch. During the read operation in which the contents of the designated location of bank 0 are transferred to memory data bus 65, each memory board 70, 72, 74 and 76 receives those contents through board transceiver 180 and latches then into a memory latch 500 during the deactivation of the associated CAS.



-23-

The simultaneous comparing circuitry can also include circuitry for simultaneously reading the corresponding contents of the other memory banks into a second latch. During that same read operation, the RAS signals remain activated, and cause the contents at the corresponding locations of each of the banks 100, 102, 104 and 106 to be output through their respective bank transceivers 142, 144, 146 and 148 into several bank latches 510, 515, 520, and 525 corresponding, respectively, to banks 100, 102, 104, and 106. The contents are stored during the deassertion of the CAS signal simultaneously with the storage of the contents into memory latch 500.

In the preferred embodiment, the simultaneous comparing circuitry also includes comparators, such as comparators 530, 535, 540, and 560, for comparing the contents of the selected memory bank, for example the contents of bank 0 of board 1 in latch 500, with the contents of the corresponding locations of the other memory banks, for example the contents of latches 510, 515, 520, and 525. As shown in Fig. 5, each of the comparators 530, 535, 540 and 545 has one input receiving the output of a corresponding bank latch 510, 515, 520, or 525, respectively, and another input connected to the output of memory latch 500.

Each of the comparators 530, 535, 540 and 545 preferably produces an output at a first state, such as a "1," if the contents of the memory latch 500 do not match the contents of the respective bank latch 510, 515, 520, or 525. Otherwise, the comparators 530, 535, 540, and 545 produce a "0" output at a second state. The outputs of comparators 530, 535, 540 and 545 are all inputs to an OR gate 550. If any of the inputs to OR gate 550 are at the first state, e.g., a "1," then the output of OR gate 550 is enabled, e.g., also a "1".

The self-testing memory also includes circuitry for recording errors when the contents of the locations of the selected memory bank differ from the contents of the corresponding locations of the other memory banks. In the preferred embodiment, a seven-bit counter 560, shown in Fig. 5, has a data input connected to the output of OR gate 550 and has a clock input connected to receive the associated CAS after it

**SUBSTITUTE SHEET**

-24-

passes through a delay circuit 555. Delay circuit 555 allows for propagation delay through the latches 500, 510, 515, 520, and 525, the comparators 530, 535, 540 and 545, and OR gate 550. If the output of OR gate 550 is a "1," then the CAS deassertion will cause the counter to increment. If the output of OR gate 550 is a "0," then counter 560 will not increment.

In this manner, counter 560 counts the number of times that the contents of one of the bank latches 510, 515, 520 or 525, and therefore, the contents of the corresponding memory locations stored in those latches, differ from the contents of memory latch 500, which contains the contents at the corresponding location of bank 0 of board 1. In the preferred embodiment, counter 560 is only a seven-bit counter. If there are more than  $2^7$  errors, then an overflow (OV) bit is set.

In the preferred embodiment, memory board 70 is implemented as a ten-bit slice, and there is one counter for each slice. Thus, each board has four (4) seven-bit counters recording the number of memory events.

In the preferred implementation, it is difficult to transmit the outputs of the four counters (i.e. all 40 bits) to CPU 20 because CPU bus 22 is preferably 32 bits wide. Thus, the contents of one of the counters, which would be on the highest order ten lines of memory data bus 65, are stored in register 227 and read from that register by CPU 20 in a separate memory read instruction.

The output of counter 560 is an input into the test/sig multiplexer 175 and can be output onto memory data bus 65 for input into CPU 10 at the end of the testing procedure. Preferably, this occurs during the first read operation after the diagnostic testing operation. Specifically, when CPU 20 finishes a test, it changes the contents of register 228 which deasserts lines 0, 10, 20, and 30 of memory data bus 65. In response, test control logic 190 deasserts the TEST signal and test/sig multiplexer 175 and bank multiplexer 170 gate the outputs of counter 560 to board transceiver 180, ignoring the RAS's during the first read operation following the test. During the CAS generated for that first read operation, the board transceiver 180 gates the contents of the counter to memory data bus 65.

**SUBSTITUTE SHEET**

-25-

The output of counter 560 is cleared, in the preferred embodiment, when the SE signal is activated during a signature read.

D. Fast Memory Diagnostic Method

With the elements described, a preferred embodiment of the method for performing a fast diagnostic test can be understood with the aid of the flow diagram in Fig. 9, which illustrates a preferred method of the memory test procedure. The first step is to reset error counter 560 (Step 600). Preferably, this is done during a signature read, although such timing is discretionary and not required to operate the memory test of this invention.

In the next step, the test pattern is written simultaneously into the locations in all of the memory banks (Step 610). As previously indicated, this is done by the simultaneous assertion of all the RAS and CAS as CPU 20 supplies the memory test pattern and addresses for the different locations for one of the banks.

After the pattern is written into all of the banks, the contents of bank 0 (designated 100 in Fig. 5) of board 1 (designated board 70 in Fig. 1) are read out onto memory data bus 65 (Step 620). As indicated above, this occurs because the BDONE signal causes the bank multiplexer control 170 to select the contents from bank 0 through transceiver 142, and because the BDONE signal into transceiver control 182 also causes board transceiver 180 to gate the output of bank multiplexer 170 onto the memory data bus 65. If the BDONE signal is not asserted, as it would not be for boards 72, and then neither the bank multiplexer 170 nor the board transceiver 180 would be enabled. This ensures that only the contents of bank 0 of board 1 are gated onto the memory data bus 65. This gating occurs while the corresponding CAS signal is asserted.

CPU 20 then performs its own analysis on the contents of bank 0, such as comparing those contents to the pattern which was stored (630). Such analysis, however, need proceed only for one bank.

Substantially simultaneously, each board stores the contents of bank 0 in board 1 into the corresponding memory

**SUBSTITUTE SHEET**

-26-

latch 500 and stores the contents from corresponding locations of the other banks into bank latches 510, 515, 520, and 525 (Step 640). Preferably, this storing occurs when the CAS is deasserted. The CAS into each board causes the board transceiver to receive the memory data bus contents and present them at the input to memory latch 500. Thus, all the boards simultaneously latch the signals from the memory data bus 65 when the corresponding CAS signal is deasserted, and also latch the other banks' contents into the bank latches at the same time. Fig. 7D shows the timing for the fast memory diagnostic when the data is read from the memory banks.

After the contents of the selected bank and the contents of other banks for the corresponding locations are latched, each bank's contents are simultaneously compared with the contents of the selected bank (Step 650). As shown in Fig. 5, such comparison uses comparators 530, 535, 540, and 545 for the contents of banks 0 through 3, respectively. Comparators 530, 535, 540, and 545 all operate simultaneously.

In the next step, the error counter is incremented whenever the contents of the selected memory bank and the contents of the corresponding locations in any of the other banks do not match (Step 660). As indicated previously, comparators 530, 535, 540, and 545 each produce a "1" when their inputs are not equal. When this happens, OR gate 550 is also enabled and enables the data input to counter 560. When counter 560 receives a clock signal, it increments. The clock signal is provided from the corresponding CAS signal after being delayed through delay element 55. The delay element allows time for the signals to propagate to the data input of the counter.

Next, a determination is made whether the contents of the banks have been read out entirely (Step 670). If not, then Step 620 is repeated for the next memory location within a bank. If so, then the contents of the error counter are output (Step 680). In the preferred embodiment of the invention, the contents of counter 560 are gated through test/sig multiplexer 175, bank multiplexer 170, and board transceiver 180 when the first nontest mode read operation after the fast memory diagnostic occurs for the selected board. At the end of the fast

-27-

memory diagnostic, CPU 20 resets the memory diagnostic flag which causes test set circuit 232 to deassert lines 0, 10, 20, and 30 of memory data bus 65. When test control logic circuit 190 determines that the lines 0, 10, 20, and 30 are no longer asserted, thus indicating the end of a current test, the bank multiplexer control 172 and the test/sig multiplexer 175 are configured to gate the contents of the counter 560 to board transceiver 180, and eventually to memory data bus 65, at the next read operation.

CPU 20 can then obtain the counter value and determine whether to repeat this procedure with another pattern (Step 690). If so, then the procedure is repeated (Step 600). If not, then the procedure is over.

Thus, the fast memory diagnostic tests memories in much less time than conventional methods and also requires little additional hardware.

It will be apparent to those skilled in the art that further modifications and variations can be made in the present invention. The invention in its broader aspects, therefore, is not limited to the specific details and illustrative examples shown and described. Accordingly, departure may be made from such details without departing from the spirit or scope of the general inventive concept.

