STEVAL-IHM012V1 - Cordless drill evaluation board

Introduction

This document contains cordless drill evaluation board information, including jumper settings, load connection, and device and software features. This evaluation board implements a traditional design solution detailing how the Chopper circuit controls a brush DC motor with a microcontroller as a driver. The electronic driver with a Power MOSFET and microcontroller presented in this document is cost-effective and easy for designers to implement. This solution can be typically used in cordless tools, shavers, toys and machine tools. Analog solutions are being progressively replaced by microcontroller designs even in low-cost applications. Their advantages include flexibility, using less external components, easy adaptation by simple software modifications, and control components can be designed with a potentiometer.

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Brush DC motors can be driven in voltage mode since the motor speed is proportional to the supply voltage. The chopper is driven by a high frequency PWM signal. Controlling the PWM duty cycle is equivalent to controlling the motor voltage, which in turn adjusts directly the motor speed.

A typical block diagram of a DC single switch Chopper is shown in *Figure 1*.

Figure 1. Block diagram of a single switch Chopper
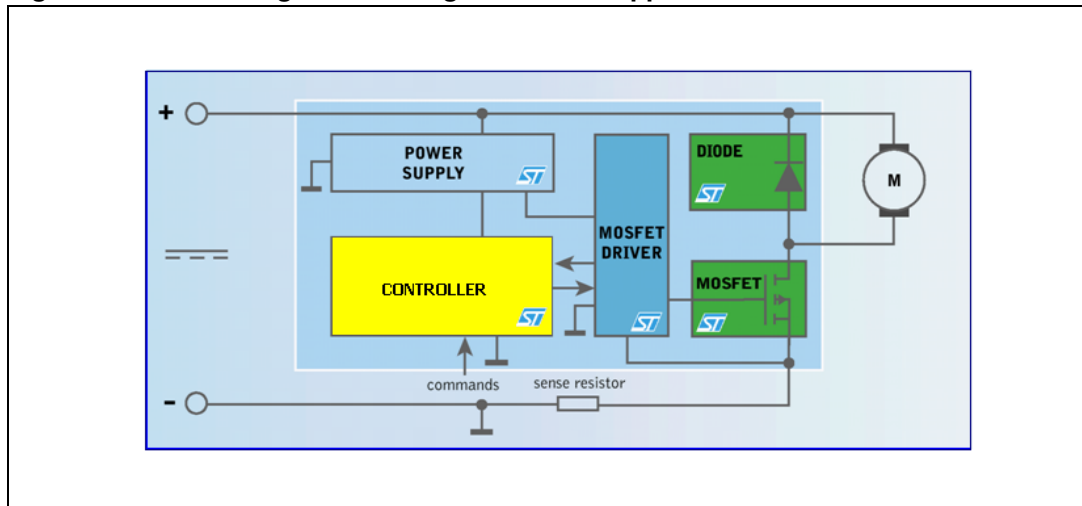
1.1 Controller

We use a microcontroller to have a flexible controller and to implement the control algorithm because an analog IC's functionality is tied to its application and the designer is limited to fixed device functions. Thus we generate the PWM signal and implement some safety protections.

Main features implemented:

● DC motor speed regulation system. Through the pot you can change the duty cycle of a PWM signal at 15 kHz:

   – POT zero position ' NO PWM signal '

   – POT increase position ' Duty Cycle: 13 ÷ 100%

● Battery voltage check. There are 3 states managed by the controller through the reading Level Battery:

   – Charged LED turn off

   – Low LED Slow flashing (warning): threshold 90% of the nominal voltage

   – Discharged Fast flashing (the motor cannot work): threshold   88% of the nominal voltage

● High current protection - Torque limitation. When the current of the motor reaches the maximum handling current (Imax) the Controller disables the PWM output regardless of the pot position. In this case the LED turns on. As soon as the current becomes less than Imax, the control switches back to the user and the LED turns off.

In this evaluation board we have chosen the ST7FULTRALITE which is a very small and less expensive microcontroller available in DIP8, DFN8 and SO8 packages:

● Extended -40°C to 125°C temperature range

● Fast 10-bit ADC

● 8-bit timer with Watchdog, 12-bit ART, 6 I/Os

● External and internal clock management

● 5 power-saving modes including Autowakeup from Halt

Note: *The microcontroller has still one I/O-ADC PIN free for other uses.*

For example this free pin could be used to change (through a potentiometer) the value of the threshold (Imax) in the high current protection. The user can directly change the max handling Torque and the potentiometer emulates the mechanical clutch present in all electrical drills.

1.2   Power MOSFET

With very low $R_{DS(on)}$, STripFET™ Power MOSFETs are suitable for high power applications such as cordless tools.

We have chosen the STD50NH02L in D-Pack package because this device can be driven directly by the ST7FULTRALITE. Thus we can avoid using the Power MOSFET driver and can economize the size and costs of the demo board (see *Figure 2*).

