NUC745 Programming Guide

Revision 1.1

05/09/2008

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Revision History

Revision	Date	Comment
1.0	07/17/2005	Initial Version for NUC745
1.1	05/09/2008	Update Header

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1 Overview

The NUC745 16/32-bit RISC micro-controller is a cost-effective, high-performance micro-controller solution for Ethernet-based system. An integrated Ethernet controller, the NUC745, is designed for use in managed communication hubs and routers.

The NUC745 is built around an outstanding CPU core: on the 16/32 ARM7TDMI based RISC processor designed by Advanced RISC Machines, Ltd. The ARM7TDMI core is a low power, general-purpose integrated circuits. Its simple, elegant, and fully static design is particularly suitable for cost-sensitive and power-sensitive applications.

The NUC745 offers a 4K-byte I-cache/SRAM, a 4K-byte D-cache/SRAM and one MACs of Ethernet controller that reduces total system cost. Most of the on-chip function blocks have been designed using an HDL synthesizer and the NUC745 has been fully verified in Nuvoton's state-of-the art ASIC test environment.

The other important peripheral functions include one USB host controller, one USB device controller, one AC97/IIS codec controller, one 2-Channel GDMA, four independent UARTS, one Watchdog timer, two 24-bit timers with 8-bit pre-scale, 31 programmable I/O ports, PS/2 keyboard controller and an advance interrupt controller. The external bus interface (EBI) controller provides for SDRAM, ROM/SRAM, flash memory and I/O devices.

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1.1 Features

1.1.1 Architecture

- Fully 16/32-bit RISC architecture
- Little/Big-Endian mode supported
- Efficient and powerful ARM7TDMI core
- Cost-effective JTAG-based debug solution

1.1.2 External Bus Interface

- 8/16-bit external bus support for ROM/SRAM, flash memory, SDRAM and external I/Os
- Support for SDRAM
- Programmable access cycle (0-7 wait cycle)
- Four-word depth write buffer
- Cost-effective memory-to-peripheral DMA interface

1.1.3 Instruction and Data Cache

- Two-way, Set-associative, 4K-byte I-cache and 4K-byte D-cache
- Support for LRU (Least Recently Used) Protocol
- Cache is configurable as an internal SRAM
- Support Cache Lock function

1.1.4 Ethernet MAC Controller

- DMA engine with burst mode
- MAC Tx/Rx buffers (256 bytes Tx, 256 bytes Rx)
- Data alignment logic
- Endian translation
- 100/10-Mbit per second operation
- Full compliance with IEEE standard 802.3
- RMII interface only
- Station Management Signaling
- On-Chip CAM (up to 16 destination addresses)
- Full-duplex mode with PAUSE feature

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- Long/short packet modes
- PAD generation

1.1.5 DMA Controller

- 2-channel General DMA for memory-to-memory data transfers without CPU intervention
- Initialed by a software or external DMA request
- Increments or decrements a source or destination address in 8-bit, 16-bit or 32-bit data transfers
- 4-data burst mode

1.1.6 USB Host Controller

- USB 1.1 compliant
- Compatible with Open HCI 1.0 specification
- Supports low-speed and full speed devices
- Build-in DMA for real time data transfer
- Two on-chip USB transceivers with one optionally shared with USB Device Controller

1.1.7 USB Device Controller

- USB 1.1 compliant
- Support four USB pipes including one control pipe and 3 configurable pipes for rich USB functions
- Support USB Mass Storage
- Support USB Virtual COM port with modem capability
- Support Full speed only

1.1.8 2 Channel AC97/I2S Audio Codec Host Interface

- AHB master port and an AHB slave port are offered in audio controller
- Always 8-beat incrementing burst
- Always bus lock when 8-beat incrementing burst
- When reach middle and end address of destination address, a DMA_IRQ is requested to CPU automatically

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1.1.9 UART

- Four UART (serial I/O) blocks with interrupt-based operation
- Support for 5-bit, 6-bit, 7-bit or 8-bit serial data transmit and receive
- Programmable baud rates
- 1, ½ or 2 stop bits
- Odd or even parity
- Break generation and detection
- Parity, overrun and framing error detection
- X16 clock mode
- Support for Bluetooth, IrDA and Micro-printer control

1.1.10Timers

- Two programmable 24-bit timers with 8-bit pre-scalar
- One programmable 24-bit Watch-Dog timer
- One-short mode, period mode or toggle mode operation

1.1.11Advanced Interrupt Controller

- 31 interrupt sources, including 2 external interrupt sources
- Programmable normal or fast interrupt mode (IRQ, FIQ)
- Programmable as either edge-triggered or level-sensitive for 2 external interrupt sources
- Programmable as either low-active or high-active for 2 external interrupt sources
- Priority methodology is encoded to allow for interrupt daisy-chaining
- Automatically mask out the lower priority interrupt during interrupt nesting
- Automatically clear the interrupt flag when the interrupt source is programmed to be edge-triggered

1.1.12GPIO

- 31 programmable I/O ports
- Pins individually configurable to input, output, or I/O mode for dedicated signals
- I/O ports Configurable for Multiple functions

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1.1.13I2C Master

- Compatible with Philips I^2C standard, support master mode only
- Support multi master operation
- Clock stretching and wait state generation
- Provide multi-byte transmit operation, up to 4 bytes can be transmitted in a single transfer
- Software programmable acknowledge bit
- Arbitration lost interrupt, with automatic transfer cancellation
- Start/Stop/Repeated Start/Acknowledge generation
- Start/Stop/Repeated Start detection
- Bus busy detection
- Supports 7 bit addressing mode
- Software mode I^2C

1.1.14Universal Serial Interface (USI)

- Support USI master mode only
- Full duplex synchronous serial data transfer
- Variable length of transfer word up to 32 bits
- Programmable data frame size from 4 to 16 bits
- Provide burst mode operation, transmit/receive can be executed up to four times in one transfer
- MSB or LSB first data transfer
- Rx and Tx on both rising or falling edge of serial clock independently
- 2 slave/device select lines

1.1.154-Channel PWM

- Four 16-bit timers
- Two 8-bit pre-scalars & Two 4-bit divider
- Programmable duty control of output waveform (PWM)
- Auto reload mode or one-shot pulse mode
- Dead zone generator

1.1.16Keypad Interface

- Scan up to 16x8 with an external 4 to 16 decoder and 4x8 array without auxiliary component

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- Programmable debounce time
- One or two keys scan with interrupt and three keys reset function.
- Support low power mode wakeup function

1.1.17PS2 Host Interface Controller

- APB slave consisted of PS2 protocol.
- Connect IBM keyboard or bar-code reader through PS2 interface.
- Provide hardware scan code to ASCII translation

1.1.18Power Management

- Programmable clock enables for individual peripheral
- IDLE mode to halt ARM Core and keep peripheral working
- Power-Down mode to stop all clocks included external crystal oscillator.
- Exit IDLE/Power-Down by interrupts
-

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2 EBI (External Bus Interface)

2.1 Overview

NUC745 supports External Bus Interface (**EBI**), which controls the access to the external memory (ROM/FLASH, SDRAM) and External I/O devices. The **EBI** has seven chip selects to select one ROM/FLASH bank, two SDRAM banks, and four External I/O banks and 25-bit address bus. It supports 8-bit, 16-bit, and 32-bit external data bus width for each bank.

The EBI has the following functions :

- SDRAM controller
- EBI control register
- ROM/FLASH interface
- External I/O interface

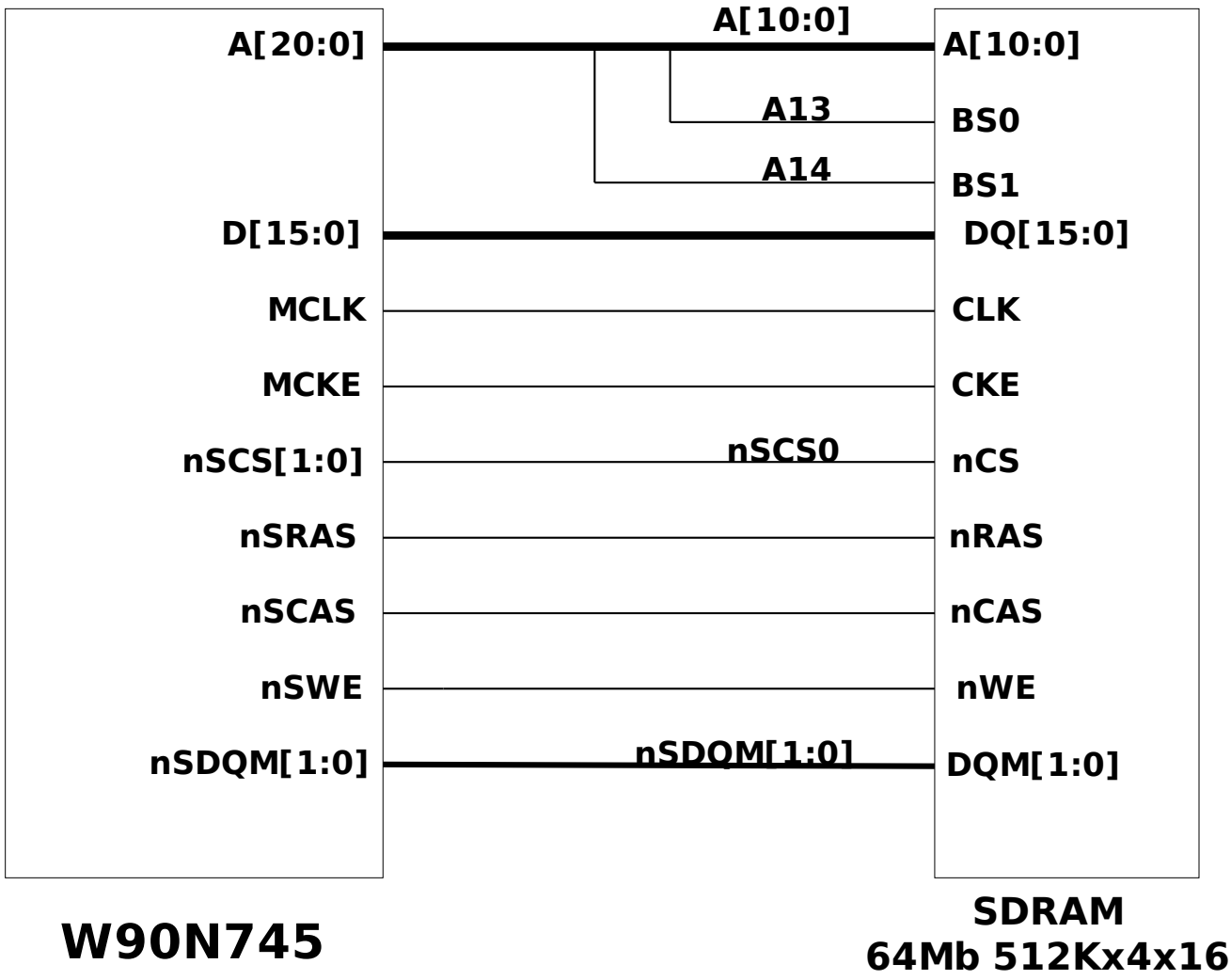
The base addresses of SDRAM, ROM/FLASH, and External I/O are all programmable. Thus they can be set in a specified address ranges in memory. The EBI also offer power-on setting to ensure the system can be boot by from ROM/FLASH.

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2.2 Block Diagram

2.2.1 SDRAM interface

Figure 2-1 SDRAM Interface



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2.3 Registers

Register	Address	R/W	Description	Reset Value
EBICON	0xFFF0.1000	R/W	EBI control register	0x0001.0000
ROMCON	0xFFF0.1004	R/W	ROM/FLASH control register	0x0000.0XFC
SDCONF0	0xFFF0.1008	R/W	SDRAM bank 0 configuration register	0x0000.0800
SDCONF1	0xFFF0.100C	R/W	SDRAM bank 1 configuration register	0x0000.0800
SDTIME0	0xFFF0.1010	R/W	SDRAM bank 0 timing control register	0x0000.0000
SDTIME1	0xFFF0.1014	R/W	SDRAM bank 1 timing control register	0x0000.0000
EXT0CON	0xFFF0.1018	R/W	External I/O 0 control register	0x0000.0000
EXT1CON	0xFFF0.101C	R/W	External I/O 1 control register	0x0000.0000
EXT2CON	0xFFF0.1020	R/W	External I/O 2 control register	0x0000.0000
CKSKEW	0xFFF0.1F00	R/W	Clock skew control register (for testing)	0xXXXX.0038

2.4 Functional Descriptions

2.4.1 EBI Control Register (EBICON)

The major function of EBICON is to control the SDRAM refreshing timing. This register can control is used to set the refresh period, clock, and valid time of nWAIT signal. Additionally, the EBI memory format configuration (Big, or Little Endian) can be known got by reading from the EBI control register. The auto-refresh rate is controlled by the REFRAT , and SDRAM clock is controlled by CLKEN.

There are two SDRAM refresh mode, auto-refresh mode and self-refresh mode. If SDRAM is operated in auto-refresh mode, SDRAM controller refreshes SDRAM every by a period specified by REFRAT. If SDRAM is in self-refresh mode, it is refreshed by SDRAM itself. Thus if SDRAM is operated in self-refresh mode, the CLKEN and REFEN can be disabled to reduce save power consumption. Another way to save reduce power consumption is just to disabling CLKEN, and SDRAM controller still refreshed SDRAM by every each specified refresh period. In this case, SDRAM is closed not functioning by disabling CLKEN to save for power saving, and but SDRAM controller still refreshes it to prevent from data lost. In sum, SDRAM is operated as follows :

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NORMAL MODE :

REFEN=1

REFMOD=0

CLKEN=1

REFRAT=(proper period)

POWER SAVING MODE 1 :

REFEN=1

REFMOD=0

CLKEN=1

REFRAT=(proper period)

POWER SAVING MODE 2 :

REFEN=0

REFMOD=1

CLKEN=0

REFRAT=(don’t care)

2.4.2 ROM/Flash control register

ROM/Flash control register is used to control the configuration of the boot ROM. In this register, the size, base address, access type and access timing are specified. The base address of the boot ROM can be set by BASADDR. Although the width of BASADDR is only 13 bits, the real start address of the boot ROM is calculated as BASADDR << 18. Thus the range of the start address of the boot ROM is from 0x0 to (2^13-1)*2^18. However, the system memory map should be concerned together when setting the base address the base address setting should be checked to prevent from using RESERVED memory address. The system memory map can be found in NUC745 spec data sheet.

After system reset, the EBI controller has uses the special power-on setting to ensure the boot ROM to be bootable. These setting are as follows:

- The EBI controller is select to the boot ROM was selected by EBI controller after reset.
- The reset value of BASADDR of ROM/Flash control register is 0.
- The default size of the boot ROM is 256Kb256KB.

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- The default value of tACC is the longest value. This value is supposed to suit support any kind of ROM/Flash.
- The boot ROM/Flash data bus width is determined by the data bus signals D [13: 12] in power-on setting. The external hardware has the responsibility to weak needs to do the pull-up, or pull-down setting on the D [13: 12] according to the boot ROM/Flash types.
- PGMODE is set in normal ROM mode.

By the configurations shown above, the instruction fetch can be sure to be performed can be fetched from the start of the boot ROM. However, if the boot ROM/Flash has more others functions, ex: such as PGMODE, or more with larger size, the software has the responsibility to correct the setting boot up program should configure the of ROM/Flash control register to let it work correctly after boot.

The ROM/Flash interface is designed for the boot ROM and it is supposed only to before read operations. However, if a flash is attached to the ROM/Flash interface, it still can be written by the writing programming command provided by of the flash. The ROM/Flash interface doesn't hold the writing command to the ROM/Flash. Thus the boot ROM/Flash is still programmable if the boot ROM/Flash allows to be written. Thus, the attached Flash can be updated also by the programming interface/sequence provided by the Flash.

2.4.3 SDRAM configuration registers

The SDRAM configuration registers enable software to set a number of operating parameters for the SDRAM controller. There are two configuration registers SDCONF0, SDCONF1 for SDRAM bank 0, bank 1 respectively. Each bank can have been set to different configurations. NUC745 also offers the flexible timing control registers to control the generation and processing of the control signal and can suit to control the timing of different speed type of SDRAMs. These timing control registers are SDTIME0 and SDTIME1 for SDRAM bank 0, bank 1 respectively each.

The configurations of SDCONF and SDTIME are dependent on the SDRAM types attached to the EBI interface. Thus the software should have the information about the SDRAM attached to the EBI interface before set the SDCONF and SDTIME according to the timing of SDRAM types. The SDRAM components supported by NUC745 can be found in NUC745 spec data sheet.

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The base address of SDRAM bank 0 and bank 1 are also programmable. By BASADDR of SDCONF, the SDRAM bank can be place in a specific address location. BASADDR is 13 bits, and the base address is calculated as BASADDR << 18. Thus the range of the base address each SDRAM bank is from 0x0 to (2^13-1)*2^18. Whenever setting the SDCONF register, the MRSET bit should be set. If this bit doesn't set when setting SDCONF, the SDRAM controller won't issue a mode register set command to SDRAM and the setting will be invalid. The SDRAM controller offers auto pre-charge mode of SDRAM for SDRAM bank0/1. If this mode is enabled, the SDRAM will issue a pre-charge command to SDRAM when for each access.

2.4.4 External I/O control registers

The NUC745 supports an external device control without glue logic. It is very cost effective because provides address decoding and control signals timing logic are not needed. The control registers can control special external I/O devices for providing the low cost external devices control solution. For instance, if there is a SRAM is attached to the external I/O bank 0. Then the SRAM can be access as memory after setting the external I/O control register of external I/O bank 0. By the way, the flash ROM also can be attached to the external I/O. There are three external I/O banks relative to four control registers called EXT0CON, EXT1CON, and EXT2CON. The base address of each external I/O bank can be set by BASADDR of external I/O control register. BASADDR is 13 bits and the base address is calculated as BASADDR << 18.

2.4.5 A system memory initialization example flow chart

Figure 2-2 System Memory Map Setting Flow

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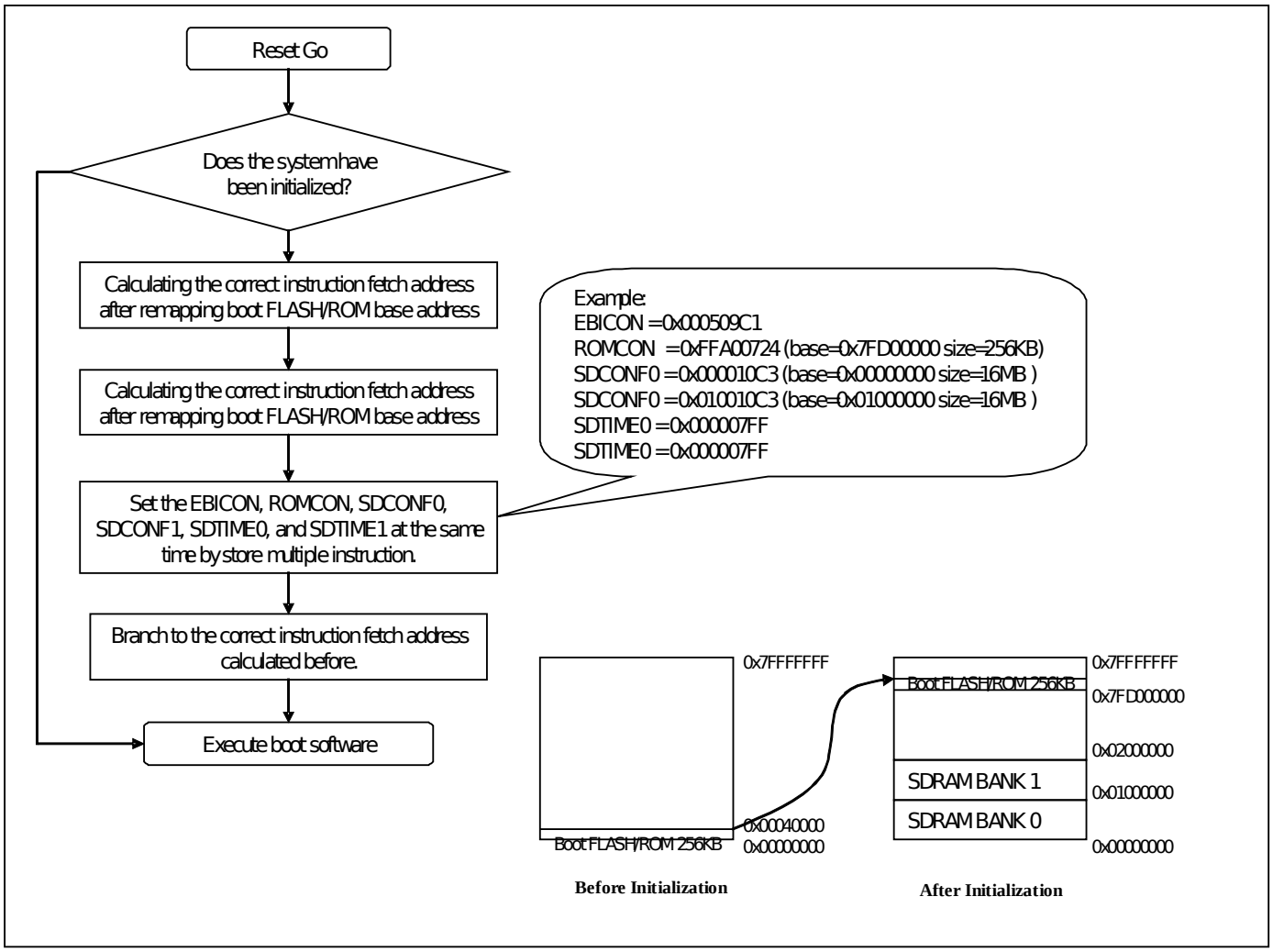


Figure 2-4 is the boot flow of Boot Monitor with remapping. The flow chart shows that most of the EBI control registers, EBICON, ROMCON, SDCONF, SDTIME should beware initialized as soon as possible immediately after reset. Each value of these control register must be known before these registers were configured. Because on doing of remapping, the control registers should be set by store multiple instructions (*STMIA*). The store multiple instructions guarantee to complete the memory initialization before next instruction execution. The system memory maps before initialization and after initialization are shown as above, too. After system reset, the system can access the 256KB boot FLASH/ROM. After the system initialization the memory map becomes the **After Initialization of** Figure 2-4.

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2.4.6 REMAPPING

RAM is normally with faster access speed and wider than ROM. For this reason, it is better to store for the vector table and interrupt handlers if the memory on system address at 0x0 is of RAM. However, if RAM is located at address 0x0 on power-up, there is not a valid instruction in the reset vector (0x0) entry. Therefore, you must allow ROM to be located at 0x0 during normal execution. The changeover remapping from the reset to the normal memory map is normally caused by writing to a memory-mapped register.

In NUC745 the memory remapping can be achieved by setting EBI control registers. The following example is a MACRO, which achieves performs the remapping when booting. The program flow of this example is as Figure 2-4.

In general, the memory remapping only needs to be preformed once at reset. Thus the reset value of SDCONF0 is used to check if the system has been initialized. If the system memory needs to do remapping, the correct instructions to be fetched after remapping is important are critical. Therefore, the MACRO will calculate the correct instruction fetch address after remapping. It does this by using labels and program counter to know get the current execution position and execution position decided at link-time. If the current execution position is different to from execution position decided at link-time, the MACRO will calculate the correct instruction fetch address after remapping according to their address relation. Finally, the value of PC will be update immediately after remapping. Because the memory bases can be controlled by registers, what we called remapping means setting the EBI control registers. The configuration values are predefined as rEBICON, rROMCON, rSDCONF0, rSDCONF1, rSDTIME0, rSDTIME1, and are stored to relative control registers by store multiple instruction (STMIA). The source code is listed as follows:

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```
; ------------------------------------------------------------------
; UNMAPROM
; --------
; Provide code to deal with mapping the reset ROM away from zero

      MACRO
$label  UNMAPROM   $w1,$w2

; This macro needs to test if the system has already been initialized
; The reset value of SDCONF0 is used to check if the system has been initialized

      LDR   $w1, =SDCONF0      ;SDCONF0=0xFFF01008
      LDR   $w1, [$w1]
      LDR   $w2, =0x800
      CMP   $w1, $w2
      BNE   %FT0

; Set mode to SVC, interrupts disabled (just paranoid)
      MRS   $w1, cpsr
      BIC   $w1, $w1, #0x1F
      ORR   $w1, $w1, #0xD3
      MSR   cpsr_fc, $w1

; Configure the EBI controller to remap the flash

; The EBI Control Registers must be set using store multiples
; Set up a stack in internal SRAM to preserve the original register contents

; Disable Cache and use the on-chip SRAM to be stack
      LDR   $w1, =CAHCNF       ; CAHCNF=0xFFF02000
      LDR   $w2, =0x0          ; SetValue = 0x0
      STR   $w2, [$w1]         ; Cache,WB disable
```

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```
; NUC745_SRAM_BASE = 0x7FE00000
; NUC745_SRAM_SIZe = 10 Kbytes

      MOV   $w1, sp
      LDR   sp,  =(NUC745_SRAM_BASE+NUC745_SRAM_SIZE)

      STR   $w1, [sp, #-4]!    ; preserve previous sp on new stack
      STMFD sp!, {r0 - r12,lr}

; The labels “$label.temp” and “$label.EndSysMapJump are absolute addresses
; calculated by linker according to the RO base.

      LDR   r2, =$label.temp
; The value of current pc is the run-time address of “$label.temp”
      MOV   r1, pc
      LDR r3, =$label.EndSysMapJump
$label.temp
      MOV lr, #0
; If r2 > r1, the system needs to remapping.
; The RO_base is NUC745_FLASH_BASE at link-time, thus we needs it to
; Calculate the correct instruction fetch address after remapping
      CMP   r2, r1
      LDRGT lr, =NUC745_FLASH_BASE

; Calculate the actual fetch address where is the location of
; the label “$label.EndSysMapJump” after remapping

      SUB   r3, r3, r2
      ADD   r1, r1, r3
      ADD   lr, lr, r1

; Load in the target values into the control registers
```

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```
      ADRL    r0, $label.SystemInitData
      LDMIA   r0, {r1-r6}
      LDR   r0, =EBICON

; Now run critical jump code
      STMIA   r0, {r1-r6}
      MOV   pc, lr
$label.EndSysMapJump

; Now running from new PROM location, since code no longer exists in low memory
; Restore registers
      LDMFD sp!, {r0 - r12,lr}
      LDR   $w1, [sp], #4
      MOV   sp,  $w1
      B     %FT0

$label.SystemInitData
      DCD rEBICON  ; REFEN=1,REFMOD=0,CLKEN=1,REFRAT=0x138,WAITVT=0

      DCD rROMCON ; base=NUC745_FLASH_BASE,size=256KB,BTSIZE=32bit,
                  ; tPA=8MCLK,tACC=8MCLK

      DCD rSDCONF0; base=0x0,size=16MB,MRSET=1,AUTOPR=1,LATENCY=3MCLK,
                  ; LENGTH=1Byte,COMPBK=2bank,DBWD=16bit,COLUM=8bit

      DCD rSDCONF1; base=0x1000000,size=16MB,MRSET=1,AUTOPR=1,LATENCY=3MCLK,
                  ; LENGTH=1Byte,COMPBK=2bank,DBWD=16bit,COLUM=8bit

