



The MIPS32® 74Kf™ core from MIPS Technologies is a high-performance, low-power, 32-bit RISC Superscalar core designed for custom system-on-chip (SoC) applications. The core is designed for semiconductor manufacturing companies, ASIC developers, and system OEMs who want to rapidly integrate their own custom logic and peripherals with a high-performance RISC processor. Fully synthesizable and highly portable across processes, it can be easily integrated into full SoC designs, allowing developers to focus their attention on end-user products.

The 74Kf core implements the MIPS32 Release 2 Architecture in a superscalar, out-of-order execution pipeline. The deeply pipelined core can support a peak issue and graduation rate of 2 instructions per cycle. The 74Kf core also implements the MIPS DSP ASE - Revision 2.0, which provides support for signal processing instructions, and includes support for the MIPS16e™ ASE and the 32-bit privileged resource architecture. This architecture is supported by a wide range of industry-standard tools and development systems.

The 74Kf core has a Level-1 (L1) Instruction Cache, which is configurable at 0, 16, 32, or 64 KB in size. It is organized as 4-way set associative. Up to four instruction cache misses can be outstanding. The instruction cache is virtually indexed and physically tagged to make the data access independent of virtual to physical address translation. Instruction cache tag and data access are staggered across 2 cycles, with up to 4 instructions fetched per cycle.

The superscalar 74Kf core can dispatch up to 2 instructions per cycle into one of the arithmetic-logic unit (ALU) or address generation (AGEN) pipes. The AGEN pipe executes all Load/Store and Control Transfer instructions while the ALU pipe executes all other instructions. Instructions are issued and executed out-of-order; however, the results are buffered and the architectural state of up to 2 instructions per cycle is updated in program order.

The L1 Data Cache is configurable at 0, 16, 32, or 64 KB in size. It is organized as 4-way set associative. Data cache misses are non-blocking and up to four may be outstanding. The data cache is virtually indexed and physically tagged to make the data access independent of virtual-to-physical address translation. The tag array also has a virtual address portion, which is used to compare against the virtual address being accessed and generate a data cache hit prediction. This virtual address hit prediction is always backed up by a comparison of the translated physical address against the physical tag. To achieve high frequencies while using commercially available SRAM generators, the cache access and hit determination is spread across three pipeline stages, dedicating an entire cycle for the SRAM access.

The synthesizable 74Kf core includes a high performance Multiply/Divide Unit (MDU). The MDU is fully pipelined to support a single cycle repeat rate for 32×32 MAC instructions. The CorExtend® block can utilize the accumulator registers in the MDU block, allowing specialized functions to be efficiently implemented

The MIPS DSP ASE - Revision 2.0 provides support for a number of powerful data processing operations. There are instructions for fractional arithmetic (Q15/Q31) and for saturating arithmetic. Additionally, for smaller data sizes, SIMD operations are supported, allowing 2×16 bit or 4×8 bit operations to occur simultaneously. Another feature of the ASE is the inclusion of additional HI/LO accumulator registers to improve the parallelization of independent accumulation routines. All 32-bit operand arithmetic DSP instructions (except multiply) are executed in the ALU pipe while the 64-bit operand arithmetic and multiply class DSP instructions are executed in the MDU pipe.

The 74Kf core features an optional IEEE 754 compliant Floating Point Unit (FPU). The FPU supports both single- and double-precision instructions. The main pipe is connected to the FPU through an in-order instruction queue, and up to 2 instructions can be written into this queue. The FPU can read up to 2 instructions from this queue and issue into its execution pipes.

The Bus Interface Unit (BIU) implements the Open Core Protocol (OCP), which has been developed to address the needs of SoC designers. This implementation features 64-bit read and write data buses to efficiently transfer data t

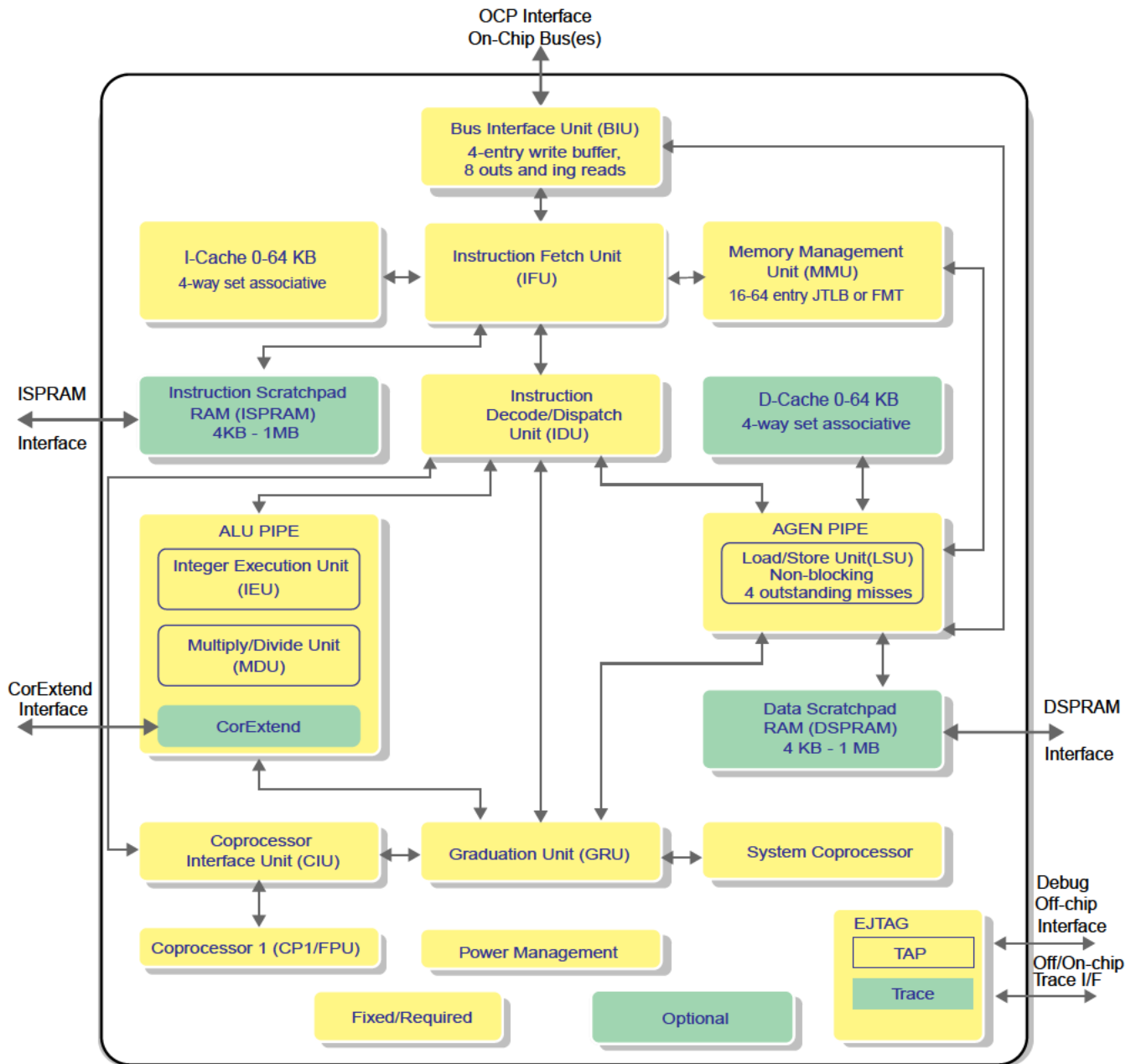
and from the L1 caches. The BIU also supports a variety of core/bus clock ratios to give greater flexibility for system design implementations.

Optional support for external Instruction and Data Scratchpad RAM arrays, with reference design supporting DMA interfaces for loading the arrays.

An Enhanced JTAG (EJTAG) block allows for software debugging of the processor, and includes a TAP controller as well as optional instruction and data virtual address/value breakpoints. Additionally, real-time tracing of instruction program counter, data address and data values can be supported.

Figure 1 shows a block diagram of the 74Kf core.

