

100 W 3-phase inverter demonstration board using the L6390 and STD5N52U for vector control

Introduction

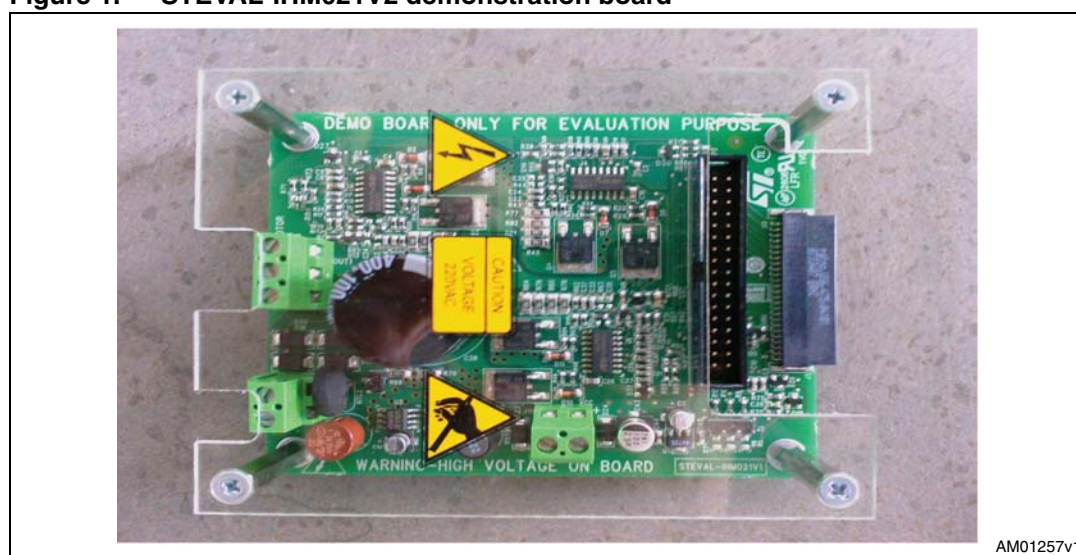
The 100 W 3-phase inverter demonstration board features the L6390 and STD5N52U for field-oriented control (FOC) of permanent magnet synchronous motors (PMSM). Also referred to by order code STEVAL-IHM021V2, this 3-phase inverter is designed to perform the FOC of sinusoidal-shaped back-EMF PMSMs with or without sensors, with nominal power up to 100 W. The flexible, open, high-performance design consists of a 3-phase inverter bridge based on:

- the STD5N52U power MOSFET in a DPAK package, with enhanced fast body-drain recovery diode
- the L6390 device, which is part of the latest high-voltage half-bridge gate driver family featuring an integrated comparator for implementation of hardware protection (i.e. overcurrent, overtemperature, etc.)
- an embedded operational amplifier suitable for advanced current sensing

The system is specifically designed to achieve fast and accurate conditioning of the current feedback, thereby matching the requirements typical of high-end applications such as field-oriented motor control. As an alternative to the STD5N52U, the STGD6NC60HD or STGDL6NC60DI IGBT devices may be used on the board without replacing the switch driving network.

The board is compatible with 110 and 230 Vac mains, and includes a power supply stage with the VIPer12A-E (in buck configuration) to generate the +15 V and +3.3 V supply voltage required by the application. Finally, the board can be interfaced with the STM3210B-EVAL (STM32 microcontroller demonstration board) through a dedicated connector.

Figure 1. STEVAL-IHM021V2 demonstration board



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1 Main features

The STEVAL-IHM021V2 100 W 3-phase inverter has the following characteristics:

- Wide range input voltage
- Maximum power up to 100 W at 230 Vac input
- The STD5N52U 4.4 A, 520 V power MOSFET
- Compatibility with other power switches in DPAK packages (the STGD6NC60HD or STGDL6NC60DI, for example)
- 15 V auxiliary power supply connector
- Connector for interfacing with the STM3210B-EVAL board

1.1 Target applications

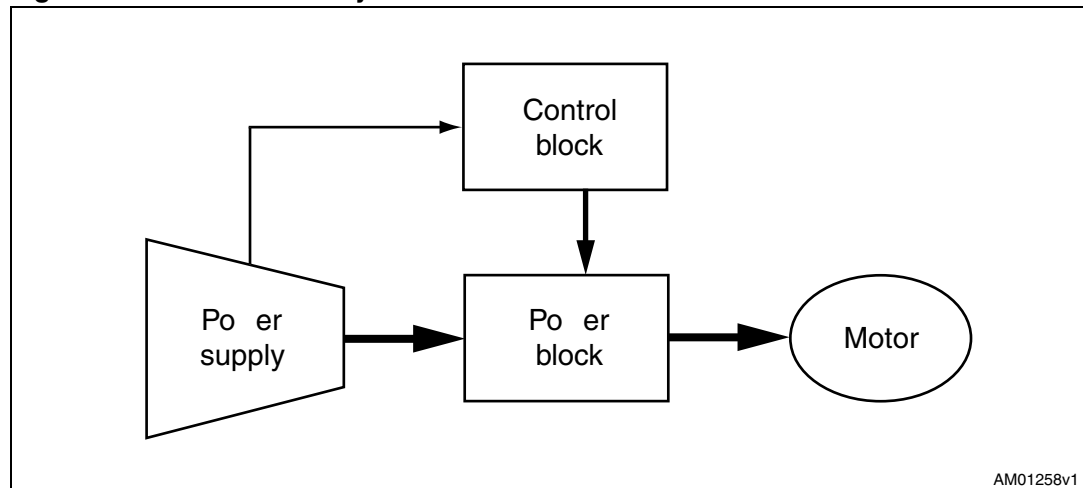
- Refrigerator compressors
- Dishwasher pumps

2 System architecture

A generic motor control system can be schematized as the arrangement of four main blocks ([Figure 2](#)).

