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Application Note

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Brown-out Protection for S08 MCUs

by:

Derek Lau, Y.H. Cheng
Hong Kong
China

1 Introduction

The S08 series MCUs include a low voltage detection (LVD) circuit to protect against brown-out conditions where the supply voltage (V_{DD}) drops below the minimum required operating voltage (V_{DDmin}). Under brown-out conditions, the program may runaway, and cause corruption of memory and register contents.

Improper configurations of the LVD may leave the MCU with no protection under brown-out conditions, especially when the CPU is running at the maximum allowed frequency.

This application note describes the parameters to consider when setting the LVD, and provides examples to show how different situations can be managed.

2 Considerations

The following parameters have to be considered when designing a suitable LVD setting:

- Low voltage detection threshold
- Low voltage warning threshold
- Operating voltage
- CPU frequency

Contents

Table 1. Parameters to be considered

Devices	Descriptions	Symbol	Condition	Min	Max
MC9S08JE/MM	low voltage detection threshold high range	V_{LVDH}	V_{DD} falling	2.11 V	
	low voltage detection threshold low range	V_{LVDL}	V_{DD} falling	1.80 V	
	low voltage warning threshold high range	V_{LVWH}	V_{DD} falling	2.36 V	
	low voltage warning threshold low range	V_{LVWL}	V_{DD} falling	2.11 V	
	CPU bus frequency	f_{BUS}	1.8V < V_{DD} <= 2.1 V		10 MHz
			2.1V < V_{DD} <= 2.4 V		20 MHz
			2.4V < V_{DD} <= 3.6 V		**24** MHz
	low voltage detection threshold	V_{LVD}	V_{DD} falling		
MC9S08LL	low voltage warning threshold	V_{LVW}	V_{DD} falling		
	CPU bus frequency	f_{BUS}	1.8V < V_{DD} <= 2.1 V		10 MHz
			2.1V < V_{DD} <= 3.6 V		20 MHz

The above table uses MC9S08JE, LL and MM series MCUs as examples to show the parameters to be considered. We have to look into the DC and the AC characteristics of individual devices. There is a minimum voltage requirement for an MCU to operate at certain CPU frequency. For example, the MC9S08JE MCU requires a minimum operating voltage (V_{DDmin}) of 1.8 V, 2.1 V, and 2.4 V to operate normally at a bus frequency of 10 MHz, 20 MHz, and 24 MHz respectively. The low voltage detection threshold (V_{LVD}), when the V_{DD} is falling, must be greater than or equal to the V_{DDmin}. Otherwise, program runaway during brown-out conditions may occur.

2.1 Low voltage detection trip point

The general rule is to choose a low voltage trip point greater than or equal to the V_{DDmin}. Some devices have only one LVD trip point while others may have two or more. Taking MC9S08JE MCU as an example, there are two LVD trip points; one is the LVD high range (V_{DD} falling) of 2.11 V and LVD low range (V_{DD} falling) of 1.80 V.

