STEVAL-IFN003V1: DC PMSM FOC motor driver based on the L6230 and STM32
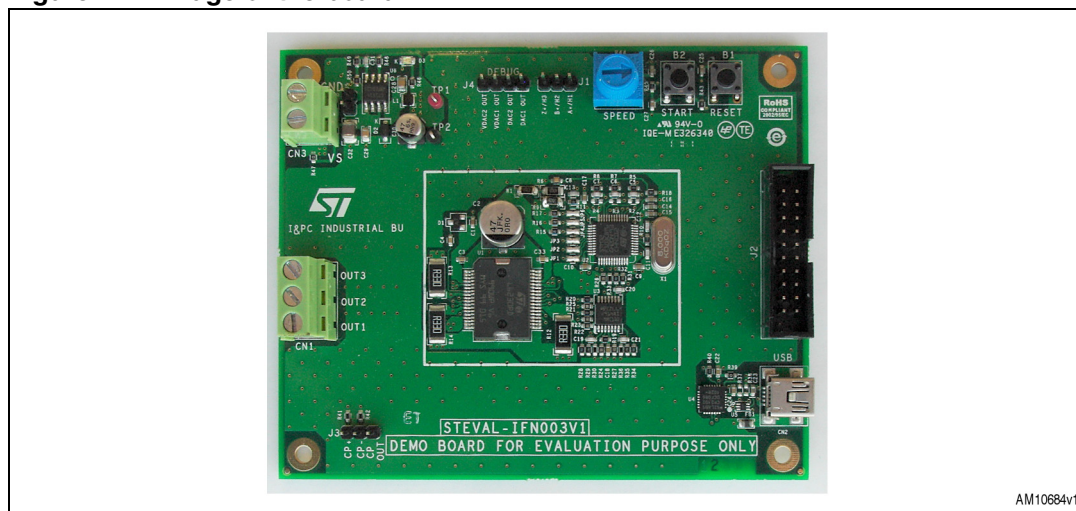
Introduction

The STEVAL-IFN003V1 is a demonstration board based on STMicroelectronic's ARM™ Cortex-M3 core-based STM32F103CB microcontrollers and the DMOS fully integrated L6230 3-phase motor driver implementing a field oriented control (FOC) of the PMSM motor.

It is designed as an evaluation environment for motor control application in the range of 8 V - 48 V of DC bus voltage (which is extendable up to 52 V) and nominal power up to 45 W, exploiting the computational power of STM32F103CB microcontrollers with internal 20 kB SRAM and 128 kB Flash, SWD debugging and the L6230 DMOS driver with 2.8 A output peak current, non-dissipative overcurrent detection/protection, cross conduction protection, uncommitted comparator, thermal shutdown, and undervoltage lockout.

The STEVAL-IFN003V1 is provided with a USB interface specific to real-time data exchange.

With dedicated hardware evaluation features, the STEVAL-IFN003V1 board is designed to help developers to evaluate the device and to develop their own applications.
The STEVAL-IFN003V1 can be used together with the STM32 PMSM single/dual FOC SDK v3.0 and constitutes a complete motor control evaluation and development platform.

Figure 1.   Image of the board

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1 Main features

The characteristics of the STEVAL-IFN003V1 PMSM field oriented control driver board are the following:

● STMicroelectronic's ARM™ Cortex-M3 core-based STM32F103xB microcontroller

● DC voltage range from 8 V to 48 V (extendable up to 52 V)

● Maximum load current of 1.4 $A_{r.m.s.}$ (2.8 A peak) for each output

● Integrated DC-DC regulator (3.3 V)

● Monolithic power stage in PowerSO package featuring overcurrent and thermal protection

● 3-shunt current sensing

● Control interface through trimmer, buttons and USB interface

● Debug outputs

● Hall sensor/encoder inputs

● Optimized layout on 4-layer board for high thermal performance.

2 Electrical characteristics of the board

The demonstration kit is designed to fit all typical low-power PMSM brushless motor applications, for example:

● Cooling fans

● Pumps

Table 1. STEVAL-IFN003V1 electrical characteristics

Parameter	Description	Value	Unit
$V_{S, Max}$	Maximum motor supply voltage	48 [1]	V
$V_{S, Min}$	Minimum motor supply voltage	8	V
I_{out}	Maximum output current	1.4	$A_{r.m.s.}$
$I_{out, peak}$	Maximum output peak current	2.8	A
$T_{j, op}$	Operating temperature	-25 to +125 °C	°C

