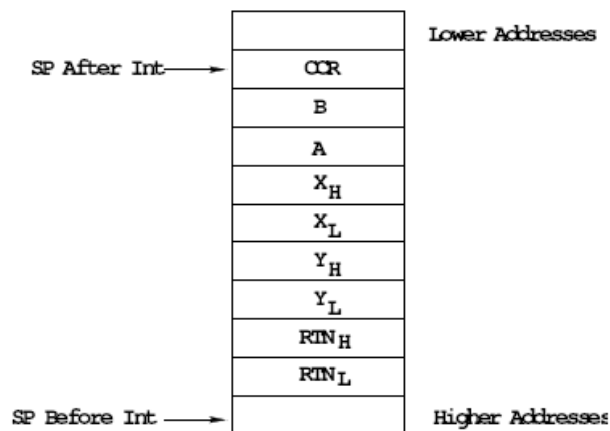


- **The Real Time Interrupt**
- Huang Section 6.6
- CRG Block User Guide
 - Exceptions on the 9S12
 - Using interrupts on the 9S12
 - The Real Time Interrupt on the 9S12

USING INTERRUPTS ON THE 9S12

What happens when the 9S12 receives an unmasked interrupt?

1. Finish current instruction
2. Clear instruction queue
3. Calculate return address
4. Push Return Address, Y, X, A, B, CCR onto stack (SP is decremented by 9)



5. Set I bit of CCR
6. If XIRQ interrupt, set X bit of CCR
7. Load Program Counter from interrupt vector for highest priority interrupt which is pending
8. The following (from the MC9S12DP256B Device User Guide) shows the exception priorities. The Reset is the highest priority, the Clock Monitor Fail Reset the next highest, etc.

Section 5 Resets and Interrupts

5.1 Overview

Consult the Exception Processing section of the HCS12 Core User Guide for information on resets and interrupts.

5.2 Vectors

5.2.1 Vector Table

Table 5-1 lists interrupt sources and vectors in default order of priority.

Vector Address	Interrupt Source	CCR Mask	Local Enable	HPRI0 Value to Elevate
\$FFFE, \$FFFF	Reset	None	None	-
\$FFFC, \$FFFD	Clock Monitor fail reset	None	PLLCF, CME, SCME	-
\$FFFA, \$FFFB	COP failure reset	None	COP Fail enct	-
\$FFFA, \$FFF9	Unimplemented instruction trap	None	None	-
\$FFFA, \$FFF7	SFAR	None	None	-
\$FFFA, \$FFF5	XIRQ	I-BI	I-BI	-
\$FFFA, \$FFF3	IRQ	I-BI	PROCR (IRGEN)	\$F2
\$FFFA, \$FFF1	Real Time Interrupt	I-BI	CRGINT (RTIE)	\$F0
\$FFEC, \$FFEF	Enhanced Capture Timer channel 0	I-BI	TIE (C0)	\$EE
\$FFEC, \$FFED	Enhanced Capture Timer channel 1	I-BI	TIE (C1)	\$EC
\$FFEA, \$FFEB	Enhanced Capture Timer channel 2	I-BI	TIE (C2)	\$EA
\$FFEA, \$FFE9	Enhanced Capture Timer channel 3	I-BI	TIE (C3)	\$E8
\$FFEA, \$FFE7	Enhanced Capture Timer channel 4	I-BI	TIE (C4)	\$E6
\$FFEA, \$FFE5	Enhanced Capture Timer channel 5	I-BI	TIE (C5)	\$E4
\$FFEA, \$FFE3	Enhanced Capture Timer channel 6	I-BI	TIE (C6)	\$E2
\$FFEA, \$FFE1	Enhanced Capture Timer channel 7	I-BI	TIE (C7)	\$E0
\$FFCE, \$FFDF	Enhanced Capture Timer overflow	I-BI	TSHCCZ (TOF)	\$CE
\$FFCC, \$FFDD	Fuse accumulator A overflow	I-BI	FACFL (FAC0)	\$CC
\$FFCA, \$FFCB	Fuse accumulator input edge	I-BI	FACFL (FA)	\$CA
\$FFC8, \$FFC9	SF0	I-BI	SFICR1 (SRE, SPTIE)	\$C8
\$FFC8, \$FFD7	SC0	I-BI	SCICRG (TIE, TCIE, RIE, LIE)	\$C8
\$FFC4, \$FFD5	SC11	I-BI	SCICRG (TIE, TCIE, RIE, LIE)	\$C4
\$FFC2, \$FFD3	ATD0	I-BI	ATD0CTL2 (ASOE)	\$C2
\$FFC0, \$FFD1	ATD1	I-BI	ATD1CTL2 (ASOE)	\$C0
\$FFC8, \$FFCF	Port J	I-BI	PTJIF (PTJIE)	\$C8
\$FFC8, \$FFCD	Port H	I-BI	PTHIF (PTHIE)	\$CC
\$FFCA, \$FFCB	Modbus Down Counter underflow	I-BI	MCCTLMCC2	\$CA