      DCD rSDTIME0 ; tRCD=8MCLK,tRDL=4MCLK,tRP=8MCLK,tRAS=8MCLK
      DCD rSDTIME1 ; tRCD=8MCLK,tRDL=4MCLK,tRP=8MCLK,tRAS=8MCLK
      ALIGN
0
        MEND
```

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3 Cache Controller

3.1 Overview

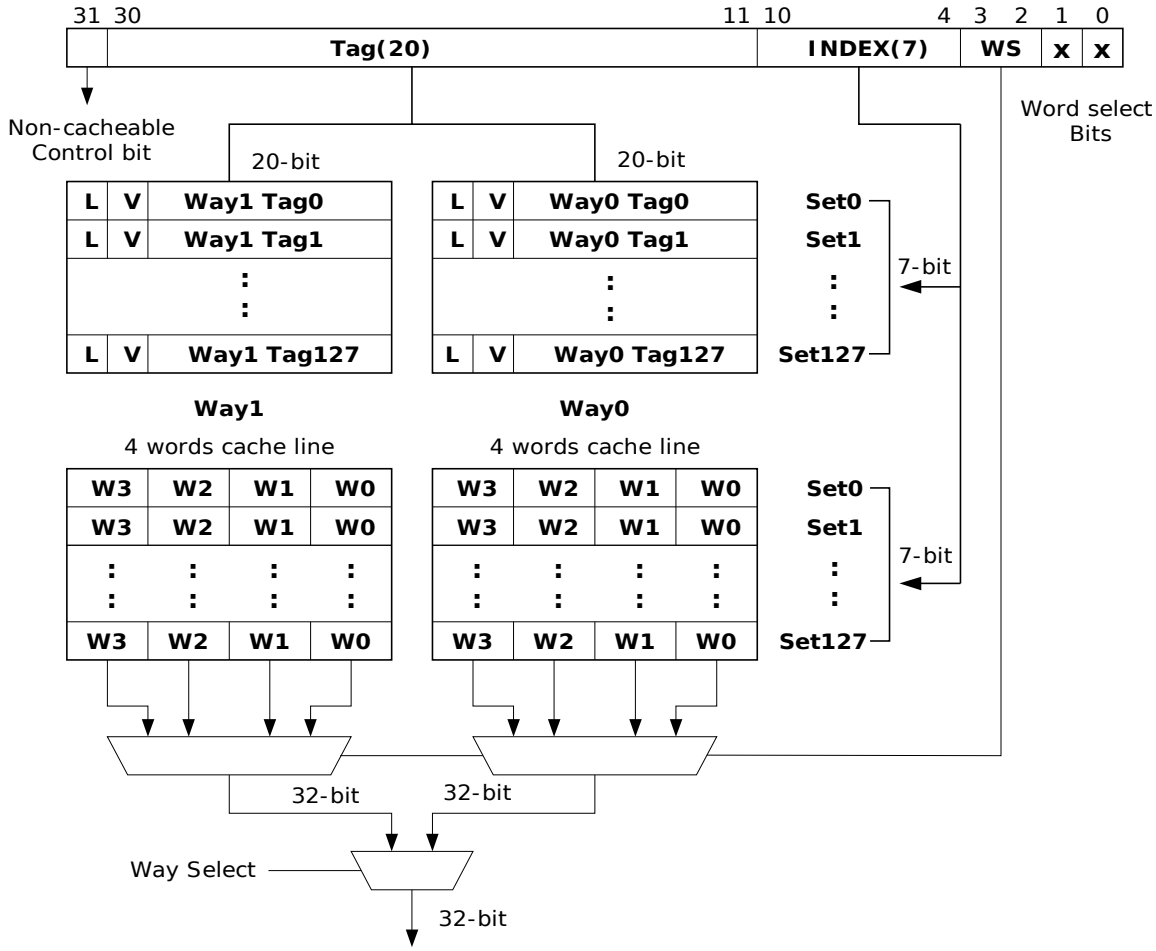
The NUC745 incorporates a 4KB Instruction cache, a 4KB Data cache, and 8 words write buffer to improve the system performance. The caches consist of high-speed SRAM that provides quicker access time than external memory. If cache is enabled, the CPU tries to fetch instructions from I-cache instead of external memory. Similarly, the CPU tries to read data from D-cache instead of external memory. But note that the CPU will write data into both D-cache and write buffer (**write-through** mode). If I-Cache / D-Cache were disabled, these cache memories can be treated as On-Chip SRAM.

To raise the cache-hit ratio, these two caches are configured as two-way set associative addressing. Both I-cache and D-Cache organization is 256 sets, two lines per set. Each cache has four words cache line size. When a miss occurs, four words must be fetched consecutively from external memory. The replacement algorithm is a LRU (Least Recently Used).

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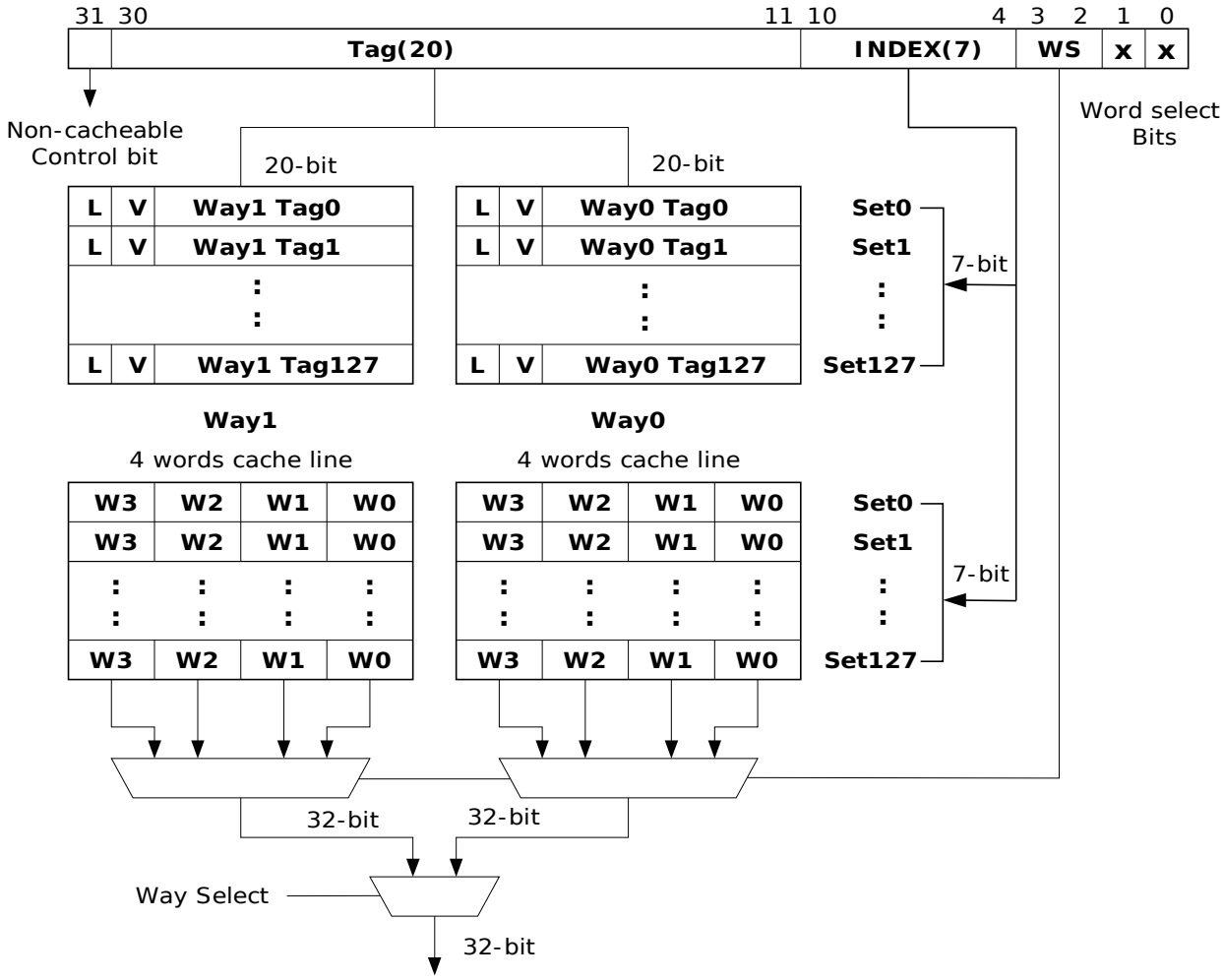
3.2 Block Diagram

Figure 3-3 Instruction Cache Organization Block Diagram



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Figure 3-4 Data Cache Organization Block Diagram



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3.3 Registers

R : read only, **W** : write only, **R/W** : both read and write, **C** : Only value 0 can be written

Register	Address	R/W	Description	Reset Value
CAHCNF	0xFFF0.2000	R/W	Cache configuration register	0x0000.0000
CAHCON	0xFFF0.2004	R/W	Cache control register	0x0000.0000
CAHADR	0xFFF0.2008	R/W	Cache address register	0x0000.0000

3.4 Functional Descriptions

3.4.1 On-Chip RAM

If I-Cache or D-Cache is disabled, it can be used as On-Chip SRAM. The size of On-Chip RAM depends on the I-Cache and D-Cache enable bits **ICAEN**, **DCAEN** in Cache Configuration Register **(CAHCNF)**. The details listed in Table 3-1.

Table 3-1 The size and start address of On-Chip RAM

ICAEN	DCAEN	On-Chip RAM	
		Size	Start Address
0	0	**8KB**	**0x7FE0.0000**
0	1	**4KB**	**0x7FE0.0000**
1	0	**4KB**	**0x7FE0.1000**
1	1	**Unavailable**	

3.4.2 Non-Cacheable Area

The cache affects the first 2GB system memory. Sometimes it is necessary to define non-cacheable areas when the consistency of data stored in memory and the cache can't be ensured. To support this feature, the NUC745 provides a non-cacheable area control bit in the address field**, A [31]**. If A [31] in the ROM/FLASH, SDRAM, or external I/O bank's access address is "0", then the accessed data is cacheable. If the A [31] value is "1", the accessed data is non-cacheable.

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Cache Control Register

The Cache controller supports one Control register **(CAHCON)** to control cache flushing, lock/unlock and drain write buffer. All the command set bits of CAHCON register are auto-clear bit. At the end of execution, the command set bit will be cleared to “0” automatically. The detail description of each bit filed can be found in NUC745 specification.

3.4.3 Cache Flushing

To prevent unpredictable error, it’s better to flush cache before enable it. Both I-Cache and D-Cache can be entirely flushed in one operation, or be flushed one line at a time. The bit **FLHA** and **FLHS** of register CAHCON are used to flush entire cache and single line, respectively. Bit **DCAH** or **ICAH** of register CAHCON is used to select D-Cache or I-Cache for the flush operation. The Cache Address Register **(CAHADR)** must be set before flush a single cache line.

Due to NUC745 does not support external memory snooping; it is necessary to flush cache if the force consistency of cache and memory is required. For example, The I-Cache should be flushed after a self-modifying code is executed. Similarly, the D-Cache should be flushed before an external device starts a DMA transfer with a cacheable memory region.

3.4.4 Cache Enable and Disable

After the cache was flushed, the cache can be enabled. Bit **ICAEN** and **DCAEN** of register **CAHCNF** is used to enable D-Cache and I-Cache. The D-Cache and I-Cache can be enabled individually, or enabled at the same time. The write buffer can be enabled by setting the **WRBEN.** Most of the time, **ICAEN**, **DCAEN** and **WRBEN** are enabled at the same time.

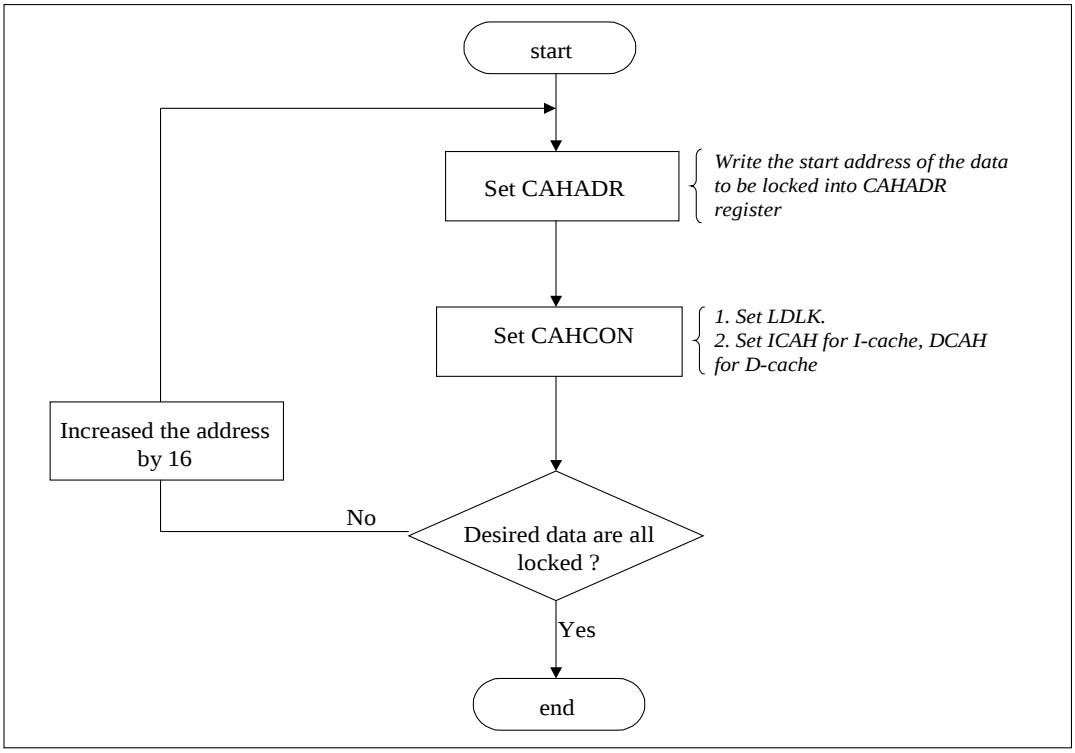
3.4.5 Cache Load and Lock

The NUC745 cache controller supports a cache-locking feature that locks critical sections of code or data into I-Cache or D-Cache. This guarantees the quick access to these critical sections. Lockdown operation can be performed with a granularity of one cache line (4 words). The smallest size, which can be locked down, is 4 words. After a line is locked, it operates as a regular instruction

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SRAM. Locked lines don't be replaced either cache misses or flush per line command. Figure 3-5 shows the steps for locking instructions or data.

Figure 3-5 Cache Load and Lock



There are some limitations during the locking cache line into the I-Cache or D-Cache.

- The code that executes load and lock operation should be held in a non-cacheable area of memory.
- The cache should be enabled and interrupts should be disabled.
- Flushed the cache before execute load and lock to ensure that the data to be locked down is not already in the cache.

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3.4.6 Cache Unlock

The unlock operation is used to unlock previously locked cache lines. The cache controller provides two unlock command, unlock line and unlock all.

The unlock line operation is performed on a cache line granularity. In case the line is found in the cache, it is unlocked and starts to operate as a regular valid cache line. In case the line is not found in the cache, no operation is done and the command terminates with no exception. To unlock one line, write the address of the line to be unlocked into the **CAHADR** Register, and then set the **ULKS** and **ICAH** bits in the CAHCON register for I-cache or set the **ULKS** and **DCAH** bits for D-cache.

The unlock all operation is performed on all cache lines of I-Cache or D-Cache. In case a line is locked, it is unlocked and starts to operate as regular valid cache line. In case a line is not locked or if it is invalid, no operation is performed. To unlock the whole instruction cache, set the **ULKA** and **ICAH** bits. To unlock the whole data cache, set the **ULKA** and **DCAH** bits.

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4 EMC (Ethernet MAC Controller)

4.1 Overview

The NUC745 provides a Ethernet MAC Controller (EMC) for WAN/LAN application. This EMC has its DMA controller, transmit FIFO, and receive FIFO.

The Ethernet MAC controller consists of IEEE 802.3/Ethernet protocol engine with internal CAM function for Ethernet MAC address recognition, Transmit-FIFO, Receive-FIFO, TX/RX state machine controller and status controller. The EMC only supports RMII (Reduced MII) interface to connect with PHY operating on 50MHz REF_CLK.

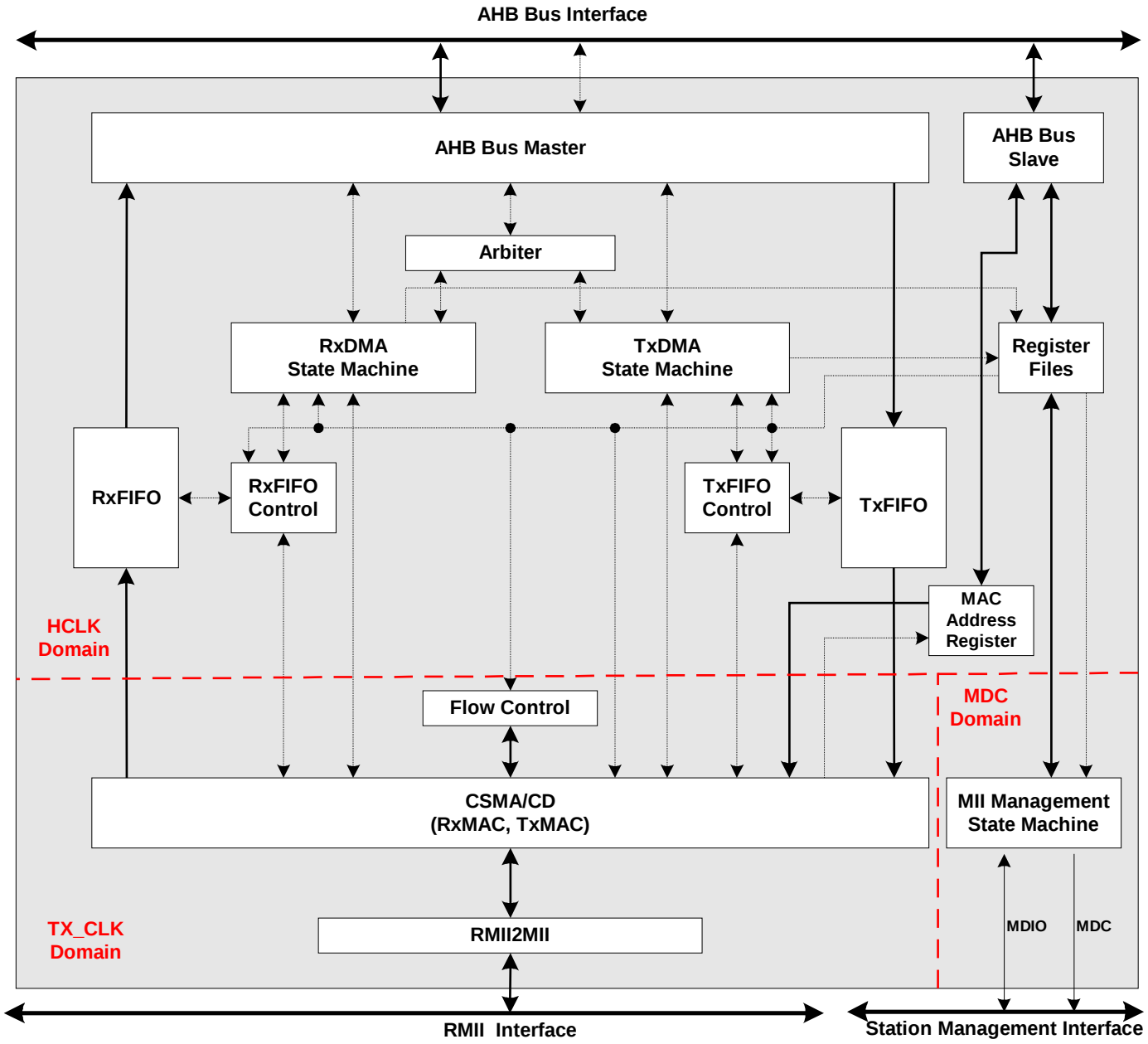
Features :

- Supports IEEE Std. 802.3 CSMA/CD protocol.
- Supports both half and full duplex for 10M/100M bps operation.
- Supports RMII interface.
- Supports MII Management function.
- Supports pause and remote pause function for flow control.
- Supports long frame (more than 1518 bytes) and short frame (less than 64 bytes) reception.
- Supports 16 entries CAM function for Ethernet MAC address recognition.
- Supports internal loop back mode for diagnostic.
- Supports 256 bytes embedded transmit and receive FIFO.
- Supports DMA function.

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4.2 Block Diagram

Figure 4-6 EMC Block Diagram



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4.3 Registers

4.3.1 EMC Control registers

Register	Address	R/W	Description	Reset Value
CAMCMR	0xFFF0.3000	R/W	CAM Command Register	0x0000.0000
CAMEN	0xFFF0.3004	R/W	CAM Enable Register	0x0000.0000
CAM0M	0xFFF0.3008	R/W	CAM0 Most Significant Word Register	0x0000.0000
CAM0L	0xFFF0.300C	R/W	CAM0 Least Significant Word Register	0x0000.0000
CAM1M	0xFFF0.3010	R/W	CAM1 Most Significant Word Register	0x0000.0000
CAM1L	0xFFF0.3014	R/W	CAM1 Least Significant Word Register	0x0000.0000
CAM2M	0xFFF0.3018	R/W	CAM2 Most Significant Word Register	0x0000.0000
CAM2L	0xFFF0.301C	R/W	CAM2 Least Significant Word Register	0x0000.0000
CAM3M	0xFFF0.3020	R/W	CAM3 Most Significant Word Register	0x0000.0000
CAM3L	0xFFF0.3024	R/W	CAM3 Least Significant Word Register	0x0000.0000
CAM4M	0xFFF0.3028	R/W	CAM4 Most Significant Word Register	0x0000.0000
CAM4L	0xFFF0.302C	R/W	CAM4 Least Significant Word Register	0x0000.0000
CAM5M	0xFFF0.3030	R/W	CAM5 Most Significant Word Register	0x0000.0000
CAM5L	0xFFF0.3034	R/W	CAM5 Least Significant Word Register	0x0000.0000
CAM6M	0xFFF0.3038	R/W	CAM6 Most Significant Word Register	0x0000.0000
CAM6L	0xFFF0.303C	R/W	CAM6 Least Significant Word Register	0x0000.0000
CAM7M	0xFFF0.3040	R/W	CAM7 Most Significant Word Register	0x0000.0000
CAM7L	0xFFF0.3044	R/W	CAM7 Least Significant Word Register	0x0000.0000
CAM8M	0xFFF0.3048	R/W	CAM8 Most Significant Word Register	0x0000.0000
CAM8L	0xFFF0.304C	R/W	CAM8 Least Significant Word Register	0x0000.0000
CAM9M	0xFFF0.3050	R/W	CAM9 Most Significant Word Register	0x0000.0000
CAM9L	0xFFF0.3054	R/W	CAM9 Least Significant Word Register	0x0000.0000
CAM10M	0xFFF0.3058	R/W	CAM10 Most Significant Word Register	0x0000.0000
CAM10L	0xFFF0.305C	R/W	CAM10 Least Significant Word Register	0x0000.0000
CAM11M	0xFFF0.3060	R/W	CAM11 Most Significant Word Register	0x0000.0000
CAM11L	0xFFF0.3064	R/W	CAM11 Least Significant Word Register	0x0000.0000
CAM12M	0xFFF0.3068	R/W	CAM12 Most Significant Word Register	0x0000.0000
CAM12L	0xFFF0.306C	R/W	CAM12 Least Significant Word Register	0x0000.0000
CAM13M	0xFFF0.3070	R/W	CAM13 Most Significant Word Register	0x0000.0000
CAM13L	0xFFF0.3074	R/W	CAM13 Least Significant Word Register	0x0000.0000
CAM14M	0xFFF0.3078	R/W	CAM14 Most Significant Word Register	0x0000.0000
CAM14L	0xFFF0.307C	R/W	CAM14 Least Significant Word Register	0x0000.0000
CAM15M	0xFFF0.3080	R/W	CAM15 Most Significant Word Register	0x0000.0000
CAM15L	0xFFF0.3084	R/W	CAM15 Least Significant Word Register	0x0000.0000
TXDLSA	0xFFF0.3088	R/W	Transmit Descriptor Link List Start Address Register	0xFFFF.FFFC
RXDLSA	0xFFF0.308C	R/W	Receive Descriptor Link List Start Address Register	0xFFFF.FFFC
MCMDR	0xFFF0.3090	R/W	MAC Command Register	0x0000.0000
MIID	0xFFF0.3094	R/W	MII Management Data Register	0x0000.0000
MIIDA	0xFFF0.3098	R/W	MII Management Control and Address Register	0x0090.0000
FFTCR	0xFFF0.309C	R/W	FIFO Threshold Control Register	0x0000.0101

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TSDR	0xFFF0.30A0	W	Transmit Start Demand Register	Undefined
RSDR	0xFFF0.30A4	W	Receive Start Demand Register	Undefined
DMARFC	0xFFF0.30A8	R/W	Maximum Receive Frame Control Register	0x0000.0800
MIEN	0xFFF0.30AC	R/W	MAC Interrupt Enable Register	0x0000.0000

4.3.2 EMC Status Registers

Register	Address	R/W	Description	Reset Value
MISTA	0xFFF0.30B0	R/W	MAC Interrupt Status Register	0x0000.0000
MGSTA	0xFFF0.30B4	R/W	MAC General Status Register	0x0000.0000
MPCNT	0xFFF0.30B8	R/W	Missed Packet Count Register	0x0000.7FFF
MRPC	0xFFF0.30BC	R	MAC Receive Pause Count Register	0x0000.0000
MRPCC	0xFFF0.30C0	R	MAC Receive Pause Current Count Register	0x0000.0000
MREPC	0xFFF0.30C4	R	MAC Remote Pause Count Register	0x0000.0000
DMARFS	0xFFF0.30C8	R/W	DMA Receive Frame Status Register	0x0000.0000
CTXDSA	0xFFF0.30CC	R	Current Transmit Descriptor Start Address Register	0x0000.0000
CTXBSA	0xFFF0.30D0	R	Current Transmit Buffer Start Address Register	0x0000.0000
CRXDSA	0xFFF0.30D4	R	Current Receive Descriptor Start Address Register	0x0000.0000
CRXBSA	0xFFF0.30D8	R	Current Receive Buffer Start Address Register	0x0000.0000

4.4 Functional Descriptions

4.4.1 Initialize Rx Buffer Descriptors

(1) Allocate memory for Rx descriptors.

(2) Write start address of (1) to *RXDLSA* register and let Rx software pointer point to this address.

(3) Set ownership bits of each descriptor to DMA.

(4) Allocate memory as data buffer and write the address to *data buffer start address* field of Rx descriptor.

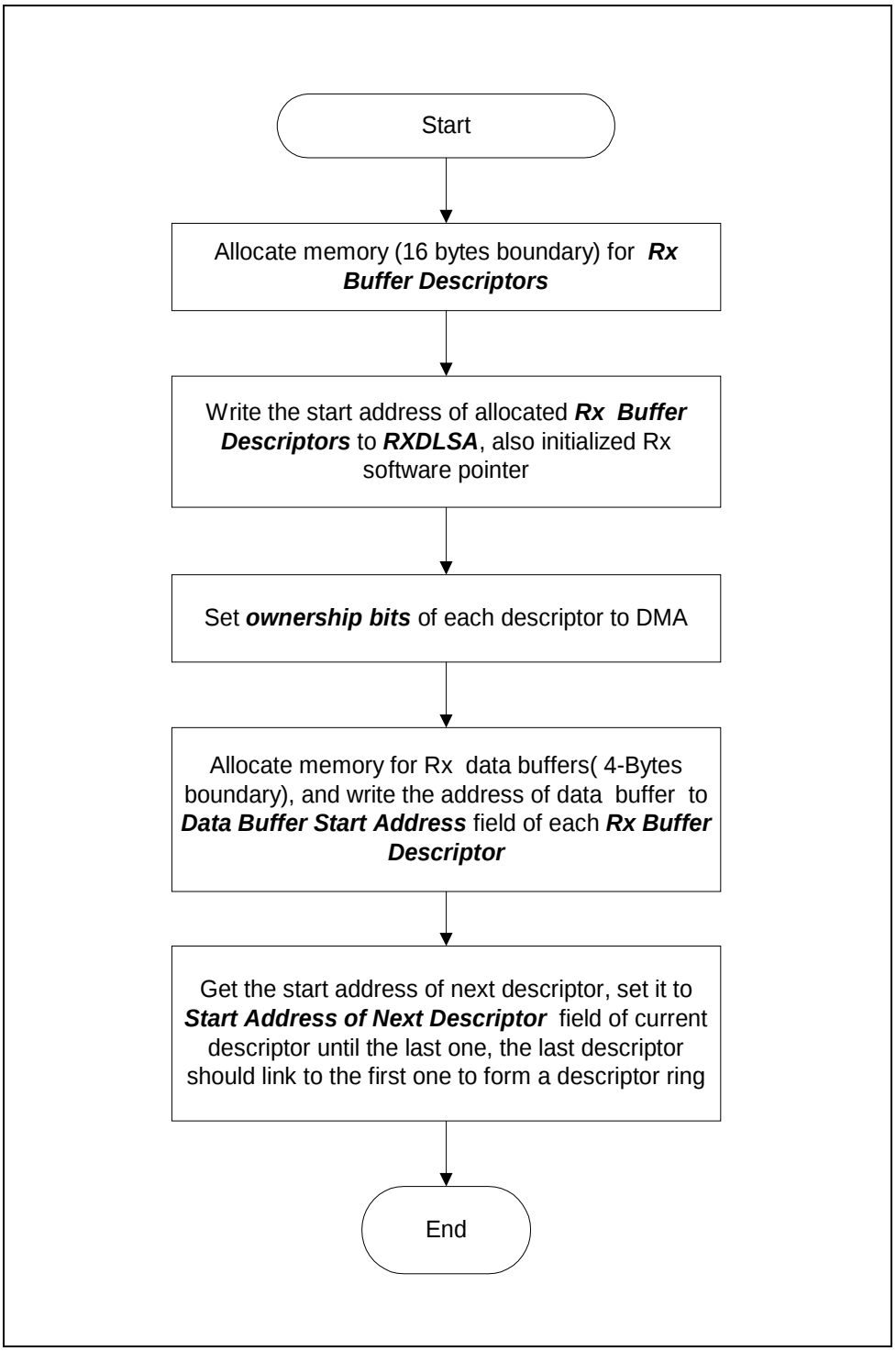
(5) Set start address of next descriptor, this field of the last descriptor should set to the address of the first descriptor.

(6) The start address of descriptor and data buffer are suggested to be aligned to 16 bytes address boundary.

Figure 4-2 lists the Rx Descriptor initialization flow.

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Figure 4-7 Rx Descriptor Initialization



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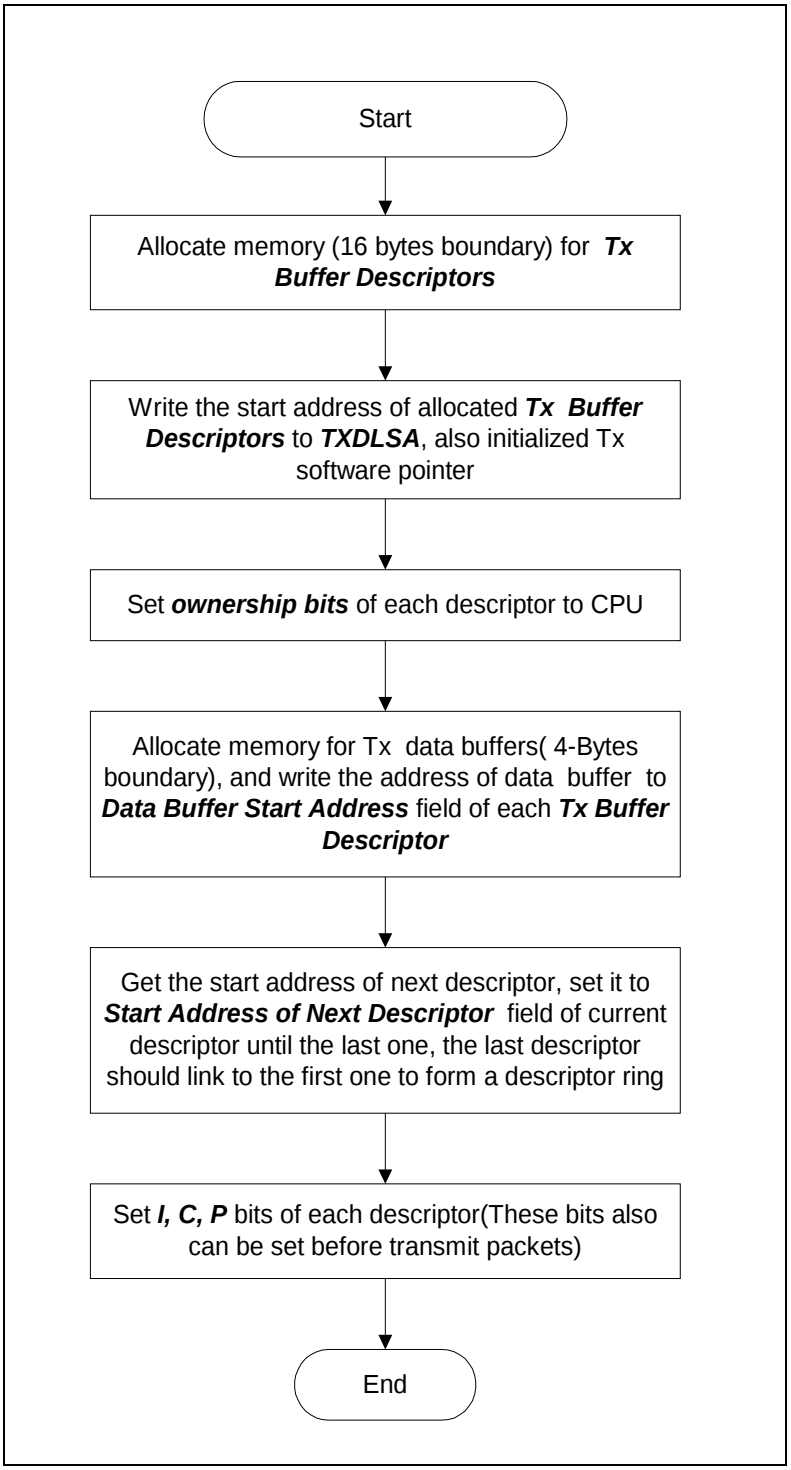
4.4.2 Initialize Tx Buffer Descriptors

(1) Allocate memory for Tx descriptors.
(2) Write start address of (1) to *TXDLSA* register and let Tx software pointer point to this address.
(3) Set ownership bits of each descriptor to CPU.
(4) Allocate memory to save frame data and write the address to *data buffer start address* field of Tx descriptor.
(5) Set start address of next descriptor, this field of the last descriptor should set to the address of the first descriptor.
(6) Set *I,C,P* bits of each descriptor(The bits can also be set before transmitting packets).
(7) The start address of descriptor and data buffer are suggested to be 16 bytes alignment.

Figure 4-3 lists the Tx Descriptor initialization flow.

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Figure 4-8 Tx Descriptor Initialization



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4.4.3 MII

4.4.3.1 MII Management Function Configure Sequence

Read	Write
1. Set appropriate MDCCR.	1. Write data to MIID register
2. Set PHYAD and PHYRAD.	2. Set appropriate MDCCR.
3. Set Write to 1'b0	3. Set PHYAD and PHYRAD.
4. Set bit BUSY to 1'b1 to send a MII management frame out.	4. Set Write to 1'b1
5. Wait BUSY to become 1'b0.	5. Set bit BUSY to 1'b1 to send a MII management frame out.
6. Read data from MIID register.	6. Wait BUSY to become 1'b0.
7. Finish the read command.	7. Finish the write command.

4.4.3.2 PHY Registers Programming

Control Register(0x00).

Bit	Function
15	Reset
14	Loopback
13	Speed (1=100MB, 0=10MB)
12	Auto-negotiation Enable
11	Power-Down
10	Isolate
09	Restart auto-negotiation
08	Duplex Mode (1=Full, 0=Half)
07	Collision test

Status Register #1(0x01)

Bit	Function
15	100BASE-T4 capable
14	100BASE-TX full duplex capable
13	100BASE-TX half duplex capable

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12	10BASE-T full duplex capable
11	10BASE-T half duplex capable
06	Accept management frames with preamble suppressed
05	Auto-negotiation complete
04	Remote fault
03	Auto-negotiation capable
02	Link status(1=Up, 0=Down)
01	Jabber condition detected
00	Extended register capable

Auto-negotiation Advertisement Register(0x04)

Protocol selection (00001-IEEE802.3)

Bit	Function
15	Next page available
13	Remote fault
10	Flow control support
09	100BASE-T4 support
08	100BASE-TX full duplex support
07	100BASE-TX half duplex support
06	10BASE-T full duplex support
05	10BASE-T half duplex support
04 ~ 00	Protocol selection (00001-IEEE802.3)

Status Register #2(0x11)

Current speed(10M/100M) and operation(full/half duplex) can read from this register, the exact bit position should refer to the PHY datasheet.

Example for auto-negotiation

(1) Set “auto-negotiation enable” and “restart auto-negotiation”(bits 12 and 9) of control register

(2) Wait auto-negotiation complete by reading “auto-negotiation complete”(bit 5) of status register #1 until it is set

(3) Read status register #2 to get speed and operation mode that is the result of auto-negotiation.

(4) Set speed and operation mode of MAC

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4.4.4 Control Frames

4.4.4.1 Receive Control Pause Frame

1. sdklfn
2.
3. Set ACP bit in MCMDR
4. The Multicast address “01-80-c2-00-00-01” should fill to CAM if AMP not set
5. Set EnCFR in MIEN if want to handle control frame receive interrupt

4.4.4.2 Send Control Pause Frame

1. Fill the destination MAC address to CAM#13
2. Fill the source MAC address to CAM#14
3. Fill length/type(0x8808), opcode(0x0001) and operand(timeslot) to CAM#15
4. Set SDPZ bit in MCMDR
5. Wait control pause frame transmission complete by reading SDPZ bit until it is 0

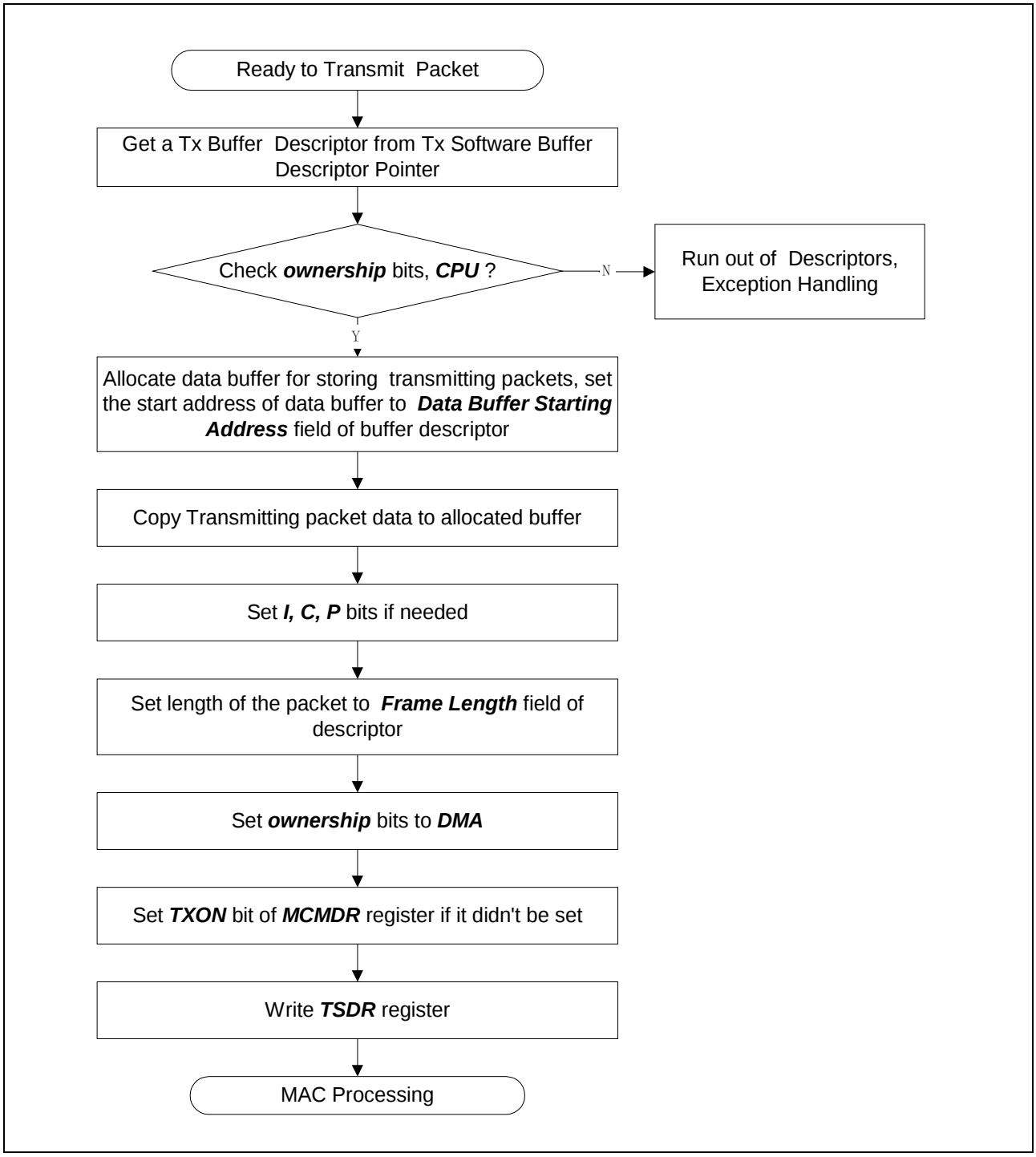
4.4.5 Packet Processing

4.4.5.1 Packet Transmission

(1) Get Tx buffer descriptor from Tx software pointer.
(2) Check ownership of (1), do nothing if ownership is DMA.
(3) Allocate data buffer and set start address to data buffer starting address field of (1).
(4) Copy packet data to data buffer.
(5) Set I,C,P bits if need.
(6) Set packet length to frame length field of (1).
(7) Set ownership to DMA.
(8) Set TXON bit of MCMDR register if it is not set.
(9) Write TSDR register.

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Figure 4-9 Packet Transmission Flow



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4.4.5.2 Tx Interrupt Service Routine

(1) Get and check status in MISTA.

(2) Set software reset bit in FIFOTHD and re-initialize MAC if bus error occur. Do the following step if no error occur.

(3) Get status from the descriptor of Tx software pointer. Do the following steps if TXCP bit is set.

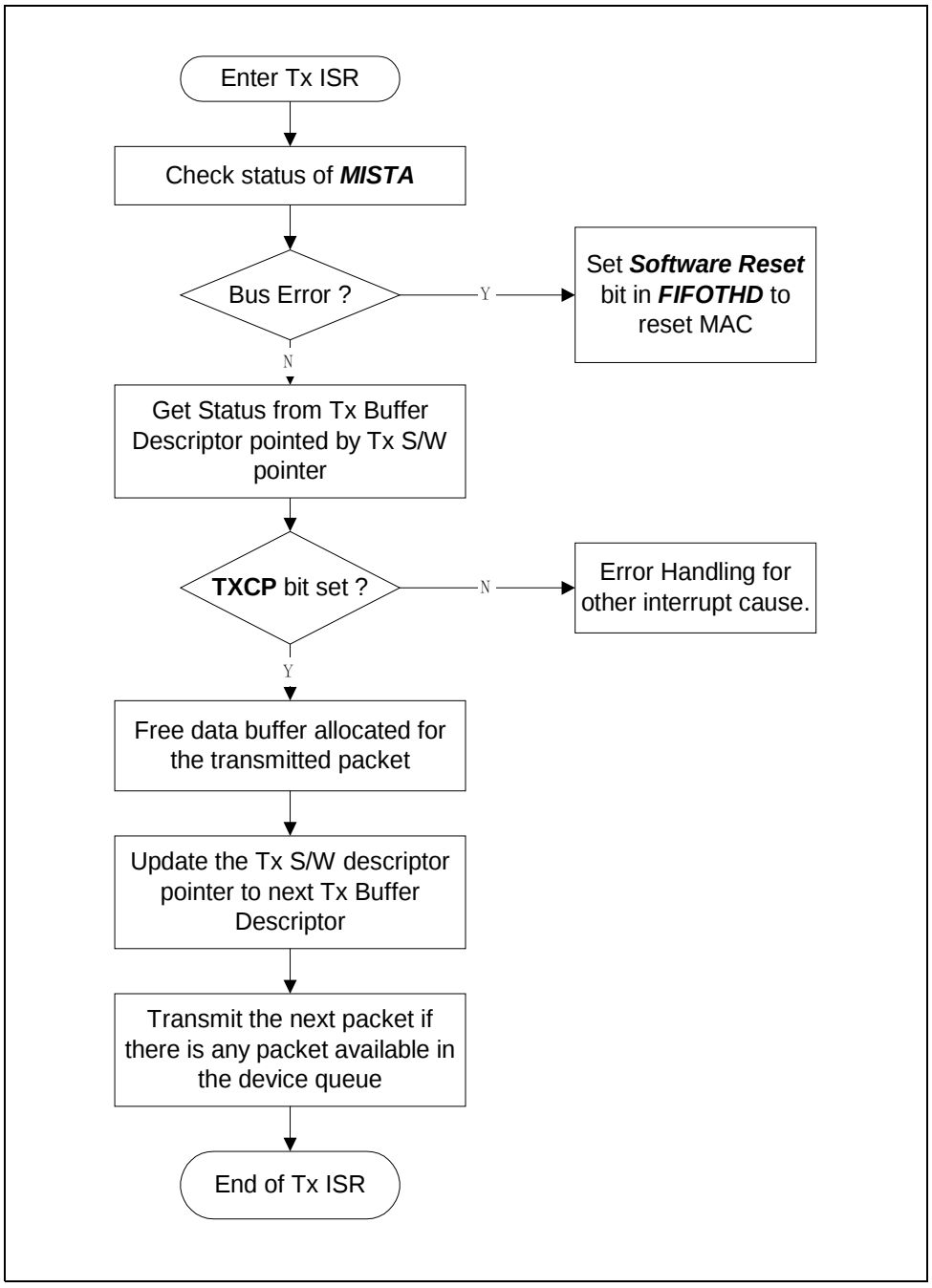
(4) Free data buffer allocated to this descriptor.

(5) Set the next descriptor to Tx software pointer.

(6) Transmit the next packet if there is packet available in device queue.

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Figure 4-10 Tx Interrupt Service Routine Flow



4.4.5.3 Rx Interrupt Service Routine

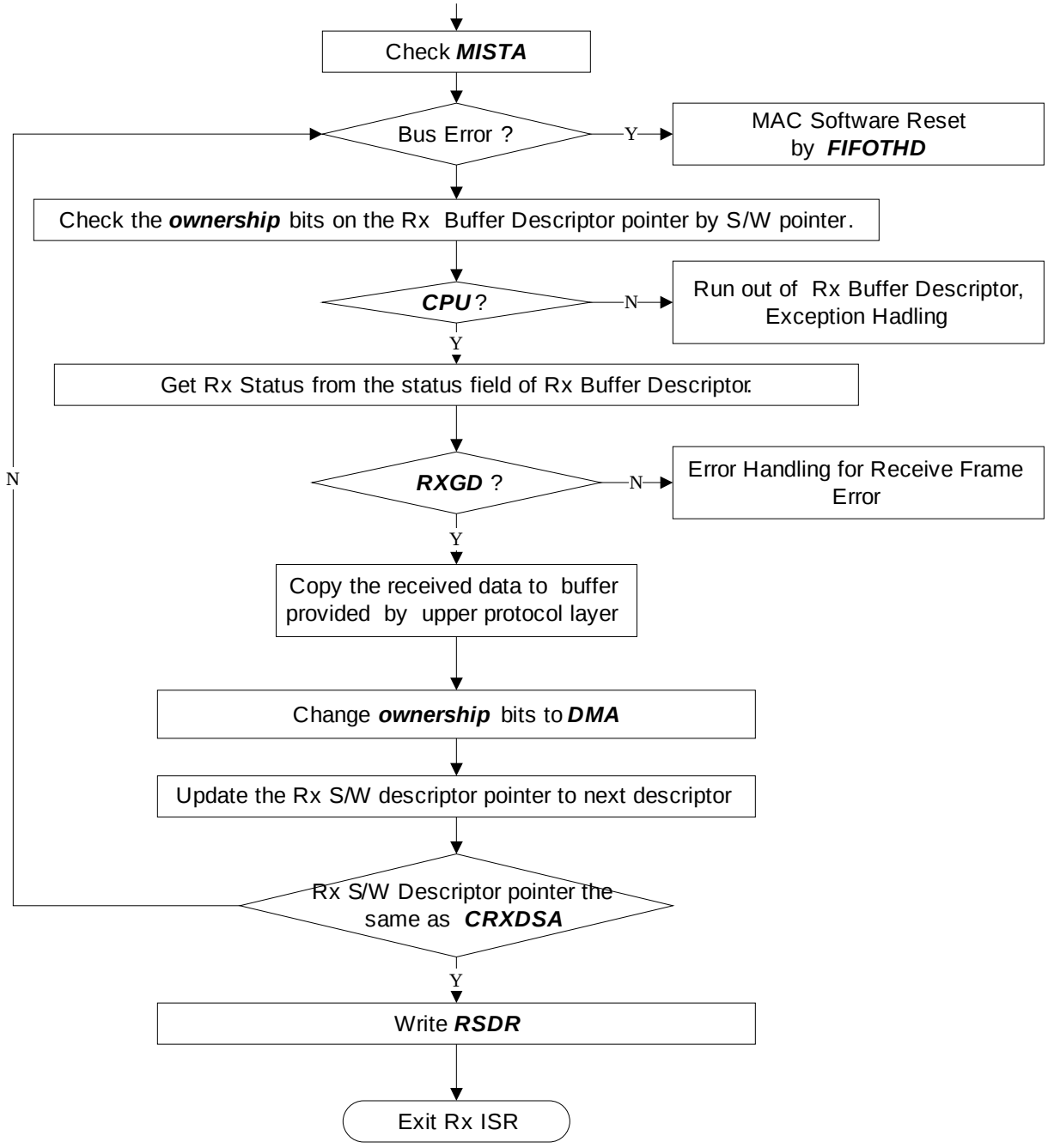
(1) Get and check status in MISTA.

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(2) Set software reset bit in FIFOTHD and re-initialize MAC if bus error occur. Do the following step if no error occur.
(3) Get ownership from the descriptor of Rx software pointer. Do the following step if ownership is CPU.
(4) Get status from the descriptor of Rx software pointer. Do the following steps if RXGD bit is set.
(5) Change ownership to DMA.
(6) Set the next descriptor to Rx software pointer.
(7) Re-start from step (3) if descriptor of Rx software pointer is not the same as the one of CRXDSA register.
(8) Write RSDR register.

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Figure 4-11 Rx Interrupt Service Routine



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5 GDMA

5.1 Overview

The NUC745 **GDMA** controller provides a data transfer mechanism without the need of CPU intervention. It can move data between two memory regions, or between memory and external devices. The GDMA has two independent channels that support single and block mode transfer. When GDMA is programmed to *single* mode, it requires a request **(nXDREQ)** for each data transfer that may be one byte, one half-word or one word. When GDMA is programmed to *block* mode, a single GDMA request will make all of the data to be transferred.

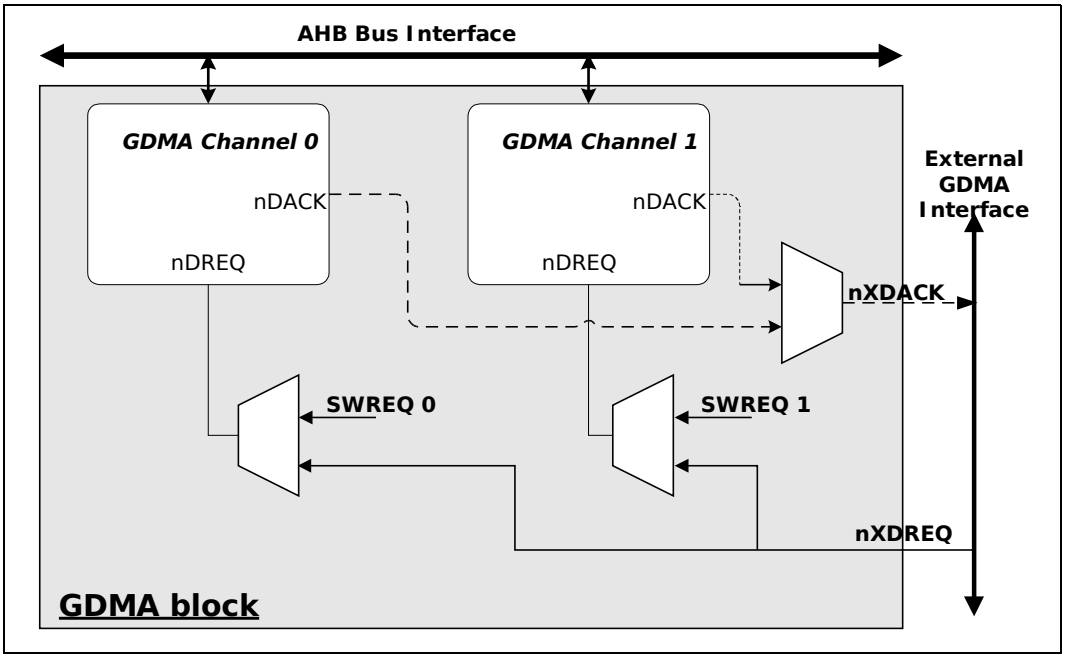
The data transfer can be started after write the control register or receive an external DMA request (nXDREQ). The GDMA will try to finish the data transfer according to the transfer mode, source address, destination address and transfer count. The device driver can recognize the completion of a GDMA operation by polling control register or when it receives a GDMA interrupt.

The NUC745 GDMA controller implements many flexible features to support the data transfers. It can increment or decrement source or destination address during the data transfer, and conduct with 8-bit (byte), 16-bit (half-word), or 32-bit (word) size data transfers. The source or destination address of the GDMA can be fixed also. Furthermore, the GDMA supports 4-data burst mode to boost performance and supports demand mode to speed up external GDMA operations.

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5.2 Block Diagram

Figure 5-12 GDMA Block Diagram



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5.3 Registers

R : read only, **W** : write only, **R/W** : both read and write, **C** : Only value 0 can be written

Register	Address	R/W	Description	Reset Value
GDMA_CTL0	0xFFF0.4000	R/W	Channel 0 Control Register	0x0000.0000
GDMA_SRCB0	0xFFF0.4004	R/W	Channel 0 Source Base Address Register	0x0000.0000
GDMA_DSTB0	0xFFF0.4008	R/W	Channel 0 Destination Base Address Register	0x0000.0000
GDMA_TCNT0	0xFFF0.400C	R/W	Channel 0 Transfer Count Register	0x0000.0000
GDMA_CSRC0	0xFFF0.4010	R	Channel 0 Current Source Address Register	0x0000.0000
GDMA_CDST0	0xFFF0.4014	R	Channel 0 Current Destination Address Register	0x0000.0000
GDMA_CTCNT0	0xFFF0.4018	R	Channel 0 Current Transfer Count Register	0x0000.0000
GDMA_CTL1	0xFFF0.4020	R/W	Channel 1 Control Register	0x0000.0000
GDMA_SRCB1	0xFFF0.4024	R/W	Channel 1 Source Base Address Register	0x0000.0000
GDMA_DSTB1	0xFFF0.4028	R/W	Channel 1 Destination Base Address Register	0x0000.0000
GDMA_TCNT1	0xFFF0.402C	R/W	Channel 1 Transfer Count Register	0x0000.0000
GDMA_CSRC1	0xFFF0.4030	R	Channel 1 Current Source Address Register	0x0000.0000
GDMA_CDST1	0xFFF0.4034	R	Channel 1 Current Destination Address Register	0x0000.0000
GDMA_CTCNT1	0xFFF0.4038	R	Channel 1 Current Transfer Count Register	0x0000.0000

5.4 Functional Descriptions

5.4.1 GDMA Configuration

Each GDMA channel has one control register, two base address registers and one transfer count register. These registers should be correctly programmed before the data transfer starts. The most important one is the control register **(GDMA_CTL)**. It is used to control the transfer behavior of the GDMA operation, such as the transfer mode, transfer count, transfer width and interrupt mask. Figure 5-2 lists the content of GDMA_CTL. The detail description of each bit-field can be found in NUC745 data sheet.

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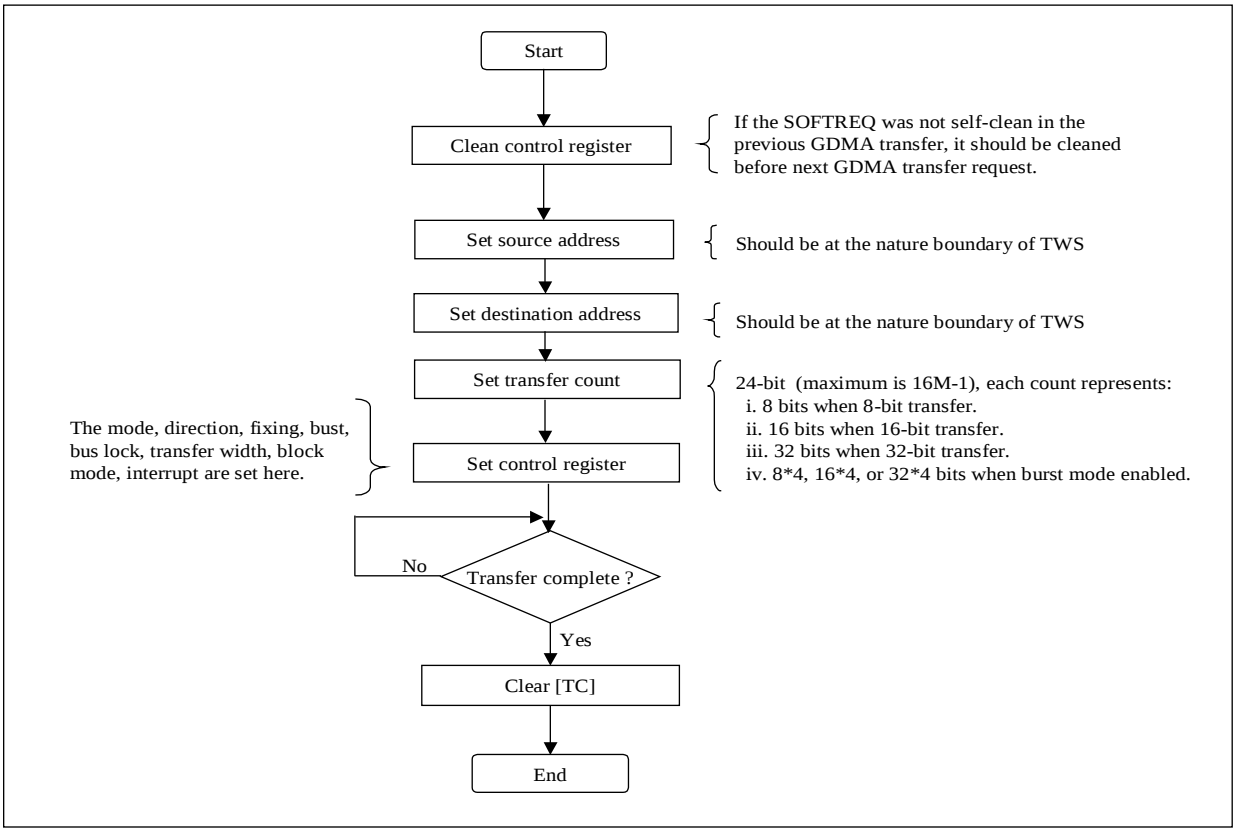
Figure 5-13 The bit-fields of the GDMA control register.

31	30	29	28	27	26	25	24
RESERVED							
23	22	21	20	19	18	17	16
RESERVED	SABNDERR	DABNDERR	GDMAERR	AUTOIEN	TC	BLOCK	SOFTREQ
15	14	13	12	11	10	9	8
DM	RESERVED	TWS		SBMS	RESERVED	BME	SIEN
7	6	5	4	3	2	1	0
SAFIX	DAFIX	SADIR	DADIR	GDMAMS		RESERVED	GDMAEN

The source base address register **(GDMA_SRCB)** is used to set the base address of source data. The destination base address register **(GDMA_DSTB)** is used to set the starting address where the source data to be stored. The number of the GDMA transfer is set by programming the transfer count register **(GDMA_TCNT)**. The GDMA operation is continued until the transfer count register is counted down to zero. Figure 5-3 shows the programming flow for GDMA operation.

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Figure 5-14 GDMA operations



5.4.2 Transfer Count

The value in register GDMA_TCNT is the transfer count, not the byte count. Normally, the number of final transferred bytes is calculated by the following equation.

Transferred bytes = [GDMA_TCNT] * Transfer width /* burst mode is disabled */

For example, supposes that [GDMA_TCNT] = 16 and the transfer width is half-word (16-bit). The number of transferred bytes should be 16 * 2 = 32. But if the burst mode is enabled, the above equation will be changed as below.

Transferred bytes = [GDMA_TCNT] * Transfer width * 4 /* burst mode is enabled */

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In case of burst mode is enabled, the transferred bytes of the above example should be 16 * 2 * 4 = 128

5.4.3 Transfer Termination

When GDMA finishes the transfer, it will set the bit [TC] of register GDMA_CTRL and generate an interrupt request if the interrupt is enabled. The device driver can either poll the bit [TC] or wait the GDMA interrupt occurs to know the transfer is completed. Note that the device driver must clear bit [TC] to clear this interrupt request to let the next GDMA operation to continue.

5.4.4 GDMA operation started by software

The GDMA can be configured as software mode to perform memory-to-memory transfer. In this mode, the transfer operation starts as soon as the setting of the GDMA control registers are set, the setting of source address, destination address, and transfer count should be programmed in advanced. The programming method of software mode is listed below:

(1) Set the GDMA to software mode (GDMAMS=00b).
(2) Set the GDMA to Block Mode.
(3) After all configuration of the GDMA, set [SOFTREQ] = 1 and [GDMAEN] = 1 to start the GDMA operation.
(4) Single mode is invalid.
(5) Demand mode is invalid.

In software mode, bit SOFTREQ and GDMAEN are self-cleared. The GDMA controller automatically clears these 2 bits after transfer completed. However, GDMAEN won't be self-clear if AUTOIEN bit is set. Hence, the driver only needs to set bit SOFTREQ to start next data transfer. If the GDMA didn't complete this transfer, it will cause the GDMA transfer error bit to be set, and the SOFTREQ won't be self-cleared. In this case, the SOFTREQ bit should be cleared before next software GDMA request.

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It should be note that the source and destination base address must be in the right alignment according to its transfer width. For example, if the transfer width is 32-bit, the source and destination base address should be word-alignment. If each one is not aligned, the GDMA will read from and write to wrong addresses and the alignment error flags, SABNDERR and DABNDERR, will be set.

Figure 5-4 shows an example code for software GDMA transfer.

Figure 5-15 Software GDMA Transfer

