# 3Φ FOC motor drive compact designs based on STM32F30x

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## INTRODUCTION

One of the most common problems related to “high-end” motor control applications is the measurement of the currents that flow into the motor phases. To achieve this purpose, the “state-of-the-art” field oriented control (FOC) drives reckon on a signal conditioning network that exploits current sensors such as shunt resistors and Hall sensors. In a typical current sensing network, the voltage drop on the shunt resistor is fed into an operational amplifier that adapts the voltage level to the range allowed by the analog to digital converter (ADC). In this way, the resolution of the current measurement is maximized, keeping low the power dissipation in the shunt resistor.

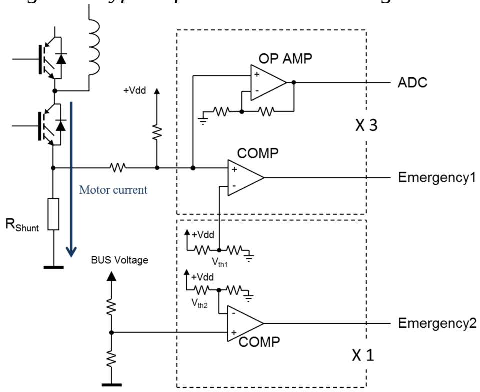
On the other hand, another main issue in these kinds of applications is the implementation of the safety features required by regulations. On top of those features there are the protection features: motor phase over current protection and DC bus over voltage protection. The first will act on failures like motor phase short circuits or phase-to-ground failures, while the second will act during reversal of electrical energy into the bus due to loss of control at high speed.

The common over current detecting networks make use of the same current sensor used by the measurement network, but in this case, a comparator is used for fast action on the control signals.

To achieve the bus voltage protection, a simple voltage divider is fed into another comparator to trigger the “over-voltage” actions on the output.

A typical three shunt network used for current sensing with over current and over voltage protection in an up-to-date motor control system, like the one shown in Figure 1, consists of three operational amplifiers and four comparators. The passive components required, polarization resistors and the voltage threshold dividers, have an impact on the cost of manufacturing and in the PCB area. The cost is doubled when considering an application with two simultaneous motor drives.

*Figure 1- typical protection and sensing network*




The number of external components required to implement these functionalities can be reduced using a microcontroller that embeds such peripherals. STMicroelectronics’ portfolio includes the STM32F30x family that contains up to four programmable gain amplifiers and up to seven fast comparators glued in the architecture design specifically for motor control applications.

## EVALUATION BOARDS

A “single motor drive” can be evaluated arranging a system composed by two boards present in the STMicrocontroller stock of evaluation boards dedicated to motor control: the STM32303C-EVAL control board and the STEVAL-IHM045V1 power board.

The STM32303C-EVAL has been designed as a complete demonstration and development platform for the ARM cortex-M4 core-based STM32F303VCT6 microcontroller.

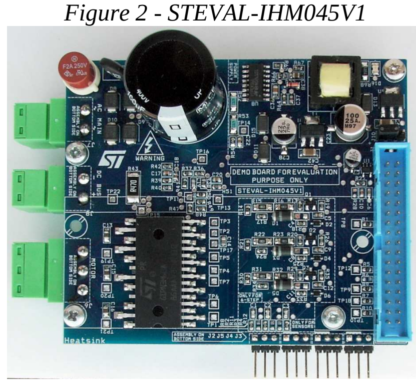
The STEVAL-IHM045V1 is a 3-phase high voltage inverter power board featuring the STGIPN3H60A (SLLIMM™-nano) dedicated to field-oriented control (FOC) of permanent magnet synchronous motors (PMSM) with nominal power up to 100W.

The “dual motor drive” systems can be evaluated using:

• two STEVAL-IHM045V1 as power stages connected to the STM32303C-EVAL

• the STEVAL-IHM042V1 (based on STM32F303 MCU and L6230 monolithic motor driver).