1. Extendable to 52 V, refer to *Section 4.1*.

3   Schematic, layout and bill of material

Figure 2.   STEVAL-IFN003V1 schematic - MCU, power stage and current sensing circuitry
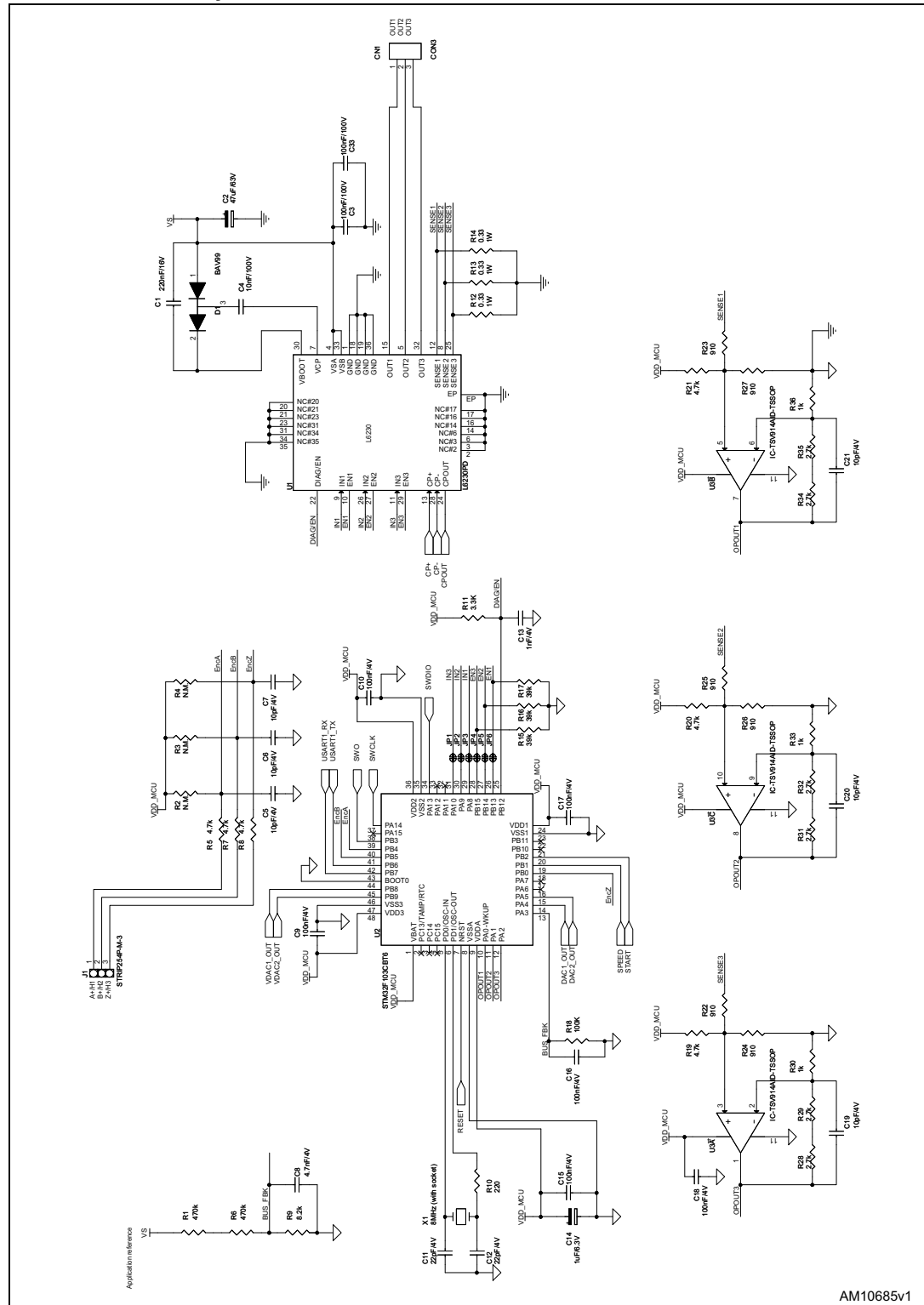
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Figure 3. STEVAL-IFN003V1 schematic - USB controller and power supply
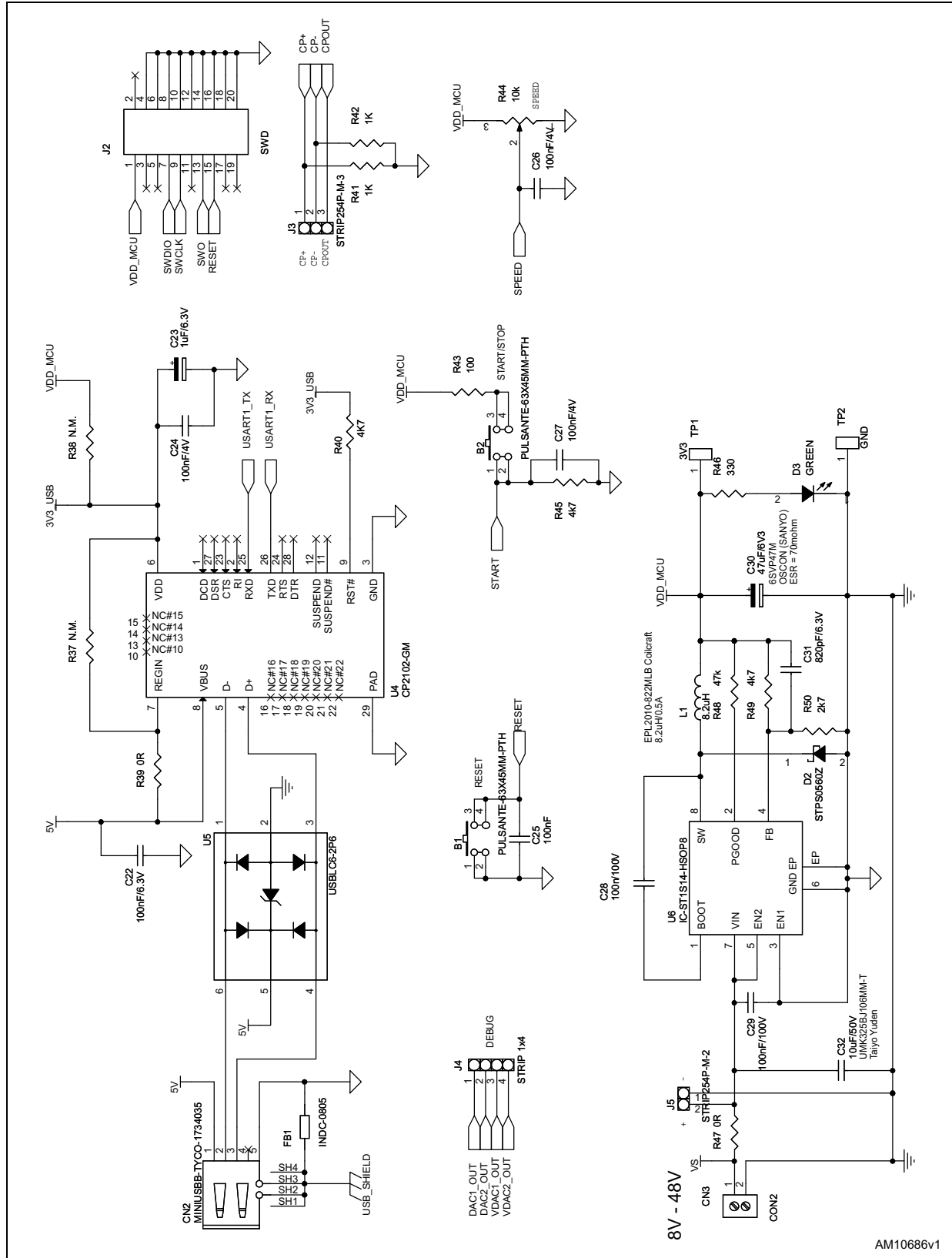