```
#define BASE0xc0000000
#define GDMA_SRCB0              (BASE+0xFF04004)
#define GDMA_DSTB0              (BASE+0xFF04008)
#define GDMA_TCNT0              (BASE+0xFF0400C)
#define GDMA_CSRC0              (BASE+0xFF04010)
#define GDMA_CDST0              (BASE+0xFF04014)
#define GDMA_CTCNT0             (BASE+0xFF04018)


void main(void)
{
   *((volatile UINT *)GDMA_CTL0)=0x0;
   *((volatile UINT *)GDMA_SRCB0)=0xc2000000;
   *((volatile UINT *)GDMA_DSTB0)=0xc2001000;
   *((volatile UINT *)GDMA_TCNT0)=0x10;
   *((volatile UINT *)GDMA_CTL0)=0x12801;

   while( !(*((volatile UINT *)GDMA_CTL0) & 0x40000) )
                ;
}
```

In this example, source base address is set as 0xC2000000 and destination base address is 0xC2001000. The transfer count is 0x10. The burst mode is not turned on in this example.

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Both source and destination base addresses are increment. The transfer width is 32-bit. The program waits GDMA transfer completed by polling TC flag. The first line of main routine that clears the GDMA control register is used to avoid that the SOFTREQ did not be self-cleared in the previous GDMA transfer. Once these code executed, the GDMA will copy 0x10*4 bytes data from 0xC2000000 to 0xC2001000.

After the transfer completed, the current source, destination, and transfer count status can be read from current status registers. These current status registers are GDMA_CSRC, GDMA_CDST, and GDMA_CTNT respectively. However, if the AUTOIEN is 1, the current status registers will be updated to the value stored in GDMA_SRCB, GDMA_DSTB, and GDMA_TCNT. The GDMAEN did not be self-cleared if AUTOIEN is 1. Therefore, it only needs to set SOFTREQ to request the GDMA transfer next time if the AUTOIEN is 1 by the same source address, destination address, and transfer count.

5.4.5 GDMA operation started by nXDREQ

The GDMA can accept the request from external device. The external device requests the GDMA transfer by asserting signal nXDREQ. When nXDREQ is used to request the GDMA transfer, it is called external nXDREQ mode. The programming method of external nXDREQ mode is the same as software mode except for the followings.

- The GDMA transfer is requested by nXDREQ pin.
- The GDMA is operated in external nXDREQ mode (GDMANS=01b).
- Single mode is valid.
- Demand mode is valid.

5.4.6 Fixed Address

Generally the GDMA continually increase or decrease the source and destination address during data transfer. The NUC745 GDMA controller provides another feature to support the fixed source/destination address to perform data transfer between system memory and external device. To

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do a Memory-to-I/O transfer, the bit **DAFIX** in register GDMA_CTL should be set. In case of I/O-to-Memory transfer, the bit **SAFIX** in register GDMA_CTL should be set.

5.4.7 Block Mode Transfer

When GDMA is programmed to block mode (**[SBMS]** = 1), it needs only one request to transfer all the data. When receiving **nXDREQ** request or the bit **SOFTREQ** is set, the GDMA begins to transfer data. After the numbers of data specified on register **GDMA_TCNT** have been transferred, the GDMA set the bit **TC** and generates an interrupt if it is enabled. Then the GDMA stops until next request is received.

5.4.8 Single Mode Transfer

The single mode transfer (**[SBMS]** = 0) is different to block mode. It can't be started via setting bit SOFTREQ. Besides, Single Mode Transfer requires an **nXDREQ** request for each data transfer that may be one byte, one-halftword, or one word. When receiving **nXDREQ** request, GDMA performs a single data transfer and then wait for next **nXDREQ**. After the numbers of data specified by register **GDMA_TCNT** have been transferred, the GDMA set the bit **TC** and generates an interrupt if it is enabled.

5.4.9 Demand Mode Transfer

The GDMA controller supports the demand mode feature to speed up external DMA transfer. When bit **DM** of register GDML_CTL is set to 1, GDMA controller transfers data as long as the signal nXDREQ is active. The amount of data transferred depends on how long the nXDREQ is active. When nXDREQ is active and GDMA gets the bus in Demand mode, GDMA controller holds the system bus until the nXDREQ signal becomes non-active. Therefore, the period of the active nXDREQ signal should be carefully tuned such that the entire operation does not exceed an acceptable interval (for example, in a DRAM refresh operation).

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6 USB Host Controller

6.1 Overview

The **Universal Serial Bus (USB)** is a low-cost, low-to mid-speed peripheral interface standard intended for modem, scanners, PDAs, keyboards, mice, and other devices that do not require a high-bandwidth parallel interface. The USB is a 4-wire serial cable bus that supports serial data exchange between a *Host Controller* and a network of peripheral devices. The attached peripherals share USB bandwidth through a host-scheduled, token-based protocol. Peripherals may be attached, configured, used, and detached, while the host and other peripherals continue operation (i.e. hot plug and unplug is supported).

The NUC745 USB *Host Controller* has the following features :

- **Open Host Controller Interface (OHCI)** Revision 1.0 compatible.
- USB Revision 1.1 compatible
- Supports both low-speed (1.5 Mbps) and full-speed (12Mbps) USB devices.
- Handles all the USB 1.1 protocol.
- Built-in DMA for real-time data transfer
- Multiple low power modes for efficient power management

The *Host Controller Driver* has the following responsibilities :

- *Host Controller* Management
- Bandwidth Allocation
- List Management
- *Root Hub* Management
- Multiple low power modes for efficient power management

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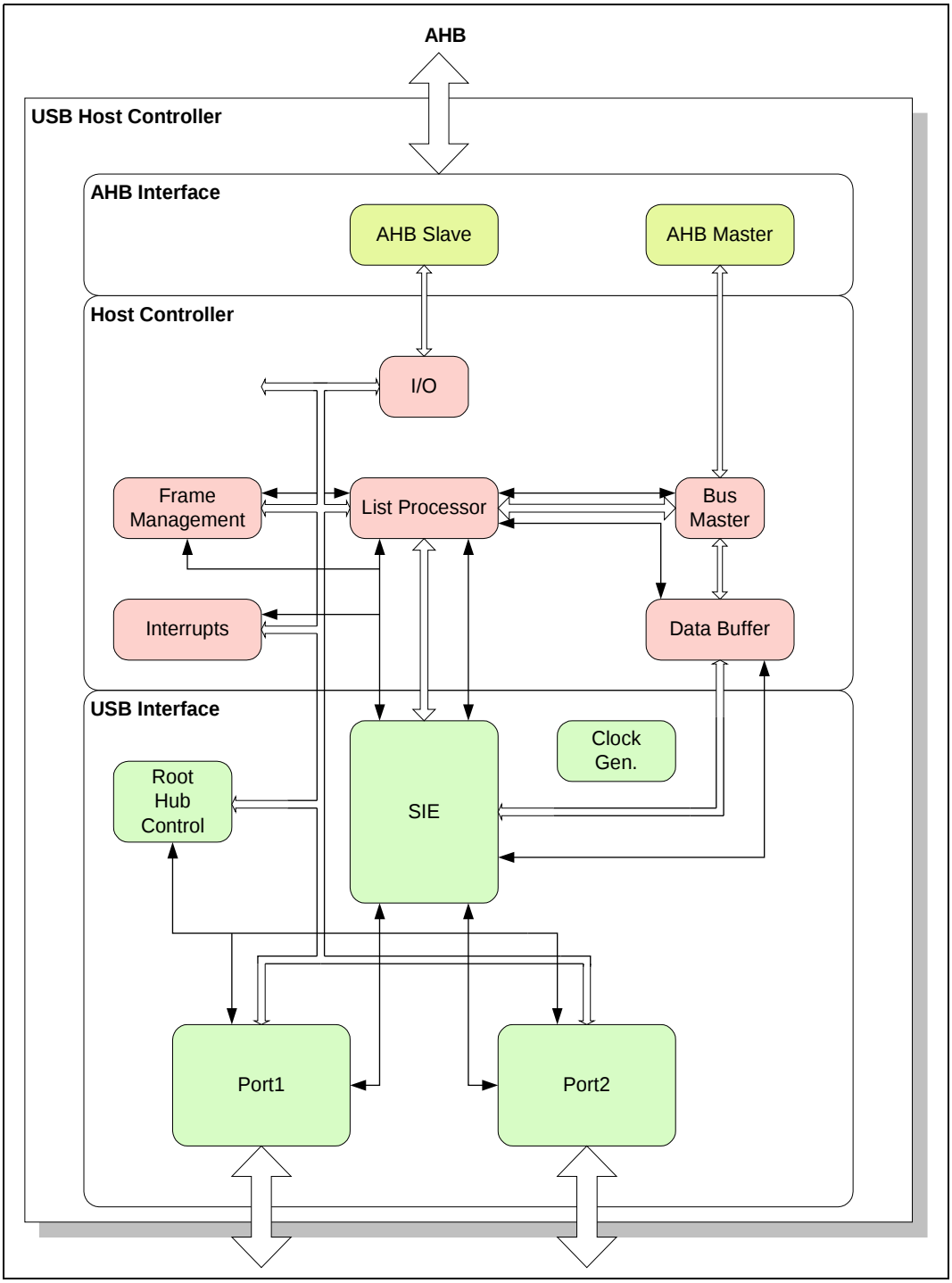
6.2 Registers Map

Register	Address	R/W	Description	Reset Value
OpenHCI Registers				
HcRevision	0xFFF0.5000	R	Host Controller Revision Register	0x0000.0010
HcControl	0xFFF0.5004	R/W	Host Controller Control Register	0x0000.0000
HcCommandStatus	0xFFF0.5008	R/W	Host Controller Command Status Register	0x0000.0000
HcInterruptStatus	0xFFF0.500C	R/W	Host Controller Interrupt Status Register	0x0000.0000
HcInterruptEnable	0xFFF0.5010	R/W	Host Controller Interrupt Enable Register	0x0000.0000
HcInterruptDisable	0xFFF0.5014	R/W	Host Controller Interrupt Disable Register	0x0000.0000
HcHCCA	0xFFF0.5018	R/W	Host Controller Communication Area Register	0x0000.0000
HcPeriodCurrentED	0xFFF0.501C	R/W	Host Controller Period Current ED Register	0x0000.0000
HcControlHeadED	0xFFF0.5020	R/W	Host Controller Control Head ED Register	0x0000.0000
HcControlCurrentED	0xFFF0.5024	R/W	Host Controller Control Current ED Register	0x0000.0000
HcBulkHeadED	0xFFF0.5028	R/W	Host Controller Bulk Head ED Register	0x0000.0000
HcBulkCurrentED	0xFFF0.502C	R/W	Host Controller Bulk Current ED Register	0x0000.0000
HcDoneHead	0xFFF0.5030	R/W	Host Controller Done Head Register	0x0000.0000
HcFmInterval	0xFFF0.5034	R/W	Host Controller Frame Interval Register	0x0000.2EDF
HcFrameRemaining	0xFFF0.5038	R	Host Controller Frame Remaining Register	0x0000.0000
HcFmNumber	0xFFF0.503C	R	Host Controller Frame Number Register	0x0000.0000
HcPeriodicStart	0xFFF0.5040	R/W	Host Controller Periodic Start Register	0x0000.0000
HcLSThreshold	0xFFF0.5044	R/W	Host Controller Low Speed Threshold Register	0x0000.0628
HcRhDescriptorA	0xFFF0.5048	R/W	Host Controller Root Hub Descriptor A Register	0x0100.0002
HcRhDescriptorB	0xFFF0.504C	R/W	Host Controller Root Hub Descriptor B Register	0x0000.0000
HcRhStatus	0xFFF0.5050	R/W	Host Controller Root Hub Status Register	0x0000.0000
HcRhPortStatus [1]	0xFFF0.5054	R/W	Host Controller Root Hub Port Status [1]	0x0000.0000
HcRhPortStatus [2]	0xFFF0.5058	R/W	Host Controller Root Hub Port Status [2]	0x0000.0000
USB Configuration Registers				
TestModeEnable	0xFFF0.5200	R/W	USB Test Mode Enable Register	0x0XXX.XXXX
OperationalModeEnable	0xFFF0.5204	R/W	USB Operational Mode Enable Register	0x0000.0000

According to the function of these registers, they are divided into four partitions, specifically for Control and Status, Memory Pointer, Frame Counter and *Root Hub*. All of the registers should be read and written as Dwords.

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6.3 Block Diagram



AHB Master

The master issues the address and data onto the bus when granted.

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AHB Slave

The configuration of the *Host Controller* is through the slave interface.

List Processing

The List Processor manages the data structures from the *Host Controller Driver* and coordinates all activities within the *Host Controller*.

Frame Management

Frame Management is responsible for managing the frame specific tasks required by the USB specification and the OpenHCI specification.

Interrupt Processing

Interrupts are the communication method for HC-initiated communication with the *Host Controller Driver*. There are several events that may trigger an interrupt from the *Host Controller*. Each specific event sets a specific bit in the ***HcInterruptStatus*** register.

Host Controller Bus Master

The *Host Controller* Bus Master is the central block in the data path. The *Host Controller* Bus Master coordinates all access to the AHB Interface. There are two sources of bus mastering within *Host Controller* : the List Processor and the Data Buffer Engine.

Data Buffer

The Data Buffer serves as the data interface between the Bus Master and the SIE. It is a combination of a 64-byte latched based bi-directional asynchronous FIFO and a single Dword AHB Holding Register.

6.4 Data Structures

Except direct access to *Host Controller* by registers, *Host Controller Driver* must maintain the following memory blocks to communicate with *Host Controller* :

- *Endpoint Descriptor* Lists
- *Transfer Descriptor* Lists
- *Host Controller Communication Area (HCCA)*

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Note1 : *All these data structures are located in system memory. The Host Controller will access these memory blocks by DMA transfer. All Endpoint Descriptors, Transfer Descriptors, HCCA, and transfer buffers must be set to non-cacheable region.*

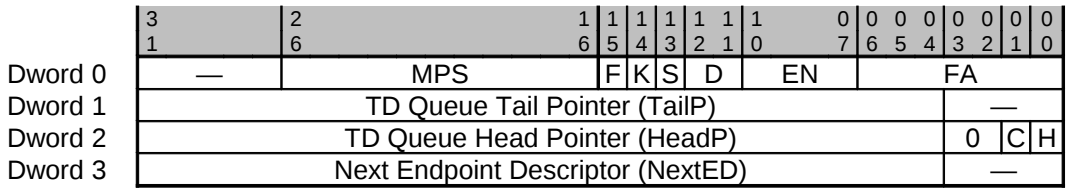
Note2 : *Endpoint Descriptors and Transfer Descriptors must be aligned with 32 bytes address boundary. Host Controller Communication Area must be aligned with 256 bytes address boundary.*

6.4.1 Endpoint Descriptor (ED) Lists

The OpenHCI *Host Controller* fulfills USB transfers by classifying Endpoints into four types of *Endpoint Descriptor* lists. The Control *ED* list is pointed by ***HcControlHeadED*** register, the Bulk *ED* list is pointed by ***HcBulkHeadED*** register, the Interrupt *ED* lists are pointed by InterruptTable of *HCCA*, and the Isochronous *ED* list is linked behind the last 1m interval Interrupt *ED*. *HCD* must create and maintain an *ED* for each endpoint of a USB device.

For all transfer types, they have the same *Endpoint Descriptor* format. The common format is listed below:

Figure 6-16 Endpoint Descriptor Format



The *Endpoint Descriptor* format of NUC745 USB *Host Controller* is compliant to OpenHCI Specification 1.0a. In this document, you can find detail descriptions about each field in *Endpoint Descriptor*.

The Control *ED* list is created by *Host Controller Driver* (*HCD*), which should add any new *ED*s to the end of the Control *ED* list. *HCD* must write the physical address of the first *ED* of Control *ED* list to ***HcControlHeadED*** register. Thus, the HC can find the Control *ED* list and process all Control *ED*s.

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Similarly, all Bulk *ED*s are placed in the Bulk *ED* list, which must be pointed by the ***HcBulkHeadED*** register. And it's the responsibility of *HCD* to maintain Bulk *ED* list and link ***HcBulkHeadED***.

The Interrupt *ED* lists are not directly pointed by any *Host Controller* operation registers, instead, they are pointed by the InterruptTable of *HCCA* (*Host Controller* Communication Area), which is a memory area created by *HCD*. In the *HCCA*, there are 32 entries InterruptTable with each entry points to an Interrupt *ED* list. The structure of Interrupt *ED* lists will be explained in the *HCCA* section.

The end of each Interrupt *ED* list must be linked to the identical 1ms-polling interval Interrupt *ED* list, which is also a part of each Interrupt *ED* list. You may have no any 1ms-polling interval Interrupt *ED*s in some of the real scenes. If it was the case, then you will have a placeholder on the node a 1ms interval Interrupt *ED* should be inserted. It is also true for 2m, 4m, 8m, 16ms, and 32ms polling interval Interrupt *ED* lists. In fact, an Interrupt *ED* list is composed of these various polling interval Interrupt *ED* lists.

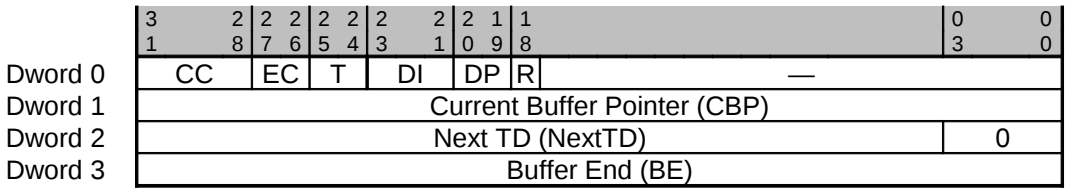
The Isochronous *ED* list must be linked to the end of the 1ms-polling interval Interrupt *ED* list, that is, the end of any one Interrupt *ED* list. *Host Controller Driver* must maintain the Interrupt *ED* lists and Isochronous *ED* list, including the maintenance of *HCCA* and InterruptTable. The *HCCA* is pointed by ***HcHCCA*** register. Of course, *HCD* is responsible for creating *HCCA* and writing the physical address of *HCCA* to ***HcHCCA*** register.

6.4.2 Transfer Descriptor

ED is used to describe the characteristics of a specific endpoint. *ED* itself does not make HC to start any data transfer on USB bus. OpenHCI employs *Transfer Descriptor*s (*TD*s) to describe the details of a USB data transfer. A *Transfer Descriptor* (*TD*) is a system memory data structure that is used by the *Host Controller* to define a buffer of data that will be moved to or from an endpoint. *Transfer Descriptor*s are linked to queues attached to *ED*s. The *ED* provides the endpoint address to/ from where the *TD* data is to be transferred. *Host Controller Driver* adds TDs to the queue and *Host Controller* removes TDs from the queue. Once the transfer of a TD was completed, *Host Controller* removed it from TD queue to the *Done Queue*. There are two *TD* types in OpenHCI, General *TD* and Isochronous *TD*. The *TD* formats are listed below:

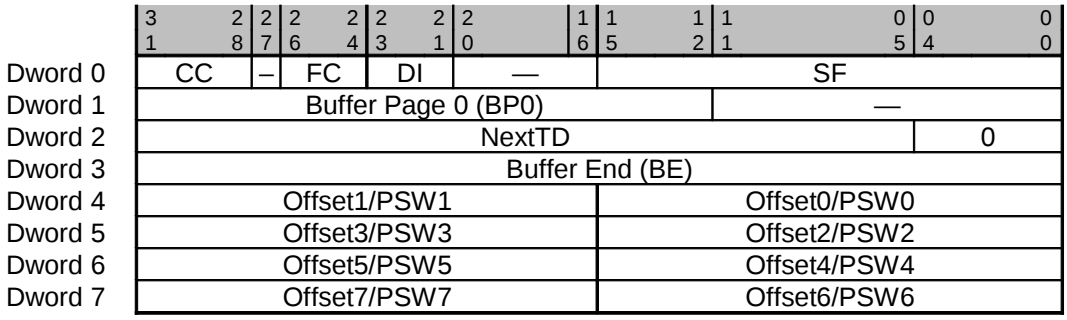
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Figure 6-17 General Transfer Descriptor Format



	31–28	27–26	25–24	23–21	20–19	18	03–00
Dword 0	CC	EC	T	DI	DP	R	—
Dword 1	Current Buffer Pointer (CBP)						
Dword 2	Next TD (NextTD)						0
Dword 3	Buffer End (BE)						

Figure 6-18 Isochronous Transfer Descriptor Format



	31–28	27	26–24	23–21	20–16	15–12	11–05	04–00
Dword 0	CC	–	FC	DI	—	SF		
Dword 1	Buffer Page 0 (BP0)					—		
Dword 2	NextTD							0
Dword 3	Buffer End (BE)							
Dword 4	Offset1/PSW1					Offset0/PSW0		
Dword 5	Offset3/PSW3					Offset2/PSW2		
Dword 6	Offset5/PSW5					Offset4/PSW4		
Dword 7	Offset7/PSW7					Offset6/PSW6		

The General and Isochronous *Transfer Descriptor* formats of NUC745 USB *Host Controller* are compliant to OpenHCI Specification 1.0a. You can find detail descriptions about each field in a General/Isochronous *Transfer Descriptor* in this document.

*Transfer Descriptor*s are created and filled by *HCD*. After receiving an *IRP* (I/O Request Packet) from USB Driver (refer to USB 1.1 Specification), according to the pipe, *HCD* must create appropriate number of *TD*s to describe the data transfer. For example, for a control pipe *IRP*, *HCD* may create three *TD*s for the SETUP stage, DATA stage, and STATUS stage transfers. The *TD*s must be linked to *TD* list of the corresponding *ED* of the pipe specified in the original *IRP*. The *TD* list of an *ED* is maintained by the *HeadP* and *TailP* fields of the *ED* itself.

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6.4.3 Host Controller Communication Area

The *Host Controller Communications Area (HCCA)* is a 256-byte structure of system memory, which is used by *HCD* to communicate with HC. *HCCA* must be aligned to 256 bytes address boundary. This memory block must be set to non-cacheable memory region, because HC accesses this memory block by DMA transfer. *HCD* must claim the physical address of *HCCA* by writing the physical address to ***HcHCCA*** register to notify HC the address of *HCCA*.

Table 6-2 HCCA (Host Controller Communication Area)

Offset	Size (bytes)	Name	Description
0	128	HccaInterrruptTable	These 32 Dwords are pointers to interrupt EDs.
0x80	2	HccaFrameNumber	Contains the current frame number. This value is updated by the HC before it begins processing the periodic lists for the frame.
0x82	2	HccaPad1	When the HC updates **HccaFrameNumber**, it sets this word to 0.
0x84	4	HccaDoneHead	When the HC reaches the end of a frame and its deferred interrupt register is 0, it writes the current value of its *HcDoneHead* to this location and generates an interrupt if interrupts are enabled. This location is not written by the HC again until software clears the WD bit in the *HcInterruptStatus* register. The LSb of this entry is set to 1 to indicate whether an unmasked *HcInterruptStatus* was set when **HccaDoneHead** was written.
0x88	116	reserved	Reserved for use by HC

The *Host Controller Communication Area* format of NUC745 USB *Host Controller* is compliant to OpenHCI Specification 1.0a. Detail descriptions about each field in *HCCA* can be found in this document.

6.5 Programming Note

This section will demonstrate how to write a *Host Controller Driver*, including

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- Initialization,
- Lists management,
- Interrupt processing, and
- *Root hub* management.

6.5.1 Initialization

The initialization of *Host Controller* contain the following steps :

1. Disable *Host Controller* interrupts by setting ***MasterInterruptEnable*** bit of ***HcInterruptDisable*** register.
2. Issue a software reset command by setting ***HostControllerReset*** bit of ***HcCommandStatus*** register and waiting for 10ms until the read value of ***HostControllerReset*** become **0.**
3. Allocate and create all necessary list structures and memory blocks, including *HCCA*, and initialize all driver-maintained lists, including *InterruptTable* of *HCCA* (Note that *HCCA* must be aligned with *256-bytes* address boundary, while *ED*s and *TD*s must be aligned with *32-bytes* address boundary).
4. Clear ***HcControlHeadED*** and ***HcBulkHeadED*** register
5. Program the physical address of software allocated *HCCA* to ***HcHCCA*** register
6. Programe frame interval value (11,999 ± 6) to ***HcFmInterval*** register and 90% of this value (recommended) to ***HcPeriodicStart*** register
7. Programe *0x628* to ***HcThreshold*** register (0x628 is the reset default value of ***HcThreshold*** register)
8. Enable all transfer list by setting ***PeriodicListEnable***, ***IsochronousEnable***, ***ControlListEnable***, and ***BulkListEnable*** bits of ***HcControl*** register
9. Let *Host Controller* transit to *USBOPERATIONAL* state by writing *10b* to ***HostControllerFunctionalState*** field of ***HcControl*** register
10. Enable desired interrupts by programming corresponding bits to ***HcInterruptEnable*** register and clear interrupt status of these interrupts by programming corresponding bits to ***HcInterruptStatus*** register
11. Turn on the *Root Hub* port power by issuing *SetGlobalPower* command (writing *0x10000*

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to ***HcRhStatus*** register) (Note that NUC745 USB *Root Hub* uses global power switching mode)

12. Enable NUC745 **AIC** (Advanced Interrupt Controller) USB interrupt, which is *IRQ9*
13. Connect Hub device driver

6.5.2 USB States

The *Host Controller* has four USB states visible to the *Host Controller Driver* via the Operational Registers : UsbOperational, UsbReset, UsbSuspend, and UsbResume. These USB states are stored in the ***HostControllerFunctionalState*** field of the ***HcControl*** register. The *Host Controller Driver* can perform some state transitions by modifying the ***HostControllerFunctionalState*** field of ***HcControl*** register. The meanings of two bits ***HostControllerFunctionalState*** field is listed in Table 6-2.

Table 6-2 HostControllerFunctionalState

HostControllerFunctionalState	
00b	UsbReset
01b	UsbResume
10b	UsbOperational
11b	UsbSuspend

You can find possible transitions of USB states in Table 6-3. The followings are some notes about the USB state transitions :

- After hardware reset, the *Host Controller* will enter UsbReset state.
- In any state, programming one to the ***HostControllerReset*** bit of ***HcCommandStatus*** register, will force the *Host Controller* to perform software reset. After software reset, the HC will enter UsbSuspend state, instead of UsbReset state.
- If HC is in UsbSuspend state, it will enter UsbResume state either by *HCD* writing 0x1 to

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HostControllerFunctionalState or by remote wakeup. To enable HC resume by remote wakeup, *HCD* must enable the ***DeviceRemoteWakeupEnable*** bit of ***HcRhStatus*** register. *HCD* can enable ***ResumeDetected*** interrupt to sense the case.

Table 6-3 USB state transition table

From state	*Convert to state*	*Conditions*
	UsbReset	Hardware Reset
UsbReset	UsbOperational	Writing 0x2 to ***HostControllerFunctionalState***
	UsbSuspend	1. Writing 0x3 to ***HostControllerFunctionalState*** 2. Issue a Software Reset command
UsbOperational	UsbSuspend	1. Writing 0x3 to ***HostControllerFunctionalState*** 2. Issue a Software Reset command
	UsbReset	Writing 0 to ***HostControllerFunctionalState***
UsbSuspend	UsbResume	1. Writing 0x3 to ***HostControllerFunctionalState*** 2. Resumed by device
	UsbOperational	Writing 0x2 to ***HostControllerFunctionalState***
	UsbReset	Writing 0 to ***HostControllerFunctionalState***
UsbResume	UsbOperational	Writing 0x2 to ***HostControllerFunctionalState***
	UsbReset	Writing 0 to ***HostControllerFunctionalState***

6.5.3 Add/Remove Endpoint Descriptors

In *Host Controller* architecture, a device endpoint is described by an *ED* (*Endpoint Descriptor*). *Host Controller* has Control, Bulk, Interrupt, and Isochronous *Endpoint Descriptor* lists. The Control and Bulk *ED* lists are referred to by ***HcControlHeadED*** register and ***HcBulkHeadED*** register respectively. The Interrupt endpoints are organized into 32 Interrupt *ED* lists with each list pointed by one of the *HCCA* InterruptTable entries. The Isochronous *ED* list is linked to the last *ED* of the Interrupt *ED* list.

While receiving an *IRP* from USB Driver, *HCD* must identify the target endpoint of this *IRP* and try

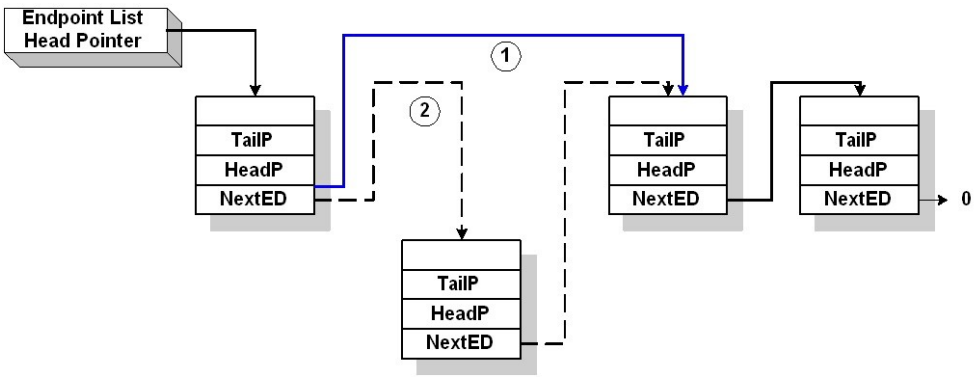
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to find out the *ED* corresponding to the endpoint. If the *ED* does not exist, *HCD* must create a new *ED* and link it to the appropriate *ED* list. The *Endpoint Descriptor*s in an *ED* list are linked together by the *NextED* field of each *ED*. Each *NextED* links to the very next *ED* in an *ED* list. The *NextED* of the last *Endpoint Descriptor* must points to *zero* to signify the end of an *ED* list.

To add an *Endpoint Descriptor* to an *ED* list, *HCD* should write physical address of the new *ED* to the *NextED* of the last *ED* and write *zero* to the *NextED* of the new *ED*.

To remove an *Endpoint Descriptor*, *HCD* should find the previous *ED* of the *ED* to be removed. *HCD* modified the *NextED* of the previous *ED* to point to the next *ED* of the *ED* to be removed, or clear it if the *ED* to be removed is the last *ED*. However, before removing an *ED*, *HCD* must make sure that *Host Controller* is not processing this *ED* and there's no any *TD* waiting for service. *HCD* can temporarily disable the processing of target *ED* list by configuring ***HcControl*** register and enable the SOF interrupt. In the next the SOF interrupt, *HCD* can guarantee that the *ED* list is not processed by *Host Controller*.

Figure 6-19 Remove an Endpoint Descriptor



6.5.4 Add/Remove Transfer Descriptors

The diagram of *Endpoint Descriptor* list linked with *Transfer Descriptor* queue is shown inFigure 10-1. The *Transfer Descriptor* queue of an *ED* is linked by its *HeadP* and *TailP* field.

According to OpenHCI specification, if *HeadP* is equal to *TailP*, then the *TD* queue is configured

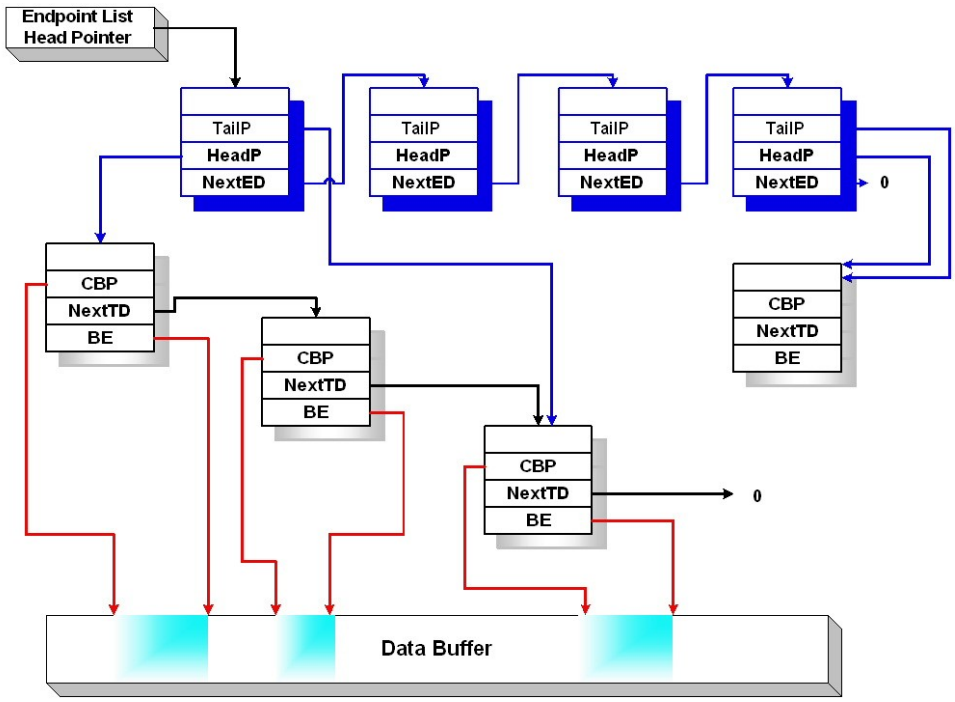
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as empty. In Figure 10-2, the *HeadP* and *TailP* pointer of last *ED* has pointed to the same *Transfer Descriptor*, that is, the *TD* queue of this *ED* is empty. The *TD* there under the *ED* is a dummy *TD*. While creating a new *ED*, *HCD* must also create a dummy *TD* for it, and let both *HeadP* and *TailP* pointer point to this dummy *TD*.

To add a new *TD* into the *TD* queue, *HCD* can use the dummy *TD*. *HCD* writes information and data buffer link to the dummy *TD*, and creates a new dummy *TD*. This can be accomplished by the following steps :

1. Writing *TD* information and data buffer link to the current dummy *TD*
2. Creating a new dummy *TD*
3. Let the *NextTD* of the current *TD* point to the new dummy *TD*
4. Let TailP of *ED* point to the new dummy *TD*

Figure 6-20 ED list and TD queue



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Once the *Host Controller* has accomplished the processing of a *TD*, in spite of success or failure, *Host Controller* will remove the *TD* from *TD* queue and put it into the *Done Queue*. *Host Controller* will follow the following steps to remove a *TD* :

1. Modify the *HeadP* pointer of the *Endpoint Descriptor* (HC always service the first *TD* of the *TD* queue) to link to the next *TD*, HC can obtain the link of the next *TD* by reading the *NextTD* pointer of the first *TD*
2. Now the *TD* has been unlinked from *TD* queue, HC moves the *TD* to the head of *Done Queue*, which is pointed by ***HcDoneHead*** register
3. HC moves the retired *TD* to the *Done Queue* by writing the contains of ***HcDoneHead*** to the *NextTD* field of the retired *TD*, and then have the ***HcDoneHead*** point to the retired *TD*

In some situation, the client software may cancel an *IRP* before the *IRP* was completed. This would result in canceling the *TD*s, which has been created for the *IRP*. To canceling *TD*s, *HCD* must ensure that the *TD*s are not being processed by HC. To achieve this, *HCD* can set the *skip* bit of the *Endpoint Descriptor* and wait for the next SOF by enabling SOF interrupt. If *HCD* can ensure the target endpoint is temporary skipped by HC, it can safely remove any *TD*s of the endpoint. After removing the *TD*s, *HCD* can clear the *sKip* bit and enable processing on the endpoint again.

In some other situation, transfer errors or endpoint stall may make an endpoint being halted, then *HCD* must remove the residual *TD*s. Under these situations, *Host Controller* will stop processing on this endpoint, because the *Halted* bit has been set. Thus, *HCD* can safely remove the *TD*s. After removing the *TD*s and overcoming the error conditions, *HCD* can clear *Halted* bit and enable processing on the endpoint again.

6.5.5 IRP Processing

The data structure of *IRP* is operation system dependent. *Host Controller driver* should be able to interpret the content of any *IRP*. The processing on *IRP*s are different for each transfer type.

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6.5.5.1 Control Transfer

For Control Transfer, *HCD* may create two or three *TD*s for a Control Transfer, depend on specific request command. For a request command without DATA stage, *HCD* will create two *TD*s for it. The first *TD* is created for SETUP stage, which has DATA0 toggle setting. It must have an eight bytes data buffer to accommodate the request command. The second *TD* is created for STATUS stage, which has DATA1 toggle setting. It must contain a zero bytes buffer.

For a request command with DATA stage, *HCD* will create three *TD*s for it. The first *TD* is created for SETUP stage, which has DATA0 toggle setting and has an eight bytes buffer to accommodate the request command. The second *TD* is created for DATA stage, which has DATA1 toggle setting and has a data buffer to accommodate the transferred data for this command. The third *TD* is created for STATUS stage, which has DATA1 toggle setting. It must contain a zero bytes buffer.

The following is an example code of Control Transfer :

```
info = TD_CC | TD_DP_SETUP | TD_T_DATA0;
td_fill(info, ctrl, 8, urb, cnt++);
if (data_len > 0)
{
    info = usb_pipeout(urb->pipe)? (TD_CC | TD_R | TD_DP_OUT | TD_T_DATA1)  :
                                   (TD_CC | TD_R | TD_DP_IN | TD_T_DATA1);
    td_fill(info, data, data_len, urb, cnt++);
}
info = usb_pipeout(urb->pipe)? (TD_CC | TD_DP_IN | TD_T_DATA1) :
                               (TD_CC | TD_DP_OUT | TD_T_DATA1);
td_fill(info, NULL, 0, urb, cnt++);
writel(OHCI_CLF, &ohci->regs->HcCommandStatus); /* start Control list */
```

6.5.5.2 Bulk Transfer

The maximum buffer size for a bulk *Transfer Descriptor* is 4096 bytes. Thus, for a Bulk Transfer, *HCD* simply generates a *TD* for each 4096 bytes data length. For example, if the transfer buffer length of an *IRP* is 9KB, then *HCD* will generate three *TD*s for this *IRP*.

Because OHCI handles the data toggles by itself, it just deed to set the toggle bits for the first *TD*.

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The data toggle setting of the subsequent *TD*s were processed by OHCI controller. OHCI controller can get the toggle value from the DataToggle bit of *Endpoint Descriptor*.

The following is an example code of Bulk Transfer :

```
info = usb_pipeout(urb->pipe)? (TD_CC | TD_DP_OUT)  :  (TD_CC | TD_DP_IN);
while(data_len > 4096)
{
    td_fill(info | (cnt? TD_T_TOGGLE : toggle), data, 4096, urb, cnt);
    data = (VOID *)((UINT32)data + 4096);
    data_len -= 4096;
    cnt++;
}
info = usb_pipeout(urb->pipe)? (TD_CC | TD_DP_OUT)  :  (TD_CC | TD_R | TD_DP_IN);
td_fill(info | (cnt? TD_T_TOGGLE : toggle), data, data_len, urb, cnt);
cnt++;
writel (OHCI_BLF, &ohci->regs->HcCommandStatus); /* start bulk list */
```

6.5.5.3 Interrupt Transfer

The maximum buffer size for an Interrupt *Transfer Descriptor* is 64 bytes. The USB Client Software should not deliver an *IRP* with transfer length exceeding 64 bytes. *HCD* makes only one *TD* for an Interrupt Transfer, which is one-shot. On completion of the *TD*, *HCD* may re-submit the identical *TD* to implement the next Interrupt Transfer. Thus it can fulfill the periodic polling of an Interrupt Endpoint.

The following is an example code of Interrupt Transfer :

```
info = usb_pipeout (urb->pipe)? (TD_CC | TD_DP_OUT | toggle)  :
                            (TD_CC | TD_R  | TD_DP_IN | toggle);
td_fill(info, data, data_len, urb, cnt++);
```

6.5.5.4 Isochronous Transfer

An Isochronous *TD* may contain one to eight consecutive packets with specified starting frame

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number. Depending on implementation of operating system, several isochronous packets to be transferred may be carried in a single *IRP*. *HCD* must prepare appropriate Isochronous *TD*s for these isochronous packets. For example, in Linux's implementation, *HCD* will generate a single Isochronous *TD* for each isochronous packet. According to the starting frame specified in the *IRP*, *HCD* will increase the starting frame of each consecutive Isochronous *TD*. The transfer length of each isochronous packet is specified by Client Software and should not be larger than 1023 bytes.

The following is an example code of Isochronous Transfer :

