A4964 Sensorless Sinusoidal Drive BLDC Controller Evaluation Board User Manual

Introduction

This user manual describes the operation and use of the APEK4964 evaluation board for the A4964 automotive, programmable BLDC controller. The A4964 is a flexible sensorless, sinusoidal motor controller that drives an external three-phase N-channel MOSFET bridge for easy implementation of a BLDC motor driver. The A4964 can be used as a standalone controller or it can be used in a system with a microcontroller, providing communication to a central ECU and intelligent fault and status handling. The A4964 can provide the supply and watchdog for the microcontroller, as well as a physical interface between a LIN bus network or a supply level PWM signal and the microcontroller. The A4964 can be easily put to sleep or woken up using software commands or signal inputs. In the sleep state, the power consumption can be reduced to a low level.

The motor can be driven using a number of modulation options, from full three-phase sinusoidal drive to two-phase trapezoidal drive and includes overdrive options in the sinusoidal mode.

Commutation between the phases is independent of any position sensor and rotor position detection is achieved by monitoring the motor back-emf (bemf). The integrated sensorless startup scheme provides highly programmable startup options, allowing the A4964 to operate over a wide range of motor and load combinations. It also includes forward and reverse pre-rotation (windmill) detection and synchronization.

Several operational modes are available, including duty-cycle (voltage) control, current (torque limit) control, and closed-loop speed control. Operating mode and control parameters can be altered through an SPI-compatible serial interface.

Integrated diagnostics provide indication of undervoltage, overtemperature, and power bridge faults and can protect the power switches under most short-circuit condition. By monitoring the contents of the status register in the A4964 via the serial interface, any fault conditions present can easily be identified.

The A4964 is fully described in its datasheet, which should be read in conjunction with this user manual.

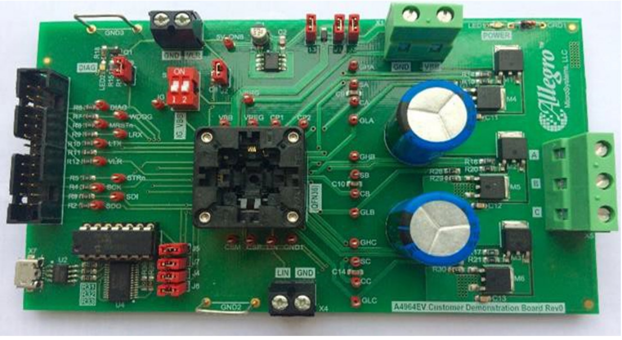

Figure 1: A4964 Evaluation Board

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Evaluation Board Features

The evaluation board is a two-sided FR4 surface-mount board, as shown in Figure 1. This board includes the necessary passive components and connections to provide a complete interface between the required microcontroller and a three-phase BLDC motor using the A4964. The board can also be run without a microcontroller with a suitably programmed A4964 sample. The board requires a single DC power supply between 5.5 V and 50 V. The board does not include any reverse battery or transient clamp circuits. The motor is connected to the board through a high-current three-way connector and the main supply is connected to the board through a high-current two-way connector. Additionally, a USB cable is provided, together with a graphical user interface (GUI) for users to control the motor, to program many of its integrated features, and to read back diagnostic information via the serial interface. A microcontroller is included on the evaluation board to provide improved serial interface communication performance between the PC and the A4964. In particular, this allows the A4964 to be continuously interrogated for data log information and to display that information in real time in the GUI. This should not discourage users from using their own microcontroller to communicate directly with the A4964, and a suitable microcontroller connection is available.

The power section of the evaluation board is designed to demonstrate the functionality of A4964 and has limited load current capability. In the supplied configuration, the board can provide a continuous motor current of ~10 A and a peak motor current of ~20 A for short period in normal room temperature conditions.

Circuit Description

The circuit diagram for the evaluation board is shown in Appendix A. This provides the basic components required to use the A4964 to drive a motor. The motor can be controlled via the serial interface, by using the on-board PWM generator, or via an externally supplied PWM signal input on the LIN terminal. The serial interface control signals can be generated by the GUI provided or by a user-provided processor or controller attached to the SPI connector on the board.

The maximum current limit for the board is determined by the sense resistors. Two 20 mΩ sense resistors in parallel are provided on the board, giving 10 mΩ total sense resistance. The maximum possible current is limited by this resistor to 20 A. The current limit can be changed by changing the sense resistor value using the equation:

$$I_{LIM} - \frac{V_{ILIM}}{R_{SENSE}}$$

where R_{SENSE} is the sense resistor value,
V_{ILIM} is the internally generated threshold voltage, and
I_{LIM} is the limitation current value.

It is recommended to keep the maximum current limit below 20 A for this evaluation board. Lower current limits (higher sense resistor values) can be useful for higher accuracy control of lower power motors. The full circuit schematic is shown in Appendix A, and the component placement and board layout is shown in Appendix B. The function, specification, and selection criteria for the components are listed in Table 2 in Appendix C.

Evaluation Board Setup and Operation

In order to run a motor using the evaluation board, the following items are required:

- USB cable
- A4964 demo board
- External motor supply (5.5 to 50 V)
- USB cable driver and software
- A4964 Serial control GUI software
- Windows® based PC

A typical connection diagram to interface the GUI is provided in Figure 2. The USB cable and GUI provided is not the only interface option to control the A4964 to drive the motor. The A4964 evaluation board can also be used in conjunction with an external microcontroller using serial interface communication or the control can be done in standalone mode by using the LIN input as described previously.

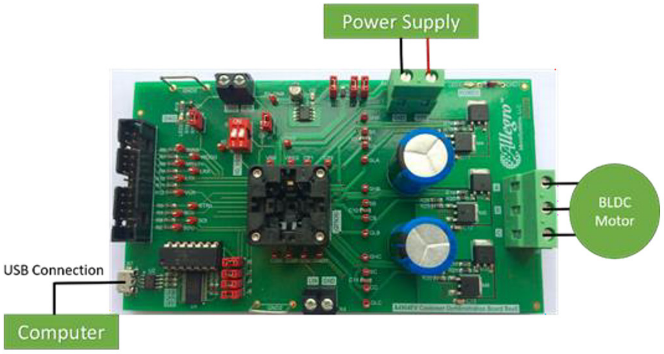


Figure 2: Connection Diagram to Interface the GUI

Evaluation Board Connections

The A4964 evaluation board has six connectors: a two-way screw connector for the main supply, a two-way connecter that provides the logic supply output from the A4964, a three-way screw connector for the motor connection, a two-way screw connector for LIN terminal for standalone mode control, a USB connector to interface to the GUI, and a 16-pin IDC cable connector to interface to an external microcontroller.

Power Connections

Power for the motor phases is provided through the two-way screw connector X1. A positive supply, between 5.5 and 50 V, is connected to X1, labelled VBB. The supply return is labelled

GND at X1. The power source for the motor phase current must be capable of providing the necessary continuous input current at the required input voltage to drive the motor up to the board current limit plus any inrush current. The motor supply voltage must not exceed 50 V in any conditions or permanent damage may occur to the A4964, other components on the board and possibly the motor. The current limit of the supply should initially be set to twice the maximum operating current for the motor being driven.

The A4964 can provide logic voltage levels of either 5 V or 3.3 V to different target devices such as external MCU through X2 connector as long as the provided current does not exceed 70 mA. The logic level of the target device must be connected to the X2 connector at the point, labelled VLR, and the return path must be connected to X2, at a point labelled GND.

Load Connections

A three-phase BLDC motor is connected through the three-way screw terminal, X5, labelled SA, SB, and SC. The current to drive the motor is provided via the three-phase MOSFET bridge from the main supply connected to X1.

Control Connections

The serial interface communication between the A4964 and the Windows® based GUI is provided using a standard USB to micro USB cable by connecting the micro USB end to the connector X7 on the evaluation board and the standard USB connector to the target PC (see Software Installation section for further details).

If an external microcontroller is to be used to communicate directly with the serial interface of the A4964, then the signals STRn, SCK, SDI, SDO, and GND must be connected to terminals 18, 22, 24, 26, and 16 of the connector X3 respectively. In this case, the jumpers J4, J5, J6, and J7 must be removed.

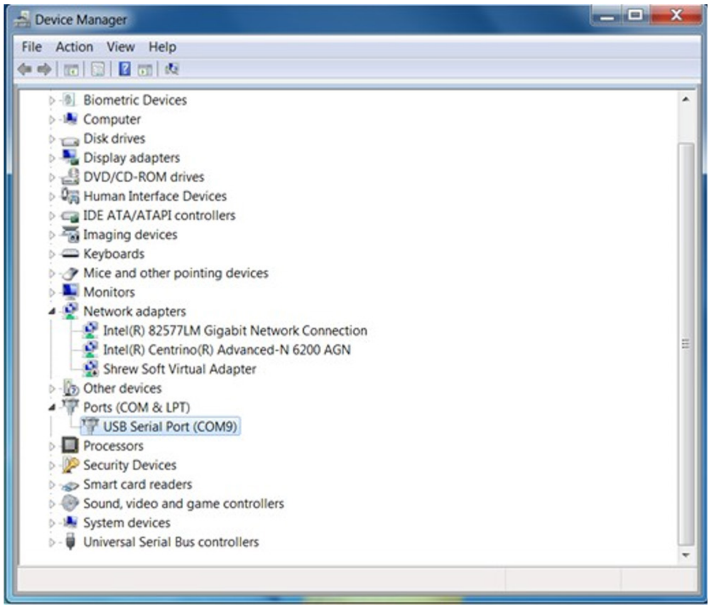
If standalone control of the motor is required, an externally generated PWM signal can be applied to connector X4 at a LIN terminal. The positive signal level must be connected to the point labelled LIN and the return path must be connected to the point labelled GND. The duty cycle of the PWM signal would then determine the demand input. In standalone mode, the DIAG terminal can also be shorted to the LIN terminal to shut down the system in case any fault condition exists.

Software Installation

A USB cable is provided for users to operate the A4964 evaluation board from a Windows® based desktop or laptop PC using the A4964 serial control GUI. Hardware drivers must be installed for the USB cable before use. A driver installer can be downloaded for the correct Windows version from the drivers page on the FTDI website at ftdichip.com/FTDrivers.htm.

The detailed installation guides for the hardware driver can be found through the support page on the FTDI website.

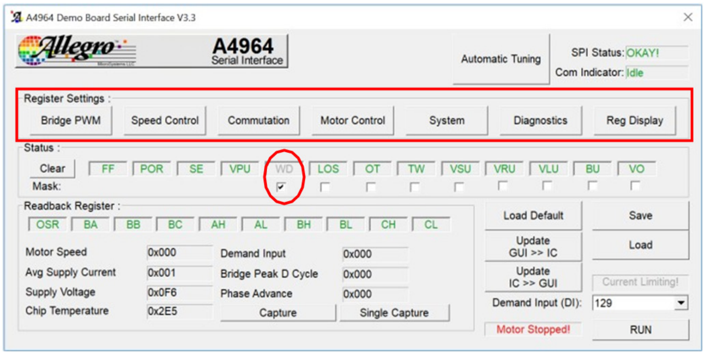
When hardware drivers are successfully installed, a virtual COM port will appear in the Device Manager as shown in Figure 3.



Biometric Devices
Computer
Disk drives
Display adapters
DVD/CD-ROM drives
Human Interface Devices
IDE ATA/ATAPI controllers
Imaging devices
Keyboards
Mice and other pointing devices
Monitors
Network adapters
Intel(R) 82577LM Gigabit Network Connection
Intel(R) Centrino(R) Advanced-N 6200 AGN
Shrew Soft Virtual Adapter
Other devices
Ports (COM & LPT)
USB Serial Port (COM9)
Processors
Security Devices
Smart card readers
Sound, video and game controllers
System devices
Universal Serial Bus controllers

Figure 3: Windows Device Manager

Allegro also provides a A4964 serial control GUI, which can be used to operate the evaluation board through the USB cable. The GUI is a standalone executable file, named A4964SerialV*xpx*.exe, where *xpx* is the version number. The latest versions can be accessed on the Allegro support website at registration.allegromicro.com. This GUI can be run directly on a Windows-based PC without installation. A screenshot of the GUI when running is shown in Figure 4.