Main features (see datasheet):

– R_{DSon}= 0.012 Ω @ 5 V

– V_{DSS}= 24 V

–   Id= 50 A

– $R_{THJ\text{-}CASE}$= 2.5 °C/W (Thermal resistance Junction-case)

1.3   Power supply

To reduce board cost we have implemented the power supply with a Zener regulator circuit (see *Figure 3*).

1.4   Freewheeling diode

For the freewheeling diode, the STPS5L25B has been chosen and is available in DPACK packaging (see *Figure 3*). We now have a more compact board in order to utilize the available area on PCB for heat dissipation.

2 STEVAL-IHM012V1 evaluation board

The STEVAL-IHM012V1 evaluation board was developed to demonstrate ST's solution for low-end cordless tools such as cordless drills or screwdrivers but it can be a good starting point for designing all the applications where it need to drive a low voltage DC brush motor.

The board is shown in *Figure 2*.

On the left side there are two connectors:

– the mains connector for battery voltage supply

On the right side there are two connectors:

– the connector for the DC Brush motor

● "speed adjustment pot "

That potentiometer emulates the standard push button mounting in the case of a cordless drill to regulate the rate of the motor.

● "ICC connector and jumpers J1 and J2"

Warning: **Before downloading firmware in the microcontroller, ensure that jumpers J1 and J2 are NOT present before the input voltage is connected. Under normal conditions these jumpers must be present before the input voltage is connected.**

With easy adjustments the STEVAL-IHM012V1 can drive DC brush motors 7.2 - 18 V. The maximum power range used on the evaluation board depends on the motor driven (maximum handling current) and relative Power MOSFET mounted on the board (see *Section 4: Application design procedure*).

This evaluation board is set up to work with a 7.2 DC brush motor (Imax is set at 8 A).

Note: *the supply current for the microcontroller is obtained from the input voltage. The Zener regulator circuit in this application is designed to ensure the minimum voltage for the microcontroller operations also if the battery voltage is the minimum allowed.*

Figure 2. STEVAL-IHM012V1 evaluation board picture
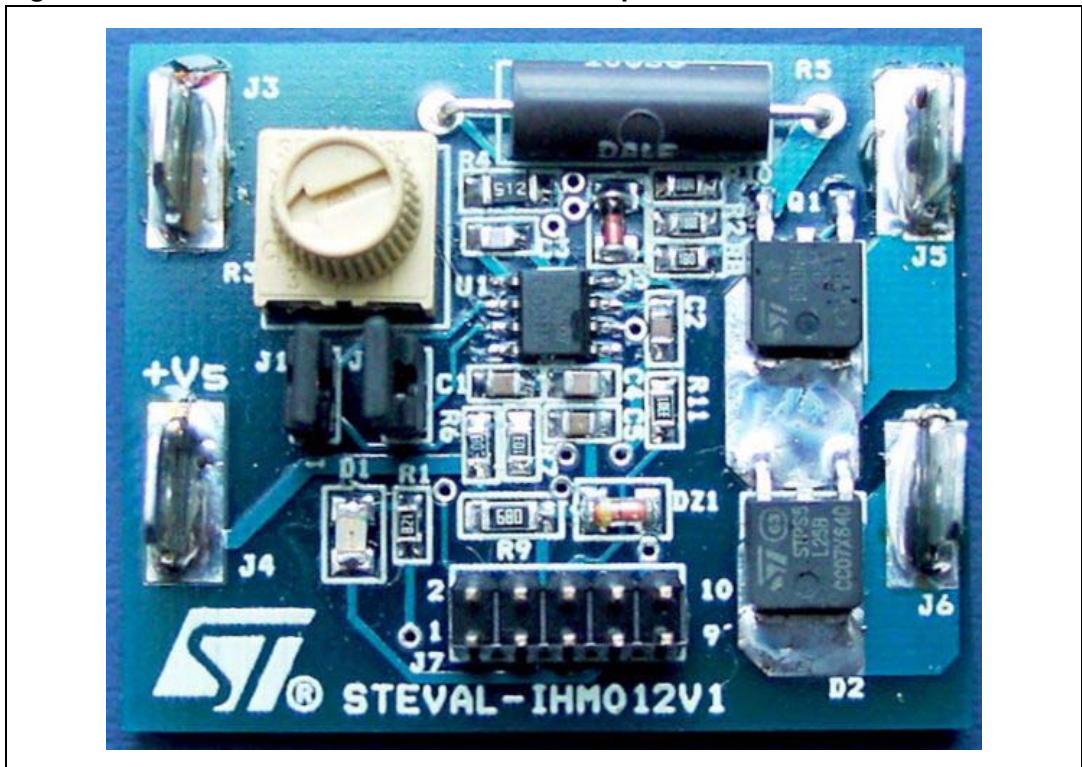
3 Size optimization design procedure

This demo board implements a general solution to drive a low voltage DC brush motor. The application is optimized for cordless hand tools (drill, saw, screwdriver).

The size is small enough to be inserted directly in the tool *Figure 2*.

To minimize the size of the board:

● The ICC connector is not needed in the manufacturing process either because the microcontroller can be already programmed before assembling.

