

# Software Developer’s Guide for PGA411-Q1

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## ABSTRACT

The objective of this guide is to explain high-level software flow for platform development with the PGA411-Q1 device.

This report starts with a high-level overview of the software development flow, describing various functions and abstractions. Then, the report then describes three layers which are: the main program loop, the PGA411-Q1 specific functions, and the hardware abstraction layer that can be adapted to any controller while keeping everything else as it is. The example software is based on a 32-bit C2000™ microcontroller.

## Contents

1	Introduction to High-Level Software Flow .....	2
2	<i>main.c</i> File .....	2
3	PGA411-Q1 Driver File <i>pga411.c</i> and <i>pga411.h</i> .....	5
3.1	PGA411-Q1 CRC Calculation Function.....	5
3.2	PGA411-Q1 Initialization Function.....	6
3.3	Default Configuration Function.....	7
3.4	SPI Communication Function .....	8
3.5	SPI Read Function.....	8
3.6	SPI Write Function.....	9
3.7	SPI Read All Function.....	9
3.8	PGA411 Change State Function .....	10
3.9	Device Unlock Function .....	10
3.10	EEPROM Unlock Function.....	10
4	HAL Hardware Layer (C2000 Specific)— <i>hal.c</i> and <i>hal.h</i> (32 bit) .....	11
4.1	PGA411-Q1 GPIO Initialization.....	11
4.2	PGA411-Q1 SPI Initialization .....	14
4.3	SPI Transmit and Receive Function .....	15
4.4	Digital Parallel Output.....	15
4.5	UART Initialization.....	16
4.6	Reading Angle and Velocity .....	18
4.7	GPIO Configuration (Input and Output) .....	19
4.8	System Initialization .....	22
5	Acknowledgments .....	23

## List of Figures

1	Software Flowchart .....	2
2	Software Sequence Flowchart .....	3
3	Initialization Sequence .....	6
4	Default Configuration Sequence.....	7
5	PGA411-Q1 SPI Response Frames .....	8
6	Block Diagram Showing High-Level Connection of TIDA-00796 .....	11
7	ORD Timing Characteristics .....	16

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## 1 Introduction to High-Level Software Flow

Figure 1 shows the high-level overview of the software flow.

There are three main components of the software flow.

1. The main.c file
2. The pga411.c file
3. The hal.c file

The hal.c file must be modified depending on the controller used in the application.

The *main.c* program loop implements the routine shown in Figure 1 for reading angle and velocity from the PGA411-Q1 device. The PGA411-Q1 related functions are called from the *pga411.c* file and the C2000 related code and functions are called from the *hal.c* file which is described in this guide. The functions are defined in the *hal.h* and *pga411.h* header files. The code used for the following explanation is based on the TIDA-00796 PGA411-Q1 files (refer to [Automotive Resolver-to-Digital Converter Reference Design for Safety Application](#)).

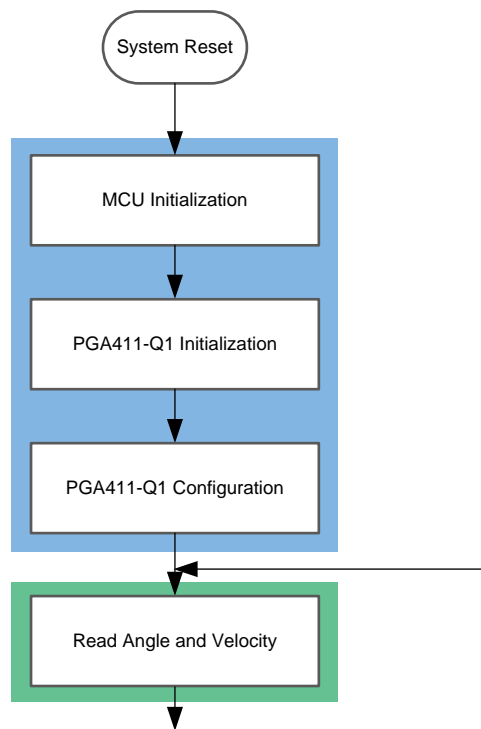
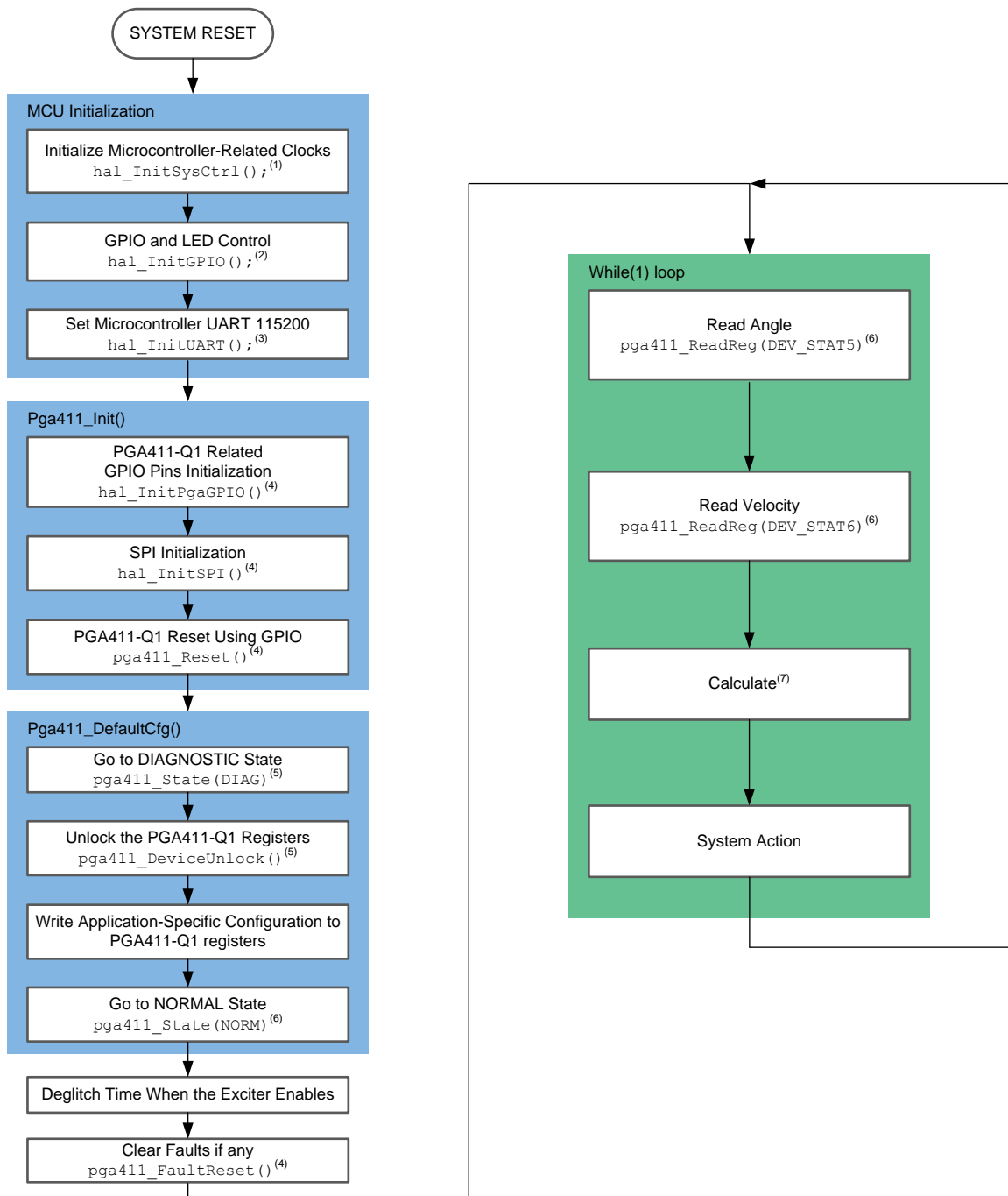


Figure 1. Software Flowchart

## 2 main.c File

Figure 1 shows the high level software chart. Figure 2 shows the flow chart for the sequence of software actions that are followed and how these actions are mapped to the software functions.

The functions starting with *PGA411*, such as *pga411\_DefaultCfg()*, are called from the *pga411.c* file that is described in Section 3. The functions starting with *hal*, such as *hal\_ToggleLED()*, are called from the *hal.c* that is described in Section 4.



- (1) See [Section 4.8](#).
- (2) See [Section 4.7](#).
- (3) See [Section 4.5](#).
- (4) See [Section 3.2](#).
- (5) See [Section 3.3](#).
- (6) See [Section 3.8](#).
- (7) See [Section 4.6](#).

Figure 2. Software Sequence Flowchart

**NOTE:** The functions starting with PGA411-Q1, such as pga411\_DefaultCfg(), are called from the pga411.c file that is described in [Section 3](#) and are required for PGA411-Q1.