**SUBSTITUTE SHEET**

WHAT IS CLAIMED IS

1. A memory subsystem in a memory coupled to a processor via a memory bus and adapted to be coupled to storage means having one of a plurality of configurations, for storing memory data to and for retrieving stored memory data from locations corresponding to memory addresses on the memory bus, said memory module comprising:

signature means for storing configuration data identifying the configuration of said storage means;

multiplexer means, coupled to said storage means and said signature means, for placing, when activated, either said memory data or said configuration data onto said memory bus in response to multiplex control signals; and

control means, coupled to said multiplexer means and said memory bus, for generating the multiplex control signals from the memory addresses on said memory bus thereby causing said multiplexer means, when activated, to transfer the memory data or the configuration data onto said memory bus.

2. The memory subsystem of claim 1 wherein said storage means includes at least one bank of memory cells, and

wherein said signature means includes means for storing the configuration data identifying the number of banks in said storage means and the size of said at least one bank.

3. The memory subsystem of claim 1 wherein each of said multiplexer means includes:

a plurality of transceivers coupled to the memory bus, and

a plurality of multiplexers having one set of inputs coupled to the at least one bank of memory cells and another set of input coupled to said signature means; and

wherein said control means includes means for forming a first multiplex control signal for activating said plurality of transceivers, thereby

activating said multiplexer means, and

means for forming a second multiplex control signal to control said multiplexers select one of the sets of inputs.

4. The memory subsystem of claim 1 wherein said memory bus includes an address bus carrying the memory addresses and a memory data bus carrying the memory data and the configuration data.

5. The memory subsystem of claim 1 wherein said signature means includes means for storing configuration data indentifying a type of error detection for the memory data.

6. A memory module coupled to a processor via a memory bus, said memory module comprising:

storage means, having one of a plurality of configurations, for storing memory data to and for retrieving stored memory data from locations corresponding to memory addresses on the memory bus;

signature means for storing configuration data identifying the configuration of said storage means;

multiplexer means, coupled to said storage means said signature means, for placing, when activated, either said memory data or said configuration data onto said memory bus in response to multiplex control signals; and

control means, coupled to said multiplexer means and said memory bus, for generating the multiplex control signals from the memory addresses on said memory bus thereby causing said multiplexer means, when activated, to transfer the memory data or the configuration data onto said memory bus.

7. The memory module of claim 6 wherein

said storage means includes at least one bank of memory cells, and

wherein said signature means includes means for storing the configuration data identifying the number and size of banks in said storage means.

8. The memory module of claim 7 wherein each said multiplexer means includes

a plurality of transceivers coupled to the memory bus, and

a plurality of multiplexers having one set of inputs coupled to the at least one bank of memory cells and another set of inputs coupled to said signature means; and

-30-

wherein said control means includes means for forming a first multiplex control signal for activating said plurality of transceivers, thereby activating said multiplexer means, and means for forming a second multiplex control signal to control said multiplexers to select one of the sets of inputs.

9. The memory module claim 6 wherein said memory bus includes an address bus carrying the memory addresses and a memory data bus carrying the memory data and the configuration data.

10. The memory module of claim 6 wherein said signature means includes means for storing configuration data identifying a type of error detection for the memory data.

11. A memory system coupled to a processor via a memory bus carrying memory select signals, memory addresses, and memory data, said memory system including a first number of memory modules and each of said modules comprising:

storage means, coupled to the memory bus and having one of a plurality of configurations, for storing memory data to and for retrieving stored data from different locations corresponding to the memory addresses on the memory bus;

signature means for storing configuration data identifying the configuration of said storage means;

multiplexer means, coupled to said storage means and said signature means, for placing, when activated, either said memory data or said configuration data onto said memory bus in response to multiplex control signal; and

control means, coupled to said multiplexer means and said memory bus, for activating said multiplexer means and for generating the multiplex control signals from the memory commands and memory addresses on said memory bus thereby causing said multiplexer means, when activated, to transfer the memory data or the configuration data onto said memory bus.

12. The memory system of claim 11 wherein for each of said modules

said storage means includes at least one bank of memory cells, and

**SUBSTITUTE SHEET**



-31-

wherein said signature means includes means for storing the configuration data identifying the number and size of banks in said storage means.

13. The memory system of claim 11 wherein for each said modules said multiplexer means includes

a plurality of transceivers coupled to the memory bus, and

a plurality of multiplexers having one set of inputs coupled to the at least one bank of memory cells and another set of inputs coupled to said signature means; and

wherein said control means includes

means for forming a first multiplex control signal for activating said plurality of transceivers, thereby activating said multiplexers, and

means for forming a second multiplex control signal to control said multiplexers, and

means for forming a second multiplex control signal to control said multiplexers to select one of the sets of inputs.

14. The memory system of claim 11 wherein said memory bus includes an address bus carrying the memory addresses and memory select signals and a memory data bus carrying the memory data and configuration data.

15. The memory system of claim 11 wherein said signature means includes means for storing configuration data identifying a type of error detection for the memory data.

16. The memory of claim 11 further including first and second memory connectors connected to said memory bus, said first memory connectors each corresponding to and being connected to a different one of said memory modules, and

said second memory connectors not being connected to any of said memory modules; and

wherein said memory controller means includes means for obtaining configuration data for said second memory connectors indicating that no memory module contained in said second memory connectors.

-32-

17. The memory system of claim 11 wherein for each of said modules said status registers include configuration read data specifying a configuration read operation of the configuration data for the corresponding one of memory bank, and wherein said control logic includes means for responding to said configuration read data to form said memory select signals to activate the multiplexer means in the corresponding memory bank to place the configuration data for the corresponding memory bank onto said memory data bus.

18. An automatic sizing memory system for transferring memory data to and from a processor and receiving addresses and commands from said processor, said memory system comprising:

memory controller means for constructing a configuration structure representing the arrangement of storage locations in said memory system and for forming memory addresses and memory select signals from the addresses and commands received from said processor, said memory controller means including configuration register means for storing said configuration structure according to configuration data descriptive of the arrangement of storage locations in said memory system, and

control logic for forming the memory addresses and memory select signals from the addresses and commands received from said processor and from the configuration structure stored in the configuration register means;

a memory bus, coupled to said memory controller means and carrying memory data, the memory addresses, and the memory select signals; and

a first number of memory modules coupled to the memory bus and each including

storage means, coupled to the memory bus and having one of a plurality of configurations, for storing memory data at and for retrieving stored memory data from different locations corresponding to the memory addresses on the memory bus,

signature means for storing configuration data identifying the configuration of said storage means,

-33-

multiplexer means, coupled to said storage mean and said signature means, for placing, when activated, either the memory data or the configuration data onto said memory bus in response to multiplex control signals; and

control means, coupled to said multiplexer means and said memory bus, for activating said multiplexer means and for generating the multiplex control signals from the memory addresses and memory select signals on said memory bus thereby causing said multiplexer means, when activated, to transfer either the memory data or the configuration data onto the memory bus.

19. The automatic sizing memory system of claim 18 wherein for each of said modules

said storage means includes at least one bank of memory cells, and

wherein said signature means includes means for storing the configuration data identifying the number of banks in said storage means and the size of said banks.

20. The automatic sizing memory system of claim 18 wherein for each of said modules said multiplexer means includes

a plurality of transceivers coupled to the memory bus, and

a plurality of multiplexers having one set of inputs coupled to at least one bank of memory cells and another set of inputs coupled to said signature means; and

wherein said control means includes means for forming a first multiplex control signal for activating said plurality of transceivers, and

means for forming a second multiplex control signal to select one of sets of inputs.

21. The automatic sizing memory system of claim 18 wherein said memory bus includes an address bus carrying the memory addresses and memory select signals and a memory data bus carrying the memory data and the configuration data.

22. The automatic sizing memory system of claim 18 wherein for each of said modules said signature means includes means for storing configuration data identifying a type of error detection for the memory data.

-34-

23. The automatic sizing memory system of claim 18 wherein each of said configuration register means includes means for specifying that configuration data for the corresponding memory bank should be read from the signature means.

24. The automatic sizing memory system of claim 23 wherein said specifying means in each of said configuration register means includes a bit set by the processor.

25. The automatic sizing memory system of claim 18 wherein each said storage means includes at least one bank of memory cells and

wherein said configuration register means includes a plurality of status registers each corresponding to a different one of said at least one memory bank and each containing a base address data identifying the starting address of each of said at least one memory banks.

26. The automatic sizing memory system of claim 25 wherein each of said status registers includes means for indicating when the base address data in the status register for the corresponding memory bank is valid.

27. The automatic sizing memory system of claim 25 wherein said status registers each include

means for comparing the addresses received from said processor to the base address data in that status register to select the ones of said at least one memory banks containing locations corresponding to each of those addresses, and

means for activating address selection signals identifying the selected memory banks.

28. The automatic sizing memory system claim 27 wherein said memory bus includes address selection lines containing the memory select signals, and

wherein said control logic includes means for enabling certain of the memory select signals on said address selection lines according to the activated address selection signals.

29. The automatic sizing memory system claim 27 wherein each of said status registers includes means for enabling an address hit signal from the activated address selection signals to indicate when addresses from the processor are within one of said memory banks.