**Figure 1 74Kf™ Core Block Diagram**



## 74Kf™ Core Features

- 14-stage ALU and 15-stage AGEN pipelines
  - 12-stage ALU fetch and execution pipe
  - 13-stage AGEN fetch and execution pipe
  - Common 2-stage graduation pipe
- 32-bit address paths
- 128-bit data path for instruction cache and 64 or 128-bit data path for data cache
- 64-bit data paths to external interface
- MIPS32 Release2 Instruction Set and Privileged Resource Architecture
- MIPS16e Code Compression
- MIPS DSP ASE - Revision 2.0
  - 3 additional pairs of accumulator registers
  - Fractional data types (Q15, Q31)
  - Saturating arithmetic
  - SIMD instructions operate on 2×16 bit or 4×8 bit simultaneously
- Instruction Fetch Unit
  - 4-instruction fetch per cycle
  - 8-entry Return Prediction Stack
  - Combined Majority Branch Predictor using three 256-entry Branch History Tables (BHT).
  - 64-entry (4-way associative) jump register cache to predict target for indirect jumps.
  - Hardware prefetching of the next 1 or 2 sequential cache lines on a miss. Number of prefetched lines (0, 1, or 2) controllable via configuration bits
- Dual Out-of-Order Instruction Issue
  - Separate ALU and AGEN pipes
- AGEN pipe executes load/store and control transfer instructions
- ALU pipe executes all other instructions
- 32 (18 ALU, 14 AGEN) completion buffers hold execution results until instructions are graduated in program order
- Programmable Memory Management Unit
  - 16/32/48/64 dual-entry, dual-ported TLB shared by Instruction and Data MMU
  - 4-entry ITLB (4KB, 16KB page size)
  - 4K, 16K, 64K, 256K, 1M, 4M, 16M, 64M, 256M byte page size supported in JTLB
  - Optional simple Fixed Mapping Translation (FMT) mechanism
- Programmable L1 Cache Sizes
  - Individually configurable instruction and data caches
  - Instruction Cache sizes of 0/16/32/64 KB
  - Data Cache sizes of 0/16/32/64 KB
  - 4-way set associative
  - 32-byte cache line size
  - Virtually indexed, physically tagged
  - Cache line locking support
  - Up to 4 outstanding I-cache misses
  - Virtual tag based hit prediction in data cache
  - Up to 4 unique outstanding D-cache line misses and 9 total load misses
  - Writeback and write-through support in data cache
  - Non-blocking data cache prefetches

- Optional parity support
- Scratchpad RAM support
  - Independent Instruction and Data Scratchpad RAMs
  - Scratchpad RAM size from 4KB to 1MB
  - Independent of cache configuration
  - 64-bit OCP interfaces for external DMA
  - OCP port runs at the same core/bus clock ratio as the BIU interface
- Front-side L2 support
  - Support for inline L2 cache.
  - L2 cache can be configured to be bypassable.
- Bus Interface
  - OCP version 2.1 interface with 32-bit address and 64-bit data
  - OCP version 2.1 interface runs at core/bus clock ratios of 1, 1.5, 2, 2.5, 3, 3.5, 4, 5, or 10 via a separate synchronous bus clock
  - Clock ratio can be changed dynamically
  - Burst size of four, 64-bit beats
  - 4-entry write buffer
  - “Simple” byte enable mode allows easier bridging to other bus standards
  - Extensions for front-side L2 cache
- Multiply/Divide Unit
  - Maximum issue rate of one 32×32 multiply per clock
  - 7-cycle multiply latency
  - Iterative SRT divide algorithm. Minimum 10 and maximum 50 clock latency (dividend (*rs*) sign extension-dependent)
- CorExtend® User Defined Instruction Set Extensions
  - Allows user to define and add instruction to the core at build time
  - Maintains full MIPS32® compatibility
  - Includes access to GPRs and Accumulator registers
  - Instruction operand format (source/destination registers) and latency specified by a programmable template
  - Allows latencies of 3, 5, or >5 cycles when destination is a GPR/Accumulator. Single-cycle latency is allowed when there is no modification to the architectural state of the 74Kf core.
  - Allows in-order issue of CorExtend instructions that do not modify the 74Kf core architectural state
  - Supported by industry-standard development tools
- Floating Point Unit (FPU)
  - IEEE-754 compliant Floating Point Unit
  - Compliant to MIPS 64-bit FPU standards
  - Supports single- and double-precision data types
  - Optionally runs at 1:1, 3:2 or 2:1 core/FPU clock ratio
  - Separate in-order dual-issue pipeline decoupled from integer pipeline
  - Asymmetric dual-issue. Load/Store and MoveToCP1/MoveFromCP1 instructions execute in one pipe, while all other instructions execute in the other pipe.
- Relocatable Reset Vector
  - Support for user (pin) programmable reset vector in a multi-core environment.

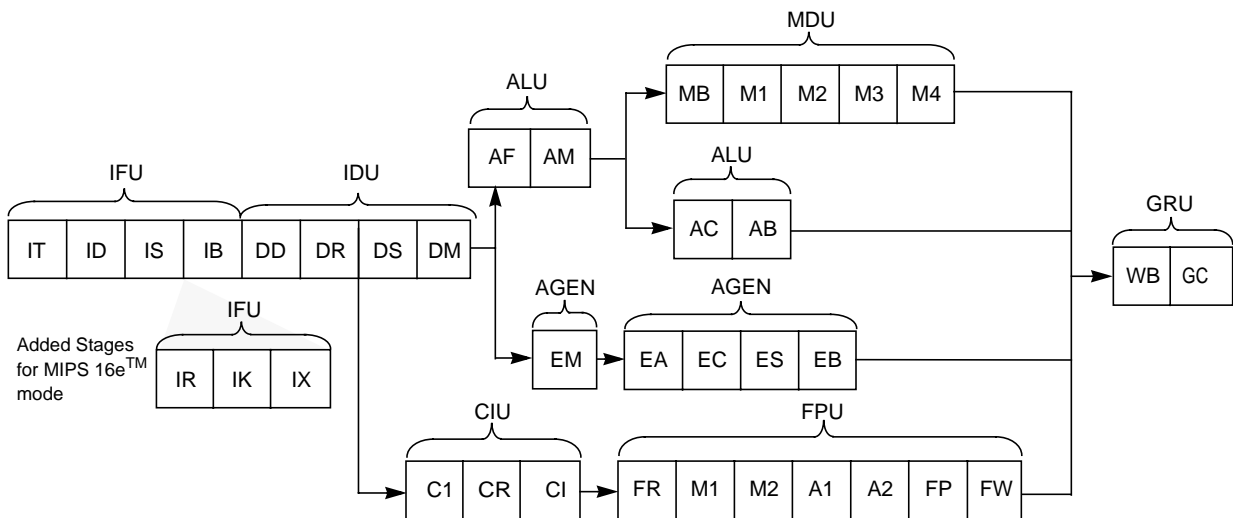
- Power Control
  - Minimum frequency: 0 MHz
  - Power-down mode (triggered by WAIT instruction)
  - Support for software-controlled clock divider
  - Support for top-level, block-level, fine grained and data cache clock gating
- EJTAG Debug 5.0
  - Support for single-stepping
  - Instruction address and data address/value breakpoints
  - TAP controller is chainable for multi-CPU debug
- Cross-CPU breakpoint support
- Relocatable debug handler
- MIPS Trace
  - PC, data address, data value, performance counter value, processor pipeline inefficiency tracing with trace compression
  - Support for on-chip and off-chip trace memory
  - PDtrace version 6 compliant
- Testability
  - Full scan design achieves test coverage in excess of 99% (dependent on library and configuration options)
  - Optional memory BIST for internal SRAM arrays

## Pipeline Flow

The 74Kf core implements a 14/15-stage pipeline. Three extra fetch stages are conditionally added when executing MIPS16e instructions. This pipe-

line allows the processor to achieve a high frequency while maintaining optimal area and power numbers. Figure 2 shows the 74Kf core pipeline.

**Figure 2 74Kf™ Core Pipeline**



### Instruction Fetch Unit (IFU)

**IT: Instruction Tag Read**

- I-cache tag arrays accessed
- Branch History Table, JRC accessed

- ITLB address translation performed
- Instruction watch and EJTAG break compares done

**ID: Instruction Data Read**

- I-cache data array accesses
- Tag compare, Detect I-cache hit

**IS: Instruction Select**

- Way select
- Target calculation start

**IB: Instruction Buffer**

- Instruction Buffer write
- Target calculation done

**IR: Instruction Recode**

- MIPS16e instruction recode

**IK: Instruction Decode**

- MIPS16e branch decode
- MIPS16e target validate

**IX: Instruction Expansion**

- MIPS16e macro expansion

**Instruction Decode and Dispatch Unit (IDU)**

**DD: Decode**

- Access Rename Map, get source register availability to resolve source dependency
- Decode instructions and assign pipe and instruction identify
- Check execution resources

**DR: Rename**

- Update Rename Map at destination register to resolve output dependency

- Send instruction information to Graduation Unit (GRU) and Coprocessor Interface Unit (CIU)
- Send instruction to Decode and Dispatch Queue (DDQ)

**DS: Select for Dispatch**

- Check for operand and resource availability and mark valid instructions as ready for dispatch
- Select 1 out of 8 (6-entry DDQ + 2 staging registers) ready instructions in each ALU and AGEN pipe independently

**DM: Instruction Mux**

- Read out the selected instruction from the previous stage and update the selection information
- Generate controls for source-operand bypass mux
- ALU pipe will start premuxing operands based on the selected instruction.
- AGEN pipe will start reading source operands from Register File and Completion Buffers.