● The potentiometer emulates the push button of the cordless drill. (To be replaced by the potentiometer/on-off switch on the tool)

● The Power MOSFET and diode can be mounted near the motor where the air flux cools them down.

● The UltraLite is available in DFN8 package (Less than 16 mm^2)

Following this procedure, the optimal design achieved is approximately 20x15 mm.

Note: *The demo board is implemented only on the top to reduce the manufacturing cost.*

4 Application design procedure

This evaluation board can be configured for different DC brush motors: 7.2 V - 18 V, here we have an example of design procedure for 7.2 V DC brush motor. If the user wants to configure the Evaluation board for other motors, there are the following adjustments to do:

● Zener regulator circuit: R_S,
● Sensing resistor: R_{SENS},
● Power MOSFET (evaluating the operating junction temperature),

4.1 Zener regulator circuit

The power supply is shown in *Figure 3*. The input current I_{IN} can be expressed by the following equation:

Equation 1

$$I_{IN} = \frac{V_S - V_{ZD}}{R_S}$$

where

– V_S = Supply voltage,
– VZD = the voltage drop, V, across the Zener diode, and
– R_S = the resistor.

Figure 3.   Zener regulator circuit
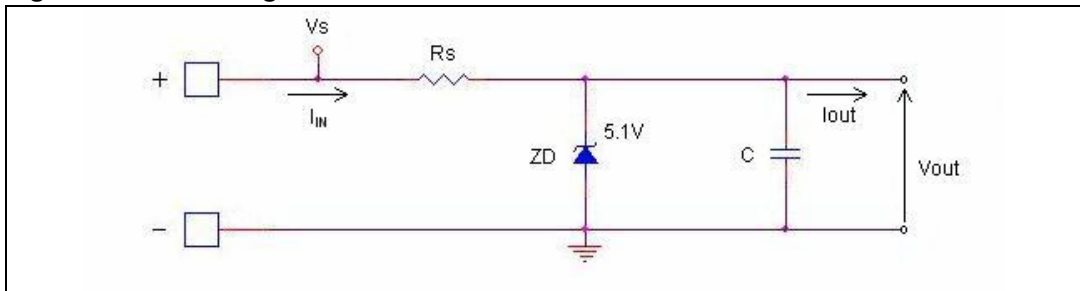
Equation 2

$$I_{IN} = I_{zener-MIN} + I_{OUT}$$

where I_{OUT} is the maximum absorbed current by the microcontroller. We can estimate I_{OUT} considering that the active on-chip peripherals are working together and thus I_{OUT} = 8 mA. The current to hold the V_Z = 5.1 V is I_{zener_MIN} = 5 mA (see datasheet).

In the NiCd and NiMH batteries the cell voltage is 1.2 V and in discharge condition it must be more than 1 V (to avoid damaging them). We have to assure that the microcontroller is supplied with 5 V in all conditions and thus we have chosen $V_S = V_{Smin}$ = 88% $V_{Nominal}$ of battery.

So R_S will be:

Equation 3

$$R_S = \frac{V_{Smin} - V_{ZD}}{I_{zener-MIN} + I_{OUT}}$$

For the 7.2 cordless drill (6 cells) we have chosen V_{Smin} = 88% $V_{Nominal}$ and thus $R_S \cong 68\ \Omega$

4.2   Sensing resistor (R_{SENS})

The value of the sensing resistor must be chosen to guarantee the right power dissipation at the maximum handling current and to guarantee at least 300 mV in order to read the motor current using the 10bit on board microcontroller ADC.

The evaluation board has been set and tested for a 7.2 DC brush motor.

The maximum current for the used motor is I_{MAX} = 8 A.

It follows that:

Equation 4

$$R_{SENS} = 0.05$$

4.3   Power MOSFET

The choice of the Power MOSFET begins by choosing devices that can handle the required current, given an adequate thermal dissipation path.

Here we have the equations for calculating the power dissipation of these MOSFETs and determining the temperature at which they operate.

To determine whether or not a Power MOSFET is suitable for that application, we must calculate its power dissipation, which consists mainly of resistive and switching losses:

Equation 5

$$PD_{TOT} = PD_{RESISTIVE} + PD_{SWITCHING}$$

One of the most severe tests for electronic drills is to evaluate the transistor's performance with the rotor blocked. In this case the rotor remains fixed for a minimum time of 20 seconds, while the Power MOSFET runs at the maximum duty cycle at maximum RMS current (in this case is fixed by the safety routine in the microcontroller)

Equation 6

$$PD_{TOT} \cong PD_{RESISTIVE} = R_{DS(on)} \bullet I_{LOAD}^{2}$$

Where:

I_{LOAD} = maximum handling current by the motor.