- Control block: its main tasks are to accept user command and motor drive configuration parameters, and to provide digital signals to implement the appropriate motor driving strategy
- Power block: it performs the power conversion from the DC bus, transferring it to the motor by means of a 3-phase inverter topology
- The motor: the STEVAL-IHM021V2 board can drive any PMSM, but the FOC itself is conceived for sinusoidal-shaped back-EMF
- Power supply block: it can accept input voltages of 86 to 260 Vac and provides the appropriate levels to supply both the control block and power block devices

Figure 2. Motor control system architecture



Of the above motor control system architecture, the STEVAL-IHM021V2 includes the Power Supply and Power hardware blocks.

The power block, based on the high voltage gate driver L6390 and power MOSFET STD5N52U, converts the signals coming from the control block into power signals capable of correctly driving the 3-phase inverter, and therefore the motor.

The power supply can be fed with 110 or 230 Vac mains, and the maximum allowed input power is 100 W at 230 Vac (refer to [Section 7](#)).

In the control block, a J3 connector is mounted on both the STEVAL-IHM021V2 and the STM3210B-EVAL, which allows the STM32 microcontroller demonstration board to be used as a hardware platform for development. Minor modifications may be applied to the “STM32 FOC firmware libraries v2.0” for these to be used as a software platform for the sensorless control of PMSMs (see [Section 9.4](#)).

3 Safety and operating instructions

3.1 General

Warning: During assembly and operation, the STEVAL-IHM021V2 demonstration board poses several inherent hazards, including bare wires, moving or rotating parts and hot surfaces. Serious personal injury and damage to property may occur if the kit or its components are used or installed incorrectly.

All operations involving transportation, installation and use, as well as maintenance, should be performed by skilled technical personnel (applicable national accident prevention rules must be observed). *Skilled technical personnel* refers to suitably-qualified people who are familiar with the installation, use and maintenance of electronic power systems.

3.2 Intended use of the demonstration board

The STEVAL-IHM021V2 demonstration board is designed for demonstration purposes *only*, and must not be used for electrical installations or machinery. Technical data and information concerning the power supply conditions are detailed in the documentation and should be strictly observed.

3.3 Installing the demonstration board

The installation and cooling of the demonstration board must be in accordance with the specifications and target application.

- The motor drive converters must be protected against excessive strain. In particular, components should not be bent or isolating distances altered during transportation or handling.
- No contact must be made with other electronic components and contacts.
- The board contains electrostatically-sensitive components that are prone to damage if used incorrectly. Do not mechanically damage or destroy the electrical components (potential health risks).

3.4 Electronic connections

Applicable national accident prevention rules must be followed when working on the main power supply with a motor drive. The electrical installation must be completed in accordance with the appropriate requirements (for example, cross-sectional areas of conductors, fusing, PE connections, etc.).

3.5 Operating the demonstration board

A system architecture that supplies power to the STEVAL-IHM021V2 demonstration board must be equipped with additional control and protective devices in accordance with the applicable safety requirements (i.e., compliance with technical equipment and accident prevention rules).

Warning: Do not touch the demonstration board after it has been disconnected from the voltage supply as several parts and power terminals containing possibly-energized capacitors need time to discharge.

4 L6390 characteristics

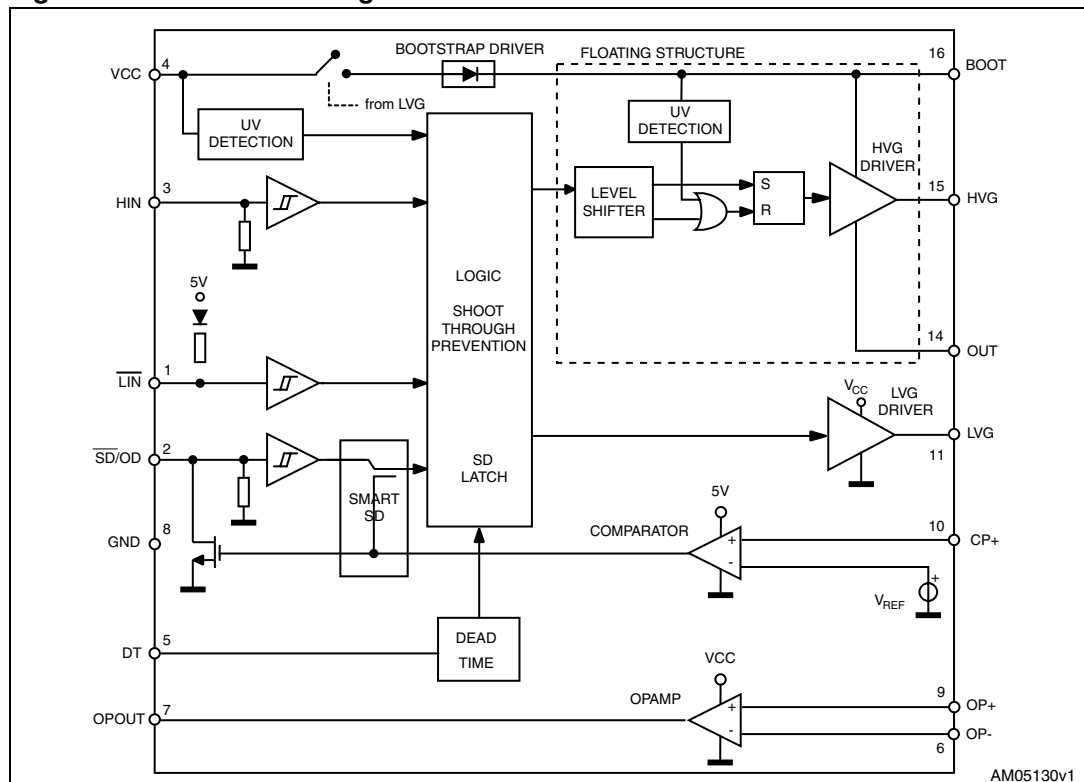
4.1 Main features

- High voltage rail up to 600 V
- dV/dt immunity ± 50 V/ns in full temperature range
- Driver current capability:
 - 270 mA source
 - 430 mA sink
- Switching times 75/35 ns RISE/FALL with 1 nF load
- 3.3, 5 V TTL/CMOS inputs with hysteresis
- Integrated bootstrap diode
- Operational amplifier for advanced current sensing
- Comparator for fault protection
- Smart shutdown function
- Adjustable dead time
- Interlocking function

4.2 Block diagram

Figure 3 shows the block diagram of the L6390 device.