*Figure 2 - STEVAL-IHM045V1*



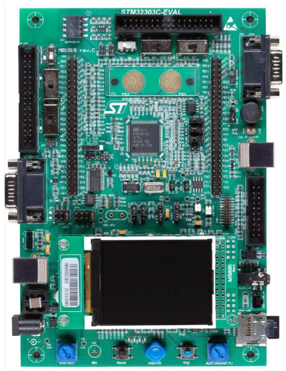
**STEVAL-IHM045V1 - Main features**

- Wide-range input voltage (30-270 Vac)
- Maximum power up to 100 W at 230 Vac input
- Efficient DC-DC power supply (15 V, 3.3 V)
- Suitable for sinusoidal FOC drive
- Easy selectable single or three shunts current reading topology with fast operational amplifier
- Configurable for direct motor currents sampling from shunts resistors
- Hardware overcurrent detecting network
- Temperature sensor
- Hall sensor/quadrature encoder inputs

**STEVAL-IHM045V1 - Key components**

| | |
|---|---|
| **STGIPN3H60A** | SLLIMM™-nano (small low-loss intelligent molded module) IPM, 3-phase IGBT inverter - 3 A - 600 V very fast IGBT |
| **VIPer06** | Fixed frequency VIPer™ plus family |
| **LD1117S33TR** | Low drop fixed positive voltage regulator |
| **STTH1R04U** | Ultrafast recovery diode |
| **STTH1L06A** | TURBO 2 Ultrafast High Voltage Rectifier |
| **STPS1150** | Power Schottky Rectifier |
| **STPS1L60MF** | Low Drop Power Schottky Rectifier |
| **TSV994** | Rail to rail input/output high merit factor op-amps |
| **TS374** | Low power quad CMOS voltage comparator |

*Figure 3 – STM32303C-EVAL*



**STM32303C-EVAL - Main features**

- ST-LINK/V2, JTAG/SWD and ETM trace debug support
- Two motor control connectors
- RS-232 communication
- 240x320 TFT color LCD connected to the SPI interface
- Joystick with 4-direction control and selector
- IrDA transceiver
- Reset, Tamper or Key button
- 4-color user LEDs and high brightness LED
- Humidity sensor
- USB FS connector
- Touch-sensing buttons
- RTC with backup battery
- CAN2.0A/B compliant connection
- Light-dependent resistor (LDR)
- Potentiometer

**STM32303C-EVAL - Key component**

| | |
|---|---|
| **STM32F303VCT6** | 32-bit microcontroller |

## BENEFITS OF STM32F30X MICROCONTROLLER'S EMBEDDED PERIPHERALS

STM32F302 and STM32F303 include more than simply a certain number of amplifiers and comparators. They have been designed bearing in mind the end applications, and there is an optimized peripheral configuration for each typical topology.

The embedded Programmable Gain Amplifiers fulfill motor control needs, showing 8.2MHz GBW and 4.7V/us slew rate.

Same achievement holds true for the embedded comparators which can typically act in 90ns, for a full range step with 100mV overdrive.

**Over-current and over-voltage protections**

STM32F30x embedded comparators are internally connected to "advanced timer" emergency inputs for efficient and comprehensive protection.

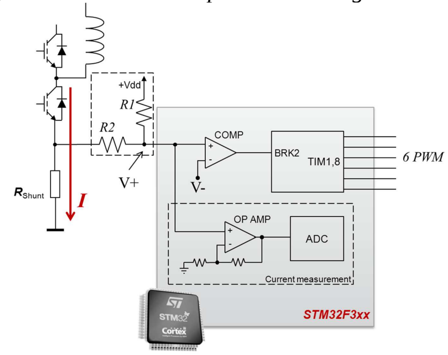
Each advanced timer has three emergency inputs, BKIN, BKIN2 and BRK_ACTH, with behavior designed to suit motor control applications. In particular, when it comes to 3-phase PMSM FOC, a desirable functionality is:

- In case of overcurrent, opening all the six inverter switches;
- In case of overvoltage, closing all the three inverter low-side switches, overriding a potential overcurrent trip due to the overvoltage action itself.