**Integer Execution Unit (IEU)**

**AF: ALU Register file Read**

- AGEN pipe will complete reading source operands from Register File and Completion Buffers.

**AM: ALU Operand Mux**

- Select source operands and set up for execution

**AC: ALU Compute**

- Integer Execution start. Logical operations, some shift and arithmetic operations complete and bypass the results.

**AB: ALU Results Bypass**

- Complete Integer Execution and bypass results

### ***EM: AGEN Operand Mux***

- Select source operands for Load/Store index computation and set up for execution

### ***EA: AGEN Effective Address Compute***

- Compute Effective Address for Load/Store instructions
- Select source operands for Store data and Branch/Jump instructions
- Start JTLB access

## **Load/Store Unit (LSU)**

### ***EC: Cache Access***

- Access D-cache and D-tag arrays. Read Virtual and Physical tags along with data
- Continue JTLB access
- AGEN pipe resolves conditional branch and Jump instruction

### ***ES: D-Cache way select***

- Select D-cache way based on Virtual tag match with Effective Address
- Start Physical Tag compare with JTLB data
- AGEN pipe redirects IFU in the event of branch mis-predict or register indirect jump

### ***EB: Cache Data Bypass***

- Complete data selection and align load data
- Bypass results (selected data) to both AGEN and ALU pipes
- Validate Virtual tag match with Physical tag comparison

## **74Kf™ Core Logic Blocks**

The 74Kf core consists of the logic blocks define in the following subsections (see [Figure 1](#)).

## **Coprocessor Interface Unit (CIU)**

### ***C1: Coprocessor Write Pointer Adjust***

- Adjust InOrder Instruction Queue write pointer

### ***CR: Coprocessor Instruction Read***

- Read instruction from InOrder Instruction Queue

### ***CI: Coprocessor Instruction Issue***

- InOrder Instruction dispatch to Coprocessor1

## **Graduation Unit (GRU)**

### ***WB: Writeback***

- Consolidate and propagate D-cache hit/miss information
- Write execution results into ALU and AGEN completion buffers
- Update all GRU structures to indicate instruction completion
- Oldest 2 entries that have completed execution are identified and their addresses are obtained to read the completion buffers and associated information to graduate 2 instructions

### ***GC: Graduation Complete***

- Two instructions are graduated and Register File data is obtained for update
- Load misses are graduated with their destination marked unavailable
- Load misses and Stores (hits and misses) are activated in the LSU for further processing

## **Instruction Fetch Unit (IFU)**

The Instruction Fetch Unit (IFU) is responsible for fetching instructions from the Instruction Cache, Instruction Scratchpad or Memory and feeding them to the execution units. The IFU can fetch up to

4 instructions at a time from an aligned PC. The IFU uses majority branch prediction based on a gshare predictor. There are three, 256-entry Branch History Tables that are indexed by different combinations of instruction PC and Global History. The majority of these 3 predictions are used to determine the predicted direction of a conditional branch. The IFU also has an 8-entry Return Prediction Stack to predict subroutine return addresses and a 64-entry jump indirect target address predictor. A 4-way, 16-entry/way buffer learns and predicts the target addresses for indirect jumps.

The IFU has a 4-entry microTLB which is used to translate the virtual address into the physical address. This translated physical address is used to compare against tags in the instruction cache to determine a hit.

The functionality of the IFU is spread across 4 core-visible pipeline stages in MIPS32 mode. Additional stages are in the shadow of execution and do not account for the minimum recirculation path in the event of a PC redirection. In the MIPS16e™ mode, the IFU takes an additional 3 stages to recode and expand the compressed code.

There is a 12-entry Instruction Buffer to decouple the instruction fetch from execution. Up to 4 instructions can be written into this buffer, but a maximum of 2 instructions can be read from this buffer by the IDU.

The IFU can also be configured to allow for hardware prefetching of cache lines on a miss. When an instruction cache miss is detected, the IFU can prefetch the next 0, 1, or 2 lines (besides the missed line) to reduce average miss latency. The number of prefetched lines can be configured by software via *Config7* register settings.

## MIPS16e™ Application-Specific Extension

The 74Kf core includes support for the MIPS16e ASE. This ASE improves code density by using 16-bit encoding of many MIPS32 instructions plus some MIPS16e-specific instructions. PC-relative loads allow quick access to constants. SAVE/RESTORE macro instructions provide for single-instruction stack frame set-up/teardown for efficient subroutine entry/exit.

## Instruction Decode and Dispatch Unit (IDU)

This unit is responsible for receiving instructions from the IFU and dispatching them to the execution units when their operands and required resources are available. Up to two instructions can be received in-order from the IFU per cycle. The instructions are assigned an instruction ID and a completion buffer ID, which identifies a buffer location to hold results temporarily. The instruction is also renamed by looking up in a Rename Map, and the source registers are replaced (if necessary) by completion buffer IDs of producer instructions, so that operands may be bypassed as soon as possible.

Renamed instructions are assigned to one of two pipes (ALU or AGEN) and written into the Decode and Dispatch Queue (DDQ). The oldest instruction that has all the operands ready and meets all resource requirements is dispatched independently to the corresponding pipe. It is possible that instructions will be dispatched out-of-order relative to program order. Dispatched instructions do not stall in the pipe and write the results into the completion buffer.

The IDU also keeps track of the progress of the instruction through the pipe, updating the availability of operands in the Rename Map and in all dependent instructions in the DDQ.

The IDU also writes the instruction ID, completion buffer ID, and related information into structures in the Graduation Unit (GRU). The GRU reads instructions and corresponding results from the completion buffer, graduates the instructions, and updates the architectural state of the machine.

## Execution Units

The 74Kf core execution unit implements two pipes: an ALU pipe for handling all arithmetic operations (logical, shift, add, subtract) and an AGEN pipe for handling all load/store operations and control transfer instructions and an autonomous multiply/divide unit (MDU) and CorExtend unit. The MDU and CorExtend pipe share control logic with the ALU pipe. There is a 31-entry, 32-bit register file that is shared by both the pipes. There is separate 18-entry, 64-bit completion buffer for the ALU pipe, and a 14-entry, 32 bit completion buffer for the AGEN pipe.



## ALU Pipe

The ALU pipe spans four stages as follows:

- The first two stages (AF, AM) of the ALU pipe are used to prepare operands, read the register file and completion buffer, and mux select all operands for the arithmetic operation.
- Execution is performed in the AC stage, which includes:
  - Arithmetic Logic Unit (ALU) for performing arithmetic and bitwise logical operations
  - Shifter
  - Leading Zero/One detect unit for implementing the CLZ and CLO instructions
  - All logical operations, some arithmetic operations {ADD (rt=0), ADDU (rt=0), LUI, SEH, SEB, ZEH, ZEB, SLT, SLTI, SLTIU, SLTU, SLL (shift<=8) and SRL (31<=shift<=25)} will complete and bypass the results from AC stage to both ALU and AGEN pipe consumers.
  - ADD, ADDU, ADDI, ADDIU instructions can bypass the results in AC to the consumers in the ALU pipe. If the consumer instructions are in the AGEN pipe, these instructions will bypass the results from the AB stage.
- The AC stage is aligned with the start of the Multiply/Divide Unit (MDU) and the CorExtend unit.
- Results bypass for all operations is performed in the AB stage. The results are also prepared for writing into the completion buffer in the following cycle. One exception to this rule are the ADD operations bypassing to the consumer instructions in the ALU pipe.

The latency of the ALU operation is 1 or 2 cycles. For 2-cycle operations, the first cycle is required to perform the arithmetic operation, and the second cycle is required to select and forward the results to potential consumer instructions. The ALU supports a throughput of 1 operation per cycle.

## AGEN Pipe

The AGEN pipe spans 5 stages as follows:

- The first stage (EM) is used to select the operands that are read from the register file and completion buffer. The register file and completion buffer read stage overlays the DM stage of the IDU and does not contribute to the pipe-stage delay of the instruction.
- The data address for load/store operations is calculated using a 32-bit adder in the EA stage.
- Data cache access and JTLB access for load/store instructions is performed in the EC stage.
- The EC stage is also used for resolving conditional branches and register indirect jumps.
- The ES and EB stages are used by the load/store instructions to select the appropriate way of data from the data cache, to compare the JTLB results with the physical tags, align the data, resolve any exceptions, and to bypass the data (if applicable) back into the ALU and AGEN pipes.
- The ES stage is also used to send the redirect PC to the IFU, if there is a mis-predicted branch/jump instruction.