```
for (cnt = 0; cnt < urb->number_of_packets / ISO_FRAME_COUNT; cnt++)
{
    iso_td_fill(TD_CC | ((ISO_FRAME_COUNT - 1) << 24) | TD_ISO |
            ((urb->start_frame + cnt * ISO_FRAME_COUNT) & 0xffff ),
               (UINT8 *) data, urb, cnt);
}
```

6.5.6 Interrupt Processing

NUC745 USB *Host Controller* may raise the following interrupts :

- SchedulingOverrun
- WritebackDoneHead
- StartOfFrame
- ResumeDetected
- UnrecoverableError
- FrameNumberOverflow
- RootHubStatusChange
- OwnershipChange

6.5.6.1 SchedulingOverrun Interrupt

This interrupt is set when the USB schedule for the current frame overruns. The presence of this interrupt means that *HCD* has scheduled too many transfers. *HCD* may temporarily stop one or more endpoints to reduce bandwidth.

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6.5.6.2 WritebackDoneHead Interrupt

This interrupt is set after *Host Controller* has written ***HcDoneHead*** to ***HccaDoneHead***. On this interrupt, *HCD* can obtain the *TD* done queue by reading ***HccaDoneHead***. *HCD* may first reverse the done queue by traveling the done queue, because the *TD*s were retired in stack order. Then *HCD* can start processing on each *TD*. More detailed description is introduced in the next section.

6.5.6.3 StartOfFrame Interrupt

This interrupt is set on each start of a frame. Generally, *HCD* will not enable this interrupt. This interrupt is generally used to identify the starting of a next frame. For example, if you are going to remove a *TD*, you must ensure that the endpoint is not currently processed by *Host Controller*. To accomplish this, *HCD* can temporarily set the *sKip* bit of its *ED* and enable ***StartOfFrame*** interrupt. In the next coming StartOfFrame interrupt, *HCD* can ensure that the endpoint is not currently processed by *Host Controller*, and it can remove the *TD*.

6.5.6.4 ResumeDetected Interrupt

This interrupt is set when *Host Controller* detects that a device on the USB bus is asserting a resume signal. If *Host Controller* is in UsbSuspend state, the resume signal will make *Host Controller* automatically enter UsbResume state. Note that if you want to make ***ConnectStatusChange*** event being treated as a resume event, you must have written a ***SetRemoteWakeupEnable*** command to ***HcRhStatus*** register.

6.5.6.5 UnrecoverableError Interrupt

The *Host Controller* will raise this interrupt when it detects a system error not related to USB or an error that cannot be reported in any other way. *HCD* may try to reset *Host Controller* in this case.

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6.5.6.6 FrameNumberOverflow Interrupt

The *Host Controller* will raise this interrupt when the MSB bit of ***FrameNumber*** (bit 15) of ***HcFmNumber*** register toggles value from 0 to 1 or 1 to 0, and after ***HccaFrameNumber*** has been updated. Because the *Host Controller* has only 16-bits frame counter, the *HCD* may want to maintain a wider range frame counter. If the *HCD* want to maintain a 32-bits frame counter, it can increase the upper 16-bits value by each two ***FrameNumberOverflow*** interrupt.

6.5.6.7 RootHubStatusChange Interrupt

When the ***OverCurrentIndicatorChange*** bit of ***HcRhStatus*** register, or the ***ConnectStatusChange***, ***PortEnableStatusChange***, ***PortSuspendStatusChange***, or ***PortResetStatusChange*** bit of ***HcRhPortStatus[1/2]*** set, the *Host Controller* would raise the ***RootHubStatusChange*** interrupt.

6.5.6.8 OwnershipChange Interrupt

This *Host Controller* would raise this interrupt when *HCD* set the ***OwnershipChangeRequest*** field of ***HcCommandStatus*** register. Due to the characteristics of embedded system, almost all applications would not have a SMM driver, the ***OwnershipChange*** interrupt would not be used.

The following is an example implementation of *Host Controller* interrupt service routine :

```
VOID hc_interrupt(int vector)
{
    OHCI_T  *ohci = _NUC745_OHCI;
    OHCI_REGS_T *regs = ohci->regs;
    INT     ints;
```

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```
    _InUsbInterrupt = 1;

    ints = ohci->regs->HcInterruptStatus;

    if ((ohci->hcca->done_head != 0) &&
        !((UINT32)(ohci->hcca->done_head) & 0x01))
    {
        ints =  OHCI_INTR_WDH;
    }
    else if ((ints = (readl(&regs->HcInterruptStatus) &
                      readl(&regs->HcInterruptEnable))) == 0)
    {
        USB_printf("Not the wanted interrupts :  %x\n", ints);
    }

    if (ints & OHCI_INTR_UE)
    {
        ohci->disabled++;
        USB_printf("Error! - OHCI Unrecoverable Error, controller disabled\n");
        hc_reset (ohci);
    }

    if (ints & OHCI_INTR_WDH)
    {
        writel(OHCI_INTR_WDH, &regs->HcInterruptDisable);
        dl_done_list(ohci, dl_reverse_done_list (ohci));
        writel(OHCI_INTR_WDH, &regs->HcInterruptEnable);
    }

    if (ints & OHCI_INTR_SO)
    {
        USB_printf("Error! - USB Schedule overrun, count : %d\n",
                       (readl(&ohci->regs->HcCommandStatus) >> 16) & 0x3);
```

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```
        writel(OHCI_INTR_SO, &regs->HcInterruptEnable);
    }

    if (ints & OHCI_INTR_SF)
    {
        UINT32 frame = ohci->hcca->frame_no & 1;

        writel(OHCI_INTR_SF, &regs->HcInterruptDisable);
        if (ohci->ed_rm_list[!frame] != NULL)
        {
            dl_del_list(ohci, !frame);
        }
        if (ohci->ed_rm_list[frame] != NULL)
            writel(OHCI_INTR_SF, &regs->HcInterruptEnable);
    }

    writel(ints, &regs->HcInterruptStatus);
    writel(OHCI_INTR_MIE, &regs->HcInterruptEnable);

    _InUsbInterrupt = 0;
}
```

6.5.7 Done Queue Processing

The *Done Queue* is built by the *Host Controller* and referred to by the ***HcDoneHead*** register. No matter successful or failed, the retired *Transfer Descriptor*s must be put into the *Done Queue* by *Host Controller*. When *Host Controller* reaches the end of a frame (1ms) and its internal deferred interrupt register is 0, it writes the location of *Done Queue* to ***HccaDoneHead*** and raises a ***WritebackDoneHead*** interrupt. *HCD* can take the *Done Queue* by servicing the ***WritebackDoneHead*** interrupt.

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6.5.7.1 Reverse Done Queue

Note that the *TD*s are queued into the *Done Queue* in stack order. The latest queued *TD* is linked at the head of the *Done Queue*, while the earliest queued *TD* is linked at the end of the *Done Queue*. *HCD* must reverse the *Done Queue* before it can start to process the retired *TD*s. The following is an example routine of reversing *Done Queue* :

```
static TD_T  *dl_reverse_done_list(OHCI_T * ohci)
{
    UINT32  td_list_hc;
    TD_T    *td_rev = NULL;
    TD_T    *td_list = NULL;
    URB_PRIV_T *urb_priv = NULL;

    td_list_hc = (UINT32)(ohci->hcca->done_head) & 0xfffffff0;
    ohci->hcca->done_head = 0;

    while (td_list_hc)
    {
        td_list = (TD_T *)td_list_hc;

        if (TD_CC_GET((UINT32)td_list->hwINFO))
        {
            urb_priv = (URB_PRIV_T *)td_list->urb->hcpriv;
            TD_CompletionCode(TD_CC_GET((UINT32)(td_list->hwINFO)));
            if (td_list->ed->hwHeadP & 0x1)
            {
                if (urb_priv && ((td_list->index + 1) < urb_priv->length))
                {
                    td_list->ed->hwHeadP =
                   (urb_priv->td[urb_priv->length - 1]->hwNextTD & 0xfffffff0) |
                   (td_list->ed->hwHeadP & 0x2);
                    urb_priv->td_cnt += urb_priv->length - td_list->index - 1;
                }
```

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```
                else
                    td_list->ed->hwHeadP &= 0xfffffff2;
            }
        }

        if ((td_list->ed->type == PIPE_ISOCHRONOUS) &&
            (td_list->hwPSW[0] >> 12) &&
            ((td_list->hwPSW[0] >> 12) != TD_DATAUNDERRUN))
        {
            /* PSW error */
          TD_CompletionCode(td_list->hwPSW[0] >> 12);
        }

        td_list->next_dl_td = td_rev;
        td_rev = td_list;
        td_list_hc = (UINT32)(td_list->hwNextTD) & 0xfffffff0;
    }  /* end of while */

    return td_list;
}
```

6.5.7.2 Processing Done Queue

Now that the *Done Queue* is inversed into its original order, *HCD* can start to process the *TD*s one by one. For each *TD*, *HCD* checks whether the *TD* was completed with any errors. While processing each *TD*, the *HCD* must determine whether an *IRP* was completed. *HCD* recorded the *TD*s linked to a specific *IRP* and would know whether all *TD*s belong to the same *IRP* had been completed. In the example code, once all *TD*s of an *IRP* had been completed, *HCD* would invoke ***sochi_return_urb( )*** to reclaim the *IRP*.

In the ***sochi_return_urb( )*** routine, *HCD* would invoke the complete routine of the *IRP*. The complete routine is a callback routine provided by *Client Software* or *USB Driver* and used to notify

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the completion of an *IRP*. The *Client Software* or *USB Driver* may collect data received by *Host Controller* or do nothing, it depends on the implementation. In addition to invoke complete routine, *HCD* may release the *IRP* or re-submit the *IRP* if it is the Interrupt Transfer type.

6.5.8 Root Hub

The *Root Hub* is integrated into *Host Controller* and the control of *Root Hub* is done by accessing register files. NUC745 *Host Controller* has provided several *Root Hub* related registers. The ***HcRhDescriptorA*** and ***HcRhDescriptorB*** registers are informative registers, which are used to describe the characteristics and capabilities of *Root Hub*. The ***HcRhStatus*** register presents the current status and reflects the change of status of *Root Hub*. The ***HcRhPortStatus*** register presents the current status and reflects the change of status of a *Root Hub* port. NUC745 *Root Hub* has two hub ports, the ***HcRhPortStatus[1]*** and ***HcRhPortStatus[2]*** are respectively dedicated to port 0 and port 1.

6.5.8.1 HcRhDescriptorA and HcRhDescriptorB

The ***HcRhDescriptorA*** and ***HcRhDescriptorB*** registers are informative registers, which are used to describe the characteristics and capabilities of *Root Hub*. The characteristics and capabilities of NUC745 *Root Hub* are listed in the followings :

- Two downstream ports
- Ports are power switched
- Power switching mode is global power switch
- Is not a compound device
- Over-current status is reported collectively for all downstream ports
- Power-on-to-power-good-time is 2ms
- Devices attached to any ports are removable

6.5.8.2 HcRhStatus

The ***HcRhStatus*** register is used to control and monitor the *Root Hub* status. The *Root Hub* can be controlled by the following actions :

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- ***ClearGlobalPower*** – write '1' to bit 0 to turn off power to all ports
- ***SetRemoteWakeupEnable*** – write '1' to bit 15 to enable device remote wakeup
- ***SetGlobalPower*** – write '1' to bit 16 to turn off power to all ports
- ***ClearRemoteWakeupEnable*** – write '1' to bit 31 to disable device remote wakeup

In addition, the ***HcRhStatus*** register also indicates the following status :

- ***OverCurrentIndicator*** – bit 2 indicates the over-current status
- ***DeviceRemoteWakeupEnable*** – bit 15 indicates the remote wakeup status. If this bit was set, the ConnectStatusChange is determined as a remote wakeup event
- ***OverCurrentIndicatorChange*** – This bit was set when the ***OverCurrentIndicator*** bit changed

6.5.8.3 HcRhPortStatus[1] and HcRhPortStatus[2]

The ***HcRhPortStatus[1]*** and ***HcRhPortStatus[1]*** register is used to control and monitor the *Root Hub* port status. ***HcRhPortStatus[1]*** is dedicated to port 0 and ***HcRhPortStatus[2]*** dedicated to port 1 respectively. The lower word is used to reflect the port status, whereas the upper word is used to reflect the changing of lower word status bits. Some status bits are implemented with special write behavior. You can do the following actions to control the *Root Hub* port :

- ***ClearPortEnable*** – write '1' to bit 0 to clear the ***PortEnableStatus*** bit
- ***SetPortEnable*** – write '1' to bit 1 to set the ***PortEnableStatus*** bit
- ***SetPortSuspend*** – write '1' to bit 2 to clear the ***PortSuspendStatus*** bit
- ***ClearSuspendStatus*** – write '1' to bit 3 to clear the ***PortSuspendStatus*** bit
- ***SetPortReset*** – write '1' to bit 4 to set port reset signaling
- ***SetPortPower*** – write '1' to bit 8 to set the ***PortPowerStatus*** bit
- ***ClearPortPower*** – write '1' to bit 9 to clear the ***PortPowerStatus*** bit

You can get the current status of the *Root Hub* port by reading the following bits :

- ***CurrentConnectStatus*** – bit 0, reflect the current connect status of the *Root Hub* port
- ***PortEnableStatus*** – bit 1, indicate whether the port is enabled or disabled

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- ***PortSuspendStatus*** – bit 2, indicate the port is suspended or not
- ***PortResetStatus*** – bit 4, indicate the *Root Hub* is asserting reset signal on this port
- ***PortPowerStatus*** – bit 8, reflect the port's power status
- ***LowSpeedDeviceAttached*** – bit 9, indicate the speed of the device attached to this port

The following bits indicate the change of status bits. Write '1' to these bits will clear the events :

- ***ConnectStatusChange*** – bit 16, indicate the connect or disconnect events
- ***PortEnableStatusChange*** – bit 17, set when hardware event clear the ***PortEnableStatus*** bit
- ***PortSuspendStatusChange*** – bit 18, set when the full resume sequence has been completed
- ***PortResetStatusChange*** – bit 20, set at the end of the 10-ms port reset signal

6.5.8.4 Virtual Root Hub

Obviously, the *Root Hub* control is quite different from a hub device. The hardware dependent parts of *Root Hub* will increase the complexity of implementing the USB Driver. Thus, to make the *Root Hub* appear as a normal hub device seems be a better solution. To accomplish this, *HCD* must be able to determine the standard request to *Root Hub* and reply the request to make the upper layer software feel like that they are communicating with a real hub device.

First, the standard request to the *Root Hub* must be intercepted. Refer to the following code :

```
static INT  sohci_submit_urb(URB_T * urb)
{
    /* some code assertted here */
    ... ... ...
    ... ... ...

    /* handle a request to the virtual root hub */
    if (usb_pipedevice(pipe) == ohci->rh.devnum)
        return rh_submit_urb(urb);
```

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```
    /* some code assertted here */
    ... ... ...
    ... ... ...
}
```

As it illustrated, all *IRP*s are forwarded to *HCD*'s ***sohci_submit_urb( )*** routine. This routine will further translate *IRP*s into *Transfer Descriptor*s, which finally make *Host Controller* issue transactions on USB bus. But *Root Hub* is not a real device on USB bus, it's embedded in *Host Controller* itself. So, in the previous program segment, the requests to the *Root Hub* must be intercepted and forwarded them to the dedicated routine ***rh_submit_urb( )***.

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7 USB Device Controller

7.1 Overview

The USBD controller interfaces the AHB bus and the USB bus. The USB controller contains both the AHB master interface and AHB slave interface. CPU programs the USB controller through the AHB slave interface. For IN or OUT transfer, the USBD controller needs to write data to memory or read data from memory through the AHB master interface. The USBD controller also contains the USB transceiver to interface the USB.

It consists of four endpoints, designated EP0, EPA, EPB and EPC. Each is intended for a particular use as described below:

- EP0: the default endpoint uses control transfer (In/Out) to handle configuration and control functions required by the USB specification. Maximum packed size is 16 bytes.

- EPA: designed as a general endpoint. This endpoint could be programmed to be an Interrupt IN endpoint or an Isochronous IN endpoint or a Bulk In endpoint or Bulk OUT endpoint.

- EPB: designed as a general endpoint. This endpoint could be programmed to be an Interrupt IN endpoint or an Isochronous IN endpoint or a Bulk In endpoint or Bulk OUT endpoint.

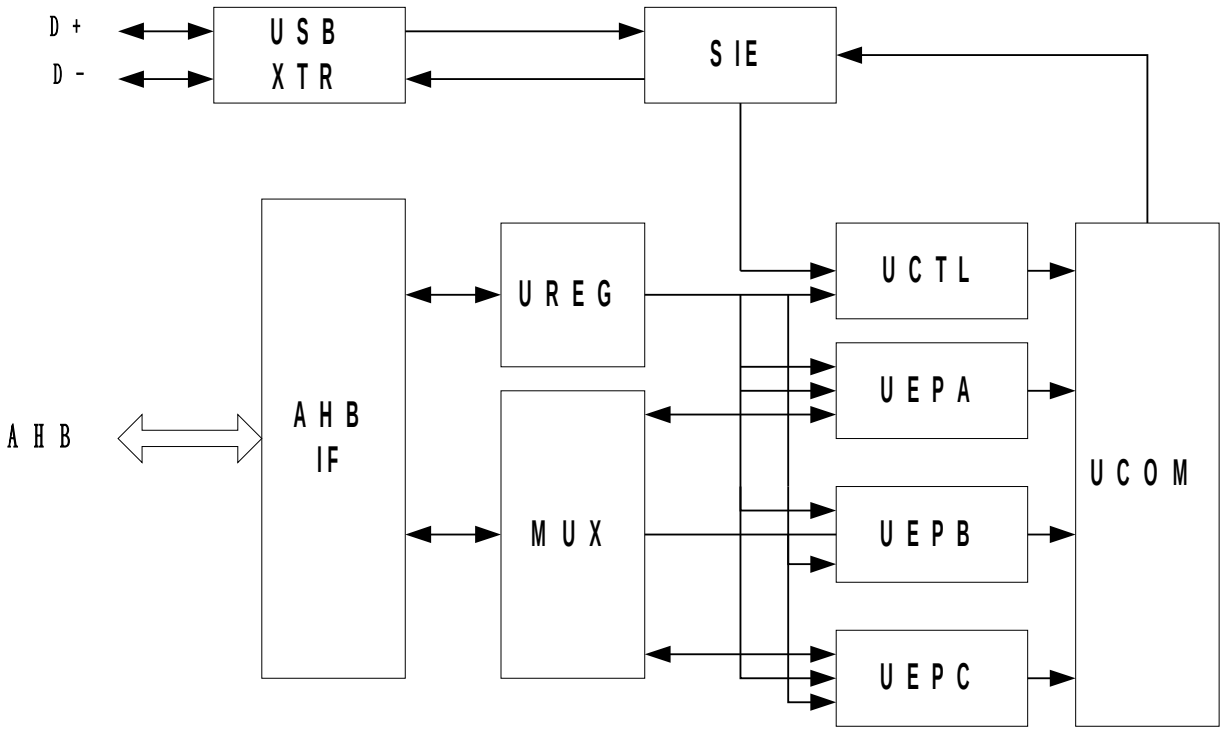
- EPC: designed as a general endpoint. This endpoint could be programmed to be an Interrupt IN endpoint or an Isochronous IN endpoint or a Bulk In endpoint or Bulk OUT endpoint.

The USB controller has built-in hard-wired state machine to automatically respond to USB standard device request. It also supports to detect the class and vendor requests. For GetDescriptor request and Class or Vendor command, the firmware will control these procedures.

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7.2 Block Diagram

Figure 7-21 USBD Controller Block Diagram



7.3 Register Map

Register	Address	R/W	Description	Reset Value
USB_CTL	0xFFF0.6000	R/W	USB control register	0x0000.0000
USB_VCMD	0xFFF0.6004	R/W	USB class or vendor command register	0x0000.0000
USB_IE	0xFFF0.6008	R/W	USB interrupt enable register	0x0000.0000
USB_IS	0xFFF0.600C	R	USB interrupt status register	0x0000.0000
USB_IC	0xFFF0.6010	R/W	USB interrupt status clear register	0x0000.0000
USB_IFSTR	0xFFF0.6014	R/W	USB interface and string register	0x0000.0000
USB_ODATA0	0xFFF0.6018	R	USB control transfer-out port 0 register	0x0000.0000
USB_ODATA1	0xFFF0.601C	R	USB control transfer-out port 1 register	0x0000.0000
USB_ODATA2	0xFFF0.6020	R	USB control transfer-out port 2 register	0x0000.0000
USB_ODATA3	0xFFF0.6024	R	USB control transfer-out port 3 register	0x0000.0000
USB_IDATA0	0xFFF0.6028	R/W	USB transfer-in data port0 register	0x0000.0000
USB_IDATA1	0xFFF0.602C	R/W	USB control transfer-in data port 1	0x0000.0000

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USB_IDATA2	0xFFF0.6030	R/W	USB control transfer-in data port 2	0x0000.0000
USB_IDATA3	0xFFF0.6034	R/W	USB control transfer-in data port 3	0x0000.0000
USB_SIE	0xFFF0.6038	R	USB SIE status Register	0x0000.0000
USB_ENG	0xFFF0.603C	R/W	USB Engine Register	0x0000.0000
USB_CTLS	0xFFF0.6040	R	USB control transfer status register	0x0000.0000
USB_CONFD	0xFFF0.6044	R/W	USB Configured Value register	0x0000.0000
EPA_INFO	0xFFF0.6048	R/W	USB endpoint A information register	0x0000.0000
EPA_CTL	0xFFF0.604C	R/W	USB endpoint A control register	0x0000.0000
EPA_IE	0xFFF0.6050	R/W	USB endpoint A Interrupt Enable register	0x0000.0000
EPA_IC	0xFFF0.6054	W	USB endpoint A interrupt clear register	0x0000.0000
EPA_IS	0xFFF0.6058	R	USB endpoint A interrupt status register	0x0000.0000
EPA_ADDR	0xFFF0.605C	R/W	USB endpoint A address register	0x0000.0000
EPA_LENTH	0xFFF0.6060	R/W	USB endpoint A transfer length register	0x0000.0000
EPB_INFO	0xFFF0.6064	R/W	USB endpoint B information register	0x0000.0000
EPB_CTL	0xFFF0.6068	R/W	USB endpoint B control register	0x0000.0000
EPB_IE	0xFFF0.606C	R/W	USB endpoint B Interrupt Enable register	0x0000.0000
EPB_IC	0xFFF0.6070	W	USB endpoint B interrupt clear register	0x0000.0000
EPB_IS	0xFFF0.6074	R	USB endpoint B interrupt status register	0x0000.0000
EPB_ADDR	0xFFF0.6078	R/W	USB endpoint B address register	0x0000.0000
EPB_LENTH	0xFFF0.607C	R/W	USB endpoint B transfer length register	0x0000.0000
EPC_INFO	0xFFF0.6080	R/W	USB endpoint C information register	0x0000.0000
EPC_CTL	0xFFF0.6084	R/W	USB endpoint C control register	0x0000.0000
EPC_IE	0xFFF0.6088	R/W	USB endpoint C Interrupt Enable register	0x0000.0000
EPC_IC	0xFFF0.608C	W	USB endpoint C interrupt clear register	0x0000.0000
EPC_IS	0xFFF0.6090	R	USB endpoint C interrupt status register	0x0000.0000
EPC_ADDR	0xFFF0.6094	R/W	USB endpoint C address register	0x0000.0000
EPC_LENTH	0xFFF0.6098	R/W	USB endpoint C transfer length register	0x0000.0000
EPA_XFER	0xFFF0.609C	R/W	USB endpoint A remain transfer length register	0x0000.0000
EPA_PKT	0xFFF0.60A0	R/W	USB endpoint A remain packet length register	0x0000.0000
EPB_XFER	0xFFF0.60A4	R/W	USB endpoint B remain transfer length register	0x0000.0000
EPB_PKT	0xFFF0.60A8	R/W	USB endpoint B remain packet length register	0x0000.0000
EPC_XFER	0xFFF0.60AC	R/W	USB endpoint C remain transfer length register	0x0000.0000
EPC_PKT	0xFFF0.60B0	R/W	USB endpoint C remain packet length register	0x0000.0000

7.4 Functional descriptions

Please refer to Universal Serial Bus Specification and Class Specification Documents for detailed USB protocol.

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7.4.1 Initialization

The initialization of USBD controller contains the following steps:

1. Set *SIE_RCV* bit of register **USB_CTL** to set the RCV source generated by the USB transceiver,
2. Set *SUSP* bit of register **USB_CTL** to enable suspend detect.
3. Set *CCMD* bit of register **USB_CTL** to enable the class command decode control.
4. Set *VCMD* bit of register **USB_CTL** to enable the vendor command decode.
5. Set bits *RST_ENDI* and *RSTI* of **USB_IE** register to enable the reset interrupt.
6. Set bits *CDII* and *CDOI* of **USB_IE** register to enable the control data in and control data out interrupt.
7. Set bits *VENI* and *CLAI* of **USB_IE** register to enable the vendor and class command interrupt of control pipe.
8. Set bits *GSTRI*, *GCFGI* and *GDEVI* of **USB_IE** register to enable the get string, configuration, and device descriptor command interrupt.
9. Set bits *RUM* and *SUSI* of **USB_IE** register to enable the USB suspend and resume detect interrupt.
10. Set **USB_IFSTR** register to enable the interface and string descriptors control. If didn't fill this register, USBD only enable the interface 0 and string descriptor 0 control.
11. Configure *CONFD* in register **USB_CONFD** to the configuration wishes to be enabled. *Note: USBD won't work if this value is not consist with CONF in register **USB_CTLS***.
12. After finished the above steps, set the *USB_EN* bit of **USB_CTL** to enable USB engine. The host will detect a device attached.

7.4.2 Endpoint Configuration

Configure the endpoint of USBD controller contains the following steps:

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1. Configure registers **EPx_INFO** according to the application.
   Using mass storage device as an example, programmer could configure endpoint A to bulk out endpoint 1, belongs to configuration 1 and interface 0, with maximum packet size 64 bytes by writing 0x20400011 to register **EPA_INFO**, and configure endpoint B to bulk in endpoint 2, belongs to configuration 1 and interface 0, with maximum packet size 64 bytes by writing 0x20400012 to register **EPB_INFO**.
   Note: This configuration must be consistent with configuration, interface and endpoint descriptors
2. Enable endpoint interrupts by configure register **EPx_IE** according to application. Such as *EPx_DMA_IE* bit to enable the endpoint DMA interrupt.
3. If the endpoint was configuring to be Isochronous IN, the programmer could set the *EPx_THRE* bit of **EPx_CTL** register to control the available space in FIFO when DMA accesses memory.
4. Set the *EPx_RST* bit of **EPx_CTL** register to reset the endpoint.
5. Set the *EPx_EN* bit of **EPx_CTL** register to active the endpoint.
6. If USB host select an alternative setting for a specified interface, configure register **EPx_INFO** accordingly.

7.4.3 Interrupt Service Routine

The interrupt service routine should check 4 registers **USB_IS** and **EPx_IS,** if any interrupt in **USB_IE** or **EPx_IE** register is enabled. After service an interrupt, ISR has to set the relative bit of that interrupt in register **USB_IC** or **EPx_IC** to clear the interrupt status.

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```
void USBD_Handler()
{
   UINT32 volatile Irq,
   Irq = inpw(REG_USB_IS);
   if (Irq & USB_RSTI)
      USB_ISR_Reset_Start();
   else if (Irq & USB_GDEVI)
      USB_ISR_Device_Descriptor();
   else if ,,,

   Irq = inpw(REG_USB_EPA_IS);
   if (Irq & USB_EPA_DMA)
      USB_ISR_EPA_DMA_Complete();
   else if ,,,

   Irq = inpw(REG_USB_EPB_IS);
   if (Irq & USB_EPB_DMA)
      USB_ISR_EPB_DMA_Complete();
   else if ,,,

   Irq = inpw(REG_USB_EPC_IS);
   if (Irq & USB_EPC_DMA)
      USB_ISR_EPC_DMA_Complete();
   else if ,,,
}
```

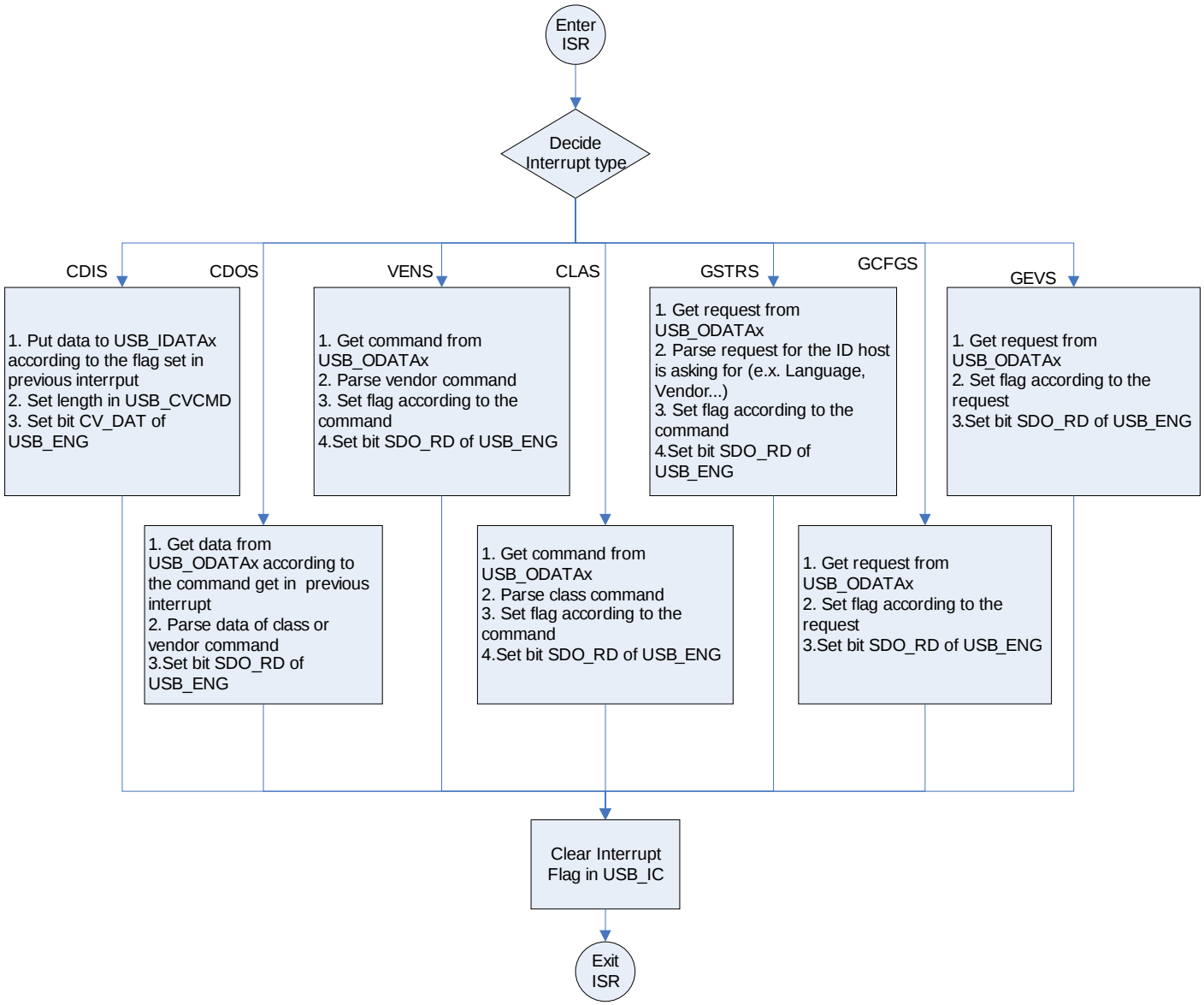
Note: If Reset End interrupt is generated, ISR must clear relative control register status if needed, such as DMA control of each endpoint. Because the reset signal only reset the engine, it wouldn't clear the control register.

7.4.4 Endpoint 0 Operation

The operation of endpoint 0 (control pipe) should base on register **USB_IS**. Figure 10-2 is the flowchart for the ISR handling endpoint 0 operations. The next section will describe how to respond the Get Device Descriptor standard request.

Figure 10-22 USBD Controller Block Diagram

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7.4.5 Get Descriptor

If the host sends the standard request to get Device descriptor, the programmer could follow the steps below.

1. A get device descriptor interrupt occurred, and the program will execute the get device descriptor sub-interrupt service routine.

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2. Check the control transfer received packet size from **USB_CTLS** register. If the size is 8 bytes, assign the device descriptor length and set the DATA OUT ready bit (*SDO_RD*) of **USB_ENG** register. Otherwise, if the size is not 8 bytes, set the Stall control bit (*CV_STL*) of **USB_ENG** register.
3. Clear the Device Descriptor interrupt in **USB_IC** register.
4. Then the control data in interrupt will occur after acknowledge the device descriptor interrupt. The program will execute the relative sub-interrupt service routine.
5. The control data in FIFO is the registers **USB_IDATA0** ~ **USB_IDATA3** (total 16 bytes). If the device descriptor length is over 16 bytes, the programmer should separate it into several 16 bytes.

Note: Each control data in interrupt only can send 16 bytes data.

6. Fill the device descriptor data into control pipe FIFO (**USB_IDATA0** ~ **USB_IDATA3**), and then set the transfer length into **USB_CVCMD** register.
7. Clear the control data in interrupt in **USB_IC** register.
8. repeat the step 4, 6, 7 until all descriptor data has been sent.

7.4.6 Endpoint A ~ C Operation

Endpoint A~C should follow steps below for receive and transmit data.

1. Check bit *EPx_RDY* of register **EPx_CTL**, endpoint is busy if this bit is set.
2. Configure register **EPx_ADDR** with the SDRAM address for DMA to/ from USBD.
3. Configure register **EPx_LENTH** with the data size intend to transmit/ receive.
4. Set bit *EPx_RDY* of register **EPx_CTL**.
5. Polling *EPx_RDY* of register **EPx_CTL** until it is cleared or wait for *EPx_DMA_IS* interrupt in register **EPx_IS**.

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7.4.7 Example

How to configure the USBD to be a mass storage? The programmer could follow the steps below to setup the hardware dependent. About the mass storage protocol, the programmer should refer to the relative specification.

1. Configure the endpoint (refer to endpoint configuration section 10.4.2). The application needs two endpoints in bulk-only mass storage. Therefore, the user can set the EPA for bulk IN, endpoint 1 and maximum packet size is 64bytes; EPB for bulk OUT, endpoint 2 and maximum packet size is 64 bytes.
2. Install the USBD interrupt service routine to Advanced Interrupt Controller (refer system library users manual).
3. Initial the USBD hardware such as interrupt enable (refer to initialization section 10.4.1).
4. After finish the above steps, plug the USBD into the host.
5. The host will ask the descriptors such as device, configuration, and string descriptor. How to answer the descriptor? The programmer could refer to Get Descriptor section 10.4.5.
6. The host will send the class command (0xa1fe) after get descriptor. This command uses to get MAX LUN. The device shall return one bytes of data that contains the maximum LUN supported by the device. The Logical Unit Numbers on the device shall be numbered contiguously starting from LUN 0 to a maximum LUN of 15 (0xF). In this application, the programmer may return 0 for one drive.
7. The host will begin to send the mass storage class command to get the removable drive information. These class commands transfer will through the EPA and EPB endpoints. The user can refer the endpoint operation section 10.4.6 to get more detail information.
8. After the above steps, the host can appreciate a removable drive plug-in. And the user can access it using Windows File explorer.

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8 Audio Controller

8.1 Overview

The audio controller consists of IIS/AC-link protocol to interface with external audio CODEC.

One 8-level deep FIFO for read path and write path and each level has 32-bit width (16 bits for right channel and 16 bits for left channel). One DMA controller handle the data movement between FIFO and memory.

The following are the property of the DMA.

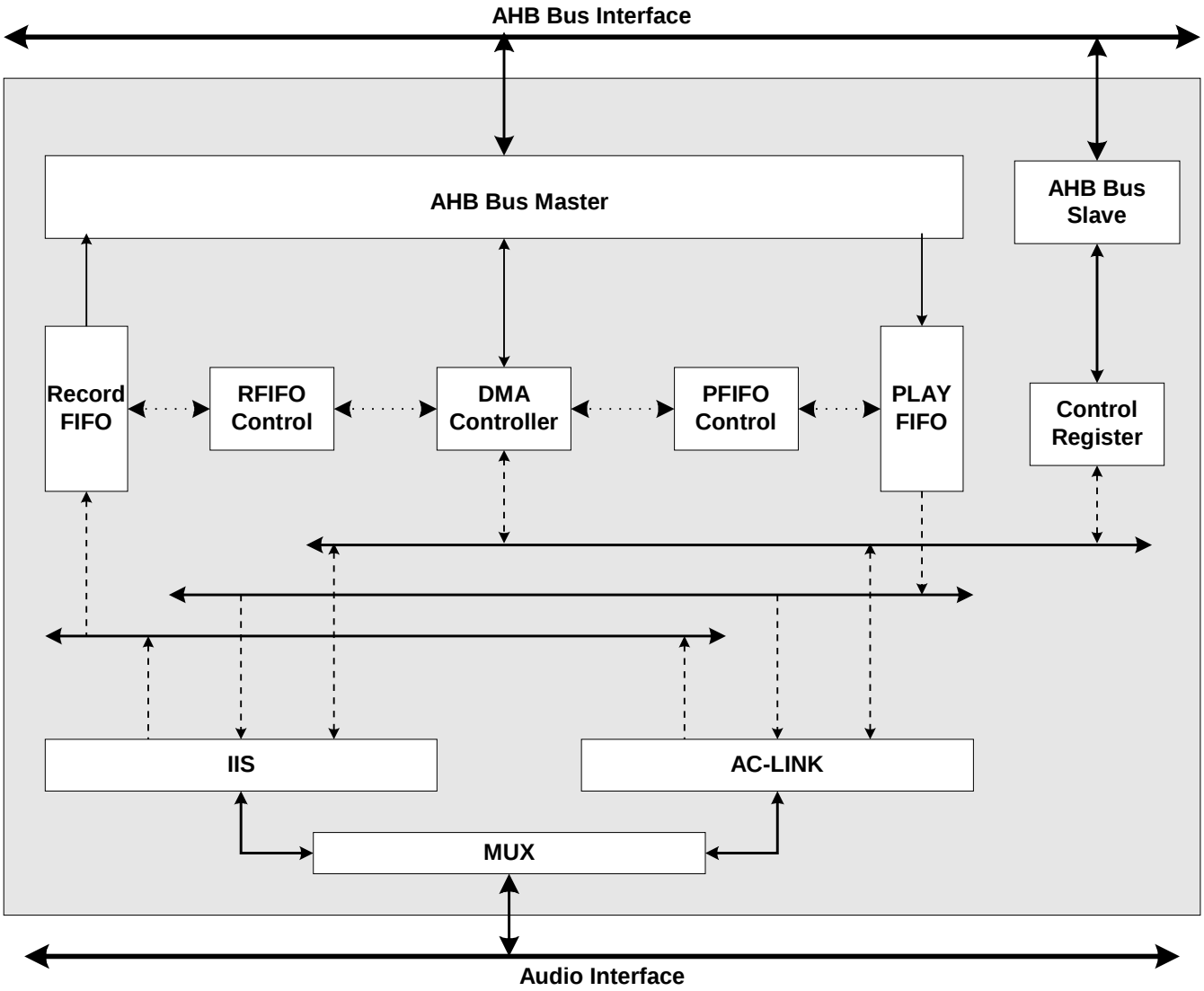
- Always 8-beat incrementing burst
- Always bus lock when 8-beat incrementing burst
- When reach middle and end address of destination address, a DMA_IRQ is requested to CPU automatically

An AHB master port and an AHB slave port are offered in audio controller.

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8.2 Block Diagram

Figure 8-23 Block diagram of Audio Controlle



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8.3 Registers

R: read only, **W**: write only, **R/W**: both read and write, **C**: Only value 0 can be written

Register	Address	R/W	Description	Reset Value
ACTL_CON	0xFFF0.9000	R/W	Audio controller control register	0x0000.0000
ACTL_RESET	0xFFF0.9004	R/W	Sub block reset control register	0x0000.0000
ACTL_RDSTB	0xFFF0.9008	R/W	DMA destination base address register for record	0x0000.0000
ACTL_RDST_LENGTH	0xFFF0.900C	R/W	DMA destination length register for record	0x0000.0000
ACTL_RDSTC	0xFFF0.9010	R	DMA destination current address register for record	0x0000.0000
ACTL_RSR	0xFFF0.9014	R/W	Record status register	0x0000.0000
ACTL_PDSTB	0xFFF0.9018	R/W	DMA destination base address register for play	0x0000.0000
ACTL_PDST_LENGTH	0xFFF0.901C	R/W	DMA destination length register for play	0x0000.0000
ACTL_PDSTC	0xFFF0.9020	R	DMA destination current address register for play	0x0000.0000
ACTL_PSR	0xFFF0.9024	R/W	Play status register	0x0000.0004
ACTL_IISCON	0xFFF0.9028	R/W	IIS control register	0x0000.0000
ACTL_ACCON	0xFFF0.902C	R/W	AC-link control register	0x0000.0000
ACTL_ACOS0	0xFFF0.9030	R/W	AC-link out slot 0	0x0000.0000
ACTL_ACOS1	0xFFF0.9034	R/W	AC-link out slot 1	0x0000.0080
ACTL_ACOS2	0xFFF0.9038	R/W	AC-link out slot 2	0x0000.0000
ACTL_ACIS0	0xFFF0.903C	R	AC-link in slot 0	0x0000.0000
ACTL_ACIS1	0xFFF0.9040	R	AC-link in slot 1	0x0000.0000
ACTL_ACIS2	0xFFF0.9044	R	AC-link in slot 2	0x0000.0000

8.4 AC97 Interface

NUC745 AC-link interface partially support the functionality defined by AC97 codec standard. NUC745 AC-link interface supports only 4 data slots of the 12 data slots. It supports 16-bits PCM. Double rate (96kHz) was not supported. Basically, it provides 2-channels playback and 2-channels record with variable sampling rate, 8000, 11025, 16000, 22025, 24000, 32000, 44100, and 48000 Hz.

NUC745 AC-link interface provides facilities of external AC97 codec register accessing. The playback and record data transfer is done by DMA transfer. These facilities greatly reduce the loading of software.

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For input and output direction, each AC-link frame contains a Tag slot and 12 data slots. However, in the 12 data slots, only 4 slots are used in NUC745, other 8 slots are not supported, and the control data and audio data are transferred in the 4 valid slots. Each slot contains 20 bits data.