With this request in mind, BRK is dedicated to overvoltage protection, BRK2 to overcurrent protection, and BRK has higher priority than BRK2.

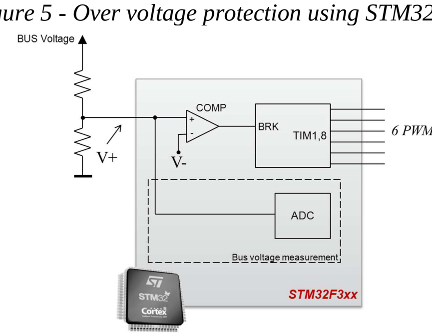
Furthermore, BRK2 can only disable PWM outputs (inactive state), while BRK can be programmed to force a predefined safe state (inactive or inactive).

*Figure 4 – Over current protection using STM32F30x*




In *Figure 4* is shown the over-current protection network that can be implemented using the internal resources of the STM32F30x. Phase current measurement and overcurrent protection share the same microcontroller pin.

*Figure 5 - Over voltage protection using STM32F30x*




In *Figure 5* is shown the over-voltage protection network that can be implemented using the internal resources of the STM32F30x.

**Motor phases current measurement**

Let’s start with STM32F302 and one three-phase motor FOC drive: the three shunt topology – as seen in the previous section – needs three op amps and three comparators.

With no compromise on performance, the microcontroller serves the purpose with two op amps with tailored multiplexers, three comparators, and minimum pin count.

The multiplexer scheme (*Figure 6*) implements the rule that the current sensing, from at least one of the three phases (say phase V), is routed to both op amps: this way, it’s always possible – for any PWM period – to amplify any couple of currents, U-V, V-W, U-W, .

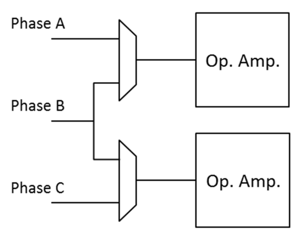
Table 1 – STM32F302 comparators and OPAMPs input pins

| PA1 | PA3 | PA7 | PB14 | PD14 | PB0 | PB11 | PD11 |
|---|---|---|---|---|---|---|---|
| COMP1 | COMP2 | COMP2 | | | COMP4 | COMP6 | COMP6 |
| OPAMP1 | OPAMP1 | OPAMP1 | OPAMP2 | OPAMP2 | OPAMP2 | | |
| | | OPAMP2 | | | | | |

The two op amp outputs correspond to ADC inputs, so that further ADC multiplexing is not needed in this case.

Table 1 recaps the microcontroller pins that can be connected to the inverter input of internal comparators (COMP1,2,4,6) for overcurrent protection and to inverter input of internal operational amplifier (OPAMP1,2) for current sensing.

*Figure 6 - Multiplexer scheme*




It’s easy to see that the perfect choice, the one that minimizes - down to three - the pincount, is to select PA1, PA7, PB0: signals coming from the three shunts U-V-W, connected to these pins, are served by three different comparators and can be amplified simultaneously by two comparators in any combination (UV, VW, UW).

Let’s move now to the STM32F303 and two three-phase motor FOC drives: Two three shunt topologies – as seen in the previous section – need six op amps and six comparators.

Once again, the microcontroller serves the purpose, even in three different ways as represented below. Six comparators are committed in each case.

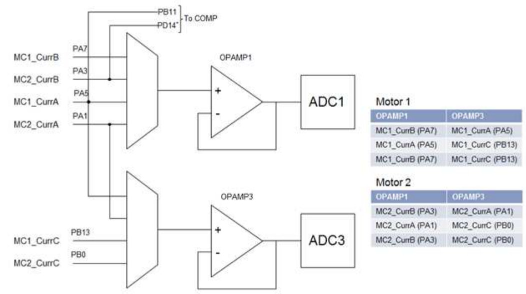
**Dual motor, dual current sampling using 2 op amps/ADC**

Figure 7 carries out dual motor control and spares two ADC/OPAMPs, thus it’s recommended when there’s another task – for instance digital PFC, single stage or interleaved – that would deserve “privileged” access to one or two ADC peripherals.