## Multiply/Divide Unit (MDU)

The 74Kf core includes a multiply/divide unit (MDU) that contains a separate pipeline for integer multiply and divide operations. This unit also executes multiply class instructions in the DSP-ASE. This pipeline operates in parallel with the integer unit pipeline and has a separate write port to the ALU completion buffer.

The MDU consists of a pipelined 32×32 multiplier, result/accumulation registers (HI and LO), a divide state machine, and the necessary multiplexors and control logic.

The MDU supports execution of one multiply or multiply-accumulate operation every clock cycle.

Divide operations are implemented with a simple 1-bit-per-clock radix 2 iterative SRT algorithm. The operands are always normalized, i.e., leading zeroes in the divisors and dividend are removed. This reduces the total number of cycles required to pro-

duce the result. Divide operations block the MDU and will not allow another MDU operation to enter until the current operation is complete. The MDU, however, looks ahead and informs the IDU that a divide operation is about to complete, which prevents any bubbles in the MDU pipeline.

Table 1 lists the repeat rate (i.e., peak rate (in cycles) at which these operations may be issued consecutively) and latency (number of cycles until a result is available) for the 74Kf core multiply and divide instructions. The approximate latency and repeat rates are listed in terms of pipeline clocks.

**Table 1 74Kf™ Core Integer Multiply/Divide Unit Latencies and Repeat Rates**

Opcode	Operand Size (mul <i>rt</i> ) (div <i>rs</i> )	Latency	Repeat Rate
MULT, MULTU, MADD, MADDU, MSUB, MSUBU	32 bits	5	1
MUL	32 bits	7	1 <sup>1</sup>
DIV, DIVU	8 bits	Min: 11 Max: 20	Min: 11 Max: 20
	32 bits	Min: 11 Max: 50	Min: 11 Max: 50

1. If there is no data dependency, a MUL can be issued every cycle.

## CorExtend® Unit

The CorExtend unit allows the user to add a functional unit to the 74Kf core pipeline with access to all programmer-visible GPR and Accumulator state.

The user will be provided with a template to define the operand format and latency for the new instruction(s) to be added. Up to 15 new instructions may be added. Each instruction may select up to 2 source GPRs and/or 1 Accumulator from the complete architectural state of 32 GPRs and 4 accumulators. The instruction may have a destination of either a GPR, an accumulator, or a private state. The latency for each instruction is also selectable to be either 3, 5, or >5 cycles. Instructions with a destination of private state have a latency of 1 cycle. The CorExtend unit may also have private architectural state, and the existence of such state can be indicated in the template to restrict out-of-order issue.

If there is no private state or there is no dependence on private state, then the IDU along with the ALU and MDU pipes manage the dependency checking, operand delivery, and results update. If a CorExtend instruction has its source and/or destination operands from its own private state, it will be issued in program order.

The CorExtend unit is synthesized along with the core and will have an external interface for access to any state within that unit. The number of completion buffers for CorExtend instructions is selectable at synthesis configuration time (from 1 to 15), and this will determine the number of CorExtend instructions that can be in flight before graduating. This is analogous to the ALU and AGEN completion buffers. The repeat rate of CorExtend instructions that can be issued back to back is also configurable at synthesis time. This parameter controls the repeat rate of instructions that may either read or write private state.

## Coprocessor Interface Unit (CIU)

The CIU provides an interface between the main integer core and the CP1 blocks. The CIU holds an in-order instruction queue (IOIQ) for the Coprocessor1 interface, a coprocessor load data queue (CLDQ), a coprocessor Store Data Queue (CSDQ), and a few other structures to pass data to and from the coprocessors.

Instructions are written in order into the IOIQ by the IDU. Coprocessor1 Load/Store instructions are sent to the AGEN pipe and to the corresponding IOIQ. Instructions exit the IOIQ and enter the Coprocessor, at which point they will read the data from the CLDQ if it is ready. If the data is not ready, the Coprocessor will either wait for the data or issue ahead, depending on its capability. A CLDQ entry is released only when its data has been consumed by the Coprocessor. If data is to be written from the Coprocessor back into the integer core, it is sent back through the CSDQ.

Even though some Coprocessor instructions do not go through the main integer pipeline, they are assigned an instruction identifier. This identifier is tracked in the Graduation Unit to generate a synchronization signal that is used to indicate to the Coprocessor that the coprocessor instruction has been cleared of all speculation and exception conditions in the integer pipe. Only coprocessor instruc-

tions that have reached such a state are allowed to commit results in the Coprocessor.

Coprocessor-based conditional branches are handled in the GRU, with condition-code information passed through the CIU.

## Floating Point Unit (FPU) / Coprocessor 1

The 74Kf core Floating Point Unit (FPU) implements the MIPS64® ISA (Instruction Set Architecture) for floating-point computation. The implementation supports the ANSI/IEEE Standard 754 (IEEE Standard for Binary Floating-Point Arithmetic) for single- and double-precision data formats. The FPU, also called “Coprocessor 1”, contains thirty-two, 64-bit floating point registers used for floating point operations

The FPU can be configured at build time to run at the same, one-half, or two-thirds the frequency of the integer core. The FPU is not as deeply pipelined as the integer core, so the maximum core frequency will only be attained when the FPU is running at a fraction of the core frequency. The FPU is connected via an internal 64-bit coprocessor interface. Note that clock cycles of floating point operation are shown using FPU clocks, not integer core clocks.

The performance of the FPU is optimized for single-precision formats. Most instructions have a one-FPU-cycle throughput and four-FPU-cycle latency. The FPU implements the MIPS64 multiply-add (MADD) and multiply-sub (MSUB) instructions with intermediate rounding after the multiply function. The result is guaranteed to be the same as executing a MUL and an ADD instruction separately, but the instruction latency, instruction fetch, dispatch bandwidth, and the total number of register accesses required are improved.

IEEE denormalized input operands and results are supported by hardware for some instructions. IEEE denormalized results are not supported by hardware in general, but a fast flush-to-zero mode is provided to optimize performance. The fast flush-to-zero mode is enabled through the *FCSR* register, and use of this mode is recommended for best performance when denormalized results are generated.

The FPU has two separate pipelines for floating point instruction execution—one for load/store

instructions and another for all other instructions. These pipelines operate in parallel with the integer core pipeline and do not stall when the integer pipeline stalls. This allows long-running FPU operations, such as divide or square root, to be partially masked by system stalls and/or other integer unit instructions.

Arithmetic instructions are always dispatched and completed in order, but loads and stores can complete out-of-order. The integer core will perform the data access for load/store operations and transfer data to and from the FPU using the CIU. Load data may arrive in the FPU out-of-order relative to program order. The exception model is ‘precise’ at all times.

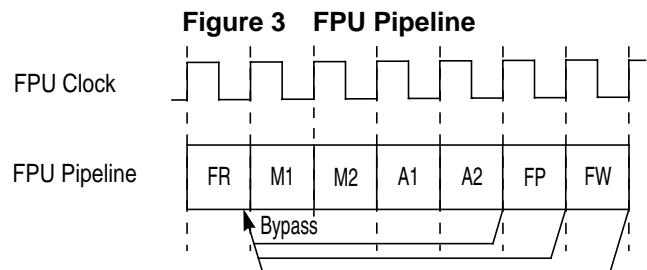
### FPU Pipeline

The FPU implements a high-performance pipeline with the following 7 stages:

- Decode, register read, and unpack (FR stage)
- Multiply tree - double pumped for double (M1 stage)
- Multiply complete (M2 stage)
- Addition first step (A1 stage)
- Addition second and final step (A2 stage)
- Packing to IEEE format (FP stage)
- Register writeback (FW stage)

The FPU implements a bypass mechanism that allows the result of an operation to be forwarded directly to the instruction that needs it, without having to write the result to the FPU register and then read it back.

Figure 3 shows the FPU pipeline.



## FPU Instruction Latencies and Repeat Rates

Table 2 contains the floating point instruction latencies and repeat rates for the 74Kf core. In this table, ‘Latency’ refers to the number of FPU cycles necessary for the first instruction to produce the result needed by the second instruction. The ‘Repeat Rate’ refers to the maximum rate at which an instruction can be executed per FPU cycle.