\$FFC8, \$FFC9	Fuse Accumulator B Overflow	I-BI	FACFL (FBOV)	\$C8
\$FFC8, \$FFC7	CRG PLL lock	I-BI	CRGINT (LOCKE)	\$C8
\$FFC4, \$FFC5	CRG Self Clock Mode	I-BI	CRGINT (SCME)	\$C4
\$FFC2, \$FFC3	BOLC	I-BI	DLCBOR (IE)	\$C2
\$FFC0, \$FFC1	IC Bus	I-BI	IBCR (IBE)	\$C0
\$FFB8, \$FFB9	SF11	I-BI	SFICR1 (SRE, SPTIE)	\$B8
\$FFB8, \$FFB0	SF2	I-BI	SFICR1 (SRE, SPTIE)	\$B8
\$FFB4, \$FFB5	EEPROM	I-BI	EEFLACC (CBE)	\$B4
\$FFB4, \$FFB9	FLASH	I-BI	FCTLACC (CBE)	\$B4
\$FFB8, \$FFB7	CAN0 wake-up	I-BI	CANRIR (WUPIE)	\$B8
\$FFB4, \$FFB5	CAN0 errors	I-BI	CANRIR (CSCE, OVRIE)	\$B4
\$FFB2, \$FFB3	CAN0 receive	I-BI	CANRIR (ROPIE)	\$B2
\$FFB0, \$FFB1	CAN0 transmit	I-BI	CANTIER (TXIE2-TXIE0)	\$B0
\$FFA8, \$FFA9	CAN1 wake-up	I-BI	CANRIR (WUPIE)	\$A8
\$FFA8, \$FFA0	CAN1 errors	I-BI	CANRIR (CSCE, OVRIE)	\$A8
\$FFA4, \$FFA5	CAN1 receive	I-BI	CANRIR (ROPIE)	\$A4
\$FFA4, \$FFA9	CAN1 transmit	I-BI	CANTIER (TXIE2-TXIE0)	\$A4
\$FFA8, \$FFA7	CAN2 wake-up	I-BI	CANRIR (WUPIE)	\$A8
\$FFA4, \$FFA5	CAN2 errors	I-BI	CANRIR (CSCE, OVRIE)	\$A4
\$FFA2, \$FFA3	CAN2 receive	I-BI	CANRIR (ROPIE)	\$A2
\$FFA0, \$FFA1	CAN2 transmit	I-BI	CANTIER (TXIE2-TXIE0)	\$A0
\$FF98, \$FF99	CAN3 wake-up	I-BI	CANRIR (WUPIE)	\$98
\$FF9C, \$FF9D	CAN3 errors	I-BI	CANRIR (CSCE, OVRIE)	\$9C
\$FF94, \$FF95	CAN3 receive	I-BI	CANRIR (ROPIE)	\$94
\$FF98, \$FF99	CAN3 transmit	I-BI	CANTIER (TXIE2-TXIE0)	\$98
\$FF98, \$FF97	CAN4 wake-up	I-BI	CANRIR (WUPIE)	\$98
\$FF94, \$FF95	CAN4 errors	I-BI	CANRIR (CSCE, OVRIE)	\$94
\$FF92, \$FF93	CAN4 receive	I-BI	CANRIR (ROPIE)	\$92
\$FF90, \$FF91	CAN4 transmit	I-BI	CANTIER (TXIE2-TXIE0)	\$90
\$FF88, \$FF89	Port F interrupt	I-BI	PTFI (PTFIE)	\$88
\$FF8C, \$FF8D	PWM Emergency Shutdown	I-BI	PWMEN (PWME)	\$8C
\$FF80 to \$FF8B			Reserved	