SPI Status: OKAY!
Com Indicator: Idle

Mask: ☑ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐

Motor Speed	0x000	Demand Input	0x000
Avg Supply Current	0x001	Bridge Peak D Cycle	0x000
Supply Voltage	0x0F6	Phase Advance	0x000
Chip Temperature	0x2E5		

Demand Input (DI): 129

Motor Stopped!

Figure 4: GUI – Main Window

When running, the GUI will continuously check the communication between the PC and the USB cable. If the hardware driver for the cable is successfully installed, the “SPI Status” window in the GUI will display “OKAY!” when the cable is connected between the PC and the evaluation board. If the cable is disconnected, or the driver has not been installed correctly, then the “SPI Status” window will display “False!”.

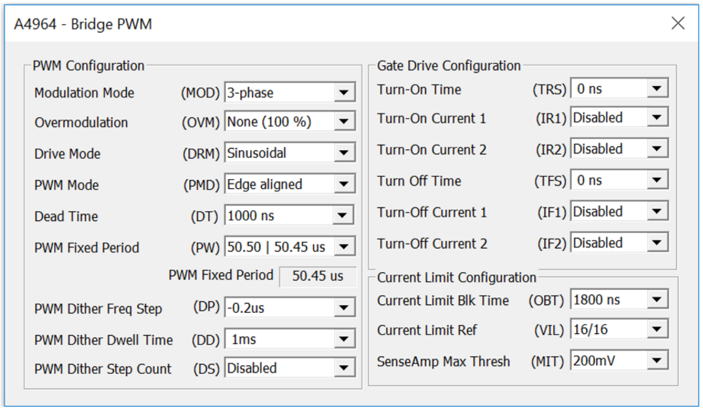
GUI General Overview

The main window of the GUI is shown in Figure 4. Various settings such as type of control, fault detection, etc., can be configured in the GUI. Settings are grouped based on their functionality in seven pop-up windows marked with red rectangle in Figure 4. The summary of each configuration option is provided in this user manual; however, if a detailed explanation of any parameter is required, it can be easily found in the datasheet by searching the relevant title.

For example, after clicking on the Bridge PWM button, the window shown in Figure 5 will open. Then, if further information about "Modulation Mode" is required, the title "Modulation Mode" can be searched in the A4964 datasheet in order to obtain full details about it.

Bridge PWM

The first pop-up window is the Bridge PWM (Figure 5).



A4964 - Bridge PWM

PWM Configuration

Modulation Mode (MOD) 3-phase

Overmodulation (OVM) None (100 %)

Drive Mode (DRM) Sinusoidal

PWM Mode (PMD) Edge aligned

Dead Time (DT) 1000 ns

PWM Fixed Period (PW) 50.50 | 50.45 us

PWM Fixed Period 50.45 us

PWM Dither Freq Step (DP) -0.2us

PWM Dither Dwell Time (DD) 1ms

PWM Dither Step Count (DS) Disabled

Gate Drive Configuration

Turn-On Time (TRS) 0 ns

Turn-On Current 1 (IR1) Disabled

Turn-On Current 2 (IR2) Disabled

Turn Off Time (TFS) 0 ns

Turn-Off Current 1 (IF1) Disabled

Turn-Off Current 2 (IF2) Disabled

Current Limit Configuration

Current Limit Blk Time (OBT) 1800 ns

Current Limit Ref (VIL) 16/16

SenseAmp Max Thresh (MIT) 200mV

Figure 5: GUI – Bridge PWM Section

The "Modulation Mode" setting defines the number of phases that are turned on at the same time. For three-phase, all of the phases will be driven with PWM signal, whereas for two-phase, one of the phases is always driven low and two other phases are driven with PWM signal. The two-phase modulation results in lower switching loss; however, with three-phase modulation, torque ripple is reduced, resulting in less audible noise at low power outputs. Both trapezoidal and sinusoidal driving mode are available in the A4964, which can be selected in the "Drive Mode" setting. If higher driving capability is required than is available in sinusoidal mode, the "Overmodulation" setting can be used.

The frequency of the applied PWM signal can be controlled in the "PWM Fixed Period" setting, and the alignment of PWM signals in the three phases can be done by using the "PWM Mode" setting.

In order to avoid short circuit in the phase of the power MOSFET bridge, a dead time is required between generating a low or high side turn-off signal and a complementary turn-on signal. The duration of the dead time can be selected using the "Dead Time" setting.

In order to reduce the radiated and conducted electromagnetic emission (EM), the dither frequency scheme can be used. By stepping the PWM frequency in a triangular pattern, the EM energy associated with the switching can be spread across a spectrum more effectively. The amount, duration, and the number of steps can be controlled using "PWM Dither Freq Step", "PWM Dither Dwell Time", and "PWM Dither Step Count" accordingly. More information about dither frequency scheme can be found in the datasheet.

In some applications, in order to comply with the EMC emission regulation, it is necessary to control the rate of change of the phase voltage. This can usually be achieved by controlling the FET gate charge and discharge rate. In the A4964, the slew rate control can be used to control the FET charge and discharge rate. The amount of the charging current applied to the gate of the FET is controlled by two parameters, labelled IR1 and IR2. For the duration defined by TR, the current defined by IR1 is initially applied to the FET. Usually IR1 is set to maximum, and turn-on duration is set to last long enough to reach the Miller region. Once the duration TR ends, the current IR2 is sourced to the gate of the FETs. IR2 is usually set lower than IR1 to increase the duration of Miller region, which would therefore result in a slower rise of the phase voltage. When the FET reaches a fully on-state, the drive output will change from current mode to voltage mode in order to maintain the MOSFET in the fully on-state. The turn-off sequence follows the same procedure in the reverse manner, and the amount of sinking currents are determined by IF1 and IF2. The duration of IF1 in this case is determined by TF. More information about slew rate control can be found in the datasheet.

The maximum current limit can be set for the system with the help of current limit configuration. The amount of current going through the motor can be determined by measuring the voltage across the sense resistor, which are connected to Terminal CSP and CSM as shown in Figure 2. Each time the output of the gate driver changes, the current limit blank time is triggered. The duration of blank time can be controlled by modifying OBT. If at the end of the blank time voltage across the sense resistor is higher than the current threshold limit defined by V_{ILIM}, all the high-side outputs are turned off, and the phase current will circulate through the low-side switches. This state is maintained until the next PWM period starts. V_{ILIM} can be calculated using the following equation:

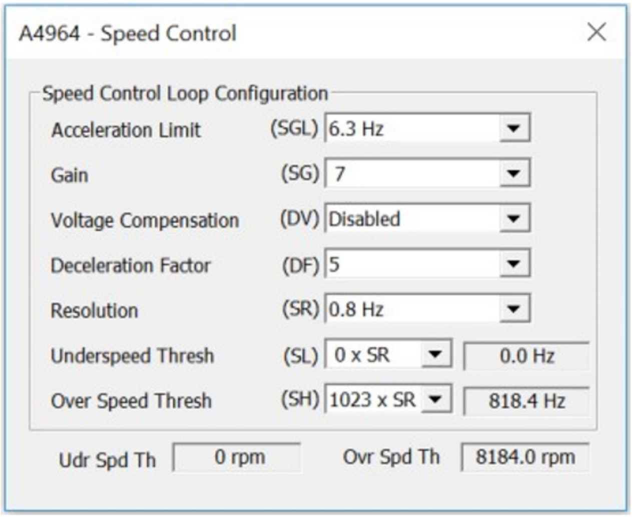
$$V_{ILIM} = V_{MIT} \times V_{ISC}$$

where V_{MIT} is the maximum threshold of the sense amplifier, which can be set by MIT variable, and
V_{ISC} is the current limit scale defined by VIL.

For example, if V_{MIT} is set to 200 mV and V_{ISC} to 1/16, then the maximum allowed voltage across the sense resistor is equal to 12.5 mV. The current limit can be disabled by clicking on the System window and disabling DIL as shown in Figure 10.

Speed Control

In this section of the GUI, the parameters relating to acceleration, deceleration, underspeed, and overspeed threshold can be modified.



A4964 - Speed Control

Speed Control Loop Configuration

Acceleration Limit	(SGL)	6.3 Hz	
Gain	(SG)	7	
Voltage Compensation	(DV)	Disabled	
Deceleration Factor	(DF)	5	
Resolution	(SR)	0.8 Hz	
Underspeed Thresh	(SL)	0 x SR	0.0 Hz
Over Speed Thresh	(SH)	1023 x SR	818.4 Hz

Udr Spd Th: 0 rpm Ovr Spd Th: 8184.0 rpm

Figure 6: GUI – Speed Control Section

The acceleration and deceleration profile that can be achieved with the A4964 is shown in Figure 7. The linear speed rise, or constant acceleration, is limited by the product of SGL and the gain SG. Once the motor reaches speed = reference speed – SGL, the acceleration will be limited by SG only. For deceleration, there is an additional variable limiting the acceleration, which is labelled DF. During deceleration, some current may flow back to the supply, resulting in the rise of voltage to a dangerous level. Therefore, introduction of this new variable into the deceleration profile gives more feasibility in terms of control.

In order to mitigate the impact of any transient disturbance of the power supply voltage on the motor control, voltage compensation DV can be used. For supply voltages between 7 to 19 V, the compensation should be set to 12 V, and for voltage ranges between 14 to 38 V, compensation should be set to 24 V.

Voltage compensation only affects open- and closed-loop speed control and does not have any impact on the closed-loop current control. More information about control modes are provided in the Motor Control section.

The minimum and maximum achievable speed can be set by the underspeed (SL) and overspeed (SH) threshold. If the motor speed is below the underspeed threshold or above the overspeed threshold, a loss of synchronization occurs, the fault LOS (shown in the content of status register in Figure 4) will flag, and the motor will stop by shutting down the FETs M1-M6 (shown in Figure 2). More information about LOS can be found in the datasheet.

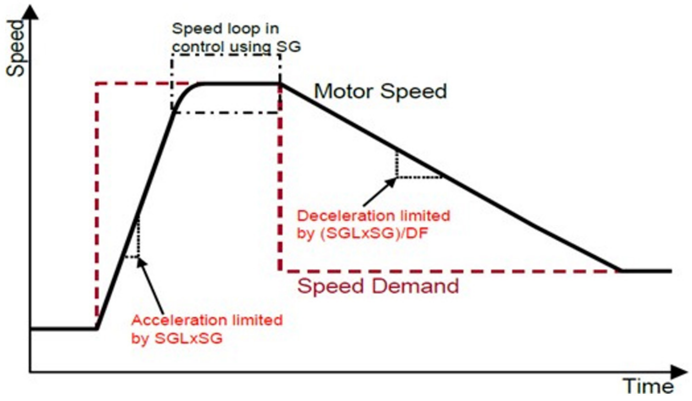
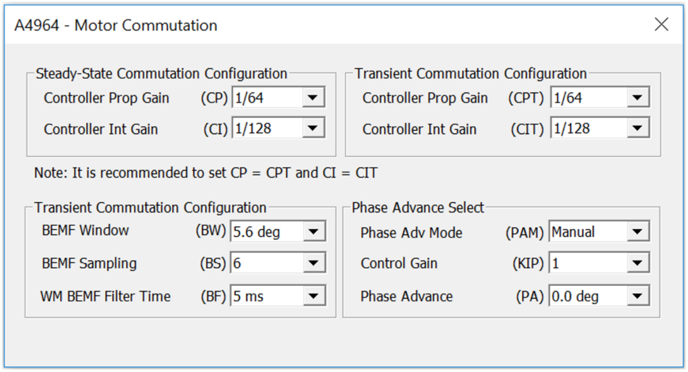

Speed
Speed loop in control using SG
Motor Speed
Deceleration limited by (SGLxSG)/DF
Speed Demand
Acceleration limited by SGLxSG
Time

Figure 7: Acceleration and Deceleration Profile

The electrical motor reference speed used in speed control mode is the product of "Resolution", SR, and "Demand Input", DI. For example, if SR is 0.2 Hz and DI is 100, then the reference speed attempted by the controller to be achieved is equal to 20 Hz.

