AN2593
Application note

STR91x interrupt management

Introduction

The objective of this application note is to explain the mechanism of the interrupt management hardware in the STR91x microcontroller family, and also to provide application developers with software recommendations for interrupt handling.

Contents

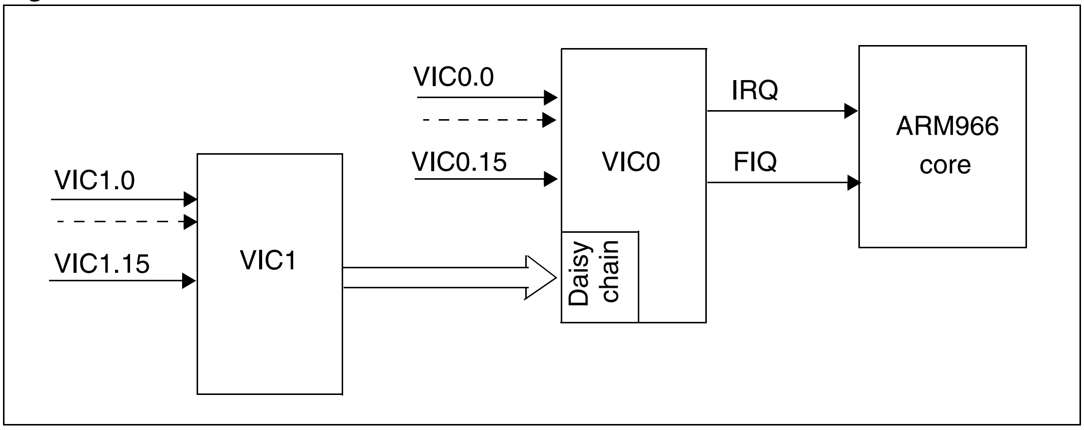
1 STR91x vectored interrupt controller VIC

1.1 VIC architecture overview

In the STR91x microcontroller, the Vectored Interrupt Controller VIC is implemented by daisy-chaining two standard ARM primecells (PL190) VICs.

Figure 1 gives an overview of the hardware connections:

Figure 1. STR91x VIC architecture



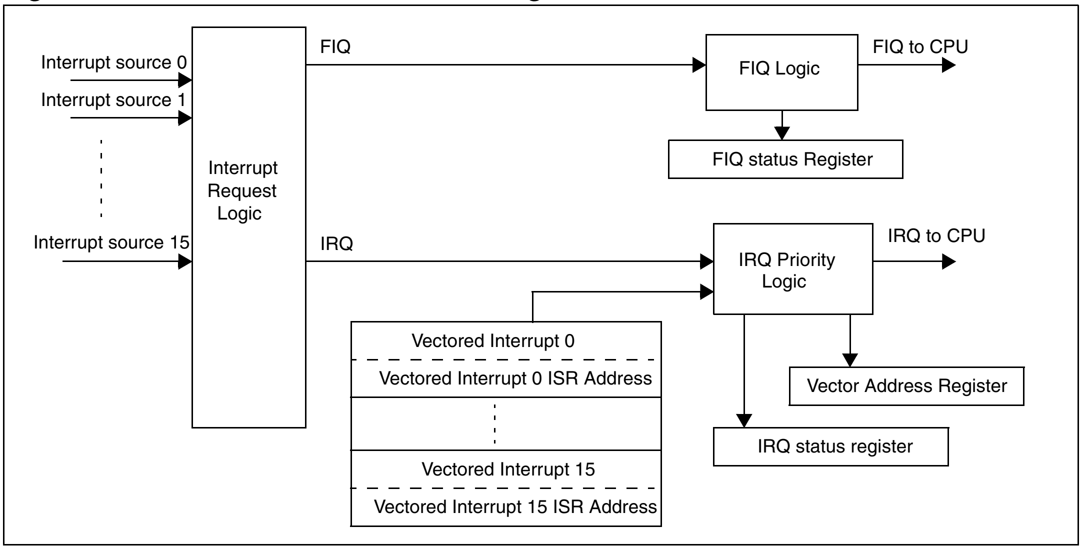
As shown in *Figure 1*, sixteen interrupt lines are connected to each VIC (see datasheet for information about each interrupt source).