The structure of output frame is shown as below:

Table 8-3 AC97 Output Frame

Slot #	0	1	2	3	4	5	6	7	8	9	10	11	12
Content	Tag	CMD ADDR	CMD DATA	PCM LEFT	PCM RIGHT	--	--	--	--	--	--	--	--
Bits	15-0	19-0	19-0	19-0	19-0								
Phase	Tag phase	Data phase											

The output frame data format is shown as following:

Table 8-4 AC97 Output Frame Data Format

Tag (slot 0)	**Bit 15**: frame validity bit, 1 is valid, 0 is invalid. **Bits 14-3**: slot validity, but in W99702, only bits 6-3 are used, bits 14-7 are unused. Bit 3 is corresponding to slot 1; bit 4 is corresponding to slot 2, etc. 1 is valid, 0 is invalid. The unused bits 14-7 should be cleared to 0. Bits 2-0 should be cleared to 0.
CMD ADDR (Slot 1)	**Bit 19**: read/write control, 1 for read and 0 for write **Bit 18-12**: control register address **Bit 11-0** should be cleared to 0
CMD DATA (Slot 2)	**Bit 19-4**: Control register write data. It should be cleared to 0 if current operation is read) **Bit 3-0** should be cleared to 0
PCM LEFT (Slot 3)	**Bit 19-4**: PCM playback data for left channel **Bit 3-0** should be cleared to 0
PCM RIGHT (Slot 4)	Bit 19-4: PCM playback data for right channel Bit 3-0: should be cleared to 0

The structure of input frame is shown as below:

Table 8-5 AC97 Input Frame

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Slot #	0	1	2	3	4	5	6	7	8	9	10	11	12
Content	Tag	Status ADDR	Status DATA	PCM LEFT	PCM RIGHT	--	--	--	--	--	--	--	--
Bits	0-15	19-0	19-0	19-0	19-0								

The input frame data format is shown as following:

Table 8-6 AC97 Input Frame Data Format

Tag (slot 0)	**Bit 15**: frame validity bit, 1 is valid, 0 is invalid. **Bits 14-3**: slot validity, but in W99702, only bits 6-3 are used, bits 14-7 are unused. Bit 3 is corresponding to slot 1; bit 4 is corresponding to slot 2, etc. 1 is valid, 0 is invalid. The unused bits 14-7 should be cleared to 0. **Bits 2-0** should be cleared to 0.
Status ADDR (Slot 1)	**Bit 19** should be cleared to 0 **Bit 18-12**: control register address which previous frame requested **Bit 11**: PCM data for left channel request, it should be always 0 when VRA=0 (VRA: Variable Rate Audio mode) **Bit 10**: PCM data for right channel request **Bit 9-0** should be cleared to 0
Status DATA (Slot 2)	**Bit 19-4**: Control register read data which previous frame requested. It should be cleared to 0 if this slot is invalid) **Bit 3-0** should be cleared to 0
PCM LEFT (Slot 3)	**Bit 19-4**: PCM record data for left channel **Bit 3-0** should be cleared to 0
PCM RIGHT (Slot 4)	**Bit 19-4**: PCM record data for right channel **Bit 3-0**: should be cleared to 0

8.4.1 Cold Reset External AC97 Codec

To reset external AC97 codec, please follow the steps below:

1. Set the *AC_C_RES* bit of **ACTL_ACCON** register for 10ms, and then clear it.
2. Check the *CODEC_READY* bit of **ACTL_ACIS0** register. If *CODEC_READY* was set, the reset operation successes.

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8.4.2 Read AC97 Registers

To read registers of external AC97 codec, please follow the steps below:

1. Set *R_WB* bit of **ACTL_ACOS1** register, and write the register index of AC97 codec register to be read to *R_INDEX[6:0]* of **ACTL_ACOS1** register.
2. Set *VALID_FRAME* and *SLOT_VALID[0]* bits of **ACTL_ACOS0** register. The register index will be delivered by slot1
3. Polling the *AC_R_FINISH* bit of **ACTL_ACCON** register until it was set or time-out
4. If time-out occurred, the external AC97 codec may not be ready or NUC745 hardware failure
5. Clear **ACTL_ACOS0** register
6. Read *R_INDEX[6:0]* of **ACTL_ACIS1** register. This echo value must be equal to the value written to **ACTL_ACOS1**. If the echo value was not correct, check the hardware.
7. Read AC97 register value from *RD[15:0]* of **ACTL_ACIS2** register

A sample code is given below:

```
static UINT16  ac97_read_register(INT nIdx)
{
      volatile INT      nWait;

      /* set the R_WB bit and write register index */
      writew(REG_ACTL_ACOS1, 0x80 | nIdx);

      /* set the valid frame bit and valid slots */
      writew(REG_ACTL_ACOS0, 0x11);

      Delay(100);

      /* polling the AC_R_FINISH */
      for (nWait = 0; nWait < 0x10000; nWait++)
```

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```
            if (readw(REG_ACTL_ACCON) & AC_R_FINISH)
                  break;

      if (nWait == 0x10000)
            _error_msg("ac97_read_register time out!\n");

      writew(REG_ACTL_ACOS0, 0);

      if (readw(REG_ACTL_ACIS1) >> 2 != nIdx)
            _debug_msg("ac97_read_register - R_INDEX of REG_ACTL_ACIS1 not match!, 0x
%x\n", readw(REG_ACTL_ACIS1));

      Delay(100);
      return (readw(REG_ACTL_ACIS2) & 0xFFFF);
}
```

8.4.3 Write AC97 Registers

To write to registers of external AC97 codec, please follow the steps below:

1. Clear *R_WB* bit of **ACTL_ACOS1** register, and write the register index of AC97 codec register to be written to *R_INDEX[6:0]* of **ACTL_ACOS1** register.
2. Write register setting value to *WD[15:0]* of **ACTL_ACOS2** register.
3. Set *VALID_FRAME*, *SLOT_VALID[0]*, and *SLOT_VALID[1]* bits of **ACTL_ACOS0** register. The register index will be delivered by slot1, and setting value will be delivered by slot2.
4. Polling the *AC_W_FINISH* bit of **ACTL_ACCON** register until it was cleared or time-out
5. Read *R_INDEX[6:0]* of **ACTL_ACIS1** register. This echo value must be equal to the value written to **ACTL_ACOS1**
6. The register value should have been written to AC97 codec. Read back AC97 register to verify

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A sample is given below:

```
static INT  ac97_write_register(INT nIdx, UINT16 sValue)
{
      volatile INT      nWait;

      /* clear the R_WB bit and write register index */
      writew(REG_ACTL_ACOS1, nIdx);

      /* write register value */
      writew(REG_ACTL_ACOS2, sValue);

      /* set the valid frame bit and valid slots */
      writew(REG_ACTL_ACOS0, 0x13);

      Delay(100);
      /* polling the AC_W_FINISH */
      for (nWait = 0; nWait < 0x10000; nWait++)
            if (!(readw(REG_ACTL_ACCON) & AC_W_FINISH))
                  break;

      writew(REG_ACTL_ACOS0, 0);

      if (ac97_read_register(nIdx) != sValue)
            _debug_msg("ac97_write_register, nIdx=0x%x, mismatch, 0x%x must be 0x
%x\n", nIdx, ac97_read_register(nIdx), sValue);