Motor Commutation



A4964 - Motor Commutation

Steady-State Commutation Configuration

Controller Prop Gain	(CP)	1/64
Controller Int Gain	(CI)	1/128

Transient Commutation Configuration

Controller Prop Gain	(CPT)	1/64
Controller Int Gain	(CIT)	1/128

Note: It is recommended to set CP = CPT and CI = CIT

Transient Commutation Configuration

BEMF Window	(BW)	5.6 deg
BEMF Sampling	(BS)	6
WM BEMF Filter Time	(BF)	5 ms

Phase Advance Select

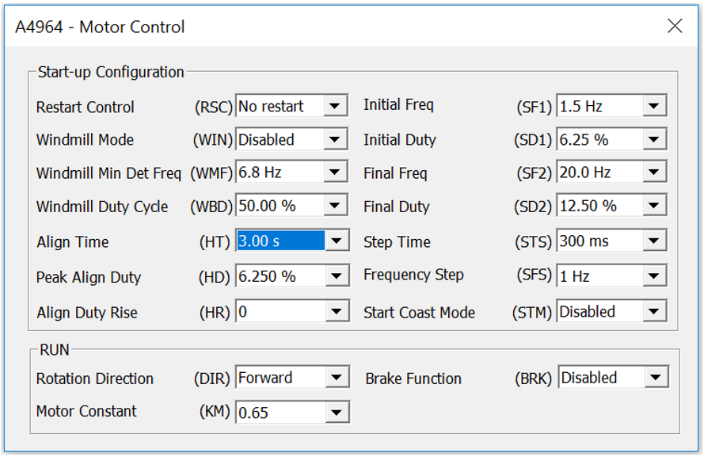
Phase Adv Mode	(PAM)	Manual
Control Gain	(KIP)	1
Phase Advance	(PA)	0.0 deg

Figure 8: GUI – Motor Commutation Section

The content of motor commutation pop-up window is shown in Figure 8. The parameters in this section affect the closed-loop control and must be properly tuned in order to allow smooth operation of the motor. The A4964 uses motor bemf for control and the "BEMF Window" and "Sampling" settings are used to achieve this.

In addition, to allow the motor to operate beyond the base speed with the same supply voltage, field weakening must be performed. This is accomplished by tuning parameters in the "Phase Advance" section. Further information about control gain adjustment, bemf sensing, and phase advance are provided in this user manual in the Setting Up for First Time Use section.

Motor Control



A4964 - Motor Control

Start-up Configuration

Restart Control (RSC) No restart
Windmill Mode (WIN) Disabled
Windmill Min Det Freq (WMF) 6.8 Hz
Windmill Duty Cycle (WBD) 50.00 %
Align Time (HT) 3.00 s
Peak Align Duty (HD) 6.250 %
Align Duty Rise (HR) 0

Initial Freq (SF1) 1.5 Hz
Initial Duty (SD1) 6.25 %
Final Freq (SF2) 20.0 Hz
Final Duty (SD2) 12.50 %
Step Time (STS) 300 ms
Frequency Step (SFS) 1 Hz
Start Coast Mode (STM) Disabled

RUN

Rotation Direction (DIR) Forward
Motor Constant (KM) 0.65
Brake Function (BRK) Disabled

Figure 9: GUI – Motor Control Section

This section of the GUI focuses on startup configuration. If there is loss of synchronization in the system, RSC can be used to restart the system if enabled. RSC can also restart the system in cases where there is a supply or logic undervoltage.

Before applying the closed-loop speed control, there is a startup sequence that consists of an alignment, followed by an open-loop commutation with increasing speed and a short motor coast period. The content of each of the startup sequences can be tuned and modified to achieve smooth and consistent startup. The startup sequence is discussed in detail in the last section of this user manual.

There are some occasions where the motor may still be rotating due to a previous running state or load condition. In these cases, it is possible to use the windmill start feature to bypass the startup sequence. The windmill startup conditions can be further studied in the datasheet.

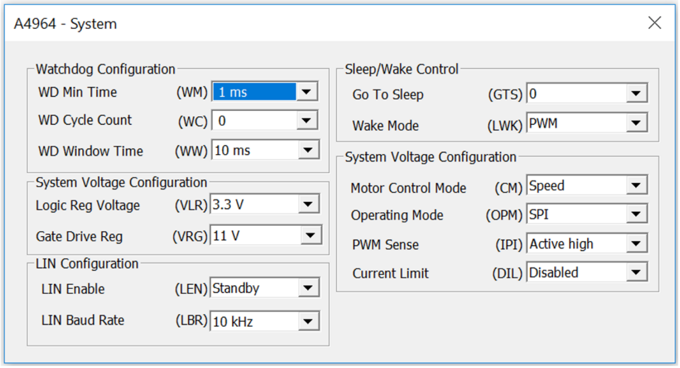
The motor rotation direction can also be controlled by modifying “Rotation Direction”, DIR. If electromagnetic brake is required, the “Brake Function”, BRK, can be used to enable all low-side FETs and disable all high-side FETs. By enabling all low-side FETs, the current continues to flow within the phases due to bemf, creating torque against the rotational direction of the motor and therefore forcing the motor to stop.

The motor constant (KM) is used to determine the application of correct duty cycle to the bridge if windmilling or coast mode are enabled. KM is related to the motor bemf constant and can be calculated based on the following equations depending on the setting for voltage compensation (DV).

$$KM = \begin{cases} \frac{642.4}{V_{BB}} \times \frac{K_{emf}}{n_{pp}}, & DV = 0 \\ 53.5 \times \frac{K_{emf}}{n_{pp}}, & DV = 1 \text{ or } 3 \\ 53.5 \times \frac{K_{emf}}{n_{pp}}, & DV = 2 \end{cases}$$

where K_{emf} is the motor bemf constant in unit of v×s / rad, and n_{pp} is the number of pole pairs.

System



A4964 - System

Watchdog Configuration

WD Min Time (WM) 1 ms
WD Cycle Count (WC) 0
WD Window Time (WW) 10 ms

System Voltage Configuration

Logic Reg Voltage (VLR) 3.3 V
Gate Drive Reg (VRG) 11 V

LIN Configuration

LIN Enable (LEN) Standby
LIN Baud Rate (LBR) 10 kHz

Sleep/Wake Control

Go To Sleep (GTS) 0
Wake Mode (LWK) PWM

System Voltage Configuration

Motor Control Mode (CM) Speed
Operating Mode (OPM) SPI
PWM Sense (IPI) Active high
Current Limit (DIL) Disabled

Figure 10: GUI – System Section

In this pop-up window, several features of the device—such as logic regulator and driver output voltage—can be modified. In addition, the type of control to be applied—such as speed or current control—can be selected. If the A4964 is used in conjunction with a microcontroller, the watchdog can be used to determine if the microcontroller is operating in an adverse state.

When watchdog is enabled, the input waveform to the WDOG terminal must follow a certain configuration, which is explained in the datasheet. If a watchdog failure occurs, the MRSTn terminal output, which is an active-low signal, can be used to disable or reset the microcontroller. A watchdog failure also disables all the switches and can put the device to sleep depending on the choice of settings. If the watchdog feature is not used, it should be disabled in order to allow correct operation of the A4964 device. This can be done by masking the WD bit in the main menu of the GUI shown in Figure 4.

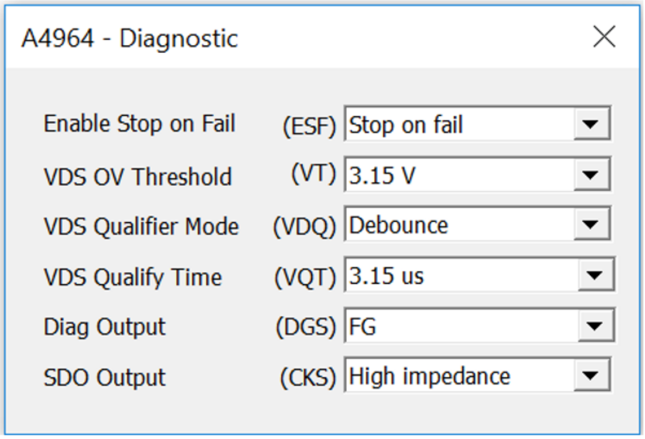
There are three control modes in the A4964: closed-loop speed control, closed-loop current control, and open-loop voltage control mode, which can be set by defining the CM bit.

There are two ways to set the demand input (speed reference) for the A4964 in the closed speed control mode. The first method is to define the required demand input in the GUI as shown in Figure 4. In this case, serial interface communication is used and therefore the “Operating Mode” OPM shown in Figure 10 must be set to SPI. The other method is to apply duty cycle to the LIN input. In this case, the OPM must be set to PWM (standalone mode). More information about the LIN interface can be found in the datasheet.

When operating in closed-loop current control mode, the current limit bit, DIL, must be enabled. In this case, the “Current Limiting!” status in the main window of the GUI, shown in Figure 4, will be shown in red if the current hasn’t reached to the defined limit. Otherwise, it will be shown in green. In closed-loop speed control or voltage control mode, if the current limit is enabled, the “Current Limiting!” status will be red if the current has reached the limit and it will be gray if the current is not at the limit.

As discussed previously, one way to put the device into sleep is to use watchdog. Another method is to make a logic low to high transition on the GTS bit. More information on sleep state and how to wake up the device can be found in the datasheet.

Diagnostics


A4964 - Diagnostic

Enable Stop on Fail	(ESF)	Stop on fail
VDS OV Threshold	(VT)	3.15 V
VDS Qualifier Mode	(VDQ)	Debounce
VDS Qualify Time	(VQT)	3.15 us
Diag Output	(DGS)	FG
SDO Output	(CKS)	High impedance

Figure 11: GUI – Diagnostic

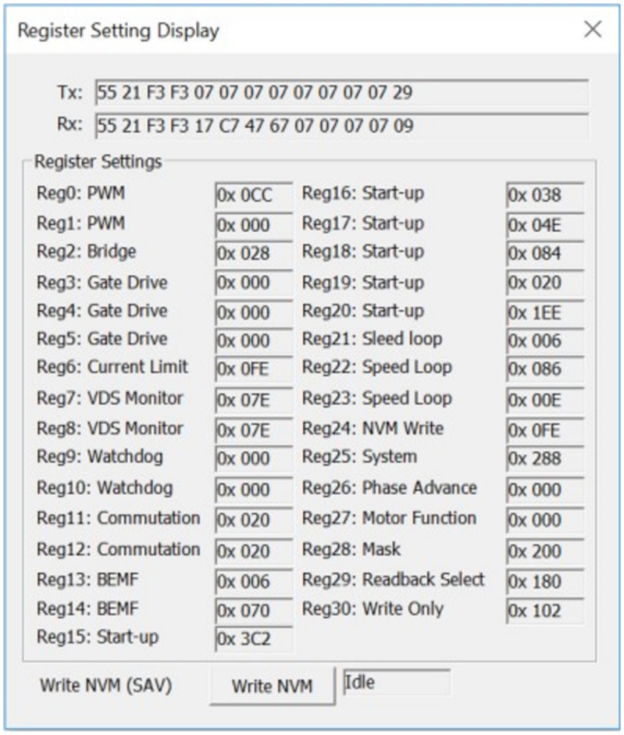
The setting in the diagnostic register should be adjusted properly in order to increase the reliability of the overall system and to prevent possible damage to the A4964 as well as other components such as FETs. The ESF bit, if set to “Stop on fail”, will disable all the A4964 outputs in several conditions such as overtemperature, drain-to-source overvoltage, and power supply (V_{BB}) undervoltage. The list of failures that can result in disabling the outputs when ESF is set to “Stop on fail” can be found in the datasheet.