The choice of connecting two VICs in a daisy-chain was made in order to allow vectored interrupt support for all 32 interrupt lines of the STR91x.

1.2 VIC operation

Figure 2 provides a schematic view of the VIC (single VIC) block diagram:

Figure 2. Overview of the VIC block diagram



1.2.1 Interrupt configurations

Any interrupt source can be configured as IRQ or as FIQ (Fast Interrupt Request).

IRQ interrupt configuration

In each VIC, an IRQ interrupt can have a priority ranging from 0 to 15 (priority 0 is the highest priority and 15 is the lowest).

In order to assign a priority level to an IRQ interrupt, using the following procedure:

1. Assign one of the vectored interrupts (from 0 to 15) to the interrupt source by configuring the selected *VIC Vector Control i register VICx_VCiR*.
2. Program the address of the interrupt service routine (ISR) in the selected vectored interrupt *Vector Address i register VIC_VAiR*.
3. Enable the IRQ interrupt by setting the corresponding bit in the *VIC Interrupt Enable register VICx_INTER*
4. Enable the selected vectored interrupt in the *VICx_VCiR* register.

Caution: Due to the VIC daisy-chained implementation, IRQ interrupts from VIC0 have always higher priority than VIC1 interrupts (hardwired priority), this means for example that an interrupt from VIC1 configured with a priority level 0 has a lower priority than a VIC0 interrupt configured with a priority level 15.

FIQ interrupt configuration

In order to configure a VIC interrupt source as FIQ, you have to set the corresponding bit in the *VIC Interrupt Select register VICx_INTSR*, and then enable the interrupt by setting the corresponding bit in the *VIC Interrupt Enable register VICx_INTER*.

Note: FIQ interrupts have the highest interrupt priority level. Unlike IRQ interrupts, FIQ interrupts have no vectored interrupt support or priority management.

Table 1 summarizes the interrupt priority levels in the VICs:

Table 1. Summary of the interrupt priorities in the VICs

Interrupt	Configured priority level in the VICs	Priority
VIC0/VIC1 FIQ	NA	Highest ↑
VIC0 IRQ	0	
	...	
	15	
VIC1 IRQ	0	
	...	
	15	↓ Lowest

1.2.2 FIQ interrupt management

For FIQ there are no priority levels. When an enabled FIQ interrupt occurs, the VIC signals it directly to the ARM core by asserting the FIQ interrupt line.

Then the ARM core switches to FIQ mode, and goes to address 0x1C where you must implement the FIQ interrupt handler.

Normally in order to lower FIQ interrupt latency only one interrupt should be configured as FIQ. But it is possible to configure several interrupts as FIQ, and in this case the application software must read the FIQ status registers of both VIC0 and VIC1 in order to determine the source of the FIQ interrupt.

When the interrupt flag is cleared in the peripheral(s) that generated the interrupt, the VIC then will stop asserting the FIQ interrupt to CPU and the flag will be cleared in the VIC FIQ status register.

1.2.3 IRQ interrupt management

There are two possible ways for handling IRQ interrupts in the VIC:

1. Vectored handling
2. Simple (Non vectored) handling

Vectored handling ensures the best interrupt latency because it takes advantage of the vectored support in the VIC.

Simple handling does not use the hardware priority management of the VIC, but it uses a software priority management. Although this method increases the interrupt latency, it can be useful in special cases where a VIC1 interrupt has to be configured with a higher priority level than a VIC0 interrupt, this is not possible when using the hardware priority management due to the hardwired priority between VIC0 and VIC1 (see *Section 1.2.1*).

