

# Hardware Abstraction Layer (HAL) Module of MotorWare™

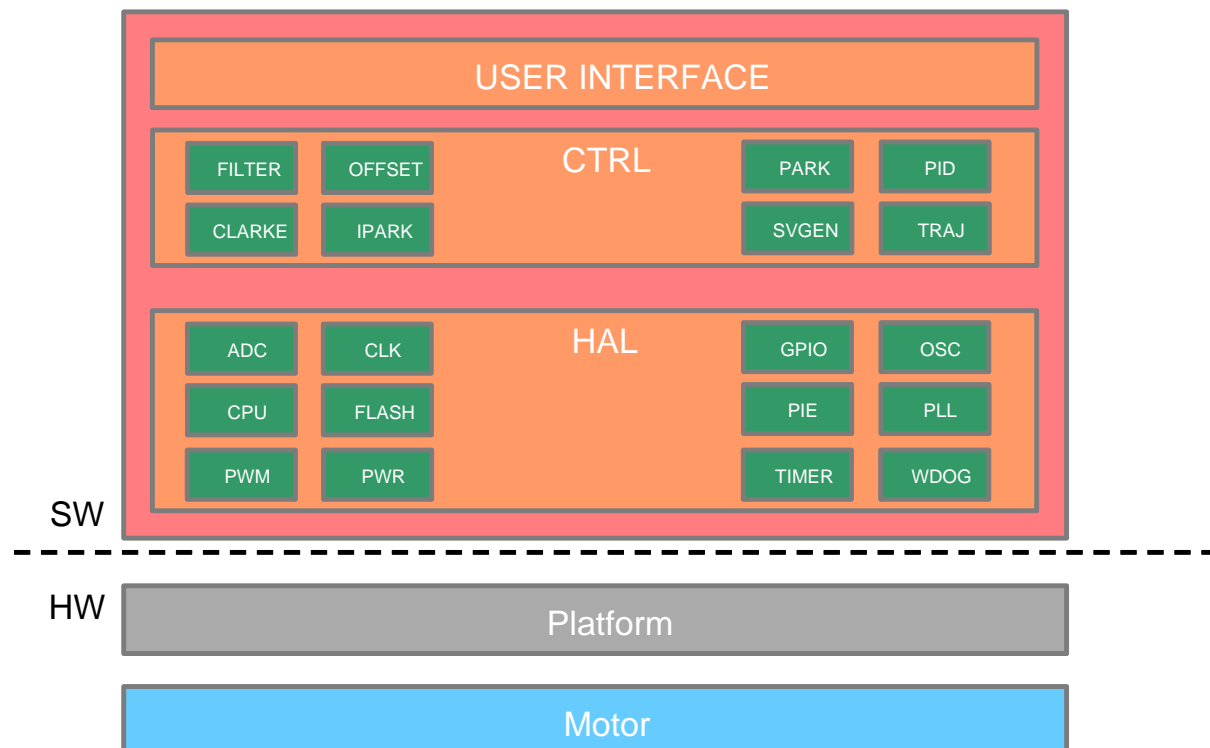
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## 1. Introduction

The purpose of the HAL module is to allow a unified software base that can be ported across multiple MCUs (i.e. f2802x, f2805x and f2806x) and hardware platforms (i.e. boostxldr8301\_revB, drv8301kit\_revD, drv8312kit\_revD and hvkit\_rev1p1).

## 2. Software Architecture

The following block diagram shows how the HAL object fits within the software architecture followed by MotorWare:



Certain guidelines are followed by the current software architecture, which allows a better use of a HAL module:

- HAL module is the only module that can interface with the hardware. In this context, hardware includes MCU peripherals, and board functionality.
- No peripheral configuration should be done at a user's interface level, since this doesn't allow portability of the code.

- HAL functions which are time critical, should be inlined for faster execution.
- Use of macros must be avoided, and use of inline functions should be used instead.

### 3. Object Definition

There are several object definitions of the HAL module, depending on the processor and board combination. The object definition of the HAL module can be found within the MotorWare product tree as shown in the following picture:

	Name
\\sw\modules\hal\boards\boost\drv8301_revB\f28x\f2802x\src	hal_obj.h
\\sw\modules\hal\boards\drv8301kit_revD\f28x\f2802x\src	hal_obj.h
\\sw\modules\hal\boards\drv8301kit_revD\f28x\f2805x\src	hal_obj.h
\\sw\modules\hal\boards\drv8301kit_revD\f28x\f2806x\src	hal_obj.h
\\sw\modules\hal\boards\drv8312kit_revD\f28x\f2802x\src	hal_obj.h
\\sw\modules\hal\boards\drv8312kit_revD\f28x\f2805x\src	hal_obj.h
\\sw\modules\hal\boards\drv8312kit_revD\f28x\f2806x\src	hal_obj.h
\\sw\modules\hal\boards\hvkit_rev1p1\f28x\f2802x\src	hal_obj.h
\\sw\modules\hal\boards\hvkit_rev1p1\f28x\f2805x\src	hal_obj.h
\\sw\modules\hal\boards\hvkit_rev1p1\f28x\f2806x\src	hal_obj.h

The following object is defined for the f2806x and combination:

```

/*! \brief   Defines the hardware abstraction layer (HAL) data
/*! \details The HAL object contains all handles to peripherals. When accessing a
/*!          peripheral on a processor, use a HAL function along with the HAL handle
/*!          for that processor to access its peripherals.
/*!
typedef struct _HAL_Obj_
{
  ADC_Handle  adcHandle;    //!< the ADC handle

  CLK_Handle  clkHandle;    //!< the clock handle

  CPU_Handle  cpuHandle;    //!< the CPU handle

  FLASH_Handle flashHandle; //!< the flash handle

  GPIO_Handle gpioHandle;   //!< the GPIO handle

  OFFSET_Handle offsetHandle_I[3]; //!< the handles for the current offset estimators
  OFFSET_Obj  offset_I[3];   //!< the current offset objects

  OFFSET_Handle offsetHandle_V[3]; //!< the handles for the voltage offset estimators

```

```

OFFSET_Obj  offset_V[3];    //!< the voltage offset objects

OSC_Handle  oscHandle;     //!< the oscillator handle

PIE_Handle  pieHandle;     //!< the PIE handle

PLL_Handle  pllHandle;     //!< the PLL handle

PWM_Handle  pwmHandle[3];  //!< the PWM handles

PWMDAC_Handle pwmDacHandle[3]; //!< the PWMDAC handles

PWR_Handle  pwrHandle;     //!< the power handle

TIMER_Handle timerHandle[3]; //!< the timer handles

WDOG_Handle wdogHandle;    //!< the watchdog handle

HAL_AdcData_t adcBias;     //!< the ADC bias

_iq         current_sf;    //!< the current scale factor, amps_pu/cnt

_iq         voltage_sf;    //!< the voltage scale factor, volts_pu/cnt

uint_least8_t numCurrentSensors; //!< the number of current sensors
uint_least8_t numVoltageSensors;  //!< the number of voltage sensors

#ifdef QEP
QEP_Handle  qepHandle[2];  //!< the QEP handle
#endif

} HAL_Obj;

```

As can be seen, the HAL object definition is a combination of number of modules per peripheral, and modules related to a particular platform. For example, there is only one ADC module that we have to configure through the HAL module, so we only include one ADC module:

```
ADC_Handle  adcHandle;    //!< the ADC handle
```

And there are three PWM pairs that we have to configure, so we add three of these:

```
PWM_Handle  pwmHandle[3]; //!< the PWM handles
```

Also, related to the platform, the following HAL parameter will have the number of current sensors:

```
uint_least8_t numCurrentSensors; //!< the number of current sensors
```

## 4. APIs and Functions

The source files that contain all the API definitions and functions are in hal.c and hal.h. As mentioned earlier in this document, those functions which are time critical (i.e. executed inside an interrupt) should be inlined, therefore some of the HAL functions are implemented in hal.h as inlined functions.

First of all, the location of all hal.c and hal.h depends on the device and board combination as shown in the following picture:

	Name
\\sw\modules\hal\boards\boostxldr8301_revB\f28x\f2802x\src	hal.h
\\sw\modules\hal\boards\drv8301kit_revD\f28x\f2802x\src	hal.h
\\sw\modules\hal\boards\drv8301kit_revD\f28x\f2805x\src	hal.h
\\sw\modules\hal\boards\drv8301kit_revD\f28x\f2806x\src	hal.h
\\sw\modules\hal\boards\drv8312kit_revD\f28x\f2802x\src	hal.h
\\sw\modules\hal\boards\drv8312kit_revD\f28x\f2805x\src	hal.h
\\sw\modules\hal\boards\drv8312kit_revD\f28x\f2806x\src	hal.h
\\sw\modules\hal\boards\hvkit_rev1p1\f28x\f2802x\src	hal.h
\\sw\modules\hal\boards\hvkit_rev1p1\f28x\f2805x\src	hal.h
\\sw\modules\hal\boards\hvkit_rev1p1\f28x\f2806x\src	hal.h

	Name
\\sw\modules\hal\boards\boostxldr8301_revB\f28x\f2802x\src	hal.c
\\sw\modules\hal\boards\drv8301kit_revD\f28x\f2802x\src	hal.c
\\sw\modules\hal\boards\drv8301kit_revD\f28x\f2805x\src	hal.c
\\sw\modules\hal\boards\drv8301kit_revD\f28x\f2806x\src	hal.c
\\sw\modules\hal\boards\drv8312kit_revD\f28x\f2802x\src	hal.c
\\sw\modules\hal\boards\drv8312kit_revD\f28x\f2805x\src	hal.c
\\sw\modules\hal\boards\drv8312kit_revD\f28x\f2806x\src	hal.c
\\sw\modules\hal\boards\hvkit_rev1p1\f28x\f2802x\src	hal.c
\\sw\modules\hal\boards\hvkit_rev1p1\f28x\f2805x\src	hal.c
\\sw\modules\hal\boards\hvkit_rev1p1\f28x\f2806x\src	hal.c

The APIs are classified into different categories: Board management, Calibration management and Peripheral management.