**SUBSTITUTE SHEET**

-35-

30. The automatic sizing memory system of claim 25 wherein each of said status registers includes means for indicating when memory data read from the corresponding memory bank contains an error.

31. The automatic sizing memory system of claim 25 wherein each of said status registers includes means for indicating the size of the corresponding memory bank.

32. The automatic sizing memory system of claim 25 wherein each of said status registers includes means for locking out access to the corresponding memory bank.

33. The automatic sizing memory system of claim 18 further including error detecting means, coupled to said memory bus, for detecting errors in the memory data.

34. The automatic sizing memory system of claim 18 further including first and second memory connectors connected to said memory bus,

said first memory connectors each corresponding to and being connected to a different one of said memory modules, and

said second memory connectors not being connected to any of said memory modules; and

wherein said memory controller means includes means for obtaining configuration data for said second memory connectors indicating that no memory module is contained in said second memory connectors.

35. The automatic sizing memory system of claim 18 wherein each of said storage means includes at least one bank of memory cells, and

wherein said configuration register means includes a plurality of status registers such corresponding to a different one of the at least one memory bank and each of said status registers including configuration read data specifying a configuration read operation of the configuration data for the corresponding memory bank, and

wherein said control means includes means for responding to said configuration read data to enable said memory select signals to cause the multiplexer means in the corresponding memory bank to place the configuration data for the corresponding memory bank onto said memory data bus.

**SUBSTITUTE SHEET**

-36-

36. A data processing system capable of automatic memory configuration and initialization comprising:

a central processing unit;

booting means, coupled to said central processing unit, for causing said central processing unit to institute memory initialization procedures including the generation of commands and addresses; and

a memory system, coupled to said central processing unit and responsive to the initialization procedures, said memory system including

memory controller means for constructing a configuration structure representing the arrangement of storage locations in said memory system and forming memory addresses and memory select signals from addresses and commands received from said processor, said memory controller means including

configuration register means for storing said configuration structure according to configuration data descriptive of the arrangement of storage locations in said memory system, and

control logic for forming the memory addresses and memory select signals from the addresses and commands received from said processor and from the configuration structure stored in the configuration register means; a memory bus, coupled to said memory controller means, for carrying memory data, the memory addresses, and the memory select signals; and

a first number of memory modules coupled to the memory bus and each including

storage means, coupled to the memory bus and having one of a plurality of configurations, for storing memory data at end for retrieving stored memory data from different locations corresponding to the memory addresses on the memory bus.

signature means for storing [the] configuration data identifying the configuration of said storage means,

**SUBSTITUTE SHEET**

-37-

multiplexer means, coupled to said storage means and said signature means, for placing, when activated, either the memory data or the configuration data onto said memory bus in response to multiplex control signals; and

control means, coupled to said multiplexer means and said memory bus, for activating said multiplexer means and for generating the multiplex control signals from the memory select signals on said memory bus thereby causing said multiplexer means, when activated, to transfer either the memory data or the configuration data onto said memory bus.

37. The data processing system in claim 36 wherein said booting means includes

a ROM including a memory initialization program containing instructions to implement the memory initialization procedures, and

means for sensing an initialization condition to cause said central processing unit to begin the initialization program.

38. The data processing system in claim 37 wherein said ROM also includes initialization programs for other portions of said data processing system.

39. The data processing system of claim 37 wherein for each module

each of said storage means includes at least one bank of memory cells, and

wherein said signature means includes means for storing the configuration data identifying the number and size of banks.

40. The data processing system of claim 39 wherein for each of said modules said multiplexer means includes

a plurality of transceivers coupled to the memory bus, and

**SUBSTITUTE SHEET**

-38-

a plurality of multiplexers having one set of inputs coupled to the at least one bank of memory cells and another set of inputs coupled to said signature means; and

wherein said control means includes

means for forming a first multiplex control signal for activating said plurality of transceivers, and

means for forming a second multiplex control signal to select one of the sets of inputs.

41. The data processing system of claim 36 wherein said memory bus includes an address bus carrying the memory addresses and memory select signals and a memory data bus carrying the memory data and the configuration data.

42. The data processing system of claim 36 wherein for each of said modules said signature means includes means for storing configuration data identifying a type of error detection for the memory data.

43. The data processing system claim 36 wherein each of said configuration register means includes means for specifying that configuration data for the corresponding memory bank should be read from the signature means.

44. The data processing system of claim 43 wherein said specifying means in each of said [status registers is] configuration register means includes a bit set by the processor.

45. The data processing system of claim 36 wherein for each of said modules said storage means includes at least one bank of memory cells and

wherein said configuration register means includes a plurality of status registers each corresponding to a different one of said at least one memory bank and each containing to a different one of said at least one memory bank and each containing base address data identifying the address of each of said at least one memory bank.

46. The data processing system of claim 45 wherein each of said status registers also includes means for indicating when the base address data in the status register for the corresponding memory bank is valid.

**SUBSTITUTE SHEET**



-39-

47. The data processing system of claim 45 wherein said status registers each include

means for comparing the addresses received from said processor to the base address data in that status register means to select the ones of said memory banks containing locations corresponding to each of those addresses, and

means for activating address selection signals identifying the selected memory banks.

48. The data processing system of claim 47 wherein said memory bus includes address selection lines containing the memory select signals, and

wherein said control logic includes means for enabling the memory select signals on said address selection lines based on the activated address selection signals.

49. The data processing system of claim 47 wherein each of said status registers includes means for enabling an address hit signal from the activated address selection signals to indicate when addresses from the processor are within one of said memory banks.

50. The data processing system of claim 45 wherein each of said status registers includes means for indicating when memory data read from the corresponding memory bank containing an error.

51. The data processing system of claim 45 wherein each of said status registers includes means for indicating the size of the corresponding memory bank.

52. The data processing system of claim 45 wherein each said status registers includes means for locking out access to the corresponding memory bank.

53. The data processing system of claim 36 further including error detecting means, coupled to said memory bus, for detecting errors in the memory data.

54. The data processing system of claim 36 further including first and second memory connectors connected to said memory bus,

said first memory connectors each corresponding to and being connected to a different one of said memory modules, and

**SUBSTITUTE SHEET**

-40-

said second memory connectors not being connected to any of said memory modules; and

wherein said memory controller means includes means for obtaining configuration data for said second memory connectors indicating that no memory module is contained in said second memory connectors.

55. The data processing system of claim 36 wherein each of said modules said storage means includes at least one bank of memory cells, and

wherein said configuration register means includes a plurality of status registers each corresponding to a different one of the at least one memory banks, each of said status registers including configuration read data specifying a read of the configuration data for the corresponding memory bank, and

wherein said control means includes means for responding to said configuration read data to form said memory select signals to cause the multiplexer means in the corresponding memory bank to place the configuration data for the corresponding memory bank onto said memory data bus.