Figure 4.   STEVAL-IFN003V1 board layout - top and inner 1 layers
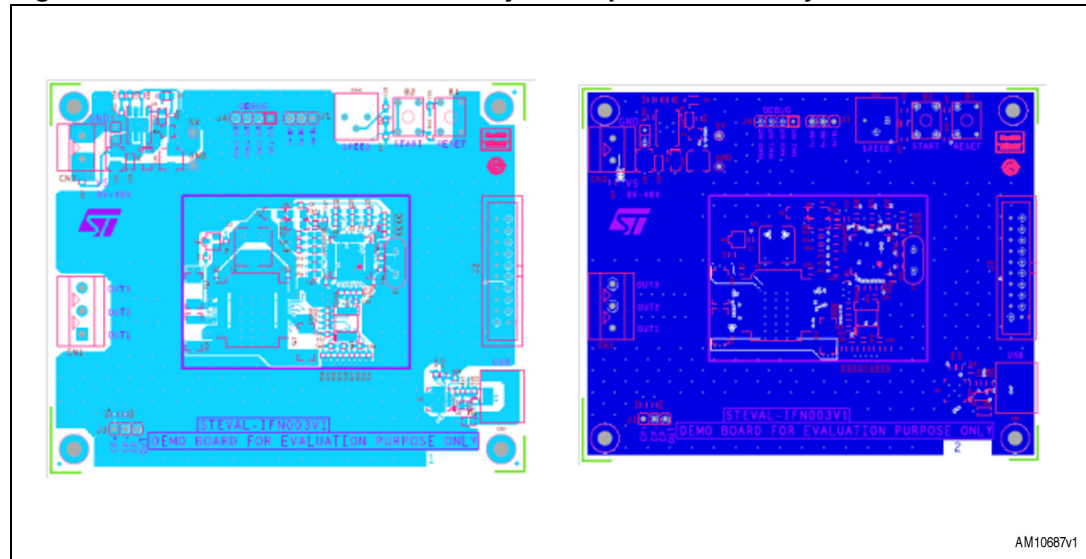
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Figure 5.   STEVAL-IFN003V1 board layout - inner 2 and bottom layers
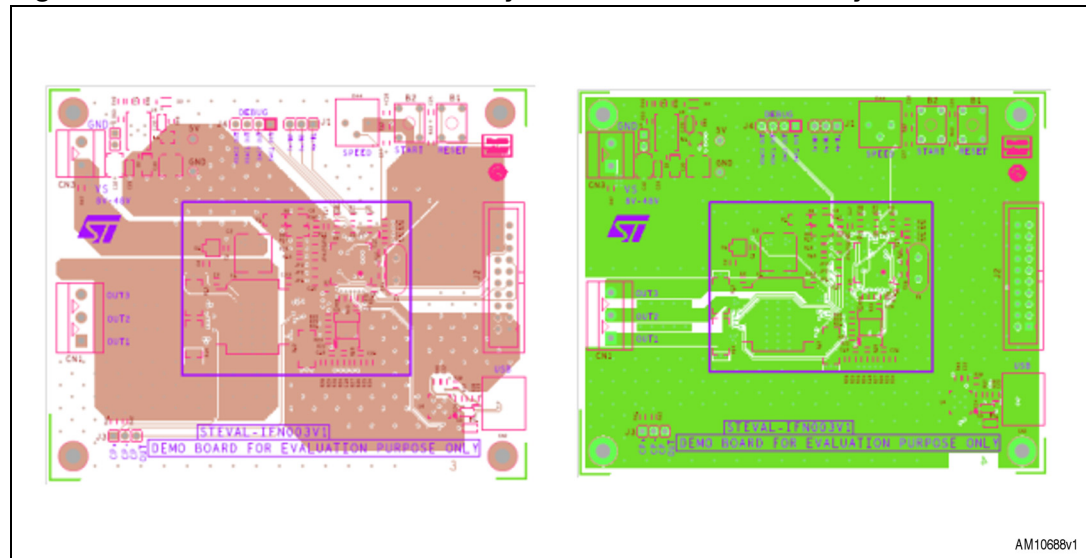
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Table 2.   STEVAL-IFN003V1 bill of material