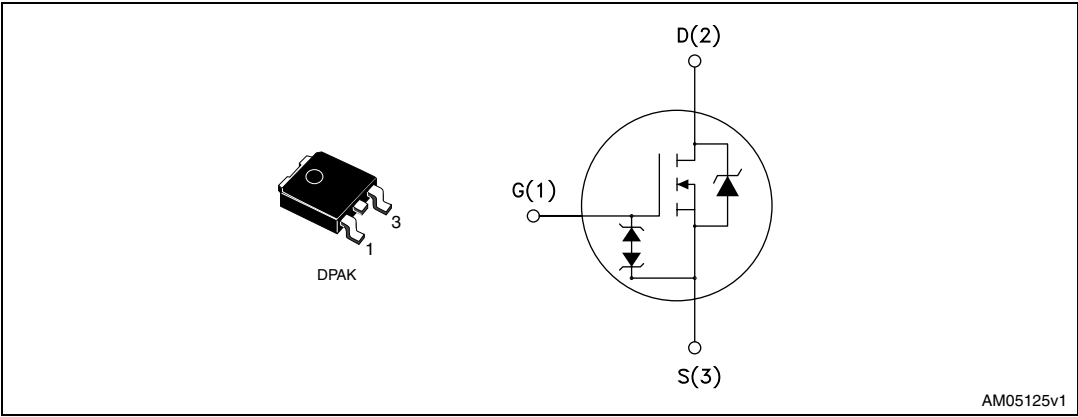
Figure 3. L6390 block diagram



5 STD5N52U characteristics

The STD5N52U is an N-channel power MOSFET in a DPAK package (520 V, 1.22 Ω , 4.4 A). The Zener-protected STD5N52U employs UltraFASTmesh™ technology and has been specifically designed for applications where a body-drain diode with an extremely low t_{rr} is required (motor control, lighting in full bridge topology, inverters for LCD TV, etc.).

Figure 4. STD5N52U



- $V_{DSS} = 520\text{ V}$
- $R_{DS(on)} < 1.5\ \Omega$
- $I_D = 4.4\text{ A}$

Table 1. STD5N52U absolute maximum ratings

Symbol	Parameter	Value	Unit
V_{DS}	Drain-source ($V_{GS} = 0$)	520	V
V_{DGR}	Drain-gate voltage ($R_{GS} = 20\text{ k}\Omega$)	520	V
V_{GS}	Gate-source voltage	± 30	V
I_D	Drain current (continuous) at $T_C = 25^\circ\text{C}$	4.4	A
I_D	Drain current (continuous) at $T_C = 100^\circ\text{C}$	2.7	A
$I_{DM}^{(1)}$	Drain current (pulsed)	17.6	A
P_{TOT}	Total dissipation at $T_C = 25^\circ\text{C}$	70	W

1. Pulse width limited by safe operating area.

Note: Stresses above the limits shown in [Table 1](#) may cause permanent damage to the device.

6 Electrical characteristics of the board

Stresses above the limits shown in [Table 2](#) may cause permanent damage to the devices present inside the board. These are stress ratings only and functional operation of the device under these conditions is not implied. Exposure to maximum rating conditions for extended periods may affect device reliability.

A 15 V bias current measurement may be useful to check the working status of the board. If the measured value is considerably higher than the typical value, some damage has occurred to the board. Supply the control board using a 15 V power supply connected to J10, respecting the polarity.

Table 2. Board electrical characteristics

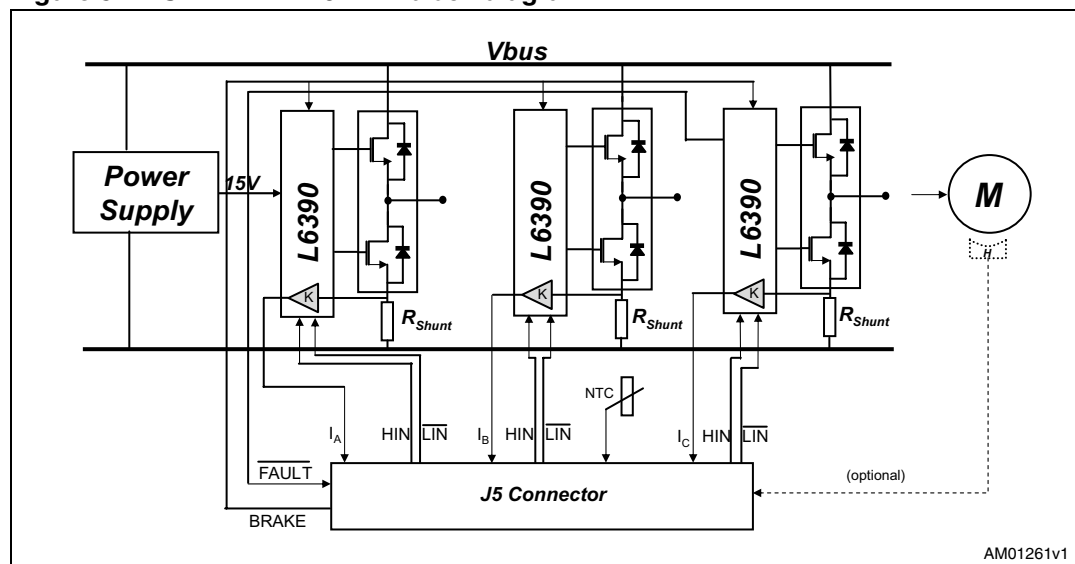
Board parameters	STEVAL-IHM021V2		Unit
	Min	Max	
15 V auxiliary supply range - J10	14.5	17	V
15 V bias current (typical)	8	10	mA
V_{mains} - J7	30	270	Vac

Warning: To avoid damaging the board when feeding the +15 V voltage supply through the auxiliary connector (J10), remove jumper J8 and supply the +15 V *before* connecting the mains.