5.3 Effects of Reset

When a reset occurs, MCU registers and control bits are changed to known start-up states. Refer to the respective module Block User Guides for register reset states.

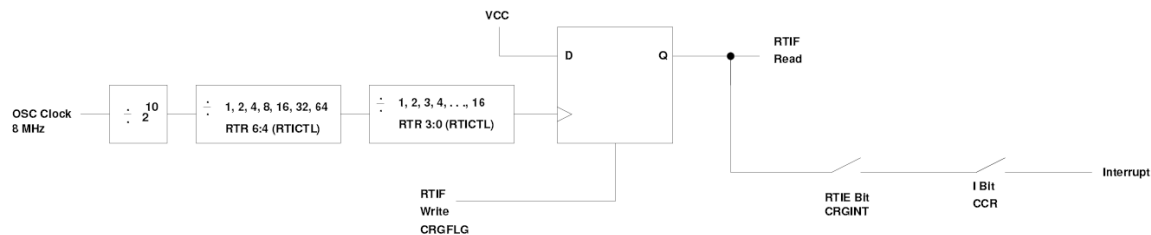
5.3.1 I/O pins

Refer to the HCS12 Core User Guides for mode dependent pin configuration of port A, B, E and K out of reset.

Refer to the PIM Block User Guide for reset configurations of all peripheral module ports.

The Real Time Interrupt

- Like the Timer Overflow Interrupt, the Real Time Interrupt allows you to interrupt the processor at a regular interval.
- Information on the Real Time Interrupt is in the CRG Block User Guide
- There are two clock sources for 9S12 hardware.
 - Some hardware uses the Oscillator Clock. The RTI system uses this clock.
 - For our 9S12, the oscillator clock is 8 MHz.
 - Some hardware uses the Bus Clock. The Timer system (including the Timer Overflow Interrupt) use this clock.
 - * For our 9S12, the bus clock is 24 MHz.



- The specific interrupt mask for the Real Time Interrupt is the RTIE bit of the CRGINT register.
- When the Real Time Interrupt occurs, the RTIF bit of the CRGFLG register is set.
 - To clear the Real Time Interrupt write a 1 to the RTIF bit of the CRGFLG register.
- The interrupt rate is set by the RTR 6:4 and RTR 2:0 bits of the RTICTL register. The RTR 6:4 bits are the Prescale Rate Select bits for the RTI, and the RTR 2:0 bits are the Modulus Counter Select bits to provide additional granularity.

RTIF	PCFP	0	LOCKIP	LOCK	TRCK	SCHIF	SM	0x0037	CRGFLG
------	------	---	--------	------	------	-------	----	--------	--------

RTIE	0	0	LOCKIE	0	0	SCHIE	0	0x0038	CRGINT
------	---	---	--------	---	---	-------	---	--------	--------

0	RTR6	RTR5	RTR4	RTR3	RTR2	RTR1	RTR0	0x003B	RTICTL
---	------	------	------	------	------	------	------	--------	--------

- To use the Real Time Interrupt, set the rate by writing to the RTR 6:4 and the RTR 3:0 bits of the RTICTL, and enable the interrupt by setting the RTIE bit of the CRGINT register

– In the Real Time Interrupt ISR, you need to clear the RTIF flag by writing a 1 to the RTIF bit of the CRGFLG register.