The drain-to-source voltage threshold VT provides protection for the system in case any short circuit occurs in the bridge FETs. When VDQ is set to “Debounce”, if the measured voltage across FETs is higher than VT when they are fully on, all the outputs will be disabled after the condition has persisted for the duration VQT. If VDQ is set to “Blank”, the comparison of voltage across the FET and overvoltage threshold VT is ignored once the output is turned on for the duration defined by VQT. When VQT ends, if the voltage across the FETs is higher than the threshold VT, then the outputs will be disabled if ESF is set to “Stop on fail”.

The DIAG terminal on the A4964 evaluation board can provide important information, such as motor electrical speed, and low- or high-level signals in case of fault conditions. The output of the DIAG pin depends on the setting of DGS. For example, if DGS is set to “Active low fault flag”, then the DIAG will output a low signal in case any fault occurs. If it is set to FG, it will then output the motor speed, and so on. More information on the different types of output waveforms depending on the setting of the DGS can be found in the datasheet.

When CKS is set to “High impedance”, the SDO terminal output works as it would during normal serial interface communication. When CKS is set to “Divided system clock”, it will output the square waveform at a ratio of clock frequency when no data is being transmitted (STRn = 1). This generated waveform will allow more precise calibration of the timing settings, if required.

Register Display


Register Setting Display

Tx: 55 21 F3 F3 07 07 07 07 07 07 07 07 29

Rx: 55 21 F3 F3 17 C7 47 67 07 07 07 07 09

Register Settings

Reg0: PWM	0x 0CC	Reg16: Start-up	0x 038
Reg1: PWM	0x 000	Reg17: Start-up	0x 04E
Reg2: Bridge	0x 028	Reg18: Start-up	0x 084
Reg3: Gate Drive	0x 000	Reg19: Start-up	0x 020
Reg4: Gate Drive	0x 000	Reg20: Start-up	0x 1EE
Reg5: Gate Drive	0x 000	Reg21: Sleed loop	0x 006
Reg6: Current Limit	0x 0FE	Reg22: Speed Loop	0x 086
Reg7: VDS Monitor	0x 07E	Reg23: Speed Loop	0x 00E
Reg8: VDS Monitor	0x 07E	Reg24: NVM Write	0x 0FE
Reg9: Watchdog	0x 000	Reg25: System	0x 288
Reg10: Watchdog	0x 000	Reg26: Phase Advance	0x 000
Reg11: Commutation	0x 020	Reg27: Motor Function	0x 000
Reg12: Commutation	0x 020	Reg28: Mask	0x 200
Reg13: BEMF	0x 006	Reg29: Readback Select	0x 180
Reg14: BEMF	0x 070	Reg30: Write Only	0x 102
Reg15: Start-up	0x 3C2		

Write NVM (SAV) Idle

Figure 12: GUI Register Display

The register display, shown in Figure 12, provides the hexadecimal values of the present contents of the registers. Once all register values have been tuned to a specific motor and load, these settings may be written to the non-volatile memory (NVM) inside the A4964. These values will then be used as the default power-up values and can be used to avoid reprogramming the registers at each power-on. This can then permit the A4964 to operate in a standalone mode with only a PWM control input.

To write the present register values into NVM, the main supply should first be increased to at least 24 V before clicking on the "Write NVM" button. The NVM write status box will then display "Programming!" and the DSR selection pop-up window will appear, asking "Would you like to set DSR=1". The DSR bit is not selectable in any other window and can only be set to 0 or 1 when writing to NVM. Click "Yes" or "No" and writing to the NVM will commence. If NVM is updated successfully, then the NVM write status box will display "success!". If there are any problems such that NVM is not updated successfully, then the NVM write status box will display "Failed!". If this occurs, check that the supply voltage is above 24 V and the A4964 is active and communicating with the GUI. Once any problems have been resolved, click again on the "Write NVM" button.

Action Buttons

Clear

The "Clear" button will remove all the previous fault condition shown in the "Status" section of Figure 4. If "Clear" is pressed and there is no fault in the system, the content of the status register should be shown in green. If the fault still exists, the corresponding fault will be shown in red.

Run

By pressing the "Run" button, the output of the A4964 is enabled and the motor will start running if the settings are configured properly.

Load Default

This button provides a quick way to set all parameters to their datasheet default values. After clicking the "Load Default" button, all the selections in the drop-down menus and the display buttons will be set to default values defined as the power-on reset values in the datasheet. These values will then be written to the A4964 mounted on the board if it is active.

Load

Clicking on the "Load" button allows loading previously configured parameters into the GUI and as well updating the A4964 with these new parameters. The previously configured parameters are in a text file with the ".rst" extension. Successful loading occurs if the A4964 device is powered on and the USB connection between A4964 and PC exists at the time of the loading.

When the A4964 is initially powered up and the POR bit is set, the content of registers from A4964 will be loaded into the GUI. Also, if the GUI window is opened after the A4964 is powered up, the contents of the registers in the GUI will be again updated with A4964 register values. Thereafter, each time a parameter is changed in the GUI, the register values of the A4964 will be automatically updated with the changes.

If the USB is connected after the A4964 is powered up and the GUI window is opened, the registers content from A4964 will not be loaded into the GUI and vice versa. In this case, the register values of the GUI and A4964 can be different, and therefore the options "Update GUI » IC" and "Update IC » GUI" which are described next can be useful.

Update GUI » IC

This option allows the contents of the GUI to be uploaded to the A4964. By default, the contents of the GUI are loaded to the A4964 whenever a parameter is changed. This option ensures that the current contents of all registers in the GUI are loaded to the A4964 and is useful for cases where the USB cable is disconnected and connected.

Update IC » GUI

When power is first applied to the A4964, the register parameter settings that are saved in NVM will be loaded to the GUI. If the GUI window is opened after the A4964 is powered up, the present contents of registers from the A4964 will be loaded to the GUI. This option ensures that the current contents of all A4964 registers are loaded to the GUI and is useful for cases where the USB cable is disconnected and connected.

Save

The settings of operating parameters in the GUI can be saved to a text file (with the file extension ".rst") for future testing. To save the parameters, click "Save", input the file name in the pop-up window, and choose a folder where the configuration file will be saved. Then click "Save" in the pop-up window.

Demand Input

By increasing or decreasing the demand input, the user can alter the motor reference speed or current limit depending on the control mode operation.

The motor electrical reference speed in closed-loop speed control mode is equal to demand input (DI) multiplied by resolution SR. For example, if demand input is equal to 200 and resolution is equal to 0.8 Hz, then the motor electrical speed should be equal to 160 Hz at steady state.

The amount of current limit in current control mode is defined by the following equation:

$$I_{LIM} - \frac{V_{ILIM}}{R_{SENSE}}$$

where Rsense is the sense resistor.

In this case, demand input sets V_{ILIM} as a ratio of the maximum threshold of V_{MIT}. V_{MIT} can be set by modifying the variable MIT that can be found in the "Bridge PWM" section of the GUI. For example, when demand input is 256 and V_{MIT} is set to 200 mV, V_{ILIM} will be 50 mV.

Motor Status

Should there be any fault during operation of the A4964, the "Status" section of the GUI will provide information about the type of the fault. Some of the faults that are shown in the "Status" are overtemperature, supply undervoltage, regulator undervoltage, etc. Once a specific type of fault occurs, the associated fault will be marked in red and if there is no fault, it will be marked in green.

When the A4964 is initially powered, the bits VLU, VRU, VSU, WD, SE, POR, and FF will be shown in red. If watchdog is not used, the WD bit must be masked as previously discussed. The other faults can be cleared by clicking on the "Clear" button. However, if the aforementioned faults genuinely exist in the system and is not due to initial power on, even after clicking on the "Clear" button, the fault will still be shown in the status section, and its source must be removed from the system in order to clear the fault in the GUI.

Capture

Data acquisition is possible by pressing the "Capture" button. The data acquisition window will provide information about motor speed, average supply current, supply voltage, chip temperature, demand input, applied bridge peak duty cycle, and applied phase advance. To ensure correct reading for motor speed and average supply current, the number of pole pairs and sense resistor value must be configured correctly. The information in the capture window is updated at approximately 700 ms intervals; however, this strongly depends on the operating system and number of applications opened in the system background.

Setting Up for First Time Use

Before operating the evaluation board for the first time, it should be set into a safe condition to avoid overcurrent stress to any components or attached load. The jumpers should be in their default position as shown in Table 1, and switch S1 should be in the "On" position.

Set Supply Current to Minimum

Before connecting the supply for the first time, ensure the supply current limit is set to a low value to avoid unexpected current caused by any component or load problems.

After connecting the power supply to VBB (connector X1), the power supply current should be approximately 15 mA at 12 V without any motor connected.

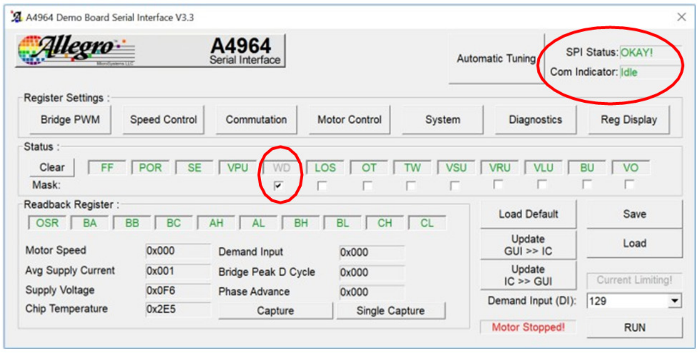
Interface the GUI

Table 1: Default Jumper Connections

Jumper	Terminal Details	Default Setting
J1	Supply Voltage to VBB input	Short
J2	VLR output to on board connector	Short
J3	Supply Voltage to VBB (bypass diode)	Short
J4	Clock signal for SCK input	Short
J5	Signal from master device to SDI	Short
J6	Strobe signal from STRn to the target device	Short
J7	Signal output from SDO to master device	Short
J8	Signal from DIAG to LED	Short
J13	Signal from VBB to on Board 5 V regulator	Short

Once the supply voltage and current have been checked, the board can be connected to the PC that has the GUI installed. The procedure for proper installation of the USB driver as well as the GUI has already been discussed in the Software Installation section. The connection can be done by connecting one end of the provided micro USB to the PC and the other end to the evaluation board (connector X7). After connecting the two devices together, open the GUI software. If the connection has been successful, the "SPI status" window indicates "OKAY!" as shown in Figure 13, otherwise it will indicate "False!".

There is one more step needed before setting up the control parameters of the motor in the GUI and connecting the motor to the board. Since watchdog is not used when interfacing the GUI, it must be masked in order to avoid the device going into sleep mode or disabling the output as discussed in section "System". In order to mask the watchdog, simply checkmark the "WD" bit as shown in Figure 13, then press the "Clear" button. If the operation is successful, all the text under the "Status" and "Readback Register" should be shown in green and the WD will be grayed out as shown in Figure 13. At this point, the motor can be connected and it is now possible to configure the control setting to run the motor.



A4964 Demo Board Serial Interface V3.3

SPI Status: OKAY!
Com Indicator: Idle

Mask: WD ☑ LOS □ OT □ TW □ VSU □ VRU □ VLU □ BU □ VO □

Motor Speed: 0x000
Avg Supply Current: 0x001
Supply Voltage: 0x0F6
Chip Temperature: 0x2E5
Demand Input: 0x000
Bridge Peak D Cycle: 0x000
Phase Advance: 0x000
Demand Input (DI): 129

Current Limiting!
Motor Stopped!