7 Board architecture

The STEVAL-IHM021V2 can be schematized as shown in [Figure 5](#).

Figure 5. STEVAL-IHM021V2 block diagram

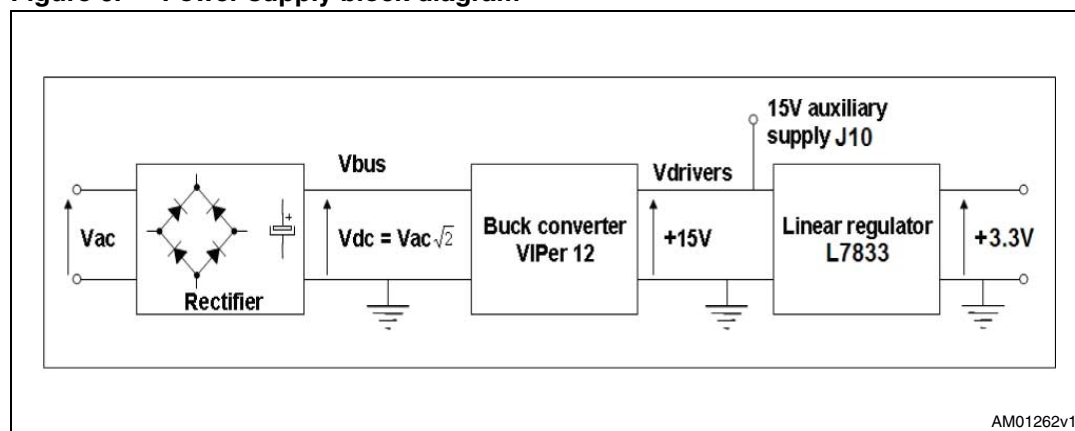


7.1 Power supply

The power supply can address an AC input voltage ranging from 30 Vac up to 270 Vac. The alternating current input is rectified by a diode bridge and a bulk capacitor to generate a direct current bus voltage approximately equal to $\sqrt{2}$ Vac (neglecting the voltage drop across the diodes and the bus voltage ripple). A VIPer12A-E is then used in a buck converter configuration to generate the +15-V supply voltage of the gate drivers. Finally, a linear regulator (L78L33ABUTR) is used to generate the 3.3 V used to pull up the low-side gate driver inputs so as to prevent the undesired turn-on of low-side switches when the J5 connector is unplugged.

[Figure 6](#) shows a block diagram of the power supply.

Figure 6. Power supply block diagram



7.2 Gate driving

As mentioned previously, gate driving of the switches is performed by the latest of the L6390 family of devices. Refer to [Section 8.1](#) for detailed information on the gate driving circuit and dead-time insertion. A fault signal is also fed back to the J5 connector if an overcurrent event is detected.

7.3 Amplifying network

The voltages across the three shunt resistors are amplified by K to correctly condition the current feedback signals and optimize the output voltage range for a given phase current range and A/D converter input dynamics. Refer to [Section 8.3](#) for more detailed information on how to dimension the op-amp conditioning network depending on your needs.

7.4 Brake feature

The brake feature performs motor braking by switching simultaneously to the low-side power MOSFET, thus shortening the motor phases.

Warning: This feature is mandatory in applications that require the motor to operate in a flux-weakening region. In these conditions, the back-EMF generated by the rotor's spinning is greater than the bus voltage, and the brake feature prevents the motor from acting as a generator and destructively charging the bus capacitance. Refer to [Section 8.4](#) for additional information.

7.5 Temperature feedback

Temperature feedback is performed by way of an NTC. It enables monitoring of the power stage temperature so as to prevent any damage to the inverter caused by overtemperature.