The operating junction temperature is:

Equation 7

$$T_J = T_A + R_{TH-TOT} \bullet PD_{TOT}$$

Where

T_A = Ambient Temperature

R_{TH_TOT} = Total thermal resistance

The total power dissipation will be:
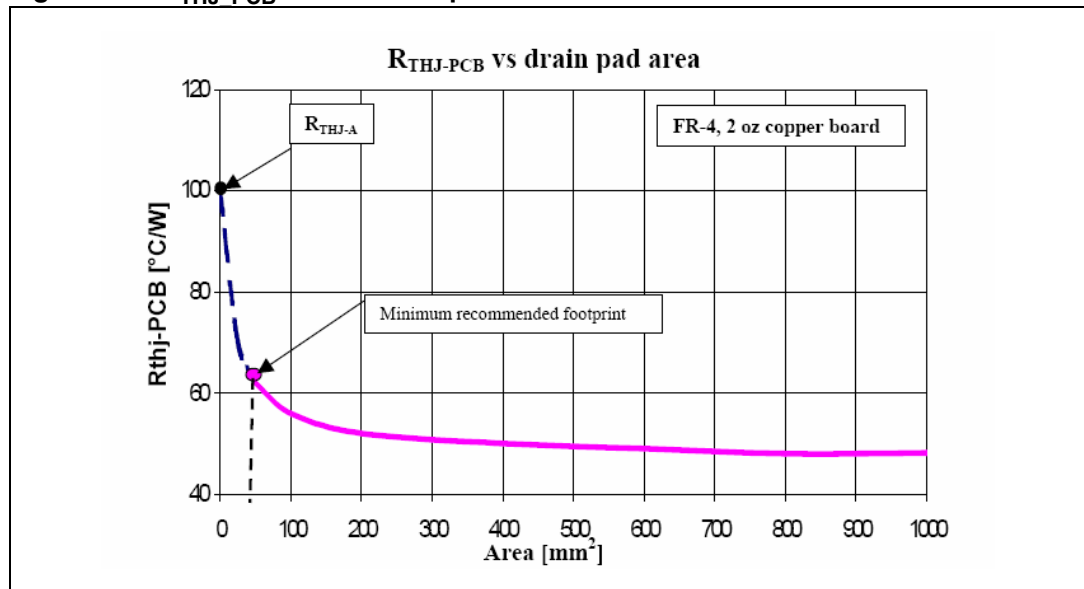
Equation 8

$$PD_{TOT} = R_{DS(on)} \bullet I_{LOAD}^2 = 0.012 \bullet (8)^2 = 0.77W$$

In the evaluation board the available copper area on PCB for heat dissipation is almost 400 mm^2. This is shown in *Figure 4*:

Equation 9

$$R_{THJ-PCB} \cong 50° \text{ C/W}$$

Figure 4. R_{THJ_PCB} **versus drain pad area for DPACK**

The total thermal resistance is:

Equation 10

$$R_{TH-TOT} = R_{THJ-CASE} + R_{THJ-PCB} = 2.5 + 50 = 52.5° \text{ C/W}$$

Thus

Equation 11

$$T_J - T_A = R_{TH-TOT} \bullet PD_{TOT} = 52.5 \bullet 0.77 = 40.4° \text{ C}$$

In the worst case we can take T_A= 40 °C and T_J = 80 is lower T_{JMAX} = 175 °C.

The above consideration has to be done if the final designer chooses to change the Power MOSFET to increase current capabilities.

5 Software

The software is written in C language, structured, and commented.

The main functions necessary for the proper operations of the evaluation board can be found in the following .c files:

● main.c
● pwm_ar_timer_12bit.c

The follow .h files have to be included:

● st7fliteus5.h
● pwm_ar_timer_12bit.h
● utility.h

The option byte set in this project is shown in *Figure 5*.

Figure 5. Option byte for STEVAL-IHM012V1 firmware
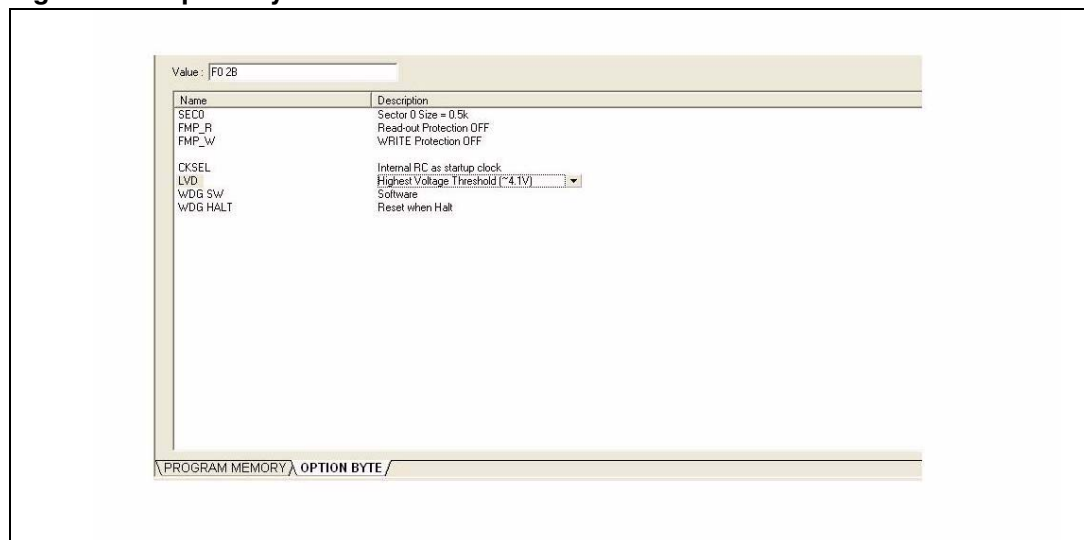
Note: *the overall code with the actual function is very small, almost 213 Byte.*

