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BLDC MOTOR TESTBENCH

Developed with STM32 Microcontroller.

Technology and Communication
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ABSTRACT

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Brushless DC motors contribute to a vast number of applications nowadays. For novice engineers, understanding the principle of a working motor would be a valuable experience encouraging their future careers. This project implemented a beginner-friendly library for controlling a BLDC motor in an STM32 environment, with the working principle of the motor and a simple test bench for the project.

A NUCLEO-L152RE development board was chosen as the microcontroller unit. The used motor was a Nanotec DF45M024053-A2 BLDC motor and an X-NUCLEO-IHM07M extension board was chosen as its driver. A specific library for operating and basic testing the motor was developed using Atollic TrueSTUDIO for STM32 9.3.0 IDE, which included the bare metal programs for operating the microcontroller and their application in driving the motor.

The testbench was designed with a simplified setup and real-time data acquisition capability, making it suitable for students with different technical knowledge levels. The testbench was tested using speed, load, and efficiency parameters, providing practical insights into BLDC motor behaviours. The results show the efficacy of the testbench in making it an attractive option for educational purposes with the resources of an average laboratory.

Keywords BLDC motor, brushless, testbench, STM32, and documentation

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LIST OF ABBREVIATIONS

BLDC	Brushless Direct Current
CPU	Central Processing Unit
CMSIS	Cortex Microcontroller Software Interface Standard
IDE	Integrated Development Environment
GPIO	General Pin Input/Output
LED	Light-emitting Diode
EMF	Electromotive Force
PWM	Pulse Width Modulation
CW, CCW	Clockwise, Counter-Clockwise
RPM	Round Per Minute

1 INTRODUCTION

Brushless direct current (BLDC) motors contribute a large number of applications in today's world, ranging from big industrial systems to small household gadgets such as mini electronic brushes. However, there is a gap in educational resources for students studying BLDC motors: traditional pedagogical approaches often focus on theoretical knowledge, diagrams, and simulations, but may lack practical experience.

The scope of this thesis aims to encourage other students in VAMK to pick up a follow-up project with BLDC, which is based on this basic motor controller program (or template) with a STM32 microcontroller. The aim of this project is to develop a simple, affordable, and user-friendly testbench to enhance students' learning experience. The testbench will enable students to explore the operation, control, and performance characteristics of BLDC motors through practical experimentation, providing a deeper understanding of the technology. For operating this template system, students need to understand the working principle of the motor, how to control the microcontroller with understanding of so-called registers and system testing with laboratory equipment.

This project serves as a template for controlling a BLDC motor, with detailed instructions to operate the system. This can be used on any course with STM32 microcontroller related, for students to develop other projects.

The following thesis is organized to provide a thorough analysis of the conception, creation, and application of a simplified testbench for a specific BLDC motor. To make it easier to explore the research, it is divided into multiple chapters:

Chapter 1: Introduction

The introduction presents the problem and background on BLDC motor, and the significance of its testbench in education.

Chapter 2: Literature Review

This chapter give a comprehensive review of relevant literature on brushless DC motors and testbenches. Present the explanation of the fundamental principles of brushless DC motors the role for testbench in motor testing.

Chapter 3: Methodology

Detailed description of the experimental setup and testbench design and explanation of the data acquisition and measurement instruments are reviewed. Description of the motor under test and the variables to be measured.

Chapter 4: Test and Measurement

Describe the motor behaviours under tests and the variables to be measured and discuss the data collection process. Presentation of the results and analysis obtained from the testbench is provided.

Chapter 5: Conclusion

Briefly state the outcome of the project as well as the summary of the main findings and their significance. Some recommendations for future research are given.

References and Appendices

2 LITERATURE REVIEW

The theoretical concepts behind the research are described in this section of the thesis. The BLDC motor and the frame of its testbench are the two basic components.

2.1 BLDC Motor

The BLDC motor follows the same principle as traditional brushed motors. Both types of motors rely on the interaction between magnetic fields to generate motion.

2.1.1 Basics of Electric Motor

A DC motor converts electrical energy into mechanical energy by rotation (see Figure 1) and comprises two parts: the stationary part “stator” and the moving part "rotor”. The attraction force between two magnetic fields enables the rotation to occur. Usually, one of the two is generated by a permanent magnet while the other is generated through an electromagnet, or solenoid, carrying a current.

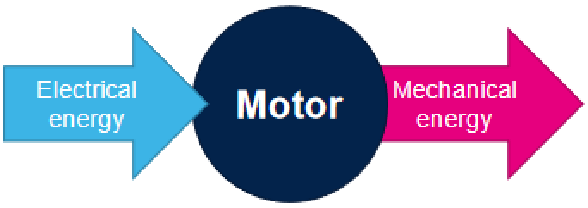


Figure 1. What does an electric motor do? /1/

The phase relation between the rotor and stator magnetic field (or load angle) is always greater than 0° to keep the rotation; in case of reverse motion, negative angle is applied. The torque depends on both current and that load angle. There will be a back electromotive force opposing the motion itself, but not mentioned in providing the basic concept as below:

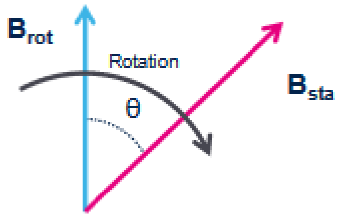


Figure 2. Output torque related to load angle and current /1/

The formula for the torque applied on the rotor:

$$\tau \propto B_{rot} \cdot B_{sta} \cdot \sin(\theta) \quad (1)$$

Where:

τ is the output torque. (Nm)

B_{rot} is the magnetic field generated by the rotor. (Tesla)

B_{sta} is the magnetic field generated by the stator. (Tesla)

θ is the load angle between the two magnetic field. (degree)

The maximum output torque, and then the maximum efficiency, is obtained when the load angle is 90°.

The main difference between brushed and brushless motors lies in how they achieve this interaction and manage the commutation process:

Brushed motors uses a commutator and brushes to reverse the polarity of the rotor magnets, creating a rotating magnetic field. This physical contact between brushes and the commutator is what causes wear and limits their efficiency.

Brushless DC motor achieves commutation electronically, using sensors or sensor-less technology to determine the rotor position. This allows precise control of the motor and eliminates the need for physical contact, improving efficiency and reducing wear and tear. /3/

In the scope of this project, only brushless DC motor is investigated.

2.1.2 Brushless DC Motor

The most common version of BLDC motor is the three-phase. Its rotor contains a permanent magnet, and the stator consists of three solenoids positioned 120 degrees from each other. The stator electromagnetic field is continuously adjusted in accordance with the position of the rotor, attempting to maintain the load angle as near to 90° as possible.

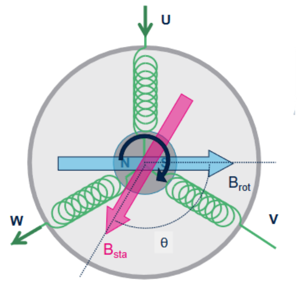


Figure 3. Structure and working principle of BLDC motor

To operate the three phase BLDC motor, six-step driving algorithm is applied and it does require the precise position of the rotor and the intended rotating direction. In a sensor-less motor, BEMF feedback is used to determine the proper sequence. On the other hand, in the scope of this project, a sensored motor with hall-effect sensors is used.

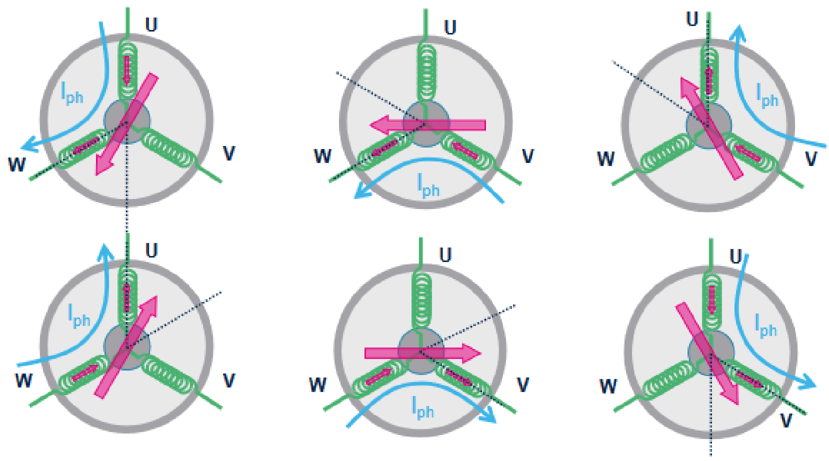


Figure 4. 6-step driving with rotor position /1/

In the normal state, none of the coils is energized and the rotor is stationary. Applying voltage across two ends of the solenoids generates a combined magnetic field with its vector along the pointer (see Figure 4), which causes the rotor (with permanent magnet) to turn to align itself with said magnetic field.

There are six ways to energize the pair of solenoids, hence the name “six-step algorithm”. Each pair yields magnetic fields in different directions, which is 60 degrees apart from each other. By combining right coils at proper time, the motor is commutated and rotating. /6/

2.2 Simple Testbench for BLDC Motor

A testbench for a Brushless DC (BLDC) motor should involve verifying its functionality, performance, and behaviours under various conditions. /7/. A simple testbench for a BLDC motor controlled by a microcontroller through a driver can consist of components described in the following subsections:

2.2.1 Physical Connection

The integrity of the motor design must be ensured by setting it up according to the manufacturer instructions, followed by basic measurement with a multimeter and oscilloscope. /8/

The BLDC motor is connected to the Motor Driver as described below:

- Identify the motor wires. A typical BLDC motor has three main wires, often color-coded, or labelled as U, V, W. Also identify the output terminals of the motor driver.

- Connect the U, V, W motor wires to the corresponding U, V, W output terminals on the motor driver. Ensure correct polarity and secure connections (using terminal blocks, soldering, or other appropriate methods) according to the manufacturer datasheet and/or instructions.

The Motor Driver is connected to the power supply as follows:

- Ensure that the power supply meets the voltage and current requirements specified for both the motor and the motor driver.
- Connect the power supply to the input terminals of the motor driver, following the polarity and voltage specifications.

The microcontroller Interface is connected by the following steps:

- Connect the control lines from the microcontroller to the input control pins of the motor driver. It may include connections for functions like speed control, direction control or emergency control.
- If the motor uses Hall-effect sensors for commutation, connect them to the corresponding pins on the motor driver according to the datasheets.
- Instead, if encoders or other feedback sensors are used to measure speed, position, or other parameters, connect these to the appropriate input pins on the motor driver or microcontroller.

It is very important that grounding and shielding are performed with utmost care:

- Ensure proper grounding for all components to avoid ground loops and signal interference. Connect the ground of the power supply, motor driver, microcontroller, and any other components together.
- Shielding: Use shielded cables for connections, especially for sensors and feedback lines, to minimize interference.

Basic tests are performed to ensure the functionality of the motor and driver with the microcontroller.

2.2.2 Microcontroller Interface

The right microcontroller for the project must be selected and the communication between the microcontroller and the motor driver is set up to control the speed, direction, and other parameters of the motor. /9/

A microcontroller or development board that is most suitable for interfacing with the motor driver is selected. Common choices include Arduino, Raspberry Pi, STM32 for hobbyists, depending on the project requirements and the availability for support.

Pinout configuration is checked during setting up phase:

The pins on the microcontroller that will be used to control the motor driver and their functionalities are checked.

Before running the motor, the microcontroller should be calibrated if needed to ensure the signal output matches the motor driver's expectations.

The below aspects should be check in the software development process:

Appropriate libraries or code that allows the microcontroller to communicate with the motor driver, if available, or a simple library is developed to control the motor speed, direction, and other parameters.

2.2.3 Test Control

This step defines various designed tests for the motor under different situations. Developed codes allow users to trigger these tests systematically and control the motor based on the defined scenarios; also, to troubleshoot the motor with that simple control test system.

Test Scenario Design includes implementing a routine to test the responsiveness of the motor to different commands. The commands could be the following:

- Speed control: The ability of the motor to maintain different speeds by varying the input.
- Torque and Load testing with different values applied to the motor and observing how it handles them under recommendation of manufacturer.
- Direction control by ensuring the motor can change its direction accurately and smoothly.
- Data Logging mechanisms for recording important parameters during tests (speed, current, voltage, etc.).

2.2.4 Documentation

A simple documentation version for the BLDC motor test bench should cover all the hardware, software components, the manual for executing the tests, the result of different test scenarios, and a comprehensive analysis. (Inspired from Wireless Testbench Documentation, MathWorks, 2023.)

Test Setup is as follows:

- Equipment used: BLDC Motor, Motor Driver, Microcontroller, Power Supply, Sensors (if used), Testing Tools.
- Physical connection: The motor is connected to the motor driver as manufacturer instructions.
- Microcontroller Interface uses specific pins on the microcontroller to control the motor driver for speed, direction, etc.

Test Scenarios are described in the documentation:

- Speed Control Testing: Verifing motor response at various speeds.
- Torque and Load Testing: Evaluating motor's ability to handle increasing loads.

- Direction Control Testing: Testing the accuracy and smoothness of direction changes.
- Efficiency Testing: Observing motor efficiency under different loads and speeds.
- Acceleration and Deceleration Testing: Examining motor response during speed changes.

Observations, Result and Analysis are concluded after the tests, as well as a brief conclusion

3 METHODOLOGY

In this section, the resources used in the project are reviewed and the conducting methods are detailly described.

3.1 Resources

The resources used, apart from personal work and online materials, can be categorized into three main parts**:** Laboratory Facilities, Hardware Components and Software.

3.1.1 Laboratory Facilities

The project was developed in Technobothnia Laboratory, in Embedded Systems Engineering section, and all the measuring equipment, tools and infrastructure can be found there. The main equipment used in the project was:

- MSOX2012A Mixed Signal Oscilloscope with 2 Analog Plus 8 Digital Channels
- Fluke 179 Multimeter
- PS3010L Adjustable DC Power Supply

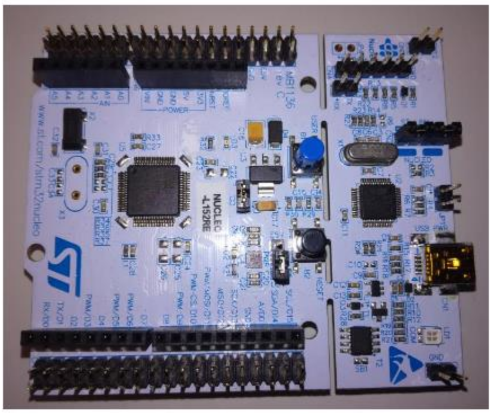
Some other basic equipment and electrical components were utilized to ensure the quality of the progress.

3.1.2 Hardware Components

The chosen hardware in the project consists of a Nucleo-L152RE Development board serving as a controller; an X-NUCLEO-IHM07M1 motor expansion board acting as a motor driver and a DF45M024053 Nanotec Brushless DC motor.

The Nucleo-L152RE development board was introduced in the STM32 Nucleo-64 board family produced by STMicroelectronics. With a STM32 microcontroller, which is extensively utilized in real-world embedded system applications and has a 32-bit ARM CPU core, this development board is suitable for this project since it is an inexpensive and flexible choice for research and building prototypes.

- STM32 microcontroller in LQFP64 package
- 32-bit processor
- 32 MHz clock FCLK
- 512 kB of Flash memory
- 80 kB of RAM
- 16 kB of true EEPROM
- USB communication (LD1)
- user LED (LD2)
- power LED (LD3)
- Two push-buttons: USER and RESET
- Two types of extension resources – Arduino™ Uno V3 connectivity
- ST morpho extension pin headers for full access to all STM32 I/Os
- Flexible board power supply: – USB VBUS or external source (3.3 V, 5 V, 7 - 12 V)
- On-board ST-LINK/V2-1 debugger and programmer with SWD connector
- Selection-mode switch to use the kit as a standalone ST-LINK/V2-1



https://www.st.com/resource/en/user_manual/dm00105823.pdf

Figure 5. Nucleo L152RE Development board

X-NUCLEO-IHM07M1 is a three-phase brushless DC motor driver expansion board based on the L6230 driver chip and produced by the same manufacturer STMicroelectronics. It provides an affordable and easy-to-use solution for driving a three-phase brushless DC motor and it is compatible with the ST Morpho connectors, which can be stacked with other boards onto a single STM32 Nucleo board. /10/

DF45M024053-A2 BLDC Motor, produced by Nanotec Electronic GmbH & Co. KG, is available with an integrated inductive 2-channel encoder with a resolution of 1,024 CPR and Hall sensors. It is suitable in the scope of this project due to its smooth and stable operation and its rated speed up to 5260 rpm is perfect for any follow-up project /11/. It is a 3-phase BLDC motor and contains 16 poles of permanent magnet in the rotor part, and 12 stator windings.

3.1.3 Software

The coding part was done with help of Atollic TrueStudio for STM32 9.3.0, a commercial C/C++ IDE built on Eclipse by STMicroelectronics. It provides professional extensions, features and utilities that are well compatible with products by the same manufacturer. /12/

The project software was built on the C Embedded Project template inside the TrueStudio IDE, which contains the Cortex Microcontroller Software Interface Standard library (CMSIS) as the project foundation.

The RealTerm Serial terminal program was used to capture data transmitted from the microcontroller for debugging and transmitting data for the testbench. /13/

3.2 Implementation

The base of the testbench consists of two parts: system building and coding for motor testing.

3.2.1 System Building

The rough connection of the system was illustrated as the following diagram:

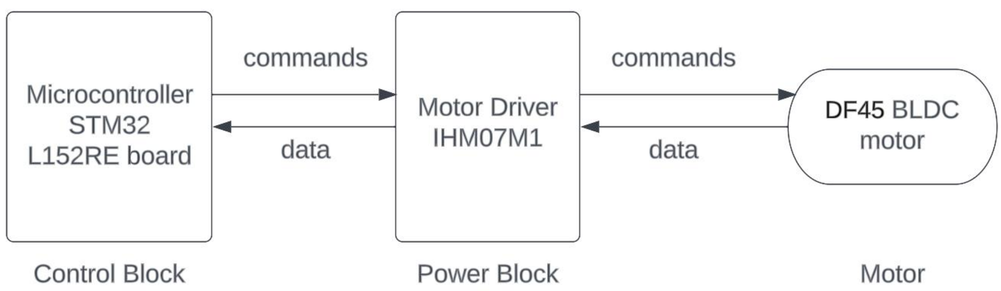


Figure 6. BLDC motor control system

This system diagram followed as the User manual for IHM07M1 from STMicroe-lectronics. /14/

The motor driver IHM07M1 was connected directly onto the Nucleo L152RE development board by ST-morpho connectors. The hardware setting of the STM32 Nucleo board followed the jumper settings in the User manual mentioned above.

The circuit diagram for the L6230 motor driver and the Hall sensors are shown in APPENDIX 1 and 2.

The motor was connected to the driver with the connections as referenced in the motor datasheet and shown in Table 1.

Table 1. Motor and Driver connection pins

X-Nucleo-IHM07M1 3-phase motor driver		DF45M024053 A2 BLDC motor
J3	A+	H1
	B+	H2
	Z+	H3
	5V	VCC
	GND	GND
J2	OUT1	U
	OUT2	V
	OUT3	W

3.2.2 Testing Program

The method for controlling the motor driver used in this project was directly accessing peripheral function registers by the C language. This meant that no third-party library of functions was used, providing flexibility in control and customization for the project. /15/

The testing program was designed into individual functions which are located in separate code files. After generating the template C embedded file from Atollic TrueStudio, several created files with *baremetal* (headers and c sources) name were used to set up early testing; for example, accessing function registers associated with the GPIO ports for LED test.

4 TEST AND MEASUREMENT

4.1 Functionalities

Following the mentioned method in “Testing program”, several code files were created to test fundamental functionalities of the motor.

4.1.1 Back EMF and Sensors Signals

The objective here was to verify the motor hall sensors and its solenoids functionality by capturing those signals emitted from the motor.

The back EMF signal was tested from the motor itself, and the result yielded the same as mentioned in the motor datasheet. (see APPENDIX 3)

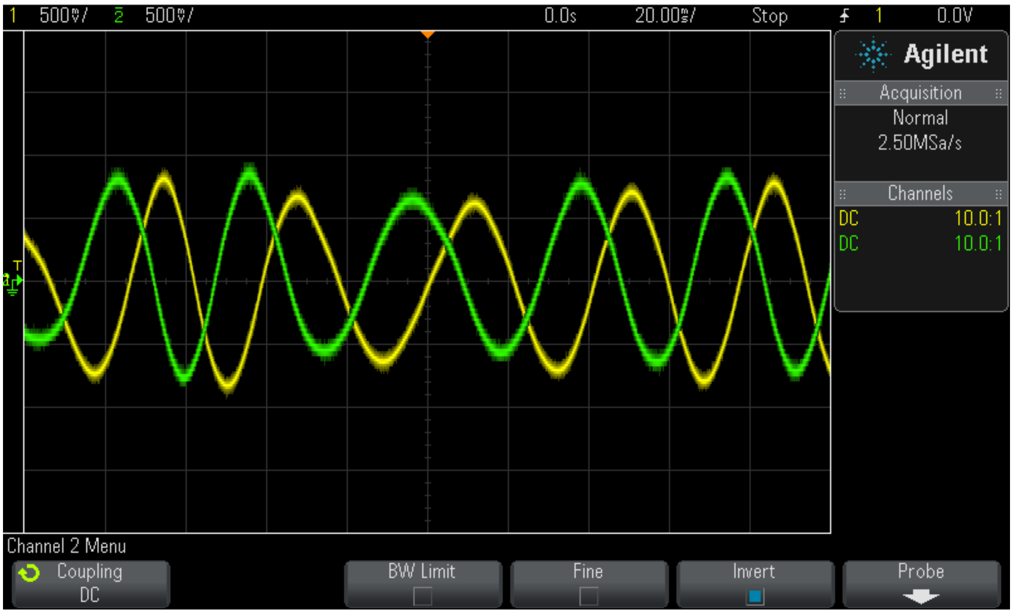


Figure 7. Back EMF signal from testing

There are three pins connected from the oscilloscope to the motor:

- **GND** to PIN3 or W port
- **1** to PIN2 or V port
- **2** to PIN1 or U port

Yellow (1) was the V-W line. Green (2) was inverted to match the W-U line. This was the counter CW rotation; the CW rotation should be as expected from the graph.

On the other hand, Hall sensors data were captured in the RealTerm Terminal.

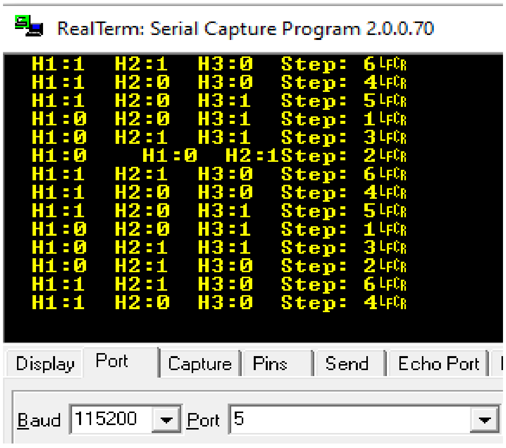


Figure 8. Hall signal data captured in RealTerm

A separated code file include function to visualize the signal data was used:

- H1, H2, H3 are hall sensor signal 1,2 and 3 respectively.
- Steps from 1 to 6 are the six combinations of signal (reference from motor datasheet), with H1 is the most significant bit, H3 is the least significant bit. Those steps follow the same sequence as expected.

The two tests above were performed with manually rotated motor.

4.1.2 Driver Output Pins

The objective was to test the functionality of the PWM pins from the X-Nucleo-ihm07m1 driver by measuring their outputs.

There are three pins marked as IN1, IN2 and IN3 in the PWM section of the driver circuit (see /14/), which are connected to PA8, PA9 and PA10 on the microcontroller. PC10, PC11 and PC12 are their enabling pins, or switch, respectively.

In the six-step algorithm, two out of three solenoids in a combination should have a specific directional electric current at precise time to drive the motor; thus, testing the control signal beforehand is crucial.

	A			B		OUT1	Y1
IN1	PA8	LOW	EN1	PC10	LOW	3V	
IN1	PA8	LOW	EN1	PC10	HIGH	LOW 0V	
IN1	PA8	HIGH	EN1	PC10	LOW	3v	
IN1	PA8	HIGH	EN1	PC10	HIGH	HIGH 24V	

A			B			OUT2	Y2
IN2	PA9	LOW	EN2	PC11	LOW	3V	
IN2	PA9	LOW	EN2	PC11	HIGH	LOW 0V	
IN2	PA9	HIGH	EN2	PC11	LOW	3V	
IN2	PA9	HIGH	EN2	PC11	HIGH	HIGH 24V	

A			B			OUT3	Y3
IN3	PA10	LOW	EN3	PC12	LOW	3V	
IN3	PA10	LOW	EN3	PC12	HIGH	LOW 0V	
IN3	PA10	HIGH	EN3	PC12	LOW	3V	
IN3	PA10	HIGH	EN3	PC12	HIGH	HIGH 24V	

Figure 9. Truth table for L6230 driver pinout

The above Truth table was tested using a multimeter and oscilloscope:

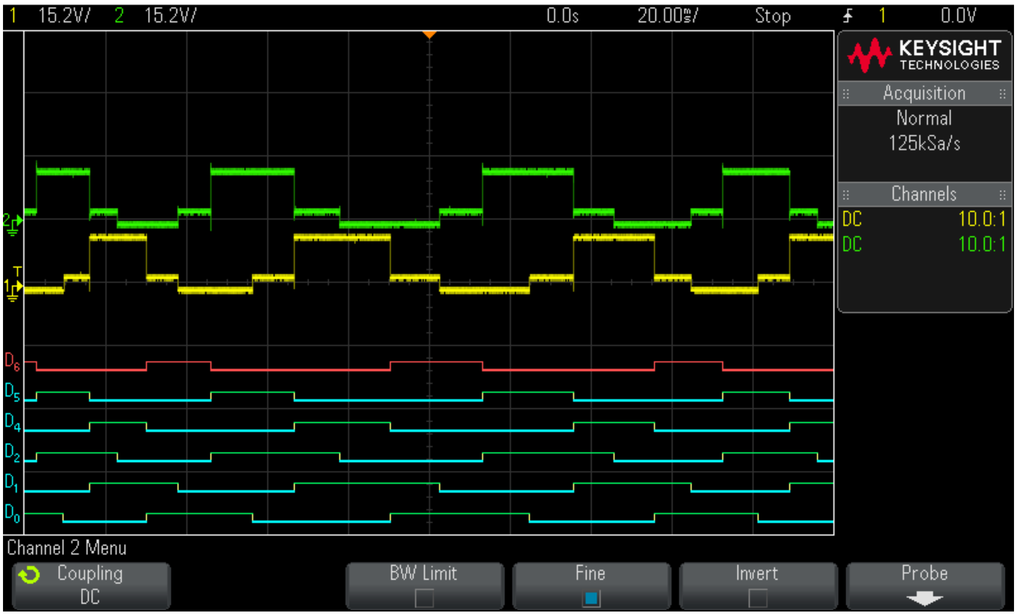


Figure 10. Output signals to the motor

- D0: PA15 or Hall1 port
- D1: PB3 or Hall2 port
- D2: PB10 or Hall3 port
- D4: PA8
- D5: PA9
- D6: PA10
- Ch1: OUT1
- Ch2: OUT2

The test was performed by manually rotating the motor, and the result was as expected from motor datasheet (APPENDIX3, wiring diagram).

Following tests were executed with the same wiring connections to oscilloscope as the previous test.

4.1.3 Motor Test Scenarios

This section presents different simple test scenarios for the BLDC motor.

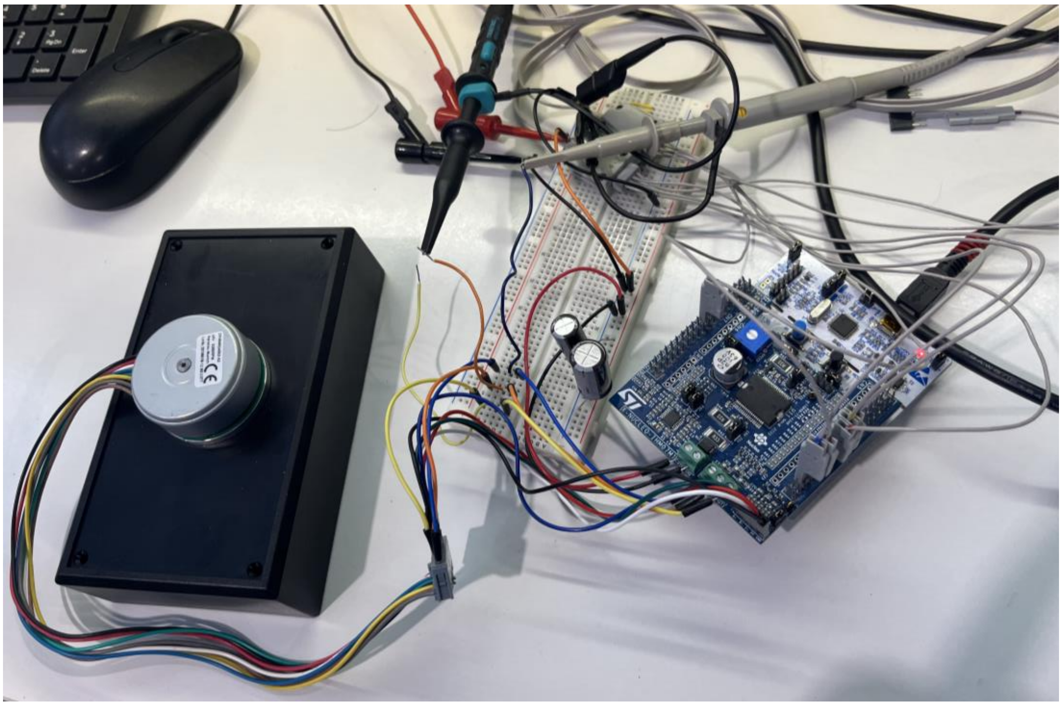


Figure 11. Motor test system

Two capacitors were added in parallel to the system to for smoother start and stop rotation.

Firstly, the motor was tested at full speed with the program developed to test the 6-step algorithm. A simple parameter to change the direction of the motor was also applied.

Figure 12. Motor at Full Speed, CW

Figure 13. Motor at Full Speed, CCW

Theoretically, the motor speed could be calculated based on the frequency of any Hall signal, with the formula below:

$$\text{Motor}_{\text{speed}}(RPM) = 60 \times \frac{2}{16} \times f_{h\_sensor} = \frac{15}{2} \times f_{h\_sensor} \qquad (2)$$

Where

60 is the number of seconds in one minute

2 is the factor to convert electrical cycles to revolutions

16 is the number of magnetic poles

f_{h_sensor} is the electrical frequency of any Hall signals. (Hz)

The maximum speed stated in the datasheet was 6700 RPM and the measured speed was 6355 RPM. There was a drop in the output voltage compared to the input voltage (21 to 24) that caused the difference.

Next, a PWM signal was applied to control the output voltage, and the motor speed linearly changed based on the duty cycle.

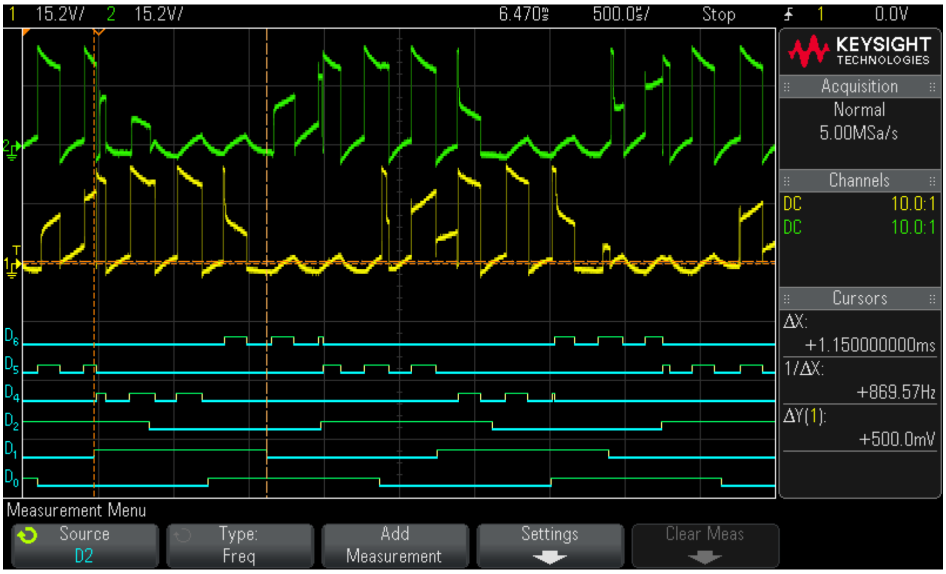


Figure 14. 50% duty cycle, 3260 RPM

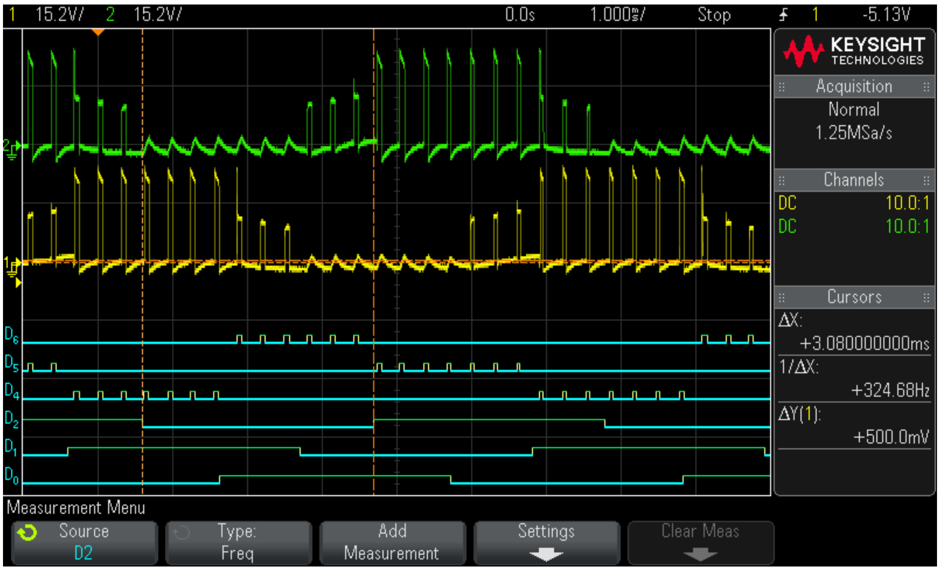


Figure 15. 20% duty cycle, 1217 RPM

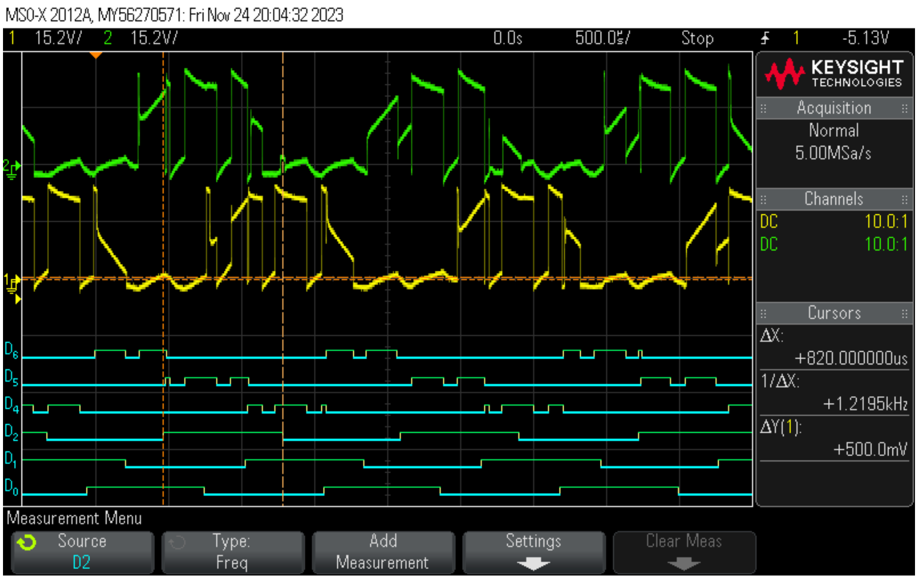


Figure 16. 70% duty cycle, 4573 RPM

A function was made to control the motor speed with a PWM duty cycle and its visualisation on the terminal. The function parameter can be changed for acceleration, deceleration, and direction testing.

Different voltages and load were applied to observe the motor behaviours, and it ran as intended.

External meters were used to verify the capture results in speed, voltage, load, and torque.

4.2 Result and Analysis

Despite mistakes were found during the development process of the testbench, the motor could be set up running for different tests and yields the results as theoretically expected from relevant datasheets and formulas.

The developed program serves with its basic functions to test the motor and can be further developed for future projects used with this specific motor and driver. The testbench was completed using a minimum amount of laboratory equipment, ensuring that any student can rebuild the testbench and simulate their own test scenarios.

Important notes were included in the developed code, with details test results, there were some differences between the theoretical values and each measured value; however, these were insignificant.

Further development could be a program where users choose the desired RPM, and the motor automatically reacts to maintain that RPM on different loads.

5 CONCLUSION

From the measurements and tests, the conclusions reached was as follows:

- The 6-step algorithm was controlled and drove the motor running as expected.
- The motor speed linearly increased and decreased with the applied voltage and the duty cycle of the PWM control signal.
- The testbench software simulated different scenarios with a minimum budget and equipment, but still ensured the functionalities of the motor.

This thesis successfully developed a practical testbench for a brushless DC motor and addressed the lack of practical resources for one in future Embedded Systems related courses. Future projects can be developed from this project, using the bare-metal programs for STM32 Arm microcontrollers, and improvising the structure of this testbench.

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/10/ X-NUCLEO-IHM07M1. n.d. STMicroelectronics. Accessed 7/11/2023. https://www.st.com/en/ecosystems/x-nucleo-ihm07m1.html

/11/ DF45 - Brushless DC flat motor. n.d. Nanotec. Accessed 11/11/2023. https://en.nanotec.com/products/1544-df45-brushless-dc-flat-motor

/12/ TrueSTUDIO. n.d. STMicroelectronics. Accessed 11/11/2023. https://www.st.com/en/development-tools/truestudio.html

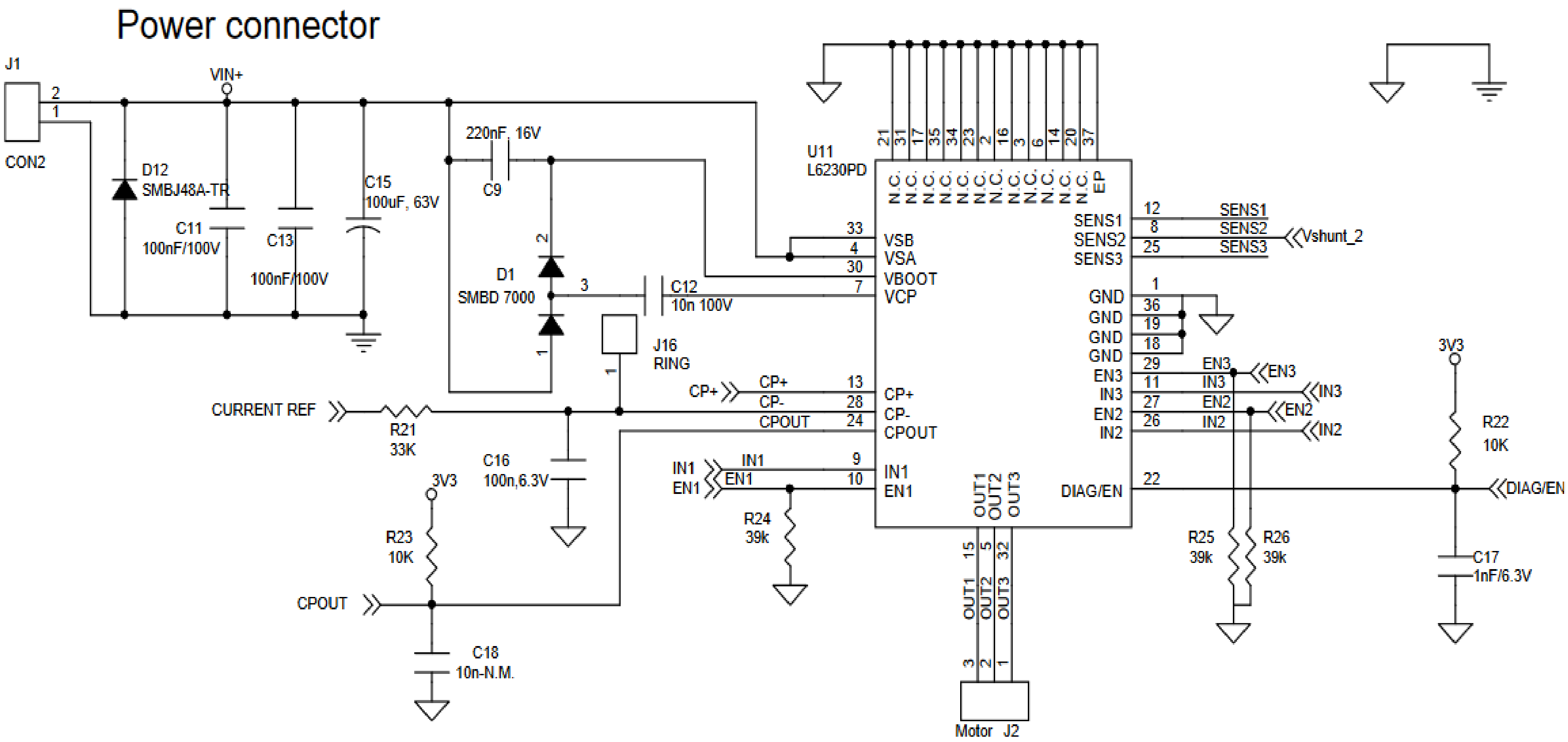
/13/ RealTerm: Serial/TCP Terminal. n.d. SourceForge. Accessed 11/11/2023. https://sourceforge.net/projects/realterm/

/14/ Getting started with X-NUCLEO-IHM07M1. 2021. STMicroelectronics. Accessed 14/11/2023. https://www.st.com/resource/en/user_manual/um1943-getting-started-with-the-xnucleoihm07m1-motor-driver-expansion-board-based-on-the-l6230-for-stm32-nucleo-stmicroelectronics.pdf

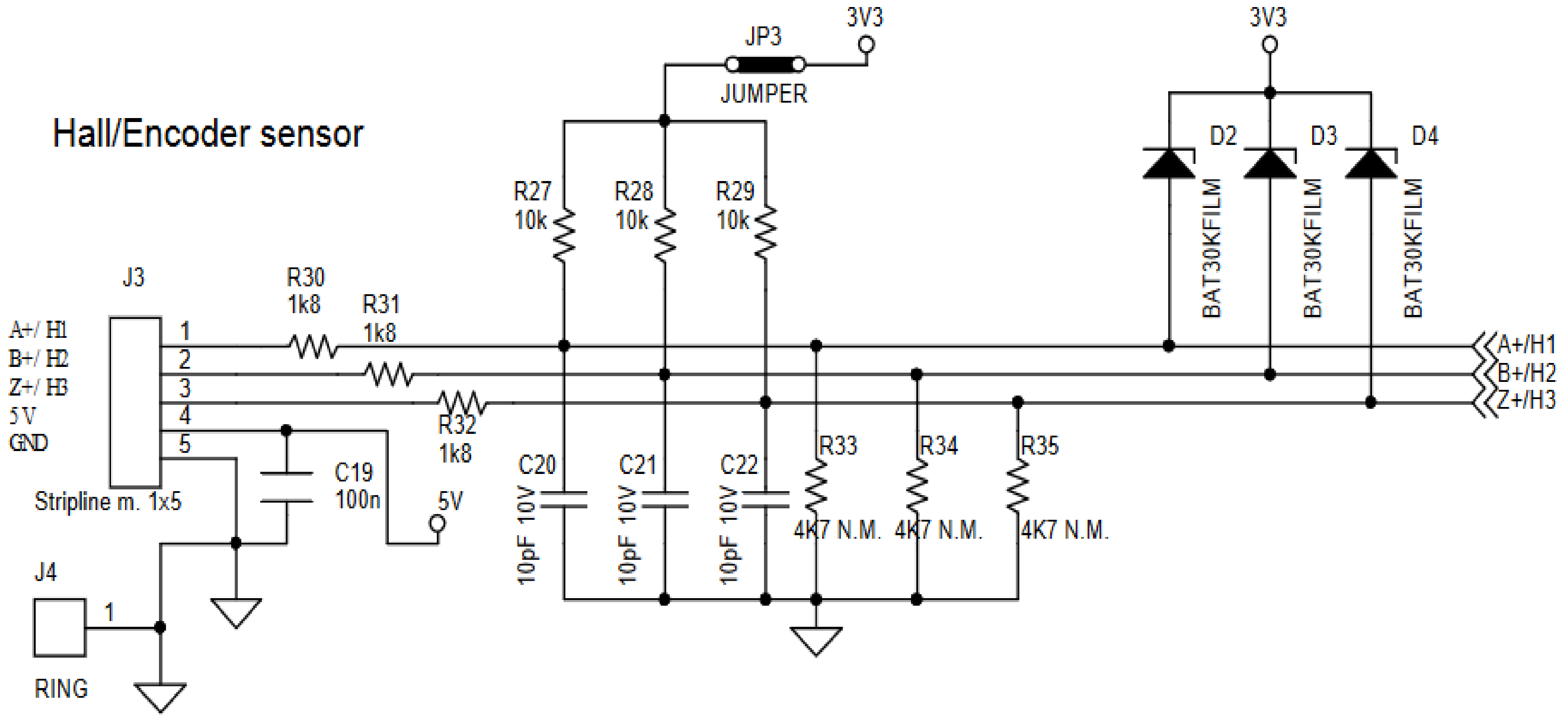
/15/ Mazidi Muhammad Ali. 2018. STM32 Arm Programming for Embedded Systems, p.4. MicroDigitalEd.

APPENDIX 1

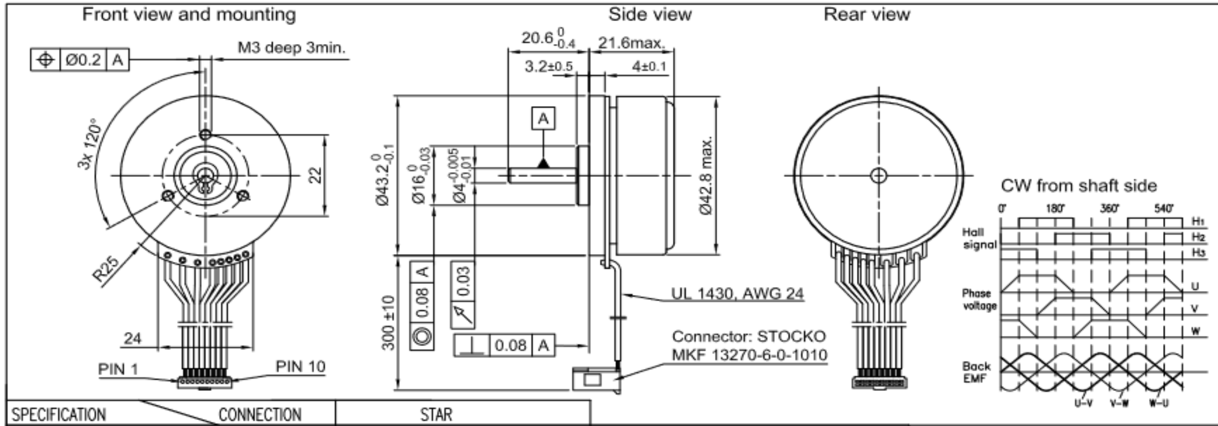
L6230 DMOS driver for three-phase brushless DC motor



APPENDIX 2

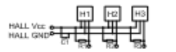

Hall/Encoder sensor
J3
Stripline m. 1x5
A+/ H1
B+/ H2
Z+/ H3
5V
GND
1
2
3
4
5
R30
1k8
R31
1k8
R32
1k8
C19
100n
5V
J4
1
RING
JP3
JUMPER
3V3
R27
10k
R28
10k
R29
10k
C20
C21
C22
10pF 10V
10pF 10V
10pF 10V
R33
R34
R35
4K7 N.M.
4K7 N.M.
4K7 N.M.
3V3
D2
D3
D4
BAT30KFILM
BAT30KFILM
BAT30KFILM
A+/H1
B+/H2
Z+/H3

APPENDIX 3



Connector : STOCKO MKF 13270-6-0-1010		Wire Color
PIN1	U	Grey
PIN2	V	Brown
PIN3	W	Yellow
PIN4	GND	Black
PIN5	Hall 2	Green
PIN6	Hall 1	Blue
PIN7	Hall 3	White
PIN 8	VHall 3.3...18VDC	Red

HALL CONNECTION

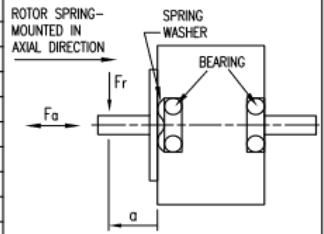


C1 -- 0.1uF (25V)
R1/ R2/ R3 -- 10kΩ

SPECIFICATION \ CONNECTION	STAR
NO. OF POL./PHASE	16/3
VOLTAGE RATED (VDC)	24
NO LOAD CURRENT (A)	<0.3
CURRENT RATED/PEAK (A)	2.36/ 7.0
RESISTANCE/PHASE TO PHASE (Ohms) @20°C	0.8 ±10% C
INDUCTANCE/PHASE TO PHASE (mH) @1KHz	0.33 ±20% C
TORQUE RATED/PEAK (Nm) [lb-in]	0.084/0.25 [0.74/2.22]
TORQUE CONSTANT (Nm/A)	0.0335
POWER RATED (W)	50
SPEED RATED/NO LOAD (RPM)	5260/6700 B
ROTOR INERTIA (Kg-m²) [lb-in²]	1.35x10⁻⁵ [0.046]
WEIGHT (Kg) [lb]	0.12 [0.26]

TEMPERATURE RISE: MAX.80°C	
AMBIENT TEMPERATURE -20°~ 50°C	1
INSULATION RESISTANCE 100 MOhm (UNDER NORMAL TEMPERATURE AND HUMIDITY)	
INSULATION CLASS B 130° [266°F]	
DIELECTRIC STRENGTH 500VAC FOR 1 MIN. (BETWEEN THE MOTOR COILS AND THE MOTOR CASE)	
AMBIENT HUMIDITY MAX. 85% (NO CONDENSATION)	

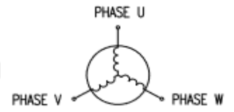
PERMISSIBLE RADIAL+AXIAL FORCE



AXIAL-FORCE Fa (N)	Fa=10 max.	
DISTANCE a (mm)	10	
RADIAL-FORCE Fr (N)	28 max.	
	AXIAL	RADIAL
SHAFT PLAY (mm)	0.14	0.02
AT LOAD MAX: (N)	4	4

WIRING DIAGRAM							
	FUNCTION	Dir. ⟷					
MOTOR 16 POL.	U	X	HI	HI	X	LOW	LOW
	V	HI	X	LOW	LOW	X	HI
	W	LOW	LOW	X	HI	HI	X
HALL 48 IMPL. REV.	+5V						
	H1	0	0	0	1	1	1
	H2	0	1	1	1	0	0
	H3	1	1	0	0	0	1
	GND						

STAR CONNECTION



REV	DESCRIPTION	DATE	APVD
1	CHANGE AMBIENT TEMP.	16.01.15	J.D.
C	UPDT. DATA	17.10.14	J.D.
B	VALUE CHANGED	08.08.14	J.D.

Nanotec® PLUG & DRIVE

DF45M024053-A2

SCALE FREE	
X	±0.5
1PL	±0.2
2PL	±0.1
ANGLE	±30'

	SIGNATURE	DATE
APVD	G.S.	07.07.14
CHKD		
DRN	J.D.	07.07.14

BRUSHLESS DC MOTOR

DWG.NO DF45M024053-A2