### 4.1. Board Management

A few examples of board management HAL APIs are the ones that do not configure a peripheral directly, or manage variables related to a specific board, such as number of current sensors, number of quadrature encode modules (QEP), etc. Some examples of these APIs are:

- HAL\_getBias() and HAL\_setBias

- HAL\_getCurrentScaleFactor() and HAL\_setCurrentScaleFactor()
- HAL\_getNumCurrentSensors() and HAL\_setNumCurrentSensors()
- HAL\_getNumVoltageSensors() and HAL\_setNumVoltageSensors()
- HAL\_getOffsetBeta\_lp\_pu() and HAL\_setOffsetBeta\_lp\_pu()
- HAL\_getOffsetValue() and HAL\_setOffsetValue()
- HAL\_getVoltageScaleFactor() and HAL\_setVoltageScaleFactor()
- HAL\_setupFaults
- HAL\_readAdcData
- HAL\_setOffsetInitCond()
- HAL\_setParams()
- HAL\_updateAdcBias()
- HAL\_writeDacData()
- HAL\_writePwmData()
- HAL\_setTrigger()

## 4.2. Calibration Management

A few examples of calibration management HAL APIs are the ones that run certain code to adjust a calibration offset based on a device temperature sensor, or based on an ADC calibration subroutine. Some examples of these APIs are:

- HAL\_cal()
- HAL\_AdcCalChanSelect()
- HAL\_AdcCalConversion()
- HAL\_AdcOffsetSelfCal()
- HAL\_getOscTrimValue()
- HAL\_OscTempComp()
- HAL\_osc1Comp()
- HAL\_osc2Comp()

## 4.3. Peripheral Management

These APIs are the ones that configure a device peripheral, or a set of peripherals. Some of these functions are translated into a single function call to a peripheral configuration API, although they are still needed to allow the portability of the software architecture to work. An example of the simplest peripheral configuration is:

```
// enable global interrupts
HAL_enableGlobalInts(handle);
```

Which is implemented as follows:

```
void HAL_enableGlobalInts(HAL_Handle handle)
{
    HAL_Obj *obj = (HAL_Obj *)handle;
```

```
CPU_enableGlobalInts(obj->cpuHandle);  
  
return;  
} // end of HAL_enableGlobalInts() function
```

As can be seen, from the top level, a HAL function is called. In the HAL module itself, a CPU bit is changed. This HAL function might seem unnecessary, but it is actually needed to allow the top level to be fully portable to other MCUs or boards, which might modify another bit or bits to enable global interrupts.

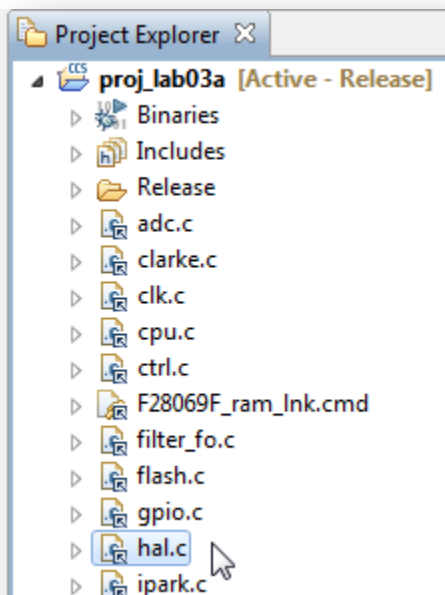
Some of the Peripheral management functions are:

- HAL\_acqAdcInt()
- HAL\_acqPwmInt()
- HAL\_disableGlobalInts()
- HAL\_disableWdog()
- HAL\_disablePwm()
- HAL\_enableAdcInts()
- HAL\_enableDebugInt()
- HAL\_enableGlobalInts()
- HAL\_enablePwm()
- HAL\_enablePwmInt()
- HAL\_getAdcSocSampleDelay()
- HAL\_initIntVectorTable()
- HAL\_readTimerCnt()
- HAL\_reloadTimer()
- HAL\_startTimer()
- HAL\_stopTimer()
- HAL\_setTimerPeriod()
- HAL\_getTimerPeriod()
- HAL\_setAdcSocSampleDelay()
- HAL\_setGpioHigh()
- HAL\_toggleGpio()
- HAL\_setGpioLow()
- HAL\_setupAdcs()
- HAL\_setupTimers()
- HAL\_setupClks()
- HAL\_setupFlash()
- HAL\_setupGpios()
- HAL\_setupPeripheralClks()

- HAL\_setupPie()
- HAL\_setupPII()
- HAL\_setupPwms()
- HAL\_setupPwmDacs()
- HAL\_readPwmCmpA()
- HAL\_readPwmCmpB()
- HAL\_readPwmPeriod()

## 5. Usage in MotorWare

The following picture shows where the HAL object is added within a MotorWare project:



### 5.1.HAL Global Variables

The following global variables are declared in a MotorWare project related to the HAL module in proj\_labxx.c:

```
// the globals
HAL_Handle halHandle;

HAL_PwmData_t gPwmData = {_IQ(0.0), _IQ(0.0), _IQ(0.0)};

HAL_AdcData_t gAdcData;
```

And the global HAL object declared in hal.c:

```
// the globals
```

```
HAL_Obj hal;
```

## 5.2.HAL Configuration

In a MotorWare project, there are several HAL functions that are called only once, related to the configuration of the Hardware. As an example, consider proj\_lab03a of MotorWare Release 13. All of these functions deal with configuration of either a peripheral, or a driver IC (i.e. DRV8301).

```
// initialize the hardware abstraction layer
halHandle = HAL_init(&hal,sizeof(hal));

...

// set the hardware abstraction layer parameters
HAL_setParams(halHandle,&gUserParams);

...

// setup faults
HAL_setupFaults(halHandle);

// initialize the interrupt vector table
HAL_initIntVectorTable(halHandle);

// enable the ADC interrupts
HAL_enableAdcInts(halHandle);

// enable global interrupts
HAL_enableGlobalInts(halHandle);

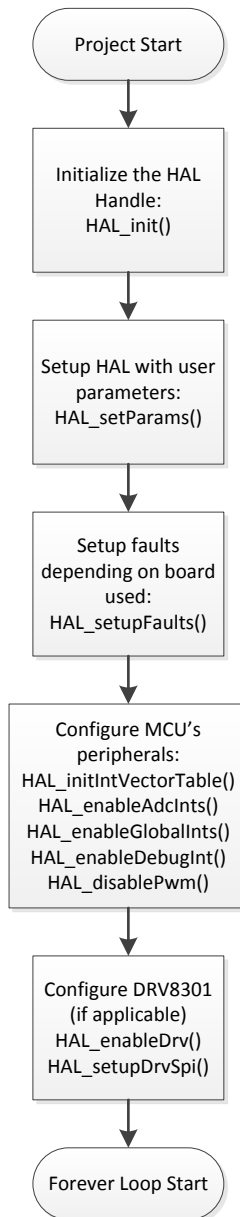
// enable debug interrupts
HAL_enableDebugInt(halHandle);

// disable the PWM
HAL_disablePwm(halHandle);

#ifdef DRV8301_SPI
// turn on the DRV8301 if present
HAL_enableDrv(halHandle);
// initialize the DRV8301 interface
HAL_setupDrvSpi(halHandle,&gDrvSpi8301Vars);
#endif
```

The following state machine summarizes the HAL configuration function calls:





### 5.3.HAL Background Functions

Considering the same example, proj\_lab03a of MotorWare 13, there are a few functions that are executed in the background loop (commonly called the forever loop, outside of any interrupts). These functions are PWM enable and disable, ADC bias updates and DRV8301 status updates:

```

for(;;)
{
...
    if(CTRL_isError(ctrlHandle))
    {
...
        // disable the PWM
    }
}
  
```

```

    HAL_disablePwm(halHandle);
}
else
{
...
    if(ctrlState == CTRL_State_OffLine)
    {
        // enable the PWM
        HAL_enablePwm(halHandle);
    }
    else if(ctrlState == CTRL_State_OnLine)
    {
        // update the ADC bias values
        HAL_updateAdcBias(halHandle);

        // Return the bias value for currents
        gMotorVars.I_bias.value[0] = HAL_getBias(halHandle,HAL_SensorType_Current,0);
        gMotorVars.I_bias.value[1] = HAL_getBias(halHandle,HAL_SensorType_Current,1);
        gMotorVars.I_bias.value[2] = HAL_getBias(halHandle,HAL_SensorType_Current,2);

        // Return the bias value for voltages
        gMotorVars.V_bias.value[0] = HAL_getBias(halHandle,HAL_SensorType_Voltage,0);
        gMotorVars.V_bias.value[1] = HAL_getBias(halHandle,HAL_SensorType_Voltage,1);
        gMotorVars.V_bias.value[2] = HAL_getBias(halHandle,HAL_SensorType_Voltage,2);

        // enable the PWM
        HAL_enablePwm(halHandle);
    }
    else if(ctrlState == CTRL_State_Idle)
    {
        // disable the PWM
        HAL_disablePwm(halHandle);
...
    }
...
}
}
...
#ifdef DRV8301_SPI
    HAL_writeDrvData(halHandle,&gDrvSpi8301Vars);

    HAL_readDrvData(halHandle,&gDrvSpi8301Vars);
#endif

} // end of while(gFlag_enableSys) loop

// disable the PWM

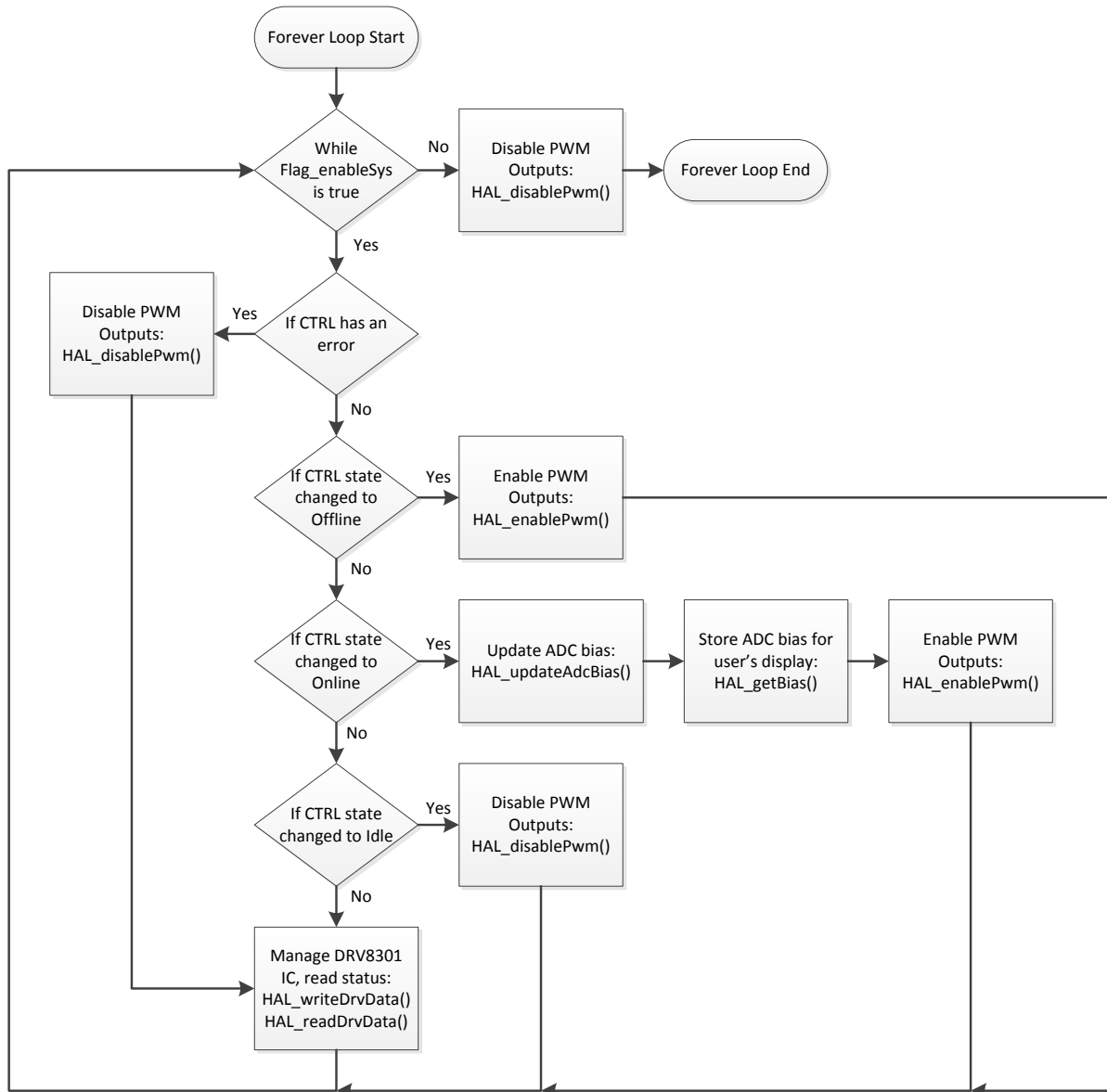
```

```

HAL_disablePwm(halHandle);
...
} // end of for(;;) loop