8 STEVAL-IHM021V2 schematic diagrams

Figure 7. Inverter schematic

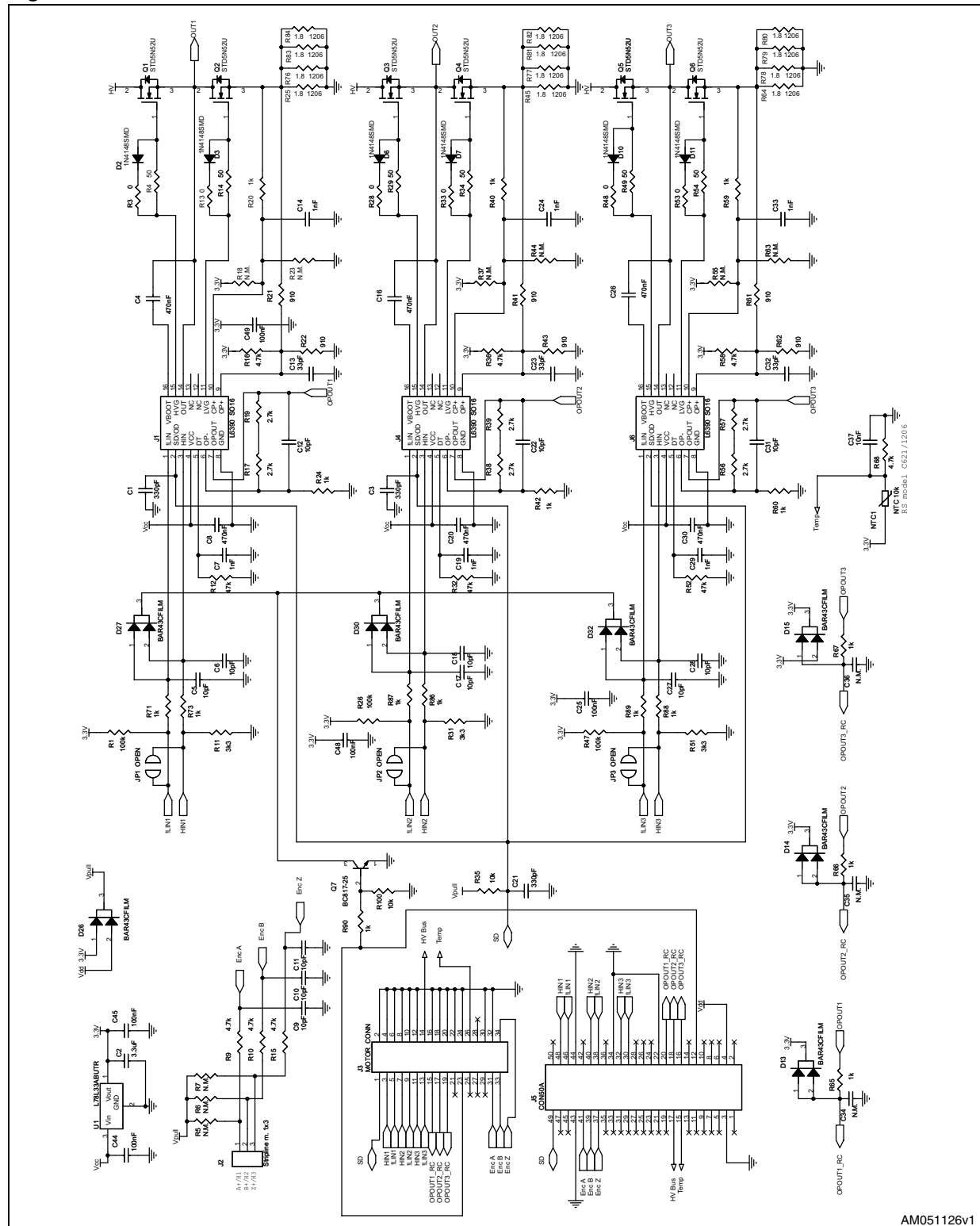
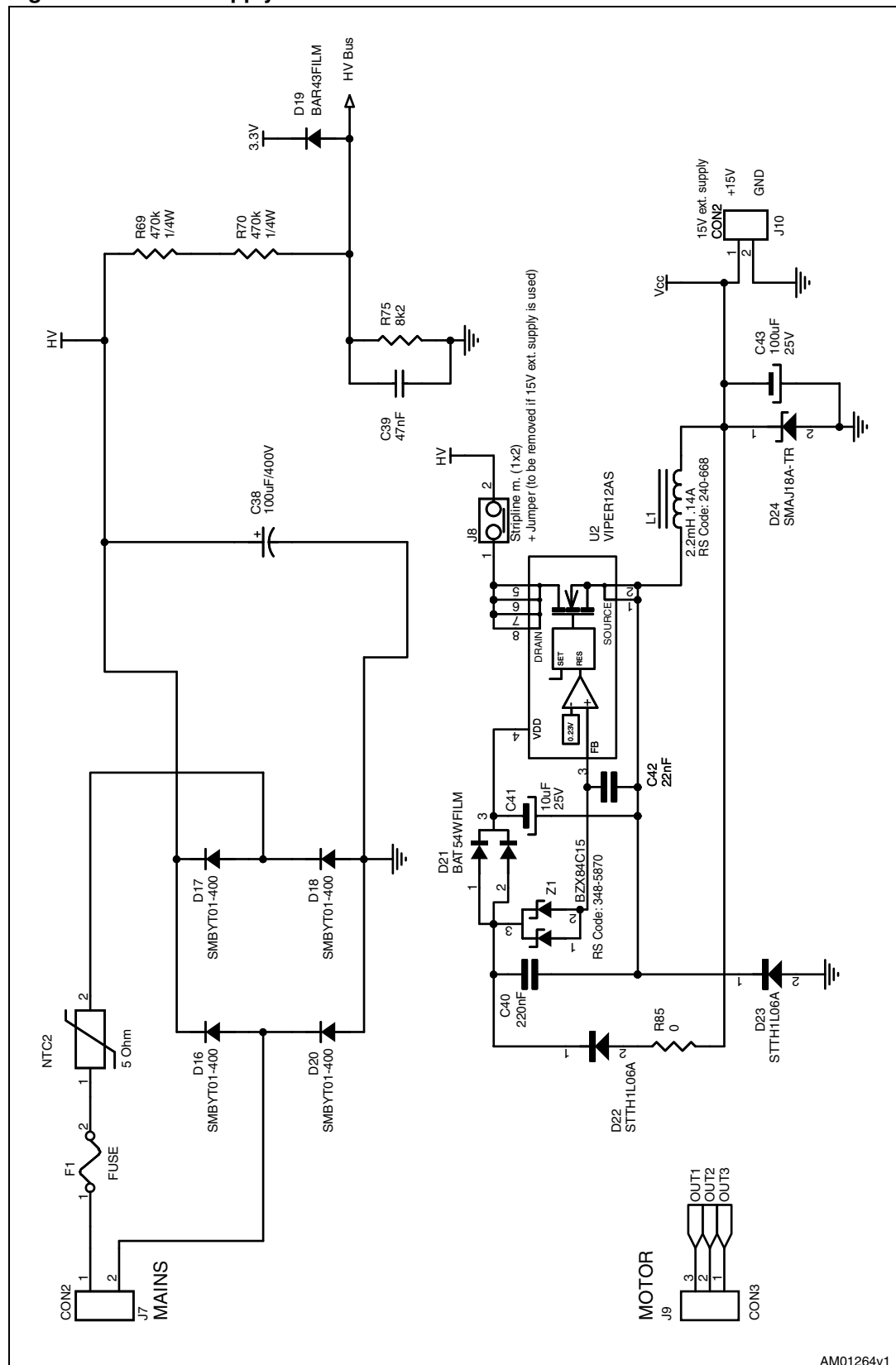