      return 0;
}
```

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8.4.4 AC97 Playback

NUC745 audio controller provides DMA function for transferring PCM data from main memory to external AC97 codec. It supports single-channel or 2 channels transfer. The data arrangement in playback DMA buffer was shown in the following figure:

Figure 8-24 AC97 Playback Data in DMA Buffer

	DMA buffer (2 channels)
0x10000	Left channel – LSB byte
0x10001	Left channel – MSB byte
0x10002	Right channel – LSB byte
0x10003	Right channel – MSB byte
0x10004	Left channel – LSB byte
0x10005	Left channel – MSB byte
0x10006	Right channel – LSB byte
0x10007	Right channel – MSB byte
…	…

	DMA buffer (1 channel)
0x10000	Left channel – LSB byte
0x10001	Left channel – MSB byte
0x10002	Left channel – LSB byte
0x10003	Left channel – MSB byte
0x10004	Left channel – LSB byte
0x10005	Left channel – MSB byte
0x10006	Left channel – LSB byte
0x10007	Left channel – MSB byte
…	…

To playback PCM data to external AC97 codec, please follow the steps below:

1. Set the *IIS_AC_PIN_SEL*, *AUDIO_EN, AUDCLK_EN*, *ACLINK_EN*, *PFIFO_EN*, *T_DMA_IRQ*, and *DMA_EN* bits of **ACTL_ACCON** (*IIS_AC_PIN_SEL: select I2S or AC97, AUDIO_EN: enable* NUC745 *audio controller, ACLINK_EN: enable* NUC745 *AC-link interface, PFIFO_EN: enable playback FIFO, T_DMA_IRQ: enable transmit DMA*

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complete IRQ, and DMA_EN: enable DMA transfer)

2. If left and right channels data want to be played, write *0x3* to *PLAY_SINGLE[1:0]* of **ACTL_RESET** register. If left channel only data want to be played, write *0x1* to *PLAY_SINGLE[1:0]* of **ACTL_RESET** register. If right channel only data wants to be played, write *0x2* to *PLAY_SINGLE[1:0]* of **ACTL_RESET** register
3. Pull *ACTL_RESET_BIT* bit of **ACTL_RESET** register high for 10ms to reset NUC745 audio controller. And pull *AC_RESET* bit of **ACTL_RESET** register high for 10ms to reset NUC745 AC97 interface.
4. Reset the external AC97 codec.
5. Install interrupt service routine and enable NUC745 audio controller play interrupt. The play IRQ number is 6.
6. Program AC97 codec playback sampling rate. (refer to AC97 specification)
7. Allocate memory for playback DMA buffer, its base address must be 4 bytes aligned.
8. Write base address of playback DMA buffer to **ACTL_PDSTB** register with *bit 31* set (indicates it is non-cacheable region), and write the DMA buffer length to **ACTL_PDST_LENGTH** register
9. Fill DMA buffer with PCM data to be played and then set AC_PLAY bit of **ACTL_RESET** register to start playback
10. In playback ISR, check **ACTL_PSR** register. If *P_DMA_MIDDLE_IRQ* bit was set, fill PCM data to the first half of DMA buffer. Otherwise, if *P_DMA_END_IRQ* bit was set, fill PCM data to the second half of DMA buffer
11. After all PCM data has been played, clear the AC_PLAY bit of **ACTL_RESET** register to stop playback

8.4.5 AC97 Record

NUC745 audio controller provides DMA function for transferring PCM data from external AC97 codec to main memory. It supports single-channel or 2 channels transfer. The data arrangement in record DMA buffer was shown in the following Figure:

Figure 8-25 AC97 Data in Record DMA buffer

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	DMA buffer (2 channels)
0x10000	Left channel – LSB byte
0x10001	Left channel – MSB byte
0x10002	Right channel – LSB byte
0x10003	Right channel – MSB byte
0x10004	Left channel – LSB byte
0x10005	Left channel – MSB byte
0x10006	Right channel – LSB byte
0x10007	Right channel – MSB byte
…	…

	DMA buffer (1 channel)
0x10000	Left channel – LSB byte
0x10001	Left channel – MSB byte
0x10002	Left channel – LSB byte
0x10003	Left channel – MSB byte
0x10004	Left channel – LSB byte
0x10005	Left channel – MSB byte
0x10006	Left channel – LSB byte
0x10007	Left channel – MSB byte
…	…

To record PCM data from external AC97 codec, please follow the steps below:

1. Set the *IIS_AC_PIN_SEL*, *AUDIO_EN, AUDCLK_EN*, *ACLINK_EN*, *RFIFO_EN*, *R_DMA_IRQ*, and *DMA_EN* bits of **ACTL_ACCON** register.
2. If both left and right channels audio data want to be recorded, write *0x3* to *RECORD_SINGLE[1:0]* of **ACTL_RESET** register. If left channel only wants to be recorded, write *0x1* to *RECORD _SINGLE[1:0]* of **ACTL_RESET** register. If right channel only wants to be recorded, write *0x2* to *RECORD _SINGLE[1:0]* of **ACTL_RESET** register.
3. Pull *ACTL_RESET_BIT* bit of **ACTL_RESET** register high for 10ms to reset NUC745 audio controller. And pull *AC_RESET* bit of **ACTL_RESET** register high for 10ms to reset NUC745 AC97 interface.
4. Reset the external AC97 codec.
5. Install interrupt service routine and enable NUC745 audio controller record interrupt. The record IRQ number is 6.

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6. Program AC97 codec record sampling rate. (refer to AC97 specification)
7. Allocate memory for record DMA buffer, whose base address must be 4 bytes aligned.
8. Write base address of record DMA buffer to **ACTL_RDSTB** register with *bit 31* set (indicates non-cacheable memory area), and write the DMA buffer length to **ACTL_RDST_LENGTH** register
9. Set *AC_RECORD* bit of **ACTL_RESET** register to start recording.
10. In record ISR, check **ACTL_RSR** register. If *R_DMA_MIDDLE_IRQ* bit was set, read PCM data from the first half of record DMA buffer. Otherwise, if *R_DMA_END_IRQ* bit was set, read PCM data from the second half of record DMA buffer.

Once enough PCM data has been gathered, and recording wants to be stopped, just clear the *AC_RECORD* bit of **ACTL_RESET** register to stop recording.

8.5 I2S Interface

NUC745 IIS interface entirely support the functionality defined by I2S codec standard. NUC745 I2S interface supports 16 bits I2S and MSB-justified format. It supports 16-bits PCM. Basically, it provides 2-channels playback and 2-channels record with variable sampling rate, 8000, 11025, 12000, 16000, 22025, 24000, 32000, 44100, and 48000 Hz. Even double rate (96kHz or 88.2Khz) are supported.

NUC745 I2S interface dose not provides facilities of external I2S codec register accessing. It should be accessed by the serial interface (such as L3 in Philips codec) through NUC745 GPIO pin. The playback and record data transfer are done by DMA transfer. These facilities greatly reduce the loading of software.

8.5.1 I2S Play

NUC745 audio controller provides DMA function for transferring PCM data from main memory to external I2S codec. It supports single-channel or 2 channels transfer. It should set base and address by programming register **AUDIO_PDESB** and **ACTL_PDES_LENGTH**. The data arrangement in playback DMA buffer was shown in the following figure:

Figure 8-26 I2S Play Data in DMA buffer

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Length

Base ADDR.	DMA buffer (2 channels)
0x10000	Left channel – LSB byte
0x10001	Left channel – MSB byte
0x10002	Right channel – LSB byte
0x10003	Right channel – MSB byte
0x10004	Left channel – LSB byte
0x10005	Left channel – MSB byte
0x10006	Right channel – LSB byte
0x10007	Right channel – MSB byte
…	…

	DMA buffer (1 channel)
0x10000	Left channel – LSB byte
0x10001	Left channel – MSB byte
0x10002	Left channel – LSB byte
0x10003	Left channel – MSB byte
0x10004	Left channel – LSB byte
0x10005	Left channel – MSB byte
0x10006	Left channel – LSB byte
0x10007	Left channel – MSB byte
…	…

Note: The DMA buffer is double buffering. It will trigger an interrupt when half-length of the DMA buffer is played.

To playback PCM data by external I2S codec, please follow the steps below:

1. Initial the L3 interface through three GPIO pin to control the external audio CODEC. Including turn on the DAC and set the volume.
2. Set the bit *IIS_RESET* of **ACTL_RESET** to reset IIS
3. Set the bits *AUDCLK_EN to enable the audio controller clock*, *PFIFO_EN to enable the playback FIFO*, *DMA_EN to enable DMA*, *the BLOCK_EN[0] to enable IIS interface*, and *AUDIO_EN* to enable the audio controller. These bits are all in the register **ACTL_CON.**
4. Set the register **ACTL_IISCON** to set the sampling rate. And set the sampling rate of the external codec through L3 interface.
5. Set the *bit [3]* **ACTL_IISCON** to determine the data format. And set the data format of external codec through L3 interface. One is IIS compatible format; another is MSB-justified format.
6. Set the register **ACTL_PDSTB** and **ACTL_PDST_LENGTH** to set the DMA play destination base address and the DMA play buffer length.
7. Set the register **ACTL_RESET** to set channel and start to play.

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8.5.2 I2S Record

NUC745 audio controller provides DMA function for transferring PCM data from external I2S codec to main memory. It supports single-channel or 2 channels transfer. It should set base and address by programming register **AUDIO_RDESB** and **ACTL_RDES_LENGTH**. The data arrangement in record DMA buffer was shown in the following figure:

Figure 8-27 I2S Record Data in DMA buffer

Length

Base ADDR.	DMA buffer (2 channels)
0x10000	Left channel – LSB byte
0x10001	Left channel – MSB byte
0x10002	Right channel – LSB byte
0x10003	Right channel – MSB byte
0x10004	Left channel – LSB byte
0x10005	Left channel – MSB byte
0x10006	Right channel – LSB byte
0x10007	Right channel – MSB byte
…	…

	DMA buffer (1 channel)
0x10000	Left channel – LSB byte
0x10001	Left channel – MSB byte
0x10002	Left channel – LSB byte
0x10003	Left channel – MSB byte
0x10004	Left channel – LSB byte
0x10005	Left channel – MSB byte
0x10006	Left channel – LSB byte
0x10007	Left channel – MSB byte
…	…

Note: The DMA buffer is double buffering. It will trigger an interrupt when half-length of the DMA buffer is recorded.

To playback PCM data by external I2S codec, please follow the steps below:

1. Initial the L3 interface through three GPIO pin to control the external audio CODEC. Including turn on the ADC and set the volume.
2. Set the bit *IIS_RESET* of **ACTL_RESET** to reset IIS
3. Set the bits *AUDCLK_EN to enable the audio controller clock*, RFIFO_*EN to enable the record FIFO*, *DMA_EN to enable DMA*, *the BLOCK_EN[0] to enable IIS interface*, and *AUDIO_EN* to enable the audio controller. These bits are all in the register **ACTL_CON.**
4. Set the register **ACTL_IISCON** to set the sampling rate. And set the sampling rate of the external codec through L3 interface.
5. Set the *bit [3]* **ACTL_IISCON** to determine the data format. And set the data format of external codec through L3. NUC745 support two formats of IIS. One is IIS compatible format another is MSB-justified format.

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6. Set the register **ACTL_RDSTB** and **ACTL_RDST_LENGTH** to set the DMA record destination base address and the DMA record buffer length.
7. Set the register **ACTL_RESET** to set channel and start to record. Then play the sound, which record before and verify it.

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9 UART

9.1 Overview

Universal Asynchronous Receiver/Transmitter (UART) performs a serial-to-parallel conversion for the input data. The character bits received from UART receive pin **(SIN)** are shifted to Receive FIFO one after by one. The driver reads the receive FIFO to get the input character. The UART also performs a parallel-to-serial conversion for output data. The driver writes the output characters to the transmitter FIFO. Then the character bits are shifted to UART transmit pin **(SOUT)** in sequence.

The UART provides control/status registers and an interrupt for device driver to control the transmitting operation, receiving operation and error handling. There are five types of interrupts including *line status interrupt*, *transmitter FIFO empty interrupt*, *receiver threshold level reaching interrupt*, *time out interrupt*, and *MODEM status interrupt*. The provided status information includes the type and condition of the transfer operations being performed by the UART, as well as any found error conditions (parity, overrun, framing, or break interrupt).

NUC745's Asynchronous serial communication block include 4 **UART** blocks and accessary logic. The feature of each UART could be found in datasheet.

9.2 Registers

R : read only, **W** : write only, **R/W** : both read and write, **C** : Only value 0 can be written

Register	Address	R/W	Description and Condition	Reset value
UART0				
UART0_RBR	0xFFF8.0000	R	Receive Buffer Register (DLAB = 0)	Undefined
UART0_THR	0xFFF8.0000	W	Transmit Holding Register (DLAB = 0)	Undefined
UART0_IER	0xFFF8.0004	R/W	Interrupt Enable Register (DLAB = 0)	0x0000.0000
UART0_DLL	0xFFF8.0000	R/W	Divisor Latch Register (LS) (DLAB = 1)	0x0000.0000
UART0_DLM	0xFFF8.0004	R/W	Divisor Latch Register (MS) (DLAB = 1)	0x0000.0000

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UART0_IIR	0xFFF8.0008	R	Interrupt Identification Register	0x8181.8181
UART0_FCR	0xFFF8.0008	W	FIFO Control Register	Undefined
UART0_LCR	0xFFF8.000C	R/W	Line Control Register	0x0000.0000
Reserved	0xFFF8.0010			
UART0_LSR	0xFFF8.0014	R	Line Status Register	0x6060.6060
Reserved	0xFFF8.0018			
UART0_TOR	0xFFF8.001C	R/W	Time Out Register	0x0000.0000
UART1				
UART1_RBR	0xFFF8.0100	R	Receive Buffer Register (DLAB = 0)	Undefined
UART1_THR	0xFFF8.0100	W	Transmit Holding Register (DLAB = 0)	Undefined
UART1_IER	0xFFF8.0104	R/W	Interrupt Enable Register (DLAB = 0)	0x0000.0000
UART1_DLL	0xFFF8.0100	R/W	Divisor Latch Register (LS) (DLAB = 1)	0x0000.0000
UART1_DLM	0xFFF8.0104	R/W	Divisor Latch Register (MS) (DLAB = 1)	0x0000.0000
UART1_IIR	0xFFF8.0108	R	Interrupt Identification Register	0x8181.8181
UART1_FCR	0xFFF8.0108	W	FIFO Control Register	Undefined
UART1_LCR	0xFFF8.010c	R/W	Line Control Register	0x0000.0000
UART1_MCR	0xFFF8.0110	R/W	Modem Control Register	0x0000.0000
UART1_LSR	0xFFF8.0114	R	Line Status Register	0x6060.6060
UART1_MSR	0xFFF8.0118	R	MODEM Status Register	0x0000.0000
UART1_TOR	0xFFF8.011c	R/W	Time Out Register	0x0000.0000
UART1_UBCR	0xFFF8.0120	R/W	UART1 Bluetooth Control Register	0x0000.0000
UART2				
UART2_RBR	0xFFF8.0200	R	Receive Buffer Register (DLAB = 0)	Undefined
UART2_THR	0xFFF8.0200	W	Transmit Holding Register (DLAB = 0)	Undefined
UART2_IER	0xFFF8.0204	R/W	Interrupt Enable Register (DLAB = 0)	0x0000.0000
UART2_DLL	0xFFF8.0200	R/W	Divisor Latch Register (LS) (DLAB = 1)	0x0000.0000
UART2_DLM	0xFFF8.0204	R/W	Divisor Latch Register (MS) (DLAB = 1)	0x0000.0000
UART2_IIR	0xFFF8.0208	R	Interrupt Identification Register	0x8181.8181
UART2_FCR	0xFFF8.0208	W	FIFO Control Register	Undefined
UART2_LCR	0xFFF8.020c	R/W	Line Control Register	0x0000.0000
Reserved	0xFFF8.0210			
UART2_LSR	0xFFF8.0214	R	Line Status Register	0x6060.6060
Reserved	0xFFF8.0218			
UART2_TOR	0xFFF8.021c	R/W	Time Out Register	0x0000.0000
UART2_IRCR	0xFFF8.0220	R/W	IrDA Control Register	0x0000.0040

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UART3				
UART3_RBR	0xFFF8.0300	R	Receive Buffer Register (DLAB = 0)	Undefined
UART3_THR	0xFFF8.0300	W	Transmit Holding Register (DLAB = 0)	Undefined
UART3_IER	0xFFF8.0304	R/W	Interrupt Enable Register (DLAB = 0)	0x0000.0000
UART3_DLL	0xFFF8.0300	R/W	Divisor Latch Register (LS) (DLAB = 1)	0x0000.0000
UART3_DLM	0xFFF8.0304	R/W	Divisor Latch Register (MS) (DLAB = 1)	0x0000.0000
UART3_IIR	0xFFF8.0308	R	Interrupt Identification Register	0x8181.8181
UART3_FCR	0xFFF8.0308	W	FIFO Control Register	Undefined
UART3_LCR	0xFFF8.030c	R/W	Line Control Register	0x0000.0000
UART3_MCR	0xFFF8.0310	R/W	Modem Control Register	0x0000.0000
UART3_LSR	0xFFF8.0314	R	Line Status Register	0x6060.6060
UART3_MSR	0xFFF8.0318	R	MODEM Status Register	0x0000.0000
UART3_TOR	0xFFF8.031c	R/W	Time Out Register	0x0000.0000

9.3 Functional Descriptions

9.3.1 Baud Rate

The UART includes a programmable baud rate generator. The crystal clock input is divided by divisor to produce the clock that transmitter and receiver need. The equation is

Baud Rate = Crystal clock / (16 * [Divisor + 2])

For NUC745 , the crystal clock input is 15 MHZ. The DLL and DLM registers consist of the low byte and high byte of the divisor. The DLL and DLM registers aren't accessible until the DLAB bit of LCR register is set 1. The driver should program, the correct value into the DLL/DLM registers according to the desired baud rate. Table 11-1 lists some general baud rate settings.

Table 9-7 General Baud Rate Settings

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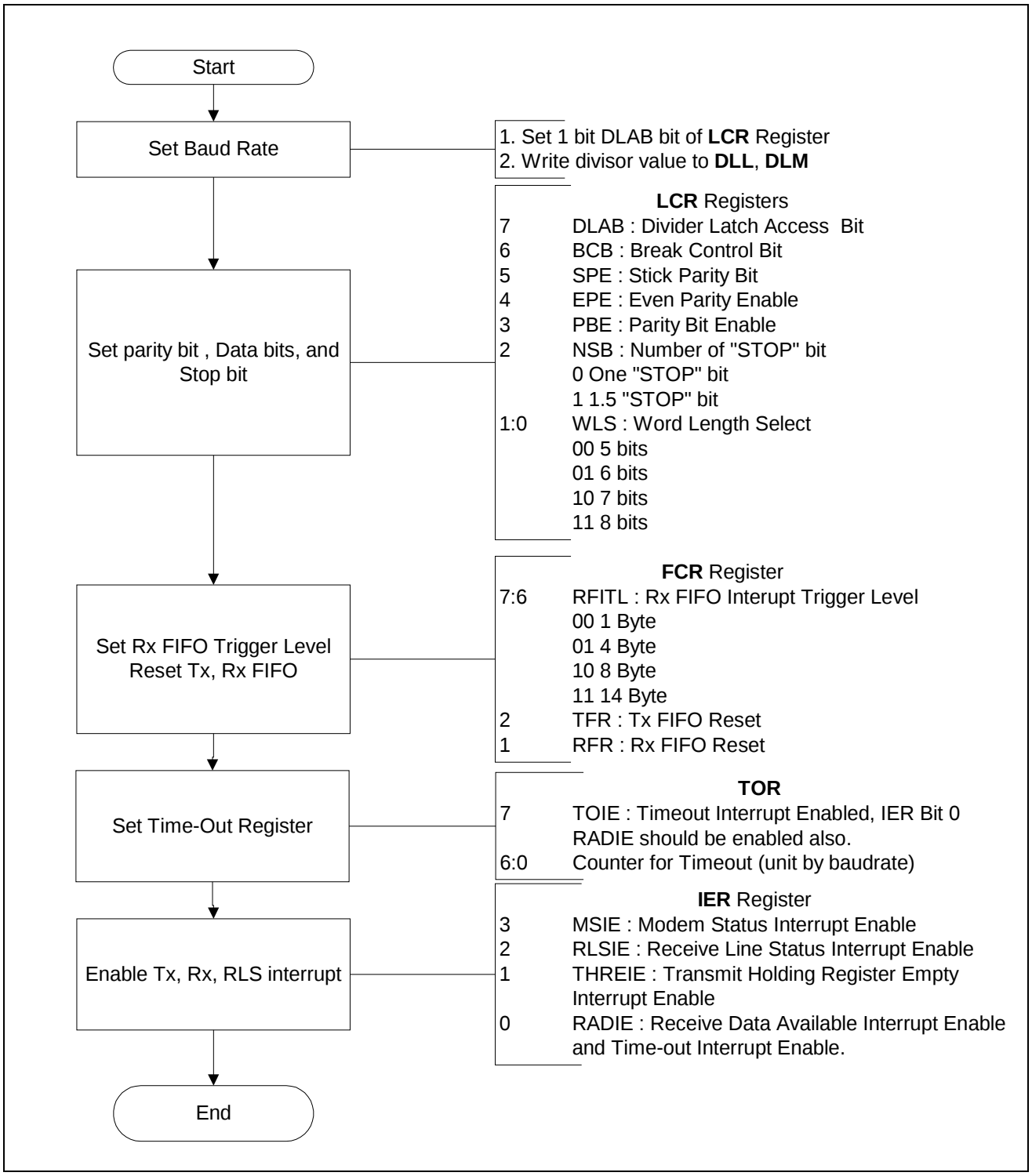
Baud Rate	DLM	DLL	Real	Error rate [%]
115200	0	6	117187.5	1.725
57600	0	14	58593.75	1.725
38400	0	22	39062.5	1.725
19200	0	47	19132.65	-0.35
9600	0	96	9566.33	-0.35

9.3.2 Initializations

Before the transfer operation starts, the serial interface of UART must be programmed. The driver should set the baud rate, parity bit, data bit and stop bit. If the transfer operation is done triggered by interrupt, the TX, RX and RLS interrupts need to be enabled. Figure 11-1 shows the initialization flow of UART.

Figure 9-28 UART initialization

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9.3.3 Polled I/O Functions

The driver can transmit and receive data through UART by polling mode. The poll functions check UART buffer by reading status register. If there's at least one data byte available in receive FIFO, the [RFDR] bit is set 1. It indicates that driver can read receive FIFO to get new data bytes. If the transmitter is empty, the [TE] bit is set 1. Then the data bytes can be written into the transmit FIFO. The data bytes in the transmit FIFO will be shifted to SOUT serially. Figure 11-2 and Figure 11-3 show the programming flow of transmit data and receive data in polling mode.

Figure 9-29 Transmit data in polling mode

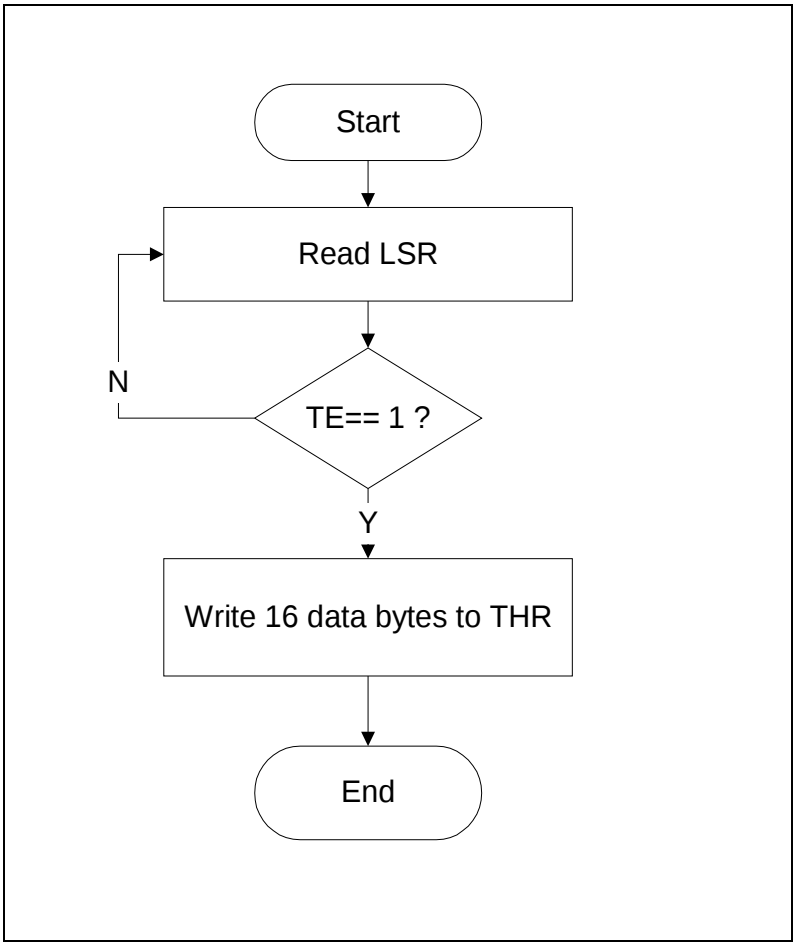
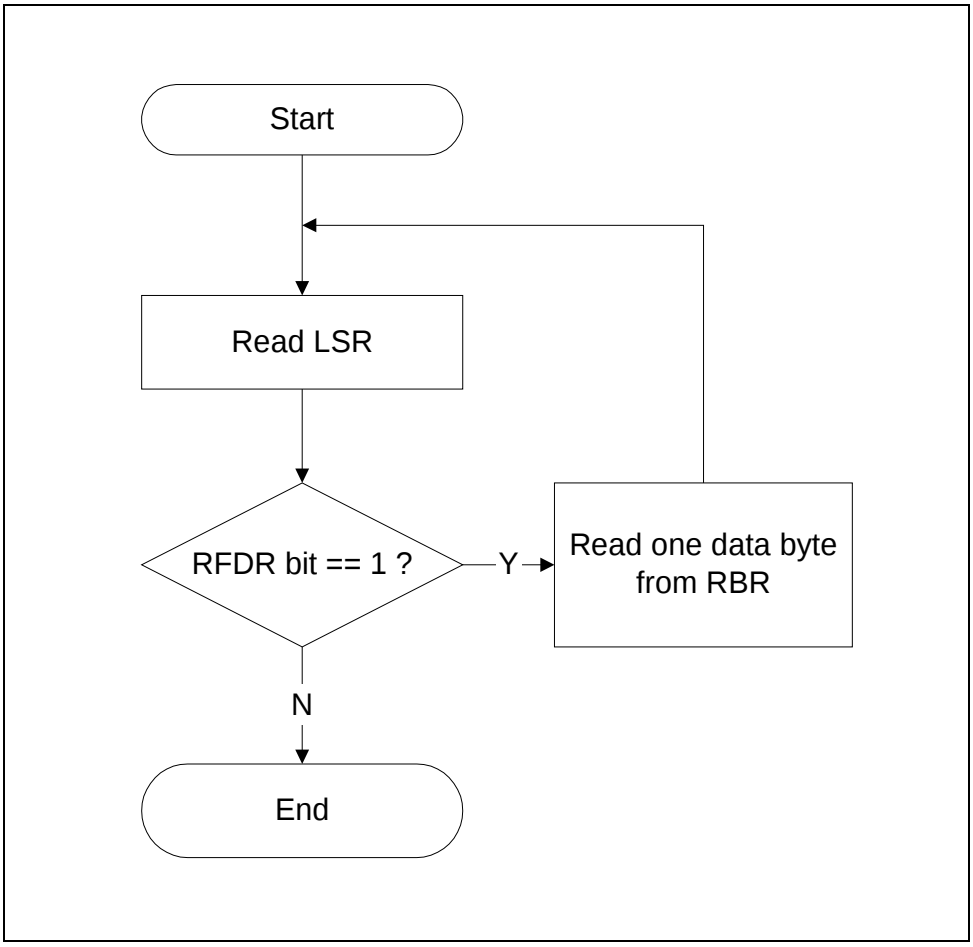


Figure 9-30 Receive data in polling mode

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9.3.4 Interrupted I/O Functions

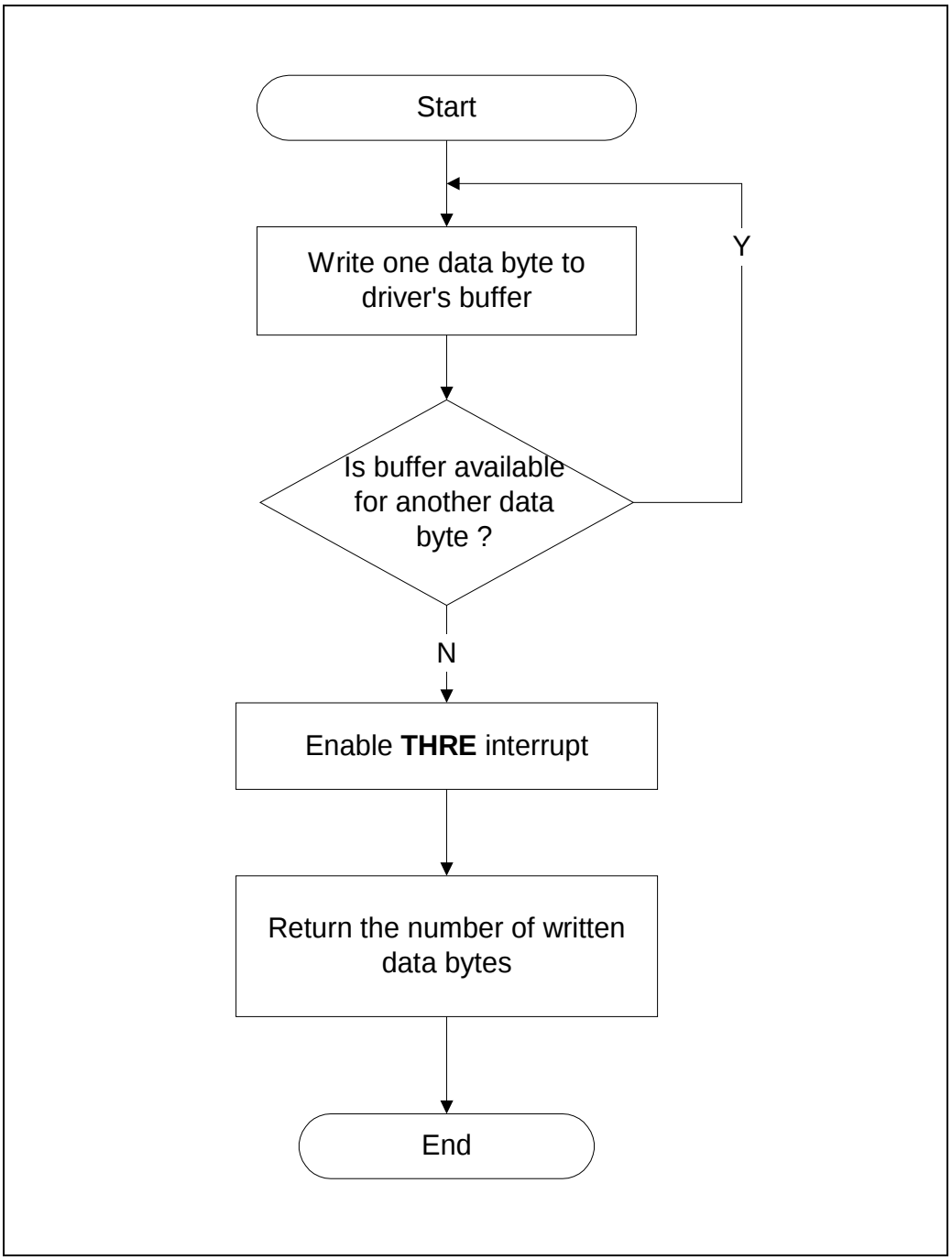
The data bytes also can be transmitted and received through UART by interrupt control. The interrupt service routine is responsible to move data bytes from driver's buffer to transmit FIFO whenever the THRE interrupt happens. If RDA or TOUT interrupts occurs, the interrupt service routine should move the data bytes from receive FIFO to driver's buffer.

On interrupt mode, the input and output functions are different from the polling functions. They read or write the driver's buffer instead of Tx /Rx FIFO. The output function writes the data bytes into driver's buffer and then enables THRE interrupt. The ISR will read the data bytes from driver's buffer and write them to the Tx FIFO when the transmitter FIFO empty interrupt occurs, or get the data bytes from Rx FIFO the driver receiving buffer when the *receiver threshold level reaching interrupt* occurs. When the input function is called, it reads the data bytes from driver's receiving buffer and then return.

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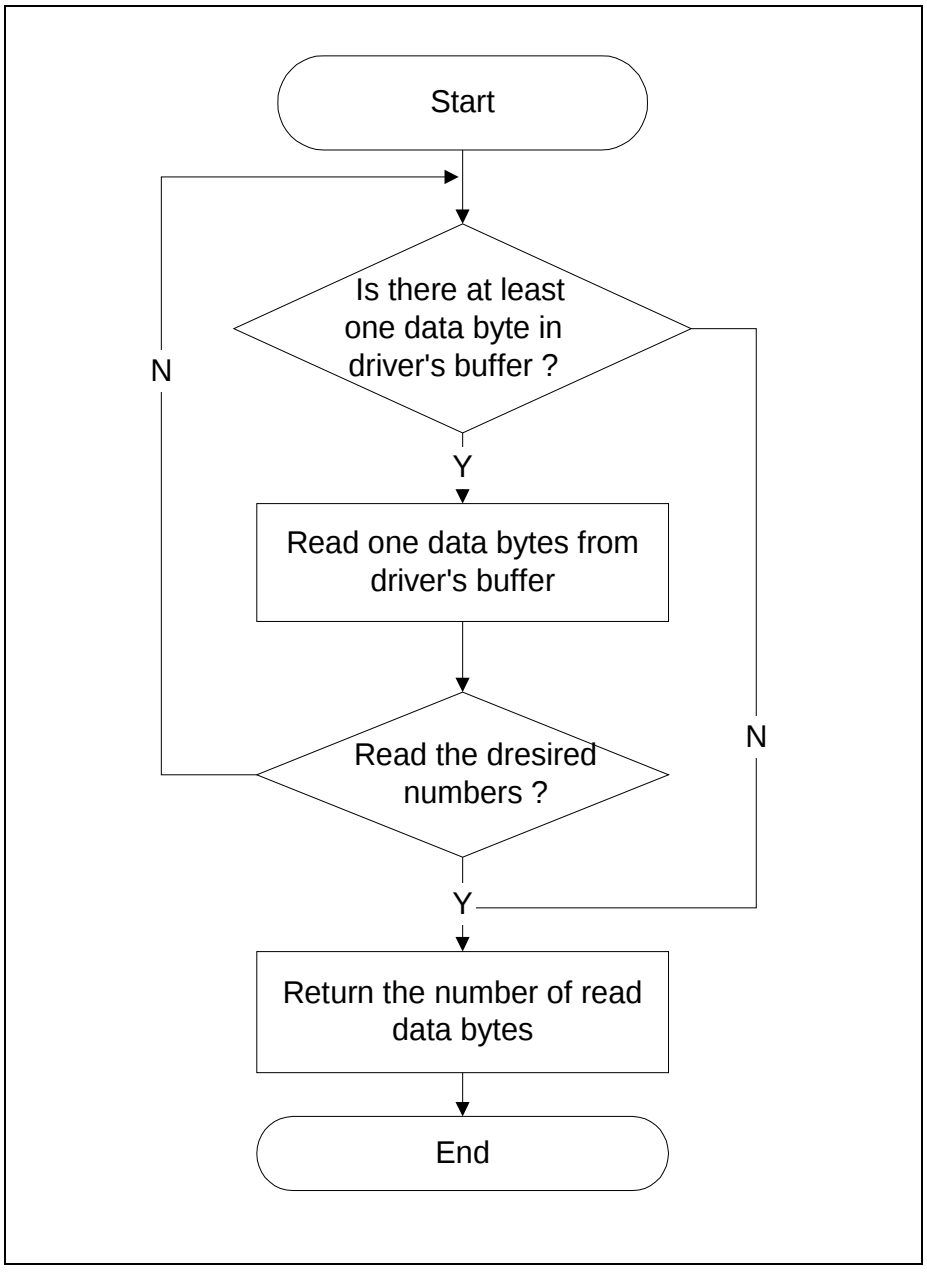
The Figure 11-4, Figure 11-5 and Figure 11-6 show the flow of output function, input function, and interrupt service routine.

Figure 9-31 Output function in interrupt mode



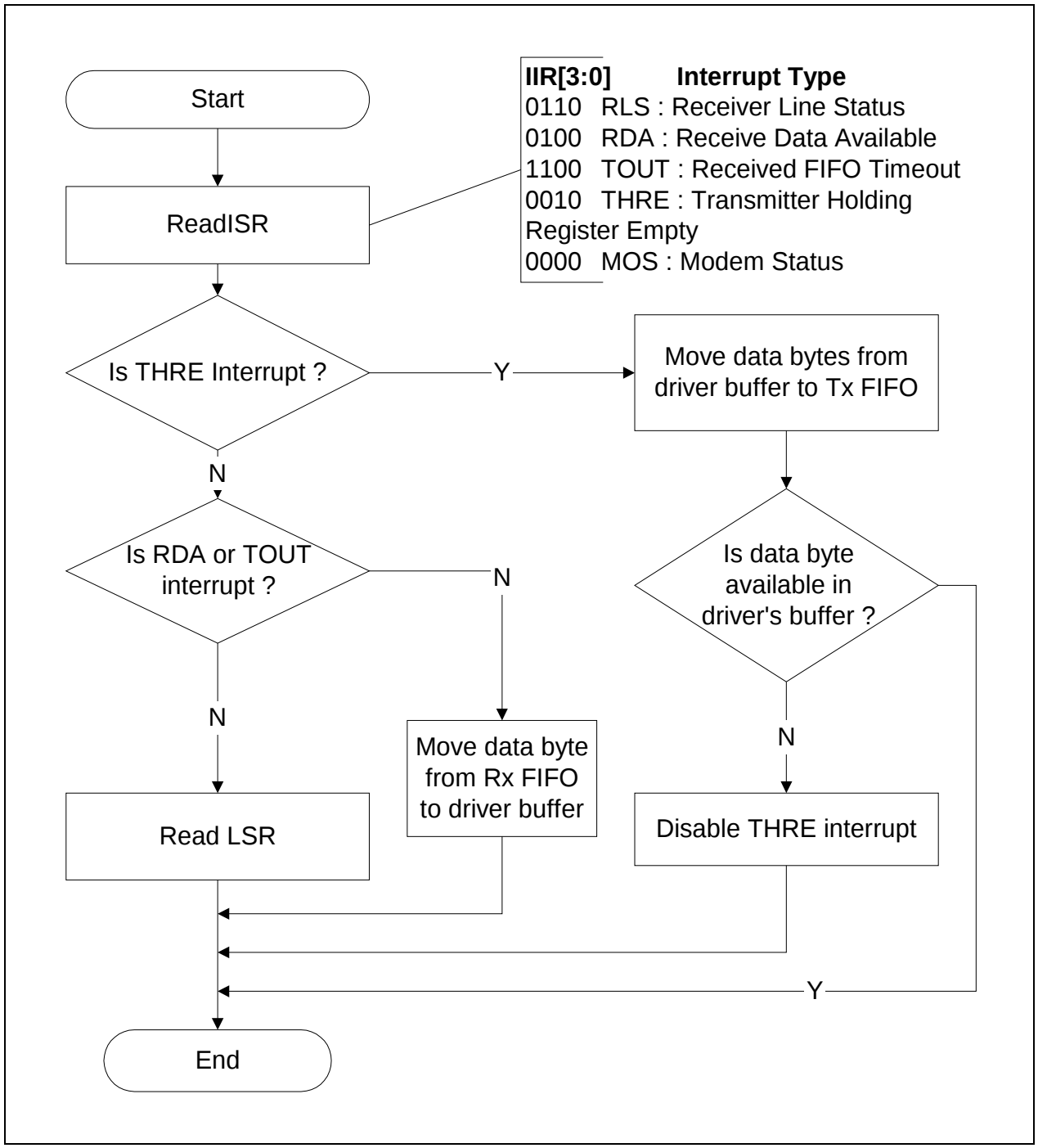
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Figure 9-32 Input functions in interrupt mode



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Figure 9-33 Interrupt Service Routine



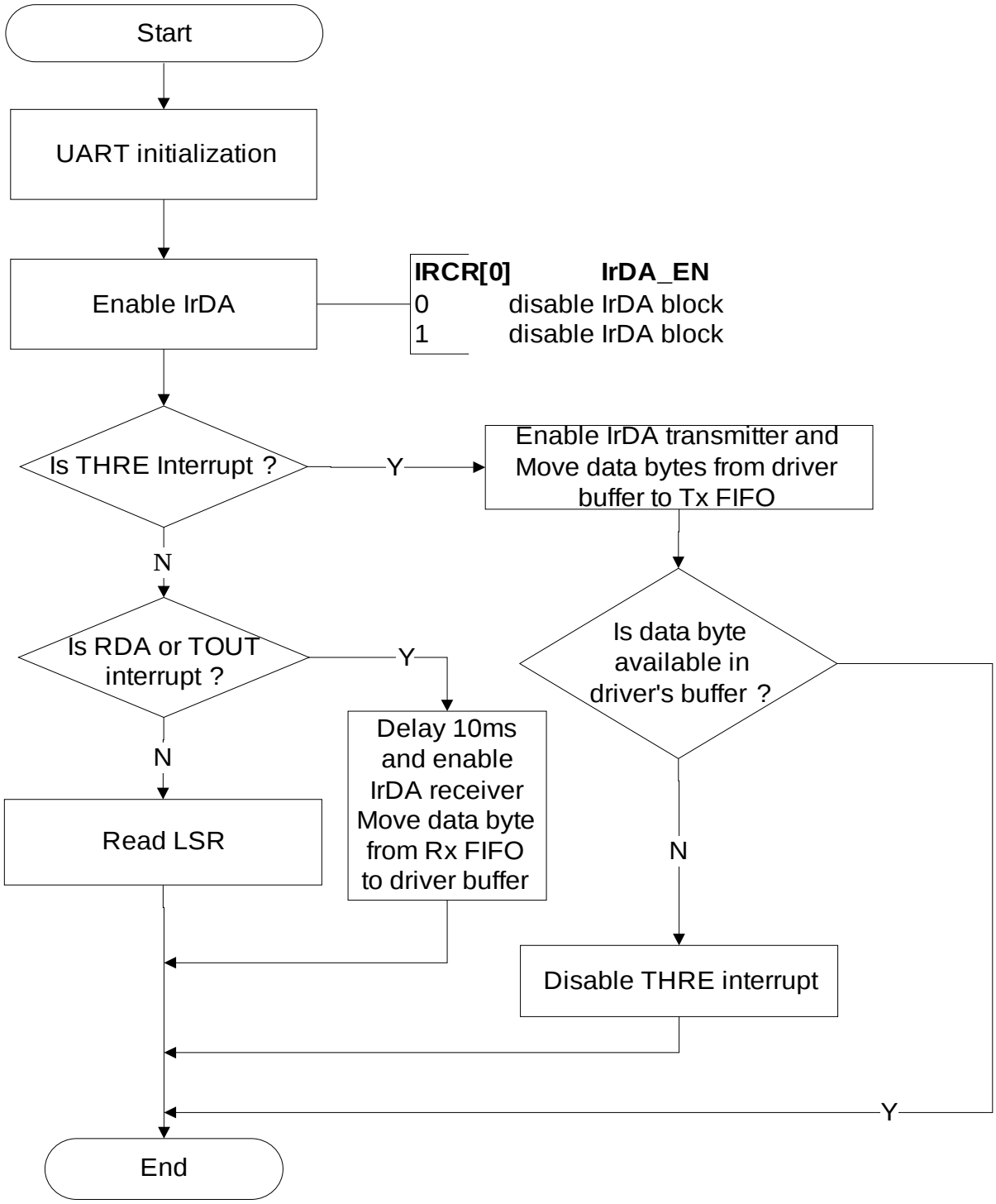
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9.3.5 IrDA SIR

The IrDA SIR block contains an IrDA SIR protocol encoder/decoder. The IrDA SIR protocol is half-duplex only. So it cannot transmit while receiving, and vice versa. The IrDA SIR physical layer specifies a minimum 10ms transfer delay between transmission and reception. This feature should be implemented by software.

Figure 9-34 IrDA Tx/Rx

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10 Timers

10.1 Overview

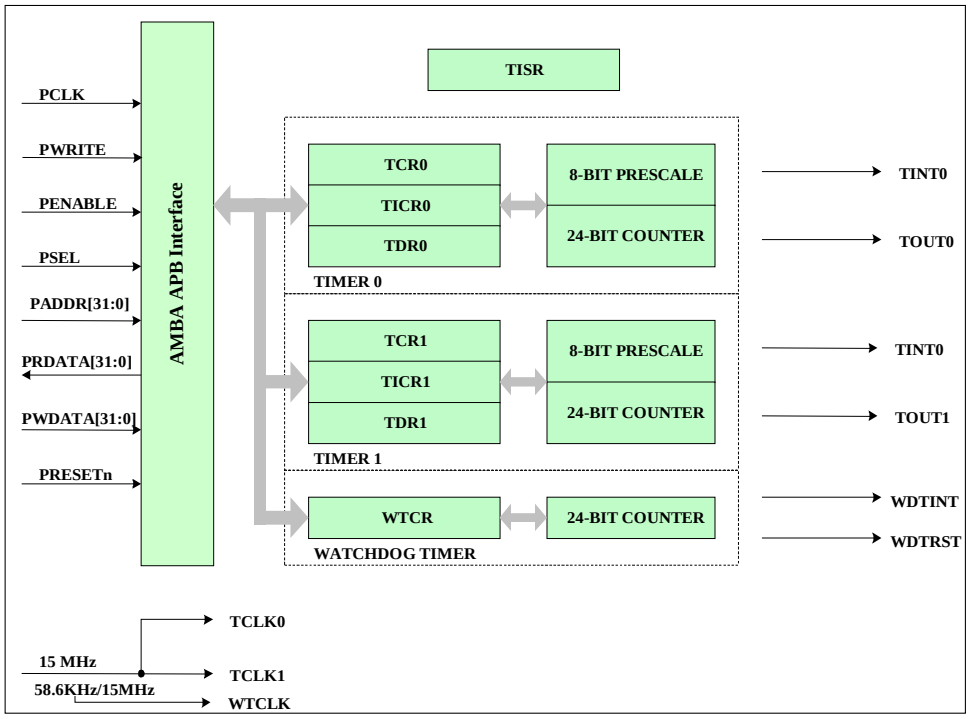
The NUC745 Timer module includes two channels, TIMER0 and TIMER1, which allow user to easily implement a counting scheme. Each channel has independent clock source. The input clock is divided by an 8-bit pre-scalar and then referenced by a 24-bit down counter. When the counter counts down to zero, the Timer will assert an interrupt request if the interrupt is enabled. A general software-counting scheme is to set a software counter, and add 1 to it upon every interrupt.

The Timer module also includes a watchdog timer. It supports the system restart if the system goes into problem. This prevents system from hanging for an infinite period of time. The watchdog timer is a free running counter with programmable time-out intervals. When the specified time internal interval expires, it asserts an interrupt to inform software to reset the counter. If the counter doesn't be reset during 512 WDT clocks, the watchdog timer will generate a system restart signals to reset the whole system. Normally, the program should implement a task to periodically reset the counter if the watchdog timer is enabled.

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10.2 Block Diagram

Figure 10-35 Timer Block Diagram



10.3 Registers

R : read only, **W** : write only, **R/W** : both read and write, **C** : Only value 0 can be written

Register	Address	R/W/C	Description	Reset Value
TCR0	0xFFF8.1000	R/W	Timer Control Register 0	0x0000.0005
TCR1	0xFFF8.1004	R/W	Timer Control Register 1	0x0000.0005
TICR0	0xFFF8.1008	R/W	Timer Initial Control Register 0	0x0000.0000
TICR1	0xFFF8.100C	R/W	Timer Initial Control Register 1	0x0000.0000
TDR0	0xFFF8.1010	R	Timer Data Register 0	0x0000.0000
TDR1	0xFFF8.1014	R	Timer Data Register 1	0x0000.0000

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TISR	0xFFF8.1018	R/C	Timer Interrupt Status Register	0x0000.0000
WTCR	0xFFF8.101C	R/W	Watchdog Timer Control Register	0x0000.0000

10.4 Functional Descriptions

10.4.1 Interrupt Frequency

The frequency of timer interrupt depends on the following equation :

Freq. = Crystal clock / ((pre-scaler+1) * counter))

For NUC745, the crystal clock input is 15 MHZ. According to the equation, user can decide the values of pre-scalar and counter to get the desired interrupt frequency. Table 4-1demonstrates several reference values.

Table 10-8 Timer Reference Setting Values

Frequency (1/sec)	[Pre-Scalar]	[Counter]
18	0	0xCB735
40	0	0x5B8D8
100	0	0x249F0

10.4.2 Initialization

The driver should set the operating mode, pre-scalar and counter before enable the timer interrupt. The Timer supports *one-shot*, *periodic* and *toggle* mode for user to implement the counting scheme.

- In *one-shot* mode, the interrupt signal is generated once and it's not happen again unless the timer is re-enabled later.

- In *periodic* mode, the interrupt signal is generated periodically.

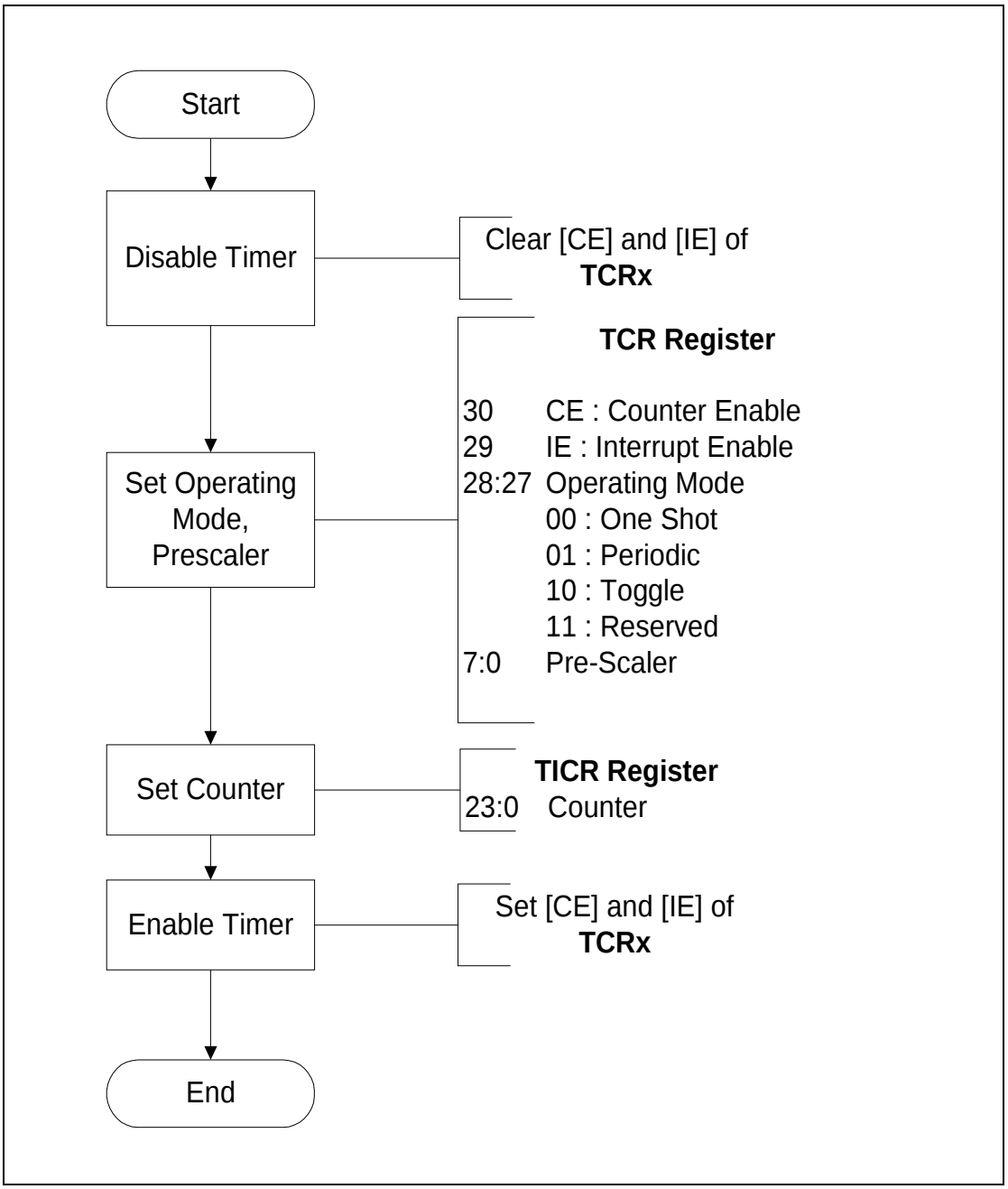
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- In *toggle* mode, the interrupt signal is generated on each low-to-high or high-to-low transition with 50% duty cycle.

Figure 12-2 shows the initialization sequence.

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Figure 10-36 Timer Initialization Sequence

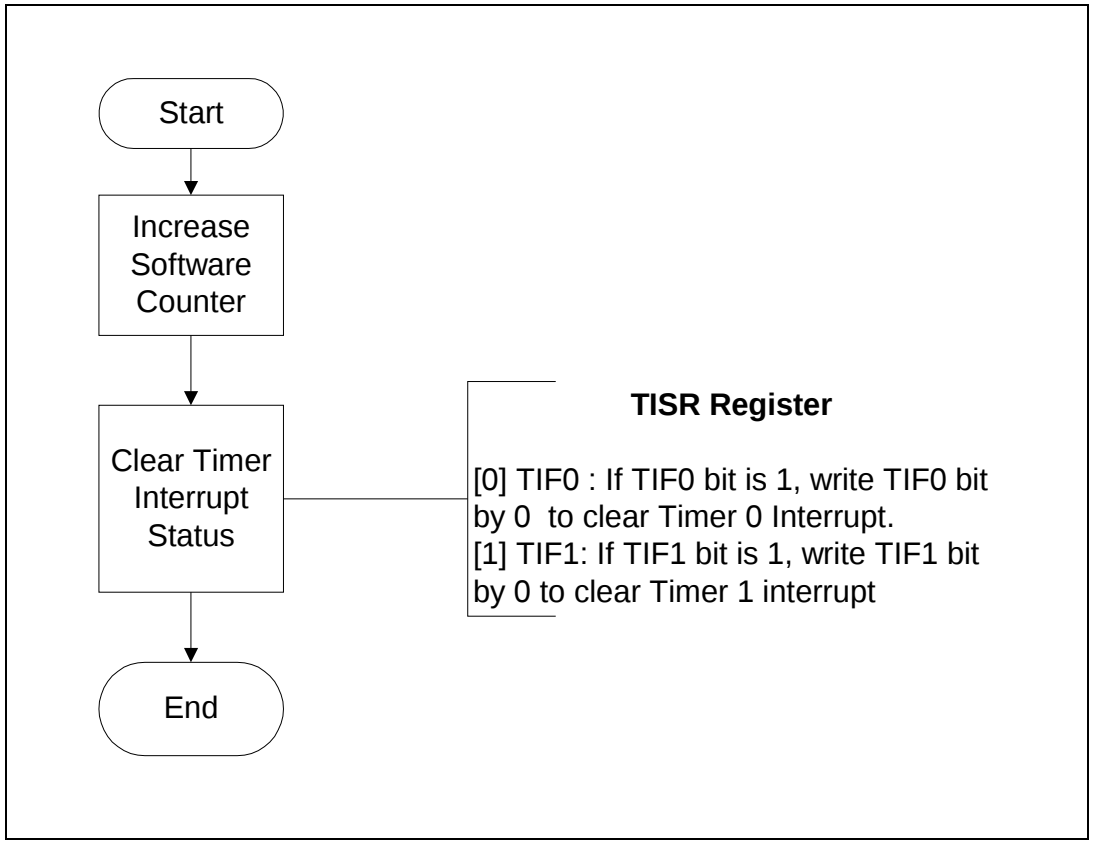


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10.4.3Timer Interrupt Service Routine

A common timer interrupt service routine is very simple. It increases the software counter and clears the timer interrupt status. Figure 12-3 shows the flow chart of such an interrupt service routine.

Figure 10-37 Timer Interrupt Service Routine



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10.4.4Watchdog Timer

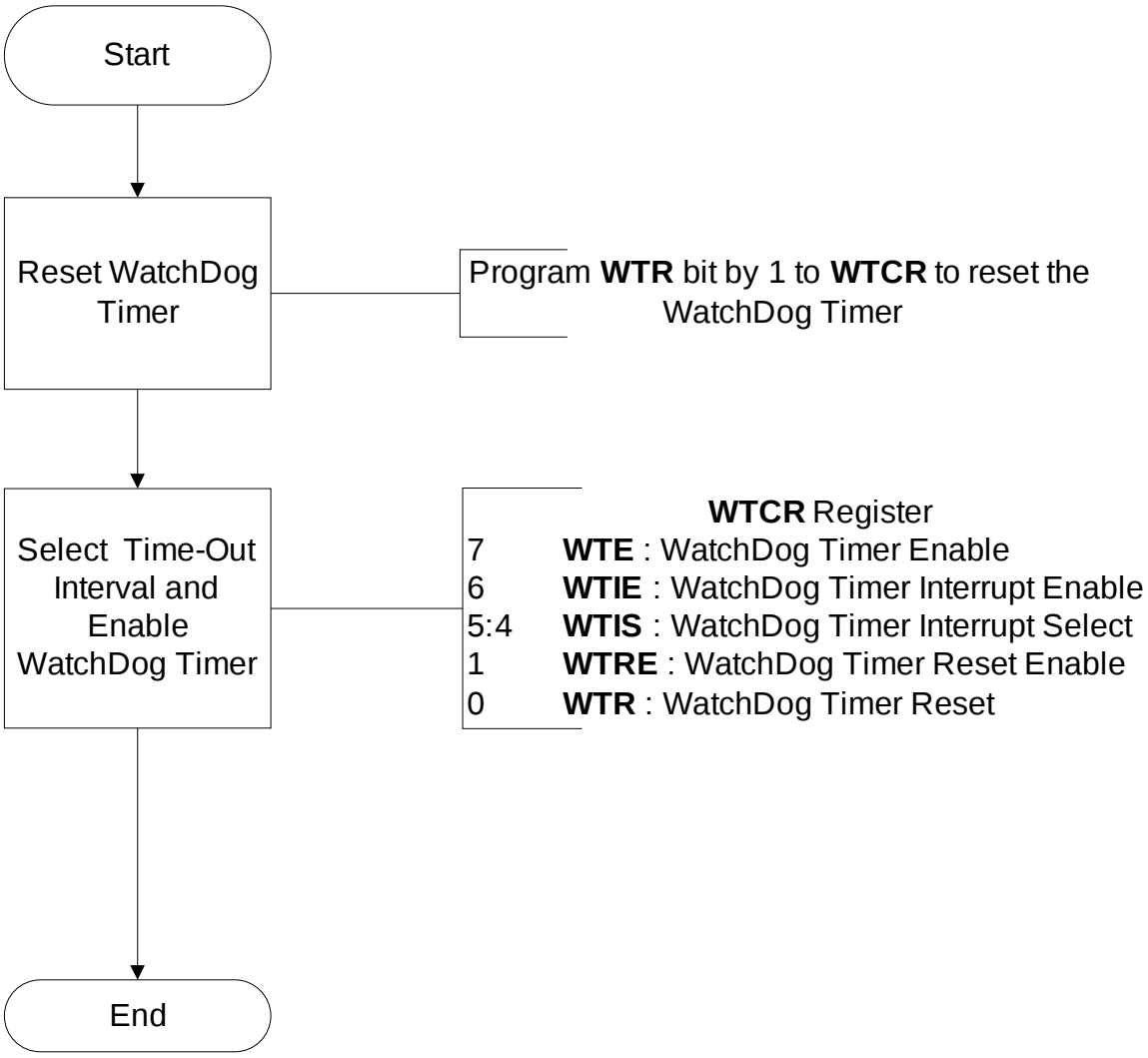
The register **WTCR** is used to control watchdog timer. The bit *WTR* should be set before enable watchdog timer. It ensures that the watchdog timer restarts from a known state. Figure 12-4 and Figure 12-5 illustrate how to use watchdog timer. Table 12-2 list the WatchDog Timeout period.

Table 10-2 WatchDog Timer Reset Time (Using 15MHz crystal)

WTIS[5:4]	Interrupt Time-out	Reset Time-out	Actual time *WTCLK* = 1	Actual time *WTCLK* = 0
00	2^{14} clocks	2^{14} + 1024 clocks	0.28 sec	1.1 msec
01	2^{16} clocks	2^{16} + 1024 clocks	1.12 sec	4.3 msec
10	2^{18} clocks	2^{18} + 1024 clocks	4.47 sec	17 msec
11	2^{20} clocks	2^{20} + 1024 clocks	17.9 sec	70 msec

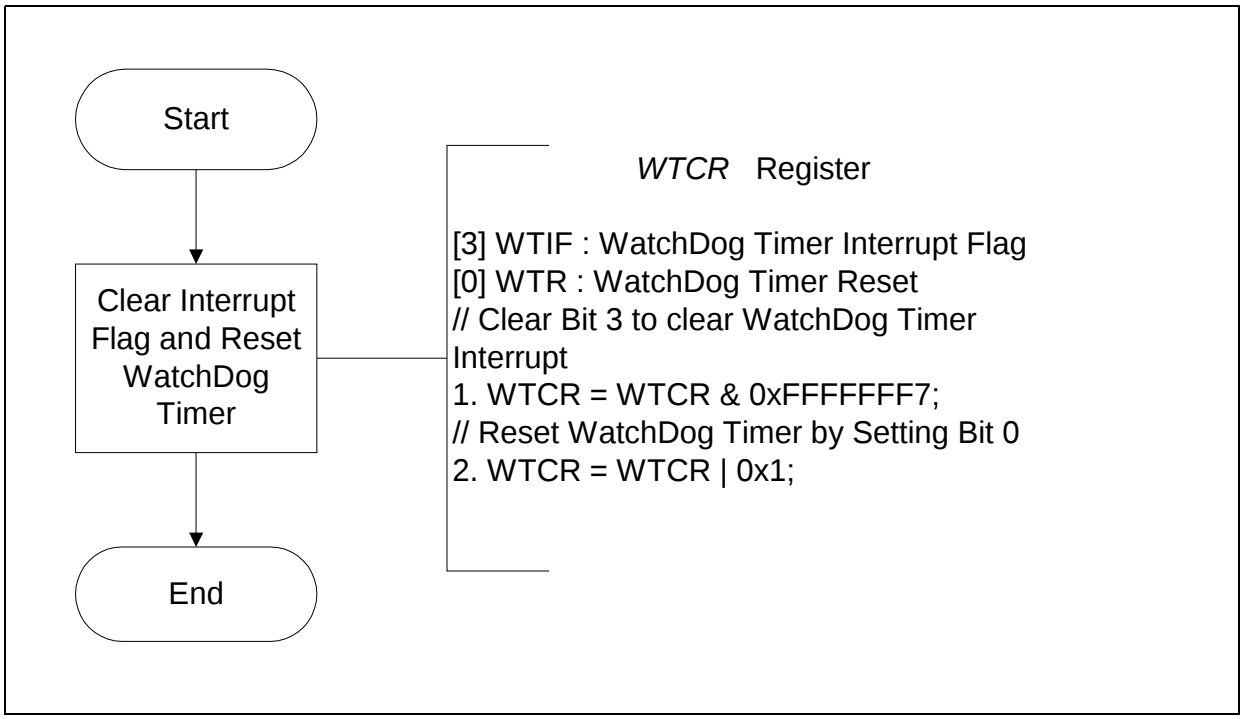
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Figure 10-38 Enable Watchdog Timer



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Figure 10-39 Watchdog Timer ISR



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11 AIC (Advanced Interrupt Controller)

11.1 Overview

The NUC745 incorporates the **advanced interrupt controller (AIC)** that is capable of dealing with the interrupt requests from 32 different interrupt sources. Currently, 31 interrupt sources are defined. Each interrupt source is uniquely assigned to an *interrupt channel (1 to 31)*. Every interrupt channel can be enabled or disabled individually. A channel is treated as active if its corresponding interrupt source has an interrupt request. Several status registers are used to distinguish the state of these interrupt channels. The AIC will assert an interrupt request to CPU core (ARM7TDMI) only if there's at least one interrupt channel is active and enabled.

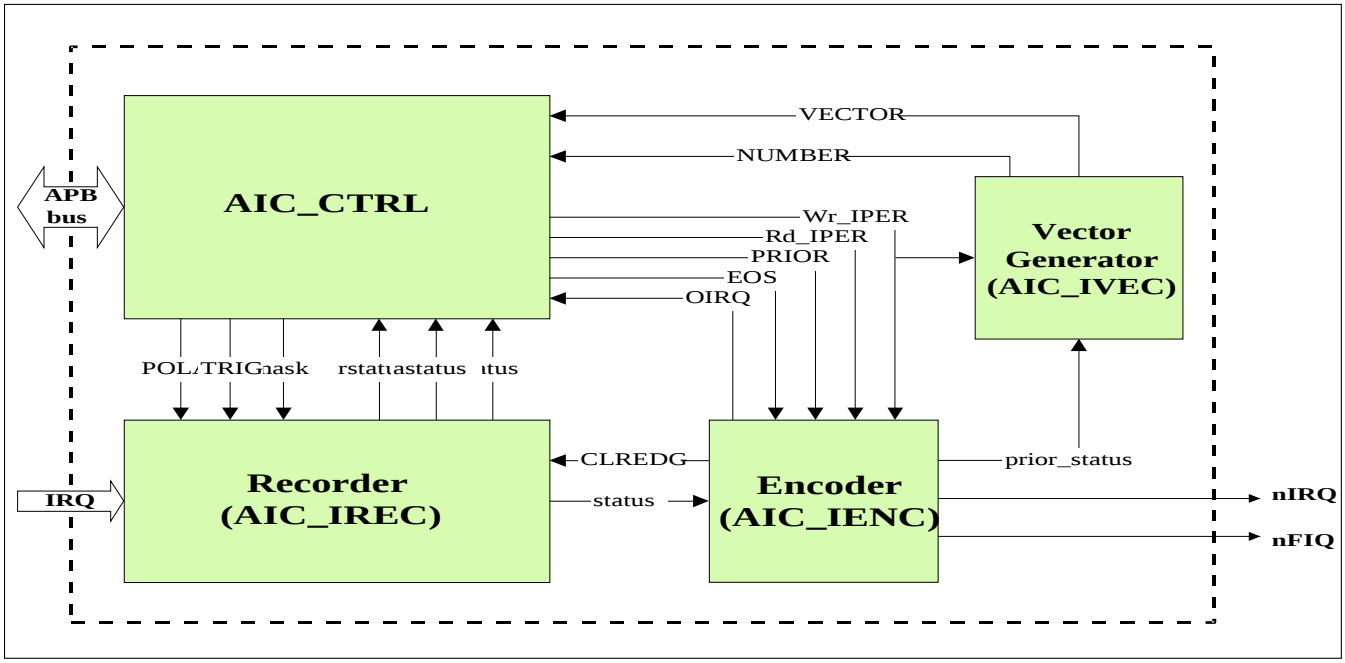
The software driver can implement a priority scheme based on the status register. However, the AIC itself implements a proprietary eight-level priority scheme to improve the interrupt dispatch time. It differentiates the available 31 interrupt sources into eight priority levels, level 0 is the highest one and the level 7 is the lowest. Within each priority level, a lower channel number interrupt source has a higher priority. The AIC will assert the FIQ request if the active and enabled interrupt channel is assigned to priority level 0. For the interrupt channels that are assigned to other priority level, AIC will assert an IRQ request. The IRQ can be preempted by the occurrence of the FIQ. Interrupt nesting is performed automatically by the AIC.

Although the internal interrupt sources of NUC745 are intrinsically high-level sensitive, the driver can configure each interrupt source to be either low-level sensitive, high-level sensitive, negative-edge triggered, or positive-edge triggered.

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11.2 Block Diagram

Figure 11-40 AIC block diagram



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11.3 Registers

R : read only, **W** : write only, **R/W** : both read and write, **C** : Only value 0 can be written

Table 11-9 AIC Register Definition

Register	Address	R/W	Description	Reset Value
AIC_SCR1	0xFFF8.2004	R/W	Source Control Register 1	0x0000.0047
AIC_SCR2	0xFFF8.2008	R/W	Source Control Register 2	0x0000.0047
AIC_SCR3	0xFFF8.200C	R/W	Source Control Register 3	0x0000.0047
AIC_SCR4	0xFFF8.2010	R/W	Source Control Register 4	0x0000.0047
AIC_SCR5	0xFFF8.2014	R/W	Source Control Register 5	0x0000.0047
AIC_SCR6	0xFFF8.2018	R/W	Source Control Register 6	0x0000.0047
AIC_SCR7	0xFFF8.201C	R/W	Source Control Register 7	0x0000.0047
AIC_SCR8	0xFFF8.2020	R/W	Source Control Register 8	0x0000.0047
AIC_SCR9	0xFFF8.2024	R/W	Source Control Register 9	0x0000.0047
AIC_SCR10	0xFFF8.2028	R/W	Source Control Register 10	0x0000.0047
AIC_SCR11	0xFFF8.202C	R/W	Source Control Register 11	0x0000.0047
AIC_SCR12	0xFFF8.2030	R/W	Source Control Register 12	0x0000.0047
AIC_SCR13	0xFFF8.2034	R/W	Source Control Register 13	0x0000.0047
AIC_SCR14	0xFFF8.2038	R/W	Source Control Register 14	0x0000.0047
AIC_SCR15	0xFFF8.203C	R/W	Source Control Register 15	0x0000.0047
AIC_SCR16	0xFFF8.2040	R/W	Source Control Register 16	0x0000.0047
AIC_SCR17	0xFFF8.2044	R/W	Source Control Register 17	0x0000.0047
AIC_SCR18	0xFFF8.2048	R/W	Source Control Register 18	0x0000.0047
AIC_SCR19	0xFFF8.204C	R/W	Source Control Register 19	0x0000.0047
AIC_SCR20	0xFFF8.2050	R/W	Source Control Register 20	0x0000.0047
AIC_SCR21	0xFFF8.2054	R/W	Source Control Register 21	0x0000.0047
AIC_SCR22	0xFFF8.2058	R/W	Source Control Register 22	0x0000.0047
AIC_SCR23	0xFFF8.205C	R/W	Source Control Register 23	0x0000.0047
AIC_SCR24	0xFFF8.2060	R/W	Source Control Register 24	0x0000.0047
AIC_SCR25	0xFFF8.2064	R/W	Source Control Register 25	0x0000.0047
AIC_SCR26	0xFFF8.2068	R/W	Source Control Register 26	0x0000.0047
AIC_SCR27	0xFFF8.206C	R/W	Source Control Register 27	0x0000.0047
AIC_SCR28	0xFFF8.2070	R/W	Source Control Register 28	0x0000.0047
AIC_SCR29	0xFFF8.2074	R/W	Source Control Register 29	0x0000.0047

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AIC_SCR30	0xFFF8.2078	R/W	Source Control Register 30	0x0000.0047
AIC_SCR31	0xFFF8.207C	R/W	Source Control Register 31	0x0000.0047
AIC_IRSR	0xFFF8.2100	R	Interrupt Raw Status Register	0x0000.0000
AIC_IASR	0xFFF8.2104	R	Interrupt Active Status Register	0x0000.0000
AIC_ISR	0xFFF8.2108	R	Interrupt Status Register	0x0000.0000
AIC_IPER	0xFFF8.210C	R	Interrupt Priority Encoding Register	0x0000.0000
AIC_ISNR	0xFFF8.2110	R	Interrupt Source Number Register	0x0000.0000
AIC_IMR	0xFFF8.2114	R	Interrupt Mask Register	0x0000.0000
AIC_OISR	0xFFF8.2118	R	Output Interrupt Status Register	0x0000.0000
AIC_MECR	0xFFF8.2120	W	Mask Enable Command Register	Undefined
AIC_MDCR	0xFFF8.2124	W	Mask Disable Command Register	Undefined
AIC_SSCR	0xFFF8.2128	W	Source Set Command Register	Undefined
AIC_SCCR	0xFFF8.212C	W	Source Clear Command Register	Undefined
AIC_EOSCR	0xFFF8.2130	W	End of Service Command Register	Undefined
AIC_TEST	0xFFF8.2200	W	ICE/Debug mode Register	Undefined

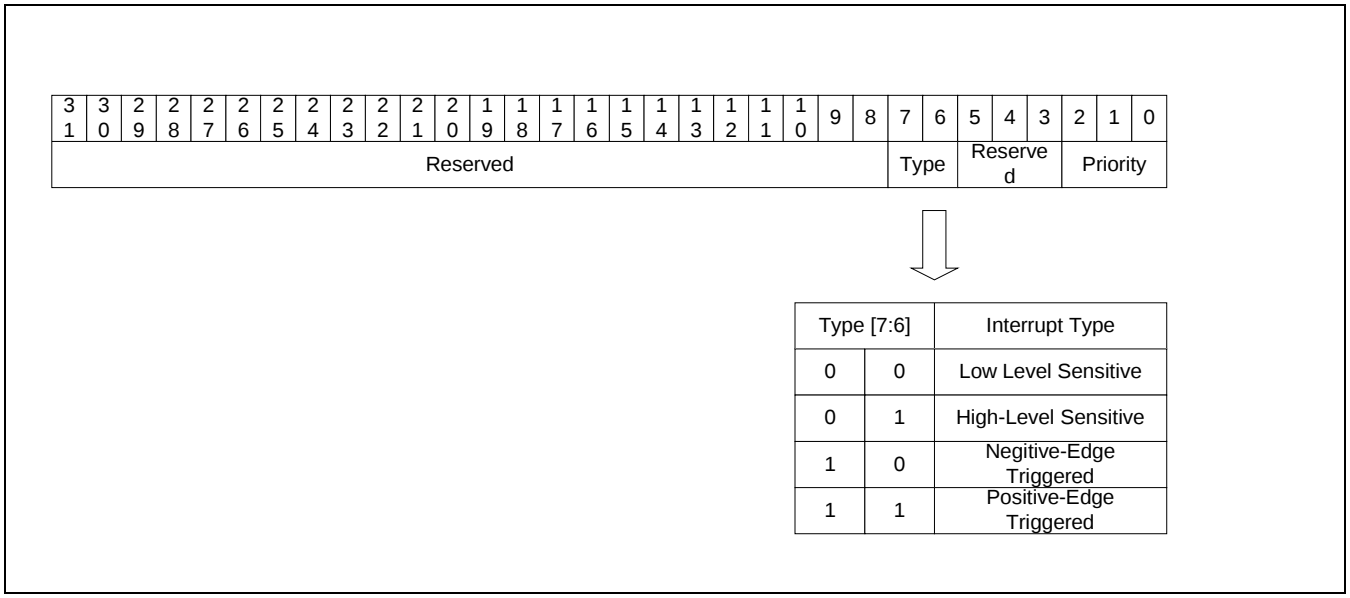
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11.4 Functional Descriptions

11.4.1 Interrupt channel configuration

Each interrupt channel has an independent source control register to set its type and priority. The interrupt type of all NUC745 internal peripherals is positive-level triggered. This shouldn't be changed during normal operation. For the channel 2, 3, 4 and 5, the device driver must set the pertinent interrupt type according to the external devices. The priority level of each interrupt channel is completely decided by the interrupted device. After power-on or reset, all the channels are assigned to priority level 0 7 by AIC. Figure 13-2 shows the content of source control register.

Figure 11-41 Source Control Register



Type [7:6]		Interrupt Type
0	0	Low Level Sensitive
0	1	High-Level Sensitive
1	0	Negitive-Edge Triggered
1	1	Positive-Edge Triggered

11.4.2 Interrupt Masking

The NUC745 AIC provides a set of registers to mask individual interrupt channel. The **Mask Enable Command Register (AIC_MECR)** is used to enable interrupt. Write 1 to a bit of MECR will enable the corresponding interrupt channel. Oppositely, the **Mask Disable Command Register**

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(AIC_MDCR) is used to disable the interrupt. Write 1 to a bit of MDCR will disable the corresponding interrupt channel. Write 0 to a bit of AIC_MECR or AIC_MDCR has no effect. Therefore, the device driver can arbitrarily change these two registers without keeping their original values. If it's necessary, the device driver can read the **Interrupt Mask Register (AIC_IMR)** to know whether the interrupt channel is enabled or disabled. If the interrupt channel is enabled, its corresponding bit is read as 1, otherwise 0.

11.4.3Interrupt Clearing and Setting

For the interrupt channels that are level sensitive, the device driver doesn't need to write the **Source Clear Command Register (AIC_SCCR)** or **End of Service Command Register (AIC_EOSCR) to** clear any AIC status. As soon as the device's interrupt status has been was cleared, the AIC de-asserts the interrupt request. For the interrupt channels that are edge-triggered, the device driver must clear AIC status to de-assert the interrupt request. To clear AIC status, the device driver may either write **Source Clear Command Register (AIC_SCCR)** or **End of Service Command Register (AIC_EOSCR)**. Write 1 to a bit of AIC_SCCR will clear the corresponding interrupt. The usage of AIC_EOSCR will be discussed in the section *Hardware Priority Scheme*.

The register **Source Set Command Register (AIC_SSCR)** is used to active an interrupt channel when it is programmed to edge-triggered. Write 1 to a bit of AIC_SSCR will set the corresponding interrupt. This feature is useful in auto-testing or software debugging.

11.4.4Software Priority Scheme

The AIC provides an **Interrupt Status Register (AIC_ISR)** to identify the interrupt sources. If an interrupt channel is both active and enabled, its corresponding bit in AIC_ISR is set as 1. The interrupt handler of FIQ or IRQ can get the interrupt sources by reading AIC_ISR. And the service sequence is completely decided by software algorithm.

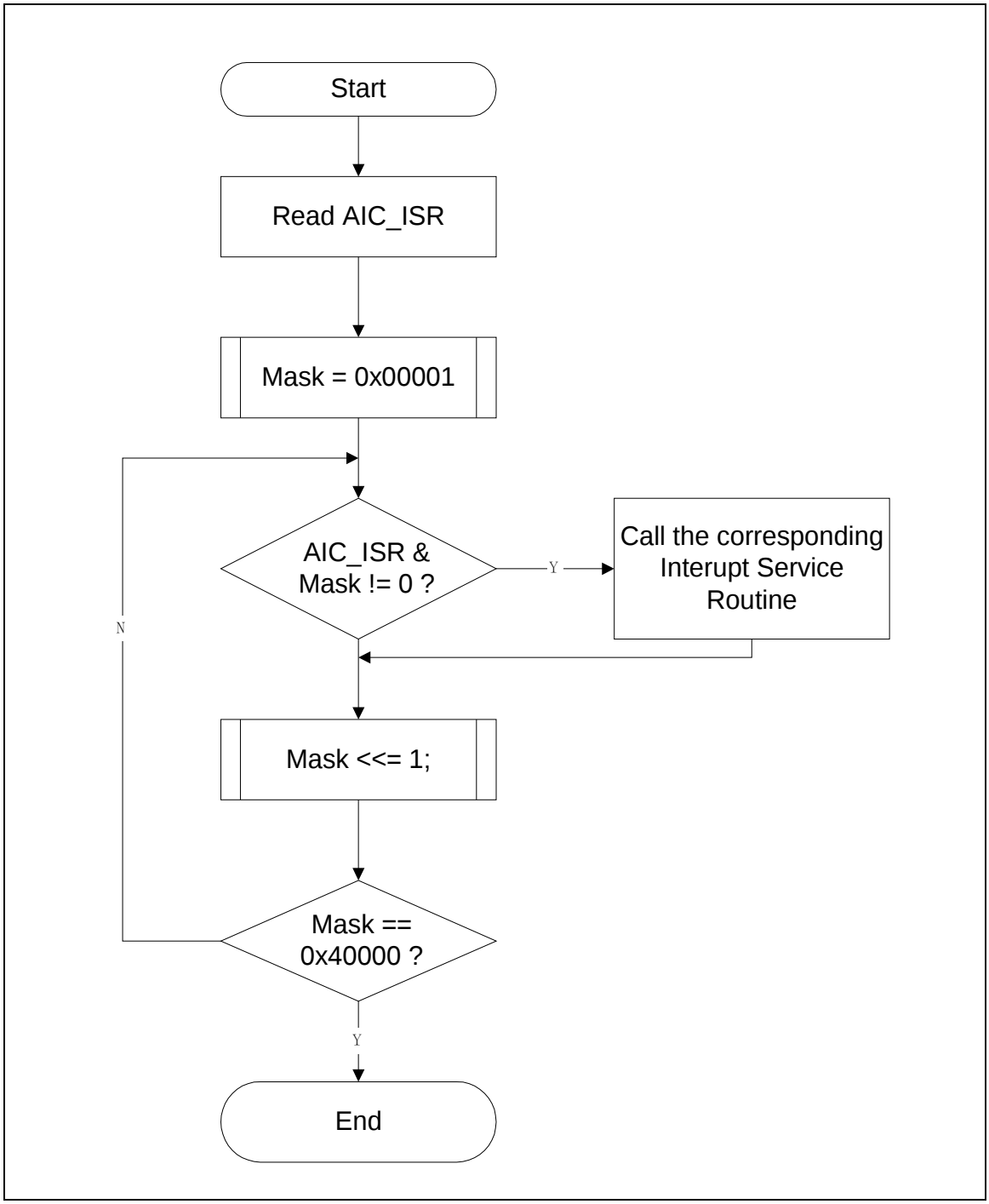
Generally, there's a function table to keep the interrupt service routines of internal peripherals and external devices. When the interrupt is recognized by CPU core, the FIQ or IRQ exception handler is executed firstly. Then it will call the proper interrupt service routine according to the AIC_ISR content.

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Figure 13-3 demonstrates a sequential priority scheme where channel 1 has the highest priority and channel 17 18 has the lowest priority.

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Figure 11-42 Sequential Priority Scheme



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11.4.5Hardware Priority Scheme

The AIC implements a proprietary 8-level priority scheme. To use this mechanism, the proper AIC_SCRx should be programmed before enable the interrupt channels. Similarly, the FIQ or IRQ exception handler is executed firstly when the interrupt is recognized. The exception handler and interrupt service routine should follow certain rules to let this mechanism work correctly. The rules are listed below.

1. Reads IRQ Priority Encoding Register (AIC_IPER) to get the Vector (IRQ Channel x 4), and at this mean time, the AIC_ISNR will be loaded by the current interrupt channel number, the Vector (IRQ Channel Number x 4) represents the interrupt channel number that is active, enabled, and has the highest priority, multiplied by 4, then stored on the AIC_IPER. The data (Vector) got from AIC_IPER is convenient for the following interrupt service route address calculation. enabled, and has the highest priority.

2. Branch to the corresponding interrupt service routine by adding Vector to the base of interrupt service routine table.

3. Write any value to AIC_EOSCR to finish the interrupt.

The priority level of the interrupt channel that is active and enabled is treated as **current priority level**. It is pushed into the **Priority Encoder** when AIC_IPER is read. In the same time, the AIC_ISNR was loaded by the current encoded interrupt channel number. This prevents AIC from asserting an interrupt request if the following active and enabled interrupt has lower priority level. Therefore, the interrupt service routine must write AIC_EOSCR to pop the current priority level from priority Encoder to let AIC service the interrupt channel with lower priority. This hardware priority control is helpful to implement a nesting interrupt system.

In contrast with the software priority scheme, the Vector provides a quicker method to reach the interrupt service routine. The branch address can be easily got that adds Vector to the base of interrupt service routine table. Figure 13-4 shows an example assembly code.

Figure 11-43 Interrupt Service Routine with Vector

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```
STMFD   SP!, {R0-R2}             ; Push registers on stack

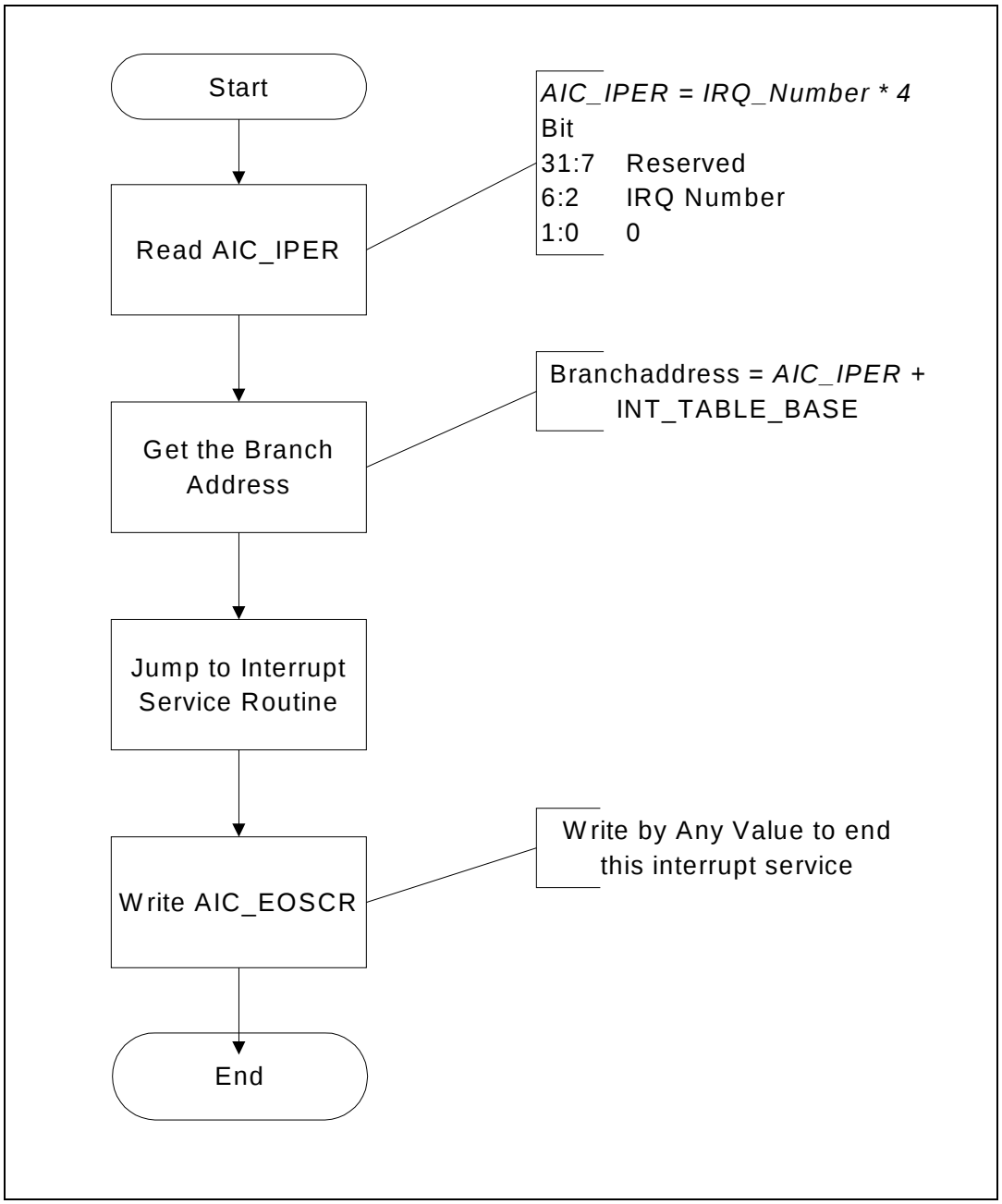
;Goto_Handler, jump to the correct handler
LDR     R2, =AICBase
LDR     R1, [R2,#AIC_IPER]       ; gets the highest pending
vector
LDR     PC, [PC, R1]             ; jump to correct handler
NOP

;table of handler start address
DCD     Fake_Interrupt
DCD     Int1_Interrupt
DCD     Int2_Interrupt
DCD     Int3_Interrupt
DCD     Int4_Interrupt
DCD     Int5_Interrupt
DCD     Int6_Interrupt
DCD     Int7_Interrupt
DCD     Int8_Interrupt
DCD     Int9_Interrupt
DCD     Int10_Interrupt
DCD     Int11_Interrupt
DCD     Int12_Interrupt
DCD     Int13_Interrupt
DCD     Int14_Interrupt
DCD     Int15_Interrupt
DCD     Int16_Interrupt
DCD     Int17_Interrupt
DCD     Int18_Interrupt
DCD     Int19_Interrupt
DCD     Int20_Interrupt
DCD     Int21_Interrupt
DCD     Int22_Interrupt
DCD     Int23_Interrupt
DCD     Int24_Interrupt
DCD     Int25_Interrupt
DCD     Int26_Interrupt
DCD     Int27_Interrupt
DCD     Int28_Interrupt
DCD     Int29_Interrupt
DCD     Int30_Interrupt
DCD     Int31_Interrupt
```