```

The following state machine summarizes the HAL function calls in the forever loop (outside of the interrupt):



### 5.4.HAL Functions in Interrupt

The following functions are called in our proj\_lab03a example of MotorWare 13.

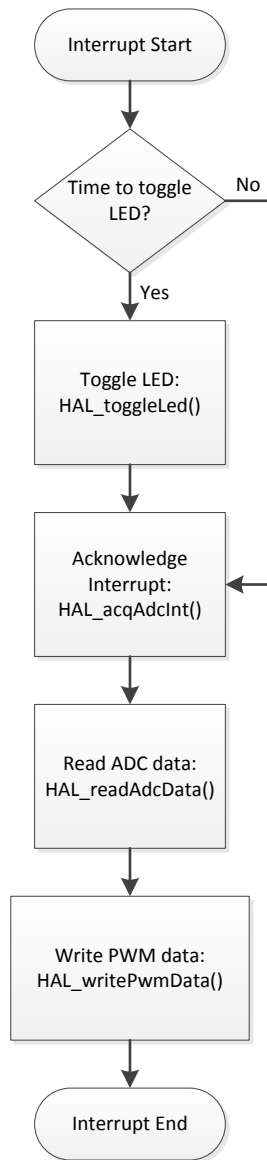
```

interrupt void mainISR(void)
{
...

```

```
    HAL_toggleLed(halHandle,(GPIO_Number_e)HAL_Gpio_LED2);  
...  
    // acknowledge the ADC interrupt  
    HAL_acqAdcInt(halHandle,ADC_IntNumber_1);  
  
    // convert the ADC data  
    HAL_readAdcData(halHandle,&gAdcData);  
...  
    // write the PWM compare values  
    HAL_writePwmData(halHandle,&gPwmData);  
...  
    return;  
} // end of mainISR() function
```

The following state machine summarizes the HAL function calls in the interrupt:

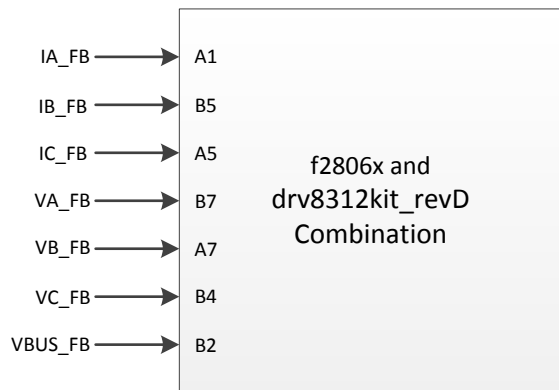


## 6. Examples of Modifying the HAL Module

This section shows a few examples on how to change the HAL module. The examples shown here are tested with MotorWare release 13.

### 6.1.Changing ADC Channels

The HAL module configures the ADC channels according to the board of interest. For example, the f2806x and the drv8312kit\_revD board combination uses the following ADC connections:



Which is configured as shown in the following code snippet, taken from hal.c, function HAL\_setupAdcs() located in the following location: sw\modules\hal\boards\drv8312kit\_revD\f28x\f2806x\src

```
// configure the SOCs for drv8312kit_revD
// EXT IA-FB
ADC_setSocChanNumber(obj->adcHandle,ADC_SocNumber_0,ADC_SocChanNumber_A1);
ADC_setSocTrigSrc(obj->adcHandle,ADC_SocNumber_0,ADC_SocTrigSrc_EPWM1_ADCSOCA);
ADC_setSocSampleDelay(obj->adcHandle,ADC_SocNumber_0,ADC_SocSampleDelay_9_cycles);

// EXT IA-FB
// Duplicate conversion due to ADC Initial Conversion bug (SPRZ342)
ADC_setSocChanNumber(obj->adcHandle,ADC_SocNumber_1,ADC_SocChanNumber_A1);
ADC_setSocTrigSrc(obj->adcHandle,ADC_SocNumber_1,ADC_SocTrigSrc_EPWM1_ADCSOCA);
ADC_setSocSampleDelay(obj->adcHandle,ADC_SocNumber_1,ADC_SocSampleDelay_9_cycles);

// EXT IB-FB
ADC_setSocChanNumber(obj->adcHandle,ADC_SocNumber_2,ADC_SocChanNumber_B5);
ADC_setSocTrigSrc(obj->adcHandle,ADC_SocNumber_2,ADC_SocTrigSrc_EPWM1_ADCSOCA);
ADC_setSocSampleDelay(obj->adcHandle,ADC_SocNumber_2,ADC_SocSampleDelay_9_cycles);

// EXT IC-FB
ADC_setSocChanNumber(obj->adcHandle,ADC_SocNumber_3,ADC_SocChanNumber_A5);
ADC_setSocTrigSrc(obj->adcHandle,ADC_SocNumber_3,ADC_SocTrigSrc_EPWM1_ADCSOCA);
ADC_setSocSampleDelay(obj->adcHandle,ADC_SocNumber_3,ADC_SocSampleDelay_9_cycles);

// ADC-Vhb1
ADC_setSocChanNumber(obj->adcHandle,ADC_SocNumber_4,ADC_SocChanNumber_B7);
ADC_setSocTrigSrc(obj->adcHandle,ADC_SocNumber_4,ADC_SocTrigSrc_EPWM1_ADCSOCA);
ADC_setSocSampleDelay(obj->adcHandle,ADC_SocNumber_4,ADC_SocSampleDelay_9_cycles);

// ADC-Vhb2
```

```

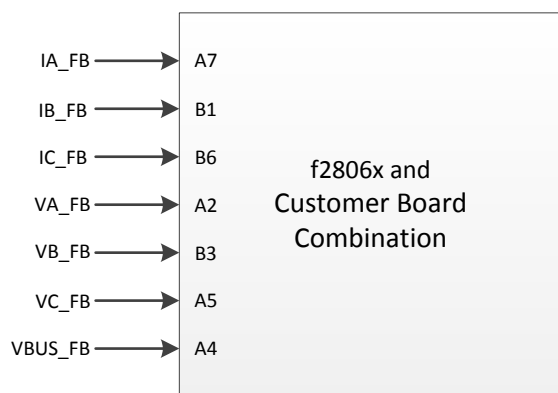
ADC_setSocChanNumber(obj->adcHandle,ADC_SocNumber_5,ADC_SocChanNumber_A7);
ADC_setSocTrigSrc(obj->adcHandle,ADC_SocNumber_5,ADC_SocTrigSrc_EPWM1_ADCSOCA);
ADC_setSocSampleDelay(obj->adcHandle,ADC_SocNumber_5,ADC_SocSampleDelay_9_cycles);

// ADC-Vhb3
ADC_setSocChanNumber(obj->adcHandle,ADC_SocNumber_6,ADC_SocChanNumber_B4);
ADC_setSocTrigSrc(obj->adcHandle,ADC_SocNumber_6,ADC_SocTrigSrc_EPWM1_ADCSOCA);
ADC_setSocSampleDelay(obj->adcHandle,ADC_SocNumber_6,ADC_SocSampleDelay_9_cycles);

// VDCBUS
ADC_setSocChanNumber(obj->adcHandle,ADC_SocNumber_7,ADC_SocChanNumber_B2);
ADC_setSocTrigSrc(obj->adcHandle,ADC_SocNumber_7,ADC_SocTrigSrc_EPWM1_ADCSOCA);
ADC_setSocSampleDelay(obj->adcHandle,ADC_SocNumber_7,ADC_SocSampleDelay_9_cycles);

```

Now let's change the connections, as if we had a customer's board, which has a different ADC configuration as in the following diagram:



The only piece of code that's affected is in the HAL module. The configuration of the ADC, done in function HAL\_setupAdcs() would be like this (changes are highlighted):

```

// configure the SOCs for customer board
// EXT IA-FB
ADC_setSocChanNumber(obj->adcHandle,ADC_SocNumber_0,ADC_SocChanNumber_A7);
ADC_setSocTrigSrc(obj->adcHandle,ADC_SocNumber_0,ADC_SocTrigSrc_EPWM1_ADCSOCA);
ADC_setSocSampleDelay(obj->adcHandle,ADC_SocNumber_0,ADC_SocSampleDelay_9_cycles);

// EXT IA-FB
// Duplicate conversion due to ADC Initial Conversion bug (SPRZ342)
ADC_setSocChanNumber(obj->adcHandle,ADC_SocNumber_1,ADC_SocChanNumber_A7);
ADC_setSocTrigSrc(obj->adcHandle,ADC_SocNumber_1,ADC_SocTrigSrc_EPWM1_ADCSOCA);
ADC_setSocSampleDelay(obj->adcHandle,ADC_SocNumber_1,ADC_SocSampleDelay_9_cycles);