FIG. 1

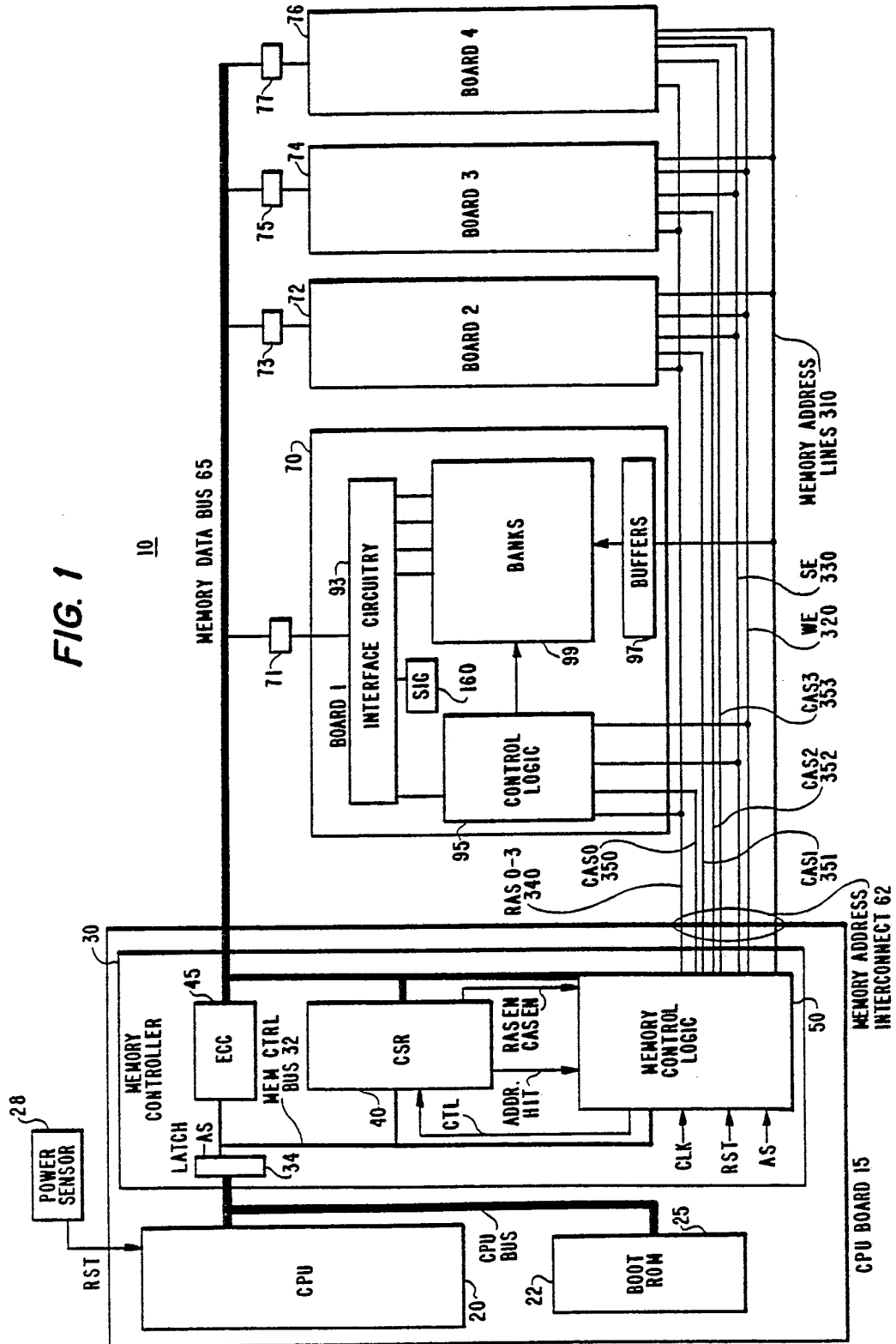


FIG. 2

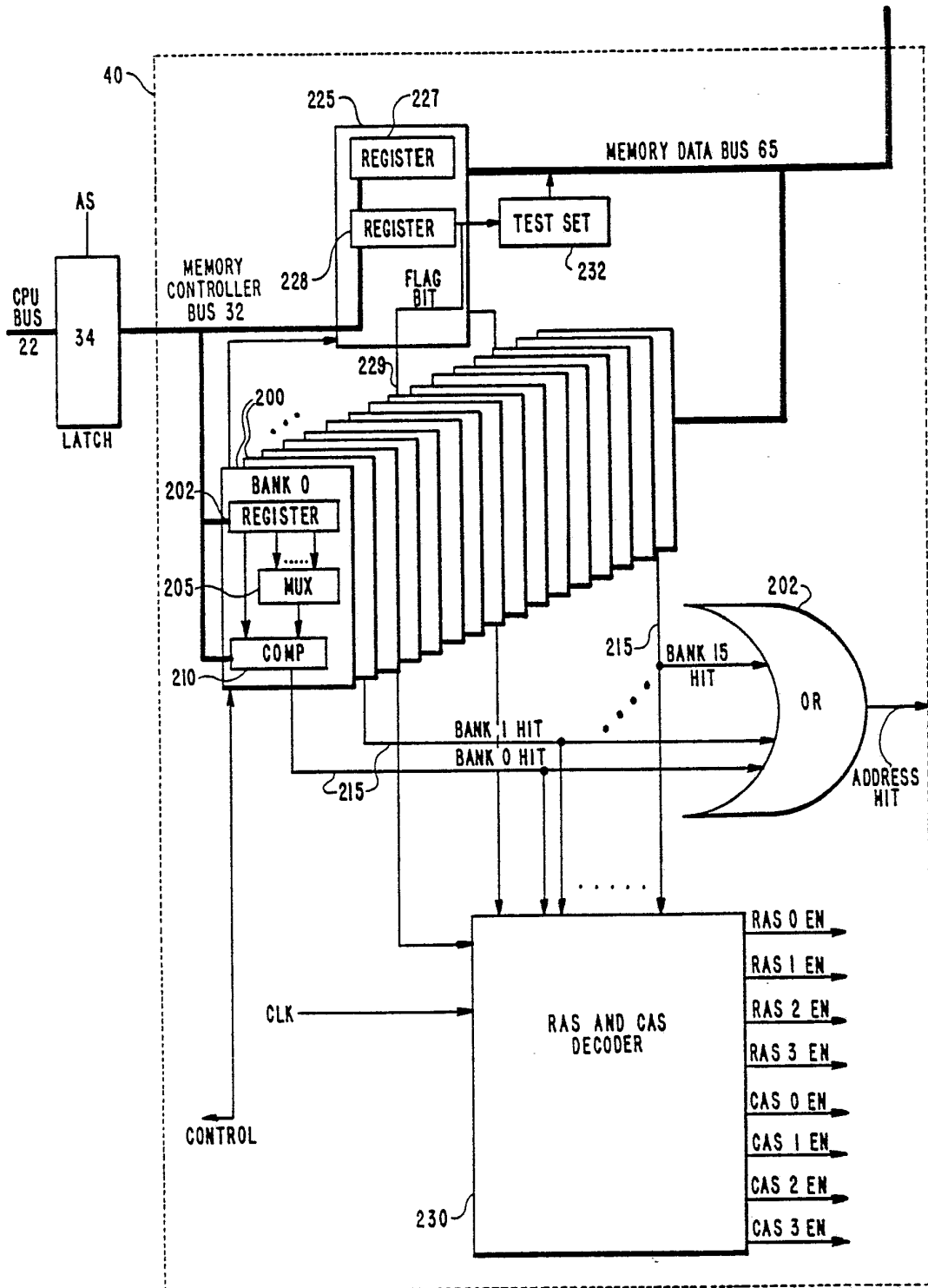


FIG. 3

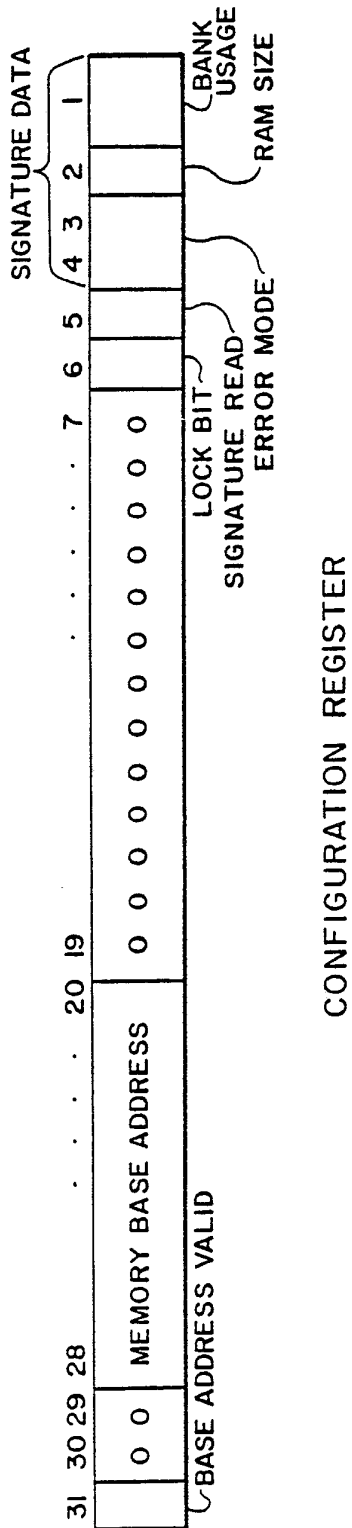
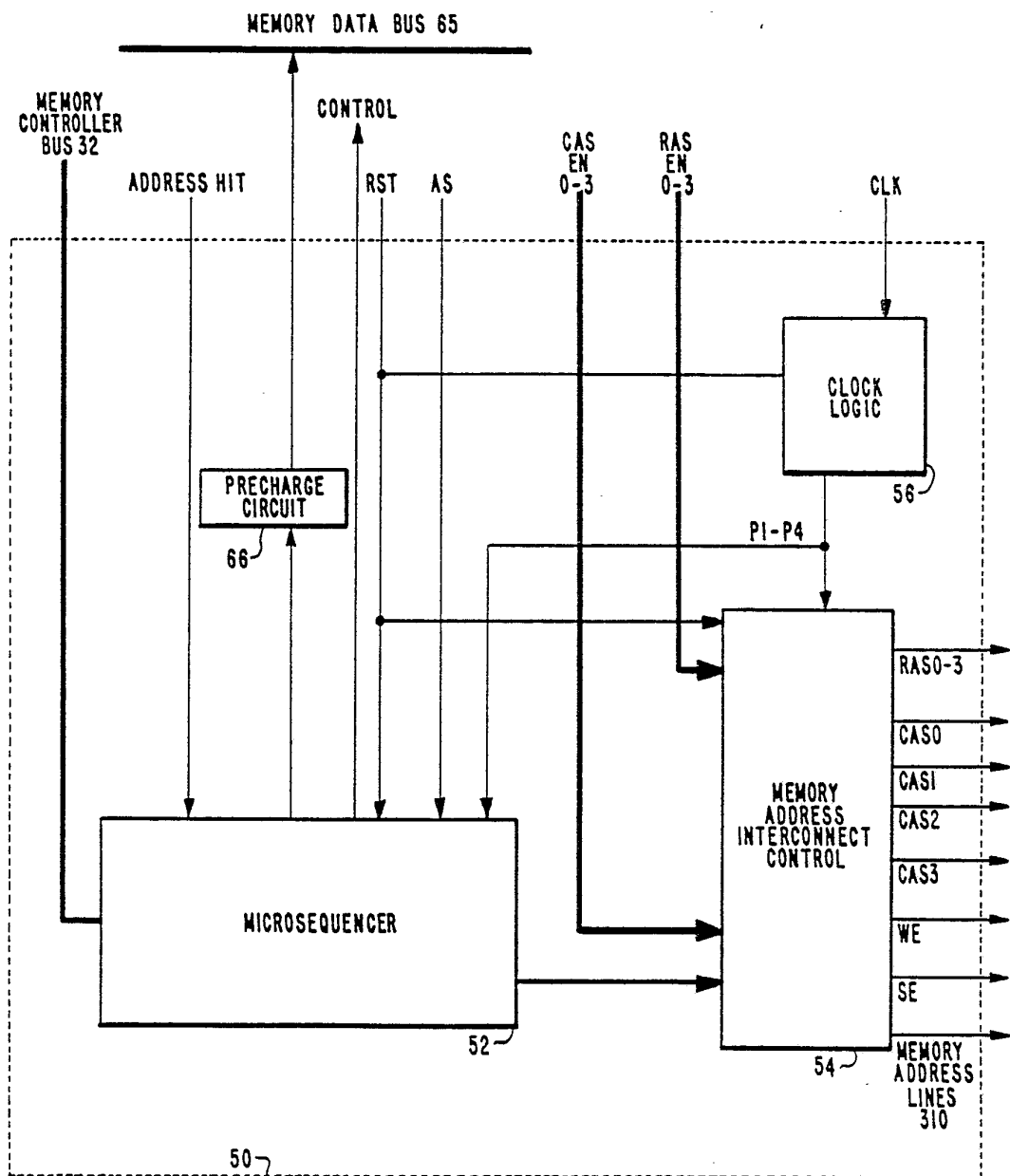


FIG. 4



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FIG. 5

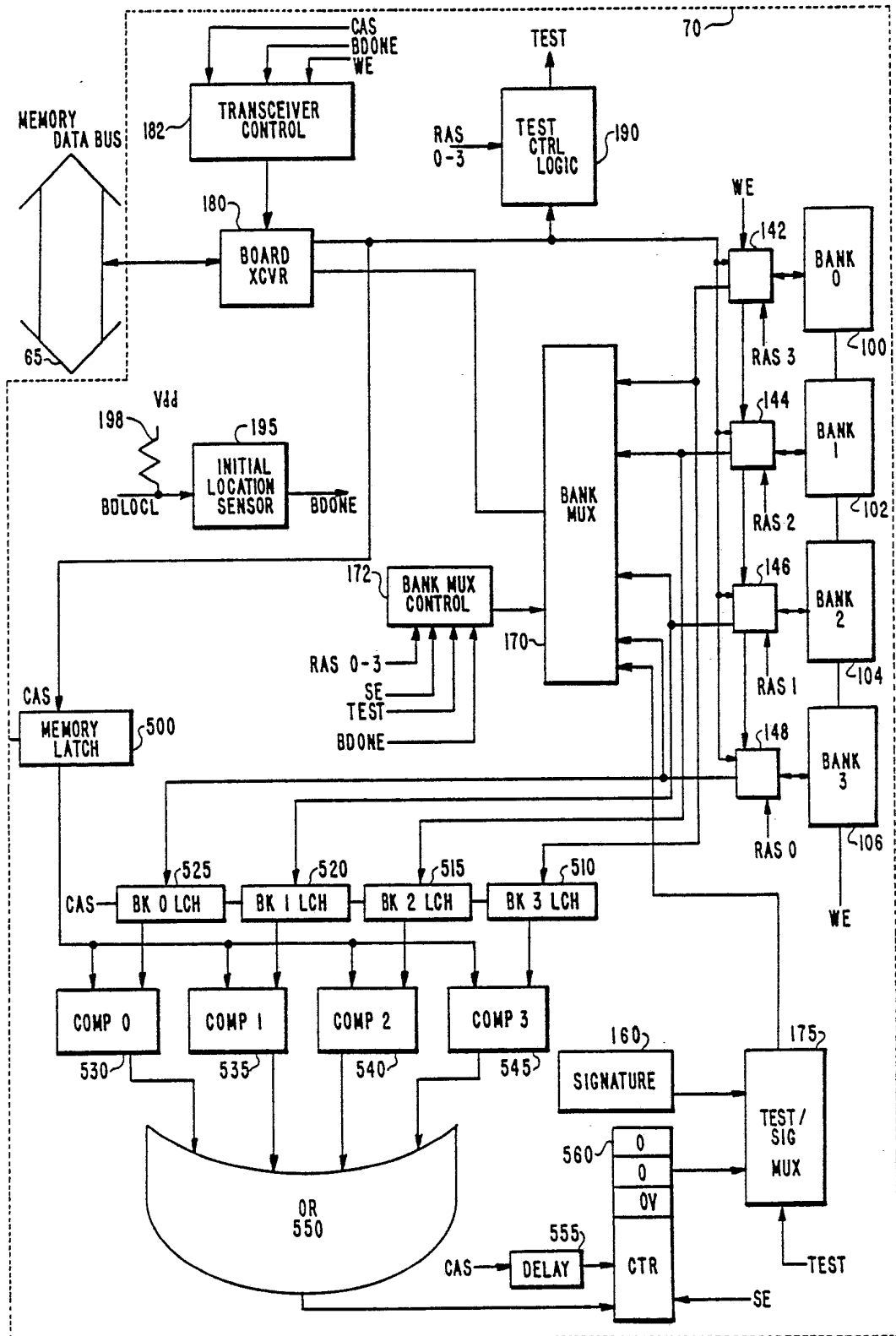
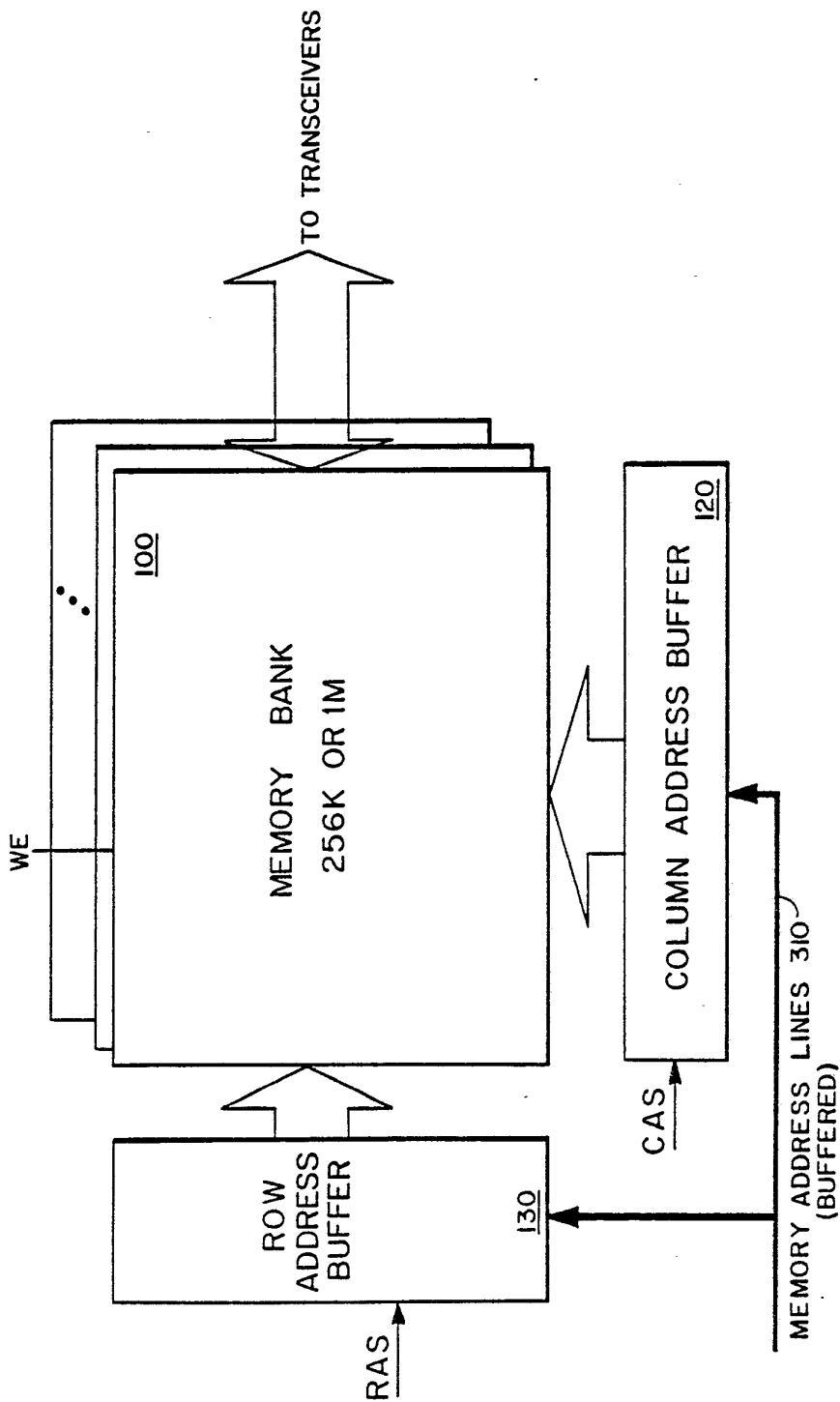


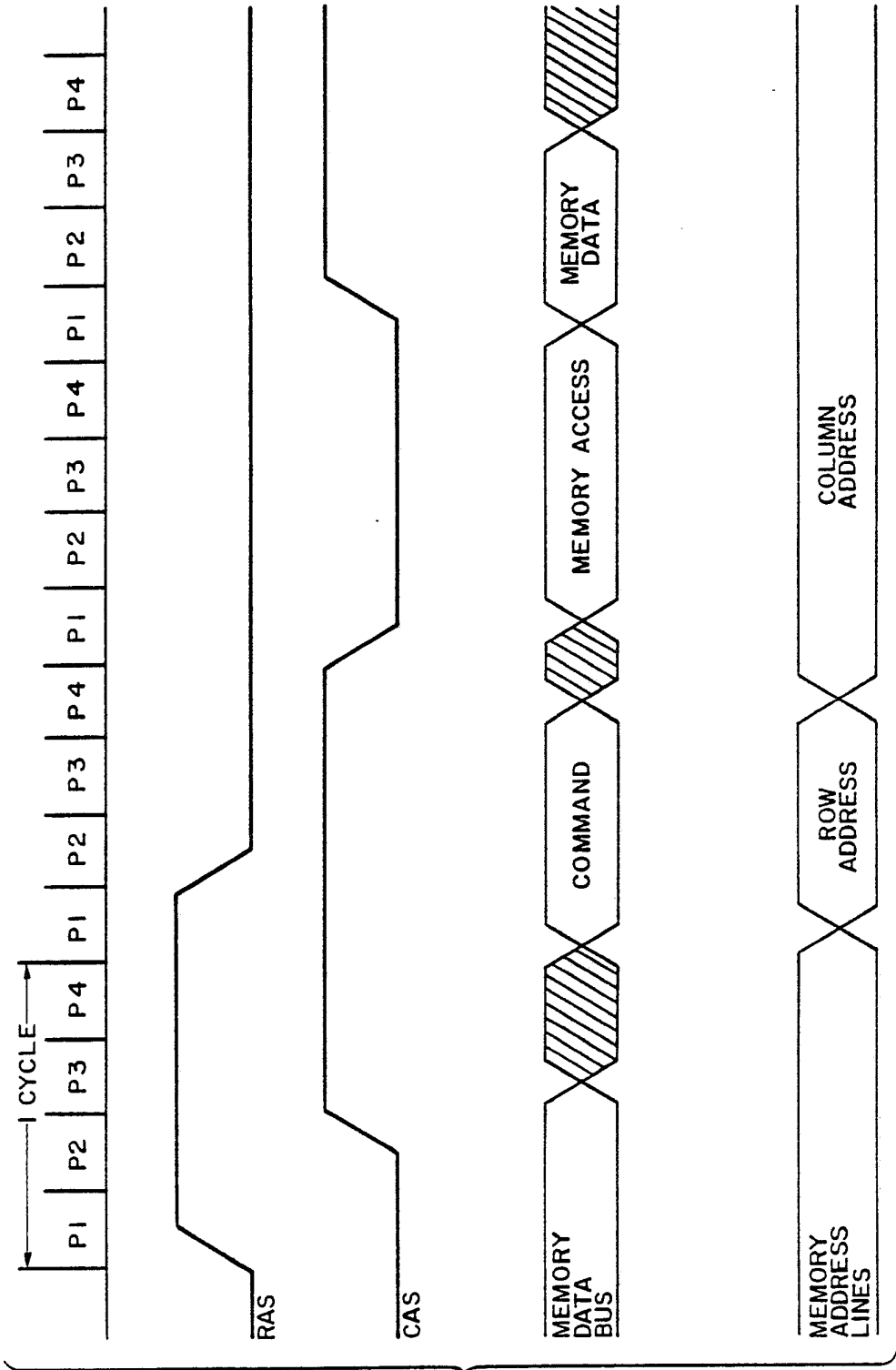
FIG. 6



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**FIG. 7A**  
READ TIMING



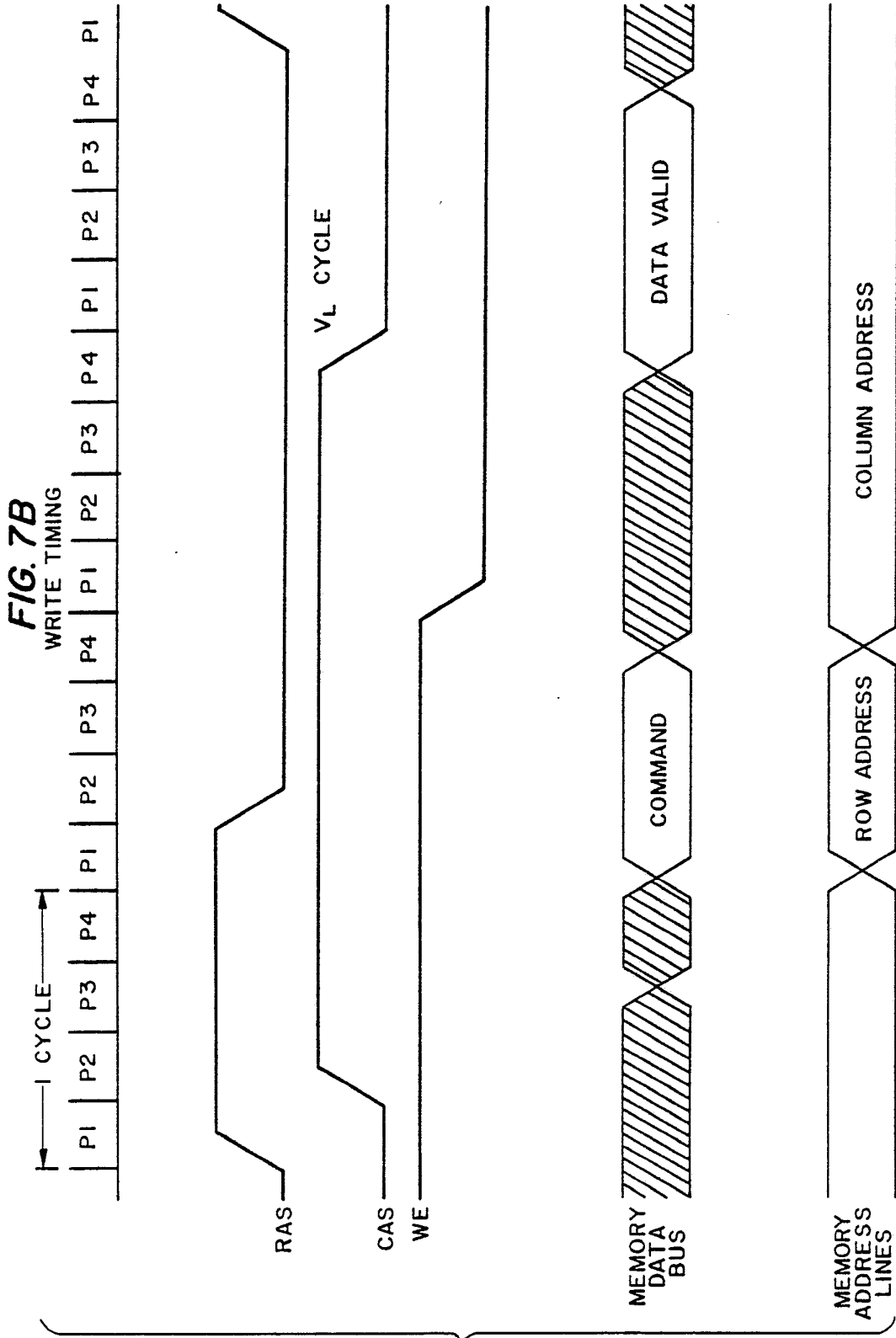
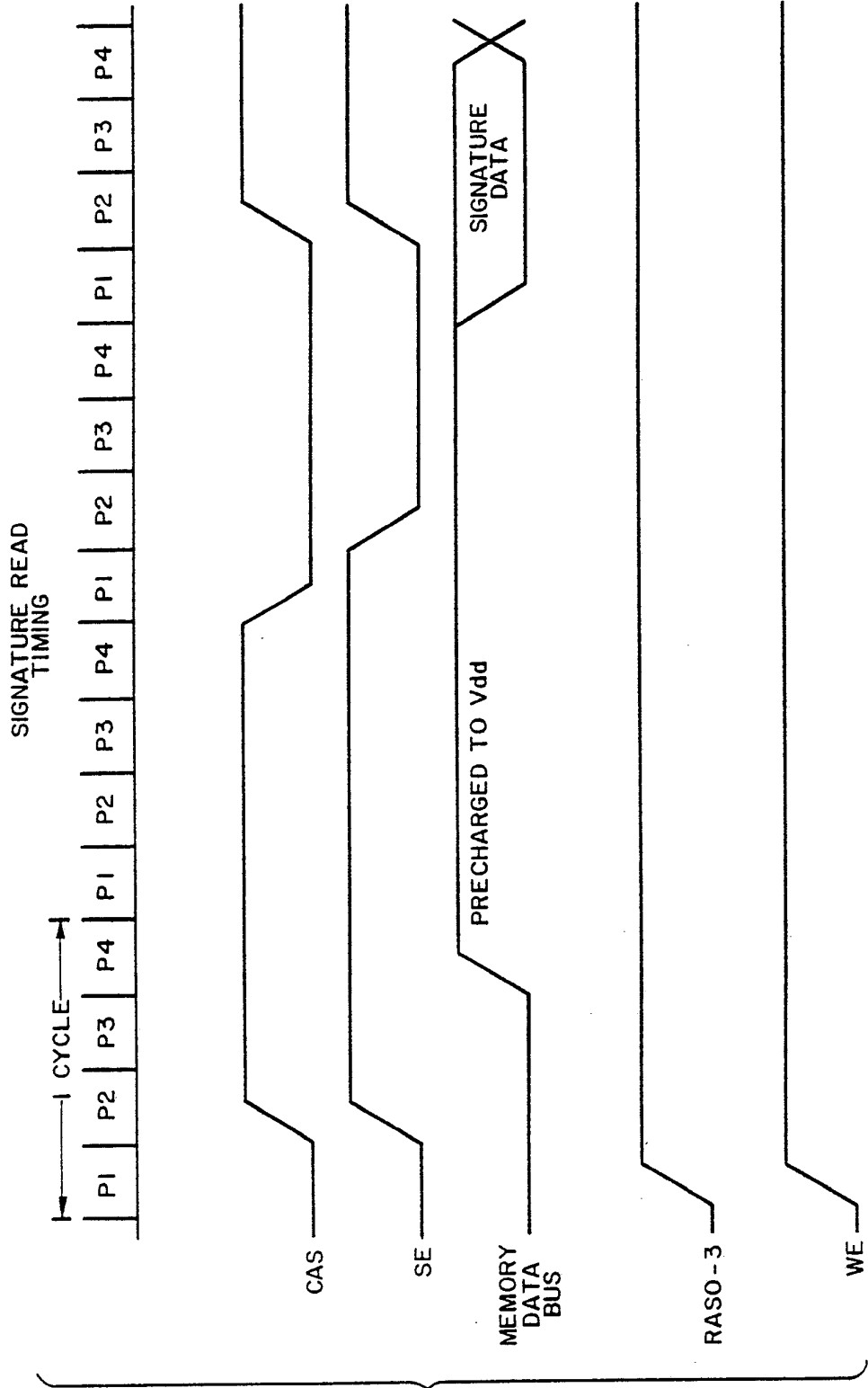


FIG. 7C



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FIG. 7D

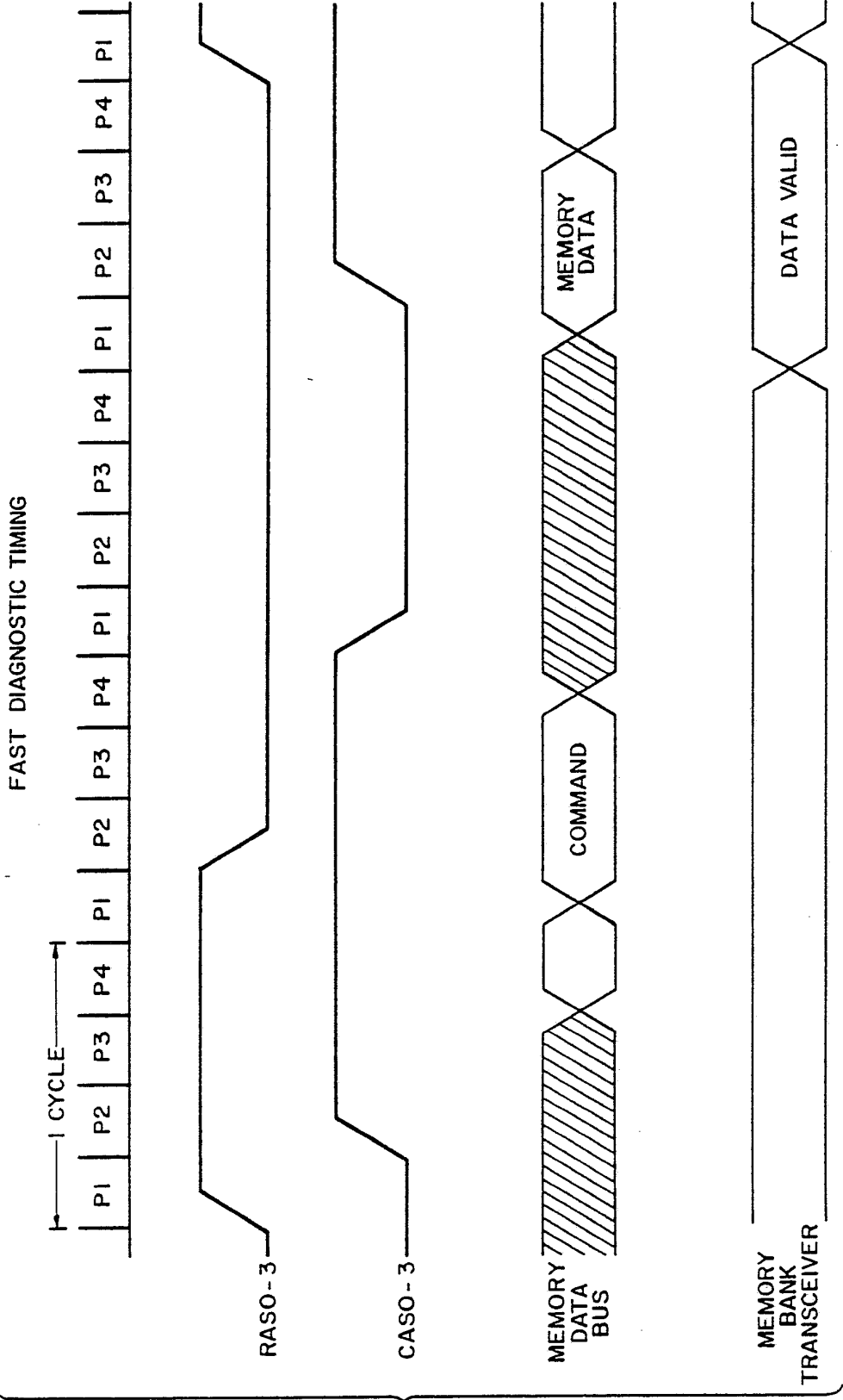
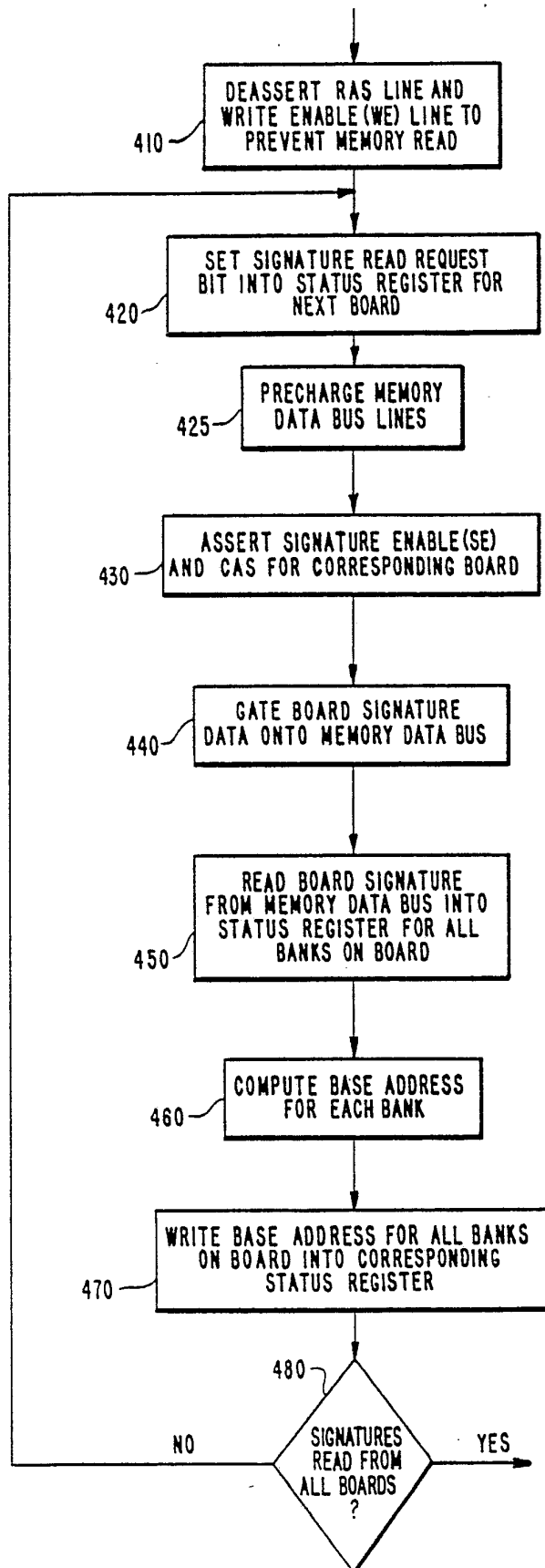
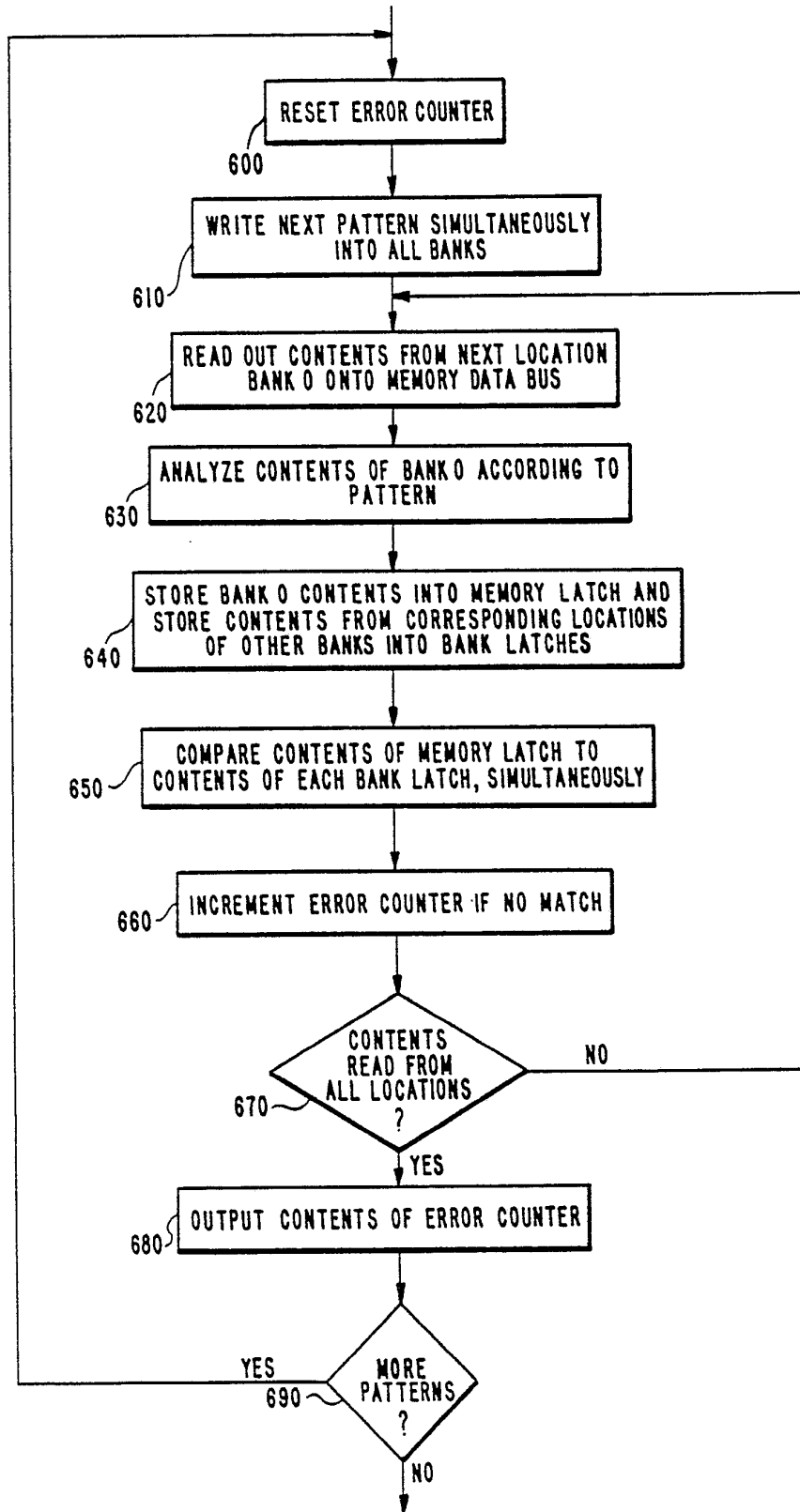


FIG. 8



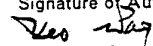
12/12

FIG. 9



# INTERNATIONAL SEARCH REPORT

International Application No. PCT/US88/01334

<b>I. CLASSIFICATION OF SUBJECT MATTER</b> (if several classification symbols apply, indicate all) <sup>6</sup>		
According to International Patent Classification (IPC) or to both National Classification and IPC IPC (4): G06F: 12/00; 12/06 U.S. Cl.: 364/200; 364/900		
<b>II. FIELDS SEARCHED</b>		
Minimum Documentation Searched <sup>7</sup>		
Classification System	Classification Symbols	
U.S.	364/200, 900	
Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched <sup>8</sup>		
<b>III. DOCUMENTS CONSIDERED TO BE RELEVANT</b> <sup>9</sup>		
Category *	Citation of Document, <sup>11</sup> with indication, where appropriate, of the relevant passages <sup>12</sup>	Relevant to Claim No. <sup>13</sup>
Y	US, A, 4,414,627 (NAKAMURA) 31 December 1985, see entire document	1, 2, 4, 6, 7, 11, 12, 14, 16, 18, 19, 21, 23, 25, 28, 28, 29, 34, 36, 39, 41, 43, 45, 46, 48, 49, 54
Y	US, A, 4,562,532 (NISHIZAWA) 31 December 1985, see entire document	1, 2, 4, 6, 7, 9, 11, 12, 14, 16, 17, 18, 19, 21, 25, 28, 29 34, 35, 36, 39 41, 45, 48, 49 54, 55
Y, P	US, A, 4,688,219 (TAKEMAE) 18 August 1987, see entire document	30, 33, 50, 53
Y	US, A, 4,519,032 (MENDELL) 21 May 1985, see entire document	1, 2, 4,-7, 9-12 14-15, 17-19, 21-22, 25, 27-33, 36-39, 41, 42, 45, 47-53, 55
* Special categories of cited documents: <sup>10</sup> "A" document defining the general state of the art which is not considered to be of particular relevance "E" earlier document but published on or after the international filing date "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) "O" document referring to an oral disclosure, use, exhibition or other means "P" document published prior to the international filing date but later than the priority date claimed		"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art. "&" document member of the same patent family
<b>IV. CERTIFICATION</b>		
Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report	
14 JUNE 1988	18 JUL 1988	
International Searching Authority	Signature of Authorized Officer	
ISA/US	 Leo Li Wang	

III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claim No
Y	US, A, 4,316,244 (GRONDALSKI) 16 February 1982, see entire document	1, 6, 11, 18, 36 2, 7, 12, 19, 39, 4, 9, 14, 21, 41
A	US, A, 4,468,729 (SCHWARTZ) 28 August 1984	
A	US, A, 4,571,676 (MANTELLINA) 18 February 1986	
A,P	US, A, 4,701,878 (GUNKEL) 20 October 1987	
A,P	US, A, 4,740,916 (MARTIN) 26 April 1988	
A	US, A, 4,025,903 (KAUFMAN) 24 May 1977	
A	US, A, 4,592,011 (MANTELLINA) 27 May 1986	
A	US, A, 4,507,730 (JOHNSON) 26 March 1985	
A	US, A, 4,334,307 (BOURGEOIS) 8 June 1982	
A	US, A, 4,456,966 (BRINGOL) 26 June 1984	