It is very important that ISR must write AIC_EOSCR to restore to normal interrupt state once it read the AIC_IPER. Otherwise, the next interrupt may not be serviced correctly Figure 13-5 shows the programming flow of using hardware priority scheme.

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Figure 11-44 Using hardware priority scheme



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12 General-Purpose Input/Output (GPIO)

12.1 Overview

The General-Purpose Input/Output (**GPIO**) module possesses 31 pins and serves multiple function purposes. Each port can be configured by software to meet various system configurations and design requirements. Software must configure each pin before starting the main program. If a pin is not used for multiplexed functions, the pin can be configured as I/O port

Two extended interrupts nIRQ2 (GPIO0 pin) and nIRQ3 (nWAIT pin) are used the same interrupt request (channel #31) of AIC. It can be programmed as low/high sensitive or positive/negative edge triggered. When interrupt #31 assert in AIC, software can poll **XISTATUS** status register to identify which interrupt occur.

These 31 IO pins are divided into 7 groups according to its pheripheral interface definition.

- Port0: 5-pin input/output port
- Port1: 2-pin input/output port
- Port2: 10-pin input/output port
- Port3: Reserved
- Port4: 1-pin input/output port
- Port5: 13-pin input/output port
- Port6: Reserved

Table 14-10 GPIO Multiplexed Functions Table

PORT0	Configurable Pin Functions			
0	GPIO0	AC97_nRESET (I2S_MCLK)	nIRQ2	USBPWREN
1	GPIO1	AC97_DATAI (I2S_DATAI)	PWM0	DTR3
2	GPIO2	AC97_DATAO (I2S_DATAO)	PWM1	DSR3
3	GPIO3	AC97_SYNC (I2S_LRCLK)	PWM2	TXD3
4	GPIO4	AC97_BITCLK (I2S_BITCLK)	PWM3	RXD3

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PORT1	Configuration Pin Functions			
0	GPIO18	-	nXDACK	-
1	GPIO19	-	nXDREQ	-
PORT2	**Configuration Pin Functions**			
0	GPIO20	PHY_RXERR	KPCOL0	-
1	GPIO21	PHY_CRSDV	KPCOL1	-
2	GPIO22	PHY_RXD[0]	KPCOL2	-
3	GPIO23	PHY_RXD[1]	KPCOL3	-
4	GPIO24	PHY_REFCLK	KPCOL4	-
5	GPIO25	PHY_TXEN	KPCOL5	-
6	GPIO26	PHY_TXD[0]	KPCOL6	-
7	GPIO27	PHY_TXD[1]	KPCOL7	-
8	GPIO28	PHY_MDIO	KPROW0	-
9	GPIO29	PHY_MDC	KPROW1	-
PORT3	**Configuration Pin Functions**			
Reserved				
PORT4	**Configuration Pin Functions**			
0	GPIO30	nWAIT	nIRQ2	-
PORT5	**Configuration Pin Functions**			
0	GPIO5	TXD0	-	-
1	GPIO6	RXD0	-	-
2	GPIO7	TXD1	-	-
3	GPIO8	RXD1	-	-
4	GPIO9	TXD2	CTS1	PS2CLK
5	GPIO10	RXD2	RTS1	PS2DATA
6	GPIO11	SCL0	SFRM	TIMER0
7	GPIO12	SDA0	SSPTXD	TIMER1
8	GPIO13	SCL1	SCLK	KPROW3
9	GPIO14	SDA1	SSPRXD	KPROW2
10	GPIO15	nWDOG	USBPWREN	-
11	GPIO16	nIRQ0	-	-
12	GP1O17	nIRQ1	USBOVRCUR	-
PORT6	**Configuration Pin Function**			
Reserved				

12.2 Register Map

Register	Address	R/W	Description	Reset Value
GPIO_CFG0	0xFFF8.3000	R/W	GPIO port0 configuration register	0x0000.0000
GPIO_DIR0	0XFFF8.3004	R/W	GPIO port0 direction control register	0x0000.0000
GPIO_DATAOUT0	0xFFF8.3008	R/W	GPIO port0 data output register	0x0000.0000
GPIO_DATAIN0	0xFFF8.300C	R	GPIO port0 data input register	0xXXXX.XXXX
GPIO_CFG1	0xFFF8.3010	R/W	GPIO port1 configuration register	0x0000.0000
GPIO_DIR1	0XFFF8.3014	R/W	GPIO port1 direction control register	0x0000.0000
GPIO_DATAOUT1	0xFFF8.3018	R/W	GPIO port1 data output register	0x0000.0000
GPIO_DATAIN1	0xFFF8.301C	R	GPIO port1 data input register	0xXXXX.XXXX
GPIO_CFG2	0xFFF8.3020	R/W	GPIO port2 configuration register	0x0000.0000

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GPIO_DIR2	0XFFF8.3024	R/W	GPIO port2 direction control register	0x0000.0000
GPIO_DATAOUT2	0xFFF8.3028	R/W	GPIO port2 data output register	0x0000.0000
GPIO_DATAIN2	0xFFF8.302C	R	GPIO port2 data input register	0x0000.0000
GPIO_CFG4	0xFFF8.3040	R/W	GPIO port4 configuration register	0x0015.5555
GPIO_DIR4	0XFFF8.3044	R/W	GPIO port4 direction control register	0x0000.0000
GPIO_DATAOUT4	0xFFF8.3048	R/W	GPIO port4 data output register	0x0000.0000
GPIO_DATAIN4	0xFFF8.304C	R	GPIO port4 data input register	0xXXXX.XXXX
GPIO_CFG5	0xFFF8.3050	R/W	GPIO port5 configuration register	0x0000.0000
GPIO_DIR5	0XFFF8.3054	R/W	GPIO port5 direction control register	0x0000.0000
GPIO_DATAOUT5	0xFFF8.3058	R/W	GPIO port5 data output register	0x0000.0000
GPIO_DATAIN5	0xFFF8.305C	R	GPIO port5 data input register	0xXXXX.XXXX
GPIO_DBNCECON	0xFFF8.3070	R/W	GPIO input debounce control register	0x0000.0000
GPIO_XICFG	0xFFF8.3074	R/W	Extend Interrupt Configure Regitser	0xXXXX.XXX0
GPIO_XISTATUS	0xFFF8.3078	R/W	Extend Interrupt Status Register	0xXXXX.XXX0

12.3 Functional Description

12.3.1 Multiple Functin Setting

The GPIO input/output and multiple function are configured by setting the GPIO_CFGn register. The GPIO_CFGn register setting sequence is described as follows.

1. Read **GPIO_CFGn** to a variable.
2. Clean the corresponding field, *PTxCFGy*(two bit) of the GPIO pin in the variable.
3. Set the corresponding field, *PTxCFGy* of the GPIO pin in the variable.
4. Write the variable to **GPIO_CFGn**

Note: the x:port number, and y:pin number, for example PT0CFG1 as the pin 1 in port 0.

Programmer should not change the value of whole register except the corresponding field of the register. A Sample code configure GPIO PORT0 pin1 as PWM output is given below:

```
int GPIO_CFG=0;
GPIO_CFG=inpw(0xFFF83000);// Get GPIO_CFG0 value
GPIO_CFG=GPIO_CFG&0xFF3;// Clean PT0CFG1
GPIO_CFG=GPIO_CFG|(0x2<<2); // Set PT0CFG1 as PWM0
outpw(xFFF83000,GPIO_CFG);// Write value to GPIO_CFG0
```

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12.3.2GPIO Output Mode

Before the system use the GPIO pin as output pin, program need to configure the GPIO direction register(GPIO_DIRn). The configuration sequence is described as follows.

1. Set **GPIO_CFGn** *PTxCFGy* as GPIO purpose according to the adove method of Multiple function setting
2. Set the **GPIO_DIRn** *OMDENx[y]* value as 1 (output mode).
3. Set the **GPIO_DIRn** *PUPENx[y]* value(internal pull-up enable or disable).

After the above steps, user can change the GPIO pin output value(high or low) by write 1 or 0 to GPIO data output register(GPIO_DATAOUTn). Programmer should not change the value of whole register except the corresponding field of the register.

A sample code set GPIO PORT0 pin1 as GPIO output, then change the output between high and low is given below:

```
int GPIO_CFG=0;
// Set GPIO1 as I/O pin
GPIO_CFG=inpw(0xFFF83000);// Get GPIO_CFG0 value
GPIO_CFG=GPIO_CFG&0xFF3; // Set PT0CFG1, GPIO1 as I/O pin
outpw(xFFF83000,GPIO_CFG);// Write value to GPIO_CFG0

// Set GPIO1 as output mode, disable internal pull-up
GPIO_CFG=inpw(0xFFF83004);// Get GPIO_DIR0 value
GPIO_CFG=GPIO_CFG|(1<<17);// GPIO1 output mode
GPIO_CFG=GPIO_CFG&(0<<1) //disable pull-up
outpw(xFFF83004,GPIO_CFG);// Write value to GPIO_DIR0

// set GPIO1 output 1
GPIO_CFG=inpw(0xFFF83008);// Get GPIO_DATAOUT0 value
GPIO_CFG=GPIO_CFG|(1<<1);// GPIO1 output 1
outpw(xFFF83008,GPIO_CFG);// Write value to GPIO_DATAOUT0

// set GPIO1 output 0
GPIO_CFG=inpw(0xFFF83008);// Get GPIO_DATAOUT0 value
```

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```
    GPIO_CFG=GPIO_CFG&(0<<1);// GPIO1 output 0
    outpw(xFFF83008,GPIO_CFG);// Write value to GPIO_DATAOUT0
```

12.3.3GPIO Input Mode

Before the system use the GPIO pin as input pin, program need to configure the GPIO direction register(GPIO_DIRn). The configuration sequence is described as follows.

1. Set **GPIO_CFGn** *PTxCFGy* as GPIO purpose according to the adove method of Multiple function setting
2. Set the **GPIO_DIRn** *OMDENx[y]* value as 0 (input mode).

After the above steps, user can get the GPIO pin input value(high or low) by read the GPIO data input register(GPIO_DATAINn).

A sample code set GPIO PORT0 pin1 as GPIO input, then get the input value is given below:

```
    int GPIO_CFG=0;
    int value=0;
    // Set GPIO1 as I/O pin
    GPIO_CFG=inpw(0xFFF83000);// Get GPIO_CFG0 value
    GPIO_CFG=GPIO_CFG&0xFF3; // Set PT0CFG1, GPIO1 as I/O pin
    outpw(xFFF83000,GPIO_CFG);// Write value to GPIO_CFG0

    // Set GPIO1 as input mode
    GPIO_CFG=inpw(0xFFF83004);// Get GPIO_DIR0 value
    GPIO_CFG=GPIO_CFG&(0<<17);// GPIO1 input mode
    outpw(xFFF83004,GPIO_CFG);// Write value to GPIO_DIR0