The functions starting with hal, such as hal\_ToggleLED(), are called from the hal.c that is described in [Section 4](#) and are required for the controller only.

```
int main(void)
{
    /* copy fast codes from FLASH to RAM if running from FLASH */
#ifdef DEBUG
    memcpy(&RamfuncsRunStart, &RamfuncsLoadStart, (UInt32)&RamfuncsLoadSize);
#endif
    hal_InitSysCtrl(); /* inits clock domains, PLL */
    hal_InitGPIO(); /* practically default config + LED */
    hal_InitUART(); /* inits UART 115200 8N1 */
    pga411_Init(); /* inits PGA411 driver */
    pga411_DefaultCfg(); /* default config defined in "pga411_regs" */
    HAL_DELAY_US(10000); /* 10 ms deglitch period when the exciter enables */
    pga411_FaultReset(); /* clear faults if any */

    /* endless loop */
    while (1)
    {
        HAL_DELAY_US(100000); /* 100 ms delay */
        hal_ToggleLED(); /* LED on the controlSTIC is blinking periodically */
        /* VT100 */
        hal_PutsUART(VT100_CLRSCR); /* clear entire screen */
        hal_PutsUART(VT100_GOHOME); /* more cursor to upper left corner */
        /* read angle and print */
        main_GetAngleAndPrint();
        /* read velocity and print */
        main_GetVeloAndPrint();
    }

#pragma diag_suppress 112 /* to get rid of warning that code is unreachable */
    return 0;
#pragma diag_default 112 /* restore error level */
}
```

### 3 PGA411-Q1 Driver File *pga411.c* and *pga411.h*

#### 3.1 PGA411-Q1 CRC Calculation Function

This CRC calculation routine is designed for a 32-bit C2000 little endian controller. Verify the output of the routine with the examples listed in [Table 1](#) or see the [PGA411-Q1 Resolver Sensor Interface](#) data sheet. The SPI uses the 24 most significant bits (MSBs) of the SPI frame to generate a CRC value or to check for SPI CRC errors. The polynomial in [Equation 1](#) is applied for CRC calculation on both the master and slave SPI frames.

$$\text{SPI\_CRC6} = X^6 + X^4 + X^3 + X + 1 \quad (1)$$

The operation occurs one bit at a time and begins with the MSB. The initial seed value is 0x3F.

---

**NOTE:** The input of the function corresponds to a complete 32 bit frame but only top 24 bits are used for the calculation.

---

**Table 1. SPI CRC Examples**

24-BIT SPI FRAME	CRC-6
0xAE0000	0x11
0x950055	0x22
0x855555	0x29
0x0D2FFE	0x0D
0x85FFFF	0x38

```

/* CRC6 calculation - optimized for PGA411 */
Uint16 pga411_crc2(Uint32 datin)
{
    Uint16 byte_idx, bit_idx, crc = (CRC_INITSEED << 2);

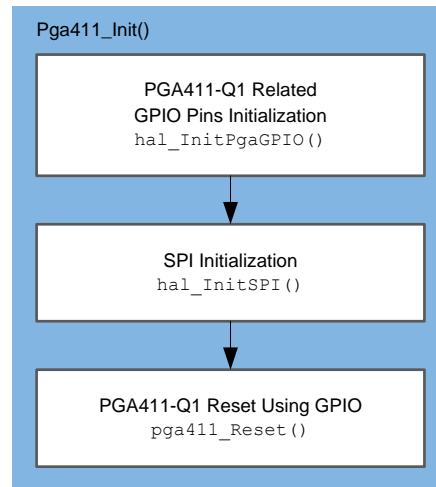
    /* byte by byte starting from most significant (3-2-1) */
    for (byte_idx = CRC_BYTECOUNT; byte_idx >= 1; byte_idx--)
    {
        /* XOR-in new byte from left to right */
        crc ^= ((datin >> (byte_idx << 3)) & 0x000000FF);

        /* bit by bit for each byte */
        for (bit_idx = 0; bit_idx < 8; bit_idx++)
        {
            crc = crc << 1 ^ (crc & 0x80 ? (CRC_POLYNOM << 2) : 0);
        }
    }

    return (crc >> 2 & CRC_INITSEED); /*restore two bit offset */
}

```

### 3.2 PGA411-Q1 Initialization Function



**Figure 3. Initialization Sequence**

The following function and routines enable SPI communication that calls the functions defined in [Section 4](#).

```

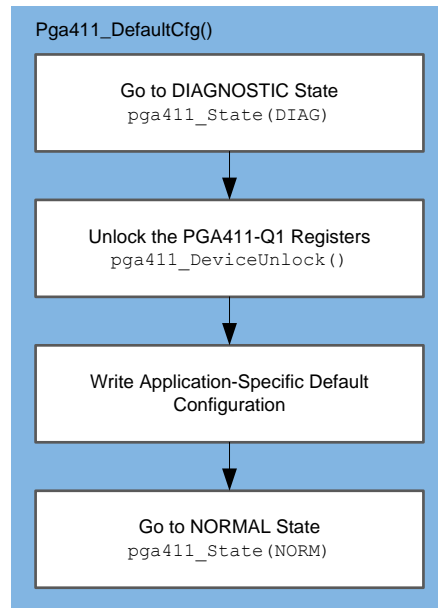
/* Initialization PGA411-Q1 related hardware */
void pga411_Init(void)
{
    hal_InitPgaGPIO(); /* init GPIO */
    hal_InitSPI(); /* init SPI periphery */
    pga411_Reset(); /* perform PGA411 reset */
}

/* Perform PGA411-Q1 reset using GPIO */
void pga411_Reset(void)
{
    HAL_PGA_RESET_N_LOW; /* RESET_N low */
    HAL_DELAY_US(500); /* hold in reset for 500us */
    HAL_PGA_RESET_N_HIGH; /* release from reset */
    HAL_DELAY_US(10000); /* wait at least 10 ms*/
}

/* Perform PGA411-Q1 FAULT reset using GPIO */
void pga411_FaultReset(void)
{
    HAL_PGA_FAULTRES_LOW; /* assert FAULTRES low - open collector */
    HAL_DELAY_US(1000); /* hold in the state for 1ms */
    HAL_PGA_FAULTRES_HIZ; /* return back to high-z*/
}
  
```

### 3.3 Default Configuration Function

This function writes the default configuration into the PGA411-Q1 device.



**Figure 4. Default Configuration Sequence**

```

/* Write default configuration to PGA */
void pga411_DefaultCfg(void)
{
    int i;
    /* go to diagnostic state */
    pga411_State(DIAG);
    /* unlock registers */
    pga411_DeviceUnlock();

    /* first 12 registers to default */
    /* note: for some u need to unlocked them first ! */
    for (i = 0; i < 12; i++)
    {
        pga411_XmitSPI(WRITE, i, pga411_regs[i].def_val);
    }

    /* go to normal state */
    pga411_State(NORMAL);
}
  
```

### 3.4 SPI Communication Function

The following function is for SPI communication that calls the functions defined in [Section 4](#). Depending on the *dir* parameter, the appropriate SPI address is selected.

```

/* Xmit data to PGA over SPI, for reg use defined macros */
pga411_spi_frame_t pga411_XmitSPI(Uint16 dir, Uint16 reg, Uint16 wdata)
{
    pga411_spi_frame_t out, in;

    /* do we read data ? */
    if (dir == READ) { out.addr = pga411_regs[reg].read_addr; } /* read address */
    /* or write data ? */
    else { out.addr = pga411_regs[reg].write_addr; } /* write address */

    /* compose the rest of the frame */
    out.dataout = wdata; /* real data (W) or dummy data (R) */
    out.reserved = 0x00; /* always zero */
    out.mcrc = pga411_crc2(out.frame); /* calculate TX CRC */
    in.frame = hal_Xmit4BSPI(out.frame);

    /* check RX CRC */
    if (pga411_crc2(in.frame) != in.scr)
    {
        hal_assert(); /* if error -> terminate */
    }

    return (in);
}
    
```

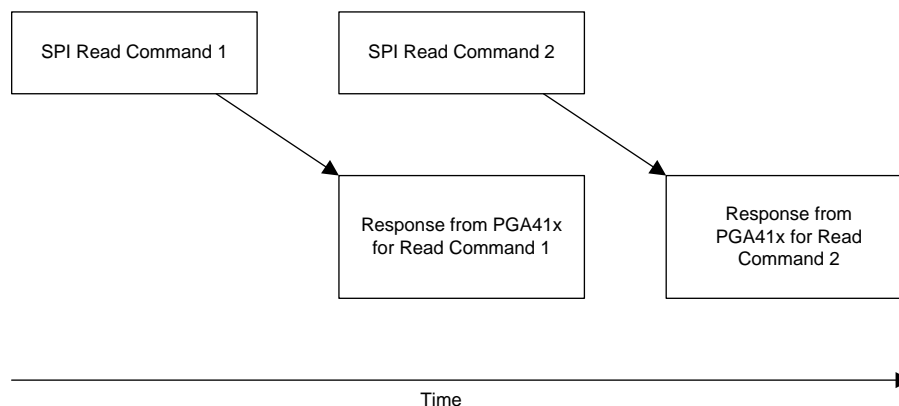
### 3.5 SPI Read Function

The following function is for a SPI read. The response from SPI frame *N* reports the angle captured by SPI frame *N – 1*.

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**NOTE:** Upon receiving a SPI read of the angle or velocity data, the PGA411-Q1 device goes through 1 to 2 clock cycles to load the angle or velocity data into the SPI to send out.