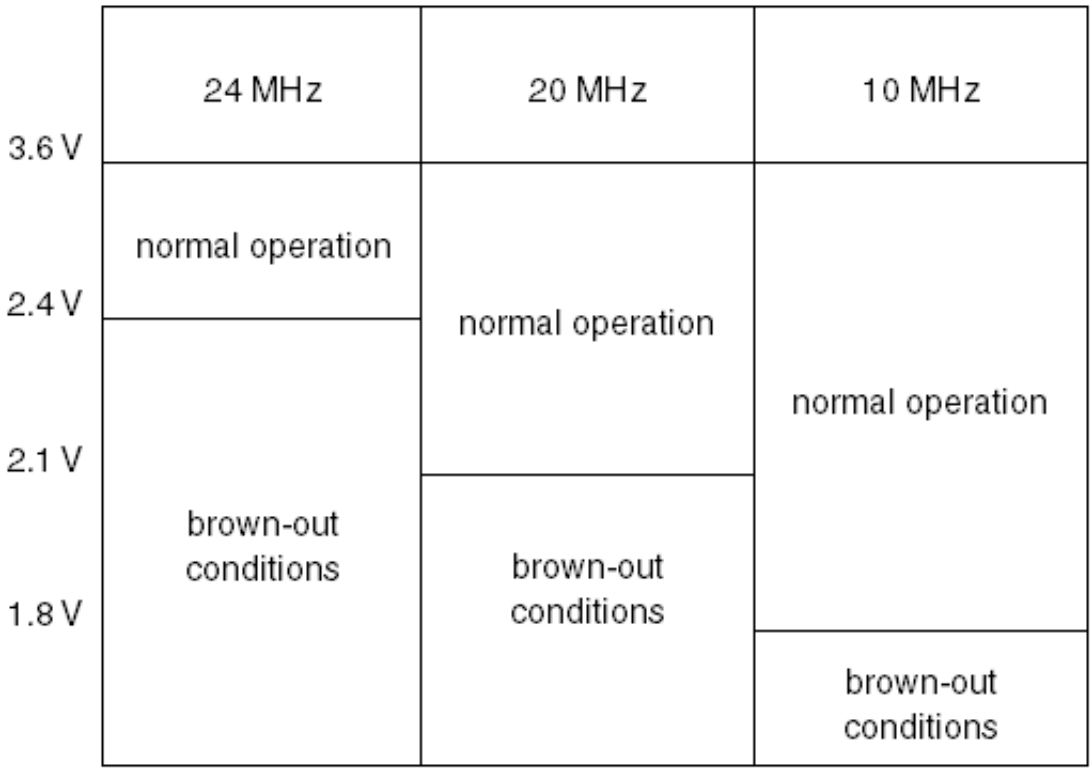

Figure 1. Bus frequency and operating voltage of MC9S08JE MCU

The bus frequency affects the selection of the LVD trip point. When the MC9S08JE MCU operates at a bus frequency of 20 MHz, choosing V_{LVDH} of 2.11 V with value greater than the V_{DDmin} of 2.1 V can provide brown-out protection. Choosing V_{LVDL} of 1.8 V is not suitable because brown-out conditions occur when V_{DD} falls between the voltage range of 1.8 V and 2.1 V. There may be some situations that there is no LVD available that is greater than or equal to the V_{DDmin}. For example, when the CPU operates at 24 MHz, the V_{DDmin} is 2.4 V, but the maximum V_{LVD} that can be chosen is V_{LVDH} of 2.11 V, which is below 2.4 V. Therefore, you must rely on the low voltage warning detection to provide brown-out protection. The following table shows the low voltage trip points selected for different bus frequencies.

Table 2. Suitable low voltage detection/warning setting

MCU	f_{BUS}	V_{DDmin}	LVD/LVW
MC9S08JE/MM	10 MHz	1.8 V	V_{LVDL} (1.8 V)
	20 MHz	2.1 V	V_{LVDH} (2.11 V)
	24 MHz	2.4 V	V_{LVWH} (2.36 V)
MC9S08LL	10 MHz	1.8 V	V_{LVD} (1.80 V)
	20 MHz	2.1 V	V_{LVW} (2.08 V)

2.2 Enable low voltage detection setting

The proper low voltage detection reset or interrupt should be set to provide brown-out protection as early as possible, and must be set before increasing the bus frequency. If low voltage detection or warning interrupt is used, the interrupt mask should be clear before increasing the bus frequency.

3 Managing low voltage detection/warning

The low voltage detection can be configured to output reset or interrupt, while the low voltage warning can only output interrupt. There are two suggestions for how to manage the low voltage detection/warning interrupt:

- Reset the MCU
- Reduce the bus frequency

The first method of resetting the MCU provides for the LVW to generate a reset as an equivalent function of the LVD reset.

3.1 Resetting the MCU

The MCU can be reset by putting an illegal opcode in the interrupt routine. The instruction “BGND” of opcode 0x82 is selected because the BGND instruction is considered illegal if the MCU is running at normal user mode. This can be achieved by putting the following instruction into the interrupt routine:

```
asm BGND// illegal opcode reset
```

NOTE

Some programs use 0x8D or 0xAC as illegal opcodes to reset the MCU. It is not possible for the S08 MCU with version 4 (S08CPUV4) or above, as they are assigned to RTC and CALL instructions. The version of the CPU is shown at the chapter title of Central Processor Unit.

3.2 Reducing the bus frequency

The bus frequency can be reduced by setting the bus frequency divider (BDVI) bits of the MCG control register 2. The BDIV bits can be changed at any time, and the actual switch to the new frequency will occur immediately.

3.3 Implementations

The following examples are used to elaborate how to reset the MCU or change the bus frequency by reference to the MC9S08JE/MM MCU.