Vectored handling of IRQ interrupts

When an IRQ interrupt from VIC0 or from VIC1 occurs, then depending on its priority level, two cases are possible:

- If the interrupt has a lower priority than the current interrupt being processed, then it remains pending in the VIC until it becomes the higher priority interrupt.
- If the interrupt has the highest priority level then the *VIC0 Vector Address register VIC0_VAR* will be loaded with the address of the interrupt service routine and an IRQ interrupt will be signalled to CPU.

Note: The VIC0_VAR will be loaded with the ISR address of the interrupt independently from the origin of the interrupt either from VIC0 or from VIC1.

The vectored flow for handling an IRQ interrupt is the following:

1. In the IRQ interrupt handler, the software should read the VIC0 vector address register *VIC0_VAR* in order to determine the address of the interrupt service routine and jump to it.
2. If the interrupt originates from VIC0, then reading the VIC0 vector address register in step 1 will update the priority logic of VIC0: so interrupts with the same or lower priority levels will be masked by the VIC.

   But if an interrupt originates from VIC1 then you must also perform a read from the VIC1 vector address register *VIC1_VAR* in order to update the priority logic in VIC1.
3. After finishing the interrupt processing including the clearing of the interrupt flags, you must write any value in the VIC0 vector address register if the interrupt originates from VIC0, or in the VIC1 vector address register if the interrupt is from VIC1, this in order to indicate to the VIC that interrupt processing has finished, so it can update the priority logic: then a same or lower level interrupt will be able to interrupt the CPU.

Simple (non vectored) handling of IRQ interrupts

This method of handling IRQ interrupts does not use the VIC hardware priority management, so this means you do not have to read or write the *VIC0_VAR* or *VIC1_VAR* registers to update the hardware priority logic.

This method can be used when there is a need to give higher priority to a VIC1 interrupt over a VIC0 interrupt.

The flow for simple (non vectored) IRQ handling is the following:

1. An IRQ interrupt occurs.
2. Branch to the interrupt handler.
3. Read the VICs IRQ Status registers to determine the source that generated the interrupt, and prioritize the interrupts if there are multiple active interrupt sources.
4. Branch to the corresponding interrupt service routine.
5. Execute the interrupt service routine.
6. Clear the interrupt. If a software interrupt generated the request, you must write to the VICx_SWINTCR register.
7. Check the IRQ Status registers of both VICs to ensure that no other interrupt is active. If there is an active request, go to Step 4.
8. Return from the interrupt.

2 Software recommendations for handling interrupts

2.1 Handling FIQ interrupts

When a FIQ interrupt occurs the CPU will jump to address 0x1C.

You must implement the FIQ service routine at address 0x1C.

A FIQ handler should be coded as follows:

```
@0x1C FIQHandler:
         ; save context
         ; read FIQ Status Register(VICx_FSR) to determine FIQ src
         ; service FIQ interrupt
         ; restore context
```

Normally only one interrupt source is configured as FIQ, so when this interrupt occurs, you process it directly without needing to read the VICx_FSR register to determine the interrupt source.

2.2 Handling IRQ interrupts

Note: In this section, only vectored handling of interrupts is explained.

When an IRQ interrupt occurs CPU will jump to address 0x18.

Then user has two options for managing the IRQs, the first option is:

- Jumping directly to the Interrupt service routine by doing a relative jump to the value indicated in the VIC0 Vector Address register (mapped at 0xFFFFFF030):

  @0x18 LDR PC, [PC, #-0xFF0]

If choosing this option, then you need to define your ISR as "irq" by adding the "__irq " attribute when defining the interrupt service routine function, example:

```
__irq void TIM0_IRQHandler (void) //example with IAR EWARM
```

The attribute __irq which is compiler dependent is added in order to instruct the preprocessor to add necessary code for saving the registers in the stack at the beginning of the interrupt service routine and restoring the registers at the end of interrupt processing.