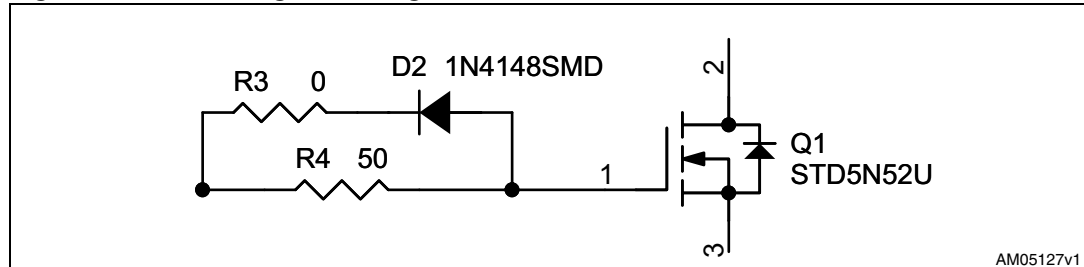
Figure 8. Power supply schematics



8.1 Gate driving circuit

Figure 9 shows the circuit used to turn the power MOSFETs on and off.

Figure 9. Detailed gate driving circuit



During the turn-on phase, the power MOSFET gate capacitances are charged through 50-Ω resistors while the turn-off is secured by the D3 diode (or similar).

Use of the L6390 device guarantees a minimum adjustable dead time (DT). This dead time is applied to the HVG and LVG outputs whenever a dead time shorter than DT is present on the HIN and LIN inputs. The R12, R32 and R52 values being equal to 47 kΩ, set the minimum dead time to approximately 600 ns.

8.2 Overcurrent protection

Hardware overcurrent protection has been implemented on the board, taking advantage of the comparator integrated inside the L6390. The internal connection between the comparator output and the shutdown block makes the intervention time of the overcurrent protection extremely low, slightly above 100 ns.

Since the overcurrent protection acts as soon as the voltage on CP+ rises above Vref (approximately equal to 0.53 V), and given the default value of the shunt resistors (equal to $1.8/4 = 0.45 \Omega$), it follows that the default value for the maximum allowed current (I_{CP}) is equal to:

Equation 1

$$I_{CP} = \frac{V_{Ref}}{R_{shunt}} \cong 1.15 \text{ A}$$

If necessary, the threshold can be decreased by adding R37 (and similarly R55 and R18) with the formula:

Equation 2

$$I_{CP} = \frac{1}{R_{shunt}} \cdot \frac{R40 + R37}{R37} \left[V_{ref} - 3.3 \frac{R40}{R37 + R40} \right] \quad \text{with } R37 \gg R40$$

Similarly, the threshold can be increased by adding R44 (and similar) with the formula:

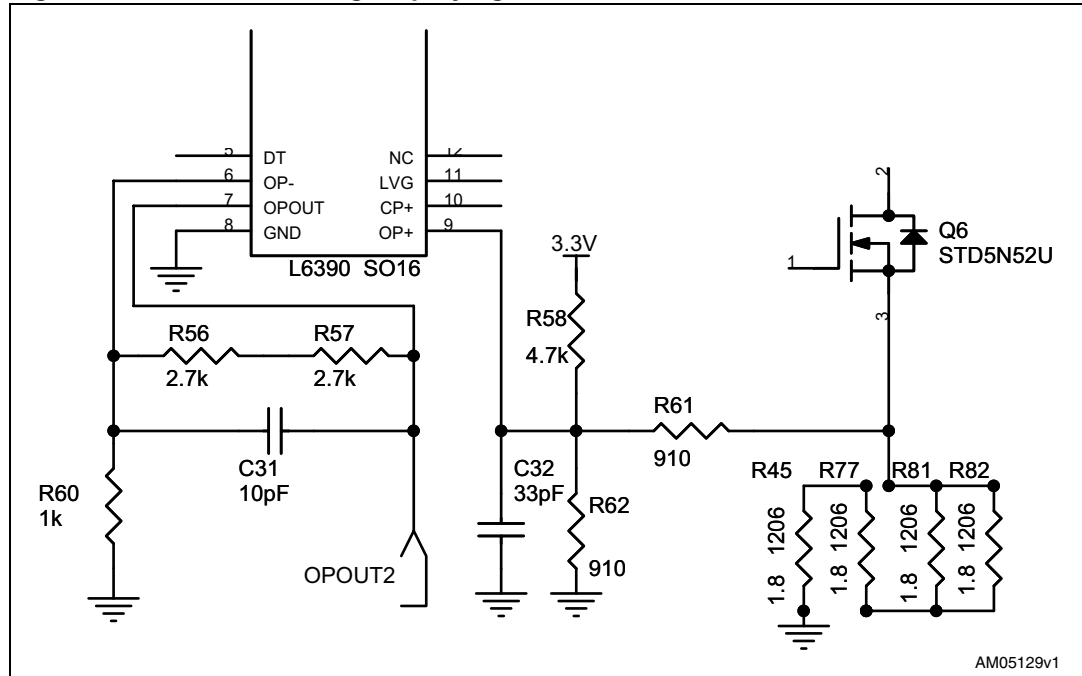
Equation 3

$$I_{CP} = \frac{V_{ref}}{R_{shunt}} \cdot \left(1 + \frac{R40}{R44} \right) \quad \text{with } R37 \gg R40$$

8.3 Current sensing amplifying network

Figure 10 shows the current sensing amplifying network during phase 2.