---



**Figure 5. PGA411-Q1 SPI Response Frames**

```

/* Read data from defined register */
Uint16 pga411_ReadReg(Uint16 reg)
{
    /* first read returns whatever */
    pga411_XmitSPI(READ, reg, SPI_DUMMY);
    /* second read returns requested data */
    return (pga411_XmitSPI(READ, reg, SPI_DUMMY).datain);
}
    
```



### 3.6 SPI Write Function

The following function is for a SPI write.

```
/* Write data to defined register */
void pga411_WriteReg(Uint16 reg, Uint16 data)
{
    /* here we just making it nice, can be macro too */
    pga411_XmitSPI(WRITE, reg, data);
}
```

### 3.7 SPI Read All Function

The following function is for a SPI read all.

```
/* Read all registers from PGA */
void pga411_ReadAll(void)
{
    int i;
    Uint16 rx_data;

    /* register by register (27+1) */
    /* PGA411 always returns previous read register value */
    /* thats why 28 reads are needed (first read returns whatever data) */
    for (i = 0; i < PGA411_REG_COUNT + 1; i++)
    {
        rx_data = pga411_XmitSPI(READ, i, SPI_DUMMY).datain;

        /*boolean trick - save data if not first cycle */
        if (i)
        {
            pga411_regs[i - 1].real_val = rx_data;
        }
    }
}
```

### 3.8 PGA411 Change State Function

This function changes between the DIAGNOSTIC and NORMAL states based on the state parameter (defined by enum).

```
enum {READ, WRITE}; /* Enmus selects SPI operation */
enum {DIAG, NORMAL}; /* Operational states of PGA */
/* Change state diagnostic/normal */
void pga411_State(Uint16 state)
{
    Uint16 temp;

    /* Enter Diagnostic state */
    if (state == DIAG)
    {
        /* read content of DEV_CONTROL3 register */
        temp = pga411_ReadReg(DEV_CONTROL3);
        temp |= 0x0004; /* set bit SPIDIAG */
        pga411_WriteReg(DEV_CONTROL3, temp); /* finish R-M-W */
    }
    /* Go back to normal state */
    else
    {
        /* read content of DEV_CONTROL1 register */
        temp = pga411_ReadReg(DEV_CONTROL1);
        temp |= 0x0001; /* set bit DIAGEXIT */
        pga411_WriteReg(DEV_CONTROL1, temp); /* finish R-M-W */
    }
}
```

### 3.9 Device Unlock Function

---

**NOTE:** To access the DEV\_CONTROL1 and DEV\_CONTROL2 registers, a predefined device unlock sequence must be applied to the DEV\_UNLK\_CTRL1 register in the following order:

1. Write 0x000F to DEV\_UNLK\_CTRL1
  2. Write 0x0055 to DEV\_UNLK\_CTRL1
  3. Write 0x00AA to DEV\_UNLK\_CTRL1
  4. Write 0x00F0 to DEV\_UNLK\_CTRL1
- 

```
/* Device unlock (must be in diagnostic state) */
void pga411_DeviceUnlock(void)
{
    pga411_WriteReg(DEV_UNLK_CTRL1, 0x000F);
    pga411_WriteReg(DEV_UNLK_CTRL1, 0x0055);
    pga411_WriteReg(DEV_UNLK_CTRL1, 0x00AA);
    pga411_WriteReg(DEV_UNLK_CTRL1, 0x00F0);
}
```

### 3.10 EEPROM Unlock Function

---

**NOTE:** To access the DEV\_EE\_CTRL1, a predefined EEPROM unlock sequence must be applied to the DEV\_EE\_CTRL4 register in the following order:

1. Write 0x000F to DEV\_EE\_CTRL4
  2. Write 0x0055 to DEV\_EE\_CTRL4
  3. Write 0x00AA to DEV\_EE\_CTRL4
  4. Write 0x00F0 to DEV\_EE\_CTRL4
- 

```
/* EEPROM unlock (must be in diagnostic state) */
void pga411_EEPROMUnlock(void)
```

```

{
    pga411_WriteReg(DEV_EE_CTRL4, 0x000F);
    pga411_WriteReg(DEV_EE_CTRL4, 0x0055);
    pga411_WriteReg(DEV_EE_CTRL4, 0x00AA);
    pga411_WriteReg(DEV_EE_CTRL4, 0x00F0);
}

```

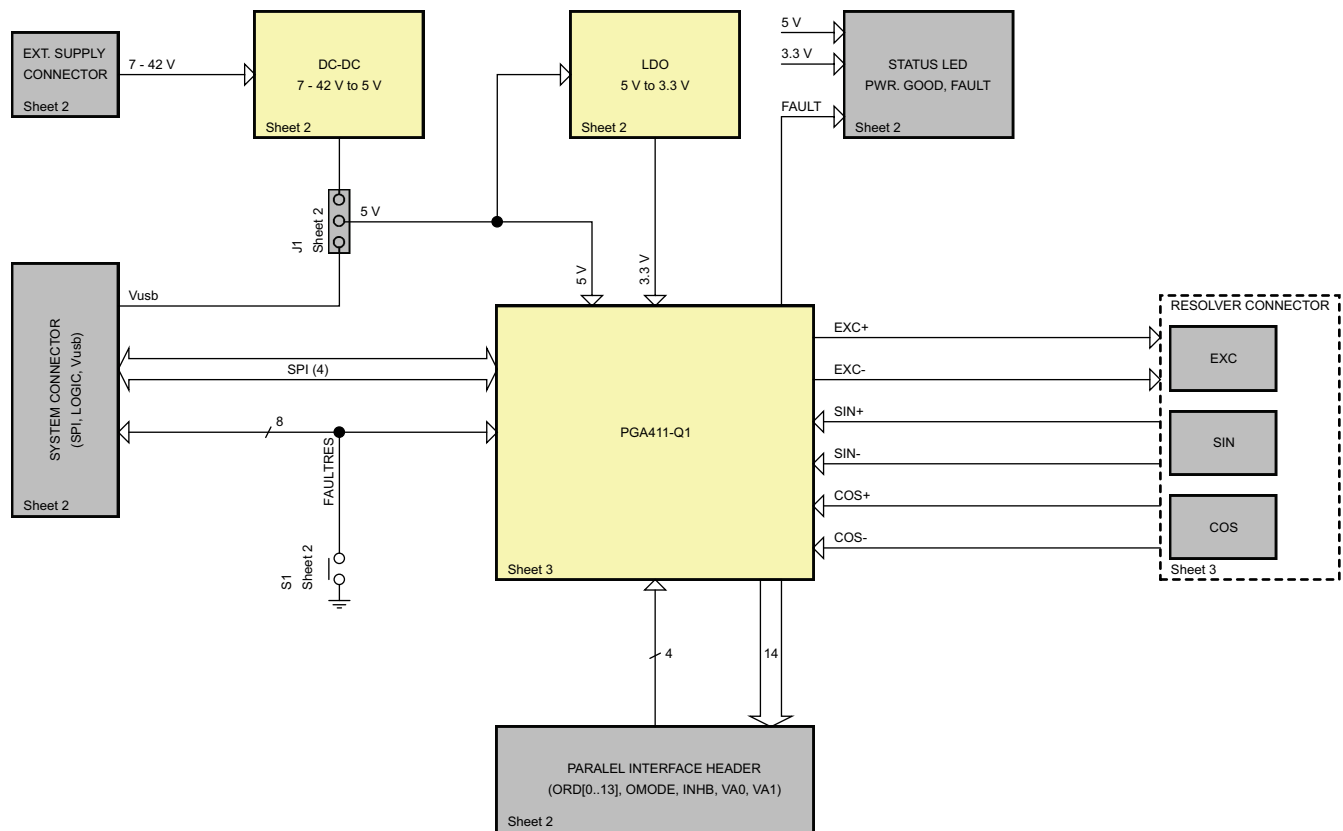
#### 4 HAL Hardware Layer (C2000 Specific)—hal.c and hal.h (32 bit)

This layer can be adapted for different hardware platforms and architectures. For example when the methods to access the GPIO registers must be changed and updated. The following example is for the TMS320F28069M device which is a 32-bit microcontroller with 16-bit registers.

##### 4.1 PGA411-Q1 GPIO Initialization

The primary function of this routine is to configure the GPIO of the PGA411-Q1 device for this specific application. The commands that follow are based on the configuration used in the TIDA-00796 schematic.

The pins that are connected to the PGA411-Q1 device and used in this application will be configured as either an input or output in the routine that follows.