• The following table shows all possible values, in ms, selectable by the RTICTL register (assuming the system uses a 8 MHz oscillator):

RTR 3:0	RTR 6:4							
	000 (0)	001 (1)	010 (2)	011 (3)	100 (4)	101 (5)	110 (6)	111 (7)
0000 (0)	Off	0.128	0.256	0.512	1.024	2.048	4.096	8.192
0001 (1)	Off	0.256	0.512	1.204	2.048	4.096	8.192	16.384
0010 (2)	Off	0.384	0.768	1.536	3.072	6.144	12.288	24.576
0011 (3)	Off	0.512	1.024	2.048	4.096	8.192	16.384	32.768
0100 (4)	Off	0.640	1.280	2.560	5.120	10.240	20.480	40.960
0101 (5)	Off	0.768	1.536	3.072	6.144	12.288	24.570	49.152
0110 (6)	Off	0.896	1.792	3.584	7.168	14.336	28.672	57.344
0111 (7)	Off	1.024	2.048	4.096	8.192	16.384	32.768	65.536
1000 (8)	Off	1.152	2.304	4.608	9.216	18.432	36.864	73.728
1001 (9)	Off	1.280	2.560	5.120	10.240	20.480	40.960	81.920
1010 (A)	Off	1.408	2.816	5.632	11.264	22.528	45.056	90.112
1011 (B)	Off	1.536	3.072	6.144	12.288	24.576	49.152	98.304
1100 (C)	Off	1.664	3.328	6.656	13.312	26.624	53.248	106.496
1101 (D)	Off	1.729	3.584	7.168	14.336	28.672	57.344	114.688
1110 (E)	Off	1.920	3.840	7.680	15.360	30.720	61.440	122.880
1111 (F)	Off	2.048	4.096	8.192	16.384	32.768	65.536	131.072

• Here is a C program which uses the Real Time Interrupt:

```
#include "hcs12.h"
#include "vectors12.h"
#include "DDebug12.h"
#define enable() asm(" cli")
void INTERRUPT rti_isr(void);
main()
{
    DDRA = 0xff;
    PORTA = 0;
    RTICTL = 0x63; /* Set rate to 16.384 ms */
    CRGINT = 0x80; /* Enable RTI interrupts */
    CRGFLG = 0x80; /* Clear RTI Flag */
    UserRTI = (unsigned short) &rti_isr;
    enable();
    while (1)
    {
        asm(" wai"); /* Do nothing -- wait for interrupt */
    }
}
void INTERRUPT rti_isr(void)
{
    PORTA = PORTA + 1;
    CRGFLG = 0x80;
}
```

- Note that in the above program, the do-nothing loop has the instruction

```
asm("_wai"); /* Do nothing -- wait for interrupt */
```

The assembly-language instruction WAI (Wait for Interrupt) stacks the registers and puts the 9S12 into a low-power mode until an interrupt occurs.

- This allows the 9S12 to get into the ISR more quickly (because the time needed for pushing the registers on the stack has already been done), and lowers the power consumption of the 9S12 (because it doesn't have to execute a continuous loop while waiting for the interrupt).

What happens when an 9S12 gets in unmasked interrupt:

1. Completes current instruction
2. Clears instruction queue
3. Calculates return address
4. Stacks return address and contents of CPU registers
5. Sets I bit of CCR
6. Sets X bit of CCR if an XIRQ interrupt is pending
7. Fetches interrupt vector for the highest-priority interrupt which is pending
8. Executes ISR at the location of the interrupt vector

What happens when an 9S12 exits an ISR with the RTI instruction:

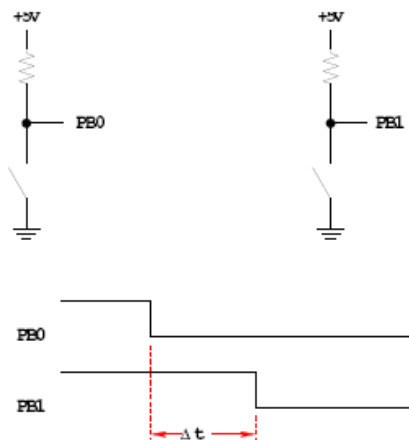
1. If no other interrupt pending,
 - (a) 9S12 recovers stacked registers
 - (b) Execution resumes at the return address
2. If another interrupt pending
 - (a) 9S12 stacks registers
 - (b) Subtracts 9 from SP
 - (c) Sets I bit of CCR
 - (d) Sets X bit of CCR if an XIRQ interrupt is pending
 - (e) Fetches interrupt vector for the highest-priority interrupt which is pending
 - (f) Executes ISR at the location of the interrupt vector

Capturing the Time of an External Event

- One way to determine the time of an external event is to wait for the event to occur, then read the TCNT register:
- For example, to determine the time a signal on Bit 0 of PORTB changes from a high to a low:

```
while ((PORTB & 0x01) != 0) ;    /* Wait while Bit 0 high */
time = TCNT;                      /* Read time after goes low */
```
- Two problems with this:
 1. Cannot do anything else while waiting
 2. Do not get exact time because of delays in software
- To solve problems use hardware which latches TCNT when event occurs, and generates an interrupt.
- Such hardware is built into the 9S12 — called the Input Capture System

Measure the time between two events

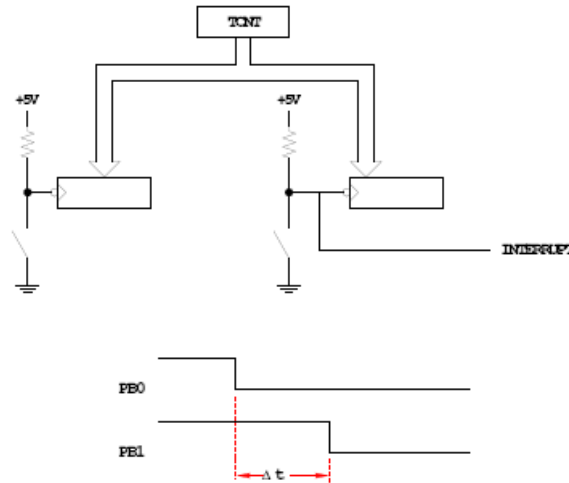


How to measure Δt ?

Wait until signal goes low, then measure TCNT

```
while ((PORTB & 0x03) == 0x01) ;
start = TCNT;
while ((PORTB & 0x03) == 0x02) ;
end = TCNT;
dt = end - start;
```

- Problems:
- 1) May not get very accurate time
 - 2) Can't do anything while waiting for signal level to change.



Solution: Latch TCNT on falling edge of signal
Read latched values when interrupt occurs