The second option for servicing interrupt is:

- Jumping to an IRQHandler as a first step in which you perform a context save, then jumping to the ISR after reading the VIC0 vector address register (VIC0_VAR).

```
@0x18     LDR PC, IRQHandler
...
IRQHandler:
          ; Save context
          ; Read ISR address from VIC0 vector Address Register
          ; Branch with Link to ISR
          ; Restore context
```

For both options, in the ISR code you will need to manage the VIC priority:

- If the interrupt comes from VIC0 then you will need to write any value to *VIC0_VAR* register at the end of the interrupt processing in order to update the VIC priority. There is no need to do a read of *VIC0_VAR*, this was done when jumping to the ISR.
- If the interrupt comes from VIC1 AND if nested interrupt management (and thus also priority management) is needed then in this case you will need to do a read of VIC1_VAR at the beginning of the ISR and a write to VIC1_VAR at the end of the ISR processing in order to update the VIC1 priority logic.

2.3 Nested interrupt management

2.3.1 With interrupt nesting support

When supporting nested interrupts, an interrupt service routine can be interrupted by a higher priority interrupt.

It is important to know that the ARM core will disable IRQs when an IRQ interrupt occurs. So in order to be able to support interrupt nesting you must re-enable interrupts in the interrupt service routine, then disable them when exiting the ISR.

Two inline assembly code macros should be used: IENABLE and IDISABLE.

The IENABLE macro ensures the reenabling of interrupts in system mode in order to allow interrupt nesting. IDISABLE disables IRQs when exiting from the interrupt service routine and returning to IRQ mode.

```
#define IENABLE asm(" MRS LR, SPSR"); /* Copy SPSR_irq to LR */ \
asm("STMFD SP!, {LR} "); /* Save SPSR_irq */ \
asm("MSR CPSR_c, #0x1F ");  /* Switch to SYS mode with IRQ enabled*/ \
asm("STMFD SP!, {LR} ") ;  /* Save SYS mode LR */

#define IDISABLE asm("LDMFD SP!, {LR}") ;  /* Restore SYS mode LR */ \
asm("MSR CPSR_c, #0x92") ; /* Switch to IRQ mode with IRQ disabled*/ \
asm("LDMFD SP!, {R0}") ;  /* Restore SPSR_irq to R0 */ \
asm("MSR SPSR_cxsf, R0") ; /* Copy R0 to SPSR_irq */
```

Example : Timer0 interrupt (interrupt on VIC0)

```
void TIM0_IRQHandler (void)
{
/* switch to system mode with IRQ enabled*/
IENABLE;

/* clear interrupt flag and process interrupt */
...
...
...
/* switch to IRQ mode with IRQ disabled*/
IDISABLE;

/* write any value to VIC0 Vector address register */
VIC0->VAR = 0xFF
}
```

2.3.2 Without interrupt nesting support

If your application does not need nested interrupt support then you should not insert the IENABLE and IDISABLE macros.

But you still need to write any value to VIC0 Vector Address register at end of interrupt processing, if the interrupt originates from VIC0, this is in order to update the VIC0 priority logic after reading the VIC0 Vector Address in order to jump to the interrupt service routine.

Because there is no priority managment to be done, you are not obliged to do a read of VIC1 Vector address register at the start of a VIC1 interrupt service routine nor to do a write to this register at the end of interrupt processing.

3 Daisy-chained vectored interrupt service routine limitation

3.1 Description of the limitation

For daisy-chained interrupts, if the VAR of only one VIC is read, it does not update the hardware priority in the other VIC. This means the daisy chained interrupt controller doesn't realize the interrupt is being serviced and keeps the interrupt request active.

For daisy-chained interrupts, the processor must read the VAR register of both interrupt controllers and branch to the addresses provided. However the address provided by reading the daisy-chained VAR register must be manipulated to skip the interrupt preamble. If two daisy chained interrupts occur soon after each other and the daisy chained VAR register address isn't branched to, the interrupt controller priority logic may be updated incorrectly. This may cause a low priority interrupt to be missed.

