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(54) **REGISTER FILE INDEXING METHODS AND APPARATUS FOR PROVIDING INDIRECT CONTROL OF REGISTER ADDRESSING IN A VLIW PROCESSOR**

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**G06F 9/35** (2006.01)  
**G06F 9/44** (2006.01)  
**G06F 9/355** (2006.01)  
**G06F 9/30** (2006.01)

(52) **U.S. Cl.** ..... **712/229; 712/230; 712/24; 712/206; 712/215; 712/207; 712/211; 712/220; 711/214; 711/216**

(58) **Field of Classification Search** ..... **712/229, 712/230, 24, 206, 215, 207, 211; 711/214, 711/216, 220**

See application file for complete search history.

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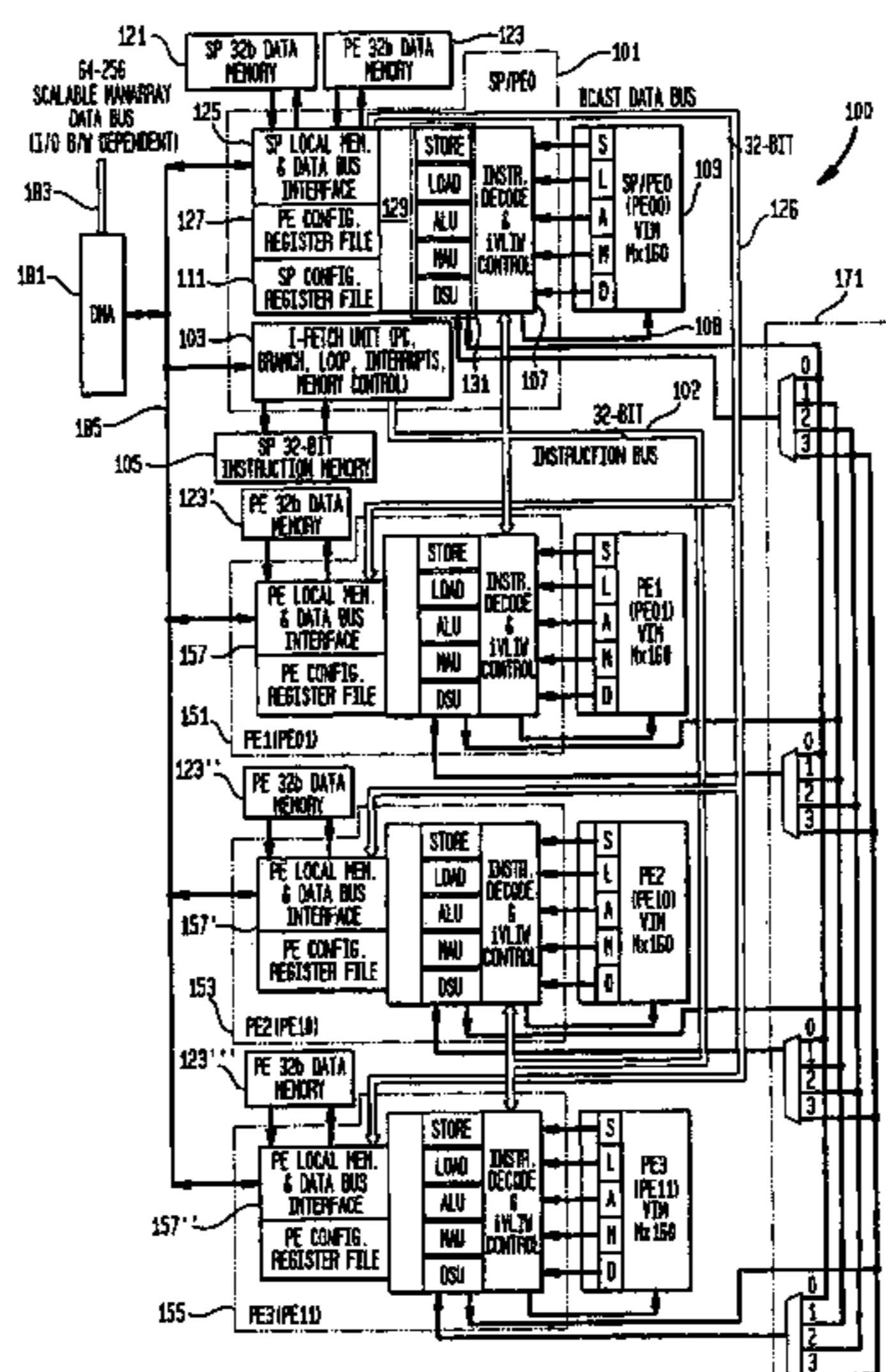
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(57) **ABSTRACT**

A double indirect method of accessing a block of data in a register file is used to allow efficient implementations without the use of specialized vector processing hardware. In addition, the automatic modification of the register addressing is not tied to a single vector instruction nor to repeat or loop instructions. Rather, the technique, termed register file indexing (RFI) allows full programmer flexibility in control of the block data operational facility and provides the capability to mix non-RFI instructions with RFI instructions. The block-data operation facility is embedded in the iVLIW ManArray architecture allowing its generalized use across the instruction set architecture without specialized vector instructions or being limited in use only with repeat or loop instructions. The use of RFI in a processor containing multiple heterogeneous execution units which operate in parallel, such as VLIW or iVLIW processors, allows for efficient pipelining of algorithms across multiple execution units while minimizing the number of VLIW instructions required.

**47 Claims, 12 Drawing Sheets**



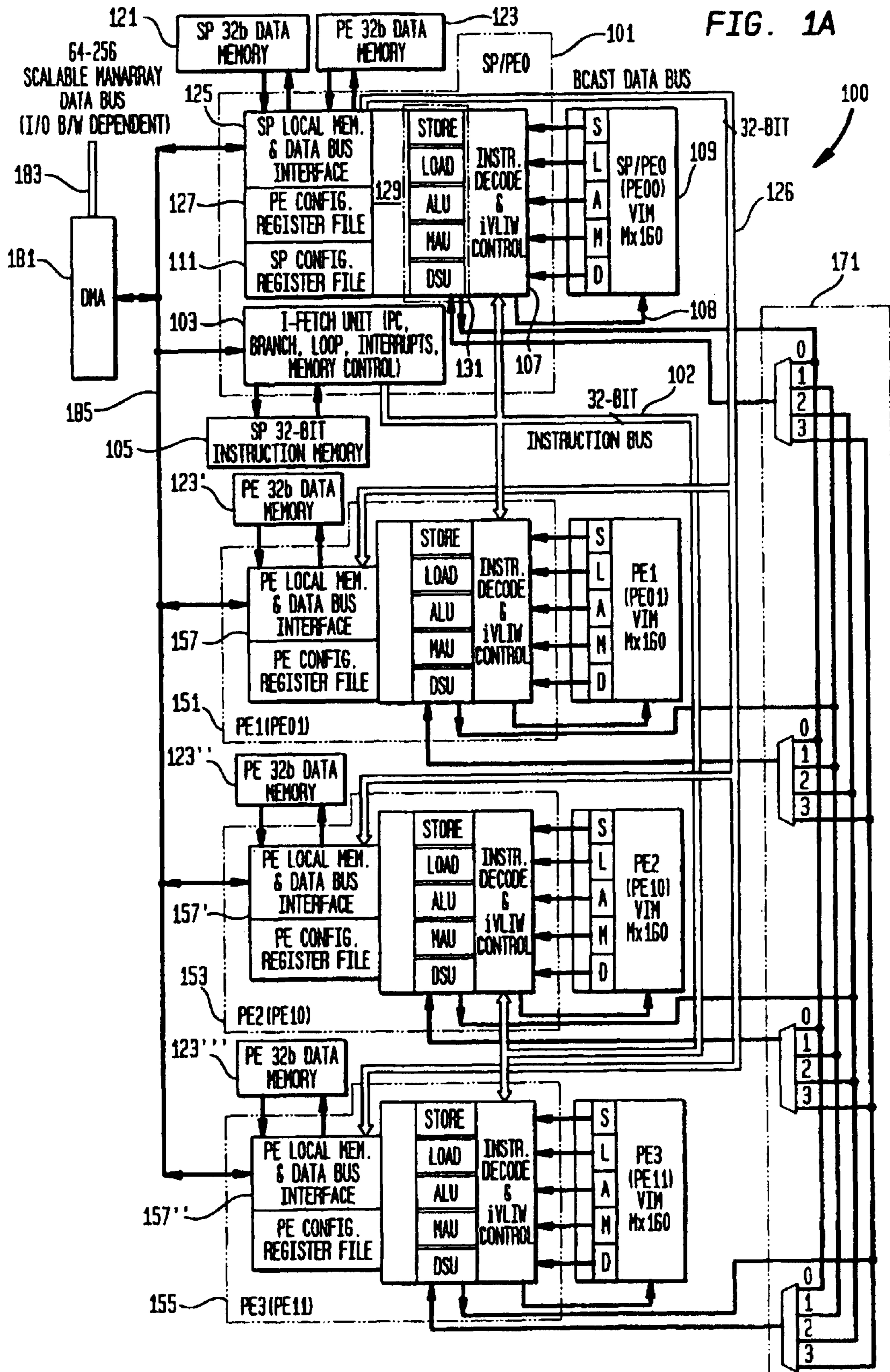


FIG. 1B  
(PRIOR ART)