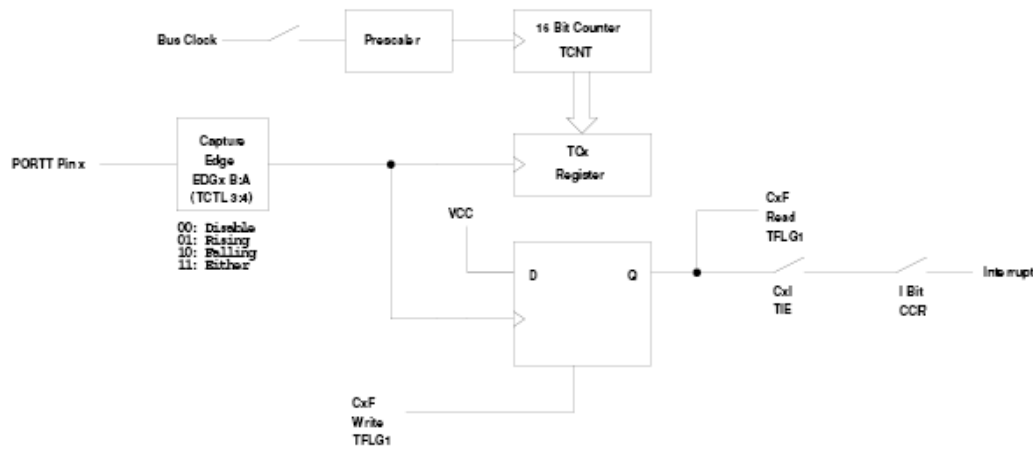
The 9S12 Input Capture Function

- The 9S12 allows you to capture the time an external event occurs on any of the eight PORTT pins
- An external event is either a rising edge or a falling edge
- To use the Input Capture Function:
 - Enable the timer subsystem (set TEN bit of TSCR1)
 - Set the prescaler
 - Tell the 9S12 that you want to use a particular pin of PORTT for input capture
 - Tell the 9S12 which edge (rising, falling, or either) you want to capture
 - Tell the 9S12 if you want an interrupt to be generated when the capture occurs

A Simplified Block Diagram of the 9S12 Input Capture Subsystem

INPUT CAPTURE

Port T Pin x set up as Input Capture (IOS_x = 0 in TOIS)



Registers used to enable Input Capture Function

Write a 1 to Bit 7 of TSCR1 to turn on timer

TEN	TSWAI	TSBCK	TFFCA					0x0046 TSCR1
-----	-------	-------	-------	--	--	--	--	--------------

To turn on the timer subsystem: TSCR1 = 0x80;

TOI	0	0	0	TCRE	PR2	PR1	PR0	0x0046 TSCR2
-----	---	---	---	------	-----	-----	-----	--------------

Set the prescaler in TSCR2

Make sure the overflow time is greater than the time difference you want to measure

PR2	PR1	PR0	Period (μ s)	Overflow (ms)
0	0	0	0.0416	2.73
0	0	1	0.0833	5.46
0	1	0	0.1667	10.92
0	1	1	0.3333	21.84
1	0	0	0.6667	43.69
1	0	1	1.3333	86.38
1	1	0	2.6667	174.76
1	1	1	5.3333	349.53

To have overflow rate of 21.84 ms:

TSCR2 = 0x03;

Write a 0 to the bits of TIOS to make those pins input capture

IOCS7	IOCS6	IOCS5	IOCS4	IOCS3	IOCS2	IOCS1	IOCS0	0x0040 TIOS
-------	-------	-------	-------	-------	-------	-------	-------	-------------

To make Pin 3 an input capture pin: $TIOS = TIOS \& \sim 0X08;$

Write to TCTL3 and TCTL4 to choose edge(s) to capture

EDG7B	EDG7A	EDG6B	EDG6A	EDG5B	EDG5A	EDG4B	EDG4A	0x004A TCTL3
-------	-------	-------	-------	-------	-------	-------	-------	--------------

EDG3B	EDG3A	EDG2B	EDG2A	EDG1B	EDG1A	EDG0B	EDG0A	0x004B TCTL4
-------	-------	-------	-------	-------	-------	-------	-------	--------------

EDGnB	EDGnA	Configuration
0	0	Disabled
0	1	Rising
1	0	Falling
1	1	Any

To have Pin 3 capture a rising edge:

$TCTL4 = (TCTL4 | 0x40) \& \sim 0x80;$

When specified edge occurs, the corresponding bit in TFLG1 will be set.

To clear the flag, write a 1 to the bit you want to clear (0 to all others)

C7F	C6F	C5F	C4F	C3F	C2F	C1F	C0F	0x008E TFLG1
-----	-----	-----	-----	-----	-----	-----	-----	--------------

To wait until rising edge on Pin 3: $\text{while} ((TFLG1 \& 0x08) == 0);$

To clear flag bit for Pin 3: $TFLG1 = 0x08;$

To enable interrupt when specified edge occurs, set corresponding bit in TMSK1 register

C7I	C6I	C5I	C4I	C3I	C2I	C1I	C0I	0x004C TIE
-----	-----	-----	-----	-----	-----	-----	-----	------------

To enable interrupt on Pin 3: $TIE = TIE | 0x08;$

To determine time of specified edge, read 16-bit result registers TC0 thru TC7

To read time of edge on Pin 3:

$\text{unsigned int time};$

$\text{time} = TC3;$