The firmware parameters are set for the 7.2 DC brush motor, if the designer wishes to change the motor he must change the firmware parameters in the file utility.h

Parameters:

● Setting DC motor type multiplied by 10: i.e. 7.2 DC brush motor
   – #define Motor_Type 72
● Setting Isafe (maximum handling current in load conditions). The values must be multiplied (in Amper) by 10. In the firmware the default values are 8 A so we have:
   – #define Isafe 80

Note: *we have another parameter Imin, it has been set to a value slightly higher than the current in no load conditions, in order to be sure that the I safe is set to a value greater than the minimum current drain by the motor.*

● The default value is 3 A:
   – #define Imin 30

The working principle of using a Power MOSFET to drive DC brush motor is to change the duty cycle of the PWM control signal generated by the 12-bit autoreload timer (AT) inside the software.

Note: *Before downloading firmware in the microcontroller, ensure that jumpers J1 and J2 are NOT present before the input voltage is connected. Thus under normal conditions these jumpers must be present before the input voltage is connected. See Figure 2.*

5.1 Main.c

The battery voltage check function and the "Speed Pot" reading are implemented in this module as described above. The reading of the "Speed Pot" and Safe Battery routine are synchronized on the Overflow event (OVF interrupt) of the Auto-reload timer through the "enable" flag.

Enable is true at the end of each OVF interrrupt.

The "Speed Pot" is read every 5 cycles (look at variable "count") of the Auto-reload timer. The voltage battery is read every (10000 +1) cycles (look at the variable "counter") in standard mode, and it will be read every (2000+1) cycles in battery safe mode.

Note: *in this way the "Speed Pot" reading and voltage battery reading won't be done in the same PWM period.*

The value of duty cycle is updated in the PWM AT OVF routine. See flowchart in Figure 6.

Figure 6.   Main programming flowchart
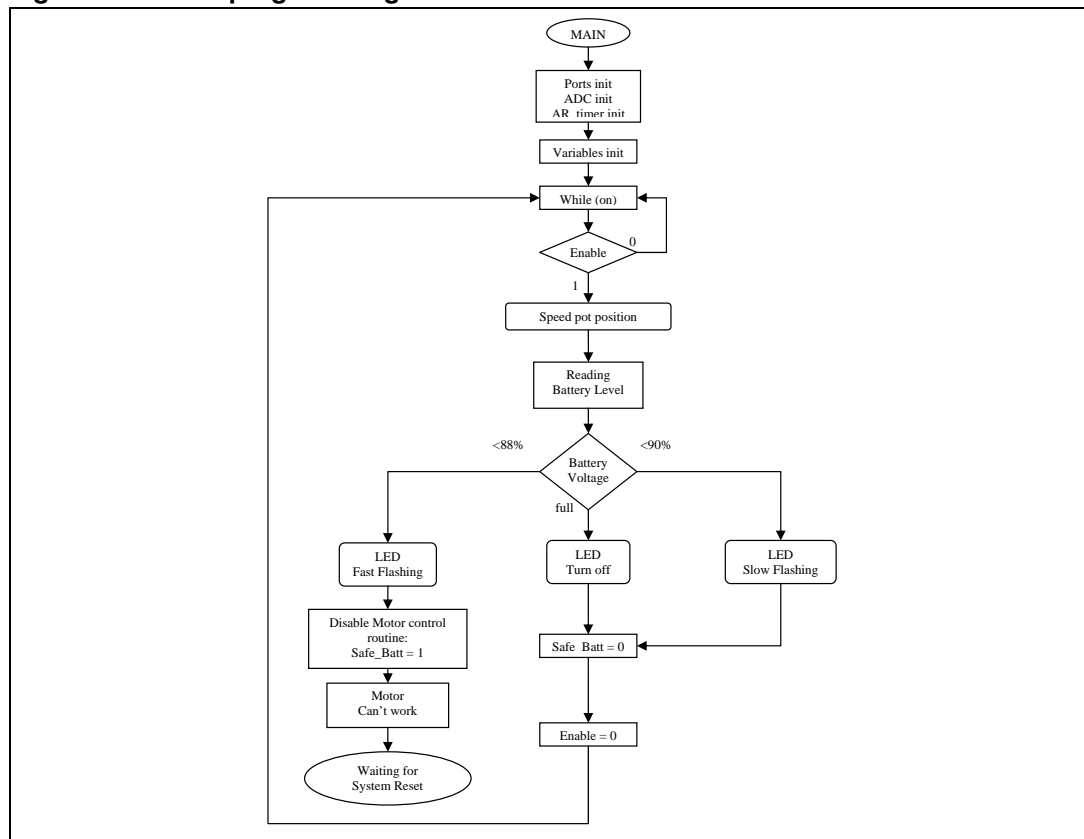
5.2 pwm_ar_timer_12bit.c

The AT timer in OF mode is used as the main time counter. This interrupt is handled in the AR_TIMER_OF_Interrupt routine in the pwm_ar_timer_12bit module. This module generates the PWM control signal to the frequency of 15 kHz, implements the high current protection routine, and software counter incrementing (time base 68 µsec). See *Figure 7*.