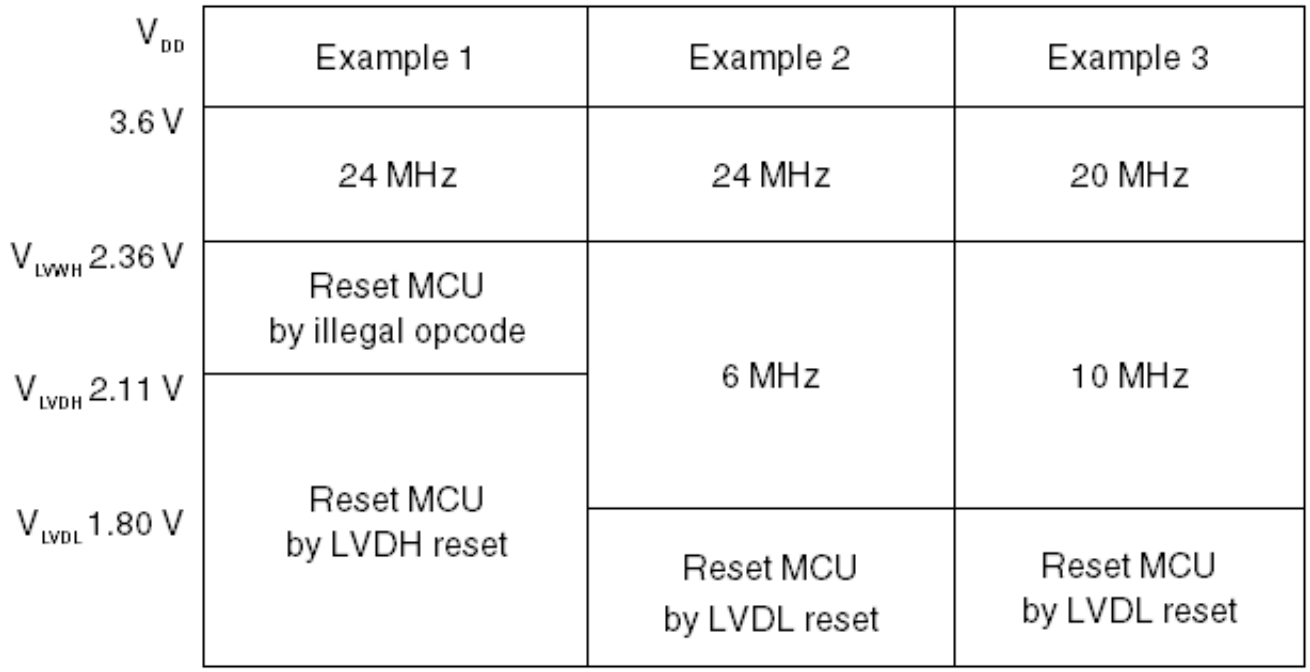

Figure 2. Examples of LVD settings

3.3.1 Example 1

This example is for normal operating bus frequency of 24 MHz. The MCU will be reset if the V_{DD} drops below the V_{LVWH}. The assembly implementation of the interrupt routine is preferred because the illegal opcode will immediately be detected, while the c implementation requires PSHH instruction be executed before the illegal opocde can be detected.

```
void MCU_init(void){
SPMSC1 = 0x1C;/* enable low voltage detection reset */
SPMSC3 =0x38;/* set LVDH, LVWH and enable LVW interrupt */
}

"for c implementation:"
__interrupt void isrVlvd(void){
asm BGND;/* illegal opcode reset */
}

 "for asm implementation:"
           XDEF  isrVlvd
isrVlvd: BGND;/* illegal opcode reset */
```

3.3.2 Example 2

This example is for the bus frequency of 24 MHz. The low voltage warning interrupt routine will be called if the V_{DD} drops below V_{LVWH}. In the interrupt routine, the bus frequency will be reduced to 6 MHz. It waits until the low voltage warning is not detected for a certain period of time (half of the for loop wait time). If no LVW is detected, the original 24 MHz bus frequency is used. If COP reset is enabled, the routine should also feed the watchdog.

```
void MCU_init(void){
SPMSC1 = 0x1C;/* enable low voltage detection reset */
SPMSC3 =0x18;/* set LVDL, LVWH and enable LVW interrupt */
```

```
}

__interrupt void isrVlvd(void)
{
MCGC2=0x80;/* reduce the frequency to ¼ original frequency
   to reduce cycle time, MCGC2_BDIV= 2 is not used */
VlvdLoop();
{

Void VlvdLoop(void)
{
  unsigned int i;

for (i=0; i<0xFFFF; i++){
if (SPMSC3_LVWF==1){
SPMSC3_LVWACK=1;/* clear LVW flag */
MCGC2_BDIV= 2;/* reduce the frequency to ¼ original frequency*/
i=0;
 }
 if (i>=7FFF){
 MCGC2_BDIV= 0; /* set back the original frequency */
 }
}
}
```