Reference	Part/value	Manufacturer	Manufacturer code
B1	Button 63 x 45 mm		
B2	Button 63 x 45 mm		
CN1	3-wire power connector		
CN2	Mini-USB type B connector		
CN3	2-wire power connector		
C1	220 nF/16 V		
C2	47 µF/63 V		

Table 2.   STEVAL-IFN003V1 bill of material (continued)

Reference	Part/value	Manufacturer	Manufacturer code
C3, C33	100 nF/100 V		
C4	10 nF/100 V		
C5, C6, C7, C19, C20, C21	10 pF/4 V		
C8	4.7 nF/4 V		
C9, C10, C15, C16, C17, C18, C24, C26, C27	100 nF/4 V		
C11, C12	22 pF/4 V		
C13	1 nF/4 V		
C14, C23	1 µF/6.3 V		
C22, C25	100 nF/6.3 V		
C28, C29	100 nF/100 V		
C30	47 µF/6.3 V		
C31	820 pF/6.3 V		
C32	10 µF/50 V		
D1	BAV99		
D2	STPS0560Z	STMicroelectronics	STPS0560Z
D3	Green LED diode		
FB1	60 Ω ferrite	Murata	BLM21PG600SN1D
J1, J9	Strip line 1 x 3		
J2, J3, J4, J5, J6, J7	Jumper SMD 2 x 1		
J8	SWD - flat connector 10 x 2		
J10	Strip line 1 x 4		
J11	Strip line 1 x 2		
L1	8.2 µH	Coilcraft	EPL2010
R1	470 kΩ		
R2, R3, R4, R37, R38	N.M.		
R5, R7, R8, R19, R20, R21	4.7 kΩ		
R6	470 kΩ		
R9	8.2 kΩ		
R10	220 Ω		
R11	3.3 kΩ		
R12, R13, R14	0.33 Ω – 1 W		
R15, R16, R17	39 kΩ		
R18	100 kΩ		
R22, R23, R24, R25, R26, R27	910 Ω		

Table 2.   STEVAL-IFN003V1 bill of material (continued)

| Reference	Part/value	Manufacturer	Manufacturer code
R28, R29, R31, R32, R34, R35	2.7 kΩ		
R30, R33, R36, R41, R42	1 kΩ		
R39, R47	0 Ω		
R40, R45, R49	4.7 kΩ		
R43	100 Ω		
R44	10 kΩ		
R46	330 Ω		
R48	47 kΩ		
R50	2.7 kΩ		
TP1	Ring test point		
TP2	Ring test point		
U1	L6230	STMicroelectronics	L6230PD
U2	STM32F103CB	STMicroelectronics	STM32F103CBT6
U3	TSV914A	STMicroelectronics	TSV914AIPT
U4	CP2102	Silicon Labs	CP2102-GM
U5	USBLC6-2	STMicroelectronics	USBLC6-2P6
U6	ST1S14	STMicroelectronics	ST1S14PHR
X1	Xtal 8 MHz		

4 General description

4.1 Power supply

The STEVAL-IFN003V1 board is designed to be powered via CN3 connector 'VS'.

The VS supply voltage is used to directly supply the L6230 power stage and it is applied at the input of the ST1S14 step-down power switching regulator to generate the 3.3 V able to supply the microcontroller, the operational amplifiers and the board pull-ups (refer to *Figure 6*).

Figure 6. Power supply section
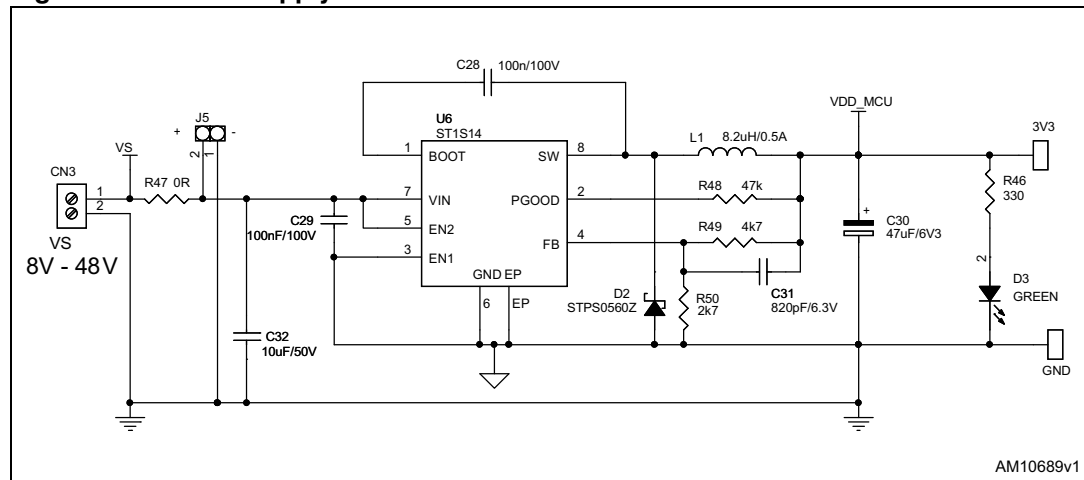
If the system requirements need a power stage supply voltage higher than 48 V (up to 52 V), it is possible to disconnect the switching regulator from the VS connector removing the R47 resistor and supply it through the connector J5 to keep generating 3.3 V on the board.