**Table 2 74Kf™ Core FPU Latency and Repeat Rate**

Opcode <sup>1</sup>	Latency (FPU cycles)	Repeat Rate (FPU cycles)
ABS.[S,D], NEG.[S,D], ADD.[S,D], SUB.[S,D], C.cond.[S,D], MUL.S	4	1
MADD.S, MSUB.S, NMADD.S, NMSUB.S, CABS.cond.[S,D]	4	1
CVT.D.S, CVT.PS.PW, CVT.[S,D].[W,L]	4	1
CVT.S.D, CVT.[W,L].[S,D], CEIL.[W,L].[S,D], FLOOR.[W,L].[S,D], ROUND.[W,L].[S,D], TRUNC.[W,L].[S,D]	4	1
MOV.[S,D], MOVE.[S,D], MOVN.[S,D], MOVT.[S,D], MOVZ.[S,D]	4	1
MUL.D	5	2
MADD.D, MSUB.D, NMADD.D, NMSUB.D	5	2
RECIP.S	13	10
RECIP.D	26	21
RSQRT.S	17	14
RSQRT.D	36	31
DIV.S, SQRT.S	17	14
DIV.D, SQRT.D	32	29
MTC1, DMTC1, LWC1, LDC1, LDXC1, LUXC1, LWXC1	4 <sup>2</sup>	1
MFC1, DMFC1, SWC1, SDC1, SDXC1, SUXC1, SWXC1	1	1

1. Format: S = Single, D = Double, W = Word, L = Longword
2. Best case assuming 2:1 clock ratio

## Load/Store Unit (AGEN pipe)

The Load/Store Unit is responsible for interfacing with the core pipe and handling load/store instruction to read/write data from data caches and/or memory. This unit is capable of handling loads and stores issued out-of-order. Loads, however, are not issued by the IDU until all prior stores have been issued.

Data cache sizes of 0K, 16K, 32K and 64K bytes are supported. The cache is 4-way set associative and uses an LRU replacement algorithm. There are separate virtual and physical tag arrays corresponding to the data array. The virtual tag is accessed in parallel with the data cache array and is compared against the virtual address to predict the way. The physical tag is always compared with the result of the JTLB to validate the way selection.

In addition to the data cache, the LSU also supports a scratchpad RAM for sizes ranging from 4KB to 1MB. The LSU interfaces to a 16/32/48/64 dual-entry JTLB. The LSU can handle both integer and floating point load/store instructions and has a 64 bit data path.

Loads are non-blocking in the 74Kf core. Loads that miss in the data cache are allowed to graduate with their destination register marked unavailable. Consumers of this destination register are held back at the IDU until all their operands become available. Consumers that have already been dispatched are replayed through the pipe and held back at the IDU on its second pass through the pipe. Loads that hit in the data cache and bypass to the AGEN pipe have a 4-cycle load-use latency, while those that bypass to the ALU pipe will have a 3-cycle load-use latency.

Graduated load misses and store hits and misses are sent in order to the Load/Store Graduation Buffer (LSGB). The LSGB has corresponding data and address buffers to hold all relevant attributes. LSGB entries are processed in a FIFO order, with data cache updates and requests made at one canonical point. Cache fill requests are merged and processed at this point. A 4-entry Fill Store Buffer (FSB) tracks outstanding fill requests and fills the data cache when the line is completely received. Each FSB entry can hold an entire cache line. The Load Data Queue (LDQ) keeps track of outstanding load misses and forwards the critical data to the main pipe as soon as it becomes available. The FSB also

holds data for store instructions (regardless of a hit or miss in the cache) that have not yet updated the cache. Loads that reference the same line as the pending store in the FSB will receive the store data bypassed (if they are younger than the store), and the incoming line is merged with the store data before being written into the cache. Loads that are older than the store are tracked in the Load Data Queue (LDQ) and will receive the data when it arrives from the BIU.

## Graduation Unit (GRU)

The Graduation Unit is responsible for committing execution results into architectural state and releasing buffers and resources used by these instructions. The GRU is also responsible for evaluating the exception conditions reported by execution units and taking the appropriate exception. Asynchronous interrupts are also funneled into the GRU, which prioritizes those events at the existing conditions and takes the appropriate interrupt.

The GRU receives information about the program order of instruction from the Graduation FIFO (GFIFO). The GFIFO is written by the IDU at dispatch time. The GFIFO entry has a pointer to the completion buffer and associated structures where various attributes such as PC, exception information, etc. are held.

The GRU will read up to 2 completed instructions from the GFIFO every cycle and then read the corresponding completion buffer and associated information. After processing the exception conditions, the destination register(s) are updated and the completion buffers are released. The GRU also sends graduation information to the IDU, so that it can update the rename maps to reflect the state of execution results (i.e., GPRs, Accumulators, etc.). The GRU also sends resolved branch information to the IFU, so that branch history tables can be updated.

Load misses and store hits/misses are sent to the LSGB for further processing. When the LSU receives the data back from outside, it directly updates the architectural state, but the GRU ensures that the LSGB is kept up-to-date, so that only the latest data is written. If there is no space in the LSGB, the GRU will stop graduating load/store instructions, which holds the releasing of completion buffers.

The GRU also handles instructions such as CACHE, MTC0, and TRAP-on-condition type operations that require serialized operation. During such operations, the GRU throttles down to graduating 1 instruction per cycle; otherwise, the GRU will always attempt to graduate 2 instructions per cycle.

## System Control Coprocessor (CP0)

In the MIPS architecture, CP0 is responsible for the virtual-to-physical address translation and cache protocols, the exception control system, the processor's diagnostic capability, the operating modes (kernel, user, supervisor, and debug), and whether interrupts are enabled or disabled. Configuration information, such as cache size and associativity, and the presence of features like MIPS16e or a floating point unit, are also available by accessing the CP0 registers.

CP0 also contains the state used for identifying and managing exceptions. Exceptions can be caused by a variety of sources, including boundary cases in data, external events, or program errors.

### Interrupt Handling

The 74Kf core supports six hardware interrupt pins, two software interrupts, a timer interrupt, and a performance counter interrupt. These interrupts can be used in any of three interrupt modes, as defined by Release 2 of the MIPS32 Architecture:

- Interrupt compatibility mode, which acts identically to that in an implementation of Release 1 of the Architecture.
- Vectored Interrupt (VI) mode, which adds the ability to prioritize and vector interrupts to a handler dedicated to that interrupt, and to assign a GPR shadow set for use during interrupt processing. The presence of this mode is denoted by the *VInt* bit in the *Config3* register. This mode is architecturally optional. As it is always present on the 74Kf core, the *VInt* bit will always read 1.
- External Interrupt Controller (EIC) mode, which redefines the way in which interrupts are handled, in order to provide full support for an external interrupt controller that handles prioritization and vectoring of interrupts. This mode is optional in the Release 2 architecture. The presence of this mode is denoted by the *VEIC*

bit in the *Config3* register. On the 74Kf core, the *VEIC* bit is set externally by the static input, *SI\_EICPresent*, to allow system logic to indicate the presence of an external interrupt controller.

If the 74Kf core is configured to use shadow registers, the VI and EIC interrupt modes can specify which shadow register to use on entry to a particular vector. The shadow registers further improve interrupt latency by avoiding the need to save context when invoking an interrupt handler.

## Modes of Operation

The 74Kf core supports four modes of operation: user mode, supervisor mode, kernel mode, and debug mode. User mode is most often used for application programs. Supervisor mode provides an intermediate privilege level with access to the *ksseg* address space. Supervisor mode is not supported with the fixed mapping MMU. Kernel mode is typically used for handling exceptions and operating system kernel functions, including CP0 management and I/O device accesses. An additional Debug mode is used during system bring-up and software development. Refer to “EJTAG Debug Support” on page 18 for more information on debug mode.

## Memory Management Unit (MMU)

The 74Kf core contains a Memory Management Unit (MMU) that is primarily responsible for converting virtual addresses to physical addresses and providing attribute information for different segments of memory. At synthesis time, the type of MMU can be chosen independently from the following options:

- Translation Lookaside Buffer (TLB)
- Fixed Mapping Translation (FMT)

The following sections explain the MMU options in more detail.

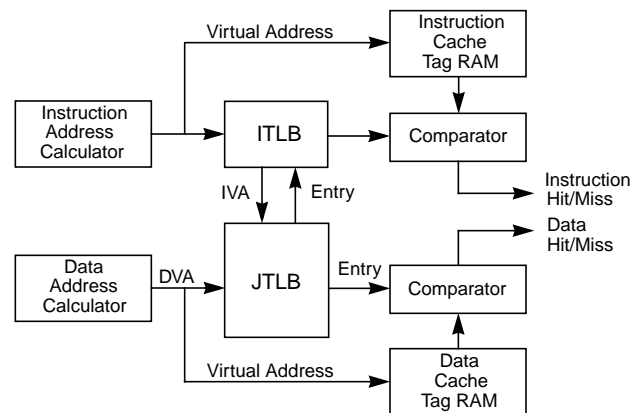
### Translation Lookaside Buffer (TLB)

The basic TLB functionality is specified by the MIPS32 Privileged Resource Architecture. A TLB provides mapping and protection capability with per-page granularity. The 74Kf core implementation allows a wide range of page sizes to be present simultaneously.