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Figure 6. Block Diagram Showing High-Level Connection of TIDA-00796

**Table 2. Table Showing Relevant Pins of PGA411-Q1**

PIN		LOGIC INPUT OR OUTPUT	DESCRIPTION
NAME	NO.		
AMODE	28	Input	Accelerated mode select
BMODE0	5	Input	Resolution select, input low is 10-bit mode, input high is 12-bit mode
ECLKSEL	3	Input	Clock select input
FAULT	16	Output	Fault-detection signal output (open drain structure)
FAULTRES	14	Input	Fault reset input (faults are reset when this pin is LOW)
INHIB	13	Input	Inhibit function and output data hold
NCS	17	Input	Chip select for the serial peripheral interface (SPI)
NRESET	12	Input	Reset input
OMODE	29	Input	Data output format select
ORD0	57	Output	Data output, 0 for parallel angle and velocity. Encoder output U
ORD1	56	Output	Data output, 1 for parallel angle and velocity. Encoder output V
ORD10	47	Output	Data output, 10 for parallel angle and velocity
ORD11	46	Output	Data output, 11 for parallel angle and velocity
ORD12	45	Output	Optional pin (data output, 12 for parallel angle and velocity - unused)
ORDCLK	44	Output	ORD Clock
ORD2	55	Output	Data output select 2 for parallel angle and velocity. Encoder output W
ORD3	54	Output	Data output select 3 for parallel angle and velocity. Encoder output U1
ORD4	53	Output	Data output select 4 for parallel angle and velocity. Encoder output V1
ORD5	52	Output	Data output select 5 for parallel angle and velocity. Encoder output W1
ORD6	51	Output	Data output select 6 for parallel angle and velocity. Encoder output A
ORD7	50	Output	Data output select 7 for parallel angle and velocity. Encoder output B
ORD8	49	Output	Data output select 8 for parallel angle and velocity. Encoder output Z
ORD9	48	Output	Data output select 9 for parallel angle and velocity
OUTA	1	Output	Incremental encoder, output A
OUTB	2	Output	Incremental encoder, output B
OUTZ	64	Output	Incremental encoder, output Z
PRD	15	Output	Data parity output. The PRD pin can be routed to the parallel interface header.
SCLK	18	Input	SPI clock
SDI	19	Input	SPI data input
SDO	20	Output	SPI data output
VA0	31	Input	Data output select 0 for angle and velocity
VA1	32	Input	Data output select 1 for angle and velocity

**Table 3. Piccolo F28069 controlStick Pinout (C2000 GPIOs that must be Initialized<sup>(1)</sup>)**

	A	B	C	D
1	ADC-A6 / COMP3(+VE)	ADC-A2 / COMP1(+VE)	ADC-A0	3V3
2	ADC-A4 / COMP2 (+VE)	ADC-B1	EPWM-4B / GPIO-07	Tz1 / GPIO-12
3	SCL-A / GPIO-33	ADC-B6 / COMP3 (-VE)	EPWM-4A / GPIO-06	ADC-A1
4	SDA-A / GPIO-32	ADC-B0	EPWM-3B / GPIO-05	5V0 (Disabled by Default)
5	EPWM-1A / GPIO-00	ADC-B4 / COMP2 (-VE)	EPWM-3A / GPIO-04	SPISOMI-A / GPIO-17
6	EPWM-1B / GPIO-01	ADC-A5	EPWM-2B / GPIO-03	SPISIMO-A / GPIO-16
7	SPISTE-A / GPIO-19	ADC-B2 / COMP1 (-VE)	EPWM-2A / GPIO-02	GND
8	SPICLK-A / GPIO-18	GPIO-34 / (LED)	PWM1A-DAC (Filtered)	GND

<sup>(1)</sup> Additional pins will be needed for parallel output interface.

```

/* PGA411-Q1 GPIO configuration */
void hal_InitPgaGPIO(void)
{
    /* note: for better portability we configure all pins again */
    asm(" EALLOW"); /* Enable EALLOW protected register access */
    /* FAULTRES, negative logic */
    GpioCtrlRegs.GPBMUX1.bit.GPIO33 = 0; /* 0=GPIO          1=COMP2OUT  2=rsvd
3=COMP3OUT */
    GpioCtrlRegs.GBPBUD.bit.GPIO33 = 1; /* pull up disabled (external) */
    GpioCtrlRegs.GPBQSEL1.bit.GPIO33 = 0; /* no qualification */
    GpioCtrlRegs.GPBDIR.bit.GPIO33 = 0; /* input by default - output collector */
    GpioDataRegs.GPBSET.bit.GPIO33 = 1; /* default value 1, ignored anyway */
    /* OUTA - however GPIO only, no QEP at control stick pinout */
    GpioCtrlRegs.GPBMUX1.bit.GPIO32 = 0; /* 0=GPIO          1=COMP2OUT  2=rsvd
3=COMP3OUT */
    GpioCtrlRegs.GBPBUD.bit.GPIO32 = 1; /* pull up disabled driven by PGA */
    GpioCtrlRegs.GPBQSEL1.bit.GPIO32 = 0; /* no qualification */
    GpioCtrlRegs.GPBDIR.bit.GPIO32 = 0; /* input by default */
    GpioDataRegs.GPBSET.bit.GPIO32 = 1; /* default value 1, ignored anyway */
    /* OUTB - however GPIO only, no QEP at control stick pinout */
    GpioCtrlRegs.GPAMUX1.bit.GPIO0 = 0; /* 0=GPIO          1=COMP2OUT  2=rsvd
3=COMP3OUT */
    GpioCtrlRegs.GPAPUD.bit.GPIO0 = 1; /* pull up disabled driven by PGA */
    GpioCtrlRegs.GPAQSEL1.bit.GPIO0 = 0; /* no qualification */
    GpioCtrlRegs.GPADIR.bit.GPIO0 = 0; /* input by default */
    GpioDataRegs.GPASET.bit.GPIO0 = 1; /* default value 1, ignored anyway */
    /* OUTZ - however GPIO only, no QEP at control stick pinout */
    GpioCtrlRegs.GPAMUX1.bit.GPIO1 = 0; /* 0=GPIO          1=COMP2OUT  2=rsvd
3=COMP3OUT */
    GpioCtrlRegs.GPAPUD.bit.GPIO1 = 1; /* pull up disabled driven by PGA */
    GpioCtrlRegs.GPAQSEL1.bit.GPIO1 = 0; /* no qualification */
    GpioCtrlRegs.GPADIR.bit.GPIO1 = 0; /* input by default */
    GpioDataRegs.GPASET.bit.GPIO1 = 1; /* default value 1, ignored anyway */
    /* BMODE0 - low = 10b resolution, high = 12b resolution */
    GpioCtrlRegs.GPAMUX1.bit.GPIO7 = 0; /* 0=GPIO          1=COMP2OUT  2=rsvd
3=COMP3OUT */
    GpioCtrlRegs.GPAPUD.bit.GPIO7 = 1; /* pull up disabled */
    GpioCtrlRegs.GPAQSEL1.bit.GPIO7 = 0; /* no qualification */
    GpioCtrlRegs.GPADIR.bit.GPIO7 = 1; /* output by default */
    GpioDataRegs.GPASET.bit.GPIO7 = 1; /* default 12b resolution */
    /* EXTCLKIN - external clock for PGA411 >> NOT SUPPORTED YET << */
    GpioCtrlRegs.GPAMUX1.bit.GPIO6 = 0; /* 0=GPIO          1=COMP2OUT  2=rsvd
3=COMP3OUT */
    GpioCtrlRegs.GPAPUD.bit.GPIO6 = 1; /* pull up disabled */
    GpioCtrlRegs.GPAQSEL1.bit.GPIO6 = 0; /* no qualification */
    GpioCtrlRegs.GPADIR.bit.GPIO6 = 1; /* output by default */
    GpioDataRegs.GPACLEAR.bit.GPIO6 = 1; /* keep low */
    /* AMODE - accelerated mode */
    GpioCtrlRegs.GPAMUX1.bit.GPIO5 = 0; /* 0=GPIO          1=COMP2OUT  2=rsvd
3=COMP3OUT */
    GpioCtrlRegs.GPAPUD.bit.GPIO5 = 1; /* pull up disabled */
    GpioCtrlRegs.GPAQSEL1.bit.GPIO5 = 0; /* no qualification */
    GpioCtrlRegs.GPADIR.bit.GPIO5 = 1; /* output by default */
    GpioDataRegs.GPACLEAR.bit.GPIO5 = 1; /* accelerated mode disabled by default */
    /* FAULT - fault detection, active = high - Z */
    GpioCtrlRegs.GPAMUX1.bit.GPIO4 = 0; /* 0=GPIO          1=COMP2OUT  2=rsvd
3=COMP3OUT */
    GpioCtrlRegs.GPAPUD.bit.GPIO4 = 1; /* pull up disabled - external pull up */
    GpioCtrlRegs.GPAQSEL1.bit.GPIO4 = 0; /* no qualification */
    GpioCtrlRegs.GPADIR.bit.GPIO4 = 0; /* input by default */
    GpioDataRegs.GPASET.bit.GPIO4 = 1; /* default value 1, ignored anyway */
    /* PRD - data parity output */
    GpioCtrlRegs.GPAMUX1.bit.GPIO3 = 0; /* 0=GPIO          1=COMP2OUT  2=rsvd
3=COMP3OUT */
    GpioCtrlRegs.GPAPUD.bit.GPIO3 = 1; /* pull up disabled - driven by PGA */
    GpioCtrlRegs.GPAQSEL1.bit.GPIO3 = 0; /* no qualification */