4.2 L6230 power stage

The L6230 is a DMOS fully integrated 3-phase motor driver with overcurrent protection, optimized for FOC application thanks to the independent current senses.

Realized in BCDmultipower technology, the device combines isolated DMOS power transistors with CMOS and bipolar circuits on the same chip.

An uncommitted comparator with open drain output is available (refer to the demonstration board schematic in *Figure 2*).

● Features:
  – Operating supply voltage from 8 to 52 V
  – 2.8 A output peak current (1.4 A RMS)
  – $R_{DS(on)}$ 0.73 Ω typ. value @ T_J = 25 °C
  – Integrated fast freewheeling diodes
  – Operating frequency up to 100 kHz
  – Non-dissipative overcurrent detection and protection
  – Cross conduction protection

– Diagnostic output
– Uncommitted comparator
– Thermal shutdown
– Undervoltage lockout

Figure 7. L6230 block diagram
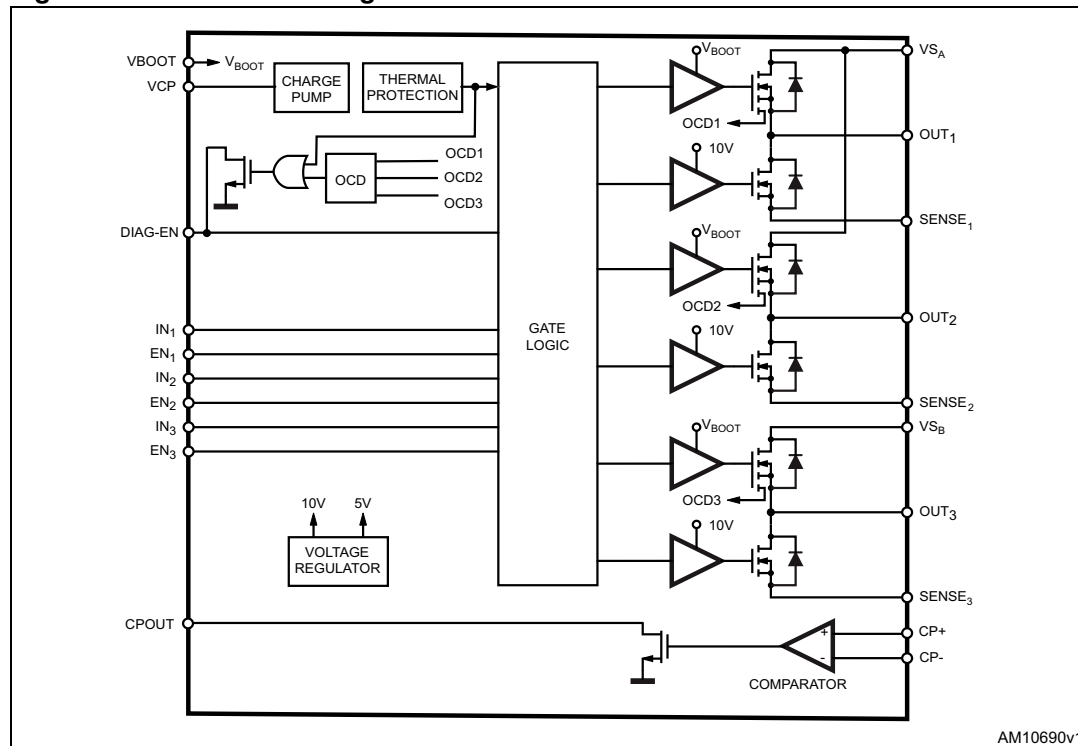
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Table 3. L6230 absolute maximum ratings

Symbol	Parameter	Conditions	Value	Unit
V_S	Supply voltage	$V_{SA} = V_{SB} = V_S$	60	V
V_{OD}	Differential voltage between: VSA, OUT1, OUT2, SENSEA and VSB, OUT3, SENSEB	$V_{SA} = V_{SB} = V_S = 60$ V; $V_{SENSEx} = GND$	60	V
V_{BOOT}	Bootstrap peak voltage	$V_{SA} = V_{SB} = V_S$	$V_S + 10$	V
V_{IN}, V_{EN}	Logic inputs voltage range		-0.3 to +7	V
V_{CP-}, V_{CP+}	Voltage range at CP- and CP+ pins		-0.3 to +7	V
V_{SENSE}	Voltage range at SENSEx pins		-1 to +4	V
$I_{S(peak)}$	Pulsed supply current (for each VS pin)	$V_{SA} = V_{SB} = V_S$; $T_{PULSE} < 1$ ms	3.55	A
I_S	RMS supply current (for each VS pin)	$V_{SA} = V_{SB} = V_S$	1.4	A
T_{stg}, T_{OP}	Storage and operating temperature range		-40 to 150	°C

Note: *Stresses above the limits shown in Table 3 may cause permanent damage to the device.*

The L6230 integrates a non-dissipative overcurrent detection circuit (OCD) for full protection.