Figure 10. Current sensing amplifying network



The voltage at node “OPOUT2” can be computed as the sum of a bias and a signal component, respectively equal to:

Equation 4

$$V_{BIAS} = 3.3 \frac{R41 // R43}{R36 + R41 // R43} \left(1 + \frac{R38 + R39}{R42} \right)$$

Equation 5

$$V_{\text{SIGN}} = I \cdot R_{\text{SHUNT}} \cdot \frac{R_{36} // R_{43}}{R_{41} + R_{36} // R_{43}} \left(1 + \frac{R_{38} + R_{39}}{R_{42}} \right)$$

With the default values this gives:

- $V_{\text{BIAS}} = 1.86 \text{ V}$
- $V_{\text{SIGN}} = 2.91 \cdot R_{\text{SHUNT}} \cdot I$

As such, the maximum current amplifiable without distortion is equal to:

Equation 6

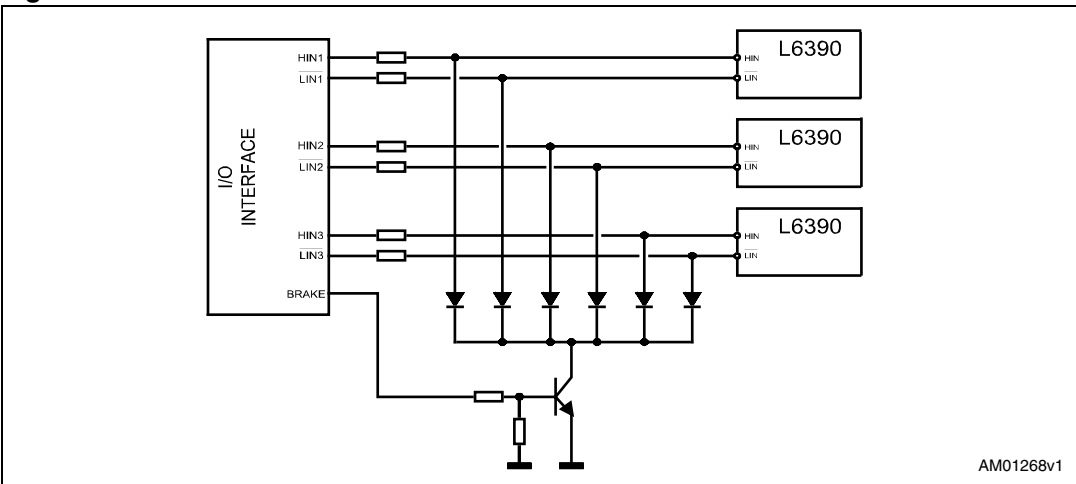
$$I_{MAX} = \frac{3.3 - 1.86}{2.91 \cdot R_{SHUNT}} = \frac{0.495}{R_{SHUNT}} = 1.1 \text{ A}$$

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

8.4 Brake function

The STEVAL-IHM021V2 demonstration board provides a brake function that, through the pull-up of a single brake signal, simultaneously turns the three low-side switches ON, shorting the 3-phase load. The feature is accessed using one single small-signal bipolar transistor (Q7), whose function is to pull down the cathodes of six small signal diodes connected to each of the six logic inputs (HIN1, LIN 1, HIN2, LIN 2, HIN3, LIN 3) of the L6390 gate drivers. The in-series resistors together with the input lines avoid any conflict with the external controller input signals, giving priority to the brake signal (see [Figure 11](#)).

Figure 11. Brake circuit



The brake signal is active high and 3.3/5 V compatible.

Table 3. Truth table

HINx	$\overline{LIN} x$	$\overline{SD}$	Brake	LVGx	HVGx	Load
x	x	0	x	0	0	Tri-state
x	x	1	1	1	0	brake
0	0	1	0	1	0	Normal operation
0	1	1	0	0	0	
1	0	1	0	0	0	
1	1	1	0	0	1	

Warning: This feature is mandatory in applications that require the motor to operate in the flux-weakening region. In these conditions, the back-EMF generated by the rotor spinning is greater than the bus voltage and the brake feature prevents the motor from acting as a generator, and destructively charging the bus capacitance.

9 Using the STEVAL-IHM021V2 with the “STM32 PMSM FOC SDK v3.0” firmware library

The “STM32 PMSM FOC SDK v3.0” is a firmware library for STM32 that can be used in conjunction with STEVAL-IHM021v2 to perform the field-oriented control (FOC) of a permanent magnet synchronous motor (PMSM) in both sensor and sensorless configurations.

This section describes how to configure “STM32 PMSM FOC SDK v3.0” with its related PC configuration tool (ST MC Workbench) in order to be compatible with the STEVAL-IHM021V2.