```

```

    GpioCtrlRegs.GPADIR.bit.GPIO3 = 0;    /* input by default */
    GpioDataRegs.GPASET.bit.GPIO3 = 1;    /* default value 1, ignored anyway */
    /* RESET_N - resets PGA, active low */
    GpioCtrlRegs.GPAMUX1.bit.GPIO2 = 0;    /* 0=GPIO          1=COMP2OUT  2=rsvd
3=COMP3OUT */
    GpioCtrlRegs.GPAPUD.bit.GPIO2 = 1;    /* pull up disabled */
    GpioCtrlRegs.GPAQSEL1.bit.GPIO2 = 0;    /* no qualification */
    GpioCtrlRegs.GPADIR.bit.GPIO2 = 1;    /* output by default */
    GpioDataRegs.GPASET.bit.GPIO2 = 1;    /* device's running by default */
    /* ECLKSEL - switches between internal/external clock >> NOT SUPPORTED YET << */
    GpioCtrlRegs.GPAMUX1.bit.GPIO12 = 0;    /* 0=GPIO          1=COMP2OUT  2=rsvd
3=COMP3OUT */
    GpioCtrlRegs.GPAPUD.bit.GPIO12 = 1;    /* pull up disabled */
    GpioCtrlRegs.GPAQSEL1.bit.GPIO12 = 0;    /* no qualification */
    GpioCtrlRegs.GPADIR.bit.GPIO12 = 1;    /* output by default */
    GpioDataRegs.GPACLEAR.bit.GPIO12 = 1;    /* internal oscillator by default */
    asm(" EDIS"); /* Disable EALLOW protected register access */
}

```

## 4.2 PGA411-Q1 SPI Initialization

The primary function of this routine is to initialize the SPI of the PGA411-Q1 device. [Table 3](#) shows the high level connection of the PGA411-Q1 device with the C2000 microcontroller.

```

/* SPI init */
void hal_InitSPI(void)
{
    asm(" EALLOW"); /* Enable EALLOW protected register access */
    /* enable peripheral clock */
    SysCtrlRegs.PCLKCR0.bit.SPIAENCLK = 1; /* SPI-A */
    /* init GPIOs */
    GpioCtrlRegs.GPAPUD.bit.GPIO16 = 0; /* Enable pull-up on GPIO16 (SPISIMOA) */
    GpioCtrlRegs.GPAPUD.bit.GPIO17 = 0; /* Enable pull-up on GPIO17 (SPISOMIA) */
    GpioCtrlRegs.GPAPUD.bit.GPIO18 = 0; /* Enable pull-up on GPIO18 (SPICLKA) */
    GpioCtrlRegs.GPAPUD.bit.GPIO19 = 0; /* Enable pull-up on GPIO19 (SPISTEA) */
    GpioCtrlRegs.GPAQSEL2.bit.GPIO16 = 3; /* Asynch input GPIO16 (SPISIMOA) */
    GpioCtrlRegs.GPAQSEL2.bit.GPIO17 = 3; /* Asynch input GPIO17 (SPISOMIA) */
    GpioCtrlRegs.GPAQSEL2.bit.GPIO18 = 3; /* Asynch input GPIO18 (SPICLKA) */
    GpioCtrlRegs.GPAQSEL2.bit.GPIO19 = 3; /* Asynch input GPIO19 (SPISTEA) */
    GpioCtrlRegs.GPAMUX2.bit.GPIO16 = 1; /* 0=GPIO          1=SPISIMOA  2=rsvd      3=TZ2
*/
    GpioCtrlRegs.GPAMUX2.bit.GPIO17 = 1; /* 0=GPIO          1=SPISOMIA  2=rsvd      3=TZ3
*/
    GpioCtrlRegs.GPAMUX2.bit.GPIO18 = 1; /* 0=GPIO          1=SPICLKA   2=SCITXDB
3=XCLKOUT */
    GpioCtrlRegs.GPAMUX2.bit.GPIO19 = 1; /* 0=GPIO/XCLKIN  1=SPISTEA   2=SCIRXDB
3=ECAP1 */
    /* Initialize SPI periphery */
    SpiaRegs.SPICCR.bit.SPISWRESET = 0; /* Reset SPI and hold */
    SpiaRegs.SPICCR.all = 0x0007; /* Loopback off 8-bit character, Clock Polarity 0 */
    SpiaRegs.SPICTL.all = 0x0006; /* master, xmit enable */
    SpiaRegs.SPIBRR = 0x0009; /* SYSCLK = 80Mhz = LSPCLK, baud rate = LSPCLK/(SPIBRR+1) = 8 MHz */
    SpiaRegs.SPISTS.all = 0x0000; /* reset all status information */
    SpiaRegs.SPIPRI.bit.FREE = 1; /* priority control settings - free run */
    SpiaRegs.SPICCR.bit.SPISWRESET = 1; /* Release from SPI reset */
    /* reset both fifos */
    SpiaRegs.SPIFFTX.bit.TXFIFO = 0;
    SpiaRegs.SPIFFRX.bit.RXFIFORESET = 0; /*and keep them in reset during configuration */
    /* configure fifos */
    SpiaRegs.SPIFFTX.all = 0xC004; /* Enable FIFO's, do not use interrupts */
    SpiaRegs.SPIFFRX.all = 0x0004; /* Set RX FIFO, do not use interrupts */
    SpiaRegs.SPIFFCT.all = 0x0000; /* no delay between FIFO and TXBUF */
    /* releasing fifos from reset */
    SpiaRegs.SPIFFTX.bit.TXFIFO = 1;
    SpiaRegs.SPIFFRX.bit.RXFIFORESET = 1; /* OK */
}

```

```

/* error checking, fifo pointers should be zero */
if ((SpiaRegs.SPIFFTX.bit.TXFFST != 0) || (SpiaRegs.SPIFFRX.bit.RXFFST != 0)) { hal_assert();
}

asm(" EDIS"); /* Disable EALLOW protected register access */
}

/* Exchanges 4 Bytes via SPI, blocks until finished, 32b architecture = no pointer */

```

### 4.3 SPI Transmit and Receive Function

```

Uint32 hal_Xmit4BSPI(Uint32 frame)
{
    Uint32 rxval = 0x00000000; /* incoming data */
    /* empty RX and TX 4B FIFOs */
    SpiaRegs.SPIFFTX.bit.TXFIFO = 0; /* reset FIFOs */
    SpiaRegs.SPIFFRX.bit.RXFIFORESET = 0;
    asm(" NOP"); /* probably not needed */
    asm(" NOP"); /* probably not needed */
    SpiaRegs.SPIFFTX.bit.TXFIFO = 1;
    SpiaRegs.SPIFFRX.bit.RXFIFORESET = 1; /* release from reset */
    /* quick & dirty ! */
    SPIA_PUSH(frame >> 24); /* first byte (from most significant) */
    SPIA_PUSH(frame >> 16);
    SPIA_PUSH(frame >> 8);
    SPIA_PUSH(frame); /* last byte */

```

---

**NOTE:** The SPI is an 8-bit transfer which is why 4 bytes are transferred one by one starting with the most significant byte.

---

```

/* wait until the transmission is finished */
while (SpiaRegs.SPIFFRX.bit.RXFFST < 4) {EMPTY_LOOP};

/* get data from RX FIFO */
rxval = SPIA_POP; /* first byte (from the most significant) */

rxval = ((rxval << 8) | SPIA_POP);

rxval = ((rxval << 8) | SPIA_POP);

rxval = ((rxval << 8) | SPIA_POP); /* last byte */

/* NCS must remain high at least 200ns */
HAL_DELAY_US(1);

return (rxval);
}

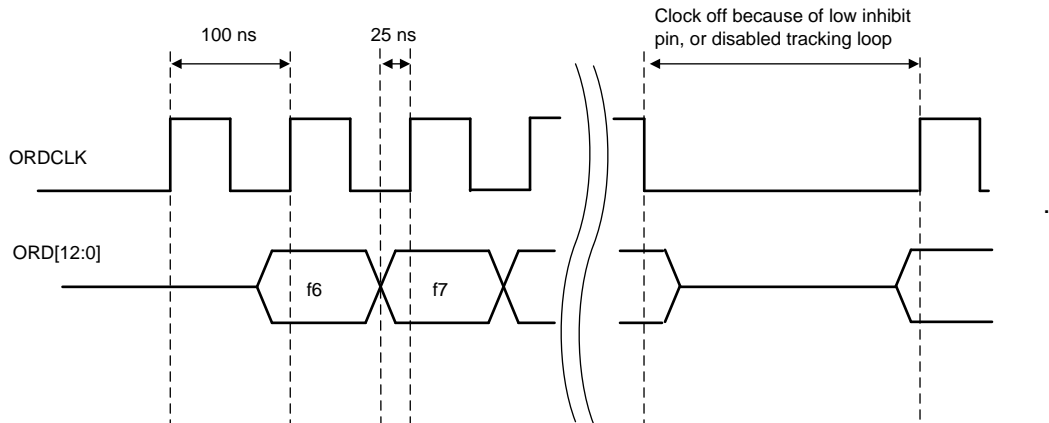
```

### 4.4 Digital Parallel Output

The digital parallel output is the default data interface of the PGA411-Q1 output. To enable the parallel output interface, set the OMODE pin high ( $V_{IO}$ ). The device is configured in the encoder-emulated output mode (described as follows) when the OMODE pin is set low (DGND).

The digital parallel output provides an update to the angle or velocity sample value every 100 ns at the ORD[11:0] pins which can be expressed as a 10-Msps output-update rate.

When the parallel output interface is enabled, the angle and velocity data is read from the ORD11 (MSB) to ORD0 (LSB) pins. The digital data at the parallel output is in 2s complement format. While this format is not important for the angle output because the value is always positive, the velocity output can be either positive or negative depending on the direction of the resolver rotation. In the case the resolver sensor rotation is clockwise (CW) and the value of the digital parallel-output velocity is positive. If the resolver sensor rotation is counter-clockwise (CCW), the output value is negative. In the case where the device is used in 10-bit mode (BMODE0 is low) the ORD10 and ORD11 pins are low (zeros) for a positive angle or velocity output or high (ones) for a negative velocity.



**Figure 7. ORD Timing Characteristics**

While the OMODE selection pin switches the ORD[11:0] pins between the parallel data output and the emulated encoder output, the VA0 and VA1 pins enable and disable the ORD[11:0] pins while also selecting the output parameter. Setting the ORD[11:0] pins in a high impedance (Hi-Z) state allows for systems to use multiple PGA411-Q1 devices controlled by a single MCU. See the PGA411-Q1 data sheet for an example of multiple PGA411-Q1 devices controlled by a single MCU.

Table 4 lists the VA0 and VA1 pin configurations.

**Table 4. ORD[11:0] Output Selection**

VA0	VA1	FUNCTION
0	0	ORD[11:0] set to Hi-Z
1	1	
0	1	Angle output at ORD[11:0]
1	0	Velocity output at ORD[11:0]

The INHB pin controls the update of the data output for the PGA411-Q1 device. When the INHB pin is high (VIO), the output data is sampled at the ORD[11:0] pins as soon as the data is available. When the INHB pin is set low (DGND), the data output at the ORD[11:0] pins is held at the last sampled output. In a synchronous data-transfer system sampling the data at the output of the PGA411-Q1 device on every clock period is possible by applying a clock signal at the INHB input with a frequency lower than 10 MHz.

TI recommends the following sequence to read angle outputs on parallel interface (this code was not implemented as part of the TIDA-00796 reference design, refer to the following sequence for an example):

1. Take INHB pin to High (PGA411-Q1 updates the output if the Inhibit is high)
2. Wait until ORDCLK is high
3. Read the ORD[12:0] outputs.

#### 4.5 UART Initialization

The primary function of this routine is to initialize the UART. This configuration helps the TMS320F28069M device on the control stick communicate over the USB with the computer through a UART-to-USB serial converter.



```

/* UART init */
void hal_InitUART(void)
{
    asm(" EALLOW"); /* Enable EALLOW protected register access */
    /* enable peripheral clock */
    SysCtrlRegs.PCLKCR0.bit.SCIAENCLK = 1; /* SCI-A */
    /* init GPIOs */
    GpioCtrlRegs.GPAPUD.bit.GPIO28 = 0; /* Enable pull-up for GPIO28 (SCIRXDA) */
    GpioCtrlRegs.GPAPUD.bit.GPIO29 = 0; /* Enable pull-up for GPIO29 (SCITXDA) */
    GpioCtrlRegs.GPAMUX2.bit.GPIO28 = 1; /* 0=GPIO          1=SCIRXDA    2=SDAA      3=TZ2
*/
    GpioCtrlRegs.GPAMUX2.bit.GPIO29 = 1; /* 0=GPIO          1=SCITXDA    2=SCLA      3=TZ3
*/
    GpioCtrlRegs.GPAQSEL2.bit.GPIO28 = 3; /* Asynch input GPIO28 (SCIRXDA) */
    /* serial port settings */
    SciaRegs.SCICCR.all = 0x0007; /* 8N1, no loopback, async, idle-line protocol */
    SciaRegs.SCICTL1.all = 0x0003; /* enable TX, RX, internal SCICLK, Disable RX ERR, SLEEP,
TXWAKE */
    SciaRegs.SCIHBAUD    = 0x0000; /* 115200 baud @LSPCLK = 80MHz (80 MHz SYSCLK). */
    SciaRegs.SCILBAUD    = 0x0055;
    SciaRegs.SCICTL1.all = 0x0023; /* Relinquish SCI from Reset */
    asm(" EDIS"); /* Disable EALLOW protected register access */
}

/* UART send character */
void hal_PutcUART(unsigned char c)
{
    while (SciaRegs.SCICTL2.bit.TXRDY == 0) {EMPTY_LOOP}

    SciaRegs.SCITXBUF = c;
}

/* UART send string */
void hal_PutsUART(char * s)
{
    while (*s) { hal_PutcUART(*s++); }
}

/* set LED on the control stick */
void hal_SetLED(void)
{
    GpioDataRegs.GPBCLEAR.bit.GPIO34 = 1; /* GPIO34 pin is set to 0 (turn LED on) */
}

/* clear LED on the control stick */
void hal_ClearLED(void)
{
    GpioDataRegs.GPBSET.bit.GPIO34 = 1; /* GPIO34 pin is set to 1 (turn LED off) */
}

/* toggle LED on the control stick */
void hal_ToggleLED(void)
{
    GpioDataRegs.GPBTOGGLE.bit.GPIO34 = 1; /* GPIO34 pin is toggle */
}

/* pseudo assert */
void hal_assert(void)
{
    __asm("          ESTOP0"); /* stops emulation at this point */

    while (ENDLESS); /* just in case */
}

```

## 4.6 Reading Angle and Velocity

The angle and velocity data are also available in the register memory space and can be polled through the SPI. The corresponding locations are the bits in the DEV\_STAT5 register for angle data value and the bits in the DEV\_STAT6 register for velocity data value.

Use the following equations to convert the PGA411-Q1 parallel output or SPI data into meaningful angle and velocity values:

- 10-bit angle:

$$\varphi \text{ (degrees)} = 360 \times \frac{\text{ORDx}}{2^{10}} \quad (2)$$

- 12-bit angle:

$$\varphi \text{ (degrees)} = 360 \times \frac{\text{ORDx}}{2^{12}} \quad (3)$$

- 10-bit velocity:

$$\vartheta \text{ (RPM)} = 60 \times \frac{f_{\text{clk}} \times (\text{ORDx} + 1)}{2^{21}}$$

where

- where  $f_{\text{clk}}$  is the device clock frequency (typically 20 MHz) (4)

- 12-bit velocity

$$\vartheta \text{ (RPM)} = 60 \times \frac{f_{\text{clk}} \times (\text{ORDx} + 1)}{2^{25}} \quad (5)$$

### 4.6.1 Angle Calculation Example

The following code snippet reads angle data from the PGA411-Q1 device, calculates the corresponding angle and prints the result over a serial port to the host system.

The provided example uses Texas Instruments' IQmathLib library ([processors.wiki.ti.com/index.php/IQmath\\_Library\\_for\\_C28x](http://processors.wiki.ti.com/index.php/IQmath_Library_for_C28x)). An alternate approach uses the traditional float or fixed point (Q number format) arithmetic. The final approach should be considered based on the hardware architecture.

```

/* angle calculation for the PGA411 using IQmathLib library */
/* _iq19 stores -4096 to 4095.999998093 with 0.000001907 resolution */
{
    Uint16 angle_raw; /* raw data from the PGA411 register */
    _iq angle; /* IQ math angle */

    /* read data from the PGA411 */
    angle_raw = pga411_ReadReg(DEV_STAT5);
    angle_raw &= 0x1FFF; /* preserve only ORDANGLE bits */

    /* multiply minimal step (LSB) by ORDANGLE value */
    angle = _IQ19mpy(_IQ19(360.0/4096), _IQ19(angle_raw)); /* 12b example */

    /* convert IQ variable to string */
    _IQ19toa(outbuf, "%4.5f", angle);

    /* print-out the buffer */
    hal_PutsUART(outbuf);
}
    
```

### 4.6.2 Velocity Calculation Example

Similarly to the angle calculation example, the next code snippet reads velocity data from the PGA411-Q1 device, calculates velocity and prints the result over a serial port.

The velocity calculation is more complex than the angle calculation. Velocity data (10 or 12 bit) from the PGA411-Q1 are stored in 2's-complement format. However, because of different word size, the data must be first converted. This conversion occurs as follows:

- Step 1. Check the sign (bit 11).
- Step 2. Convert to the positive integer.
- Step 3. Preserve only the ORDVELOCITY bits.
- Step 4. Cast to float format.
- Step 5. Multiply by  $-1$  if the sign is negative

The IQmathLib library is used for the final velocity calculation and string conversion. The final implementation should consider target architecture, especially float and negative integer data representation.

```

/* velocity calculation for the PGA411 using IQmathLib library */
/* _iq14 stores -131072 to 131071.999938965 with 0.000061035 resolution */
{
    Int16 velocity_raw; /* raw data from the PGA411 register */
    float velocity_float; /* temp for 2nd complement to float conversion */
    _iq velocity; /* IQ math velocity */

    /* read data from the PGA411 */
    velocity_raw = pga411_ReadReg(DEV_STAT6);

    /* convert 2nd complement to float */
    if(velocity_raw & 0x0800) /* negative number ? */
    {
        /* convert to positive number first */
        velocity_float = (((~velocity_raw) +1) & 0x07FF);
        velocity_float *= -1; /* and make it negative */
    }
    else
    {
        /* positive number, preserve only needed bits */
        velocity_float = (velocity_raw & 0x07FF);
    }

    velocity = _IQ14mpy(_IQ14(60*20000000/33554432),_IQ14(velocity_float + 1)); /* 12b
example */

    /* convert IQ variable to string */
    _IQ14toa(outbuf, "%7.5f", velocity);

    /* print-out the buffer */
    hal_PutsUART(outbuf);
}

```

## 4.7 GPIO Configuration (Input and Output)

The primary function of this routine is to configure the GPIO of the TMS320F28069 device used on the control stick ([www.ti.com/product/TMS320F28069M/toolssoftware](http://www.ti.com/product/TMS320F28069M/toolssoftware)).

At the system reset, all the GPIOs are set as the input. Later, in the program, the GPIOs are reconfigured for a specific application (see [Section 4.1](#)).

```

/* Input - output configuration (ControlSTICK compatible) */
void hal_InitGPIO(void)
{
    asm(" EALLOW"); /* Enable EALLOW protected register access */
    /* Group A pins */
    GpioCtrlRegs.GPACTRL.all = 0x00000000; /* QUALPRD = SYSCLKOUT for all group A GPIO */
    GpioCtrlRegs.GPAQSEL1.all = 0x00000000; /* No qualification for all group A GPIO 0-15 */
    GpioCtrlRegs.GPAQSEL2.all = 0x00000000; /* No qualification for all group A GPIO 16-31 */
    GpioCtrlRegs.GPADIR.all = 0x00000000; /* All group A GPIO are inputs */
    GpioCtrlRegs.GPAPUD.all = 0x00000000; /* all pullups enabled GPIO 0-31 */
    /* */
}

```

```

    GpioCtrlRegs.GPAMUX1.bit.GPIO0 = 0;      /* 0=GPIO          1=EPWM1A    2=rsvd
3=rsvd */
    GpioCtrlRegs.GPAMUX1.bit.GPIO1 = 0;      /* 0=GPIO          1=EPWM1B    2=rsvd
3=COMP1OUT */
    GpioCtrlRegs.GPAMUX1.bit.GPIO2 = 0;      /* 0=GPIO          1=EPWM2A    2=rsvd
3=rsvd */
    GpioCtrlRegs.GPAMUX1.bit.GPIO3 = 0;      /* 0=GPIO          1=EPWM2B    2=SPISOMIA
3=COMP2OUT */
    GpioCtrlRegs.GPAMUX1.bit.GPIO4 = 0;      /* 0=GPIO          1=EPWM3A    2=rsvd
3=rsvd */
    GpioCtrlRegs.GPAMUX1.bit.GPIO5 = 0;      /* 0=GPIO          1=EPWM3B    2=SPISIMOA
3=ECAP1 */
    GpioCtrlRegs.GPAMUX1.bit.GPIO6 = 0;      /* 0=GPIO          1=EPWM4A    2=EPWMSYNCI
3=EPWMSYNCO */
    GpioCtrlRegs.GPAMUX1.bit.GPIO7 = 0;      /* 0=GPIO          1=EPWM4B    2=SCIRXDA
3=ECAP2 */
    GpioCtrlRegs.GPAMUX1.bit.GPIO8 = 0;      /* 0=GPIO          1=EPWM5A    2=rsvd
3=ADCSOCAO */
    GpioCtrlRegs.GPAMUX1.bit.GPIO9 = 0;      /* 0=GPIO          1=EPWM5B    2=SCITXDB
3=ECAP3 */
    GpioCtrlRegs.GPAMUX1.bit.GPIO10 = 0;     /* 0=GPIO          1=EPWM6A    2=rsvd
3=ADCSOCBO */
    GpioCtrlRegs.GPAMUX1.bit.GPIO11 = 0;     /* 0=GPIO          1=EPWM6B    2=SCIRXDB
3=ECAP1 */
    GpioCtrlRegs.GPAMUX1.bit.GPIO12 = 0;     /* 0=GPIO          1=TZ1       2=SCITXDA
3=SPISIMOB */
    GpioCtrlRegs.GPAMUX1.bit.GPIO13 = 0;     /* 0=GPIO          1=TZ2       2=rsvd
3=SPISOMIB */
    GpioCtrlRegs.GPAMUX1.bit.GPIO14 = 0;     /* 0=GPIO          1=TZ3       2=SCITXDB
3=SPICLKB */
    GpioCtrlRegs.GPAMUX1.bit.GPIO15 = 0;     /* 0=GPIO          1=ECAP2     2=SCIRXDB
3=SPISTEB */
    GpioCtrlRegs.GPAMUX2.bit.GPIO16 = 0;     /* 0=GPIO          1=SPISIMOA  2=rsvd
3=TZ2 */
    GpioCtrlRegs.GPAMUX2.bit.GPIO17 = 0;     /* 0=GPIO          1=SPISOMIA  2=rsvd
3=TZ3 */
    GpioCtrlRegs.GPAMUX2.bit.GPIO18 = 0;     /* 0=GPIO          1=SPICLKA   2=SCITXDB
3=XCLKOUT */
    GpioCtrlRegs.GPAMUX2.bit.GPIO19 = 0;     /* 0=GPIO/XCLKIN  1=SPISTEA   2=SCIRXDB
3=ECAP1 */
    GpioCtrlRegs.GPAMUX2.bit.GPIO20 = 0;     /* 0=GPIO          1=EQEP1A    2=MDXA
3=COMP1OUT */
    GpioCtrlRegs.GPAMUX2.bit.GPIO21 = 0;     /* 0=GPIO          1=EQEP1B    2=MDRA
3=COMP2OUT */
    GpioCtrlRegs.GPAMUX2.bit.GPIO22 = 0;     /* 0=GPIO          1=EQEP1S    2=MCLKXA
3=SCITXDB */
    GpioCtrlRegs.GPAMUX2.bit.GPIO23 = 0;     /* 0=GPIO          1=EQEP1I    2=MFSXA
3=SCIRXDB */
    GpioCtrlRegs.GPAMUX2.bit.GPIO24 = 0;     /* 0=GPIO          1=ECAP1     2=EQEP2A
3=SPISIMOB */
    GpioCtrlRegs.GPAMUX2.bit.GPIO25 = 0;     /* 0=GPIO          1=ECAP2     2=EQEP2B
3=SPISOMIB */
    GpioCtrlRegs.GPAMUX2.bit.GPIO26 = 0;     /* 0=GPIO          1=ECAP3     2=EQEP2I
3=SPICLKB */
    GpioCtrlRegs.GPAMUX2.bit.GPIO27 = 0;     /* 0=GPIO          1=HRCAP2    2=EQEP2S
3=SPISTEB */
    GpioCtrlRegs.GPAMUX2.bit.GPIO28 = 0;     /* 0=GPIO          1=SCIRXDA   2=SDAA
3=TZ2 */
    GpioCtrlRegs.GPAMUX2.bit.GPIO29 = 0;     /* 0=GPIO          1=SCITXDA   2=SCLA
3=TZ3 */
    GpioCtrlRegs.GPAMUX2.bit.GPIO30 = 0;     /* 0=GPIO          1=CANRXA    2=EQEP2I
3=EPWM7A */
    GpioCtrlRegs.GPAMUX2.bit.GPIO31 = 0;     /* 0=GPIO          1=CANTXA    2=EQEP2S
3=EPWM8A */
    /* Group B pins */
    GpioCtrlRegs.GPBCTRL.all = 0x00000000;   /* QUALPRD = SYSCLKOUT for all group B GPIO */