To implement the overcurrent detection, a sensing element that delivers a small but precise fraction of the output current is implemented with each high-side Power MOSFET. This current is compared with an internal reference current IREF.

When the output current reaches the detection threshold (typ. I_{SOVER} = 2.8 A), the OCD comparator signals a fault condition. When a fault condition is detected, an internal open drain MOSFET connected to pin DIAG-EN is turned on.

The DIAG-EN pin is used to signal the fault condition to an MCU and to shut down the 3-phase bridge simply by connecting the pin to an external R-C network (R_{11} - C_{13}).

4.3 Current sensing circuitry

The load current is monitored through three sensing resistors, one for each channel.

The voltage across the shunt resistors are conditioned by operational amplifiers (TSV914A) which provide the proper feedback signals to the MCU A-D converter. The op amp output voltage range is optimized for a given phase current range and the MCU A-D converter input dynamics (refer to *Figure 8*).

Figure 8.   Current sensing circuitry
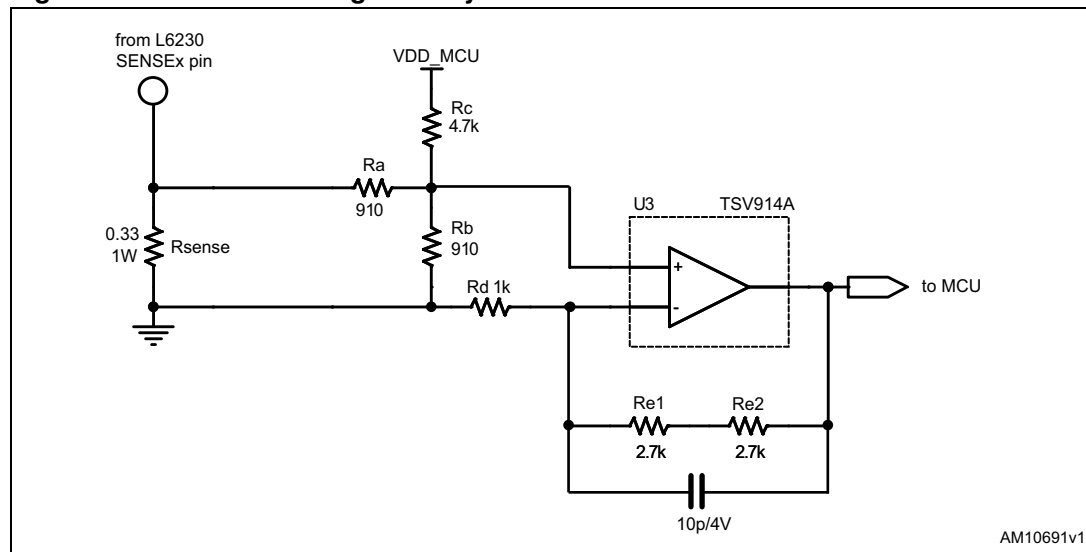
The voltage at the op amp output which is applied to the MCU A-D converter input can be calculated as the sum of two contributes:

Equation 1

$$V_{bias} = V_{DD\_MCU} \cdot \frac{(R_a \| R_b)}{(R_a \| R_b) + R_c} \cdot \left(1 + \frac{R_{e1} + R_{e2}}{R_d}\right)$$

Equation 2

$$V_{signal} = I \cdot R_{sense} \cdot \frac{(R_c \| R_b)}{(R_c \| R_b) + R_a} \cdot \left(1 + \frac{R_{e1} + R_{e2}}{R_d}\right)$$

With the mounted resistor values this gives:

- V_bias=1.86 V
- $V_{signal} = 2{,}92 \cdot R_{sense} \cdot I$

The maximum current manageable without distortion is equal to:

Equation 3

$$I_{max} = \frac{V_{DD\_MCU} - V_{bias}}{2.92 \cdot R_{sense}} = \frac{0.495}{R_{sense}} = 1.5\,A$$

Note that the I_{MAX} value can be modified by simply changing the value of the sense resistors.

4.4 STM32F103CB microcontroller

The STM32F103xx performance line family incorporates the high-performance ARM Cortex™-M3 32-bit RISC core operating at a 72 MHz frequency, high-speed embedded memories (Flash memory up to 128 Kbytes and SRAM up to 20 Kbytes), and an extensive range of enhanced I/Os and peripherals connected to two APB buses. All devices offer two 12-bit ADCs, three general purpose 16-bit timers plus one PWM timer, as well as standard and advanced communication interfaces: up to two I^{2}Cs and SPIs, three USARTs, a USB and a CAN.

The STM32F103xx medium-density performance line family operates from a 2.0 to 3.6 V power supply. It is available in both the -40 to +85 °C temperature range and the -40 to +105 °C extended temperature range. A comprehensive set of power-saving modes allows the design of low-power applications.

The STM32F103xx medium-density performance line family includes devices in 5 different package types: from 36 pins to 100 pins. Depending on the device chosen, different sets of peripherals are included. Please refer to the STM32F103xB datasheet for an overview of the complete range of peripherals proposed in this family.