9.1 Environmental considerations

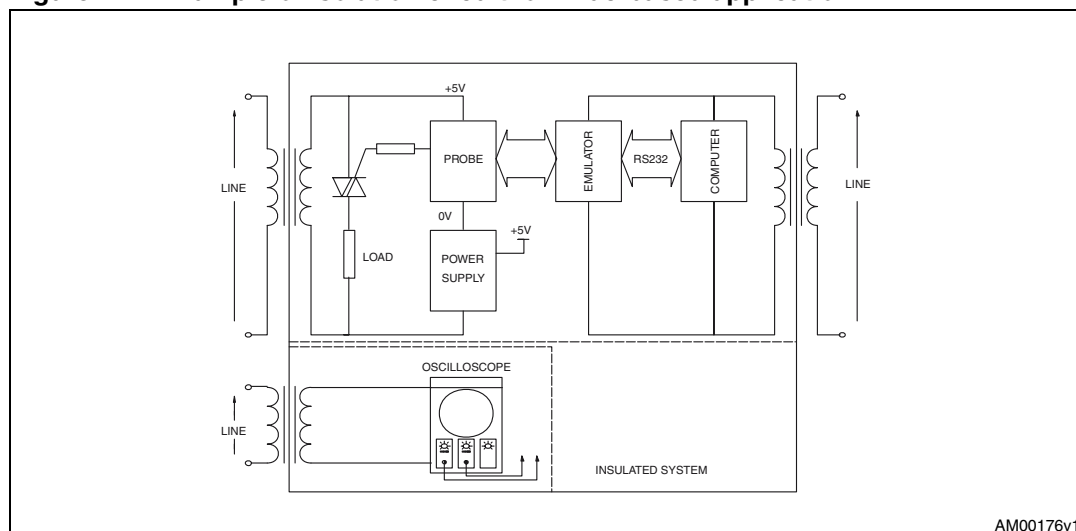
Warning: The STEVAL-IHM021V2 demonstration board must only be used in a power laboratory. The voltage used in the drive system presents a shock hazard.

The kit is not electrically isolated from the DC input. This topology is very common in motor drives. The microprocessor is grounded by the integrated ground of the DC bus. The microprocessor and associated circuitry are hot and MUST be isolated from user controls and communication interfaces.

Warning: Any measurement equipment must be isolated from the main power supply before powering up the motor drive. To use an oscilloscope with the kit, it is safer to isolate the DC supply AND the oscilloscope. This prevents a shock from occurring as a result of touching any single point in the circuit, but does NOT prevent shocks when touching two or more points in the circuit.

An isolated AC power supply can be constructed using an isolation transformer and a variable transformer. An example of an isolation circuit in a Triac-based application is shown in figure 13. Although this application note was written for Triac, the isolation constraints still apply for switching semiconductor devices such as MOSFETs.

Note: Isolating the application rather than the oscilloscope is highly recommended in any case.

Figure 12. Example of isolation circuit for Triac-based application

9.2 Hardware requirements

The following items are required to run a permanent magnet synchronous motor with the STEVAL-IHM021V2 and “STM32 PMSM FOC SDK v3.0”:

- The STEVAL-IHM021V2 board
- Any available STM32-based control stage featuring a motor control connector (e.g. STM32100B-EVAL)
- A high-voltage insulated AC power supply up to 230 Vac
- A J-link programmer (not included in the package)
- A J-link insulating board (not included in the package)
- A 3-phase brushless motor with permanent magnet rotor (not included in the package)
- An insulated oscilloscope (as necessary)
- An insulated multimeter (as necessary)

9.3 Software requirements

To customize, compile and download the “STM32 PMSM FOC SDK v3.0” motor control firmware, the IAR tool “EWARM v6.10” (or later) must be installed. The free, 32 k limited version (referenced as the “KickStart” version) is available for downloading at:

<http://supp.iar.com/Download/SW/?item=EWARM-KS32-442A>.

Web distribution of “STM32 PMSM FOC SDK v3.0” can be downloaded from:

http://www.st.com/internet/com/SOFTWARE_RESOURCES/SW_COMPONENT/FIRMWARE/stm32_pmsm_foc_motorcontrol_fwlib.zip

The ST MC Workbench PC configuration tool for “STM32 PMSM FOC SDK v3.0” can be downloaded from:

http://www.st.com/internet/com/SOFTWARE_RESOURCES/TOOL/CONFIGURATION_UTILITY/motorcontrol_workbench.zip

Refer to user manual UM1052 “STM32F103xx or STM32F100xx PMSM single/dual FOC SDK v3.0” for detailed information about “STM32 PMSM FOC SDK v3.0”

9.4 Configuration of STM32 PMSM FOC SDK v3.0 for the STEVAL-IHM021v2

When using the ST MC Workbench configuration PC tool, the following parameters should be set in the “Power stage” section:

Table 4. ST MC Workbench configuration PC tool: power stage parameters

Parameter	STEVAL-IHM032v1 default value	Unit
ICL Shutout	Disabled	
Dissipative brake	Disabled	
Bus voltage sensing	Enabled	
Bus voltage divider	125	
Min rated voltage	60	V
Max rated voltage	380	V
Nominal voltage	325	V
Temperature sensing	Enabled	
$V_0^{(1)}$	1055	mV
T_0	25	°C
$\Delta V/\Delta T^{(1)}$	22	mV/°C
Max working temperature on sensor	70	°C
Overcurrent protection	Enabled	
Comparator threshold	0.5	V
Overcurrent network gain	0.45	V/A
Expected overcurrent threshold	1.11	A
Overcurrent feedback signal polarity	Active low	
Overcurrent protection disabling network	Enabled	
Overcurrent protection disabling network polarity	Active high	
Current sensing	Enabled	
Current reading topology	Three shunt resistor	
Shunt resistor(s) value	0.45	Ω
Amplifying network gain	2.9	
T-noise	1250	ns
T-rise	1250	ns
Power switches: min dead-time	500	ns
Power switches: max switching frequency	50	kHz

Table 4. ST MC Workbench configuration PC tool: power stage parameters

Parameter	STEVAL-IHM032v1 default value	Unit
U,V,W driver: high side driving signal	Active high	
U,V,W driver: low side driving signal complemented from high side	Disabled	
U,V,W driver: low side driving signal polarity	Active low	

1. These values are computed for $V_{dd_micro} = 3.3\text{ V}$

10 References

This user manual provides information on the hardware features and use of the STEVAL-IHM021V2 demonstration board. For additional information on supporting software and tools, refer to the following:

- STD5N52U datasheet
- L6390 datasheet
- <http://www.st.com/mcu/> web site, which is dedicated to the complete STMicroelectronics microcontroller portfolio.

11 Revision history

Table 5. Document revision history

Date	Revision	Changes
10-Nov-2011	1	Initial release.

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