```

```

// EXT IB-FB
ADC_setSocChanNumber(obj->adcHandle,ADC_SocNumber_2,ADC_SocChanNumber_B1);
ADC_setSocTrigSrc(obj->adcHandle,ADC_SocNumber_2,ADC_SocTrigSrc_EPWM1_ADCSOCA);
ADC_setSocSampleDelay(obj->adcHandle,ADC_SocNumber_2,ADC_SocSampleDelay_9_cycles);

// EXT IC-FB
ADC_setSocChanNumber(obj->adcHandle,ADC_SocNumber_3,ADC_SocChanNumber_B6);
ADC_setSocTrigSrc(obj->adcHandle,ADC_SocNumber_3,ADC_SocTrigSrc_EPWM1_ADCSOCA);
ADC_setSocSampleDelay(obj->adcHandle,ADC_SocNumber_3,ADC_SocSampleDelay_9_cycles);

// ADC-Vhb1
ADC_setSocChanNumber(obj->adcHandle,ADC_SocNumber_4,ADC_SocChanNumber_A2);
ADC_setSocTrigSrc(obj->adcHandle,ADC_SocNumber_4,ADC_SocTrigSrc_EPWM1_ADCSOCA);
ADC_setSocSampleDelay(obj->adcHandle,ADC_SocNumber_4,ADC_SocSampleDelay_9_cycles);

// ADC-Vhb2
ADC_setSocChanNumber(obj->adcHandle,ADC_SocNumber_5,ADC_SocChanNumber_B3);
ADC_setSocTrigSrc(obj->adcHandle,ADC_SocNumber_5,ADC_SocTrigSrc_EPWM1_ADCSOCA);
ADC_setSocSampleDelay(obj->adcHandle,ADC_SocNumber_5,ADC_SocSampleDelay_9_cycles);

// ADC-Vhb3
ADC_setSocChanNumber(obj->adcHandle,ADC_SocNumber_6,ADC_SocChanNumber_A5);
ADC_setSocTrigSrc(obj->adcHandle,ADC_SocNumber_6,ADC_SocTrigSrc_EPWM1_ADCSOCA);
ADC_setSocSampleDelay(obj->adcHandle,ADC_SocNumber_6,ADC_SocSampleDelay_9_cycles);

// VDCBUS
ADC_setSocChanNumber(obj->adcHandle,ADC_SocNumber_7,ADC_SocChanNumber_A4);
ADC_setSocTrigSrc(obj->adcHandle,ADC_SocNumber_7,ADC_SocTrigSrc_EPWM1_ADCSOCA);
ADC_setSocSampleDelay(obj->adcHandle,ADC_SocNumber_7,ADC_SocSampleDelay_9_cycles);

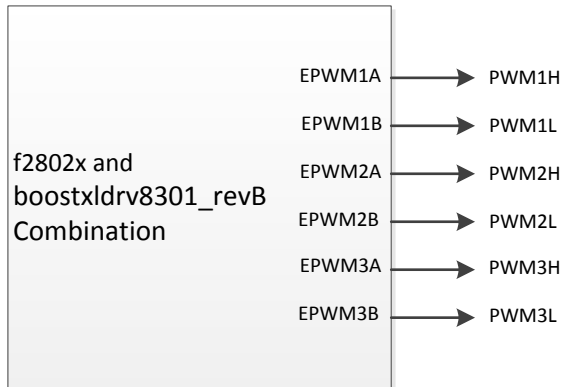
```

Keep in mind that the first two channels need to be repeated, so that the ADC initial conversion bug (SPRZ342) is handled.

## 6.2.Changing PWM Channels

Similar to the previous example, the PWM outputs can also be changed to accommodate another board compared to the TI motor control kits. For example, if we consider the booster pack + Launchpad and f2802x combination, this is how the PWM outputs are connected:





There are two functions that configure the PWM connections. One is in HAL\_setupGpios() to setup the GPIOs as PWM outputs:

```
// PWM1H
GPIO_setMode(obj->gpioHandle,GPIO_Number_0,GPIO_0_Mode_EPWM1A);

// PWM1L
GPIO_setMode(obj->gpioHandle,GPIO_Number_1,GPIO_1_Mode_EPWM1B);

// PWM2H
GPIO_setMode(obj->gpioHandle,GPIO_Number_2,GPIO_2_Mode_EPWM2A);

// PWM2L
GPIO_setMode(obj->gpioHandle,GPIO_Number_3,GPIO_3_Mode_EPWM2B);

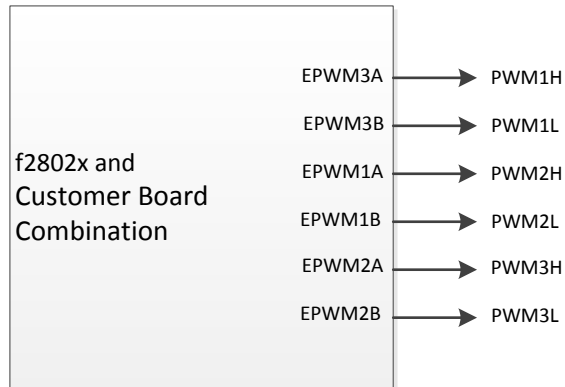
// PWM3H
GPIO_setMode(obj->gpioHandle,GPIO_Number_4,GPIO_4_Mode_EPWM3A);

// PWM3L
GPIO_setMode(obj->gpioHandle,GPIO_Number_5,GPIO_5_Mode_EPWM3B);
```

And the second function that handles this configuration is HAL\_init(), which assigns the address of the PWM modules used:

```
// initialize PWM handle
obj->pwmHandle[0] = PWM_init((void *)PWM_ePWM1_BASE_ADDR,sizeof(PWM_Obj));
obj->pwmHandle[1] = PWM_init((void *)PWM_ePWM2_BASE_ADDR,sizeof(PWM_Obj));
obj->pwmHandle[2] = PWM_init((void *)PWM_ePWM3_BASE_ADDR,sizeof(PWM_Obj));
```

Now, consider the following customer's board connection instead:



The following code snippet shows how to enable these GPIOs as outputs in HAL\_setupGpios(). In fact, the configuration is the same, although the comments are changed reflecting new order of connections.

```
// PWM2H
GPIO_setMode(obj->gpioHandle,GPIO_Number_0,GPIO_0_Mode_EPWM1A);

// PWM2L
GPIO_setMode(obj->gpioHandle,GPIO_Number_1,GPIO_1_Mode_EPWM1B);

// PWM3H
GPIO_setMode(obj->gpioHandle,GPIO_Number_2,GPIO_2_Mode_EPWM2A);

// PWM3L
GPIO_setMode(obj->gpioHandle,GPIO_Number_3,GPIO_3_Mode_EPWM2B);

// PWM1H
GPIO_setMode(obj->gpioHandle,GPIO_Number_4,GPIO_4_Mode_EPWM3A);

// PWM1L
GPIO_setMode(obj->gpioHandle,GPIO_Number_5,GPIO_5_Mode_EPWM3B);
```

A second function that handles this configuration is HAL\_init(). The assigned addresses are changed according to the PWM output connections:

```
// initialize PWM handle
obj->pwmHandle[0] = PWM_init((void *)PWM_ePWM3_BASE_ADDR,sizeof(PWM_Obj));
obj->pwmHandle[1] = PWM_init((void *)PWM_ePWM1_BASE_ADDR,sizeof(PWM_Obj));
obj->pwmHandle[2] = PWM_init((void *)PWM_ePWM2_BASE_ADDR,sizeof(PWM_Obj));
```

This way, every time we reference “obj->pwmHandle[PWM\_Number\_1]” we will be referencing outputs PWM1H and PWM1L of the actual inverter, regardless of what EPWM it is assigned to. Similarly when we reference “obj->pwmHandle[PWM\_Number\_2]” we will be referencing outputs PWM2H and PWM2L, and when referencing “obj->pwmHandle[PWM\_Number\_1]” we will be referencing outputs PWM3H and PWM3L. So in summary:

- pwmHandle[PWM\_Number\_1] → f2802x: EPWM3A/EPWM3B → Inverter: PWM1H/PWM1L
- pwmHandle[PWM\_Number\_2] → f2802x: EPWM1A/EPWM1B → Inverter: PWM2H/PWM2L
- pwmHandle[PWM\_Number\_3] → f2802x: EPWM2A/EPWM2B → Inverter: PWM3H/PWM3L

Finally, the start of conversion of the ADC samples needs to be changed in HAL\_setupAdcs() function, since now the conversions will be triggered by Inverter outputs PWM1H/PWM1L, which are now assigned to f2802x: EPWM3A/EPWM3B. To change this, the following code snippet shows a highlighter text, which changes from a value of “ADC\_SocTrigSrc\_EPWM1\_ADCSOCA” to a value of “ADC\_SocTrigSrc\_EPWM3\_ADCSOCA”:

```
//configure the SOCs for customer board
// sample the first sample twice due to errata sprz342f
ADC_setSocChanNumber(obj->adcHandle,ADC_SocNumber_0,ADC_SocChanNumber_B1);
ADC_setSocTrigSrc(obj->adcHandle,ADC_SocNumber_0,ADC_SocTrigSrc_EPWM3_ADCSOCA);
ADC_setSocSampleDelay(obj->adcHandle,ADC_SocNumber_0,ADC_SocSampleDelay_7_cycles);

ADC_setSocChanNumber(obj->adcHandle,ADC_SocNumber_1,ADC_SocChanNumber_B1);
ADC_setSocTrigSrc(obj->adcHandle,ADC_SocNumber_1,ADC_SocTrigSrc_EPWM3_ADCSOCA);
ADC_setSocSampleDelay(obj->adcHandle,ADC_SocNumber_1,ADC_SocSampleDelay_7_cycles);

ADC_setSocChanNumber(obj->adcHandle,ADC_SocNumber_2,ADC_SocChanNumber_B3);
ADC_setSocTrigSrc(obj->adcHandle,ADC_SocNumber_2,ADC_SocTrigSrc_EPWM3_ADCSOCA);
ADC_setSocSampleDelay(obj->adcHandle,ADC_SocNumber_2,ADC_SocSampleDelay_7_cycles);

ADC_setSocChanNumber(obj->adcHandle,ADC_SocNumber_3,ADC_SocChanNumber_B7);
ADC_setSocTrigSrc(obj->adcHandle,ADC_SocNumber_3,ADC_SocTrigSrc_EPWM3_ADCSOCA);
ADC_setSocSampleDelay(obj->adcHandle,ADC_SocNumber_3,ADC_SocSampleDelay_7_cycles);

ADC_setSocChanNumber(obj->adcHandle,ADC_SocNumber_4,ADC_SocChanNumber_A3);
ADC_setSocTrigSrc(obj->adcHandle,ADC_SocNumber_4,ADC_SocTrigSrc_EPWM3_ADCSOCA);
ADC_setSocSampleDelay(obj->adcHandle,ADC_SocNumber_4,ADC_SocSampleDelay_7_cycles);

ADC_setSocChanNumber(obj->adcHandle,ADC_SocNumber_5,ADC_SocChanNumber_A1);
ADC_setSocTrigSrc(obj->adcHandle,ADC_SocNumber_5,ADC_SocTrigSrc_EPWM3_ADCSOCA);
ADC_setSocSampleDelay(obj->adcHandle,ADC_SocNumber_5,ADC_SocSampleDelay_7_cycles);

ADC_setSocChanNumber(obj->adcHandle,ADC_SocNumber_6,ADC_SocChanNumber_A0);
ADC_setSocTrigSrc(obj->adcHandle,ADC_SocNumber_6,ADC_SocTrigSrc_EPWM3_ADCSOCA);
ADC_setSocSampleDelay(obj->adcHandle,ADC_SocNumber_6,ADC_SocSampleDelay_7_cycles);

ADC_setSocChanNumber(obj->adcHandle,ADC_SocNumber_7,ADC_SocChanNumber_A7);
ADC_setSocTrigSrc(obj->adcHandle,ADC_SocNumber_7,ADC_SocTrigSrc_EPWM3_ADCSOCA);
```