Figure 9 shows the general block diagram of the device family.

It is possible to get more information regarding the features of the microcontroller and its operating mode in the STM32F103xx reference manual.

Figure 9. **STM32F103xx performance line block diagram**
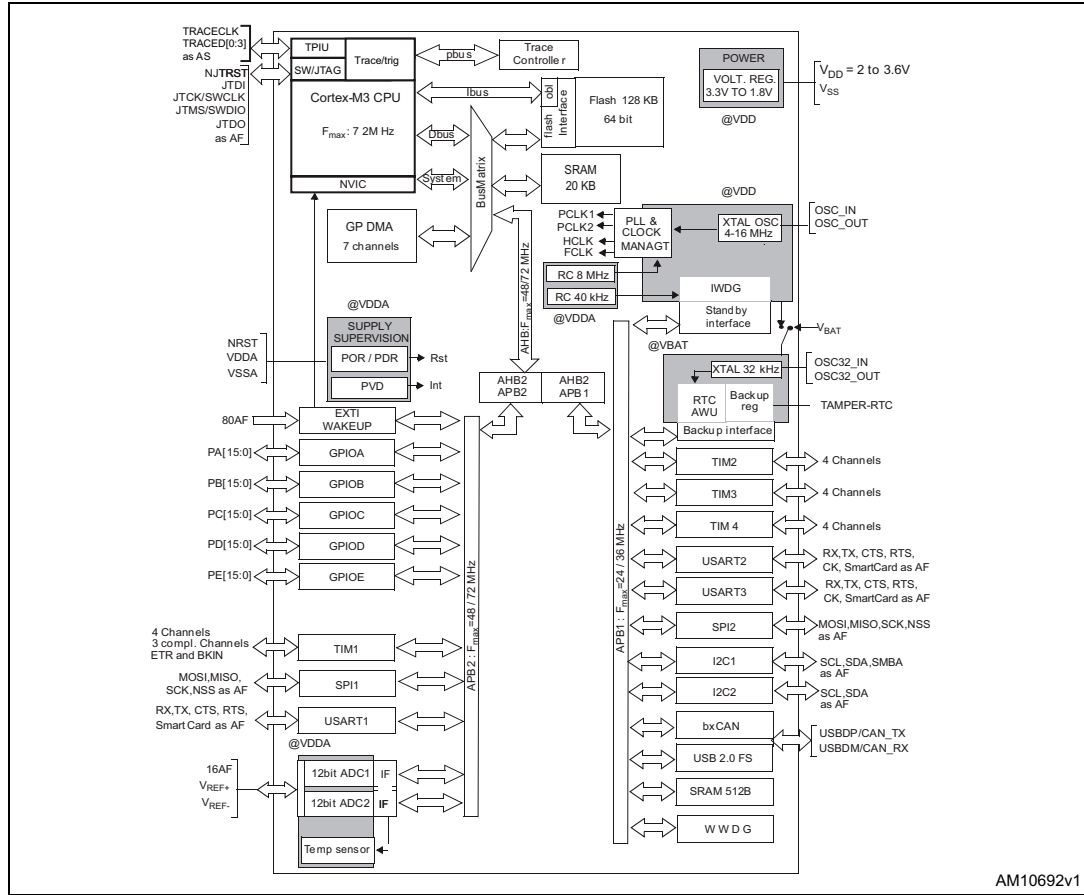
4.5 USB interface

The CP2102 is a highly-integrated USB-to-UART bridge controller providing a simple solution for updating RS-232 designs to USB using a minimum of components and PCB space. The CP2102 includes a USB 2.0 full-speed function controller, USB transceiver, oscillator, EEPROM, and asynchronous serial data bus (UART) with full modem control signals. No other external USB components are required.

For more details refer to the CP2102 device datasheet.

5 Using the STEVAL-IFN003V1 with the STM32 FOC firmware library

The "STM32 FOC firmware library v3.0" provided together with the STM3210B-MCKIT performs the field oriented control (FOC) of a permanent magnet synchronous motor (PMSM) in both sensor and sensorless configurations.

It is possible to configure the firmware to work with the STEVAL-IFN003V1 board and to establish a real-time communication for debugging/tuning purposes using the ST motor control workbench release 1.1 or higher.

This section describes the customization to be applied to the "STM32 FOC firmware library v3.0" in order for the firmware to be compatible with the STEVAL-IFN003V1 and with the ST motor control workbench release 1.1 or higher.

5.1 Hardware requirements

The following items are required to run the STEVAL-IFN003V1 together with the "STM32 FOC firmware library":

- The STEVAL-IFN003V1 board
- A DC power supply (up to 48 V)
- A programmer/debugger dongle for the control board (not included in the package). To program/debug the STEVAL-IFN003V1, a dongle with single wire debugging capabilities (SWD) is required. Use of an insulated dongle is always recommended.
- A 3-phase brushless motor with permanent magnet rotor (not included in the package)
- A USB cable with mini-USB connector (type B) to establish a real-time communication (not included in the package).
- An insulated oscilloscope (as needed)
- An insulated multimeter (as needed).

5.2 Software requirements

To customize, compile and download the "STM32 FOC firmware library v3.0", a tool chain must be installed. Please refer to the UM1052 user manual for major details on how to set up the proper tool chain.