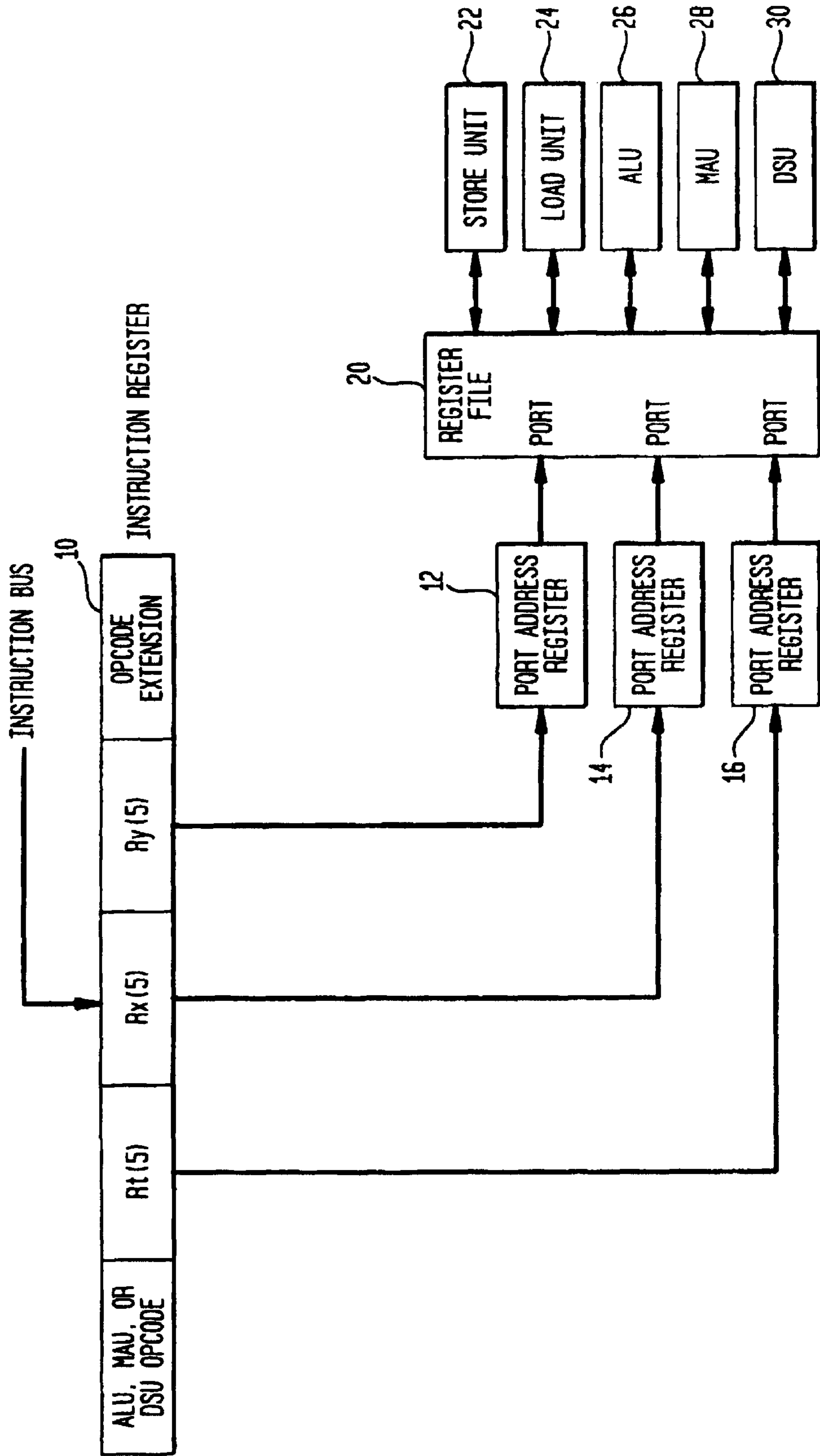


FIG. 2A

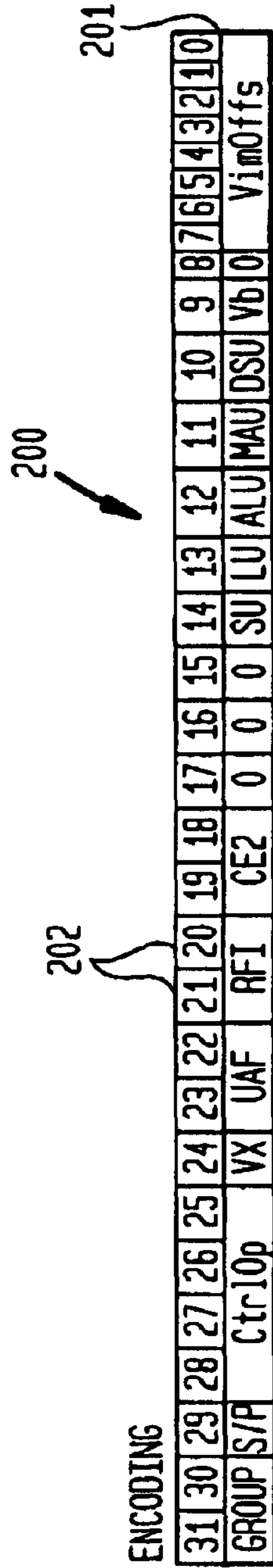


FIG. 2B

SYNTAX/OPERATION		OPERATION
INSTRUCTION	OPERANDS	OPERATION
XV.[SP]	V[01], VIMOFFS, E={SLAMD}, F={ADMINJ}.[R]	Execute (V[01]+VIMOFFS)[SU] if (C=S) Execute (V[01]+VIMOFFS)[LU] if (C=L) Execute (V[01]+VIMOFFS)[ALU] if (C=A) Execute (V[01]+VIMOFFS)[MAU] if (C=M) Execute (V[01]+VIMOFFS)[DSU] if (C=D)
[TF].XV.[SP]	V[01], VIMOFFS, E={SLAMD}, F=N, [R]	(V[01]+VIMOFFS)[UAF]ALU if (F=or F=A) (V[01]+VIMOFFS)[UAF]MAU if (F=M) (V[01]+VIMOFFS)[UAF]DSU if (F=D)
		DO OPERATION ONLY IF T/F CONDITION IS SATISFIED IN F0

203

**FIG. 3A**

The MRF for SP and PEs is as follows:

Address	SP (Mnemonic)	PE (Mnemonic)	Register Name
101000	Reserved	Reserved	Reserved
101001	Reserved	Reserved	Reserved
111010	⋮	⋮	⋮
111011	Reserved	Reserved	Reserved
111100	MRFXAR	MRFXAR	MRF Extension Address Register (Default is 0x00000000)
111101	MRFXDR1	MRFXDR1	MRF Extension Data Register-1(MRFX1 registers mapped here)
111110	MRFXDR2	MRFXDR2	MRF Extension Data Register-2(RFI registers mapped here)
111111	RFILSD	RFILSD	RFI Enable Address for Load, Store, and DSU block operations

301  
302  
303  
304

**FIG. 3B**

MRF Extension 1 (MRFX1) Registers are the following:

MRFX1 address	SP (Mnemonic)	PE (Mnemonic)	Register Name
000	Reserved	Reserved	Reserved
001	Reserved	Reserved	Reserved
⋮	⋮	⋮	⋮
111	Reserved	Reserved	Reserved

305

**FIG. 3C**

MRF Extension 2 (MRFX2) Registers are the following:

MRFX2 address	SP (Mnemonic)	PE (Mnemonic)	Register Name
000	RFIDLS0	RFIDLS0	1st RFI DSU(H1), Load(B0), & Store(B1) Control Register
001	RFIAM0	RFIAM0	1st RFI ALU(H1) & MAU(H0) Control Register
010	RFIDLS1	RFIDLS1	2nd RFI DSU(H1), Load(B0), & Store(B1) Control Register
011	RFIAM1	RFIAM1	2nd RFI ALU(H1) & MAU(H0) Control Register
100	RFIDLSI	RFIDLSI	DSU(H1), Load(B0), & Store(B1) Port Index Save/Restore Context
101	RFIAM1	RFIAM1	ALU(H1) & MAU(H0) Port Index Save/Restore Context
110	Reserved	Reserved	Reserved
111	RFIStart	RFIStart	2nd Control Group Start bits (H1) & 1st Control Group Start bits(H0)