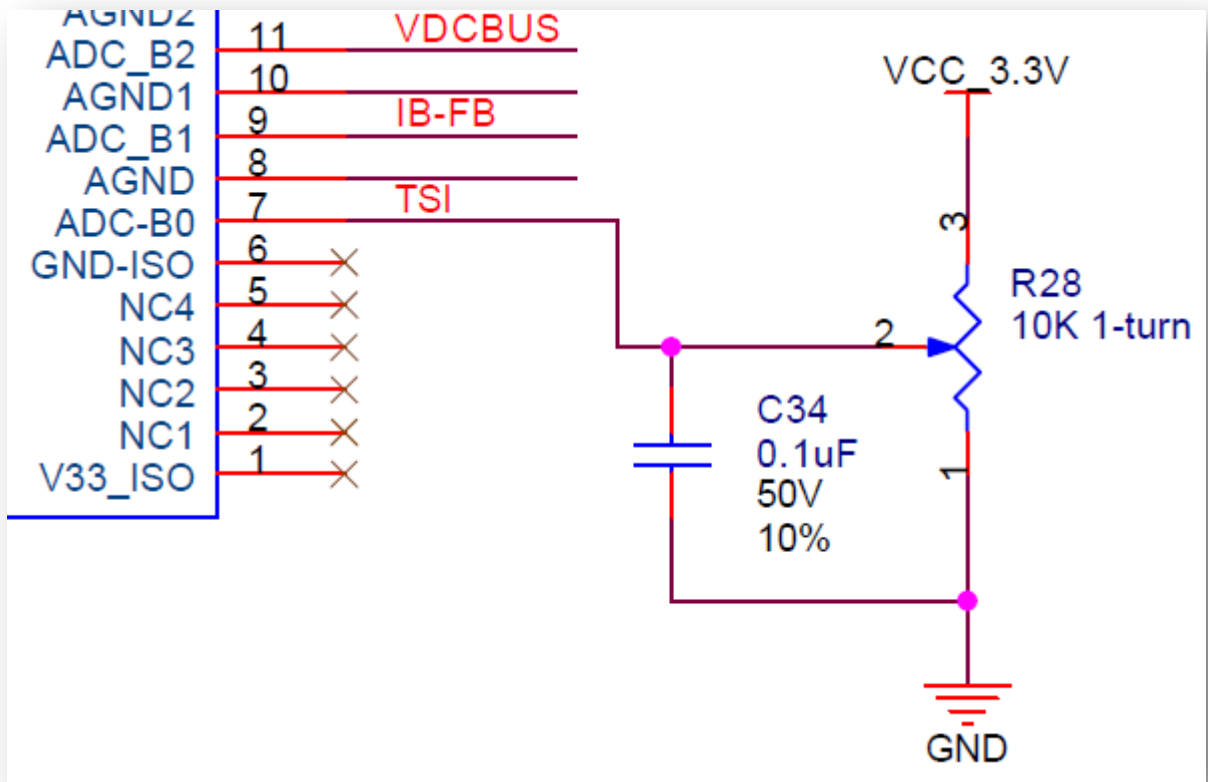
```
ADC_setSocSampleDelay(obj->adcHandle,ADC_SocNumber_7,ADC_SocSampleDelay_7_cycles);
```

### 6.3.Adding a Potentiometer Read

As an example, let us change the HAL module so that we can add a potentiometer read. For this example, we will assume we have an f2806x and a drv8301kit\_revD combination. Let us also assume that we are running proj\_lab03a of MotorWare 13. So the files that will change in this case are:

- sw\modules\hal\boards\drv8301kit\_revD\f28x\f2806x\src\hal.h
- sw\modules\hal\boards\drv8301kit\_revD\f28x\f2806x\src\hal.c
- sw\solutions\instaspin\_foc\src\proj\_lab03a.c

First of all, we need to configure a start of conversion channel. We will assign the start of conversion 8 to this potentiometer we want to read. The potentiometer we would like to read is connected to ADC-B0 according to drv8301kit\_revD schematics as shown in the following picture:

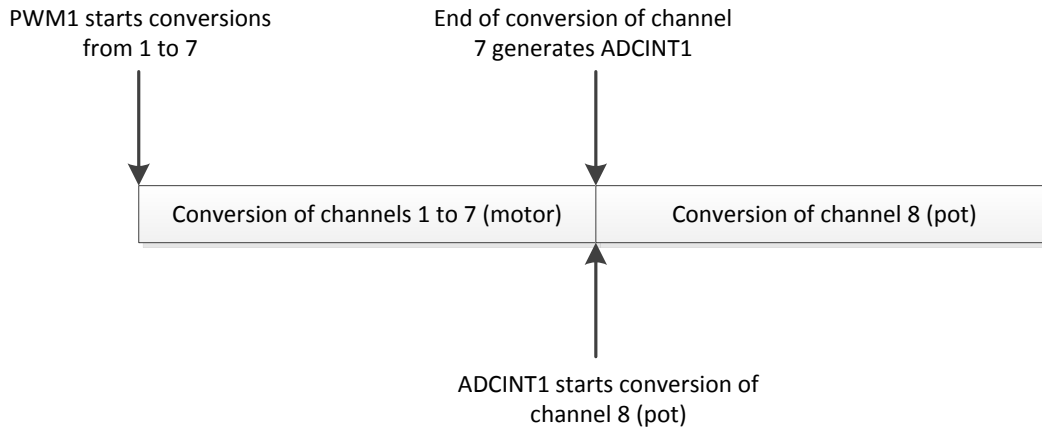


This is done in function HAL\_setupAdcs() of hal.c file as follows:

```
// Potentiometer
// Configure it so that ADCINT1 will trigger a potentiometer conversion
ADC_setSocChanNumber(obj->adcHandle,ADC_SocNumber_8,ADC_SocChanNumber_B0);
```

```
ADC_setupSocTrigSrc(obj->adcHandle, ADC_SocNumber_8, ADC_Int1TriggersSOC);
ADC_setSocSampleDelay(obj->adcHandle, ADC_SocNumber_8, ADC_SocSampleDelay_9_cycles);
```

It is very important to use ADCINT1 as the trigger source, since we don't want the potentiometer conversion to delay motor control related conversions. Since ADCINT1 is triggered by the end of conversion of the other 7 channels (dedicated to motor control), the potentiometer will always be triggered once the time critical channels are converted. Looking at this in a time diagram would look something like this:



The second change is in hal.h file. A new function is created to read the potentiometer. This function simply reads the ADC result register and scales the value to an IQ24 value. This function is listed here:

```
//! \brief Reads the Potentiometer
//! \param[in] handle The hardware abstraction layer (HAL) handle
//! \return The potentiometer value from _IQ(-1.0) to _IQ(1.0)
static inline _iq HAL_readPotentiometerData(HAL_Handle handle)
{
    HAL_Obj *obj = (HAL_Obj *)handle;

    _iq value;

    // convert potentiometer from IQ12 to IQ24.
    value = _IQ12toIQ((_iq)ADC_readResult(obj->adcHandle, ADC_ResultNumber_8));

    return(value);
} // end of HAL_readPotentiometerData() function
```

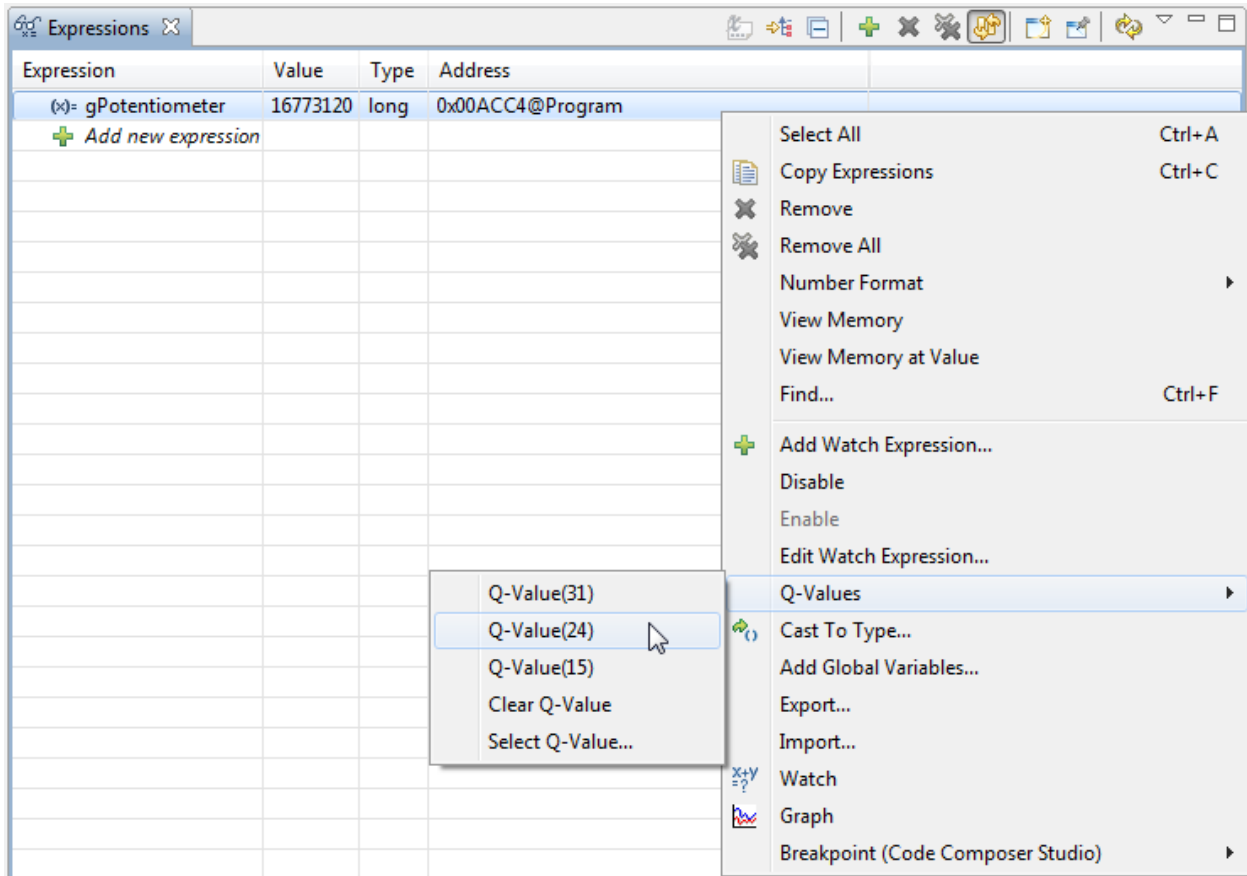
The third change is in the project itself. Since we are working on proj\_lab03a, we only need to declare a global variable to store the converted value:

```
_iq gPotentiometer = _IQ(0.0);
```