3.3.3 Example 3

This example shows how the bus frequency can be switched between 20 MHz and 10 MHz according to the V_{DD}. The LVW interrupt routine will be called if the V_{DD} drops below V_{LVWH}. In the interrupt routine, the bus frequency will be reduced to 10 MHz, and the LVWH interrupt will be disabled. A 20 ms timer interrupt will be enabled to check if the LVWH flag is set. If no LVWH flag is set for 40 ms, the bus frequency will be set to 20 MHz.

```
void MCU_init(void){
SPMSC1 = 0x1C;/* enable LVD reset */
SPMSC3 =0x18;/* LVDL and LVWH are set, LVW interrupt enabled */
TPM1SC = 0x00; /* stop and reset counter */
TPM1MOD = 0x00U;/* period value setting */
(void)(TPM1SC == 0);/* overflow int. flag clearing (first part) */
TPM1SC = 0x4C;  /* int. flag clearing (2nd part) and timer control register setting */
 asm CLI;                              /* enable interrupts */
}

__interrupt void isrVtpm1ovf(void)
{
  static byte LVW_NotDetectedCount=0;
  TPM1SC_TOF=0;/* clear timer interrupt flag */
  if (SPMSC3_LVWF==1){      /* low voltage detected */
    if (SPMSC3_LVWIE==0)/* don't clear LVW flag if LVW interrupt enable */
      SPMSC3_LVWACK = 1; /* clear LVW flag */
   LVW_NotDetectedCount=0;       /* LVW detected */
  }
  else{
    if (++LVW_NotDetectedCount>0x2){
      MCGC2_BDIV = 0;       /* frequency = 20 MHz */
      SPMSC3_LVWIE = 1;      /* enable LVW interrupt */
      TPM1SC_TOIE=0;        /* disable timer interrupt */
    }
  }
}

__interrupt void isrVlvd(void)
{
MCGC2_BDIV = 1; /* reduce the frequency by half */
SPMSC3_LVWIE = 0;/* disable LVW interrupt */
  SPMSC3_LVWACK = 1;/* clear LVW flag */
```

```
  TPM1SC_TOIE = 1;/* enable timer interrupt */
}
```

4 Further protection

Under brown-out conditions, the program runaway, and corruptions of memory and registers contents may occur. You can further protect the memory and registers contents by protecting the flash contents and filling the unused flash area with an illegal opcode of “0x82”.

4.1 Protecting Flash Contents

It is a good practice to protect the flash contents by setting the Nonvolatile Flash Protection register (NVPROT) or the Flash Protection register (PROT). For some S08 MCUs, it is not possible to decrease the flash protection and hence, it is not possible to protect all the flash areas for some applications with bootloader or EEPROM emulation. Some S08 MCUs, including the MC9S08JE and MM series MCUs, have added the Flash Protection Defeat register (FPROTD) which enables decreasing flash protection. Applications with bootloader or EEPROM emulations can follow the steps below for flash protection:

1. Protect all flash by programming NVPROT to zero:

   ```
   const byte NVPROT_INIT @0x0000FFBD = 0x00; // protect all flash
   ```

2. Unprotect the flash areas to be programmed:

   ```
   FPROTD = 0x55;
   FPROTD = 0xAA;// enable decrease flash protection
   FPROT = 0x03; // unprotect 0x10000-0x107FF
   FPROTD = 0;// disable decrease flash protection
   /* programming flash  */
   ```

3. Protect all flash areas:

   ```
   FPROT = 0;         // protect all flash
   ```

4.2 Filling Unused Flash Areas

When using codewarrior version 6.3, unused flash area can be filled using the FILL command in the linker parameter file, project.prm. The following code tells the linker to fill 0x82 into all unused flash areas of 0xC000 to 0xFF9D.

```
ROM =  READ_ONLY    0xC000 TO 0xFF9D FILL 0x82;
```

5 Conclusions

The S08 series MCUs include a low voltage detection (LVD) circuit to protect against brown-out conditions. The default low voltage detection reset is normally set for low bus frequency operation. The LVD settings should be set according to the bus frequency and DC characteristics of the individual device. In general, do not let the MCU fall into brown-out conditions without protection.

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Europe, Middle East, and Africa:
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Japan:
Freescale Semiconductor Japan Ltd.
Headquarters
ARCO Tower 15F
1-8-1, Shimo-Meguro, Meguro-ku,
Tokyo 153-0064
Japan
0120 191014 or +81 3 5437 9125
support.japan@freescale.com

Asia/Pacific:
Freescale Semiconductor China Ltd.
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China
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support.asia@freescale.com

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