Figure 13: GUI – Main Window

Controlling the Motor with the GUI

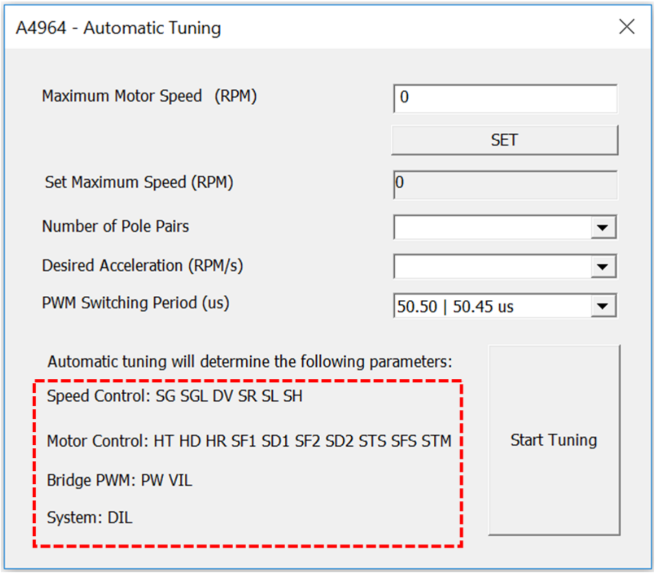
A number of example settings to run motors for different applications are provided in Appendix D. Once the desired setting is determined, open a blank text file (e.g., using Notepad), copy and paste the determined setting into the file. Next, save the file with the ".rst" extension. In the main window of the GUI, click "Load", locate the file and open it. At this point, the GUI should be updated with the new parameters and the GUI then updates the A4964 with these parameters automatically.

Click the "Run" button and the motor should start to operate. If the motor started successfully, further tuning may not be needed, and the speed can be further increased or decreased by changing the DI. The A4964 GUI also provides an automatic tuning feature, which can be used to adjust the control setting gains should the user prefer not to use the provided files. If in both cases, loading the file or using automatic tuning feature, there is startup problem, the guidelines provided in the Tuning Parameters for Speed Control section can be followed and with minimum changes, the motor should be able to run.

Automatic Tuning for Speed Control Mode

The A4964 GUI provides an automatic tuning feature to adjust the gains for the closed-loop speed control. To use the automatic tuning feature, first ensure that the board is powered, and the PC is connected to the GUI via the USB connection. Then click on the "Load Default" button to load the registers with the default values and mask the watchdog bit WD as shown in Figure 13 if watchdog is not used. The parameters that are changed during automatic tuning is shown and marked in Figure 14.

Once the default values are loaded in the GUI, click on the "Automatic Tuning" button. The pop-up window shown in Figure 14 should open.



A4964 - Automatic Tuning

Maximum Motor Speed (RPM): 0

Set Maximum Speed (RPM): 0

Number of Pole Pairs:

Desired Acceleration (RPM/s):

PWM Switching Period (us): 50.50 | 50.45 us

Automatic tuning will determine the following parameters:

Speed Control: SG SGL DV SR SL SH

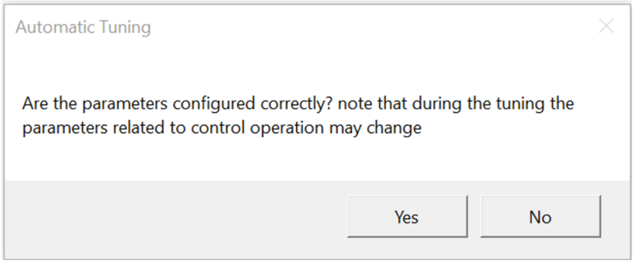
Motor Control: HT HD HR SF1 SD1 SF2 SD2 STS SFS STM

Bridge PWM: PW VIL

System: DIL

Figure 14: Automatic Tuning Window

In order to start tuning, two important motor parameters (rated speed (no load) and number of pole pairs) are required which can be easily found in the specific motor datasheet. The user then must provide the desired acceleration and PWM switching period. It should be noted that if fast acceleration is required, the current limiting function may have to be disabled by setting the DIL bit to 1. To do this in the GUI, click on the “System” tab and set “Current Limit” to “Disabled”. Once all the parameters are defined, click on the “SET” button to ensure the “Set Maximum Speed” window is updated with the latest motor rated speed and then click on the “Start Tuning” button. A new pop-up message will appear to confirm all the parameters are configured properly as shown in Figure 15. By clicking “Yes”, the gains will be adjusted accordingly. Next, by clicking on the “RUN” button in the main window of the GUI, the motor should be able to run. If there is doubt about any of the parameters, click “No”, fix the values, and click on “Start Tuning” again.



Automatic Tuning

Are the parameters configured correctly? note that during the tuning the parameters related to control operation may change

Figure 15: Automatic Tuning Message

The only parameter that must be tuned in the “Auto Tuning” window is the desired acceleration. If the requested acceleration is too high and is more than the capability of the motor, there can be a startup problem. It is recommended to start with a low acceleration profile and increase it step by step until the motor can no longer fulfil the desired acceleration. In rare cases where it is not possible to start up the motor with any of the provided acceleration profiles, a small adjustment to the control gain settings will be necessary for which the guidelines provided in the next section can be used.

Tuning Parameters for Speed Control

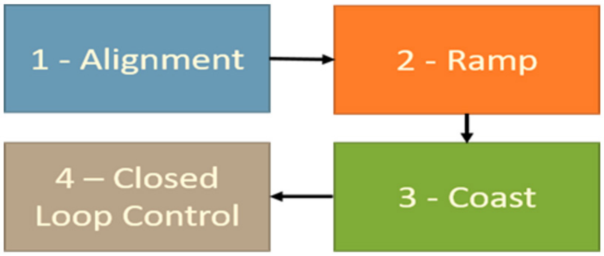


Figure 16: Startup Sequence

The startup sequence summary is shown in Figure 16. In order to achieve successful startup of the motor, the parameters for each of the sequences must be modified and tuned. Before starting the parameter tuning, load the default setting (shown in Appendix D) to ensure the initial settings are set properly and only the relevant parameters that require tuning are changed.

Alignment

The first settings that must be tuned for the specific type of motor are those related to alignment. This is used to move the rotor to a known position before initiating a forced commutation sequence to start the motor. This function is helpful for motor and loads with high inertia. Consider a simplified drawing of typical BLDC as shown in Figure 17.

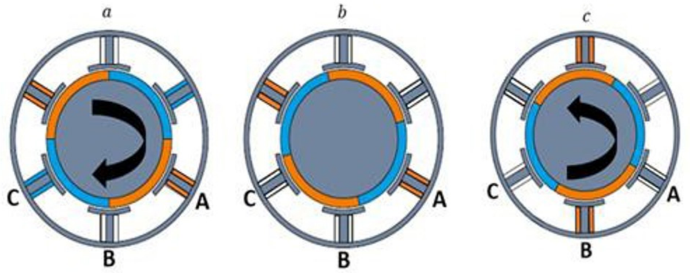


Figure 17: Illustration of rotor movement

The winding of phase A is energized to form a magnetic pole shown in orange in Figure 17a. The blue and orange colors indicate magnetic poles of different polarities. The rotor starts rotating clockwise as shown in Figure 17a until its blue magnetic pole is fully aligned with the stator, which is shown in Figure 17b. At this point, in order to further rotate the rotor, phase B of the stator must be commutated. However, for example, for the duration of phase A turn-on, it is not possible for the rotor to fully align itself with the stator due to its high inertia. Thus, it is placed at the location shown in Figure 17c. At this point, by commutating phase B, rather than moving clockwise, the rotor will try to rotate counterclockwise, causing disturbance in the motor performance. Therefore, the alignment function in the A4964 helps placing the rotor into a known position in order to achieve correct commutation sequence in the next startup stage, which is ramp.

The state flow diagram to tune the parameters for alignment is shown in Figure 18. Depending on the position of the rotor and its inertia, the parameters relating to alignment (HT, HD, and HR) must be tuned.

These parameters can be found in the “Motor Control” section of the GUI as shown in Figure 9. For example, if the inertia is high and initial rotor position is far from the known position, the hold time, HT, must be increased to provide more time for the rotor to move to the desired position. Increasing the peak duty during alignment parameter, HD, and reducing the alignment duty cycle ramp time, HR, results in faster movement of the rotor to the known position, which can be used if a long hold time is not desired. It should be noted that during alignment, once the motor reaches the known position, it will remain in that position until HT ends and the ramp sequence begins.

If there are any problems with tuning the parameters in this section, the motor will start vibrating and juddering at a certain position. For example, if HT is set to 3 seconds and motor juddering is observed after 2 seconds of running the motor, it means that the parameters in the alignment section must be tuned.

Otherwise, if the motor vibration occurs after three seconds, the problem is due to other untuned parameters in the next sequences of startup. The worst-case condition is if the rotor is 180° far from the known position and motor inertia is high. In this case, longer HT, larger value of HD, and lower value of HR is required in order to allow the rotor reach to the known position and achieve robust startup. It should be noted that a high value of HD can also result in motor vibration, and so if the motor starts to vibrate, this value must be reduced.

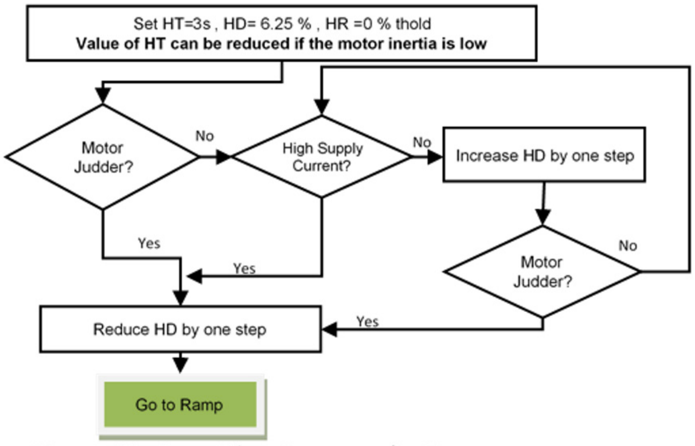


Figure 18: State Flow Diagram for Alignment Sequence Tuning Parameters

Untuned Parameters for Ramp and Closed-Loop Sequence

The untuned parameters in both ramp and closed-loop sequence can result in stopping of the motor. In order to check at which stage of startup this had occurred, the waveform of the signal FG must be observed. The FG signal provides the electrical speed of the motor and can be measured by connecting a probe to the point labelled DIAG. The DIAG provides several measurements. To ensure that it provides motor electrical speed, click on "Diagnostic" in the main window of the GUI and set the DIAG output, DGS, to FG. Once done, run the motor and observe the waveform of FG. Measure the frequency of the signal FG on the oscilloscope. An example of frequency measurement is shown in Figure 19. If the measured frequency is higher than the value defined by parameter SF2, it is confirmed that the ramp sequence is implemented successfully and tuning must be done for the parameters of the closed-loop sequence. If the motor stops or judders before the frequency reaches the value defined by SF2, it indicates the parameters for the ramp sequence are not well tuned. SF2 is among the parameters that must be tuned for the ramp sequence and the importance of it is discussed in the next section.

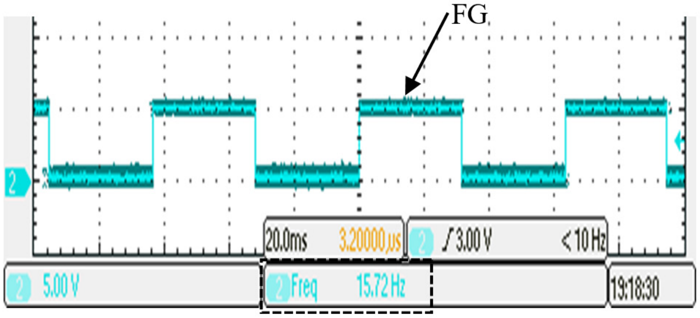


Figure 19: Frequency Measurement of the Signal FG

Ramp

The next important startup sequence after alignment is ramp. The parameters to be tuned for this sequence are SF1, SD1, SF2, SD2, SFS, and STS, which are provided in "Motor Control" section of the GUI as shown in the Figure 9. In order to implement sensorless closed-loop motor control, measurement of the bemf signal is required. The bemf signal level is equivalent to the motor speed. Therefore, the purpose of the ramp sequence is to push the motor speed high enough to be able to measure bemf effectively before entering the closed-loop sequence.

When the ramp sequence begins, sinusoidal or trapezoidal (depending on the choice of drive mode) waveforms are applied to stator phases to create rotating magnetic fields that allow the motor to rotate. The initial frequency of the waveforms and the peak applied duty cycle are determined by the parameters SF1 and SD1. For two-phase modulation, the peak applied duty cycle at zero-degree position for each phase, is defined as:

Phase A = (SD1 ÷ 2) %
Phase B = 0 Phase C = SD1 %

For three-phase modulation, the peak applied duty cycle for each phase at zero-degree position is defined as:

Phase A = 50 %
Phase B = 50 – (SD1÷ 2) % Phase C= 50 + (SD1÷ 2) %

The applied frequency will then increase to the final value defined by SF2, and the duty cycle by which the phases will be modulated will increase to a final value defined by SD2. This increase is done in steps, where duration of steps is determined by STS and the amount of frequency increasing in each step is determined by SFS. Figure 20 illustrates the waveform of applied duty cycle with respect to time for a three-phase sinusoidal modulation. It should be noted that the applied duty cycle is equivalent to the amount of phase voltage. With time advancement, it can be noted that the peak duty cycle and frequency of the signal increases. This increase continues until the frequency of the signal has reached the value defined by SF2, after which the next sequence (coast or closed-loop control) will initiate depending on the configuration, which will be discussed later.

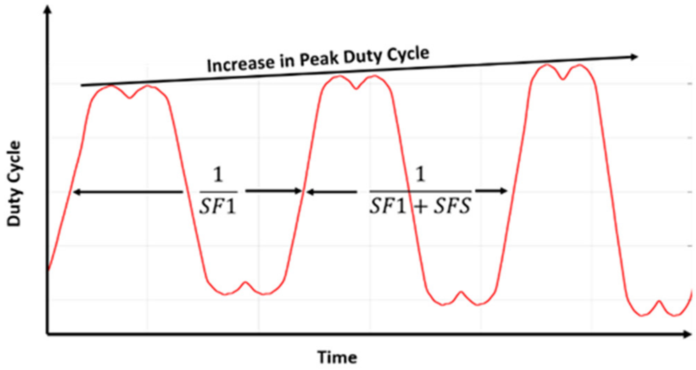


Figure 20: Ramp Sequence, Illustration of Duty Cycle with Respect to Time

Tuning the Parameters for Ramp

The state flow diagram to tune parameters for the ramp sequence is provided in Figure 21. In order to tune parameters for ramp, one should realize the interdependency between the applied duty cycle and frequency. Consider Figure 17 once again. If high frequency step is applied to the phases, it means the rotor must also react to the applied frequency, or otherwise it will lose synchronism. In order for the rotor to react to the high-frequency step, a high duty cycle step is also required. Higher duty cycle results in higher phase voltages.

This creates stronger magnetic poles in each phase and therefore results in faster acceleration of the rotor. However, it should be noted that for the high inertia motors, a high-frequency step may not be possible, as even the highest applied duty cycle step may still not result in fast enough acceleration of the rotor compared to the applied frequency.

To tune, start with low values of SF1 and SD1. This should avoid any sudden oscillation in the rotor if its inertia is low. Also, start with a low frequency step SFS but set the duration of step STS to a high value. Usually, motor manufacturers provide the motor voltage (bemf) constant. If the motor has low-voltage constant, a higher value of SF2 is needed and vice versa. For motors with high inertia, SD2 must be high. If the inertia is low, SD2 must be low. Once the successful ramp sequence is achieved, the frequency step SFS can be increased and the step time STS can be reduced to achieve the desired acceleration during ramp.

If there is a problem for startup in this sequence, the motor usually starts rotating initially and then it begins to slip and lose synchronism if the parameters are not set properly.

Coast

During coast, all switches are turned off for a very short duration, which allows full measurement of bemf signal and detection of zero-crossing point. This mode is useful for a high inertia motor where it is harder to detect bemf due to lower acceleration and therefore speed during ramp. It should also be noted that for very low inertia motors, the coast mode can completely stop the motor, therefore causing disturbance in the turn-on sequence. If a high inertia motor is used, it is recommended to enable coast mode. If the inertia is low, however, it is recommended to disable it. Coast mode can be enabled or disabled by changing the bit STM in the "Motor Control" section in Figure 9.

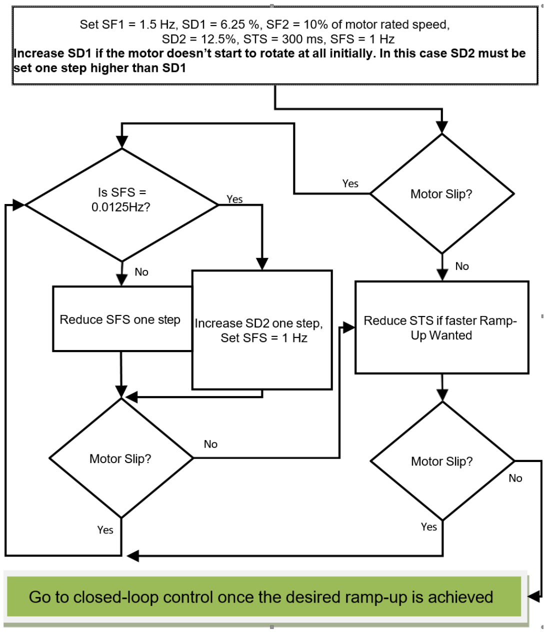

Set SF1 = 1.5 Hz, SD1 = 6.25 %, SF2 = 10% of motor rated speed, SD2 = 12.5%, STS = 300 ms, SFS = 1 Hz
Increase SD1 if the motor doesn't start to rotate at all initially. In this case SD2 must be set one step higher than SD1
Is SFS = 0.0125Hz?
Yes
No
Motor Slip?
Yes
No
Reduce SFS one step
Increase SD2 one step, Set SFS = 1 Hz
Reduce STS if faster Ramp-Up Wanted
Motor Slip?
No
Yes
Motor Slip?
No
Yes
Go to closed-loop control once the desired ramp-up is achieved

Figure 21: State Flow Diagram for Ramp Sequence Tuning Parameters

Closed-Loop Control

The last important part for the startup configuration is tuning the parameters for the closed-loop speed control. The parameters that must be tuned in closed-loop control are provided in sections "Motor Commutation" and "Speed Control". The state flow diagram to tune the parameters in this section is provided in Figure 22.

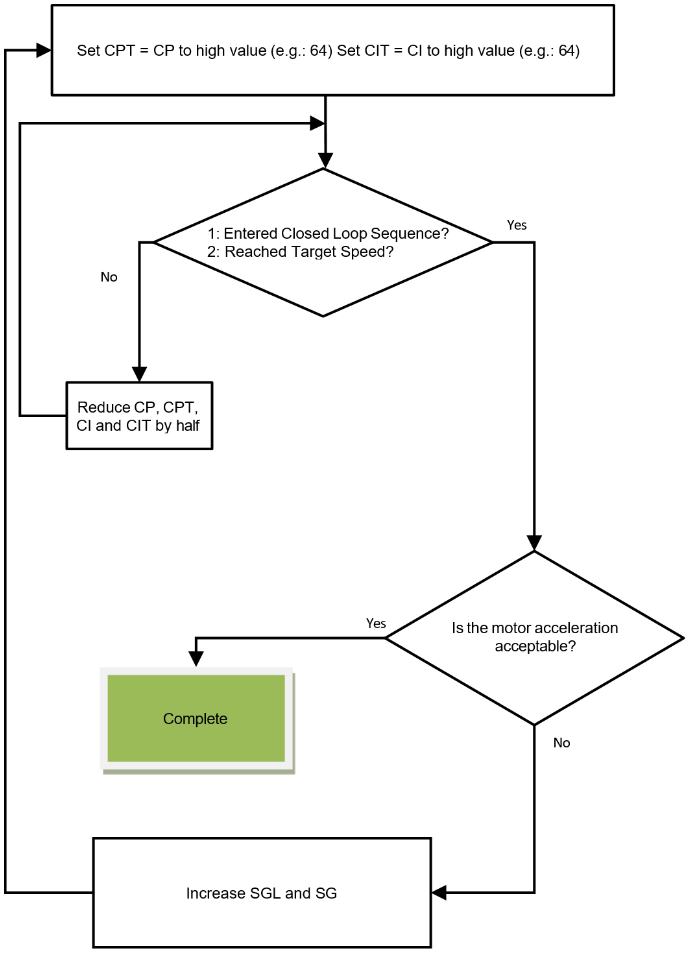

Set CPT = CP to high value (e.g.: 64) Set CIT = CI to high value (e.g.: 64)
1: Entered Closed Loop Sequence?
2: Reached Target Speed?
Yes
No
Reduce CP, CPT, CI and CIT by half
Is the motor acceleration acceptable?
Yes
No
Complete
Increase SGL and SG

Figure 22: State Flow Diagram for Close-Loop Tuning Parameters

Speed Loop Gains

Tuning the parameters for the closed-loop speed control follows the same logic as the ramp section. The acceleration during closed-loop speed control is limited by the two parameters SGL and SG. Higher gains can be used for low inertia motors and low gains should be used for high inertia motors to achieve stable performance. In addition to SGL and SG, a deceleration factor DF is added to increase control loop versatility during deceleration. If slow deceleration is required, the deceleration factor can be increased.

Position Loop Gains

The position loop gains CP, CI, CPT, and CIT also must be tuned properly for smooth speed control. If low gains are used, the estimated motor position can lag behind the actual motor position, therefore causing disturbance in the motor control due to late commutation. On the contrary, if high gains are used, the estimated motor position can be further ahead from the actual motor position, which can again result in disturbance in the performance of the motor. It is recommended to set CPT = CP and CIT = CI. Figure 22 provides a diagram, which demonstrates how to tune these parameters.

Phase Advance

Phase advance serves two purposes: to improve efficiency of the system and to allow the motor to go beyond the base speed. The state flow diagram to tune parameters for phase advance is shown in Figure 23.

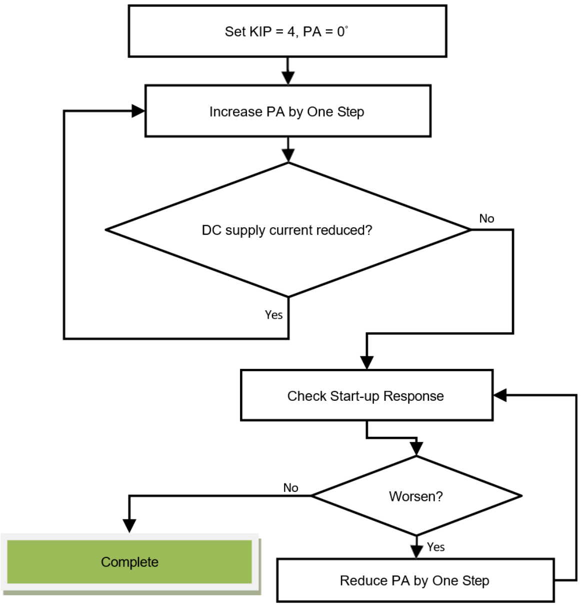


Figure 23: State Flow Diagram for Phase Advance Tuning Parameters

The efficiency improvement by using phase advance can be understood by observing Figure 24 and Figure 25. In Figure 24, the waveforms of phase current and voltage are shown without application of phase advance. It should be noted that the phase voltage signal is averaged to make the impact of phase advance clearer. Due to the inductance of the windings in the stator, when phase voltage is applied, there will always be a short delay in the rise of the current. The bemf signal is synchronized with the signal FG, as shown in Figure 24. If at a point, the bemf zero crossing occurs, the current will not be zero and there will be a sudden spike at the phase voltage. This occurs because at the point of bemf zero-crossing, both bridge FETs are in tri-state, meaning the voltage seen at the phase is due to the voltage spike in the coil inductance and center tap voltage only. This effect results in distortion in both phase voltage and current and thus leads to harmonic losses and a less efficient system. However, with the introduction of phase advance, which shifts the current waveform with respect to bemf, it is possible to align bemf zero-crossing with phase current zero-crossing as shown in Figure 25. By shifting the current waveform by 7 degrees, it can be noticed at the point the bemf zero-crossing occurs when the current is zero. Therefore, this results in a less distorted current and voltage waveform, leading to a more efficient system.

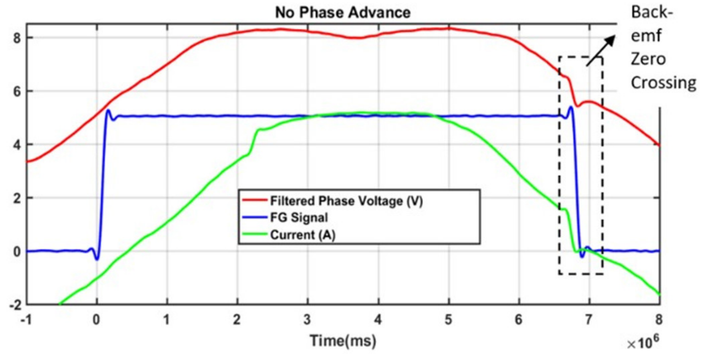


Figure 24: Phase Current and Voltage Waveform with No Phase Advance

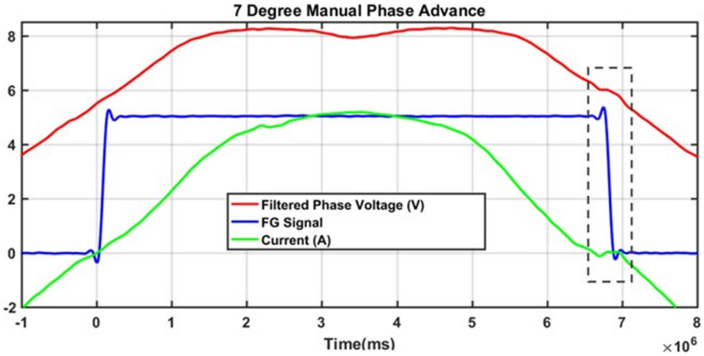


Figure 25: Phase Current and Voltage Waveform with 7-Degree Phase Advance

There are cases where even with the application of 100% duty cycle, the desired speed cannot be achieved. In these cases, phase advance can be used to force the motor to go beyond the base speed. The bemf of the motor depends on motor speed and voltage constant. In the best-case scenario, bemf can be equal to phase voltage (no load condition).

Therefore, since the phase voltage is fixed, the only way to go beyond the base speed is to reduce the voltage constant. By shifting the current with respect to bemf, a field is created in the stator that opposes the permanent magnet field. This results in a reduction of flux density, and therefore a reduction of voltage constant. Reduction of voltage constant allows an increase of speed beyond the base value. However, it should be noted that in this case, due to weakening of the field, there is less torque available, and if the motor is heavily loaded, it can result in a disturbance in motor performance.

There are two modes of phase advance operation, manual and automatic, which can be set using the parameter PAM. To adjust phase advance in manual mode, initially set PA to zero degrees. Record the waveform of the phase current at a falling edge of FG. Check if there is any sudden current change. If there is, change the phase advance slightly until a clean waveform without any distortion is achieved. If automatic phase advance operation is used, the phase advance is adjusted automatically to achieve better efficiency. To achieve automatic phase advance successfully, it is important to set PA to 0 and to have each phase going high-impedance (both high-side and low-side MOSFETs in the off-state) for a minimum of approximately 50% of the programmable dead time, DT[5:0].

Bemf Sensing

The next important parameter to be tuned is the bemf window. In order to detect bemf, the applied signal to the phases should be stopped. The duration of bemf measurement is defined by the bemf window. For low-speed motors, a small bemf window should be sufficient; however, at higher speeds the bemf window must be extended to allow detection of the zero-crossing point, which is used for closed-loop speed control. The increase in the bemf window results in more reliable control performance at high speed at the expense of a less sinusoidal waveform. The number of times the window is opened in each electrical cycle depends on bemf sampling BS. If BS is set to 1, only one window will open, and it is only for phase A. If BS is set to 2, two window will open for phase A only. If BS is 3, one window will open for each of the phases, and finally if BS is 6, two windows will open for each of the phases. The higher the number of bemf sampling, the more reliable the control can be at the cost of more disturbance in sinusoidal waveform across all phases. The bemf filter time is used for windmill and it must be tuned only if windmill is used.

Tuning Parameters for Current Control and Open Loop Voltage Control

In both control modes, the first two sequences, which are alignment and ramp, remain the same as speed control. In open-loop control mode, DI defines the applied duty cycle to the system after the first two sequences. In current control mode, the error between measured current across the sense resistor and the reference current, defined by DI, defines the duty cycle applied to the phases. For positive error, the duty cycle continues to increase until the reference current is achieved and vice versa for the negative error. In both cases, the position loop gains must be adjusted properly using the same method as shown in the last section, and speed loop gains no longer have any impact in any of the two modes. Therefore, in these two control modes, there are no additional parameters that must be tuned. The desired control mode can be selected in the GUI by clicking on “System” and then modifying “Motor Control Mode”, CM.

APPENDIX A: EVALUATION BOARD SCHEMATIC

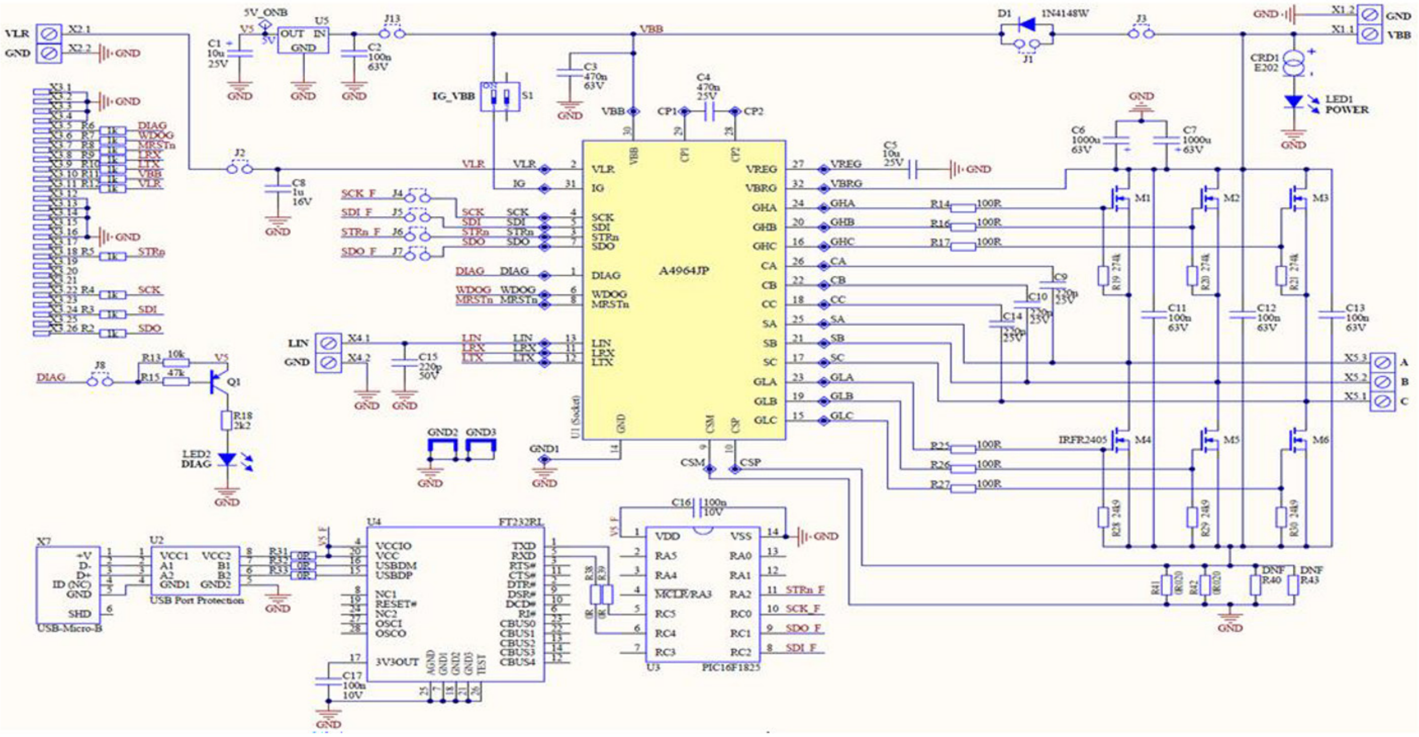


Figure 26: A4964 Evaluation Board Schematic

APPENDIX B: EVALUATION BOARD LAYOUT

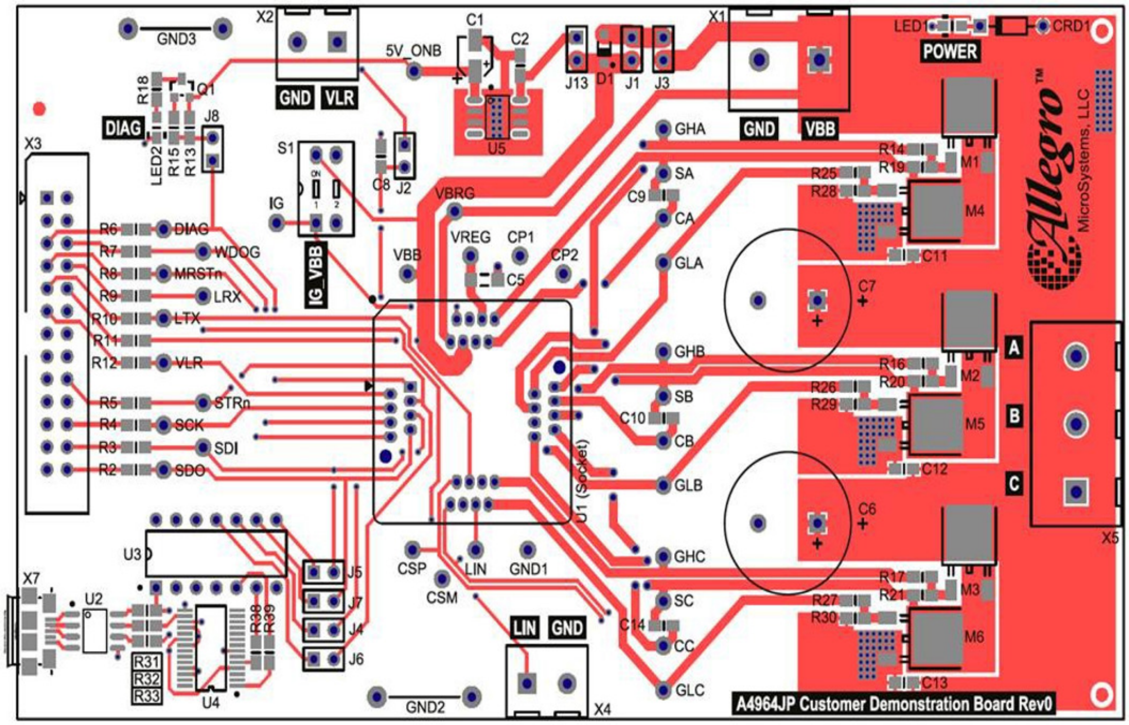


Figure 27: Top Board Layout

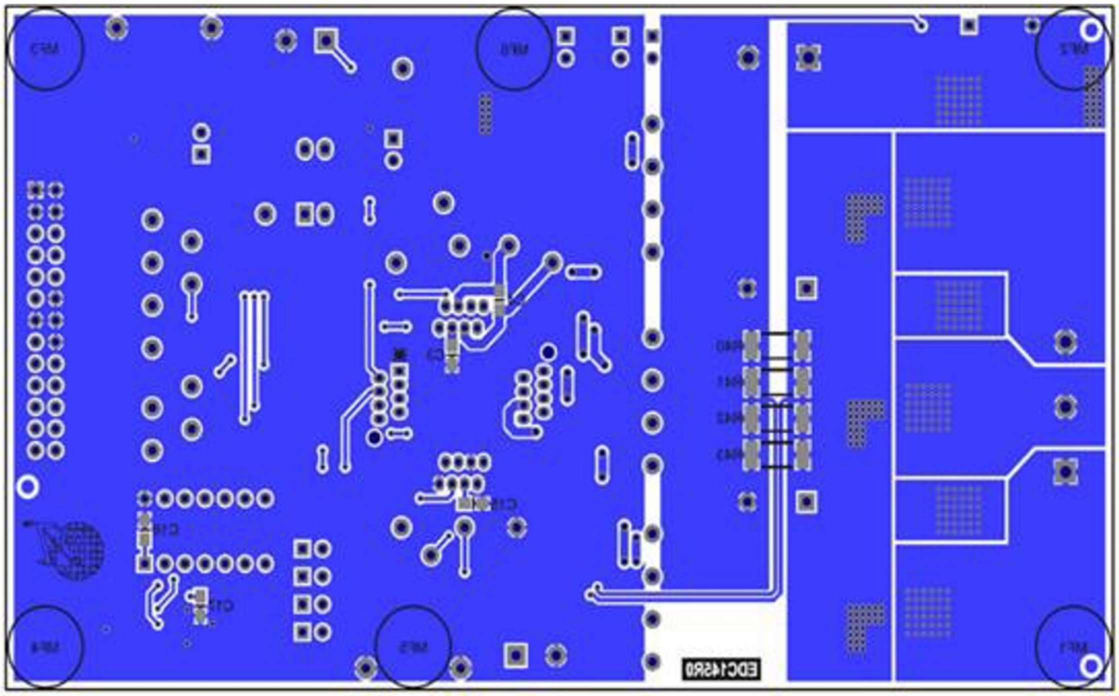


Figure 28: Bottom Board Layout

APPENDIX C: EVALUATION BOARD COMPONENTS

Table 2: Component Function, Specification, and Selection Criteria

Component	Value	Type	Notes
C1	10 µF (25 V)	X7R Ceramic Capacitor	Decoupling capacitor used for 5 V regulator output. Used to provide inrush current for diagnostic LED.
C2	100 nF (63 V)	X7R Ceramic Capacitor	Decoupling capacitor used for 5 V regulator input. Used to provide ripple current required by the regulator.
C3	470 nF (63 V)	X7R Ceramic Capacitor	Local decoupling capacitors for near VBB pin of A4964 to provide high switching currents.
C5	10 µF (25 V)	X7R Ceramic Capacitor	Output decoupling capacitor used for V_{REG} voltage. Used to reduce V_{REG} output voltage ripple.
C6, C7	1000 µF (63 V)	Electrolytic Capacitor	Motor supply decoupling capacitor. Provides a local low-impedance source to compensate for any supply wiring inductance. This capacitor provides ripple current pulses to the motor phase. Selected to be able to handle maximum motor phase ripple current.
C8	1 µF	X7R Ceramic Capacitor	VLR output decoupling capacitor. Provides a local low-impedance source to compensate for any supply wiring inductance. Provides ripple current pulses to V_{CC}. Selected to be able to handle maximum V_{CC} load ripple current.
C9, C10, C14	220 nF (25 V)	X7R Ceramic Capacitor	Bootstrap capacitors used to turn on high-side FETs.
C11, C12, C13	100 nF (63 V)	X7R Ceramic Capacitor	Local supply decoupling capacitors for V_{BB} supply pins. Provide high-frequency switching currents to the motor phase. Mounted as close as possible to VBB terminals on A4964.
C15	220 pF (50 V)	X7R Ceramic Capacitor	Local decoupling capacitors for LIN interface.
D1	0.2 A 60 V	Diode	Provides arbitrary path from supply voltage to A4964.
LED1	High-Efficiency Red LED	Red	High-efficiency LED to indicate the power supply has been applied to the device.
LED2	High-Efficiency Red LED	Red	Low-current high-efficiency red LED. Indicates when the FAULTn output is low. Provides fault indication when FAULTn is in default condition. R18 limits current through this LED to about 2 mA.
R2, R3, R4, R5, R6, R7, R8, R9, R10, R11, R12	1 kΩ	0805 Chip resistor	Logic signal current limit resistors. Provide some protection for logic inputs of A4964.
R13	10 kΩ	0805 Chip resistor	Current limit resistor. Prevent current flow from 5 V regulator to DIAG pin.
R14, R16, R17, R25 R26, R27	100 Ω	0805 Chip resistor	Filter resistors for gate of the FETs.
R15	47 kΩ	0805 Chip resistor	Current limiting resistor. Used to limit current flowing from DIAG pin to base of transistor Q1.
R18	2.2 kΩ	0805 Chip resistor	Current-limiting resistor for LED2.
R19, R20, R21, R28, R29, R30	274 kΩ	0805 Chip Resistor	Used as protection to turn off FETs in case A4964 device is fully turned off.
R31, R32, R33, R38, R39	0 Ω	0805 Chip Resistor	Jumper resistors used to provide interface between communication devices.
R41, R42	20 mΩ	2512 Chip Resistor	5 V LDO on-board regulator for on-board parts.
U2	USB port protection		Used to avoid flow of current back to USB port and limit current from USB device.
U3	PIC device		Microcontroller that provides serial interface.
U4	FTDI Chip		
U5	LDO	LM2936HVMA-5.0	5 V LDO on-board regulator for on-board parts.
CRD1	E202		Current regulator to control current going to LED1.

APPENDIX D-1: GUI DEFAULT SETTINGS

The GUI default settings are loaded via the DEFAULT button and can be used as a starting point when tuning the register settings.

Once the default settings are loaded into the GUI, the register settings can be retuned using the guidelines provided in this user manual.

To load the default settings into the GUI, follow the instructions below:

1. Open GUI, ensure that A4964 is supplied with power and USB connection exists between PC and A4964.
2. Click on the “Load Default” button in the main window of the GUI.
3. At this point, the GUI is loaded with the settings and it automatically updates the register of A4964 with these values.

```
The part number is: A4964 Config[0] is: 0CC Con-
fig[1] is: 001
Config[2] is: 028
Config[3] is: 001
Config[4] is: 001
Config[5] is: 001
Config[6] is: 0FE
Config[7] is: 07E
Config[8] is: 07F
Config[9] is: 001
Config[10] is: 001
Config[11] is: 021
Config[12] is: 021
Config[13] is: 006
Config[14] is: 070
Config[15] is: 3C2
Config[16] is: 038
Config[17] is: 04F
Config[18] is: 085
Config[19] is: 021
Config[20] is: 1EF
Config[21] is: 007
Config[22] is: 086
Config[23] is: 00F
Config[24] is: 0FE
Config[25] is: 289
Config[26] is: 001
Config[27] is: 001
Config[28] is: 201
Config[29] is: 180
Config[30] is: 102
RShunt is: 00A Npp is: 006
```

APPENDIX D-2: SETTINGS FOR LOW INERTIA MOTOR AND LOAD

These settings are used for BLDC motors with low inertia, light resistive torque loads. They work best for motors with low inertia and maximum power ratings in the range of 20 to 100 W. Some further tuning may be needed after applying these settings if the motor does not run smoothly, for which the guideline provided in this user manual can be used.

To load the new settings into the GUI, follow the instructions below:

1. Copy and paste the text provided in the table shown on the right.
2. Open Notepad and paste the text into it.
3. Save the Notepad file with the ".rst" extension
4. Open GUI, ensure that A4964 is supplied with power and USB connection exists between PC and A4964.
5. Click on the "Load" button in the main window of the GUI, locate the saved file with the ".rst" extension, and open it.
6. At this point, the GUI is loaded with the new settings and it automatically updates the register of the A4964 with these values.

```
The part number is: A4964
Config[0] is: 048
Config[1] is: 000
Config[2] is: 028
Config[3] is: 000
Config[4] is: 000
Config[5] is: 000
Config[6] is: 000
Config[7] is: 07E
Config[8] is: 07E
Config[9] is: 000
Config[10] is: 000
Config[11] is: 0CC
Config[12] is: 0CC
Config[13] is: 006
Config[14] is: 062
Config[15] is: 0C0
Config[16] is: 000
Config[17] is: 000
Config[18] is: 124
Config[19] is: 020
Config[20] is: 012
Config[21] is: 06C
Config[22] is: 006
Config[23] is: 00E
Config[24] is: 000
Config[25] is: 208
Config[26] is: 000
Config[27] is: 000
Config[28] is: 200
Config[29] is: 100
Config[30] is: 1F4
RShunt is: 00A
Npp is: 006
```

APPENDIX D-3: SETTINGS FOR LARGE FAN APPLICATION

These settings are used for BLDC motors used for vehicle engine cooling fan applications. They work best for motors with high inertia fan loads and maximum power ratings in the range of 300 to 700 W. Some further tuning may be needed after applying these settings if the motor does not run smoothly, for which the guidelines provided in this user manual can be used.

To load the new settings into the GUI, follow the instructions below:

1. Copy and paste the text provided in the table shown on the right.
2. Open Notepad and paste the text into it.
3. Save the Notepad file with the ".rst" extension
4. Open GUI, ensure that A4964 is supplied with power and USB connection exists between PC and A4964.
5. Click on the "Load" button in the main window of the GUI, locate the saved file with the ".rst" extension and open it.
6. At this point, the GUI is loaded with the new settings and it automatically updates the register of the A4964 with these values.

```
The part number is: A4964
Config[0] is: 04A
Config[1] is: 001
Config[2] is: 029
Config[3] is: 001
Config[4] is: 001
Config[5] is: 001
Config[6] is: 19F
Config[7] is: 07F
Config[8] is: 07F
Config[9] is: 001
Config[10] is: 001
Config[11] is: 0A7
Config[12] is: 0A7
Config[13] is: 007
Config[14] is: 062
Config[15] is: 3C7
Config[16] is: 238
Config[17] is: 15F
Config[18] is: 085
Config[19] is: 043
Config[20] is: 1EA
Config[21] is: 08A
Config[22] is: 182
Config[23] is: 00C
Config[24] is: 001
Config[25] is: 289
Config[26] is: 097
Config[27] is: 001
Config[28] is: 200
Config[29] is: 18F
Config[30] is: 2BC
RShunt is: 00B
Npp is: 005
```

Revision History

Number	Date	Description
–	May 4, 2017	Initial Release
1	May 10, 2017	Correct Ramp Section
2	November 8, 2017	Added information about “Capture” window in GUI and its update rate Added information about new automatic tuning feature in GUI. Added information about motor constant KM in “Motor Control” section.
3	July 27, 2018	Updated the “Commutation” section. Modified Figure 25 “State Flow Diagram for Tuning Parameters for the Closed-Loop”. Modified the “Position Loop Gains” section. Updated the “Phase Advance” section to include both automatic and manual phase advance operation. Modified “Appendix D.1” description.
4	December 9, 2022	Updated document branding and minor editorial updates throughout.

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