And we call the new function we created in a background loop, outside of the interrupt to avoid any CPU bandwidth hit.

```
gPotentiometer = HAL_readPotentiometerData(halHandle);
```

User can confirm that the value is being updated by adding the new global variable to the watch window. The value type needs to be changed to IQ24 by right clicking the variable name as shown in the following screen shot:



If we move the potentiometer all the way CCW, we see a value of 0.0 being displayed:

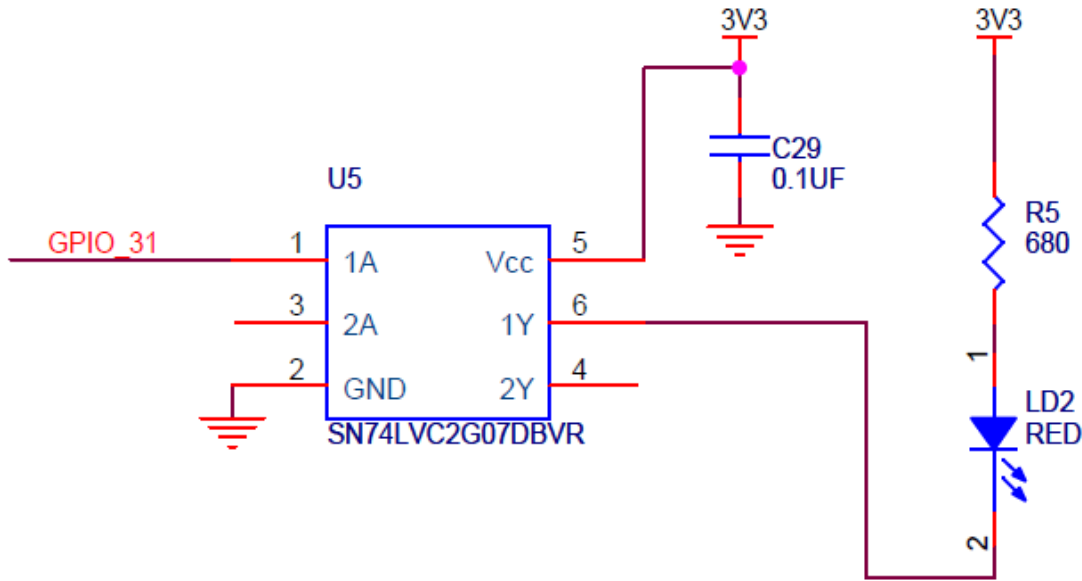
```
(x)- gPotentiometer 0.0 (Q-Value(24))
```

And if we move it all the way to CW:

```
(x)- gPotentiometer 0.9997558594 (Q-Value(24))
```

## 6.4. Adding a User PWM Output

This is another example, where a simple PWM output is added to the HAL module. Let us use the f2806x with the drv8301kit\_revD combination. We will use GPIO 31 as a PWM output, which drives the LED labeled as "LD2" in the control card.



Our goal is to have a PWM with fixed frequency, and a global variable for duty cycle. The following files are going to be affected based on proj\_lab03a MotorWare release 13:

- sw\modules\hal\boards\drv8301kit\_revD\f28x\f2806x\src\hal.c
- sw\modules\hal\boards\drv8301kit\_revD\f28x\f2806x\src\hal.h
- sw\modules\hal\boards\drv8301kit\_revD\f28x\f2806x\src\hal\_obj.h
- sw\solutions\instaspin\_foc\src\proj\_lab03a.c

#### 6.4.1. Adding a PWM Handle to the HAL Object

The first step is to add a handle of a PWM user in the HAL object.

Important Note: Additional members to the HAL object must be added to the end of the object definition. This is because an instantiation of the HAL object was built for ROM, and the ROM code expects the same object definition. Additional members of the HAL layer added at the bottom of the HAL object won't conflict with the ROMed code.

Having said that, this code example shows the new member added to the HAL object:

```

//! \brief   Defines the hardware abstraction layer (HAL) data
//! \details The HAL object contains all handles to peripherals. When accessing a
//!           peripheral on a processor, use a HAL function along with the HAL handle
//!           for that processor to access its peripherals.
//!
typedef struct _HAL_Obj_

```

```

{
...

PWM_Handle pwmUserHandle; //<! the PWM user handle

} HAL_Obj;

```

#### 6.4.2. Initializing the New Handle

The following code is needed to initialize the new handle, that is, to have a handle point to the peripheral address, so every time we reference this handle, the peripheral itself is referenced.

```

HAL_Handle HAL_init(void *pMemory,const size_t numBytes)
{
...
// initialize PWM user handle
obj->pwmUserHandle = PWM_init((void *)PWM_ePWM8_BASE_ADDR,sizeof(PWM_Obj));

return(handle);
} // end of HAL_init() function

```

#### 6.4.3. Create a Setup Function for the new PWM

The third step is to create a function to setup the PWM. The function prototype in hal.h file looks like this:

```

//! \brief Sets up the PWM (Pulse Width Modulator) for user control
//! \param[in] handle The hardware abstraction layer (HAL) handle
//! \param[in] systemFreq_MHz The system frequency, MHz
//! \param[in] pwmPeriod_usec The PWM period, usec
extern void HAL_setupPwmUser(HAL_Handle handle,
                             const uint_least16_t systemFreq_MHz,
                             const float_t pwmPeriod_usec);

```

Notice that this function takes the CPU frequency in MHz and the desired PWM period in microseconds. This is really a user's choice, but in this example, it is convenient to specify the PWM period depending on the CPU frequency. The function itself, in hal.c, is listed here:

```

void HAL_setupPwmUser(HAL_Handle handle,
                     const uint_least16_t systemFreq_MHz,
                     const float_t pwmPeriod_usec)
{
HAL_Obj *obj = (HAL_Obj *)handle;
uint16_t period_cycles = (uint16_t)((float_t)systemFreq_MHz*pwmPeriod_usec);

```



```

// turns off the output of the EPWM peripheral
PWM_setOneShotTrip(obj->pwmUserHandle);

// setup the Time-Base Control Register (TBCTL)
PWM_setCounterMode(obj->pwmUserHandle,PWM_CounterMode_Up);
PWM_disableCounterLoad(obj->pwmUserHandle);
PWM_setPeriodLoad(obj->pwmUserHandle,PWM_PeriodLoad_Immediate);
PWM_setSyncMode(obj->pwmUserHandle,PWM_SyncMode_Disable);
PWM_setHighSpeedClkDiv(obj->pwmUserHandle,PWM_HspClkDiv_by_1);
PWM_setClkDiv(obj->pwmUserHandle,PWM_ClkDiv_by_1);
PWM_setPhaseDir(obj->pwmUserHandle,PWM_PhaseDir_CountUp);
PWM_setRunMode(obj->pwmUserHandle,PWM_RunMode_FreeRun);

// setup the Timer-Based Phase Register (TBPHS)
PWM_setPhase(obj->pwmUserHandle,0);

// setup the Time-Base Counter Register (TBCTR)
PWM_setCount(obj->pwmUserHandle,0);

// setup the Time-Base Period Register (TBPRD)
// set to zero initially
PWM_setPeriod(obj->pwmUserHandle,0);

// setup the Counter-Compare Control Register (CMPCTL)
PWM_setLoadMode_CmpA(obj->pwmUserHandle,PWM_LoadMode_Zero);
PWM_setShadowMode_CmpA(obj->pwmUserHandle,PWM_ShadowMode_Shadow);

// setup the Action-Qualifier Output A Register (AQCTLA)
PWM_setActionQual_CntUp_CmpA_PwmA(obj->pwmUserHandle,PWM_ActionQual_Clear);
PWM_setActionQual_Period_PwmA(obj->pwmUserHandle,PWM_ActionQual_Set);

// setup the Dead-Band Generator Control Register (DBCTL)
PWM_setDeadBandOutputMode(obj->pwmUserHandle,PWM_DeadBandOutputMode_Bypass);

// setup the PWM-Chopper Control Register (PCCTL)
PWM_disableChopping(obj->pwmUserHandle);

// setup the Trip Zone Select Register (TZSEL)
PWM_disableTripZones(obj->pwmUserHandle);

```

```

// setup the Event Trigger Selection Register (ETSEL)
PWM_disableInt(obj->pwmUserHandle);
PWM_disableSocAPulse(obj->pwmUserHandle);

// setup the Event Trigger Prescale Register (ETPS)
PWM_setIntPeriod(obj->pwmUserHandle,PWM_IntPeriod_FirstEvent);
PWM_setSocAPeriod(obj->pwmUserHandle,PWM_SocPeriod_FirstEvent);

// setup the Event Trigger Clear Register (ETCLR)
PWM_clearIntFlag(obj->pwmUserHandle);
PWM_clearSocAFlag(obj->pwmUserHandle);

// since the PWM is configured as an up counter, the period register is set to
// the desired PWM period
PWM_setPeriod(obj->pwmUserHandle,period_cycles);

// turns on the output of the EPWM peripheral
PWM_clearOneShotTrip(obj->pwmUserHandle);

return;
} // end of HAL_setupPwmUser() function

```

The PWM is configured as an up counter only (commonly known as edge aligned), with positive duty cycle (the higher the duty cycle, the wider the high side is), with only one output (the A output, so no dead band is needed).