The ARM Prime cell support team has planned to add a new section 2.2.3 in the TRM (ARM-DDI-0181E) titled 'Daisy-chained interrupt flow sequence' to provide information about the handling of daisy-chained interrupts. Consequently ST is not planning to change the interrupt handling scheme in the STR9 firmware library, instead, as recommended by ARM, we propose a workaround for handling all daisy-chained interrupts properly (see *Section 3.4*).

3.2 Impact on user applications

The above limitation can be considered a having a low severity level since problems may occur only in a few specific timing conditions when handling nested interrupts on VIC1.

Hence, customers who do not use nested interrupts on VIC1, do not have to change their software. They can safely continue with the interrupt handling as it is implemented in the STR9 firmware library.

For those who are using nesting on VIC1 in their applications, they should apply the sequence for servicing daisy-chained interrupts recommended by ARM and given here in *Section 3.3*.

3.3 Daisy-chained interrupt flow sequence

As it was stated in a previous section, there are two daisy-chained VICs in the STR91x device. VIC0 is directly connected to the CPU and VIC1 is connected to VIC0.

The daisy-chaining works as follows:

1. An interrupt occurs.
2. The ARM processor branches to either the IRQ or FIQ interrupt vector.
3. If the interrupt is an IRQ, read the VICVectAddr Register in VIC0 and branch to the interrupt service routine. You can do this using an LDR PC instruction. Reading the VICVectorAddr register updates the interrupt controller's hardware priority register.
4. Stack the workspace
5. If the interrupt is coming from a VIC1 source, read the VICVectAddr register in the daisy chained interrupt controller VIC1. Reading the VICVectorAddr Register updates

the interrupt controller's hardware priority register in the daisy chained interrupt controller. Branch to the interrupt service routine address given by VICVectorAddr for VIC1 plus offset to skip the interrupt stacking preamble. You can do this using an LDR PC instruction.

6. Execute the "IENABLE" macro so that a higher priority can be serviced.
7. Execute the Interrupt Service Routine (ISR).
8. Clear the requesting interrupt in the peripheral, or write to the VICSoftIntClear Register if the request was generated by a software interrupt.
9. Execute the "IDISABLE" macro to disable IRQs when exiting from the interrupt service routine and returning to IRQ mode.
10. Write to the daisy chained VICVectAddr Register VIC1. This clears the respective interrupt in the daisy chained interrupt controller.
11. Return from the interrupt. This re-enables interrupts.

Note: The description of the limitation and the flow sequence handling are taken mainly from the ARM Prime Cell Vectored Interrupt Controller (PL190) Errata Notice.

3.4 Workaround using the STR9 firmware library

For already existing software that services daisy-chained nested interrupts, a possible software workaround would be to branch to the address provided by the VIC1 VAR register. This ensures that the correct ISR is serviced. (Refer to *Table 2*).

To do this an inline assembly code macro could be used:

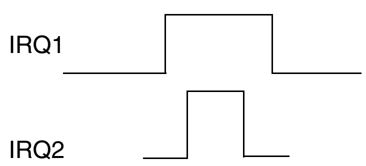
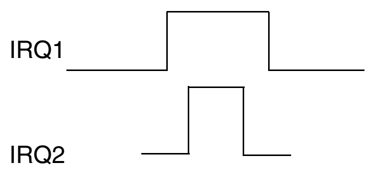
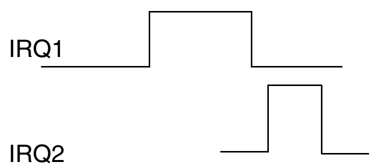
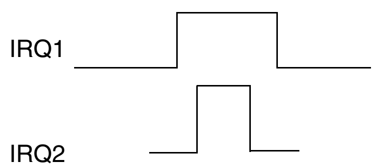
```
#define DAISY_VIC asm("MOV r11, #0xFC000000"); /*  VectorAddressDaisy address */ \
                  asm("ADD r11, r11, #0x30"); /*  VectorAddressDaisy address */ \
                  asm("LDR r11, [r11]"); /*  Update VIC1 hardware priority */ \
                  asm("ADD r11 ,r11 , #0x18"); /*  Skip the preamble (+0x18) */ \
                  asm("BX  r11");   /* Branch to the highest priority*/ \
                                    /*interrupt from VIC1 */
```

Please note that the value 0x18 used in instruction "ADD r11, r11, #0x18" is only specific to the example code given here. The offset #0x18 will be dependent on the system's interrupt stacking preamble code size.