```

```

GpioCtrlRegs.GPBQSEL1.all = 0x00000000; /* No qualification for all group B GPIO 32-44 */
GpioCtrlRegs.GPBQSEL2.all = 0x00000000; /* No qualification for all group B GPIO 50-58 */
GpioCtrlRegs.GPBDIR.all = 0x00000000; /* All group B GPIO are inputs */
GpioCtrlRegs.GPBPUD.all = 0x00000000; /* All group B pullups enabled */
/* */
GpioCtrlRegs.GPBMUX1.bit.GPIO32 = 0; /* 0=GPIO 1=SDAA 2=EPWMSYNCI
3=ADCSOCAO */
GpioCtrlRegs.GPBMUX1.bit.GPIO33 = 0; /* 0=GPIO 1=SCLA 2=EPWMSYNCO
3=ADCSOCBO */
GpioCtrlRegs.GPBMUX1.bit.GPIO34 = 0; /* 0=GPIO 1=COMP2OUT 2=rsvd
3=COMP3OUT */
GpioCtrlRegs.GPBMUX1.bit.GPIO35 = 0; /* 0=GPIO (TDI) 1=rsvd 2=rsvd
3=rsvd */
GpioCtrlRegs.GPBMUX1.bit.GPIO36 = 0; /* 0=GPIO (TMS) 1=rsvd 2=rsvd
3=rsvd */
GpioCtrlRegs.GPBMUX1.bit.GPIO37 = 0; /* 0=GPIO (TDO) 1=rsvd 2=rsvd
3=rsvd */
GpioCtrlRegs.GPBMUX1.bit.GPIO38 = 0; /* 0=GPIO/XCLKIN (TCK) 1=rsvd 2=rsvd
3=rsvd */
GpioCtrlRegs.GPBMUX1.bit.GPIO39 = 0; /* 0=GPIO 1=rsvd 2=rsvd
3=rsvd */
GpioCtrlRegs.GPBMUX1.bit.GPIO40 = 0; /* 0=GPIO 1=EPWM7A 2=SCITXDB
3=rsvd */
GpioCtrlRegs.GPBMUX1.bit.GPIO41 = 0; /* 0=GPIO 1=EPWM7B 2=SCIRXDB
3=rsvd */
GpioCtrlRegs.GPBMUX1.bit.GPIO42 = 0; /* 0=GPIO 1=EPWM8A 2=TZ1
3=COMP1OUT */
GpioCtrlRegs.GPBMUX1.bit.GPIO43 = 0; /* 0=GPIO 1=EPWM8B 2=TZ2
3=COMP2OUT */
GpioCtrlRegs.GPBMUX1.bit.GPIO44 = 0; /* 0=GPIO 1=MFSRA 2=SCIRXDB
3=EPWM7B */
GpioCtrlRegs.GPBMUX2.bit.GPIO50 = 0; /* 0=GPIO 1=EQEP1A 2=MDXA
3=TZ1 */
GpioCtrlRegs.GPBMUX2.bit.GPIO51 = 0; /* 0=GPIO 1=EQEP1B 2=MDRA
3=TZ2 */
GpioCtrlRegs.GPBMUX2.bit.GPIO52 = 0; /* 0=GPIO 1=EQEP1S 2=MCLKXA
3=TZ3 */
GpioCtrlRegs.GPBMUX2.bit.GPIO53 = 0; /* 0=GPIO 1=EQEP1I 2=MFSXA
3=rsvd */
GpioCtrlRegs.GPBMUX2.bit.GPIO54 = 0; /* 0=GPIO 1=SPISIMOA 2=EQEP2A
3=HRCAP1 */
GpioCtrlRegs.GPBMUX2.bit.GPIO55 = 0; /* 0=GPIO 1=SPISOMIA 2=EQEP2B
3=HRCAP2 */
GpioCtrlRegs.GPBMUX2.bit.GPIO56 = 0; /* 0=GPIO 1=SPICLKA 2=EQEP2I
3=HRCAP3 */
GpioCtrlRegs.GPBMUX2.bit.GPIO57 = 0; /* 0=GPIO 1=SPISTEA 2=EQEP2S
3=HRCAP4 */
GpioCtrlRegs.GPBMUX2.bit.GPIO58 = 0; /* 0=GPIO 1=MCLKRA 2=SCITXDB
3=EPWM7A */
/* Analog I/O Mux pins */
GpioCtrlRegs.AIOMUX1.bit.AIO2 = 0; /* 0,1=AIO2 2,3=ADCINA2/COMP1A */
GpioCtrlRegs.AIOMUX1.bit.AIO4 = 0; /* 0,1=AIO4 2,3=ADCINA4/COMP2A */
GpioCtrlRegs.AIOMUX1.bit.AIO6 = 0; /* 0,1=AIO6 2,3=ADCINA6/COMP3A */
GpioCtrlRegs.AIOMUX1.bit.AIO10 = 0; /* 0,1=AIO10 2,3=ADCINB2/COMP1B */
GpioCtrlRegs.AIOMUX1.bit.AIO12 = 0; /* 0,1=AIO12 2,3=ADCINB4/COMP2B */
GpioCtrlRegs.AIOMUX1.bit.AIO14 = 0; /* 0,1=AIO14 2,3=ADCINB6/COMP3B */
GpioCtrlRegs.AIODIR.bit.AIO2 = 0; /* AIO2 is an input (when selected as digital
function) */
GpioCtrlRegs.AIODIR.bit.AIO4 = 0; /* AIO4 is an input (when selected as digital
function) */
GpioCtrlRegs.AIODIR.bit.AIO6 = 0; /* AIO6 is an input (when selected as digital
function) */
GpioCtrlRegs.AIODIR.bit.AIO10 = 0; /* AIO10 is an input (when selected as digital
function) */
GpioCtrlRegs.AIODIR.bit.AIO12 = 0; /* AIO12 is an input (when selected as digital
function) */

```

```

        GpioCtrlRegs.AIODIR.bit.AIO14 = 0;          /* AIO14 is an input (when selected as digital
function) */
        /* External interrupt selection */
        GpioIntRegs.GPIOXINT1SEL.all = 0x0000;    /* GPIO0 is XINT1 source */
        GpioIntRegs.GPIOXINT2SEL.all = 0x0000;    /* GPIO0 is XINT2 source */
        GpioIntRegs.GPIOXINT3SEL.all = 0x0000;    /* GPIO0 is XINT3 source */
        XIntruptRegs.XINT1CR.all = 0x0000;        /* XINT1 disabled */
        XIntruptRegs.XINT2CR.all = 0x0000;        /* XINT2 disabled */
        XIntruptRegs.XINT3CR.all = 0x0000;        /* XINT3 disabled */
        /* Low-power mode selection */
        GpioIntRegs.GPIOLPMSEL.all = 0x00000000;  /* No pin selected for HALT and STANBY wakeup
(reset default) */
        /******
        /* APPLICATION SPECIFIC */
        /******
        /* LED on control stick, negative logic */
        GpioCtrlRegs.GPBDIR.bit.GPIO34 = 1; /* GPIO34 is an output (connected to LED on F28069
ControlSTICK) */
        GpioDataRegs.GPBSET.bit.GPIO34 = 1; /* LED is off now */
        asm(" EDIS"); /* Disable EALLOW protected register access */
    }

```

## 4.8 System Initialization

The primary function of this routine is to initialize the TMS320F28069M microcontroller. This routine must be adapted for other controllers.

```

/* System clock & control init */
void hal_InitSysCtrl(void)
{
    volatile Uint16 iVol;
    /* WDT must be disabled */
    hal_DisableWDT();
    /* IMPORTANT - compact minimalistic code reused & modified from F2806x_SysCtrl.c */
    asm(" EALLOW"); /* Enable EALLOW protected register access */
    /* get out ADC calibration data data */
    SysCtrlRegs.PCLKCR0.bit.ADCENCLK = 1; /* Enable ADC peripheral clock */
    (*Device_cal)();
    SysCtrlRegs.PCLKCR0.bit.ADCENCLK = 0; /* Return ADC clock to original state */
    /* INTOSC1 (10 MHz) as a source */
    SysCtrlRegs.CLKCTL.bit.INTOSC1OFF = 0;
    SysCtrlRegs.CLKCTL.bit.OSCCLSRCSEL = 0; /* Clk Src = INTOSC1 */
    SysCtrlRegs.CLKCTL.bit.XCLKINOFF = 1; /* Turn off XCLKIN */
    SysCtrlRegs.CLKCTL.bit.XTALOSCOFF = 1; /* Turn off XTALOSC */
    SysCtrlRegs.CLKCTL.bit.INTOSC2OFF = 1; /* Turn off INTOSC2 */

    /* Make sure the PLL is not running in limp mode */
    if (SysCtrlRegs.PLLSTS.bit.MCLKSTS != 0)
    {
        /* Failure detected, PLL in limp mode */
        hal_assert();
    }

    /* DIVSEL MUST be 0 before PLLCR can be changed from
    0x0000. It is set to 0 by an external reset XRSn
    This puts us in 1/4 */
    if (SysCtrlRegs.PLLSTS.bit.DIVSEL != 0)
    {
        SysCtrlRegs.PLLSTS.bit.DIVSEL = 0;
    }

    /* Change the PLLCR only when different */
    if (SysCtrlRegs.PLLCR.bit.DIV != DSP28_PLLCR)
    {
        /* Before setting PLLCR turn off missing clock detect logic */
        SysCtrlRegs.PLLSTS.bit.MCLKOFF = 1;
    }

```

```

SysCtrlRegs.PLLCR.bit.DIV = DSP28_PLLCR;

/* wait until PLL is locked */
while (SysCtrlRegs.PLLSTS.bit.PLLLOCKS != 1) {EMPTY_LOOP};

/* clear missing clk detection */
SysCtrlRegs.PLLSTS.bit.MCLKOFF = 0;
}

/* If switching to 1/2 */
if ((DSP28_DIVSEL == 1) || (DSP28_DIVSEL == 2))
{
    SysCtrlRegs.PLLSTS.bit.DIVSEL = DSP28_DIVSEL;
}

/* If switching to 1/1
 * First go to 1/2 and let the power settle
 * The time required will depend on the system, this is only an example
 * Then switch to 1/1 */
if (DSP28_DIVSEL == 3)
{
    SysCtrlRegs.PLLSTS.bit.DIVSEL = 2;
    HAL_DELAY_US(50L);
    SysCtrlRegs.PLLSTS.bit.DIVSEL = 3;
}

/* Low speed oscillator = XCLKOUT/1 = 80 MHz */
SysCtrlRegs.LOSPCP.all = 0x0000; /* low speed has no chance ! :-) */
asm(" EDIS"); /* Disable EALLOW protected register access */
}

```

## 5 Acknowledgments

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