#### 6.4.4. Create a Write Function

We need to create a HAL function that will write the CMPA register of the PWM with the correct scaling. The following example function was created, which takes a duty cycle as a parameter, from `_IQ(0.0)` (representing 0.0%) up to `_IQ(1.0)` (representing 100.0% duty cycle).

```

//! \brief Writes PWM data to the PWM comparator for user control
//! \param[in] handle The hardware abstraction layer (HAL) handle
//! \param[in] dutyCycle The duty cycle to be written, from _IQ(0.0) to _IQ(1.0)
static inline void HAL_writePwmDataUser(HAL_Handle handle,_iq dutyCycle)
{
    HAL_Obj *obj = (HAL_Obj *)handle;
    PWM_Obj *pwm;
    _iq period;
    _iq value;
    uint16_t value_sat;

```

```

pwm = (PWM_Obj *)obj->pwmUserHandle;
period = (_iq)pwm->TBPRD;
value = _IQmpy(dutyCycle, period);
value_sat = (uint16_t)_IQsat(value, period, _IQ(0.0));

// write the PWM data
PWM_write_CmpA(obj->pwmUserHandle,value_sat);

return;
} // end of HAL_writePwmDataUser() function

```

#### 6.4.5. Configuring GPIO as PWM Output

The following code configures GPIO 31 as a PWM output. This code is in hal.c, in HAL\_setupGpios() function.

```

// ControlCARD LED2
GPIO_setMode(obj->gpioHandle,GPIO_Number_31,GPIO_31_Mode_EPWM8A);

```

#### 6.4.6. Enable PWM Clock

This is done in HAL\_setupPeripheralClks() function of hal.c file:

```

CLK_enablePwmClock(obj->clkHandle,PWM_Number_8);

```

#### 6.4.7. Calling the Setup Function

We need to call the setup function we created, so that the PWM is configured. This is done when the HAL object is setup, in the HAL\_setParams() function in hal.c file:

```

// setup the PWM User
HAL_setupPwmUser(handle,90,(float_t)100.0);

```

As can be seen, the CPU is running at 90 MHz, and our desired PWM period is 100 microseconds, or 10 kHz frequency.

#### 6.4.8. Changing Duty Cycle in the Project

Finally, we create a global variable that we use to change the duty cycle. We add this global variable to proj\_lab03a.c, and initialize it with some duty cycle:

```

_iq gLEDduty = _IQ(0.9);

```

Then, we call the function we created inside the project. This can be done anywhere in the code, as long as it is periodically called, so the duty cycle is updated.

```

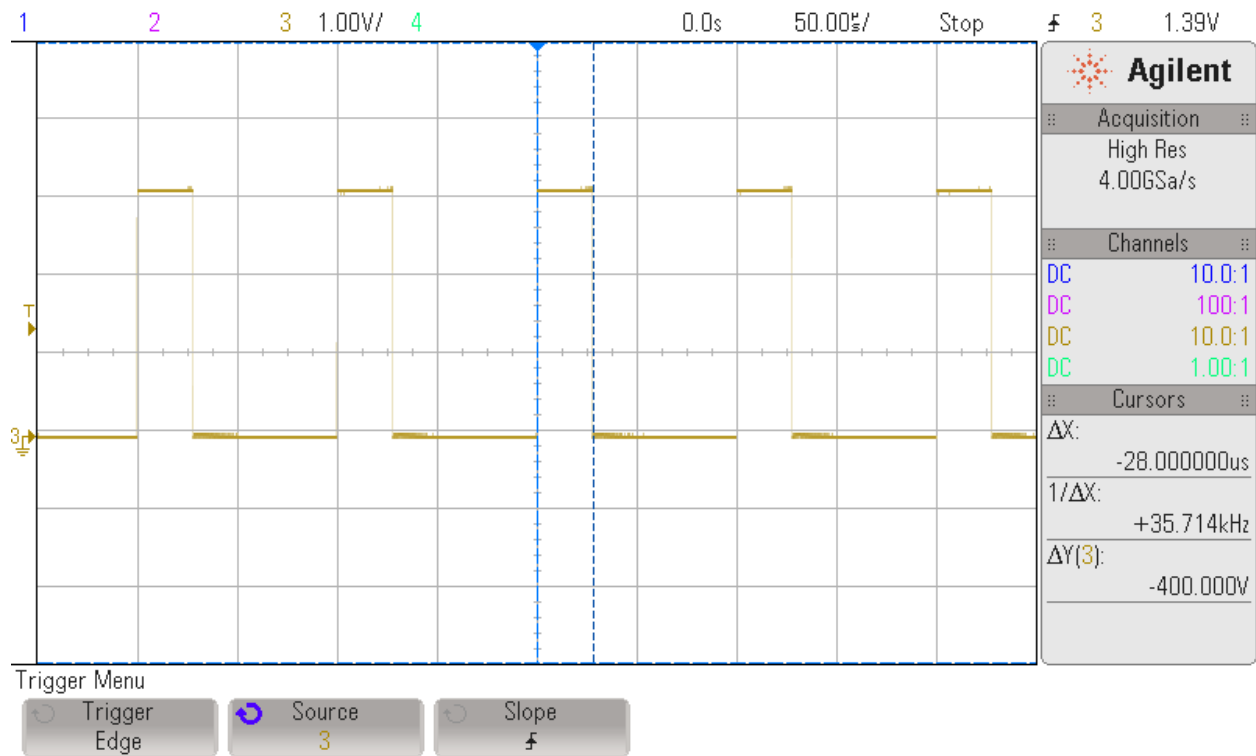
HAL_writePwmDataUser(halHandle,gLEDduty);

```

To verify, plot the PWM output in the scope. For example, in our test, we changed the duty cycle to 28%, so:

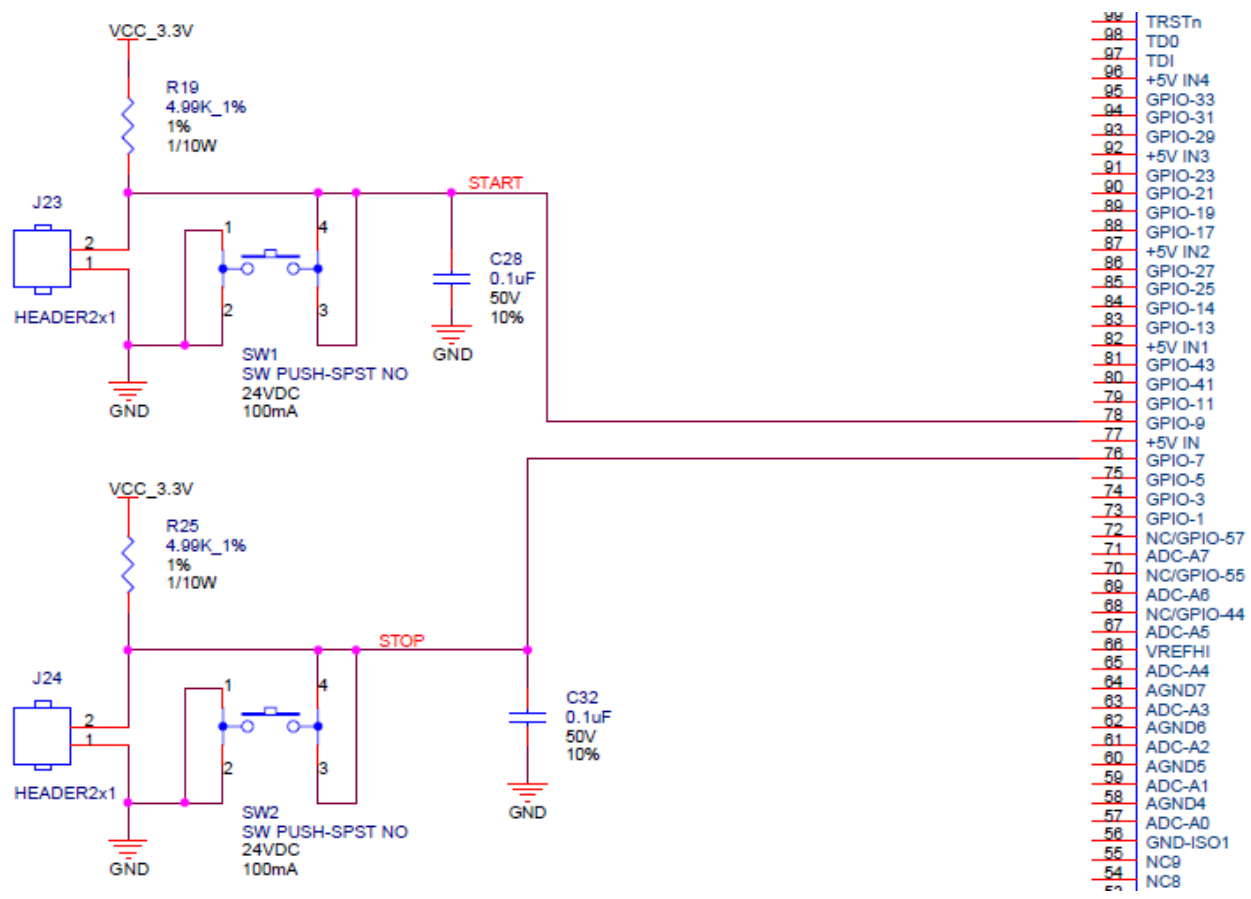
(x) gLEDduty 0.279999714 (Q-Value(24))

And this is the PWM waveform, where it can be seen that the period is what we set it to, 100 microseconds, and the 28% of that is 28 microseconds as shown in the scope below:



## 6.5. Reading Push Buttons

It is often useful to read push buttons to allow a motor to run, stop, or simply to change the state of a global variable when pushing a button. Using a combination of f2806x and drv8301kit\_revD, and proj\_lab03a of MotorWare 13, let's add a few lines of code to read the two push buttons available in this board. First of all, we need to see where those push buttons are connected to. The schematics showing where these two switches are connected:



As can be seen, SW2 is connected to GPIO-7 and SW1 is connected to GPIO-9. We need to configure the GPIOs in HAL\_setupGpios() function of hal.c file to allow those pins to be inputs:

```
// Push Button SW2
GPIO_setMode(obj->gpioHandle,GPIO_Number_7,GPIO_7_Mode_GeneralPurpose);

// Push Button SW1
GPIO_setMode(obj->gpioHandle,GPIO_Number_9,GPIO_9_Mode_GeneralPurpose);
```

We also need to define a function in hal.h that reads a GPIO as follows:

```
//! \brief Reads the specified GPIO pin
//! \details Takes in the enumeration GPIO_Number_e and reads that GPIO
//! \param[in] handle The hardware abstraction layer (HAL) handle
//! \param[in] gpioNumber The GPIO number
static inline bool HAL_readGpio(HAL_Handle handle,const GPIO_Number_e gpioNumber)
{
    HAL_Obj *obj = (HAL_Obj *)handle;

    // read GPIO
```

```
return(GPIO_read(obj->gpioHandle,gpioNumber));  
} // end of HAL_readGpio() function
```

Then, we add two HAL\_ definitions that link a switch with a specific GPIO. This is done so that in the top level source file (in this case proj\_lab03a.c) there is no reference to specific GPIO numbers. The reason for this is to allow the top level code to be fully portable to other platforms, where the push buttons might be connected to different GPIOs.

```
//! \brief Defines the GPIO pin number for drv8301kit_revD Switch 1  
//!  
#define HAL_GPIO_SW1 GPIO_Number_9  
  
//! \brief Defines the GPIO pin number for drv8301kit_revD Switch 2  
//!  
#define HAL_GPIO_SW2 GPIO_Number_7
```