Figure 7.   Flowchart of the pwm_ar_timer_12bit module
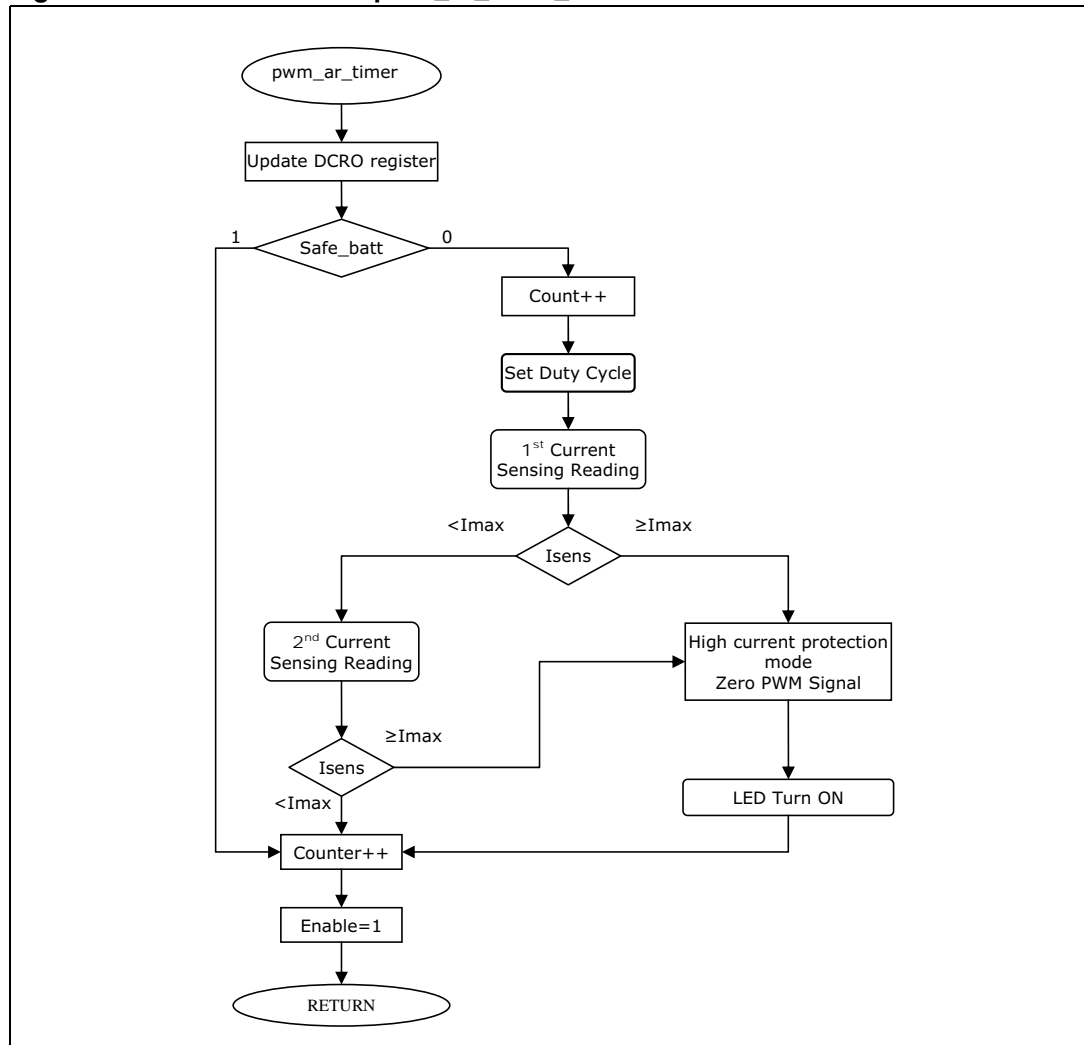
In the high current protection routine two reading operations in the same PWM OVF interrupt are performed to detect an eventual over current event through the ADC analog input. If the current signal is higher than threshold (Imax) the PWM output will be set to zero and the LED will be turned ON.

6 Field tests

We have plotted the PWM control signal (waveform in blue) and the current in the motor (waveform in black) when it runs in no load condition and in the blocked rotor condition. We have some examples which show how the high current protection routine operates.