Please consider that, as is, the "STM32 FOC firmware library v3.0" isn't fully compatible with either the STEVAL-IFN003V1 or the ST motor control workbench version 1.1 or higher.

In order to establish a real-time communication with the ST motor control workbench, it is necessary to install the firmware patch "STEVAL-IFN003V1_Patch.exe", available for download on the ST website.

Installing the "STEVAL-IFN003V1_Patch.exe" firmware patch enables the functionality of the "START/STOP" button and of the "SPEED" potentiometer.

Please note that is not advisable to install the firmware patch in the installation folder of FOC SDK v3.0 because the process is not reversible. It is advised to save the patch in a folder containing a copy of that directory and remember to create a backup copy of that folder before installing.

To summarize, the guidelines below can be followed:

- Copy the FOC SDK v3.0 installation folder (the default path is "C:\Program Files\STMicroelectronics\STM32 PMSM FOC Firmware Library v3.0" or similar) including the subfolder in a working folder (example "C:\Working\IFN003V1\")
- Apply the "STEVAL-IFN003V1_Patch.exe" firmware patch in the working folder (example "C:\Working\IFN003V1\ STM32 PMSM FOC Firmware Library v3.0").

Before establishing the real-time communication it is also necessary to install the "CP210x USB to UART Bridge VCP drivers" available for download on the "Silicon Labs" website (http://www.silabs.com).

5.3 STM32 FOC firmware library v3.0 customization

To customize the STM32 FOC firmware library v.3.0 for the STEVAL-IFN003V1, use the "ST motor control workbench" as described in the UM1052 user manual.

The required parameters for the control stage section related to the STEVAL-IFN003V1 are reported in *Table 4*.

Table 4. STEVAL-IFN003V1 motor control workbench parameters for the "control stage" section

Block	Parameter	STEVAL-IFN003V1 default value	Unit
MCU and clock frequency	STM32 sub-family	Performance line medium density	
	CPU frequency	72	MHz
	Nominal MCU supply voltage	3.30	V
Analog input	ADC channel selection for phase U	ADC12_IN0	
	ADC channel selection for phase V	ADC12_IN1	
	ADC channel selection for phase W	ADC12_IN2	
	ADC channel for current reading (1sh)	Disabled	
	Bus voltage – ADC channel	ADC12_IN3	
	Temp. feedback – ADC channel	Disabled	
DAC functionality	DAC functionality peripheral	-	
Digital I/O	Timer	TIM1	
	TIM1 remapping	No remap	
	Encoder interface – timer	TIM3	
	Encoder interface – timer remap	Partial re-map	
	Hall sensor interface – timer	TIM3	
Digital I/O	Hall sensor interface – timer remap	Partial re-map	
	Serial communication – channel	USART1	
	Serial communication – USART1 remapping	Remap	
	Dissipative brake output	Disabled	
	In-rush current limiter	Disabled	
	Overcurrent protection disabling	Disabled	

Note: In the "Drive management" section, "User Interface Add-on", the "Joystick, LCD, button" check box must be unchecked because the feature is not supported by the STEVAL-IFN003V1. Moreover, the "Serial communication" check box must be checked to enable the real-time communication.

The required parameters for the power stage section related to the STEVAL-IFN003V1 are reported in *Table 5*.

Table 5.   STEVAL-IFN003V1 motor control workbench parameters for the "power stage" section

Parameter	STEVAL-IFN003V1 default value	Unit
ICL shut-out	Disabled	
Dissipative brake	Disabled	
Bus voltage sensing	Enabled	
Bus voltage divider	125	
Min. rated voltage	8	V
Max. rated voltage	48	V
Nominal voltage	Equal to the bus voltage provided	V
Temperature sensing	Disabled	
V_0	-	mV
T_0	-	°C
$\Delta V/\Delta T$	-	mV/°C
Max. working temperature on sensor	-	°C
Overcurrent protection	Enabled	
Comparator threshold	0.50	V
Overcurrent network gain	0.33	V/A
Expected overcurrent threshold	1.5152	A
Overcurrent feedback signal polarity	Active low	
Overcurrent protection disabling network	Disabled	
Current sensing	Enabled	
Current reading topology	3-shunt resistors	
Shunt resistor(s) value	0.33	Ω
Amplifying network gain	2.76	
T-noise	1000	ns
T-rise	1000	ns
Power switches, min. dead-time	700	ns
Power switches, max. switching frequency	100	kHz
U,V,W driver, high-side driving signal	Active high	

Table 5.   **STEVAL-IFN003V1 motor control workbench parameters for the "power stage" section (continued)**

Parameter	STEVAL-IFN003V1 default value	Unit
U, V, W driver, Low-side driving signal. Complemented from high-side	Enabled	
U,V,W Driver, low-side driving signal. Polarity	Disabled	

6 References

This user manual provides information on the hardware features and use of the STEVAL-IFN003V1 demonstration board. For additional information on supporting software and tools, refer to the following:

1. STM32F103xB datasheet
2. RM0008 reference manual (STM32F103xx)
3. UM1052 user manual
4. L6230 datasheet
5. ST1S14 datasheet
6. TSV914A datasheet
7. http://www.st.com/mcu/ web site, which is dedicated to the complete STMicroelectronics microcontroller portfolio.

7 Revision history

Table 6. Document revision history

Date	Revision	Changes
14-Mar-2012	1	Initial release.

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