    // get GPIO1 input value
    value =inpw(0xFFF8300C)&0x02;
    if(value)
      printf("GPIO pin1 input value is 1.");
    else
      printf("GPIO pin1 input value is 0.");
```

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13 I²C Synchronous Serial Interface Controller

13.1 Overview

The NUC745 **I²C** includes two channels, I2C_0 and I2C_1, which is a two-wire, bi-directional serial bus that provides a simple and efficient method of data exchange between devices. The I²C standard is a true multi-master bus including collision detection and arbitration that prevents data corruption if two or more masters attempt to control the bus simultaneously.

8-bit oriented bi-directional serial data can transfers up to 100 kbit/s in Standard-mode, up to 400 kbit/s in the Fast-mode, or up to 3.4 Mbit/s in the High-speed mode. Only 100kbps and 400kbps modes are supported directly. For High-speed mode special IOs are needed. If these IOs are available and used, then High-speed mode is also supported.

Data is transferred between a Master and a Slave synchronously to SCL on the SDA line on a **byte-by-byte** basis. Each data byte is 8 bits long. There is one SCL clock pulse for each data bit with the **MSB being transmitted first**. An acknowledge bit follows each transferred byte. Each bit is sampled during the high period of SCL; therefore, the SDA line may be changed only during the low period of SCL and must be held stable during the high period of SCL. A transition on the SDA line while SCL is high is interpreted as a command (START or STOP).

The I²C Master Core includes the following features:
AMBA APB interface compatible

Compatible with Philips I²C standard, support master mode

Multi Master Operation

Clock stretching and wait state generation

Provide multi-byte transmit operation, up to 4 bytes can be transmitted in a single transfer

Software programmable acknowledge bit

Arbitration lost interrupt, with automatic transfer cancellation

Start/Stop/Repeated Start/Acknowledge generation

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Start/Stop/Repeated Start detection

Bus busy detection

Supports 7 bit addressing mode

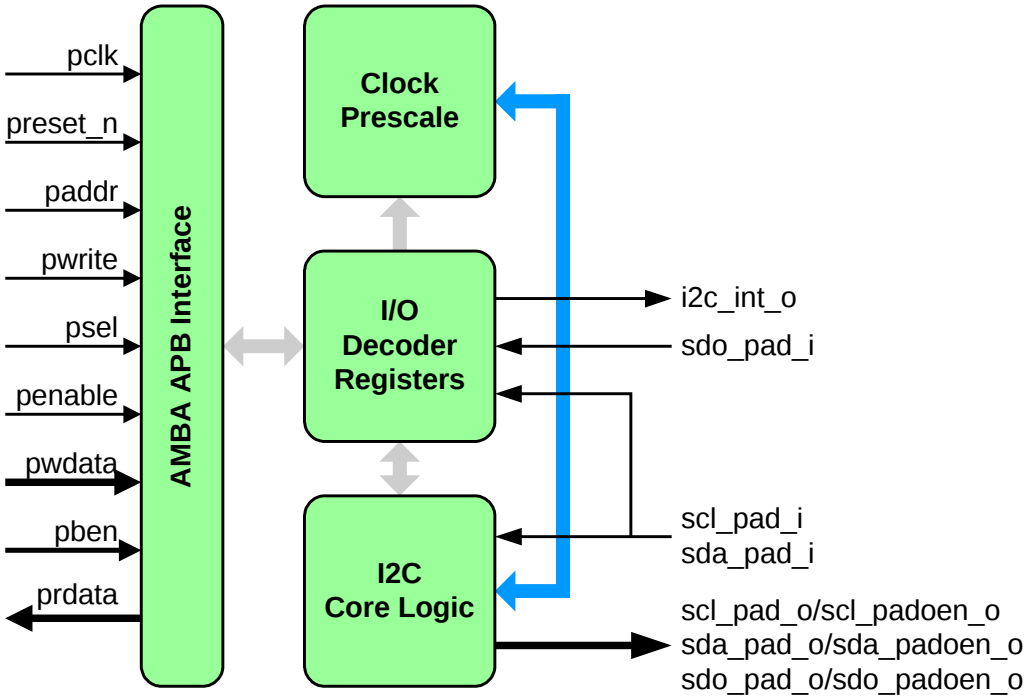
Fully static synchronous design with one clock domain

Software mode I^2C

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13.2 Block Diagram

Figure 13-45 I²C Block Diagram



13.3 Register Map

Register	Address	R/W	Description	Reset value
I2C Interface 0				
I2C_CSR0	0xFFF8.6000	R/W	Control and Status Register	0x0000.0000
I2C_DIVIDER0	0xFFF8.6004	R/W	Clock Prescale Register	0x0000.0000
I2C_CMDR0	0xFFF8.6008	R/W	Command Register	0x0000.0000
I2C_SWR0	0xFFF8.600C	R/W	Software Mode Control Register	0x0000.003F
I2C_RxR0	0xFFF8.6010	R	Data Receive Register	0x0000.0000
I2C_TxR0	0xFFF8.6014	R/W	Data Transmit Register	0x0000.0000
I2C Interface 1				
I2C_CSR1	0xFFF8.6100	R/W	Control and Status Register	0x0000.0000
I2C_DIVIDER1	0xFFF8.6104	R/W	Clock Prescale Register	0x0000.0000
I2C_CMDR1	0xFFF8.6108	R/W	Command Register	0x0000.0000
I2C_SWR1	0xFFF8.610C	R/W	Software Mode Control Register	0x0000.003F
I2C_RxR1	0xFFF8.6110	R	Data Receive Register	0x0000.0000

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I2C_TxR1	0xFFF8.6114	R/W	Data Transmit Register	0x0000.0000

13.4 Functional Description

13.4.1 Prescale Frequency

It is used to prescale the SCL clock line. Due to the structure of the I²C interface, the core uses a 5*SCL clock internally. The prescale register must be programmed to this 5*SCL frequency (minus 1). Change the value of the prescale register only when the *I2C_EN* bit is cleared.

Example: pclk = 32MHz, desired SCL = 100KHz

$$prescale = \frac{32MHz}{5*100KHz} - 1 = 63(dec) = 3F(hex)$$

13.4.2 Start and Stop Signal

The I²C core generates a START signal when the *START* bit in register **CMDR** is set and the *READ* or *WRITE* bits are also set. Depending on the current status of the SCL line, a START or Repeated START is generated.

The I²C core generates a STOP signal when the *STOP* bit in the register **CMDR** is set and the *READ* or *WRITE* bits are also set.

13.4.3 Slave Address Transfer

The core treats a Slave Address Transfer as any other write action. Store the slave device's address in the register **TxR** and set the *WRITE* bit in **CMDR** register. The core will then transfer the slave address on the bus.

13.4.4 Data Transfer

To write data to a slave, store the data to be transmitted in the **TxR** and set the *WRITE* bit in **CMDR**. To read data from a slave, set the *READ* bit in **CMDR**. During a transfer the core set the I2C_TIP flag, indicating that a **Transfer is In Progress**. When the transfer is done the *I2C_TIP* flag in **CSR** is cleared, the *IF* flag set if enabled, then an interrupt generated. The Receive Register **RxR**

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contains valid data after the IF flag has been set. The software may issue a new write or read command when the *I2C_TIP* flag is cleared.

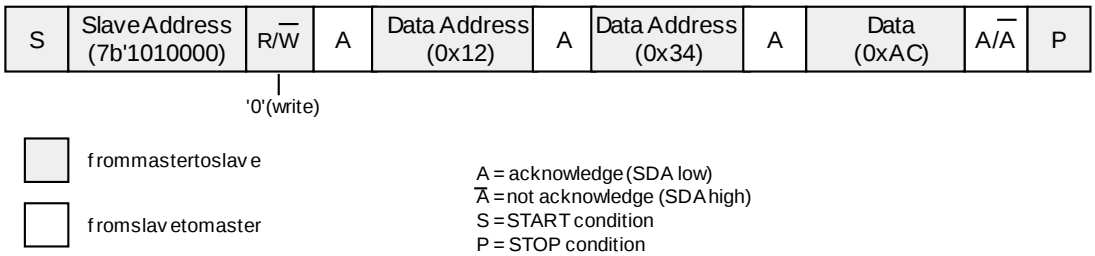
13.4.5Below list Some Examples of I2C Data Transaction

13.4.5.1Write One Byte of Data to Slave

Slave address = 0x50 (7b'1010000)
Data address = 0x1234
Data to write = 0xAC

I^2C Sequence:

1. Generate start command
2. Start multiple data transfer
   (1) Write slave address + write bit and receive acknowledge from slave
   (2) Write data address high byte and receive acknowledge from slave
   (3) Write data address low byte and receive acknowledge from slave
   (4) Write data and receive acknowledge from slave
3. Generate stop command



Commands:

1. Write a value into **DIVIDER** register to determine the frequency of serial clock.
2. Set *Tx_NUM* = 0x3 and set *I2C_EN* = 1 of **CSR** register to enable I2C core.
3. Write 0xA0 (slave address + write bit 0) to **TxR** register (*TxR[31:24]*).
4. Write address high byte (0x12) to **TxR** register (*TxR[23:16]*), and address low byte (0x34) to **TxR** register (*TxR[15:8]*).
5. Write data 0xAC to **TxR** register (*TxR[7:0]*).
6. Set *START* bit, *STOP* bit, and *WRITE* bit of **CMDR** register.
7. Wait for interrupt or *I2C_TIP* flag to negate

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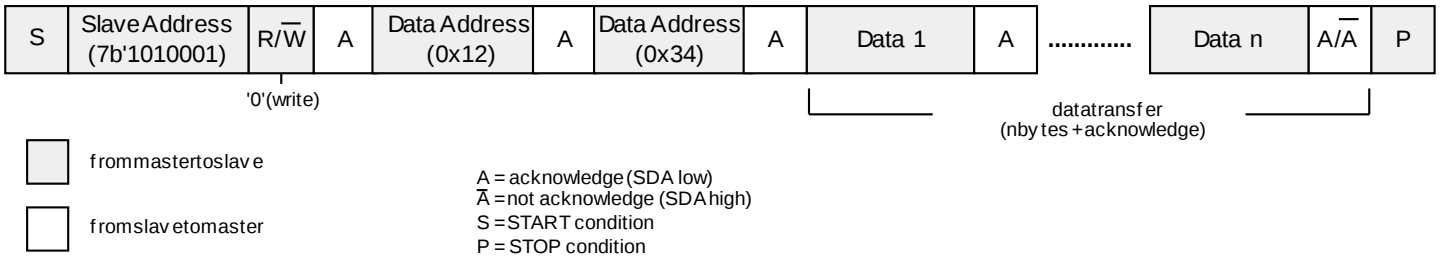
8. Read *I2C_RxACK* bit of **CSR** register, it should be '0'. If it is not ‘0’, there are some errors happened.

13.4.5.2Multi-byte (n bytes) write to a slave

Slave address = 0x51 (7b'1010001)
Data address to write to = 0x1234
Multi-byte data to write

I^{2}C Sequence:

1. Generate start command
2. Start multiple data transfer
   (1) Write slave address + write bit and receive acknowledge from slave
   (2) Write data address high byte and receive acknowledge from slave
   (3) Write data address low byte and receive acknowledge from slave
3. Write data and receive acknowledge from slave for n times
4. Generate stop command



Commands:

1. Write a value into **DIVIDER** register to determine the frequency of serial clock.
2. Set *Tx_NUM* = 0x2 and set *I2C_EN* = 1 of **CSR** register to enable I2C core.
3. Write 0xA2 (slave address + write bit 0) to **TxR** register (TxR[23:16]).
4. Write address high byte (0x12) to **TxR** register (*TxR[15:8]*), and address low byte (0x34) to **TxR** register (*TxR[7:0]*).
5. Set *START* bit, and *WRITE* bit of **CMDR** register.
6. Wait for interrupt or *I2C_TIP* flag to negate

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7. Read *I2C_RxACK* bit of **CSR** register, it should be '0'. If it is not ‘0’, there are some errors happened.
8. Write data to **TxR** register (*TxR[7:0]*).
9. Set *WRITE* bit of **CMDR** register.
10. Wait for interrupt or *I2C_TIP* flag to negate
11. Read *I2C_RxACK* bit of **CSR** register, it should be '0'. If it is not ‘0’, there are some errors happened.
12. Continue step 8 -11 before the final byte transmit
13. Write final byte to **TxR** register (*TxR[7:0]*).
14. Set *WRITE* bit, and *STOP* bit of **CMDR** register for final byte transmit.
15. Wait for interrupt or *I2C_TIP* flag to negate
16. Read *I2C_RxACK* bit of **CSR** register, it should be '0'. If it is not ‘0’, there are some errors happened.

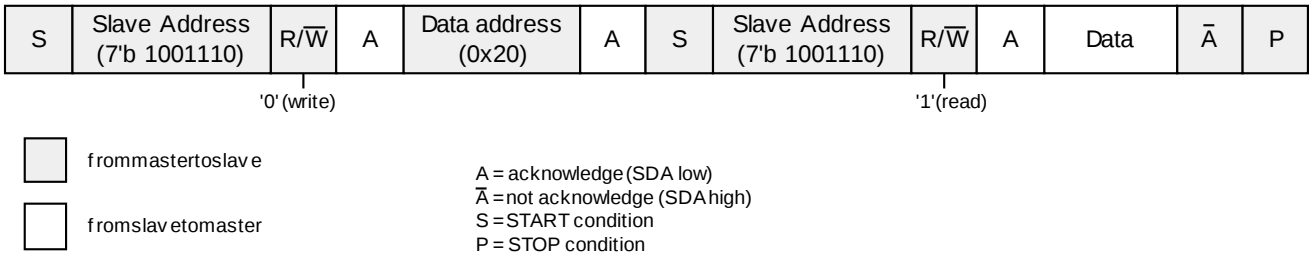
13.4.5.3Read a byte of data from an I2C memory device (Random read)

Slave address = 0x4E (7'b1001110)
Memory location to read from = 0x20

I2C sequence:

1. Generate start signal
2. Write slave address + write bit, then receive acknowledge from slave
3. Write memory location, then receive acknowledge from slave
4. Generate repeated start signal
5. Write slave address + read bit, then receive acknowledge from slave
6. Read byte from slave
7. Write not acknowledge (NACK) to slave, indicating end of transfer
8. Generate stop signal

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Commands:

1. Write a value into **DIVIDER** register to determine the frequency of serial clock.
2. Set *Tx_NUM* = 0x01 and set *I2C_EN* = 1 of **CSR** register to enable I2C core.
3. Write 0x9C (slave address + write bit 0) to *TxR[15:8]*, set 0x20 to *TxR[7:0]*.
4. Set *START* bit, and *WRITE* bit of **CMDR** register.
5. Wait for interrupt or *I2C_TIP* flag to negate
6. Read *I2C_RxACK* bit from **CSR** register, it should be '0'. If it is not ‘0’, there are some errors happened.
7. Write 0x9D (slave address + read bit 1) to *TxR[7:0]*.
8. Set *START* bit, and *WRITE* bit of **CMDR** register.
9. Wait for interrupt or *I2C_TIP* flag to negate
10. Read *I2C_RxACK* bit from **CSR** register, it should be '0'. If it is not ‘0’, there are some errors happened.
11. Set *READ* bit, set *ACK* to '1' (NACK), and set *STOP* bit of **CMDR** register.
12. Wait for interrupt or *I2C_TIP* flag to negate
13. Read *I2C_RxACK* bit of **CSR** register, it should be '0'. If it is not ‘0’, there are some errors happened.
14. Read out received data from **RxR** register, it will put on *RxR[7:0]*.

13.4.5.4Read multi-byte data from slave (Sequential read)

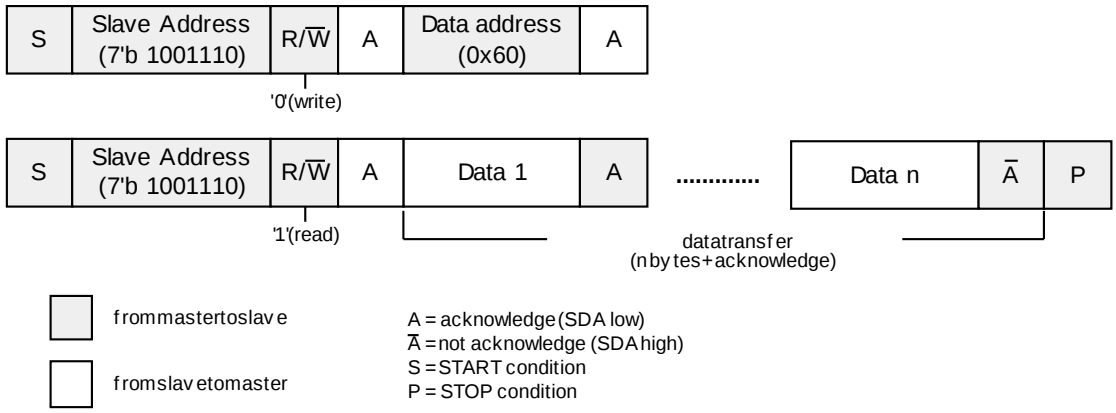
Slave address = 0x4E (7'b1001110)
Memory location to read from = 0x60

I2C sequence:

1. Generate start signal
2. Write slave address + write bit, then receive acknowledge from slave

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3. Write memory location, then receive acknowledge from slave
4. Generate repeated start signal
5. Write slave address + read bit, then receive acknowledge from slave
6. Read byte from slave and write acknowledge (ACK) for n-1 times
7. Read byte from slave and write not acknowledge (NACK) to slave, indicating end of transfer
8. Generate stop signal



Commands:

1. Write a value into **DIVIDER** register to determine the frequency of serial clock.
2. Set *Tx_NUM* = 0x01 and set *I2C_EN* = 1 of **CSR** register to enable I2C core.
3. Write 0x9C (slave address + write bit 0) to *TxR[15:8]*, set 0x60 to *TxR[7:0]*.
4. Set *START* bit, and WRITE bit of **CMDR** register.
5. Wait for interrupt or *I2C_TIP* flag to negate
6. Read *I2C_RxACK* bit from **CSR** register, it should be '0'. If it is not ‘0’, there are some errors happened.
7. Write 0x9D (slave address + read bit 1) to *TxR[7:0]*.
8. Set *START* bit, and *WRITE* bit of **CMDR** register.
9. Wait for interrupt or *I2C_TIP* flag to negate
10. Read *I2C_RxACK* bit from **CSR** register, it should be '0'. If it is not ‘0’, there are some errors happened.
11. Set *READ* bit of **CMDR** register.
12. Wait for interrupt or *I2C_TIP* flag to negate
13. Read *I2C_RxACK* bit from **CSR** register, it should be '0'. If it is not ‘0’, there are some errors happened.

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14. Read out received data from **RxR** register, it will put on RxR[7:0].
15. Continue step 11 - 14 until the final byte read
16. Set *READ* bit, set *ACK* to '1' (NACK), and set *STOP* bit of **CMDR** register.
17. Wait for interrupt or *I2C_TIP* flag to negate.
18. Read *I2C_RxACK* bit of **CSR** register, it should be '0'. If it is not ‘0’, there are some errors happened.
19. Read out received final data from **RxR** register, it will put on RxR[7:0].

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14 Universal Serial Interface

14.1 Overview

The Universal Serial Interface (USI) is a synchronous serial Interface performs a serial-to-parallel conversion on data characters received from the peripheral, and a parallel-to-serial conversion on data characters received from CPU. This interface can drive up to 2 external peripherals and is seen as the master. It can generate an interrupt signal when data transfer is finished and can be cleared by writing 1 to the interrupt flag. The active level of device/slave select signal can be chosen to low active or high active, which depends on the peripheral it's connected. Writing a divisor into DIVIDER register can program the frequency of serial clock output. This master core contains four 32-bit transmit/receive buffers, and can provide burst mode operation. The maximum bits can be transmitted/received is 32 bits, and can transmit/receive data up to four times successive.

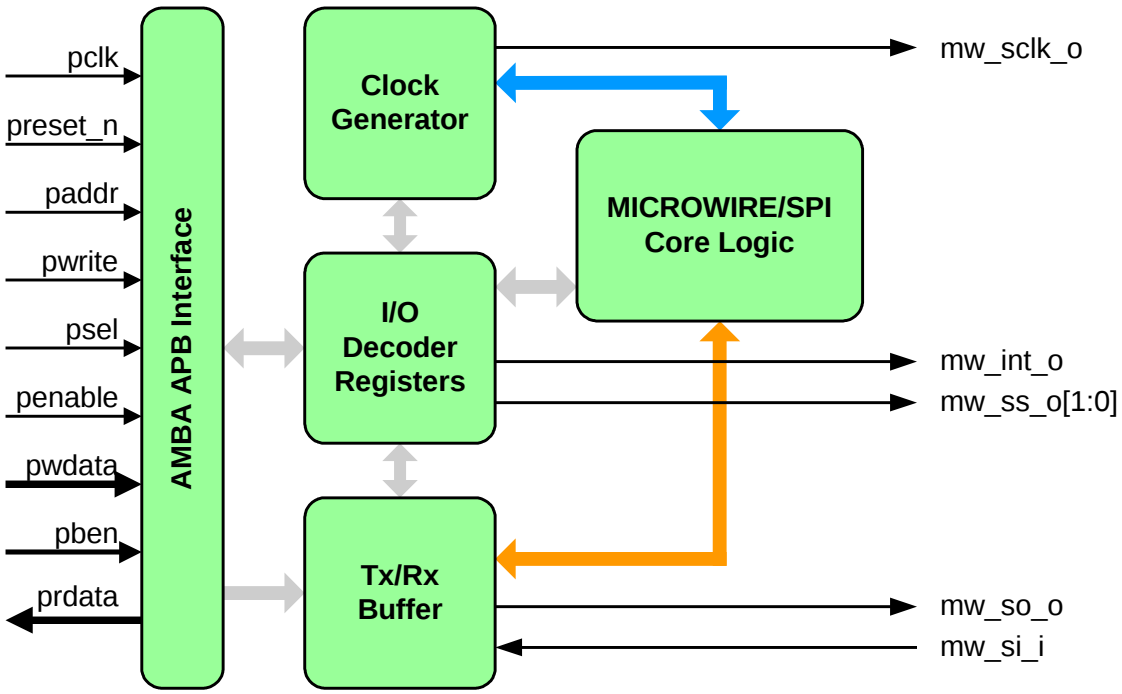
The USI (MICROWIRE/SPI) Master Core includes the following features:

- λ AMBA APB interface compatible
- λ Support USI (MICROWIRE/SPI) master mode
- λ Full duplex synchronous serial data transfer
- λ Variable length of transfer word up to 32 bits
- λ Provide burst mode operation, transmit/receive can be executed up to four times in one transfer
- λ MSB or LSB first data transfer
- λ Rx and Tx on both rising or falling edge of serial clock independently
- λ 2 slave/device select lines
- λ Fully static synchronous design with one clock domain

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14.2 Block Diagram

Figure 14-46 Universal Serial Interfacel Block Diagra



Pin descriptions:

mw_sclk_o: USI serial clock output pin.

mw_int_o: USI interrupt signal output.

mw_ss_o: USI slave/device select signal output.

mw_so_o: USI serial data output pin (to slave device).

mw_si_i: USI serial data input pin (from slave device).

14.3 Register Map

R : read only, **W** : write only, **R/W** : both read and write, **C** : Only value 0 can be written

Register	Address	R/W	Description	Reset Value
USI_CNTRL	0XFFF8.6200	R/W	Control and Status Register	0x0000.0004

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USI_DIVIDER	0xFFF8.6204	R/W	Clock Divider Register	0x0000.0000
USI_SSR	0xFFF8.6208	R/W	Slave Select Register	0x0000.0000
Reserved	0xFFF8.620C	N/A	Reserved	N/A
USI_Rx0	0xFFF8.6210	R	Data Receive Register 0	0x0000.0000
USI_Rx1	0xFFF8.6214	R	Data Receive Register 1	0x0000.0000
USI_Rx2	0xFFF8.6218	R	Data Receive Register 2	0x0000.0000
USI_Rx3	0xFFF8.621C	R	Data Receive Register 3	0x0000.0000
USI_Tx0	0xFFF8.6210	W	Data Transmit Register 0	0x0000.0000
USI_Tx1	0xFFF8.6214	W	Data Transmit Register 1	0x0000.0000
USI_Tx2	0xFFF8.6218	W	Data Transmit Register 2	0x0000.0000
USI_Tx3	0xFFF8.621C	W	Data Transmit Register 3	0x0000.0000

NOTE 1: When software programs CNTRL, the GO_BUSY bit should be written last.

14.4 Functional Description

14.4.1Active Universal Serial Interface

To activate the USI, please follow the steps below:

1. Set the *TX_BIT_LEN* bit of **USI_CNTRL** register to set the transmit bit length
2. Set the *TX_NUM* bit of **USI_CNTRL** register to set the transfer numbers
3. Set the *GO_BUSY* bit of **USI_CNTRL** register to activate Universal Serial Interface
4. Polling *GO_BUSY* bit of **USI_CNTRL** register until it was cleared, or waiting *IF* interrupt of **USI_CNTRL** register

14.4.2Initialize Universal Serial Interface

To initial the Universal Serial Interface, please follow the steps below:

1. Set **USI_DIVIDER** register to generate the serial clock on output clock
2. Set **USI_SSR** register to select the access device

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3. Set *LSB* bit of **USI_CNTRL** register to send LSB or MSB first
4. Set the *IE* bit of **USI_CNTRL** register to enable Universal Serial Interface interrupt

14.4.3Universal Serial Interface Transmit/Receive

To transmit/receive the data, please follow the steps below:

1. Fill the data into **USI_Tx0 ~ USI_Tx3** registers
2. Activate the Universal Serial Interface
3. Receive the data from **USI_Rx0 ~ USI_Rx3** registers

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15 Pulse Width Modulation (PWM) Timer

15.1 Overview

The NUC745 have 4 channels PWM.Timer. They can be divided into two groups. Each group has 1 prescaler, 1 clock divider, 2 clock selectors, 2 16-bit counters, 2 16-bit comparators, 1 Dead-Zone generator. They are all driven by PCLK (80MHz). Each channel can be used as a timer and issue interrupt independently.

Two channels PWM.Timer in one group share the same prescaler. Clock divider provides each channel with 5 clock sources (1, 1/2, 1/4, 1/8, 1/16). Each channel receives its own clock signal from clock divider which receives clock from 8-bit prescaler. The 16-bit counter in each channel receive clock signal from clock selector and can be used to handle one PWM period. The 16-bit comparator compares number in counter with threshold number in register loaded previously to generate PWM duty cycle.

The clock signal from clock divider is called PWM clock. Dead-Zone generator utilize PWM clock as clock source. Once Dead-Zone generator is enabled, output of two PWM timer in one group is blocked. Two output pin are all used as Dead-Zone generator output signal to control off-chip power device.

To prevent PWM driving output pin with unsteady waveform, 16-bit counter and 16-bit comparator are implemented with double buffering feature. User can feel free to write data to counter buffer register and comparator buffer register without generating glitch.

When 16-bit down counter reaches zero, the interrupt request is generated to inform CPU that time is up. When counter reaches zero, if counter is set as toggle mode, it is reloaded automatically and start to generate next cycle. User can set counter as one-shot mode instead of toggle mode. If counter is set as one-shot mode, counter will stop and generate one interrupt request when it reaches zero.

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The value of comparator is used for pulse width modulation. The counter control logic changes the output level when down-counter value matches the value of compare register.

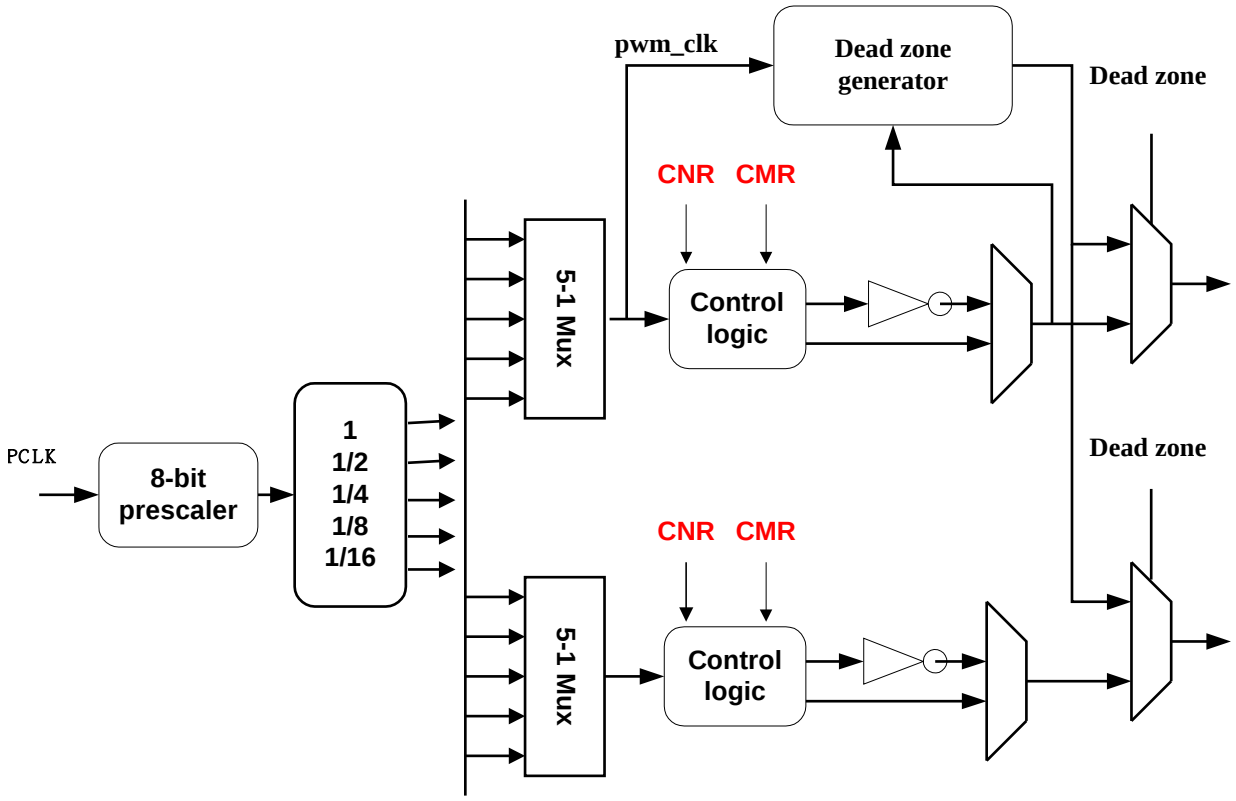
The PWM timer has the following features:

- Two 8-bit prescalers and two clock dividers
- Four clock selectors
- Four 16-bit counters and four 16-bit comparators
- Two Dead-Zone generator

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15.2 Block Diagram

Figure 15-47 PWM Block Diagram



15.3 Register Map

Register	Address	R/W/C	Description	Reset Value
PPR	0xFFF8.7000	R/W	PWM Prescaler Register	0000.0000
CSR	0xFFF8.7004	R/W	PWM Clock Select Register	0000.0000
PCR	0xFFF8.7008	R/W	PWM Control Register	0000.0000
CNR0	0xFFF8.700C	R/W	PWM Counter Register 0	0000.0000
CMR0	0xFFF8.7010	R/W	PWM Comparator Register 0	0000.0000
PDR0	0xFFF8.7014	R	PWM Data Register 0	0000.0000
CNR1	0xFFF8.7018	R/W	PWM Counter Register 1	0000.0000
CMR1	0xFFF8.701C	R/W	PWM Comparator Register 1	0000.0000
PDR1	0xFFF8.7020	R	PWM Data Register 1	0000.0000
CNR2	0xFFF8.7024	R/W	PWM Counter Register 2	0000.0000

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CMR2	0xFFF8.7028	R/W	PWM Comparator Register 2	0000.0000
PDR2	0xFFF8.702C	R	PWM Data Register 2	0000.0000
CNR3	0xFFF8.7030	R/W	PWM Counter Register 3	0000.0000
CMR3	0xFFF8.7034	R/W	PWM Comparator Register 3	0000.0000
PDR3	0xFFF8.7038	R	PWM Data Register 3	0000.0000
PIER	0xFFF8.703C	R/W	PWM Interrupt Enable Register	0000.0000
PIIR	0xFFF8.7040	R/C	PWM Interrupt Indication Register	0000.0000

15.4 Functional Description

15.4.1 Prescaler and clock selector

NUC745 has two groups (two channels in each group) of pwm timers. The clock input of the group is according to the PWM Prescaler Register (**PPR**) value. NUC745 PWM prescaler divided the clock input by PPR+1 before it is fed to the counter. Please notice that when the PPR value equals zero, the prescaler output clock will stop. Furthermore, according to the PWM Clock Select Register (**CSR**) value, the clock input of PWM timer channel can be divided by 1,2,4,8 and 16.

Consider following examples, which explain the PWM timer period.

$$\text{period} = \frac{1}{(PCLK) \div (PPR+1) \div CSR}$$

When the PCLK=80 MHz, the maximum and minimum PWM timer counting period is described as follows.

Maximum period: PPR=255(since the length of PPR is 8bit) and CSR=16

$$\text{period}_{\max} = \frac{1}{(80Mhz) \div (255+1) \div 16} = 51.2us$$

Minimum period: PCLK=80 MHz, PPR=1 and CSR=1

$$\text{period}_{\min} = \frac{1}{(80Mhz) \div (1+1) \div 1} = 0.025us$$

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The maximum and minimum interval between two interrupts are acdcroding to the $period_{max}$, $period_{min}$ and PWM Counter Register(**CNRx**) length. The maximum interval between two interrupts is (65535)*(51.2us) since the length of CNR is 16bit. Please notice that the above calculation is based on the PCLK=80MHz. Therefore, all of the values need to be recalculated when the PCLK is not equal to 80Mhz.

15.4.2Basic PWM timer operation and double buffering reload automatically

NUC745 PWM Timers have a double buffering function, enabling the reload value changed for next timer operation without stopping current timer operation. Although new timer value is set, current timer operation still operate successfully.

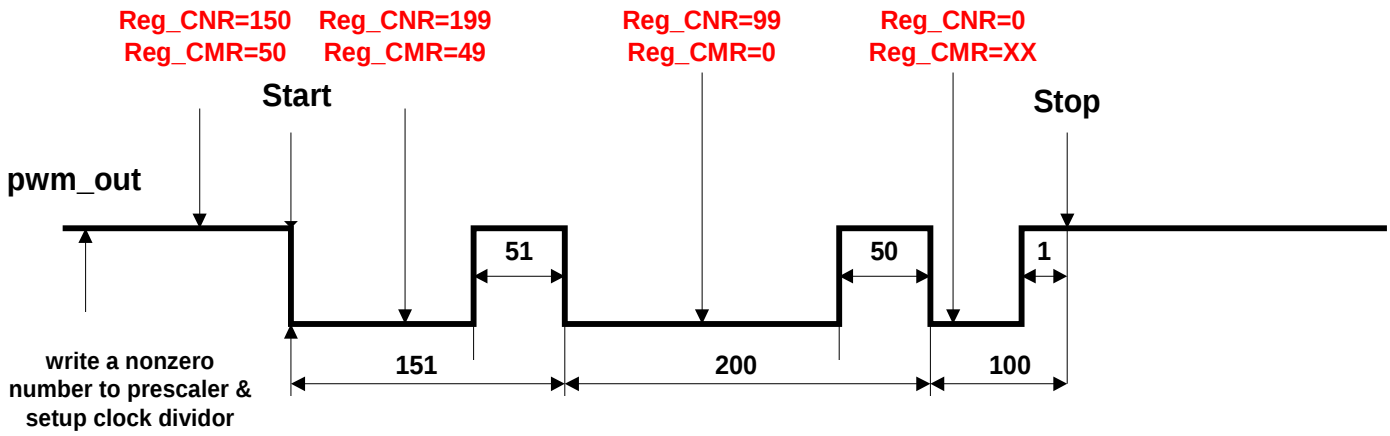
The counter value can be written into **CNR0**, **CNR1**, **CNR2**, **CNR3** and current counter value can be read from **PDR0**, **PDR1**, **PDR2**, **PDR3**.

The auto-reload operation copies from**CNR0**, **CNR1**, **CNR2**, **CNR3** to down-counter when down-counter reaches zero. If **CNR0~3** are set as zero, counter will be halt when counter count to zero. If auto-reload bit is set as zero, counter will be stopped immediately.

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Figure 15-48 PWM operation

PWM double buffering



15.4.3PWM Timer Start Procedure

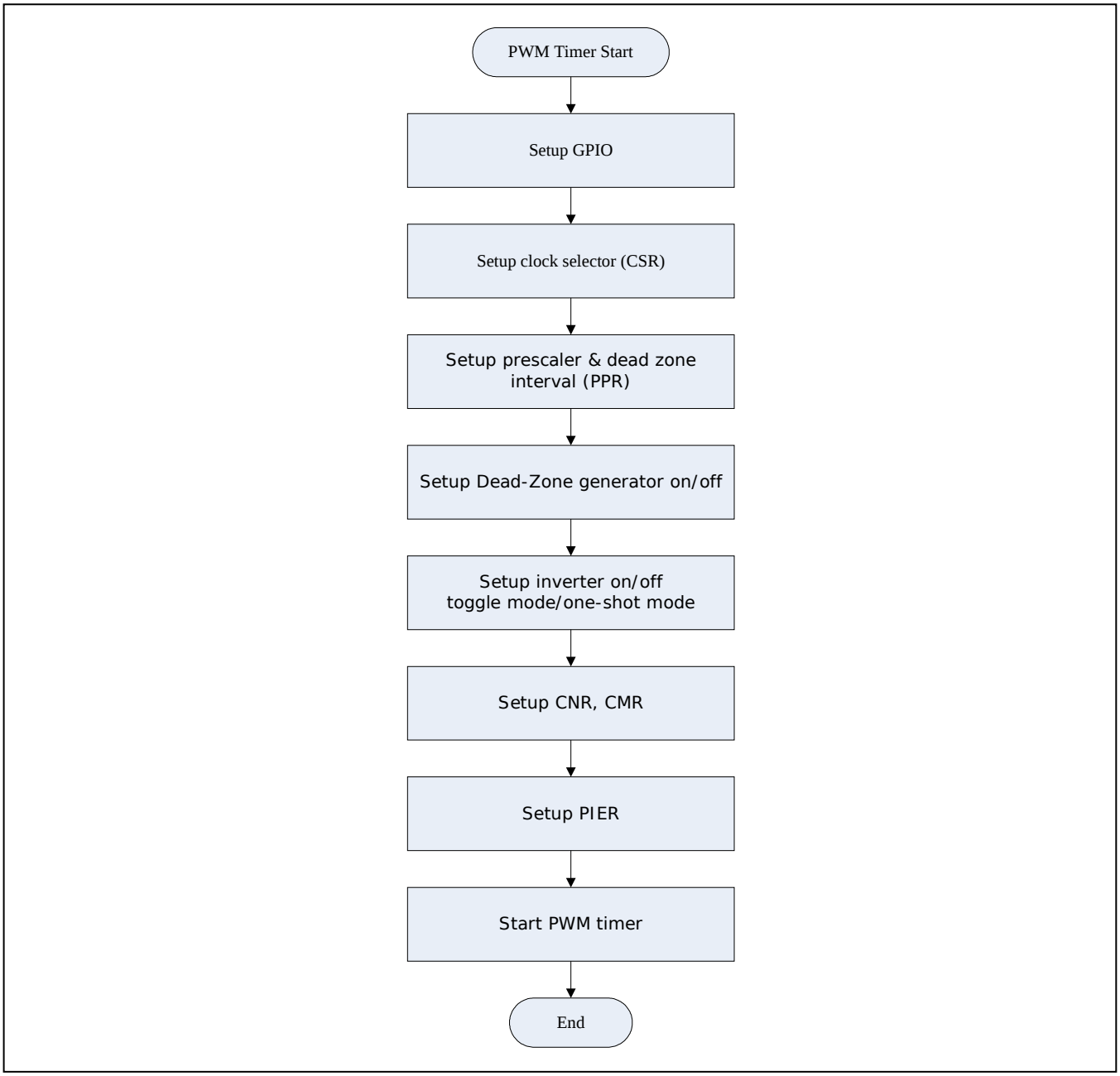
The PWM Timer start procedure is is described as follows.:

1. Setup clock selector (**CSR**)
2. Setup prescaler & dead zone interval (**PPR**)
3. Setup inverter on/off, dead zone generator on/off, toggle mode /one-shot mode, and pwm timer off. (**PCR**)
4. Setup comparator register (**CMR**)
5. Setup counter register (**CNR**)
6. Setup interrupt enable register (**PIER**)
7. Enable pwm timer (**PCR**)

A flowchart of this procedure is given in the following figure.

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Figure 15-49 PWM Timer Start Procedure



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15.4.4PWM Timer Stop Procedure

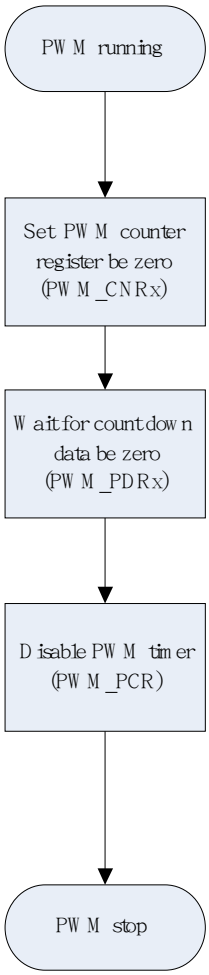
Three different methods could used to stop PWM timer, they're listed below:

Method 1: Set 16-bit down counter(**CNRx**) as 0, and monitor PDR. When **PDRx** reaches to 0, disable pwm timer (**PCR**). (Recommended)

Method 2: Set 16-bit down counter(**CNRx**) as 0. When interrupt request happen, disable pwm timer (**PCR**). (Recommended)

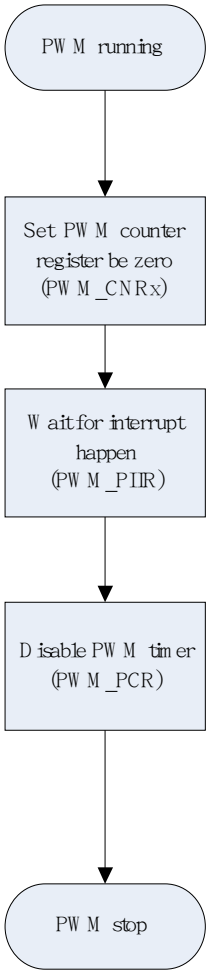
Method 3 : Disable PWM Timer directly (PWM_PCR). (Not recommended)

Figure 15-50 PWM Timer Stop flow chart (method 1)



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Figure 15-51 PWM Timer Stop flow chart (method 2)



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16 Keypad Interface

16.1 Overview

NUC745 Keypad Interface (**KPI**) is an APB slave with 4-row scan output and 8-column scan input. KPI scans an array up to 16x8 with an external 4 to 16 decoder. It can also be programmed to scan 8x8 or 4x8 key array. If the 4x8 array is selected then external decoder is not necessary because the scan signals are derived by NUC745 itself. Any 1 or 2 keys in the array that pressed are debounced and encoded. If more than 2 keys are pressed, only the keys or apparent keys in the array with the lowest address will be decoded.

KPI supports 2-keys scan interrupt and specified 3-keys interrupt or chip reset. If the 3 pressed keys matches with the 3 keys defined in **KPI3KCONF**, it will generate an interrupt or chip reset to nWDOG reset output depend on the **ENRST** setting. The interrupt is generated whenever the scanner detects a key is pressed. The interrupt conditions are 1 key, or 2 keys.

NUC745 provides two keypad connecting interface. One is allocated in LCD (GPIO30-41) interface, the other is in Ethernet RMII PHY interface and I2C interface 2 SDA1, SCL1 (GPIO42-51). Software should set KPSEL bit in **KPICONF** register to decide which interface is used as keypad connection port.

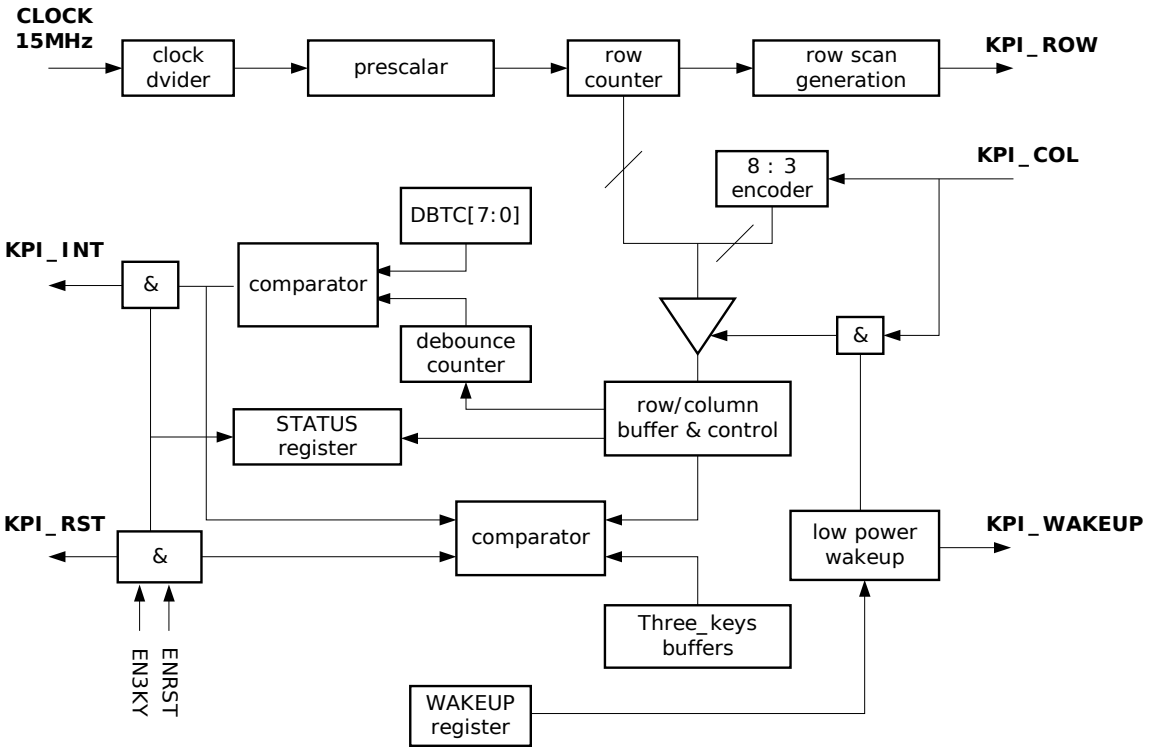
The keypad interface has the following features:

- maximum 16x8 array
- programmable debounce time
- low-power wakeup mode
- programmable three-key reset

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16.2 Block Diagram

Figure 16-52 Keypad Controller Block Diagram



16.3 Register Map

Register	Address	R/W	Description	Reset Value
KPICONF	0xFFF8.8000	R/W	Keypad controller configuration Register	0x0000.0000
KPI3KCONF	0xFFF8.8004	R/W	Keypad controller 3-keys configuration register	0x0000.0000
KPILPCONF	0xFFF8.8008	R/W	Keypad controller low power configuration register	0x0000.0000
KPISTATUS	0xFFF8.800C	R/O	Keypad controller status register	0x0000.0000

16.4 Functional Description

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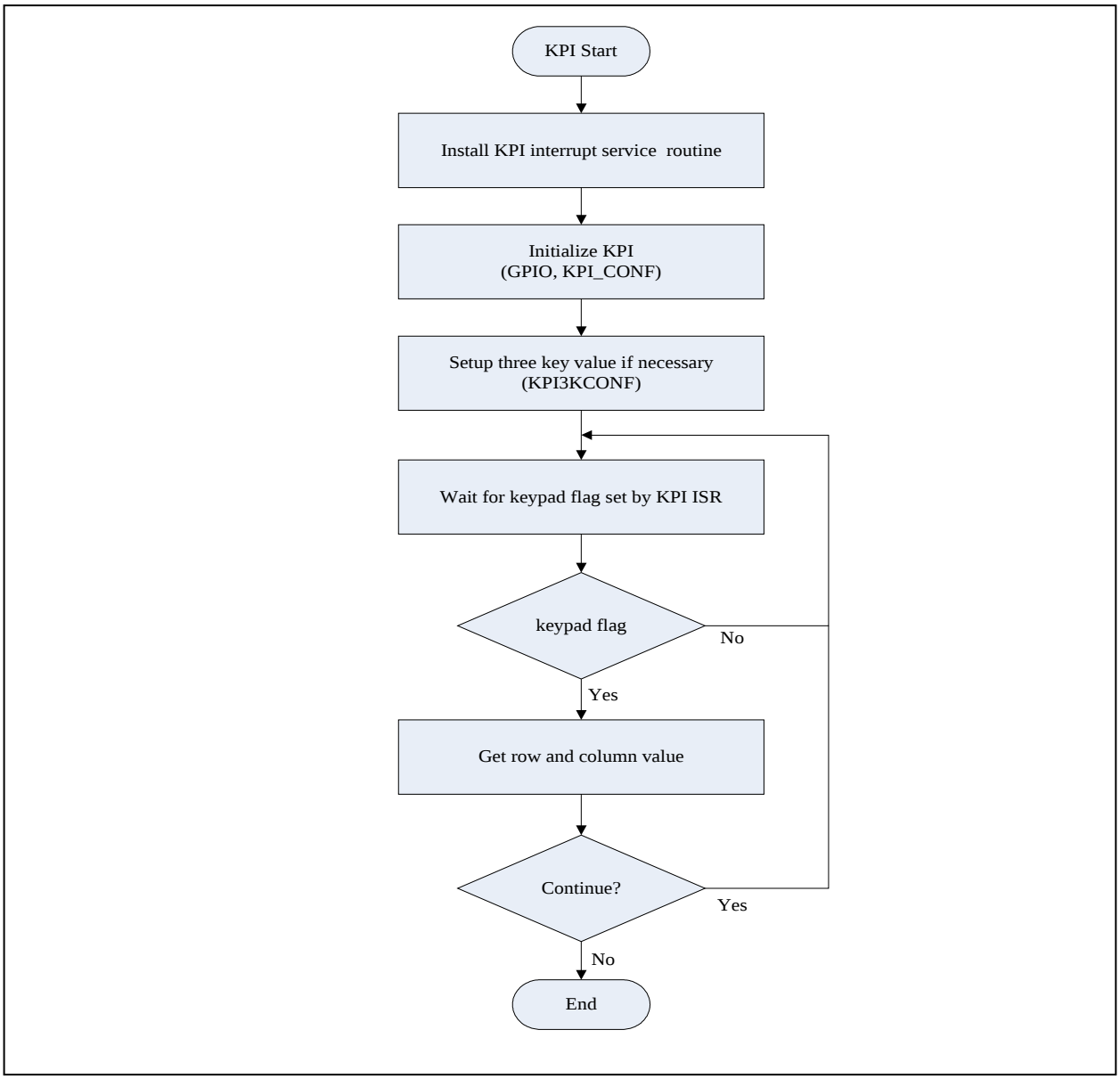
16.4.1KPI Interface Programming Flow

The KPI usage procedure is described as follows.

1. Install KPI interrupt service routine
2. Configure GPIO KPI Multiple function
3. Configure register **KPICONF**
4. Configure register **KPI3KCONF** if application needs to use this function.
5. Wait for keypad flag set by KPI ISR
6. Get KPI row and column value in register **KPISTATUS**, then go back to step 5

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Figure 16-53 KPI Interface flowchart



16.4.2KPI Low Power Mode Configuration

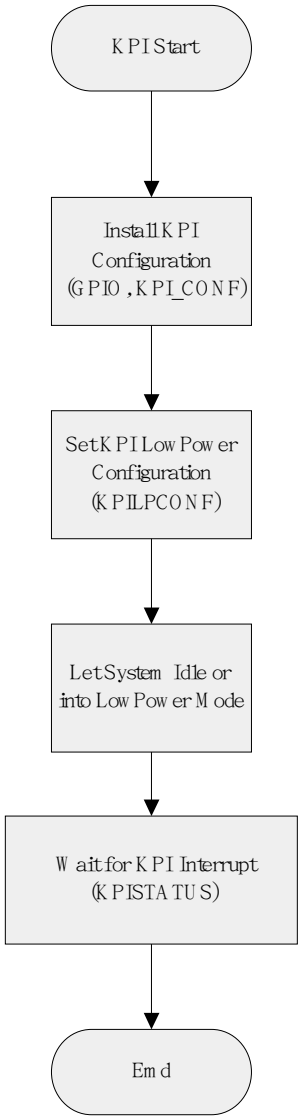
When the system enters power down or idle mode, user can use KPI interrupt to wake up it. Programming need to set *WAKE* bit and configure *LPWCEN[15:8]* and *LPWR[3:0]* register **KPILPCONF** for enable wake up function.

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Please note that the definition of the low power wakeup row address(*LPWR[3:0]*) is different between various keypad size. For 16x8 or 8x8 (with 4:16 or 3:8 decoder) keypad LPWR means “Hex” code but for 4x8 (without decoder), LPWR means “binary” code. For example, if user wants to use all keys on row 3 of 16x8 keyapd to wakeup NUC745, then 0x3 should be fill into this register but for 4x8 keypad it should be filled as 4’b1000.., and Specify columns for low power wakeup (*LPWCEN[15:8]*). For example, if user wants to use kyes in row N and column 0, 2, 5 to wake up NUC745, then the LPWCEN should be fill 8’b00100101. Figure 20-3 shows the flowchart.

Figure 16-54 KPI set Wake-Up in system low power mode flowchart

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17 PS/2 Host Interface Controller

17.1 Overview

NUC745 PS/2 host controller interface implements a bi-directional serial protocol to connect a IBM AT or PS/2 keyboard. The host controller handles the electronic interface and protocol without software involving. If any key is being pressed, released, or held down, the keyboard will send a packet of information known as a "**scan code**" to host controller. The host controller will put the scan code and its corresponding ASCII code iinto registers, then generate an interrupt to note software driver. Instead of using interrupt method, the software drives can continuously read the status register to check whether a scan code arrived or not. Besides, the host controller provides a command register for software driver to send commands to keyboard.

Some devices implementing PS/2 protocol can be connected to this host controller. For example, the BAR code scanner. But the PS/2 mouse may not work with this host controller. Because the host controller can’t distinguish “E0” (for extended byte) and “F0” (for break code) from a data byte of a mouse movement data packet.

17.2 Scan Code Set

For PS/2 keyboard, there are two different types of scan codes: "**make codes**" and "**break codes**". A make code is sent when a key is pressed or held down. A break code is sent when a key is released. Every key is assigned its own unique make code and break code. The set of make and break codes for every key comprises a "scan code set". There are three standard scan code sets, named one, two, and three. All modern keyboards default to set two. The NUC745 PS/2 host controller can identify the ASCII code of a key is being pressed, released or held down according to the scan code set two. The following figures show the key map of scan code set two. All the scan codes are shown in Hex.

Figure 17-55 Key map of PS/2 keyboard

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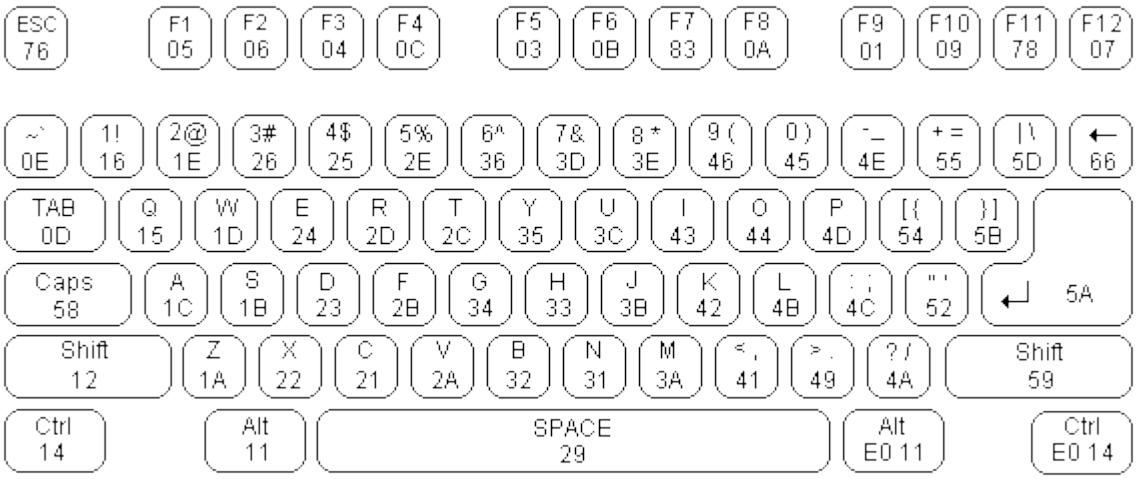
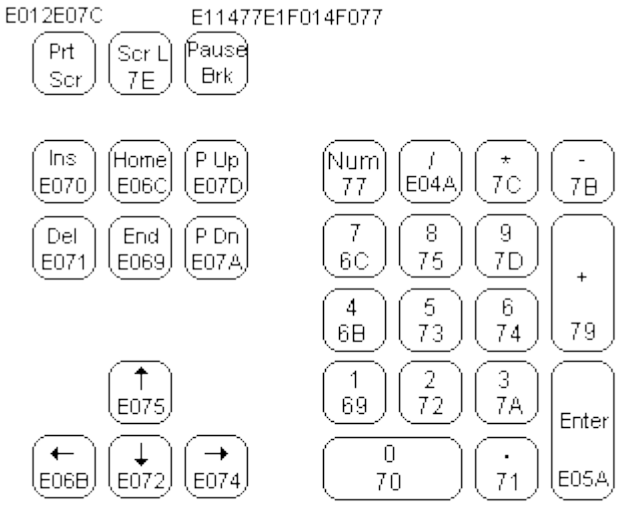


Figure 17-56 Key map of extended keyboard & Numeric keypad



Although most set two make codes are only one-byte wide, there are a handfull of "extended keys" whose make codes are two or four bytes wide. These make codes can be identified by the fact that their first byte is E0h. In addition to every key having its own unique make code, they all have their own unique break code. And certain relationships exist between make codes and break codes. Most set two break codes are two bytes long where the first byte is F0h and the second byte is the

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make code for that key. Break codes for extended keys are usually three bytes long where the first two bytes are E0h, F0h, and the last byte is the last byte of that key's make code. Figure 21.3 shows the set two make codes and break codes for a few keys.

Figure 17-57 Make Code and Break Code

Key	(Set 2) Make Code	(Set 2) Break Code
“A”	1C	F0, 1C
“5”	2E	F0, 2E
“F10”	09	F0, 90
Right Arrow	E0, 74	E0, F0, 74
Right “Ctrl”	E0, 14	E0, F0, 14

17.3 Register Map

The PS/2 interface host controller provides four control registers. The regisger PS2CMD is used to send command to a PS/2 device. The register PS2STS indicates the status of transmit and receive of PS/2 interface. The registers PS2SCANCODE and PS2ASCII are used to store the scan code and ASCII code of the key arrived.

Register	Address	R/W	Description	Reset Value
PS2CMD	0xFFF8.9000	R/W	PS2 Host Controller Command Register	0x0000.0000
PS2STS	0xFFF8.9004	R/W	PS2 Host Controller Status Register	0x0000.0000
PS2SCANCODE	0xFFF8.9008	RO	PS2 Host Controller RX Scan Code Register	0x0000.0000
PS2ASCII	0xFFF8.900C	RO	PS2 Host Controller RX ASCII Code Register	0x0000.0000

17.4 Functional Description

17.4.1Initialization

The PS/2 clock and data are shared pins. The register GPIO_CFG5 must be set for selecting PS/2 interface. After that, the software driver can send a reset command to reset a PS/2 device.

1. Configure GPIO_CFG5 (0xFFF83050) : set bits 11 ~ 8 to 0xF
2. Send Reset Command (0xFF) to PS/2 device.

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17.4.2Send Commands

The content of the command register is showed below.

Table 17-11 Command register *PS2CMD*

31	30	29	28	27	26	25	24
RESERVED							
23	22	21	20	19	18	17	16
RESERVED							
15	14	13	12	11	10	9	8
RESERVED						TRAP_SHIFT	EnCMD
7	6	5	4	3	2	1	0
PS2CMD							

To send a command, write the command code to field PS2CMD[7:0], then write 1 to bit EnCMD to start the transmit. After the transmit complete, EnCMD is automatically cleared to 0 and an interrupt is generated. Below are some of the commands the host may send to the keyboard.

Table 17-12 Command table

Command Code	Description
ED	Set Status LED's - This command can be used to turn on and off the Num Lock, Caps Lock & Scroll Lock LED's. After Sending ED, keyboard will reply with ACK (FA) and wait for another byte which determines their Status. Bit 0 controls the Scroll Lock, Bit 1 the Num Lock and Bit 2 the Caps lock. Bits 3 to 7 are ignored.
EE	Echo - Upon sending a Echo command to the Keyboard, the keyboard should reply with a Echo (EE)
F0	Set Scan Code Set. Upon Sending F0, keyboard will reply with ACK (FA) and wait for another byte, 01-03 which determines the Scan Code Used. Sending 00 as the second byte will return the Scan Code Set currently in Use
F3	Set Typematic Repeat Rate. Keyboard will Acknowledge command with FA and wait for second byte, which determines the Typematic Repeat Rate.
F4	Keyboard Enable - Clears the keyboards output buffer, enables Keyboard Scanning and returns an Acknowledgment.
F5	Keyboard Disable - Resets the keyboard, disables Keyboard Scanning and returns an Acknowledgment.
FE	Resend - Upon receipt of the resend command the keyboard will re- transmit the last byte sent.
FF	Reset - Resets the Keyboard.

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17.4.3Read scan code and ASCII code

The registers PS2SCANCODE and PS2ASCII are used to store the information sent by keyboard or other PS/2 devices.

Scan Code Register

Table 17-13 Register PS2SCANCODE

31	30	29	28	27	26	25	24
RESERVED							
23	22	21	20	19	18	17	16
RESERVED							
15	14	13	12	11	10	9	8
RESERVED					RX_shift_key	RX_release	RX_extend
7	6	5	4	3	2	1	0
RX_SCAN_CODE							

- **RX_release**

  When one key has been released, the keyboard will send its break code that is preceded by a data byte 0xF0 to host controller. This bit indicates software that host controller receives release byte (F0). This bit is read only and will update when host has received next data byte

- **RX_extend**

  A handful of the keys on keyboard are extended keys and thus require two more scan code. These keys are preceded by a data byte 0xE0. This bit indicates software that Host controller receives extended byte (E0). This bit is read only and will update when host has received next data byte

- **RX_SCAN_CODE**

  The host controller will put the received scan code into field **RX_SCAN_CODE**. But note that the host controller will not report “Extend” (0xE0) or “Break” (0xF0) scan code in this field and not generate if they are received. The software driver must read bits **RX_entend** and **RX_release** to decide whether the received data byte is an “Extend” or “Break” scan code.

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ASCII Code Register

Table 17-14 Register PS2ASCII

31	30	29	28	27	26	25	24
RESERVED							
23	22	21	20	19	18	17	16
RESERVED							
15	14	13	12	11	10	9	8
RESERVED							
7	6	5	4	3	2	1	0
RX_ASCII_CODE							

- **RX_ASCII_CODE**

  This field stores the ASCII data content transmitted from device. Therefore, this part translates the scan code into an ASCII value. It will be read as 0x2E when there is no ASCII code mapped to the scan code stored in RX_SCAN_CODE register. This filed is valid when RX_IRQ is asserted.

17.4.4Interrupt Service Routine

As soon as an interrupt occurs, the software driver needs to read the status from register PS2STS. The status shows a scan code arrived or a command has been sent.

Table 17-15 Register PS2ST

31	30	29	28	27	26	25	24
RESERVED							
23	22	21	20	19	18	17	16
RESERVED							
15	14	13	12	11	10	9	8
RESERVED							
7	6	5	4	3	2	1	0
RESERVED		TX_err	TX_IRQ	RESERVED			RX_IRQ

- **TX_IRQ**

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This Transmit Complete Interrupt bit will be set to 1 if Host controller writing command to device is finished. Software needs to write one to this bit to clear this interrupt.

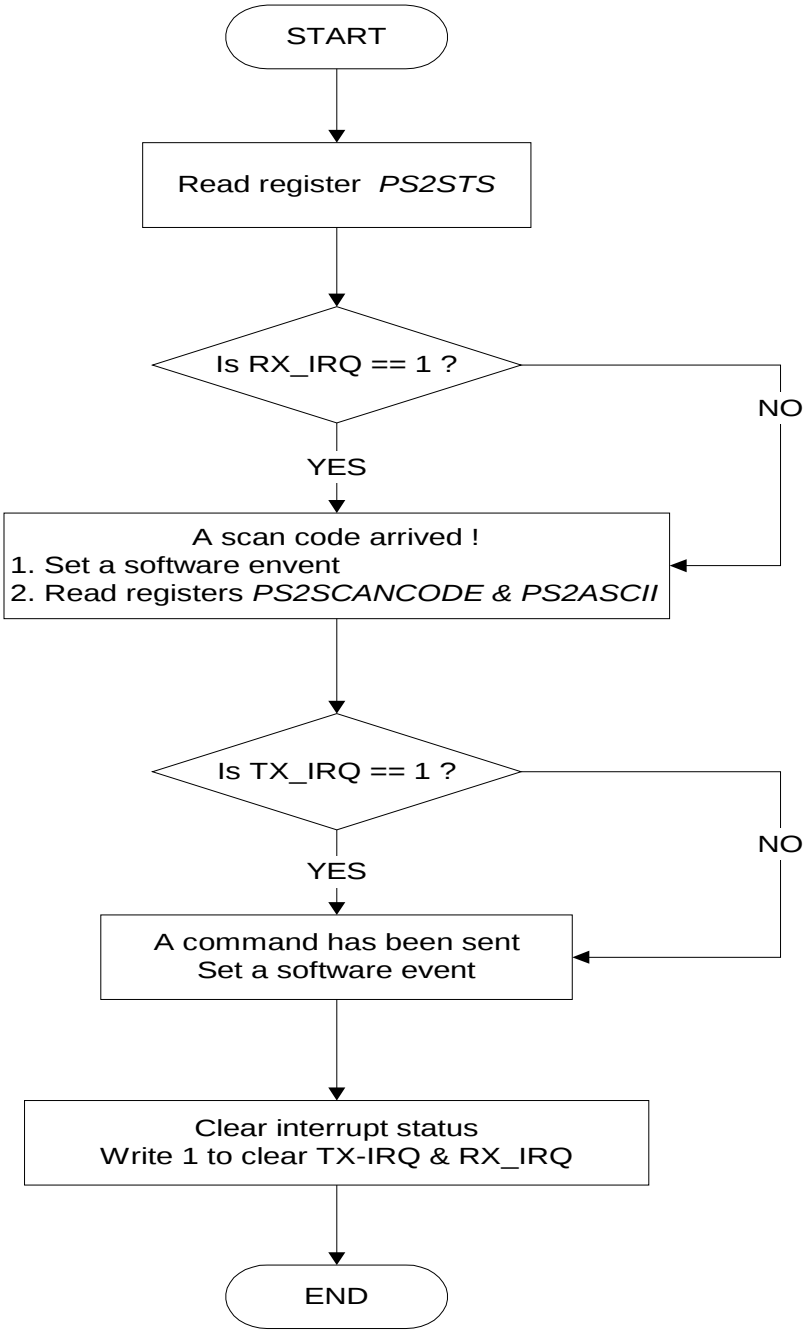
- **RX_IRQ**

  This Receive Interrupt bit will be set to 1 if Host controller receives one byte data from device. This data is stored at PS2_SCANCODE register. Software needs to write one to this bit to clear this interrupt after reading receiving data in RX_SCAN_CODE register. Note that the reception of the Extend (0xE0) and Release (0xF0) scan code will not cause an interrupt by host. The case of the shift key codes will be determined by the TRAP_SHIFT bit of PS2_CMD register.

The following figure illustrates an example interrupt service routine.

Figure 17-58 Example ISR

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2. Read interrupt status from register **PS2STS**
3. If *RX_IRQ* is set go to step 3, otherwise go to step 4
4. A scan code arrived. Set a software event and read the registers **PS2SCANCODE** and **PS2ASCII**.

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5. If TX_IRQ is set go to step 5, otherwise go to step 6.
6. A command has been sent. Set a software event.
7. Clear the interrupt by wrinting 1 to the corresponding interrupt bits.

17.4.5Example

This example tells that how to turn on/off the LEDs on the keyboard if host controller receives the scan codes including 0x77 (Num Lock), 0x58 (Caps Lock) and 0x7E (Scroll Lock). The steps for controlling the Keyboard LED are listed below:

1. Write command 0xED (Set status LED's) to register **PS2CMD**.
2. Wait for keyboard's reply 0xFA by checking register PS2SCANCODE.
3. Write LED status to register **PS2CMD**. The LED status defines in following table. The LED is turned on if the status bit is 1, otherwise the LED is turned off.

Table 17-16 LED Status byte

Bit7	Bit6	Bit5	Bit4	Bit3	Bit2	Bit1	Bit0
					Caps Lock	Num Lock	Scroll Lock

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