Example: EXTI0 interrupt (interrupt on VIC1)

```
void EXTIT0_IRQHandler (void)
{
/*VIC1 Hardware Priority update and branch to the highest priority interrupt*/
DAISY_VIC;
/* switch to system mode with IRQ enabled*/
IENABLE;
/* clear interrupt flag and process interrupt */
...
...
/* switch to IRQ mode with IRQ disabled
IDISABLE;
/* Write any value to VIC1 Vector address register */
VIC1->VAR = 0xFF}
```

Table 2. Nesting of two interrupts on VIC1, with and without "DAISY_VIC" Macro

	With DAISY_VIC Macro	**Without DAISY_VIC Macro**
Priority: IRQ1 < IRQ2		
Priority: IRQ1 > IRQ2		

Note: A software project is provided with this application note, showing an example of three nested interrupts with a TIMER output compare interrupt through VIC0 and two EXTIT interrupts through VIC1.

4 Spurious VIC interrupts

4.1 Definition

Spurious interrupts are a characteristic of the VIC. This is due to the pipelined architecture of the ARM core.

We know that when an interrupt occurs and it has the highest priority level, the VIC signals an IRQ interrupt to the CPU and the VIC0 vector address register is loaded with the ISR address.

Now suppose that just after having asserted the IRQ signal to the CPU, due to certain root causes which are explained in the next section (*Section 4.2*), the interrupt source to VIC is cleared, then in this case the VIC0 vector address register won't be loaded with the ISR address because the interrupt source was cleared in VIC. Instead, a default value is loaded from the Defaut Vector Address register VIC0_DVAR.

So consequently the CPU will then jump to the default vector instead of the interrupt ISR address: this is what we call "Spurious Interrupt".

4.2 Root causes and handling of spurious interrupts

The reason why an interrupt in VIC could get cleared before being serviced is the fact that CPU continues to executes some code in the pipeline before servicing the interrupt, and this code in the pipeline could either:

1. Clear the interrupt flag in the peripheral, so the interrupt is no longer asserted to the VIC
2. The code in the ARM pipeline disables the interrupt in the VIC

Note: The reset value of the VIC0 Default Vector Address register is 0x0 so when a spurious interrupt occurs the CPU will jump to address 0x0, which gives a surprising RESET-like behavior.

In some applications, you can not avoid the possiblility of spurious interrupts occurring.

An example of this, is when you are working on peripherals with FIFO support like UART, in these peripherals, the FIFO receive/transmit interrupt flags may be cleared simply by a read/write in the FIFO, so it could be possible that an interrupt has been signalled to the VIC but you have executed some code in pipeline which accessed the FIFO.

In order to avoid the surprising reset-like behaviour, it is important to assign a dummy handler to the Default vector address registers of VIC0 and VIC1.

```
VIC0->DVAR = (u32)Dummy_Handler;
VIC1->DVAR = (u32)Dummy_Handler;
```

In this dummy handler just write any value to VIC0 and VIC1 vector address registers.

```
void Dummy_Handler(void)
{
VIC0->VAR = 0xFF;
VIC1->VAR = 0XFF;
}
```

5 Revision history

Table 3. Document revision history

Date	Revision	Changes
31-Jan-2008	1	Initial release
26-Jan-2009	2	Added *Section 3: Daisy-chained vectored interrupt service routine limitation on page 10*