On the other hand, the CPU takes the small workload to reconfigure

OPAMP multiplexers each time the control change focus between the two motors. The figure above shows the recommended minimized pinout with a grand total of eight pins.

*Figure 7 - Dual motor, dual current sampling using two op amps/ADC:*




**Dual motor, dual current sampling using four op amps/ADC**

The scheme in *Figure 8* is recommended when there’s no other “privileged” task for the ADC: all 4 op amps and ADCs are exploited for the dual drive, thus freeing the CPU from any burden.

**Dual motor, triple current sampling, using three op amps/three ADCs**

STM32F303 multiplexers allow switching between three op amps at the same time between the two motors. Downhill, these three op amps/three ADCs will be able to sample simultaneously all 3-phase currents, if applicable safety regulations require.

*Figure 8 - Dual motor, dual current sampling using four op amps/ADC*

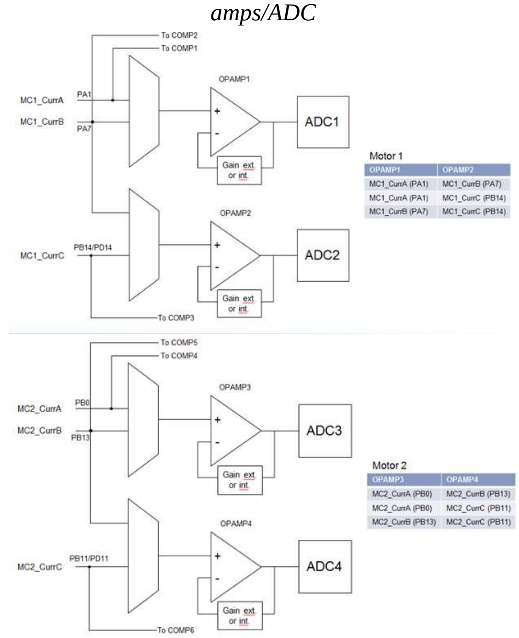


*Table 2* shows a possible solution for dual motor control in triple sampling mode. The inputs of the three op amps must be switched on-the-fly between the three pairs of inputs.

*Table 2 - STM32F303 comparators and op amps input pins for triple sampling*

| **Motor 1** | | | **Motor 2** | | |
|---|---|---|---|---|---|
| **PA7** | **PB11** | **PA1** | **PB0** | **PB13** | **PD14** |
| COMP2 | COMP6 | COMP1 | COMP4 | COMP5 | COMP3 |
| OPAMP2 | OPAMP4 | OPAMP3 | OPAMP3 | OPAMP4 | OPAMP2 |

In Table 3 are summarized the total external components required for motor current sensing and for protection exploiting the STM32F30x solutions compared with the state-of-the-art equivalent solutions.

Table 3 – External components required

| | **Single drive state-of-the-art** | **Single drive STM32F302** | **Dual drive state-of-the-art** | **Dual drive STM32F303** |
|---|---|---|---|---|
| **OPAMPs** | 3 | 0 | 6 | 0 |
| **COMP** | 4 | 0 | 7 | 0 |
| **Resistors** | 18 | 8 | 30 | 14 |
| **Shunts** | 3 | 3 | 6 | 6 |

## CONCLUSIONS

The article has shown how the utilization of a microcontroller of the STM32F30x family can considerably reduce the number of external components, the size of PCB space, and the complexity of the schematic, while gaining the advantage of robustness of security features. Furthermore, STMicroelectronics provides a complete product portfolio and set of development tools (hardware and software) dedicated for motor control, in order to speed up the evaluation and prototyping necessary for customer applications.