The TLB contains a fully associative dual-ported Joint TLB (JTLB). To enable higher clock speeds, a smaller instruction micro-TLB (ITLB) is also implemented. When an instruction address is calculated, the virtual address is compared to the contents of the appropriate ITLB. If the address is not found in the ITLB, the JTLB is accessed. If the entry is found in the JTLB, that entry is then written into the ITLB; if the address is not found in the JTLB, a TLB exception is taken. For data accesses, the virtual address is looked up in the JTLB only, and a miss causes a TLB exception.

Figure 4 shows how the ITLB and JTLB are implemented in the 74Kf core.

**Figure 4 Cache Access for Address Translation**



### Joint TLB (JTLB)

The JTLB is a dual-ported fully associative TLB cache containing 16, 32, 48, or 64 dual entries, mapping up to 128 virtual pages to their corresponding physical addresses. The address translation is performed by comparing the upper bits of the virtual address (along with the ASID) with each of the entries in the *tag* portion of the joint TLB structure.

The JTLB is organized as pairs of even and odd entries that map pages ranging in size from 4 KB to 256 MB, in factors of four, to the 4 GB physical address space. The JTLB is organized in page pairs to minimize the overall size. Each *tag* entry corresponds to two data entries: an even page entry and an odd page entry. The highest-order virtual address bit not participating in the tag comparison is used to determine which of the data entries is used. Because page size can vary on a page-pair basis, the determination of which address bits participate in



the comparison and which bit is used to make the even-odd determination is decided dynamically during the TLB look-up.

### Instruction TLB (ITLB)

The ITLB is a 4-entry structure dedicated to performing translations for the instruction stream. The ITLB maps only 4 KB or 16 KB pages/subpages. For 4 KB or 16 KB pages, the entire page is mapped in the ITLB. If the main TLB page size is between 4 KB and 16 KB, only the current 4 KB subpage is mapped. Similarly, for page sizes larger than 16 KB, the current 16 KB subpage is mapped.

The ITLB is managed by hardware and is transparent to software. The larger JTLB is used as a backup structure for the ITLB. If a fetch address cannot be translated by the ITLB, the JTLB attempts to translate it in the following clock cycle or when available. If successful, the translation information is copied into the ITLB for future use. The JTLB port used for ITLB miss access is shared with other MMU management activities.

### Fixed Mapping Translation (FMT)

The FMT is much simpler and smaller than the TLB-style MMU, and is a good choice when the full protection and flexibility of the TLB are not needed. Like a TLB, the FMT performs virtual-to-physical address translation and provides attributes for the different segments. Those segments that are unmapped in a TLB implementation (*kseg0* and *kseg1*) are handled identically by the FMT.

### Instruction Cache

The instruction cache is an on-chip memory block of 0/16/32/64 KB, with 4-way associativity. All size references made will assume a default size of 32 KB. Because the instruction cache is virtually indexed, the virtual-to-physical address translation occurs in parallel with the tag access, rather than having to wait for the physical address translation. A tag entry holds 21 bits of physical address, a valid bit, a lock bit, and an optional parity bit. There are 7 precode bits per instruction pair, making a total of 28 bits per tag entry. The data array line consists of 256 bits (8 MIPS32 instructions) of data. Each instruction doubleword (64 bits) has 8 bits of byte parity. The IFU interface consists of 128 bits (4 MIPS32 instructions) with 16 bits of parity. The LRU replacement bits (6 bits) are shared among the

4 ways of the data and tag array and are stored in a separate array.

The instruction cache block also contains and manages the two instruction line fill buffers. Besides accumulating data to be written to the cache, instruction fetches that reference data in the line fill buffer are serviced either by a bypass of that data or by data coming from the external interface. The instruction cache control logic controls the bypass function.

The 74Kf core supports instruction-cache locking. Cache locking allows critical code segments to be locked into the cache on a “per-line” basis, enabling the system programmer to maximize the efficiency of the system cache.

The cache-locking function is always available on all instruction-cache entries. Entries can then be marked as locked or unlocked on a per entry basis using the CACHE instruction.

### Data Cache

The data cache is an on-chip memory block of 0/16/32/64 KB, with 4-way associativity. Because the data cache is virtually indexed, the virtual-to-physical address translation occurs in parallel with the cache access. A tag entry holds 21 bits of physical address, a valid bit, a lock bit, and an optional parity bit. At each tag entry there is also a corresponding 21 bit virtual tag. The data entry holds 64 bits of data per way, with optional parity per byte. There are 4 data entries for each tag entry. The tag and data entries exist for each way of the cache. There is an additional array that holds the dirty and LRU replacement algorithm bits for all 4 ways (6 bits LRU, 4 bits dirty, and optionally 4 bits dirty parity).

When using 4 KB pages in the TLB and 32 or 64 KB cache sizes, virtual aliasing can occur, in which a single physical address can exist in multiple cache locations if it was accessed via different virtual addresses. For a 32 KB data cache, there is an implementation option to eliminate virtual aliasing. If this option is not selected, or a 32 or 64 KB cache is implemented, software must take care of any aliasing issues by using a page-coloring scheme or some other mechanism.

The 74Kf core supports a data-cache locking mechanism identical to that used in the instruction cache. Critical data segments are locked into the cache on

a “per-line” basis. The locked contents can be updated on a store hit, but will not be selected for replacement on a cache miss.

The cache-locking function is always available on all data cache entries. Entries can then be marked as locked or unlocked on a per-entry basis using the CACHE instruction.

## Cache Memory Configuration

The 74Kf core’s on-chip instruction and data caches are usually implemented from readily available single-port synchronous SRAMs.

The instruction tag array is accessed in one cycle, and the corresponding instruction data array is accessed in the following cycle. While the instruction data is being accessed, the tag data is compared to the translated address to determine a hit. The result of this hit is used to select the way of the instruction data in the following cycle, thus completing the 3-cycle sequence.

The data cache and tag arrays are accessed in the same cycle. The JTLB is also accessed at the same time for virtual to physical address translation. The virtual tag match with the virtual address is used to select the data cache way in order to bypass data as soon as possible. The result of the JTLB compare is used to further determine a match with the physical tag in the tag array to validate the virtual tag match. If the two comparisons do not agree, the data cache access is deemed to be a miss. The data cache refill can be done via a 64- or 128-bit interface and is a synthesis-time configuration option

Table 3 lists the attributes of the 74Kf core instruction and data caches.

**Table 3 74Kf™ Core Instruction and Data Cache Attributes**

Parameter	Instruction	Data
Size	0, 16, 32, or 64 KB <sup>1</sup>	0, 16, 32, or 64 KB
Organization	4-way set associative	4-way set associative
Line Size	32 Bytes <sup>1</sup>	32 Bytes
Read Unit	128 bits <sup>1</sup>	64 or 128 bits
Write Unit	128 bits	64 or 128 bits

**Table 3 74Kf™ Core Instruction and Data Cache Attributes (Continued)**

Parameter	Instruction	Data
Write Policies	N/A	Non-coherent write-through without write allocate, write-back with write allocate
Cache Locking	per line	per line

1. Logical size of instruction cache. The cache contains some extra bits used for precoding the instruction type.

## Cache Protocols

The 74Kf core supports the following cache protocols:

- **Uncached:** Addresses in a memory area specified as uncached are not read from the cache. Stores to uncached addresses are written directly to main memory, without changing the contents of the cache.
- **Non-Coherent Write-through, no write allocate:** Loads and instruction fetches first search the cache, reading main memory only if the desired data does not reside in the cache. On data store operations, the cache is first searched to see if the target address is in the cache. If it is, the cache contents are updated, and main memory is also written. If the cache look-up misses, only main memory is written.
- **Writeback, write allocate:** Stores that miss in the cache will cause a cache refill. Store data however, is only written to the cache. Cache lines that are written by stores will be marked as dirty. If a dirty line is selected for replacement, the cache line will be written back to main memory.
- **Uncached accelerated:** As with the uncached protocol, data is never loaded into the cache. In this mode, store data can be gathered in a write buffer before being sent out on the bus as a bursted write. This is more efficient than sending out separate individual writes, as is done in uncached mode.

## Scratchpad RAM

The 74Kf core allows blocks of scratchpad RAM to be attached to the load/store and/or instruction



units. These allow low-latency access to a fixed block of memory.

These blocks can be modified by the user. A reference design is provided that includes an SRAM array and an external DMA port that allows the system to directly access the array.

## L2 Cache Support

The 74Kf core supports building a Level 2 cache on the front side bus inline with the memory access. This L2 cache is unified and contains both instruction and data segments. The L2 cache can be configured to be by-passable, i.e., memory accesses from the 74Kf core can bypass the L2 cache directly access the main memory.

The L2 cache configuration and functional detail are provided in the document *MIPS® SOC-it® L2 Cache Controller Datasheet*, MD00502.