For these tests we used one 7.2 DC brush motor and set the software parameters to:

- #define Isafe 70 (7 A)
- #define Imin 30 (3 A)

Figure 8. Duty cycle 60% in no load condition

Figure 9. Duty cycle 60% in blocked rotor
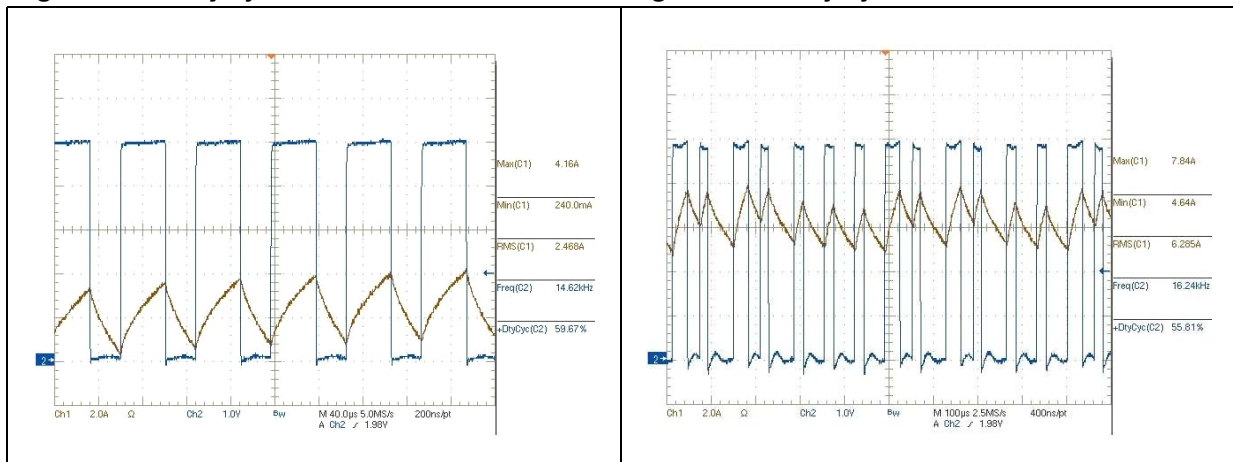
Figure 10. Duty cycle 100% in no load condition

Figure 11. Duty cycle 100% in blocked rotor
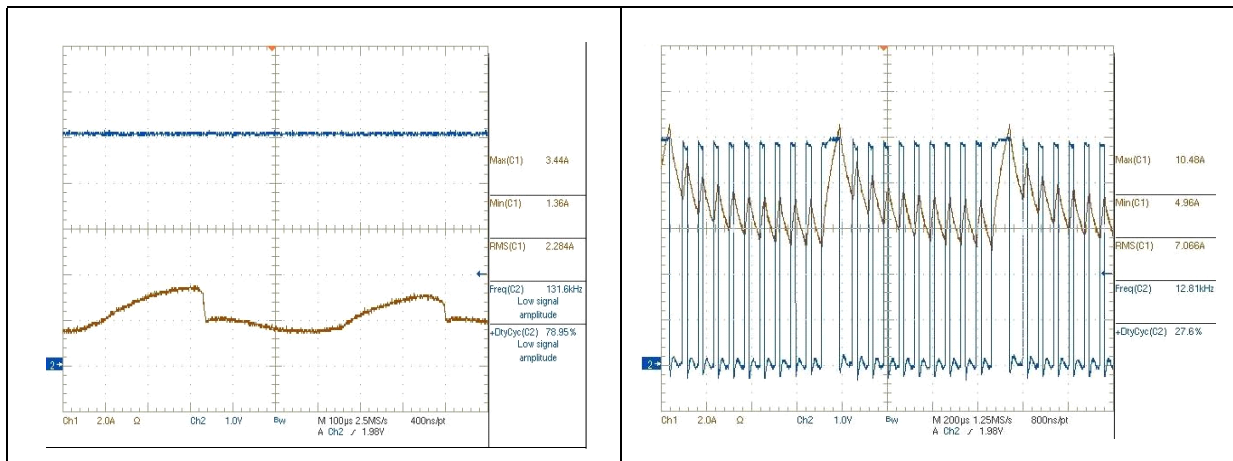
We have taken two cases one at duty cycle 60% and another at duty cycle 100%, see *Figure 8*, *Figure 9*, *Figure 10* and *Figure 11*. When the high current protection routine works, the controller limits and forces the motor current to 7 A rms.