From the project main file, we need to add two global variables as follows, where we will store the state of the push buttons:

```
bool gSw1;  
  
bool gSw2;
```

The final step is to call the function we created, and assign the returned value in our new global variables:

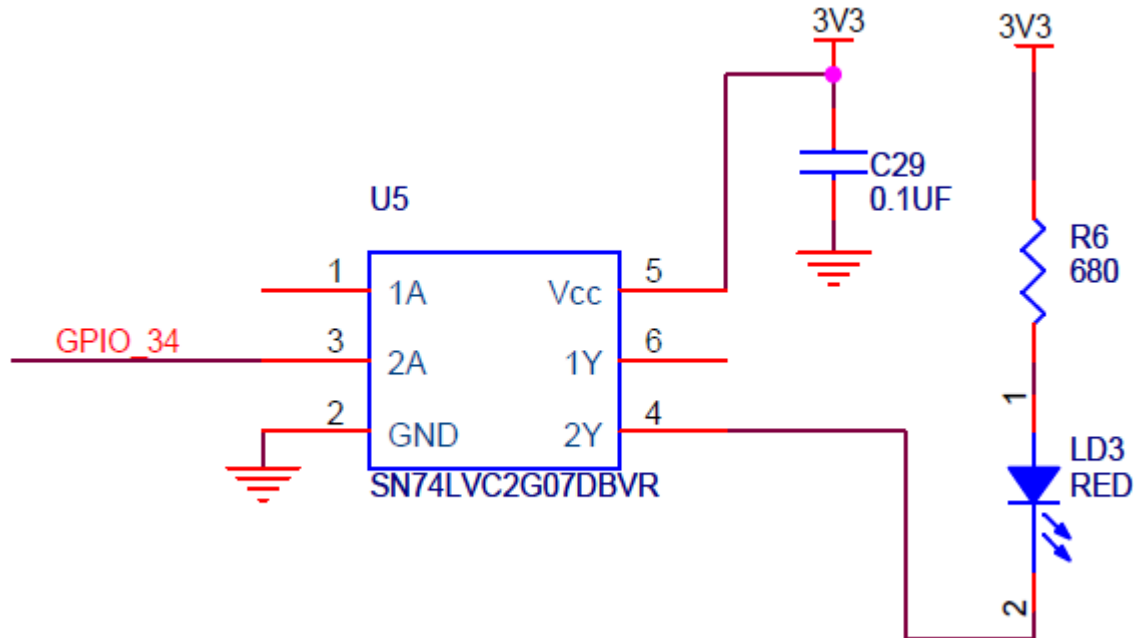
```
gSw1 = HAL_readGpio(halHandle, HAL_GPIO_SW1);  
  
gSw2 = HAL_readGpio(halHandle, HAL_GPIO_SW2);
```

If we add these global variables to the watch window, we will see that when we press the buttons, the state of the variables will change:

(x) gSw1	0
(x) gSw2	0

## 6.6. Adding a Timer Interrupt

In this example, we will enable Timer 0 interrupt, and generate an LED toggle every second. We will use the f2806x and drv8301kit\_revD combination, and proj\_lab03a of MotorWare 13. The following LED is used for the example, the one labeled “LD3” in the f2806x control card.



For this example, the following files will be updated:

- sw\drivers\pie\src\32b\f28x\f2806x\pie.c
- sw\drivers\pie\src\32b\f28x\f2806x\pie.h
- sw\modules\hal\boards\drv8301kit\_revD\f28x\f2806x\src\hal.c
- sw\modules\hal\boards\drv8301kit\_revD\f28x\f2806x\src\hal.h
- sw\solutions\instaspin\_foc\src\proj\_lab03a.c

### 6.6.1. Configuring the GPIO as an Output

The following code from HAL\_setupGpios() function in hal.c shows how GPIO 34 is configured as an output pin:

```
// ControlCARD LED3
GPIO_setMode(obj->gpioHandle,GPIO_Number_34,GPIO_34_Mode_GeneralPurpose);
GPIO_setLow(obj->gpioHandle,GPIO_Number_34);
GPIO_setDirection(obj->gpioHandle,GPIO_Number_34,GPIO_Direction_Output);
```

### 6.6.2. Configuring Timer 0 to Have a 1 Second Period

The following function is taken from hal.c, function HAL\_setupTimers(), showing that Timer 0 is already configured to have a 1 second period, since it takes the system frequency, and multiplies it times 1E6. So if the processor is running at 90 MHz, then the timer period counts would be  $90 * 1,000,000 - 1 = 89,999,999$ . This represents a period of  $(89,999,999 + 1) / 90 \text{ MHz} = 1 \text{ second}$ .

```
void HAL_setupTimers(HAL_Handle handle,const uint_least16_t systemFreq_MHz)
{
  HAL_Obj *obj = (HAL_Obj *)handle;
  uint32_t timerPeriod_cnts = ((uint32_t)systemFreq_MHz * 1000000) - 1;
```

```

// use timer 0 for frequency diagnostics
TIMER_setDecimationFactor(obj->timerHandle[0],0);
TIMER_setEmulationMode(obj->timerHandle[0],TIMER_EmulationMode_RunFree);
TIMER_setPeriod(obj->timerHandle[0],timerPeriod_cnts);
TIMER_setPreScaler(obj->timerHandle[0],0);

// use timer 1 for CPU usage diagnostics
TIMER_setDecimationFactor(obj->timerHandle[1],0);
TIMER_setEmulationMode(obj->timerHandle[1],TIMER_EmulationMode_RunFree);
TIMER_setPeriod(obj->timerHandle[1],timerPeriod_cnts);
TIMER_setPreScaler(obj->timerHandle[1],0);

return;
} // end of HAL_setupTimers() function

```

### 6.6.3. Create a PIE Function that Enables Timer 0 Interrupts

The following function and prototypes were created in pie.c and pie.h to enable Timer 0 interrupts.

Function prototype in pie.h:

```

//! \brief Enables the Timer 0 interrupt
//! \param[in] pieHandle The peripheral interrupt expansion (PIE) handle
extern void PIE_enableTimer0Int(PIE_Handle pieHandle);

```

Function implementation in pie.c, enabling interrupts in group 1, bit 7:

```

void PIE_enableTimer0Int(PIE_Handle pieHandle)
{
    PIE_Obj *pie = (PIE_Obj *)pieHandle;
    uint16_t index = 0;
    uint16_t setValue = (1 << 6);

    // set the value
    pie->PIEIER_PIEIFR[index].IER |= setValue;

    return;
} // end of PIE_enableTimer0Int() function

```

### 6.6.4. Create a HAL Function that Enables Timer 0 Interrupts

Besides the interrupt enable in the PIE module, we need to create an interrupt enable in the HAL module, the calls the PIE module interrupt enable function, and sets other flags such as CPU interrupt flags, timer register flags, etc.



Function prototype in hal.h:

```
//! \brief Enables the Timer 0 interrupt
//! \param[in] handle The hardware abstraction layer (HAL) handle
extern void HAL_enableTimer0Int(HAL_Handle handle);
```

Function implementation in hal.c:

```
void HAL_enableTimer0Int(HAL_Handle handle)
{
    HAL_Obj *obj = (HAL_Obj *)handle;

    PIE_enableTimer0Int(obj->pieHandle);

    // enable the interrupt
    TIMER_enableInt(obj->timerHandle[0]);

    // enable the cpu interrupt for TINT0
    CPU_enableInt(obj->cpuHandle,CPU_IntNumber_1);

    return;
} // end of HAL_enablePwmInt() function
```

The new function HAL\_enableTimer0Int() needs to be called in the main project source file, so in proj\_lab03a.c we add this before the forever loop:

```
// enable the Timer 0 interrupts
HAL_enableTimer0Int(halHandle);
```

#### 6.6.5. Create a HAL Function that Acknowledges Timer 0 Interrupts

We also need to create a function in the HAL module that clears the appropriate flags so that the Timer 0 interrupt can happen again. This function will be implemented as an inline function in hal.h as follows:

```
//! \brief Acknowledges an interrupt from Timer 0 so that another Timer 0 interrupt can
//!      happen again.
//! \param[in] handle The hardware abstraction layer (HAL) handle
static inline void HAL_acqTimer0Int(HAL_Handle handle)
{
    HAL_Obj *obj = (HAL_Obj *)handle;
```

```

// clear the Timer 0 interrupt flag
TIMER_clearFlag(obj->timerHandle[0]);

// Acknowledge interrupt from PIE group 1
PIE_clearInt(obj->pieHandle,PIE_GroupNumber_1);

return;
} // end of HAL_acqTimer0Int() function

```

### 6.6.6. Initialize Interrupt Vector Table

In hal.h, we have a function that initializes the interrupt vector table with mainISR(), which is our main interrupt that is triggered at the end of conversion of the ADC. For Timer 0, we need to create a function name and assign it to the vector table. We add two things to hal.h, one is an external reference to our new interrupt name, and we assign that interrupt name to the corresponding area in the vector table:

```

extern interrupt void timer0ISR(void);

//! \brief   Initializes the interrupt vector table
//! \details Points the TINT0 to timer0ISR and ADCINT1 to mainISR
//! \param[in] handle The hardware abstraction layer (HAL) handle
static inline void HAL_initIntVectorTable(HAL_Handle handle)
{
    HAL_Obj *obj = (HAL_Obj *)handle;
    PIE_Obj *pie = (PIE_Obj *)obj->pieHandle;

    ENABLE_PROTECTED_REGISTER_WRITE_MODE;

    pie->TINT0 = &timer0ISR;

    pie->ADCINT1 = &mainISR;

    DISABLE_PROTECTED_REGISTER_WRITE_MODE;

    return;
} // end of HAL_initIntVectorTable() function

```

### 6.6.7. Implement the New Timer 0 Interrupt to Toggle an LED

Finally, we implement the interrupt service routine to toggle an LED. First of all we call the acknowledge function to allow interrupts to happen again, and then we toggle the LED. In proj\_lab03a.c we have:

```
interrupt void timer0ISR(void)
{
    // acknowledge the Timer 0 interrupt
    HAL_acqTimer0Int(halHandle);

    // toggle status LED
    HAL_toggleLed(halHandle,HAL_GPIO_LED3);

    return;
} // end of timer0ISR() function
```

Where the following definition is created in hal.h to allow portability to other platforms:

```
//! \brief Defines the GPIO pin number for control card LD3
//!
#define HAL_GPIO_LED3 GPIO_Number_34
```

When running the code, the LED labeled as “LD3” in the control card will toggle every second.

## 7. References

- MotorWare: [www.ti.com/motorware](http://www.ti.com/motorware)

## 8. Revision History

- June 2014. Initial Release