310  
320  
330  
340  
350  
360  
370  
380

FIG. 4A

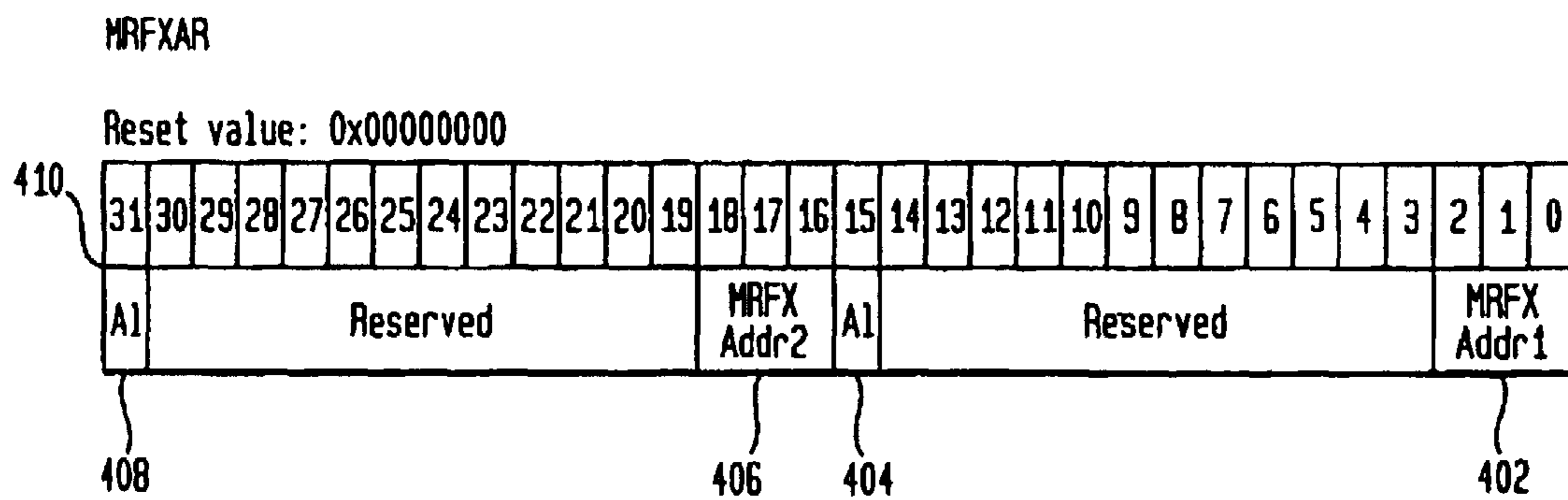


FIG. 4B

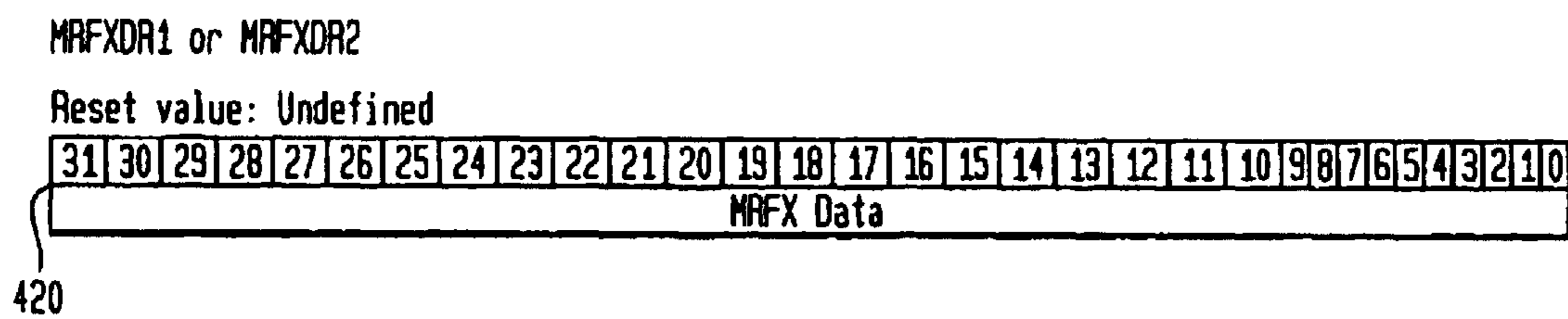


FIG. 5

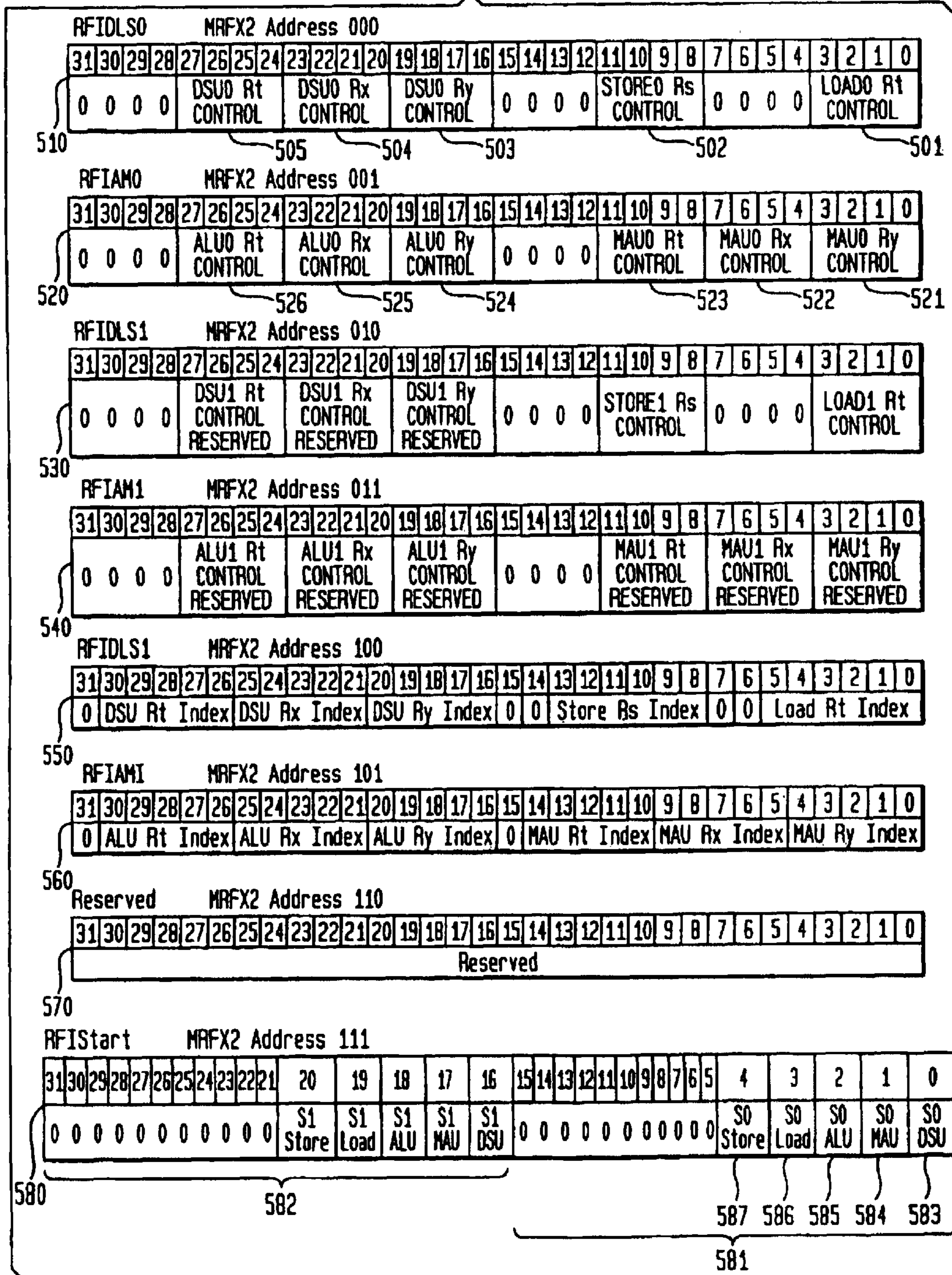


FIG. 6

600

601	602	603	604	605	606	607	608	609	610	611	612
INCREMENT CONTROL	RFBS CONTROL	INCREMENT AMOUNT	RFBS	G 4	G 3	G 2	G 1	G 0	X 1	X 0	APPLICABLE UNITS
0	000	0	1	x	x	x	x	x	0	0	ALL
0	001	1	2	x	x	x	x	0	0	1	ALL
0	010	1	4	x	x	x	0	1	0	1	ALL
0	011	1	8	x	x	0	1	1	0	1	ALL
0	100	1	16	x	0	1	1	1	0	1	ALL
0	101	1	32	0	1	1	1	1	0	1	ALL
0	110	1	64	1	1	1	1	1	0	1	LOAD/STORE
0	111	RESERVED	RESERVED	-	-	-	-	-	-	-	RESERVED
1	000	RESERVED	RESERVED	-	-	-	-	-	-	-	RESERVED
1	001	RESERVED	RESERVED	-	-	-	-	-	-	-	RESERVED
1	010	2	4	x	x	x	0	1	1	0	ALL
1	011	2	8	x	x	0	1	1	1	0	ALL
1	100	2	16	x	0	1	1	1	1	0	ALL
1	101	2	32	0	1	1	1	1	1	0	ALL
1	110	2	64	1	1	1	1	1	1	0	LOAD/STORE
1	111	RESERVED	RESERVED	-	-	-	-	-	-	-	RESERVED

620



FIG. 7A

LIM-LOAD IMMEDIATE

ENCODING

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
GROUP		S/PL/S		000			CE1	LOC	Rt5-0							IMM16															



LOC Location for LIM instruction

- 00=Load H1, do not affect H0
- 01=Load H0, do not affect H1
- 10=Load H0, H1=0x0000
- 11=Load H0, H1=0xFFFF

FIG. 7B

Syntax/Operation

Instruction	Operands	Operation
WORD		
LIM.[SP].W	Rt, IMM17	if (MSB(IMM17)==1) Rt.H1 0xFFFF if (MSB(IMM17)==0) Rt.H1 0x0000 Rt.H0 ← IMM16
T.LIM.[SP].W	Rt, IMM17	Do operation only if T condition is satisfied in F0
HALFWORD		
LIM.[SP].H1	Rt, IMM16	Rt.H1 ← IMM16
LIM.[SP].H0	Rt, IMM16	Rt.H0 ← IMM16
T.LIM.[SP].[H0H1]	Rt, IMM16	Do operation only if T condition is satisfied in F0



Arithmetic Flags Affected

None

Cycles: 1

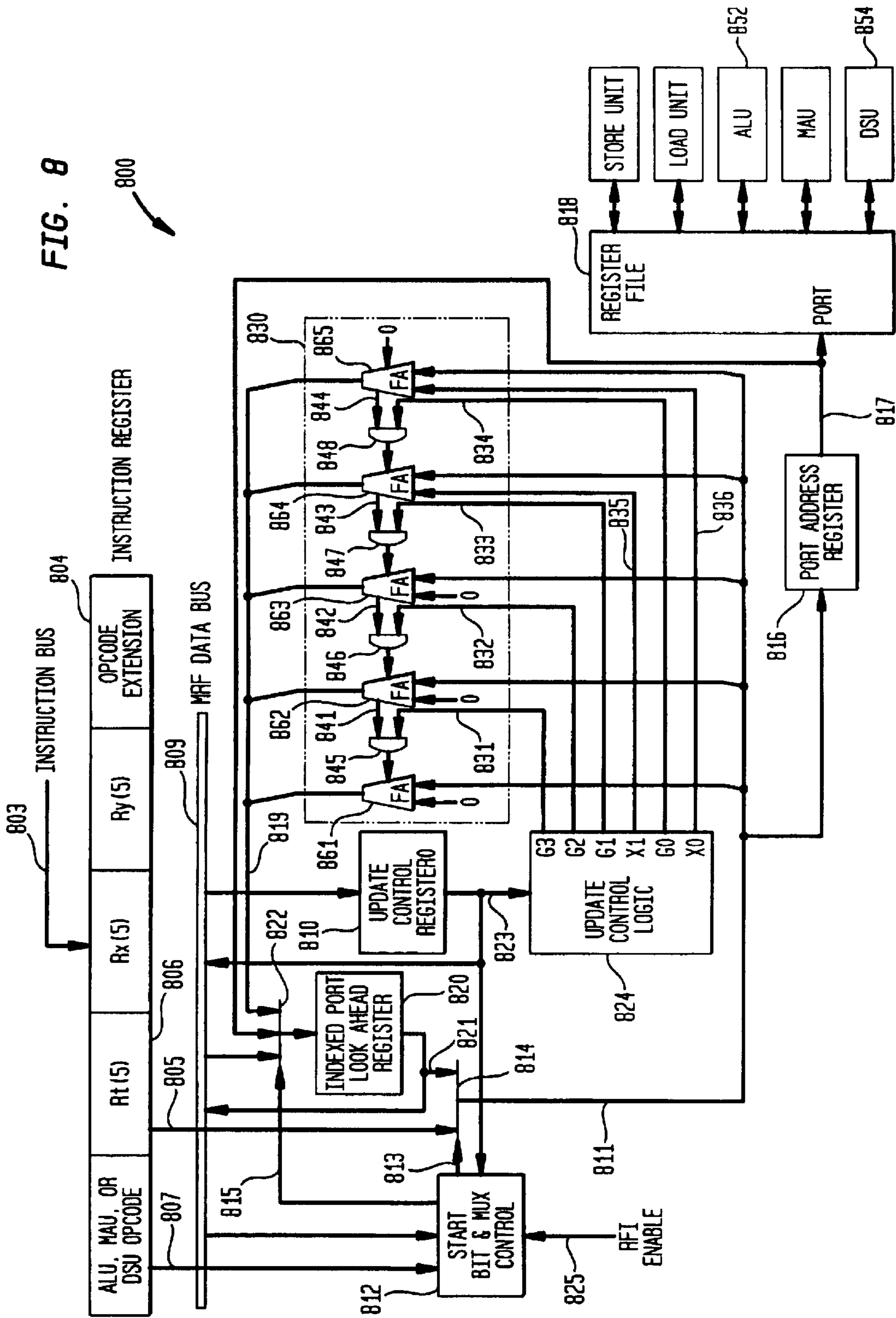
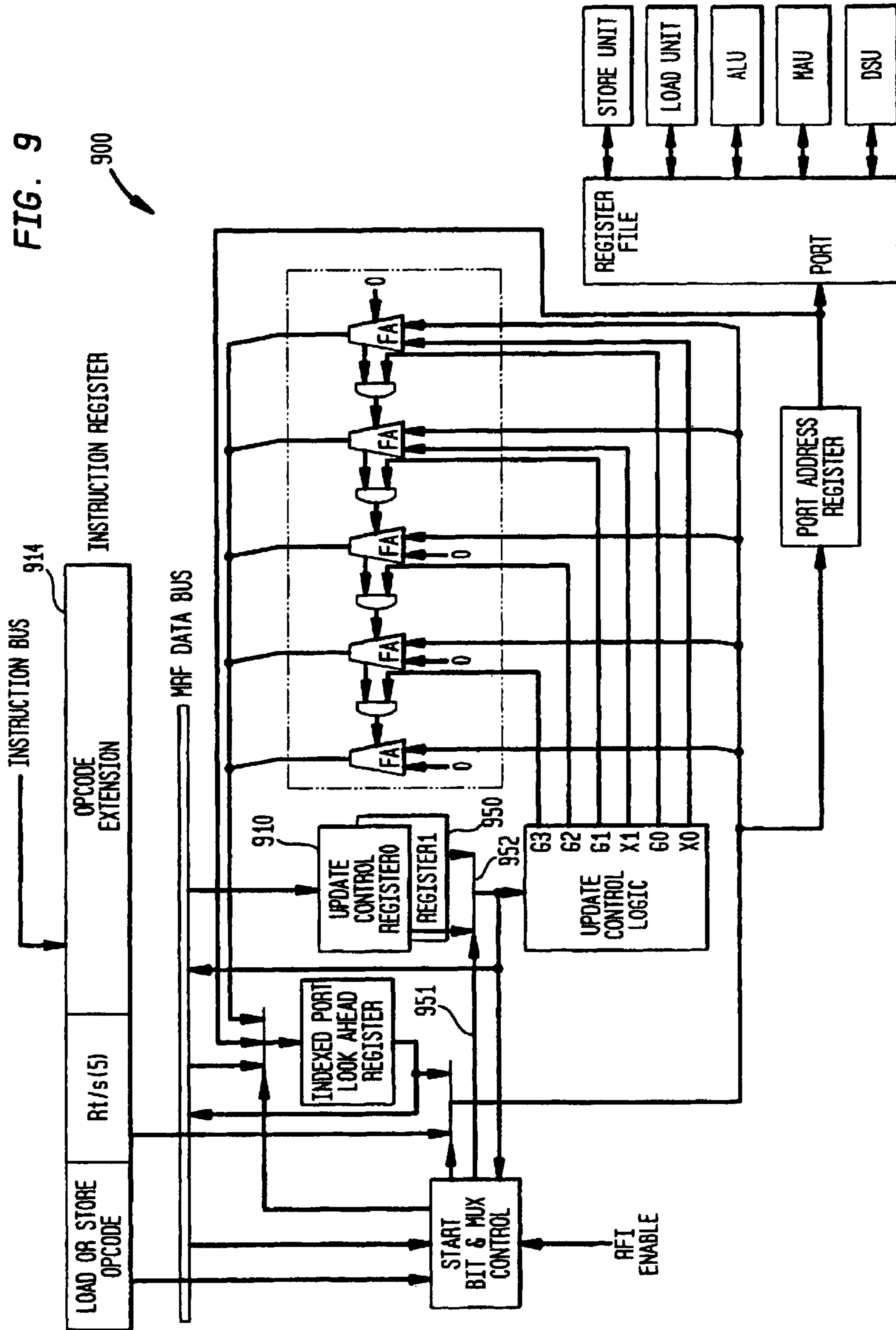
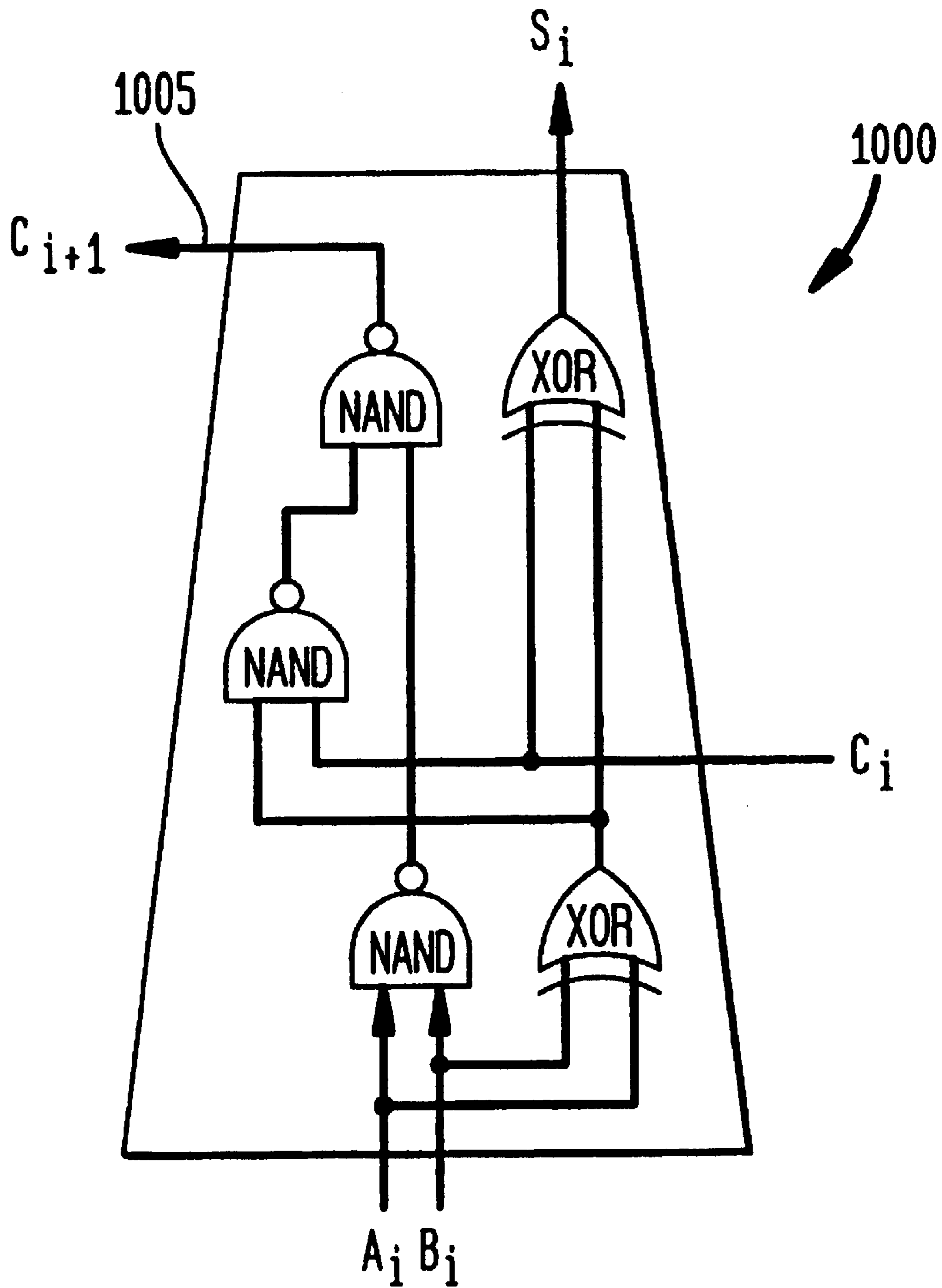


FIG. 9



**FIG. 10**





**REGISTER FILE INDEXING METHODS AND  
APPARATUS FOR PROVIDING INDIRECT  
CONTROL OF REGISTER ADDRESSING IN A  
VLIW PROCESSOR**

**Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.**

CROSS REFERENCE TO RELATED  
APPLICATIONS

The present application claims the benefit of U.S. Provisional Application Ser. No. 60/077,766 filed Mar. 12, 1998 and entitled "Register File Indexing Methods and Apparatus for Providing Indirect Control of Register in a VLIW Processor."

FIELD OF THE INVENTION

The present invention relates generally to improvements in very long instruction word (VLIW) processing, and more particularly to advantageous register file indexing (RFI) techniques for providing indirect control of register addressing in a VLIW processor.

BACKGROUND OF THE INVENTION

One important processor model is that of vector processing. This model has been used in prior art super computers for many years. Typical features of this model are the use of specialized vector instructions, specialized vector hardware, and the ability to efficiently operate on blocks of data. It is this very ability to operate typically only on vector data types that makes the model inflexible and unable to efficiently handle diverse processing requirements. In addition, in prior art vector processors, support for control scalar processing was typically done in separate hardware or in a separate control processor. Another processor model is the prior art very long instruction word (VLIW) processor model which represents a parallel processing model based on the concatenation of standard uniprocessor type single function operations into a long instruction word with no specialized multicycle vector processing facilities. To efficiently operate a block-data vector pipeline, it is important to have an efficient interface to deliver the individual vector elements. For this purpose, a successful class of prior art vector machines have been register based. The register based vector processors provide high performance registers for the vector elements allowing efficient access of the elements by the functional execution units. A single vector instruction tied to an implementation specific vector length value causes a block data multicycle operation. In addition, many vector machines have provided a chaining facility where operations on the individual vector elements are directly routed to other vector functional units to improve performance. These previous features and capabilities provide the background for the present invention. It is an object of the present invention to incorporate scalar, VLIW, and flexible vector processing capabilities efficiently in an indirect VLIW processor.

In typical reduced instruction set computer (RISC) and VLIW processors, the access of register operands is determined from short instruction word (SIW) bit-fields that represent the register address of operands stored in a register file. In register-based vector processors, specialized hardware is used. This hardware is initiated by a single vector instruction and automates the accessing of vector elements (operand data) from the dedicated vector registers. The multicycle execution on the block of data is also automated.

In the prior art, there have also been specialized hardware techniques used to support the automatic accessing or register operand data. For example, U.S. Pat. No. 5,680,600 which describes a technique for accessing a register file using a loop or repeat instruction to automate the register file addressing. This approach ties the register addressing to a loop or repeat instruction which causes a load or store instruction to be repeated while directing the register address to increment through a register file's address space. An electronic circuit is specified for reducing controller memory requirements for multiple sequential instructions. Thus, this prior art approach appears to be applied only to load and store type operations invoked by a special loop or repeat instruction. As such, it is not readily applicable to indirect VLIW ManArray processors as addressed further below.

SUMMARY OF THE INVENTION

A ManArray family of processors may suitably consist of multiple "indirect VLIW" (iVLIW) processors and processor elements (PEs) that utilize a fixed length short instruction word (SIW) of 32-bits. An SIW may be executed individually by one of up to eight execution units per processor and in synchronism in multiple PEs in a SIMD mode of operation. Another type of SIW is able to reference a VLIW indirectly to cause the issuance of up to eight SIW instructions in parallel in each processor and in synchronism in multiple PEs to be executed in parallel.

Operands are stored in register files and each execution unit has one or more read and write ports connected to the register file or files. In most processors, the registers selected for each port are addressed using bit fields in the instruction. With the indirect VLIW technique employed in the ManArray processor, the SIWs making up a VLIW are stored in a VLIW memory. Since each SIW fixes a register operand field by definition for a single operation on register accessed operand data, multiple VLIWs are required whenever a single operand field must be different as required by a processing algorithm. Thus, a suitable register file indexing technique for operation on blocks of data for use in conjunction with such processors and extendible more generally to parallel array processors will be highly advantageous.

This operand-data fixed register specification problem is solved by the present invention by providing a compact means of achieving pipelined computation on blocks of data using indirect VLIW instructions. A double indirect method of accessing the block of data in a register file is used to allow efficient implementations without the use of specialized vector processing hardware. In addition, the automatic modification of the register addressing is not tied to a single vector instruction, nor to repeat or loop instructions. Rather, the present technique, termed register file indexing (RFI) allows full programmer flexibility in control of the block data operational facility and provides the capability to mix non-RFI instructions with RFI instructions. The block-data operation facility is embedded in the iVLIW ManArray architecture allowing its generalized use across the instruction set architecture without specialized vector instructions, and without being limited to use only with repeat or loop instructions. Utilizing the present invention, chaining operations are inherently available without any direct routing between functional units further simplifying implementations. In addition, the present register file indexing architecture reduces the VLIW memory requirements which can be particularly significant depending on the types of algorithms to be coded.

Further, when expressed as unrolled loops of VLIW instructions, many computations exhibit clear register usage

patterns. These patterns are characteristic of computational pipelines and can be taken advantage of with the ManArray indirect vector processing embedded in an indirect VLIW processor as adapted as described further herein.

Among its other aspects, the present invention provides a unique initialization method for generating an operand register address, a unique double-indirect execution mechanism, a unique controlling method, and allows a register file to be partitioned into independent circular buffers. It also allows the mixing of RFI and non-RFI instructions, and a scaleable design applicable to multiple array organizations of VLIW processing elements. As addressed in further detail below, the invention reduces both the VLIW memory and, as a consequence, SIW memory requirements for parallel instruction execution in an iVLIW array processor.

These and other features, aspects and advantages of the invention will be apparent to those skilled in the art from the following detailed description taken together with the accompanying drawings.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A illustrates a 2x2 ManArray iVLIW processor suitable for use in conjunction with the present invention;

FIG. 1B illustrates a typical prior art register addressing mechanism;

FIG. 2A illustrates an XV instruction encoding with RFI enabling bits in accordance with the present invention;

FIG. 2B illustrates an XV syntax/operation description suitable for use in the present invention;

FIG. 3A illustrates a ManArray miscellaneous register file (MRF) identifying the location of the RFI control registers;

FIG. 3B illustrates the MRFX1 extension registers;

FIG. 3C illustrates the MRFX2 extension registers, and identifies the RFI registers used in the sequence processor (SP) and processing elements (PEs);

FIG. 4A illustrates an MRFXAR register which controls the selection of the extension register;

FIG. 4B illustrates the data format for MRFXDR1 and MRFXDR2 wherein the RFI control registers are mapped as specified by the MRFXAR register values of FIG. 4A;

FIG. 5 illustrates preferred RFI control registers for use in conjunction with the present invention;

FIG. 6 illustrates exemplary specific control encodings used for each RFI port;

FIG. 7A illustrates a suitable load immediate (LIM) instruction encoding which may be used for loading the RFI control values of the present invention;

FIG. 7B illustrates an LIM syntax/operation description;

FIG. 8 illustrates an exemplary RFI control block diagram for the arithmetic execution units in accordance with the present invention;

FIG. 9 illustrates an exemplary RFI control block diagram for the load and store execution units in accordance with the present invention;

FIG. 10 illustrates a conventional full adder for use in the update adder logic units in each RFI port logic in one embodiment in accordance with the present invention; and

FIG. 11 illustrates a reduced cost RFI control block diagram for the arithmetic execution units in one embodiment in accordance with the present invention.

#### DETAILED DESCRIPTION

Further details of a presently preferred ManArray architecture for use in conjunction with the present invention are

found in U.S. patent application Ser. No. 08/885,310 filed Jun. 30, 1997, U.S. patent application Ser. No. 08/949,122 filed Oct. 10, 1997, U.S. patent application Ser. No. 09/169,255 filed Oct. 9, 1998, U.S. patent application Ser. No. 09/169,256 filed Oct. 9, 1998, U.S. patent application Ser. No. 09/169,072 filed Oct. 9, 1998, U.S. patent application Ser. No. 09/187,539 filed Nov. 6, 1998, U.S. patent application Ser. No. 09/205,558 filed Dec. 4, 1998, U.S. patent application Ser. No. 09/215,081 filed Dec. 18, 1998, U.S. patent application Ser. No. 09/228,374 filed Jan. 12, 1999, and U.S. patent application Ser. No. 09/238,446 filed Jan. 28, 1999, as well as, Provisional Application Serial No. 60/092,130 entitled "Methods and Apparatus for Instruction Addressing in Indirect VLIW Processors" filed Jul. 9, 1998, Provisional Application Serial No. 60/103,712 entitled "Efficient Complex Multiplication and Fast Fourier Transform (FFT) Implementation on the ManArray" filed Oct. 9, 1998, Provisional Application Ser. No. 60/106,867 entitled "Methods and Apparatus for Improved Motion Estimation for Video Encoding" filed Nov. 3, 1998, Provisional Application Serial No. 60/113,637 entitled "Methods and Apparatus for Providing Direct Memory Access (DMA) Engine" filed Dec. 23, 1998, and Provisional Application Serial No. 60/113,555 entitled "Methods and Apparatus Providing Transfer Control" filed Dec. 23, 1998, respectively, and incorporated by reference herein in their entirety.

In a presently preferred embodiment of the present invention, a ManArray 2x2 iVLIW single instruction multiple data stream (SIMD) processor **100** shown in FIG. 1A contains a controller sequence processor (SP) combined with processing element-0 (PE0) SP/PE0 **101**, as described in further detail in U.S. application Ser. No. 09/169,072 entitled "Methods and Apparatus for Dynamically Merging an Array Controller with an Array Processing Element". Three additional PEs **151**, **153**, and **155** are also utilized to demonstrate register file indexing and its scalable nature in accordance with the present invention. It is noted that the in parenthesis for PE0 (PE00) **101**, PE1 (PE01) **151**, PE2 (PE10) **153**, and PE3 (PE11) **155**. The SP/PE0 **101** contains a fetch controller **103** to allow the fetching of short instruction words (SIWs) from a 32-bit instruction memory **105**. The fetch controller **103** provides the typical functions needed in a programmable processor such as a program counter (PC), branch capability, digital signal processing loop operations, support for interrupts, and provides the instruction memory management control which could include an instruction cache if needed by an application. In addition, the SIW I-Fetch controller **103** dispatches 32-bit SIWs to the other PEs in the system by means of a 32-bit instruction bus **102**.

In this exemplary system, common elements are used throughout to simplify the explanation, though actual implementations are not so limited. For example, the execution units **131** in the combined SP/PE0 **101** can be separated into a set of execution units optimized for the control function, e.g., fixed point execution units, and the PE0, as well as the other PEs **151**, **153** and **155**, can be optimized for a floating point application. For the purposes of this description, it is assumed that the execution units **131** are of the same type in the SP/PE0 and the other PEs. In a similar manner, SP/PE0 and the other PEs use a five instruction slot iVLIW architecture which contains a very long instruction word memory (VIM) memory **109** and an instruction decode and VIM controller function unit **107** which receives instructions as dispatched from the SP/PE0's I-Fetch unit **103** and generates the VIM addresses-and-control signals **108** required to access the iVLIWs, identified by the letters SLAMD in **109**,

stored in the VIM. The ManArray pipeline design provides an indirect VLIW memory access mechanism without increasing branch latency by providing a dynamically reconfigurable instruction pipeline for the indirect execute iVLIW (XV) instructions as described in further detail in U.S. patent application Ser. No. 09/228,374 entitled "Methods and Apparatus to Dynamically Reconfigure the Instruction Pipeline of an Indirect Very long Instruction Word Scalable Processor". The loading of the iVLIWs is described in further detail in U.S. patent application Ser. No. 09/187,539 entitled "Methods and Apparatus for Efficient Synchronous MIMD Operations with iVLIW PE-to-PE Communication". Also contained in the SP/PE0 and the other PEs is a common PE configurable register file 127 which is described in further detail in U.S. patent application Ser. No. 09/169,255 entitled "Methods and Apparatus for Dynamic Instruction Controlled Reconfiguration Register File with Extended Precision".

Due to the combined nature of the SP/PE0, the data memory interface controller 125 must handle the data processing needs of both the SP controller, with SP data in memory 121, and PE0, with PE0 data in memory 123. The SP/PE0 controller 125 also is the source of the data that is sent over the 32-bit broadcast data bus 126. The other PEs 151, 153, and 155 contain common physical data memory units 123', 123" and 123'" though the data stored in them is generally different as required by the local processing done on each PE. The interface to these PE data memories is also a common design in PEs 1, 2, and 3 and indicated by PE local memory and data bus interface logic 157, 157' and 157". Interconnecting the PEs for data transfer communications is the cluster switch 171 more completely described in U.S. patent application Ser. No. 08/885,310 entitled "Manifold Array Processor", U.S. application Ser. No. 09/949,122 entitled "Methods and Apparatus for Manifold Array Processing", and U.S. application Ser. No. 09/169,256 entitled "Methods and Apparatus for ManArray PE-to-PE Switch Control". The interface to a host processor, other peripheral devices, and/or external memory can be done in many ways. The primary mechanism shown for completeness is contained in the DMA control unit 181 that provides a scalable ManArray data bus 183 that connects to devices and interface units external to the ManArray core. The DMA control unit 181 provides the data flow and bus arbitration mechanisms needed for these external devices to interface to the ManArray core memories via bus 185.

All of the above noted patents are assigned to the assignee of the present invention and incorporated herein by reference in their entirety.

Turning now to specific details of the ManArray processor apparatus as adapted to the present invention, this approach advantageously provides an efficient and flexible block-data operation capability through a double indirect mechanism. Register File Indexing Programming View

Register file indexing (RFI) in accordance with one aspect of the present invention refers to methods and apparatus in each processing element and in the array controller for addressing the operand register file through a double indirect mechanism rather than directly through fields of an SIW, or through specialized vector instructions and vector hardware or with a required repeat or loop instruction. Each execution unit operates read and write ports of one or more register files. A read or write port consists of register selection address and control lines supplied to the register file, a data bus for register data being read from the register file for a read port, and a data bus for register data being written to the register file for a write port. The inputs to the register selec-

tion logic of these ports typically came only from bit-fields of the instruction being executed as shown in the prior art apparatus of FIG. 1B. In FIG. 1B, the instruction received in a processor's instruction register 10 typically contained register file addresses which are typically latched in port address registers, such as the registers 12, 14 and 16, and then directly used to address the register file, such as register file 20, to support the instruction execution by units, such as store unit 22, load unit 24, ALU 26, MAU 28 and DSU 30 of FIG. 1B.

In addition to this typical method for register selection, RFI operation in accordance with the present invention allows each register file port of each execution unit to also be independently controlled through a double indirect mechanism using simple control circuitry as addressed further below.

#### RFI Operation

RFI operation may advantageously be embedded in the ManArray iVLIW architecture and invoked by a double indirect mechanism. An exemplary execute VLIW (XV) instruction 200 having 32 bit encoding format 201 is shown in FIG. 2A. A syntax/operation table 203 summarizing instruction syntax, the parameters or operands, and the operations carried out by the instruction 200 is shown in FIG. 2B. ManArray RFI operation uses bits 20 and 21, RFI operation bits 202, in the execute VLIW (XV) instruction 200 as shown in FIG. 2A to enable RFI operation.

In further detail, the XV instruction 200 is used to indirectly cause individual instruction slots of a specified SP or PE VLIW Memory (VIM) to be executed. The VIM address is computed as the sum of a base VIM address register Vb (V0 or V1) plus an unsigned 8-bit offset VIMOFFS. Any combination of individual instruction slots may be executed via the execute slot parameter 'E={SLAMD}', where S=Store Unit (SU), L=Load Unit (LU), A=Arithmetic Logic Unit (ALU), M=Multiply-Accumulate Unit (MAU), and D=Data Select Unit (DSU). A blank 'E=' parameter does not execute any slots. The unit affecting flags (UAF) parameter 'F=[AMDN] overrides the UAF specified for the VLIW when it was loaded via a load VLIW (LV) instruction. The override selects which arithmetic instruction slot (A=ALU, M=MAU, D=DSU) or none (N=NONE) is allowed to set condition flags for this execution of the VLIW. The override does not affect the UAF setting specified via the LV instruction. A blank 'F=' selects the UAF specified when the VLIW was loaded. The register file indexing (RFI) parameter 'R=[01N] is used to enable or disable RFI for this XV's indirect execution of the instruction slots. With 'R=0' (the RFI operation bits 202=00 in FIG. 2A), RFI operation is enabled and the RFI control register group 0 is selected. With 'R=1' (the bits 202=01), RFI operation is enabled and the RFI Control Register group 1 is selected. With 'R=N' (the bits 202=11), RFI operation is disabled.

The XV instruction with RFI enabled causes a second indirect operation to be initiated. The second indirect operation comes into play on the next XV instruction that is executed, wherein the register port addresses are indirectly specified through automatically incrementing hardware controlled in a manner specified by separate RFI control parameters. The RFI operation is described below, in the context of the ManArray pipeline, primarily concerned with the decode and execute phases of the pipeline, RFI control consists of four parts: 1) RFI control specification; 2) RFI initialization control; 3) RFI update control; and 4) RFI instruction execution.

#### RFI Control Specification

RFI control specification is preferably performed through RFI control registers. Each control register specifies all the



RFI control information for the register ports used by a particular execution unit. There is a control field in the control register for each port and this field specifies whether or not the RFI operation is enabled for that particular port and, if enabled, specifies the RFI register update policy.

The RFI control registers are accessed through a ManArray miscellaneous register file (MRF) **300** illustrated in FIG. **3A**. This register file is unique in that additional registers can be added within the restricted MRF address space by address mapping additional registers to a single MRF address. The MRF extension registers **305** and **315**, shown in FIGS. **3B** and **3C** respectively, are accessed using the MRF extension address register (MRFXAR) **301** and the MRF extension data registers (MRFXDR) **302** and **303**. The two MRF extension data registers **302** and **303** are provided to simplify the implementation, and to separate the intended uses of each set of extension registers. A register address is written to the half-word H1 or H0 portion of the 32-bit MRFXAR register **410** of FIG. **4** using a load immediate instruction as illustrated in FIGS. **7A** and **B**. The relationships of the respective parts of FIGS. **3A–3C**, and **4A** and **4B** are more fully set forth as follows:

MRFX Addr1 402 (FIG. 4A)	MRF Extension Register Address-1. This field contains the address of a register within the MRF extension register group-1 of FIG.3B. When the MRFXDR1 302 of FIG. 3A is read or written, the MRFX1 register in FIG. 3B specified by this address is the target of the read or write operation.
MRFX Addr2 406 (FIG. 4A)	MRF Extension Register Address-2. This field contains the address of a register within the MRF Extension register group-2 of FIG.3C. When the MRFXD2 303 of FIG. 3A is read or written, the MRFX2 register in FIG. 3C specified by this address is the target of the read or write operation.
AutoIncrement (AJ1 or AJ2) 404 or 408 (FIG. 4A)	When set, this bit causes the MRFX Address field 1 402 or field 2 406 of FIG. 4A to increment by 1 after each read or write access to the MRFXDR1 302 or MRFXDR2 303 of FIG.3A.
MRFX Data (MRFX1 or MRFX2) 420 (FIG. 4B)	A Load/Store or DSU operation (COPY, BIT op) which targets the MRFXDR1 302 or MRFXDR2 303 of FIG. 3A will access the MRFX register whose address is contained in bits [2:0] of the MRFXAR1 402 or bits[8:6] MRFXAR2 406 of FIG. 4A. If the auto increment bit 404 or 408 of the selected MRFXAR is set, then the access will also cause the address in the MRFXAR1 or MRFXAR2 to be incremented after the access.

In a presently preferred embodiment, five execution units have RFI control. FIG. **3C** shows a summary of an exemplary set of RFI control registers. These MRFX2 registers **510**, **520**, **530**, **540**, **550**, **560**, **570**, and **580** are shown in further detail in FIG. **5**, with each control register assigned to the read/write ports for the specified execution units. These execution units include arithmetic logic unit (ALU), multiply accumulate unit (MAU), data select unit (DSU), load unit, and the store unit.

The registers are used in two control groups (**510–540**), two save and restore context registers (**550** and **560**), and one register **580** to control the initialization of the RFI controls for each control group. A reserved register **570** is also shown. The first control group **0** includes RFIDLS0 **310** and RFIAM0 **320** in FIG. **3C**. Further details are shown in registers **510** and **520** of FIG. **5**. The second control group **1** includes RFIDLS1 **330** and RFIAM1 **340** with further details in registers **530** and **540**.

When an iVLIW is executed, one of the control groups is specified in the XV instruction via bits **21** and **20**, the RFI bits **202** of instruction **200** of FIG. **2** to allow RFI control of

any port used by instructions in that VLIW. It will be recognized that the invention does not preclude using another mechanism for specifying the control information, or a subset of the control information, such as directly in an instruction.

Specifically, in control group **0**, RFIDLS0 **510** in FIG. **5** contains the port control information for the single Load Rt port **501**, the single Store Rs port **502**, the three operand ports for the DSU Ry **503**, Rx **504**, and Rt **505**. The second register in control group **0** RFIAM0 **520** contains the port control information for the three operand ports for the MAU Ry **521**, Rx **522**, Rt **523** and the three operands ports for the ALU Ry **524**, Rx **525**, and Rt **526**. Associated with the two control groups are initialization start bits which are contained for both control groups **0** and **1** in the RFISstart register **380** of FIG. **3C** and in more detail in register **580** of FIG. **5**. For control group **0**, the initialization start bits are located in the H0 halfword **581** with a single bit per execution unit as follows: Store ports Start **0** bit-4 **587**, Load ports Start **0** bit-3 **586**, ALU ports Start **0** bit-2 **585**, MAU ports Start **0** bit-1 **584**, and DSU ports Start bit-0 **583**. In a similar manner, the control registers RFIDLS1 **530**, RFIAM1 **540** for the second control group **1** are set up as shown in FIG. **5**. The initialization start bits for control group **1** are located in H1 halfword **582** of RFISstart **580**. The other two RFI registers RFIDLS1 **550** and RFIAM1 **560** store the port address values to save the values of the port addresses upon an interrupt in support of a context save and restore operation.

Note that the control parameters may have any format that allows a required set of control information to be represented, as the invention does not require a particular format. An exemplary format **600** for a register file port is shown in greater detail in FIG. **6**. The RFI parameters are encoded into 4-bits as shown in columns **601** and **602**. This control information specifies the type of update to be applied to generate the address of the next register to be selected on the next RFI instruction execution. In the presently preferred embodiment, the control parameters are used to select an update increment value **603** to be added to the register address, and to specify the maximum sequential (incrementing by one) register file address range (RFBS) that can be selected **604**. As described further below, the starting register along with these parameters determines the actual register set which may be selected by the index. Columns **605–611** are used to describe the operation of the indirect vector apparatus shown in FIGS. **8** and **9**. In these columns **605–611**, an “x” represents a “don’t care” state. Column **612**, the applicable units column, specifies to which execution units the control parameters apply.

#### RFI Initialization Control

RFI initialization takes place in two steps, which are best understood with reference to FIGS. **8** and **9**. FIG. **8** shows an exemplary RFI apparatus **800** for the port logic in the arithmetic units. FIG. **9** shows an exemplary RFI apparatus **900** for the port logic in the load and store units. This exemplary description represents a low cost configuration which uses control group **0** for the ALU, MAU, and DSU units and both control groups **0** and **1** for the Load and Store units. This is a subset of the architecture description outlined in FIG. **5** and represents a programmer restriction, where all options are available for all execution units in control group **0** while control group **1** is used primarily for block move, save, and restore operations. When an RFI XV instruction selects the second control group **1** in implementations which allow for only control group **0** on the arithmetic units, the arithmetic units default to the control group **0** specification even when control group **1** is specified. This subset minimizes on implementation expense and is described in more detail as follows.

First, control information as illustrated in FIG. 6 for each register file port is written into an RFI control register **810** and **910** by use of a load immediate (LIM) instruction **700** whose encoding format is shown in FIG. 7A and whose syntax/operation **710** is shown in FIG. 7B. The LIM instruction **700** is first used to load MRFXAR halfword **H1 410** of FIG. 4 to set up the desired extension RFI control register to be mapped to MRFXDR2 **303** in FIG. 3A. Then, the LIM instruction loads a data value to the desired control register by using the address for MRFXDR2. Each halfword section of a control register is loaded separately by definition of the LIM instruction.

For purposes of clarity, the LIM data path from instruction register **804** **H0** halfword bits **15-0** is not shown. This data path is selectively controlled to load the **H0** halfword of the LIM instruction to either the low or high halfword portion of any of the MRF extension registers listed in FIG. 5. For example, a LIM instruction could cause the loading of its **H0** halfword to the **H1** portion of the RFIAM0 register **520** of FIG. 5. In reference to the common arithmetic RFI port control logic of FIG. 8, one of the three control portions of RFIAM0 would be located in an update control register **0** for that port, such as **810**, for, in this case, the ALU **852**. In a similar manner, the other two port control values would be loaded into their own port update control register **0**s contained in their own RFI port control logic. Other ManArray instructions can load the RFI control registers through use of the MRF data bus **809**. The MRF data bus **809** is also used for saving the RFI port registers, for example, during a context switch operation. The specific LIM instruction description is as follows. The halfword form of the LIM instruction loads a 16-bit immediate value into the upper halfword (**H1**) or lower halfword (**H0**) of an SP or PE target register **Rt**. The 16-bit immediate value is interpreted as a sign “neutral” value, meaning that any value in the range  $-32768$  to  $65535$  is accepted. This covers the 2’s complement signed value range of  $-32768$  to  $+32767$  and the unsigned value range of  $0$  to  $65535$ .

The word form of the LIM instruction loads a signed-extended 17-bit immediate value into the target register. The 17-bit signed value may be any value in the range  $-65536$  to  $65535$ . The encoding for the word form of LIM puts the magnitude of the value into the IMM16 field and the sign bit is the LOC field bits **23** and **22** shown in FIG. 7A. LOC field determines if the upper halfword is filled with all one or all zero bits.

In the second step of RFI initialization, a start bit, e.g. bit **583** for the DSU **854**, is set in the RFI Start Register, RFIStart of FIG. 5, that is located in the start bit and mux control block **812** for each of the arithmetic execution unit’s ports and block **912** for a load or store unit’s port. Each start bit controls the initialization for all the ports belonging to an execution unit. While this is the presently preferred format, the invention is not restricted to this format. The operation of setting this bit is performed by any instruction capable of writing to this register. At least one instruction of this type is available. The next instruction which invokes RFI control for this particular group and execution unit after the setting of this bit, hereafter referred to as the “RFI instruction”, has its execution unit’s operand registers first selected by fields in the instruction word and then, with the next RFI instruction for this group and execution unit, has its execution unit’s operand registers selected under control of the RFI logic shown in FIGS. 8 and 9. With the RFI XV instruction, as described in FIGS. 2A and 2B, a VLIW set of SIWs is indirectly retrieved from a local VIM (five SIWs as described herein for a ManArray implementation as in FIG. 1A). For

example, one of the set of five SIWs is loaded into an instruction register **804** as shown in FIG. 8. The port RFI logic for the fetched SIW **Rt**’s port is also shown in FIG. 8. For the first execution of the fetched instruction, the **Rt** port address **805** is the starting address for an RFI block operation. The **Rt** port address **805** is passed through a multiplexer **814**, as controlled by the start bit and mux control block **812** via control signal **813**, to the port address register **816** via multiplexer output **811**. The **Rt** port address, now contained on output **811**, is latched into the port address register **816** at the end of the decode pipeline stage. The output of the port address register **816** directly addresses the register file **818** over signal path **817**. The operands are selected from the register file **818** and the SIW operation is executed in the specified execution unit.

Upon the next issuance of an RFI XV instruction, the operands are indirectly specified from the RFI logic. This is the second indirect specification in the operational sequence. The first indirect specification is through the RFI XV instruction which indirectly specified the SIW and the second indirect specification is through the RFI logic as set up via the RFI control parameters. In order to accomplish this, operation update control register **0 810**, update adder logic **830**, indexed port look ahead register **820**, multiplexers **814** and **822**, and update control logic **824** are used to generate the updated port address to be used in following RFI instruction executions.

The basic concept is that the address output **811** of the multiplexer **814** is available early enough in the decode cycle so that the update adder logic **830** can update the address based upon the update control logic **824** signals. The updated address **819** is selected by mux control signals **815** to pass through multiplexer **822** and loaded into the index port look ahead register **820** at the end of decode at the same time the present port address **811** is loaded into the port address register **816**. On the next RFI instruction, the look ahead register value **821** is used in place of the fetched SIW operand port address value and latched into the port address register **816** for the next execute cycle, while the update adder logic is again preparing the next port address to be used. After the first RFI instruction following the setting of the RFI start bit(s), the start bit(s) are cleared causing subsequent RFI instructions to have their SIW operand registers selected by corresponding indexed port look ahead registers. The start bit and mux control block **812** provide the control for determining whether an instruction’s registers are selected by instruction fields or by RFI indexed port look ahead registers. Its inputs come from the instruction opcode **807**, the update control register **0 810**, and an RFI enable signal **825**. These signals along with pipeline control signals (not shown) indicating an instruction’s progress in the pipeline, determine the register selection source via the multiplexer **814**.

The use of the indexed port look ahead register **820** allows non-RFI instructions to be intermixed between RFI operations without affecting the RFI register address sequence. When a non-RFI instruction is detected, the RFI logic preserves the required RFI state while the non-RFI instructions are executing.

#### RFI Update Control

When an RFI operation is invoked, the address of one or more registers in the register file **818** is supplied by the RFI logic. This logic updates the register address for the next cycle by adding or subtracting a constant from an address available in the early stages of the decode cycle while maintaining the generated port address within a particular set of register addresses. In the presently preferred embodiment,

## 11

this is done by specifying an increment value and a register file block size (RFBS) **604** as shown in FIG. **6** for each port to be controlled. In the preferred embodiment, the RFBS value is an integer power of 2, such as 1,2,4,8, etc., and logically causes the register file to be partitioned into blocks of registers with RFBS sequentially addressed registers per block. Assume a starting register  $R_s$  ( $R_{current}=R_s$  on the first update), an RFBS value  $M$ , a floor quotient  $Q=\lfloor R_s/M \rfloor$ , and a positive update increment  $k$ , then the next register number,  $R_{next}$  in a sequence is given by:

$$R_{next} = ((R_{current} + k) \bmod M) + Q * M.$$

Because the remainder of  $R_s/M$  is ignored due to the floor operation, the value of  $Q * M \neq R_s$ .

As an example, assume that the starting register port address is 5, i.e.  $R_s=R5$  which also equals  $R_{current}$  for the first operation. Also, assume the update increment is  $k=2$ , and the RFBS is  $M=8$ . In FIG. **6**, this exemplary setting corresponds to the row **620** which lists for FIG. **8** the corresponding signal values as follows:  $G3=x$  **606** and **831**,  $G2=0$  **607** and **832**,  $G1=1$  **608** and **833**,  $G0=1$  **609** and **834**,  $X1=1$  **610** and **835**, and  $X0=0$  **611** and **836**. The signals  $X1$  and  $X0$  provide the increment by 2 input to update adder logic **830**. The gate signals  $G3$ ,  $G2$ ,  $G1$ , and  $G0$  maintain the block size given an arbitrary starting register. The update adder logic **830** is made up of five standard full adders **861**, **862**, **863**, **864** and **865**, shown in further detail in FIG. **10**. The carry out signal  $C_{i+1}$  **1005** of full adder **1000** of FIG. **10** corresponds to the carry out signals **841–844** from each stage of the update adder **830**. These carry out signals are gated by AND gates **845–848** and gate signals **831–834** effectively creating the modulo-adder required by the specified control description of FIG. **6**. Under these assumptions, the successive instructions which specify this port using RFI will access registers in the following order: **R5**, **R7**, **R1**, **R3**, **R5**, **R7**, and so on. If the starting register is **R8**, then the sequence is; **R8**, **R10**, **R12**, **R14**, **R8**, **R10**, and so on. The present invention does not preclude using non-power of 2 increments and/or RFBSs, nor does it preclude using another mechanism of specifying a register address sequence within which to operate. For example, a read only memory can be used to replace the update control logic **824** and update adder logic **830** to provide any desired register port address sequences desired. Since using memory blocks may cause implementation wiring problems, being able to implement the update function in discrete logic is the presently preferred method.

FIG. **9** depicts the RFI logic **900** for the load and store units which have been identified to use two control register groups **910** and **950**, respectively. The XV instruction specifies which group is to be used via the bits **21–20** **202** of FIG. **2**. In the exemplary system, when control register group **1** is indirectly specified, the load and store SIWs fetched from the VIM use update control register **1** **950** as selected via mux control signal **951** through multiplexer **952** while the arithmetic units default to using control register group **0**. In alternative implementations, the RFI port logic of FIG. **9** can be used for each arithmetic execution unit providing two RFI contexts for all of the execution units.

In a VLIW processor, it is possible to have all ports of the register file under RFI control for a single instruction, such as the presently described XV instruction. Since the RFI port logic is independent between execution units, the ports can be individually controlled by SIW execution-unit-specific instructions. This means that if another instruction or group of instructions requires independent RFI control (i.e. a dif-

## 12

ferent set of control parameters) in addition to the XV instruction, another group of control registers could be assigned. Since the RFI set up latency is relatively small, the control register set as described in FIG. **5** can be easily shared with other RFI instructions.

Another register file indexing apparatus **1100** is shown in FIG. **11**. This RFI mechanism still uses the double indirect mechanism outlined in the other RFI approaches discussed relative to FIGS. **8** and **9**. In the approach of FIG. **11**, however, a programming restriction is enforced requiring that for the block of data being processed, RFI operations cannot be mixed with non-RFI operations. This approach is different than the approach used in FIGS. **8** and **9** which allows RFI and non-RFI instructions to be mixed. For some product definitions, this is not a problem and the simplified hardware approach of FIG. **11** can be used.

The operation of the apparatus **1100** of FIG. **11** is similar to the operation of the previous RFI approach. For example, the start bit for RFI initialization is used as previously described. The main difference in FIG. **11** is that no indexed port look ahead register, like register **820** of FIG. **8** is used. Rather, a port address register **1116** still addresses a register file **1118**, but update adder logic **1130** operation is displaced in time, as compared to the approach used in FIG. **8**, operating on the latched port address register output **1117** during the execute cycle. In preparation for the next execute cycle, the update adder logic **1130** updates the output **1117** of the port address register **1116** as specified by an RFI update control register **1110** for this port. By the end of the present execute cycle, multiplexer **1114** is controlled via control input **1113** to select an update adder logic output **1119** to pass through multiplexer **1114** to output **1111**. The multiplexer **1114** output **1111** is then latched in the port address register **1116** at the start of the next execute cycle thereby updating the register file port address as specified by the RFI control set up previously.

In addition to the XV RFI enabling apparatus, other means of enabling RFI are used. The purpose of this additional mechanism is to decouple the RFI sequencing from only being used in the VLIW (XV) programming model. It is desired to support block load, block store, and block move operations with single instruction execution, which can be independently done in the SP or concurrently in the PEs. Rather than use additional bits in SIWs to specify this operation, though this is not precluded by this invention, an alternate indirect mechanism to enable RFI is used. This savings in bits in the SIWs allows better use of the instruction format for standard operation encoding while not precluding the ability to achieve the RFI functionality provided by the present invention. This alternative mechanism operates with any SIW that can address a specific location in the MRF. Though multiple locations in the MRF could be provided for this purpose, there are other uses in specific implementations which may preclude this. For the purposes of describing this alternate RFI enabling mechanism, one location in the MRF is used, as shown for RFILSD **304** in FIG. **3A**.

To use the RFI enabling mechanism, the hardware decode logic is extended to generate the RFI enable signal not only when an XV RFI instruction is received but also whenever a load, store, or DSU instruction is received in the SP or PE instruction register which specifies the RFILSD address as the load  $R_t$ , store  $R_s$ , or DSU  $R_t$  or  $R_s$  operands. Prior to using this alternate-RFI enabling mechanism, the RFI control registers are required to be set up specifying the initial registers to be used in a block load, store, or DSU operation. No start bit is used in this alternate RFI enabling mechanism

## 13

as the starting address of the block sequence is stored in the port control registers. Upon receiving a load, store, or DSU instruction, which uses the RFILDS bits as an operand address, the RFI mode is enabled and each register operand address is substituted with the pre-setup port (operand) addresses by the RFI port logic as shown in the representative RFI logic of FIGS. 8, 9, and 11. RFI and non-RFI operations can be mixed when using the hardware of FIGS. 8 and 9. In fact, by using two contexts for the load, store, and DSU control registers, groups 0 and 1, as shown in FIG. 9, then, RFI XV operations on a first block of data, RFI operations using RFILSD on a second block of data, and non-RFI operations can be mixed. It can be appreciated that by proper extension of an arithmetic port register operand address range, an arithmetic instruction could, by referencing the RFILSD address, cause RFI to be invoked for the arithmetic instruction execution.

## RFI Instruction Execution

RFI operation is enabled through control information contained in instruction words. This control information is used to specify whether conventional register address selection fields (operand address fields contained in the instruction) are to be used or whether the RFI selection of registers is to be used. In the presently preferred embodiment, the control information in the instruction, indirect VLIW XV instruction bits 21 and 20 202 of FIG. 2, indirectly specifies a control register or set of registers which are to be used to control RFI operation. One or more of these control register groups are available for RFI control as seen in FIG. 5. The XV RFI instruction both enables RFI mode and selects a control register group for controlling the RFI operation. The group of RFI control registers 510–580 shown in FIG. 5 allow all of the register ports to be RFI controlled, meaning that every execution unit may operate in RFI mode concurrently.

It is noted that the ManArray processor finishes the execution phase of its pipeline with a write back to the register file. This approach allows the next cycle after the write-back cycle to use the results in the next operation. By judicious programming, chaining of vector operations is then inherent in the architecture. No separate bypass paths need be provided in the execution units to support chaining.

A discussion concerning an exemplary use of RFI in accordance with the present invention is now presented to illustrate several advantageous aspects of the invention. Assuming an increment value of 1, RFBS value (M) a power of 2, starting register R2, the register addresses alternate between two registers, an even register R2 and its corresponding odd register (address+1) R3. For RFBS=4, the register addresses cycle among 4 values with an increment of 1. The following table shows some address sequences.

Start Register	Increment	Register File Block Size	Sequence
R2	1	2	R2, R3, R2, R3, . . .
R2	1	4	R2, R3, R0, R1, R2, . . .
R5	1	4	R5, R6, R7, R4, R5, . . .
R5	2	4	R5, R7, R5, R7, . . .
R5	2	8	R5, R7, R1, R3, R5, . . .
R6	2	8	R6, R0, R2, R4, R6, . . .
R0	1	1	R0, R1, R2, R3, . . . R31, R0, R1 . . . for non-Load/Store units R0, R1, R2, R3, . . . R63 (cycles ALL registers) for Load/Store units

Assume it is desired to calculate a simple matrix-vector multiplication on a 4-PE SIMD VLIW ManArray processor

## 14

such as processor 100 of FIG. 1A. Further assume that the following instruction types are available.

Pseudo Instructions	Operation
LDB R <sub>N</sub> , P <sub>J</sub> +	Load Broadcast: Loads from a memory location specified by the address register P <sub>J</sub> in SP memory and stores the value into register R <sub>N</sub> of each PE (all receive the same value. P <sub>J</sub> is post-incremented by 1.
MAC R <sub>T</sub> , R <sub>X</sub> , R <sub>Y</sub>	Multiply-Accumulate: All PEs execute in SIMD fashion the operation R <sub>T</sub> = R <sub>T</sub> + (R <sub>X</sub> * R <sub>Y</sub> )
ST R <sub>S</sub> , P <sub>J</sub> +	Store: All PEs store source register R <sub>S</sub> to local PE memory location specified by P <sub>J</sub> P <sub>J</sub> is post-incremented by 1.
REP N, M	Execute the following N instruction M times

Also, assume that a 4×4 matrix A is distributed to the 4 PEs, PE0, PE1, PE2 and PE3, such that each PE contains a row of the matrix in registers R4, R5, R6 and R7 (PE0 gets row 0, PE1 gets row 1, etc.) as shown in the following table.

Register →	R4	R5	R6	R7
PE0	a00	a01	a02	a03
PE1	a10	a11	a12	a13
PE2	a20	a21	a22	a23
PE3	a30	a31	a32	a33

If a sequence of 4×1 vectors are read in from main (SP) memory 105, multiplied by the matrix and the results stored in local PE memory 123, 123', 123" and 123"', an appropriate sequential algorithm might appear as follows if it is assumed R2 is zero initially:

LDB R0, P0+	;load first element of input vector, x0
MAC R2, R4, R0	;accumulate product: a <sub>i0</sub> * x0 (I is row index and PE ID)
LDB R0, P0+	;load second element of input vector, x1
MAC R2, R5, R0	; accumulate product: a <sub>i1</sub> * x1
LDB R0, P0+	;load third element of input vector, x2
MAC R2, R6, R0	; accumulate product: a <sub>i2</sub> * x2
LDB R0, P0+	;load last element of input vector, x3
MAC R2, R7, R0	; accumulate product: a <sub>i3</sub> * x3
ST R2, P1+	;store results: each local memory gets an element of ;output vector

Performing this algorithm with VLIW instructions yields:

VLIW	SIW	SIW	Execute Action
1	LDB R0, P0+	MAC R2, R4, R0	;Load ;Load PEs and MAC x0 * a[i][0]
2	LDB R0, P0+	MAC R2, R5, R0	;Load PEs and MAC x1 * a[i][1]
3	LDB R0, P0+	MAC R2, R6, R0	;Load PEs and MAC x2 * a[i][2]
4	LDB R0, P0+	MAC R2, R7, R0	;Load PEs and MAC x3 * a[i][3]
60	ST R2, P1+		;All PEs store Store result

This requires 4 VLIW-type instructions, plus a single load LDB and a single store ST instruction, even though the only difference between these VLIW instructions is the second register specification of the MAC instruction.

Now if the example is performed using RFI, the process is as follows: Assume R2 and R0 are both initialized to zero

## 15

and register file indexing is used with the following parameters associated with the VLIW indirectly executed by an XV instruction:

Execution Unit Register Port	Increment	RFBS
Load Write Port	0	1
MAU Rx Readport	1	4

Now the code can be written in compact VLIW form where the second register RFI sequence starts with R7→R4→R5→R6→R7, etc.

VLIW	LD RFIC, P1, ctrl			;Initialize RFI control for MAU reg port
	REP 1, 5			;Repeat 1 instruction 5 times
1	LDB R0, P0+	MAC R2, R7, R0		;Load and MAC: first ;MAC is 0 and last ;load reads into next ;vector (or garbage)
	ST	R2, P1+		;Store results

The net effect is to reduce 9 instructions to 4 instructions. The fact that fewer VLIWs are used, reduces the number of iVLIWs executed and also the number of VLIWs that must be loaded in the ManArray architecture. These savings are indirect, but not insignificant since the VLIW memory (VIM) represents an expensive on chip resource. The RFI operation reduces the amount of VLIW memory needed, thus allowing for less-expensive chips.

While the present invention has been disclosed in the context of various aspects of presently preferred embodiments, it will be recognized that the invention may be suitably applied to other environments and applications consistent with the claims which follow.

We claim:

1. A data processor with register file indexing comprising: an instruction sequencer and N execution units capable of executing up to N instructions in parallel;  
a plurality of register files with registers which contain data operands read and written by the N execution units, each register file having read ports to and write ports from the N execution units; and  
read and write ports associated with each execution unit which have associated control circuitry and register file index (RFI) control registers which control the selection of a first addressing approach and a second indirect addressing approach and allow registers to be addressed using both [a] the first addressing approach in which fields of an instruction word made available to a particular execution unit directly specify addresses, and [a] the second indirect addressing approach in which the contents of [register file index] look ahead registers are utilized in specifying the addresses.
2. The apparatus of claim 1 wherein said processor is a VLIW processor.
3. The apparatus of claim 1 wherein said processor is an iVLIW processor.
4. The apparatus of claim 1 wherein said processor is one of a plurality of similarly configured processors in a ManArray architecture.
5. The apparatus of claim 1 further comprising a control mechanism whereby an instruction may optionally use one or more [RFI] look ahead registers to supply the address for its register file operands.

## 16

6. The apparatus of claim 1 further comprising a control mechanism whereby the [RFI] look ahead register may be optionally updated automatically after each use by adding or subtracting a constant from its current register address thereby selecting a different register for its next use.

7. The apparatus of claim 6 wherein said update by the control mechanism further causes the selected register to cycle through one of many possible programmable sets of registers, starting with a particular register within a set.

8. The apparatus of claim 1 further comprising a control mechanism operable such that each port's register index may be independently configured for an update method and a register address set, or optionally disabled for register file indexing.

9. The apparatus of claim 1 further comprising a crowd mechanism operable such that the [RFI] look ahead register associated with each register file port may be initialized automatically from a register field specified in an instruction.

10. A method of register file index (RFI) control comprising the steps of:

- 20 establishing an RFI control specification in RFI control registers to specify RFI control and address information for at least one register [ports] port used by a particular execution unit or units;
- 25 establishing RFI initialization control[:];
- performing RFI update control for updating a register port address in one of the RFI control registers associated with the at least one register port;
- 30 executing an RFI instruction as part of a first indirect approach to select an instruction for execution; and
- specifying the register port [addresses] address utilizing the updated register port address as part of a [double] second indirect approach to [their] select the specification of the register port address.

11. The method of claim 10 wherein said step of establishing RFI control specification is performed utilizing the RFI control registers specifying all the RFI control information for register ports accessed by a particular execution unit.

12. The method of claim 11 wherein the RFI control information specifies RFI register update policy.

13. The method of claim 10 wherein said step of establishing RFI initialization control comprises the steps of:  
writing control information into an RFI control register[:];  
and

45 setting a bit in an RFI reset register (RFIRR) corresponding to a particular RFI control group and particular execution unit.

14. The method of claim 10 wherein the step of updating a look ahead register port address comprises the step of:

50 updating a[n RFI] look ahead register for the next cycle by adding or subtracting a constant from [its] the register port address stored in the look ahead register while maintaining [its] the register port address within a particular set of register addresses.

15. The method of claim 14 wherein said updating is performed by specifying an increment value and a register file divisor (RFD) for each port to be controlled.

16. The method of claim 10 wherein the step of RFI instruction execution is enabled through control information contained in instruction words.

17. The method of claim 16 wherein said control information specifies whether standard register selection operand fields are used or whether RFI selection of registers is to be used.

65 18. The method of claim 16 wherein the control information indirectly specifies another control register or set of registers which are used to directly control RFI operation.

19. A method for data processing with register file indexing (RFI), the method including:

receiving a plurality of instruction words for execution;  
reading, based on a start of an RFI sequence indication stored in an RFI control register, a field in each of the plurality of instruction words to directly specify a first plurality of operand addresses of a plurality of registers, the plurality of registers as addressed by the first plurality of operand addresses containing a first plurality of data operands;

writing a second plurality of operand addresses to a look ahead register based on the first plurality of operand addresses as controlled by control circuitry and RFI control registers;

executing the plurality of instruction words in parallel utilizing the first plurality of data operands;

clearing the start of the RFI sequence indication;

specifying the second plurality of operand addresses of the plurality of registers by reading, based on the cleared start of the RFI sequence indication, the contents of the look ahead register, the plurality of registers as addressed by the second plurality of operand addresses containing a second plurality of data operands; and

executing the plurality of instruction words in parallel utilizing the second plurality of data operands.

20. The method of claim 19 wherein the control circuitry of the writing step further comprises:

adding or subtracting a constant to the first plurality of operand addresses.

21. The method of claim 19 further comprising:

initializing an RFI control register from a register field specified in one of the plurality of instruction words.

22. A control circuit apparatus for operating in both a register file index (RFI) mode and non-RFI mode, the control circuit apparatus comprising:

a register file storing a plurality of operands;

an instruction register holding a first instruction and a first operand address of the register file for execution with the first instruction;

RFI circuitry for calculating and holding a second operand address of the register file for execution with the first instruction; and

a multiplexer having two inputs and an output, one of the two inputs connecting to the instruction register and the other of the two inputs connecting to the RFI circuitry, the output connecting to the register file; and in response to a signal signaling RFI mode, the multiplexer selecting the first operand address during a first execution cycle and the second operand address during a second execution cycle; and upon loading the instruction register with a second instruction having a third operand address and in response to the RFI signal signaling non-RFI mode, the multiplexer selecting the third operand address; and the selected operand address specifying the operand from the register file for use by an execution unit when executing the first instruction or the second instruction in a third execution cycle.

23. The control circuit apparatus of claim 22 wherein the multiplexer selects the second operand address for execution cycles subsequent to the third execution cycle.

24. The control circuit apparatus of claim 22 wherein the RFI signal dependent on a bit in the instruction register.

25. The control circuit apparatus of claim 22 disposed in a VLIW processor.

26. The control circuit apparatus of claim 22 disposed in a iVLIW processor.

27. The control circuit apparatus of claim 22 wherein the second operand address represents the end of a block of operand addresses.

28. The control circuit apparatus of claim 22 wherein the RFI circuitry comprises an adder circuit for calculating the second operand address and a look ahead register storing the second operand address.

29. The control circuit apparatus of claim 28 wherein the RFI circuitry further comprises update control logic controlling the adder circuit for calculating the second operand address.

30. The control circuit apparatus of claim 28 wherein the second instruction is not loaded until a block of operand addresses have been calculated and executed.

31. The control circuit apparatus of claim 22 wherein the RFI mode or non-RFI mode are indications based upon information contained in the instruction register which are valid for the execution of each instruction loaded into the instruction register.

32. The control circuit apparatus of claim 22 wherein the second operand address is initialized prior to RFI operation by pre-setup loading of an initial second operand address.

33. The control circuit apparatus of claim 22 wherein the second operand address is calculated according to an increment value stored in the RFI circuitry.

34. The control circuit apparatus of claim 33 wherein the RFI circuitry comprises:

a modulo adder circuit for calculating the second operand address based on a current operand address, the increment value, and a block size; and

a look ahead register storing the second operand address and supplying the second operand address to the multiplexer.

35. The control circuit apparatus of claim 22 wherein the second operand address  $R_{next}$  is calculated upon each receipt of the signal signaling RFI mode according to  $R_{next} = ((R_{current} + k) \bmod M) + Q * M$ , wherein  $R_{current}$  is the current value of the second operand address prior to calculating,  $k$  is an increment value,  $M$  is a block size, and  $Q$  is a floor quotient  $\lfloor R_s / M \rfloor$  for a starting register operand address  $R_s$  and wherein  $R_{current}$  is equal to  $R_s$  for the first calculation of an RFI sequence.

36. A method of operating in both a register file index (RFI) mode and non-RFI mode, the method comprising:

receiving a first instruction having a first operand address;

receiving a signal indicating RFI mode;

calculating a second operand address based on the first operand address;

selecting the first operand address;

retrieving an operand using the first operand address;

executing the first instruction with the retrieved operand;

selecting the second operand address;

retrieving an operand using the second operand address;

executing the first instruction with the retrieved operand;

receiving a second instruction;

receiving a signal indicating non-RFI mode;

selecting a third operand address carried in the second instruction;

retrieving an operand using the third operand address;

and

executing the second instruction with the retrieved operand.

## 19

37. The method of claim 36 wherein the second operand address represents the end of a block of operand addresses to be executed with the first instruction.

38. The method of claim 36 wherein the received signal indicating RFI mode is based on a bit in the first instruction.

39. The method of claim 36 wherein the received signal indicating RFI mode is based on a miscellaneous register file.

40. The method of claim 36 wherein the received signal indicating RFI mode is based on the opcode carried in the receiving instruction.

41. The method of claim 36 further comprising, before the step of selecting the second operand address, the step comprising:

receiving a third instruction;

receiving a signal indicating non-RFI mode;

selecting a fourth operand address carried in the third instruction;

retrieving an operand address using the fourth operand address; and

executing a third instruction, the third instruction operating in a non-RFI mode.

42. The method of claim 36 wherein the calculating step comprises adding or subtracting from the first operand address.

43. The method of claim 36 wherein the calculating step comprises updating the second operand address upon each receipt of the signal indicating RFI mode.

## 20

44. The method of claim 43 further comprising:

initializing the second operand address prior to RFI operation with a pre-setup initial second operand address.

45. The method of claim 43 further comprising:

updating the second operand address according to an increment value.

46. The method of claim 45 further comprising:

calculating in a modulo adder circuit the second operand address based on a current value of the second operand address, the increment value, and a block size.

47. The method of claim 43 further comprising:

calculating the second operand address  $R_{next}$  upon each receipt of the signal indicating RFI mode according to  $R_{next} = ((R_{current} + k) \bmod M) + Q * M$ , wherein  $R_{current}$  is the current value of the second operand address prior to calculating,  $k$  is an increment value,  $M$  is a block size, and  $Q$  is a floor quotient  $\lfloor R_s / M \rfloor$  for a starting register  $R_s$  and wherein  $R_{current}$  is equal to  $R_s$  for the first calculation of an RFI sequence.

\* \* \* \* \*