## Bus Interface (BIU)

The Bus Interface Unit (BIU) controls the external interface signals. The primary interface implements the Open Core Protocol (OCP). Additionally, the BIU includes a write buffer.

### Open Core Protocol (OCP) Interface

Table 4 shows the OCP Performance Report for the 74Kf core. This table lists characteristics of the core and the specific OCP functionality that is supported.

**Table 4 OCP Performance Report**

Core Attribute	Description
Core name	74Kf
Vendor code	0x4d50
Core code	0x10a
Revision code	0x1
Core identity	Additional identification is available in the <i>PrID</i> and <i>EBase</i> Coprocessor0 registers.
Process dependent	Yes
Frequency range	Core is synthesizable, so these parameters vary according to process, libraries, and implementation.
Area	
Power estimate	
Special reset requirements	No

**Table 4 OCP Performance Report (Continued)**

Core Attribute	Description
Number of Interfaces	1 OCP master
<b>Master OCP Interface</b>	
Operations issued	RD, WR
Issue rate (per OCP cycle)	One per cycle for all types listed above, except for a non-standard RD (SYNC) which depends on ACK latency.
Maximum number of operations outstanding	12 operations (4 LSU reads, 4 IFU reads, and 4 WBB flushes) All writes are posted, so the OCP fabric determines the maximum number of outstanding writes.
Burst support and its effect on issue rates	Fixed burst length of four 64-bit beats, with single request per burst. Burst sequences of WRAP or XOR are supported.
High-level flow control	None
Number of threads supported and use of those threads	All transactions utilize a single thread.
Connection ID and use of connection information	None
Use of sideband signals	None
Implementation restrictions	<ol style="list-style-type: none"> <li>MReqInfo handled in a user-defined way. 3 bits used to send cacheable attribute information or encode type of L2 CACHE instruction, and 1 bit used to signify SYNC.</li> <li>MAddrSpace is used (2 bits) to indicate L2/L3 access.</li> <li>MTagId is used (4bits) to identify the transaction. Tags 0-3 identify Dcache read, tags 4,5,12,13 identify I-cache read, Tag 6 identifies SYN and Tag 7 identifies Write operation and CACHE ops. The remaining values are reserved.</li> <li>Core clock is synchronous but must be a multiple of the OCP clock. The ratios supported are 1:1, 1:1.5, 1:2, 1:2.5, 1:3, 1:3.5, 1:4, 1:5, and 1:10. A helper pulse is required by the Core to transfer data from/to the OCP interface without any hazards.</li> </ol>

### Write Buffer

The BIU contains a merging write buffer. The purpose of this buffer is to store and combine write transactions before issuing them to the external interface. The write buffer is organized as four, 32-

byte buffers. Each buffer contains data from a single 32-byte aligned block of memory.

When using the write-through cache policy, the write buffer significantly reduces the number of write transactions on the external interface and reduces the amount of stalling in the core caused by the issuance of multiple writes in a short period of time.

The write buffer also holds eviction data for write-back lines. The load-store unit opportunistically pulls dirty data from the cache and sends it to the BIU. It is gathered in the write buffer and sent out as a bursted write.

For uncached accelerated references, the write buffer can gather multiple writes together and then perform a bursted write in order to increase the efficiency of the bus. Uncached accelerated gathering is supported for word or doubleword.

Gathering of uncached accelerated stores starts on cache-line-aligned addresses, i.e., 32-byte aligned addresses. Uncached accelerated stores that do not meet the conditions required to start gathering are treated like regular uncached stores.

When an uncached accelerated store meets the requirements needed to start gathering, a gather buffer is reserved for this store. All subsequent uncached accelerated word or doubleword stores to the same 32-bit region will write sequentially into this buffer, independent of the word address associated with these latter stores. The uncached accelerated buffer is tagged with the address of the first store.

### SimpleBE Mode

To aid in attaching the 74Kf core to structures that cannot easily handle arbitrary byte-enable patterns, there is a mode that generates only “simple” byte enables. Only byte enables representing naturally aligned byte, halfword, word, and doubleword transactions will be generated.

The only case in which a read can generate “non-simple” byte enables is on an uncached tri-byte load (LWL/LWR). In SimpleBE mode, such a read will be converted into a word read on the external interface.

Writes with non-simple byte enable patterns can arise when a sequence of stores is processed by the

merging write buffer, or from uncached tri-byte stores (SWL/SWR). In SimpleBE mode, these stores will be broken into multiple write transactions.

## EJTAG Debug Support

The 74Kf core includes an Enhanced JTAG (EJTAG) block for use in software debugging of application and kernel code. For this purpose, in addition to standard user/supervisor/kernel modes of operation, the 74Kf core provides a Debug mode. Debug mode is entered when a debug exception occurs (resulting from a hardware breakpoint, single-step exception, etc.) and continues until a debug exception return (DERET) instruction is executed. During this time, the processor executes the debug exception handler routine.

The EJTAG interface operates through the Test Access Port (TAP), a serial communication port used for transferring test data in and out of the 74Kf core. In addition to the standard JTAG instructions, special instructions defined in the EJTAG specification define which registers are selected and how they are used.

There are several types of simple hardware breakpoints defined in the EJTAG specification. These breakpoints stop the normal operation of the CPU and force the system into debug mode. There are two types of simple hardware breakpoints implemented in the 74Kf core: Instruction breakpoints and Data breakpoints.

During synthesis, the 74Kf core can be configured to support the following breakpoint options:

- Zero instruction, zero data breakpoints
- Four instruction, two data breakpoints

Instruction breaks occur on instruction fetch operations, and the break is set on the virtual address. Instruction breaks can also be made on the ASID value used by the MMU. A mask can be applied to the virtual address to set breakpoints on a range of instructions.

Data breakpoints occur on load and/or store transactions. Breakpoints are set on virtual address and ASID values, similar to the Instruction breakpoint. Data breakpoints can also be set based on the value of the load/store operation. Finally, masks can be

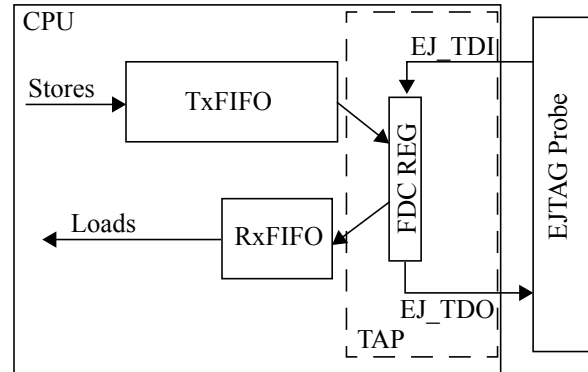
applied to the virtual address, ASID value, and the load/store value.

In debug mode, EJTAG can request that a ‘soft’ reset be masked. This request is signalled via the *EJ\_SRstE* pin. When this pin is deasserted, the system can choose to block some sources of soft reset. Hard resets, such as power-on reset or a reset switch, should not be blocked by this signal. This reset pin has no effect inside the core.

### Fast Debug Channel

The 74Kf CPU includes the EJTAG Fast Debug Channel (FDC) as a mechanism for efficient bi directional data transfer between the CPU and the debug probe. Data is transferred serially via the TAP interface. A pair of memory- mapped FIFOs buffer the data, isolating software running on the CPU from the actual data transfer. Software can configure the FDC block to generate an interrupt based on the FIFO occupancy or can poll the status.

**Figure 5 Fast Debug Channel**



### MIPS Trace

The 74Kf core includes optional MIPS Trace support for real-time tracing of instruction addresses, data addresses, data values, performance counters, and processor pipeline inefficiencies. The trace information is collected in an on-chip or off-chip memory, for post-capture processing by trace regeneration software. Software-only control of trace is possible in addition to probe-based control.

An optional on-chip trace memory may be configured in size from 256B to 8 MB; it is accessed either through load instructions or the existing EJTAG TAP interface, which requires no additional chip pins. Off-chip trace memory is accessed through a special trace probe and can be configured to use 4, 8, 16, or 64 data pins plus a clock.

## Clock and Test Considerations

The following sections describe clocking, power management, and testability features.

### Clocking

The 74Kf core has various clock domains:

- Core domain - This is the main core clock domain, controlled by the *SI\_ClkIn* clock input. CP1 domain - This domain provides the clock for Coprocessor1 block and is controlled by the *SI\_Cp1ClkIn* and *SI\_Cp1Sync* inputs. Applicable to core configure with 3:2 Core to FPU clock ratio.
- OCP domain - This domain controls the OCP bus interface logic. This domain is synchronous to *SI\_ClkIn*, but can be run at lower frequencies. core to bus ratios of 1:1, 1:1.5, 1:2, 1:2.5, 1:3, 1:3.5, 1:4, 1:5, and 1:10 are supported.
- TAP domain - This is a low-speed clock domain for the EJTAG TAP controller, controlled by the *EJ\_TCK* pin. It is asynchronous to *SI\_ClkIn*.

### Power Management

The 74Kf core offers a number of power management features, including low-power design, active

power management, and power-down modes of operation. The core is a static design that supports slowing or halting the clocks to reduce system power consumption during idle periods.

The 74Kf core provides two mechanisms for system-level low power support:

- Register-controlled power management
- Instruction-controlled power management

### Register-Controlled Power Management

The *RP* bit in the CP0 *Status* register provides a software mechanism for placing the system into a low-power state. The state of the *RP* bit is available externally via the *SI\_RP* signal pin. The external agent then decides whether to place the device in a low power mode, such as reducing the system clock frequency.

Three additional bits—*Status\_EXL*, *Status\_ERL*, and *Debug\_DM*—support the power management function by allowing the user to change the power state if an exception or error occurs while the 74Kf core is in a low-power state. Depending on what type of exception is taken, one of these three bits will be set to 1 and be reflected in the *SI\_EXL*, *SI\_ERL*, and *EJ\_DebugM* outputs. The external agent can look at these signals and determine whether to leave the low-power state to service the exception.

The following four power-down signals are part of the system interface and change state as the corresponding bits in the CP0 registers are set or cleared:

- The *SI\_RP* signal represents the state of the *RP* bit (27) in the CP0 *Status* register.
- The *SI\_EXL* signal represents the state of the *EXL* bit (1) in the CP0 *Status* register.
- The *SI\_ERL* signal represents the state of the *ERL* bit (2) in the CP0 *Status* register.
- The *EJ\_DebugM* signal represents the state of the *DM* bit (30) in the CP0 *Debug* register.

### Instruction-Controlled Power Management

The second mechanism for invoking power-down mode is through execution of the WAIT instruction. When the WAIT instruction is executed, the internal clock is suspended; however, the internal timer and

some of the input pins (*SI\_Int[5:0]*, *SI\_NMI*, and *SI\_Reset*) continue to run. When the CPU is in this instruction-controlled power management mode, any interrupt, NMI, or reset condition causes the CPU to exit this mode and resume normal operation.

The 74Kf core asserts the *SI\_Sleep* signal, which is part of the system interface, whenever it has entered low-power mode (sleep mode). It will enter sleep mode when all bus transactions are complete and there are no running instructions.

The WAIT instruction can put the processor in a mode where no instructions are running. When the WAIT instruction is seen by the IFU, subsequent instruction fetch is stopped. The WAIT instruction is dispatched down the pipe and graduated. Upon graduation of the WAIT, the GRU waits for the processor to reach a quiescent state and allows the processor to enter sleep mode.

### Local Clock Gating

A significant portion of the power consumed by the 74Kf core is often in the clock tree and clocking registers. The core has support for extensive use of local gated clocks. Clock gating can be turned on at the top level, block level, or at the register (fine grained) level. Power-conscious implementors can use these gated clocks to significantly reduce power consumption within the core.

### D-Cache Clock Gating

Any load instruction involves reading of four ways of the data array, though the required data may be available only in one of the four ways of the D-cache. The way information for four recently used D-cache lines are stored in a data structure, and a subsequent load to one of those lines enables the clock to only one of the data arrays, thereby saving the memory power required for a read operation on three ways of the D-cache. Also, for additional power savings, the D-cache data array clocks are disabled for store instructions and idle cycles. This optional feature significantly reduces the power consumed by the D-cache data array.

### Internal Scan

The 74Kf supports full mux-based scan for maximum test coverage, with a configurable number of scan chains. ATPG test coverage can exceed 99%,

depending on standard cell libraries and configuration options.

## Memory BIST

The core provides an integrated memory BIST solution for testing the internal cache SRAMs, scratchpad memories, and on-chip trace memory using BIST controllers and logic tightly-coupled to

the cache subsystem. These BIST controllers can be configured to utilize the March C+ or I A-13 algorithms.

Memory BIST can also be inserted with a CAD tool or other user-specified method. Wrapper module and signal buses of configurable width are provided within the core to facilitate this approach.

## Build-Time Configuration Options

The 74Kf core allows a number of features to be customized based on the intended application. Table 5 summarizes the key configuration option that can be selected when the core is synthesized and implemented.

For a core that has already been built, software can determine the value of many of these options by

querying an appropriate register field. Refer to the *MIPS32® 74Kf™ Processor Core Family Software User's Manual* for a more complete description of these fields. The value of some options that do not have a functional effect on the core are not visible to software.

**Table 5 Build-time Configuration Options**

Configuration Option	Choices	Software Visibility
Floating point unit	Present or not	<i>Config1<sub>FP</sub></i>
Memory Management Type	TLB or FMT	<i>Config<sub>MT</sub></i>
TLB Size	16, 32, 48, or 64 dual entries	<i>Config1<sub>MMUSize</sub></i>
Integer Register File sets	1, 2, or 4	<i>SRCTL<sub>HSS</sub></i>
{Instruction, Data} hardware breakpoints	{0,0} or {4,2}	<i>DCR<sub>IB</sub>, IBS<sub>BCN</sub></i>
Fast Debug FIFO Sizes	Min (2Tx, 2Rx), Useful (12Tx, 4Rx)	<i>FDCFG</i>
MIPS Trace support	Present or not	<i>Config3<sub>TL</sub></i>
MIPS Trace memory location	On-core, off-chip or both	<i>TCBCONFIG<sub>OnT</sub></i> <i>TCBCONFIG<sub>OffT</sub></i>
MIPS Trace on-chip memory size	256B - 8MB	<i>TCBCONFIG<sub>SZ</sub></i>
MIPS Trace triggers	0-8	<i>TCBCONFIG<sub>TRIG</sub></i>
MIPS Trace source field bits in trace word	0, 2, or 4	<i>TCBCONTR<sub>LB</sub><sub>TWSrcWidth</sub></i>
CorExtend Block	Present or not	<i>Config<sub>UDI</sub></i> <sup>1</sup>
FPU clock ratio relative to integer core	1:1, 2:1, or 3:2	<i>Config7<sub>FPR0</sub>, Config7<sub>FPR1</sub></i>
Data ScratchPad RAM interface	Present or not	<i>Config<sub>DSP</sub></i> <sup>1</sup>
Instruction ScratchPad RAM interface	Present or not	<i>Config<sub>ISP</sub></i> <sup>1</sup>
I-cache size	0, 16, 32, or 64 KB	<i>Config1<sub>IL</sub>, Config1<sub>IS</sub></i>

**Table 5 Build-time Configuration Options (Continued)**

Configuration Option	Choices	Software Visibility
D-cache size	0, 16, 32, or 64 KB	<i>Config1<sub>DL</sub>, Config1<sub>DS</sub></i>
D-cache hardware aliasing support	Present or not (for 32 KB and 64 KB only, MMU type is TLB)	<i>Config7<sub>AR</sub></i>
Cache parity	Present or not	<i>ErrCtl<sub>PE</sub></i>
Memory BIST	Integrated (March C+ or March C+ plus IFA-13), custom, or none	N/A
Clock gating	Top-level, block-level, fine-grain, D-cache, or none	N/A
Control and Observe flop	Present or not	N/A
Repeat rate for CorExtend instructions using private state	1 through 15	N/A
Number of CorExtend completion buffers	1 through 15	N/A
128-bit Data Cache interface	Present or not	N/A
Sideband inputs to external CorExtend module	Bus width (in bits)	N/A
Sideband outputs to external CorExtend module	Bus width (in bits)	N/A

1. These bits indicate the presence of external blocks. Bit will not be set if interface is present, but block is not.

## Revision History

Change bars (vertical lines) in the margins of this document indicate significant changes in the document since its last release. Change bars are removed for changes that are more than one revision old. This document may refer to Architecture specifications (for example, instruction set

descriptions and EJTAG register definitions) and change bars in those sections indicate changes since the previous version of the relevant Architecture document.

Revision	Date	Description
00.50	May 31, 2006	Initial document.
01.00	January 30, 2007	Preliminary external release.
01.01	May 18, 2007	General Access Release. Updates for single cycle ALU operations, instruction latencies and pipeline stages.
01.02	November 1, 2007	Pipeline stage merge changes; L2 support; ADD latency and Misc changes.
01.03	December 14, 2007	Add support for sequential hardware prefetching by IFU. Change ALU and AGEN pipestage count.
01.04	November 14, 2008	Corrected outstanding I-cache misses. Updates for ISPRAM, PDtrace features.
01.05	June 04, 2010	Added FDC, JRC information. Reflects ITLB page size change, additional probe data transfer width.
01.06	March 30, 2011	Minor Edits.
01.07	June 03, 2011	Corrected FDC related information.



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