7 Schematic

Figure 12. STEVAL-IHM012V1 evaluation board schematic
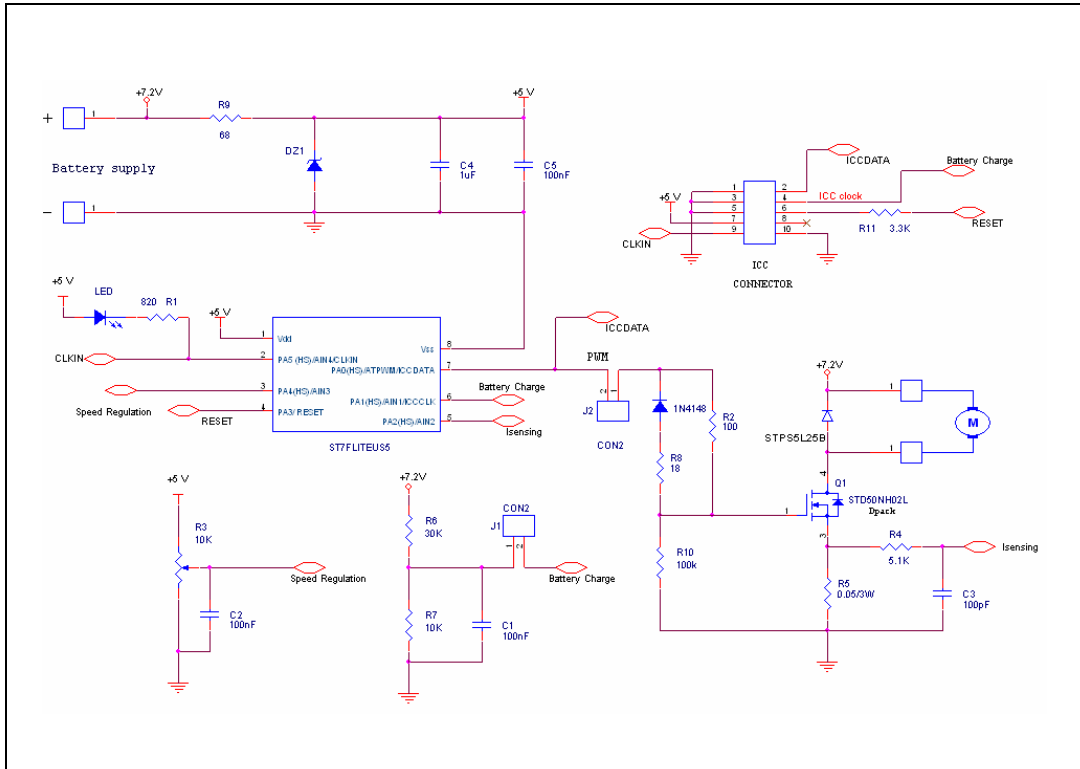
8 Bill of material (BOM)

Table 1. Bill of material

Index	Qty	Reference	Value / generic part number	Package	Manufacturer	Manufacturer's ordering code / orderable part number
1	3	C1,C2,C5	100 nF, 25 V ±5%	SMD_0805		
2	1	C3	100 pF, 50 V ±5%	SMD_0805		
3	1	C4	1 µF, 16 V ±10%	SMD_0805		
4	1	DZ1	5.1 V, 1/2 W	SMD_1206_12		
5	1	D1	LED	SMD_1206_21		
6	1	D2	STPS5L25B	SMD DPAK	ST	STPS5L25B-TR
7	1	D3	1N4148	SMD1206_21		
8	2	J1,J2	CON2	Jumper		

Table 1.   Bill of material (continued)

Index	Qty	Reference	Value / generic part number	Package	Manufacturer	Manufacturer's ordering code / orderable part number
9	4	J3,J4,J5,J6	CON1	FASTONF		
10	1	J7	ICC Con	10 pin strip header - dual in line2.54 mm pitch		
11	1	Q1	STD50NH02L	SMD_DPAK	STMicroelectronics	STD50NH02LT4
12	1	R1	820 Ω ±1%	SMD_0805		
13	1	R2	100 Ω ±1%	SMD_0805		
14	1	R3/POT	10 kΩ	VRES18		
15	1	R4	5.1 kΩ 1/4 W ±5%	SMD_1206		
16	1	R5	0.05 Ω 3 W			
17	1	R6	30 kΩ ±1%	SMD_0805		
18	1	R7	10 kΩ ±1%	SMD_0805		
19	1	R8	18 Ω ±1%	SMD_0805		
20	1	R9	68 Ω 1/4 W ±5%	SMD_1206		
21	1	R10	100 kΩ ±1%	SMD_0805		
22	1	R11	3.3 kΩ ±1%	SMD_0805		
23	1	U1	ST7FLITEUS5	SO8	ST	ST7FLITEUS5M6

9   References and related materials

It is possible to find additional information in the following website: www.st.com/

● Datasheet:
  – ST7FLITEUS5 datasheet
  – STD50NH02L datasheet
  – STPS5L25B datasheet
● Application note:
  – AN1703: Guidelines for using ST'S Power MOSFET SMD packages
  – AN2385: Power dissipation and its linear derating factor, silicon Limited Drain Current and pulsed drain current in Power MOSFETs
  – AN414: Controlling a brush DC motor with an ST6265 Microcontroller

10 Revision history

Table 2. Document revision history

Date	Revision	Changes
19-Dec-2006	1	First issue
08-Jan-2007	2	*Figure 2* changed
25-Oct-2007	3	Modified: *Figure 5* and *Table 1*

Please Read Carefully: