Sensorless, Sinusoidal Drive BLDC Controller

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Introduction

This application note describes the operation and use of the demo board for the Allegro A4964 Automotive, Programmable BLDC controller. The A4964 is a flexible sensorless, sinusoidal motor controller driving an external 3-phase N-channel MOSFET bridge for easy implelemtation of a BLDC motor driver. The A4964 can be used as a stand-alone controller or it can be used in a system with a microcontroller which provides the communication to a central ECU, and also the intelligent fault and status handling. The supply and watchdog for the microcontroller can be provided by the A4964, which also provides a physical interface bewteen 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 very 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 start-up scheme provides highly programmable start-up 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 under voltage, over temperature and power bridge faults and can protect the power switches under most short circuit condition. By monitoring the contents of the status register in A4964 via the serial interface, any fault conditions present can easily be identified.

The A4964 is fully described in the datasheet, which should be read in conjunction with this demo board document.

Board Features

The 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 micro with a suitably programmed A4964 sample. The board requires a single DC power supply between 5.5V and 50V. The board does not include any reverse battery or transient clamp circuits. The motor is connected to the board through a high-current 3-way and the main supply is connected to the board through a high-current 2-way connector. Additionally, a USB cable is provided, together with a Graphical User Interface (GUI), for users to control the motor, to programme many of the integrated features and to read back diagnostic information, via the serial interface. A microcontroller is included on the demo 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 datalog 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 connection is available.

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

Circuit Description

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

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

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

It is recommended to keep the maximum current limit below 20A for this 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 1and the component placement and board layout is shown in Appendix 2. The function, specification, and selection criteria for the components are listed in table C1 in Appendix C.

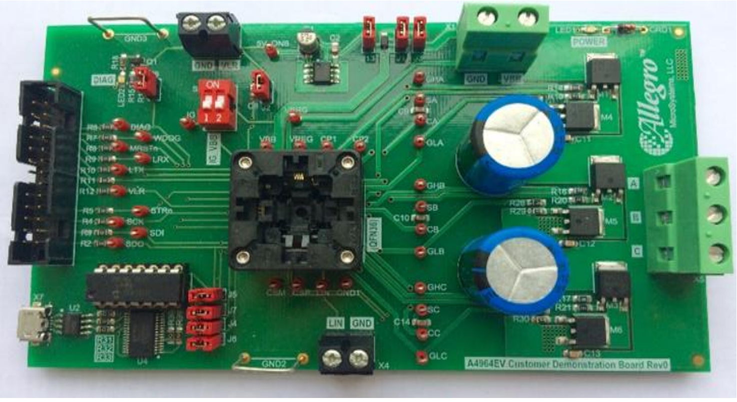

Allegro MicroSystems, LLC
A4964EV Customer Demonstration Board Rev0
LIN
GND
POWER

Figure 1: A4964 Customer Demo Board

Board Set-up and Operation

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

- USB cable
- A4964 demo board
- External motor supply (5.5-50V)
- 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 5. The USB cable and GUI provided is not the only interface option to control the A4964 to drive the motor. The A4964 demo board can also be used in conjuctinon with external microcontroller using serial interface communication or the control can be done in stand alone mode by using the LIN input as described above.

Board Connections

The A4964 demo board has six connectors. One 2-way screw connector for the main supply, and another 2-way connecter that provides the logic supply output from the A4964. A single 3-way screw connector for the motor connection, a 2-way screw connector for LIN terminal for stand-alone 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 2-way screw connector X1. A positive supply, between 5.5V and 50V, 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 50V 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 5V or 3.3V to different target devices such as external MCU through X2 connector as long as the provided current doesn't exceed 70mA. The logic level of the target device needs to be connected to the X2 connector at the point, labelled VLR, and the return path needs to be connected to X2, at a point labelled GND.

Load Connections

A 3-phase BLDC motor is connected through the 3-way screw terminal, X5, labelled SA, SB and SC. The current to drive the motor is provided via the 3-phase MOSFET bridge from the main supply connected to X1.

Control Connections

The serial interface communication between the A4964 and Windows® based GUI is provided using a standard USB to MicroUSB cable by connecting the microUSB end to the connector X7 on the demo board and the standard USB connector to the target PC (See sofware 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 need to 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 need to be removed.

If stand-alone 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 needs to be connected to the point labelled LIN and the return path needs to be connected to the point labelled GND. The duty cycle of the PWM signal would then determine the demand input. In the stand-alone mode, the DIAG terminal can also be shorted to the LIN terminal to shut down the system in case any fault condition exists.

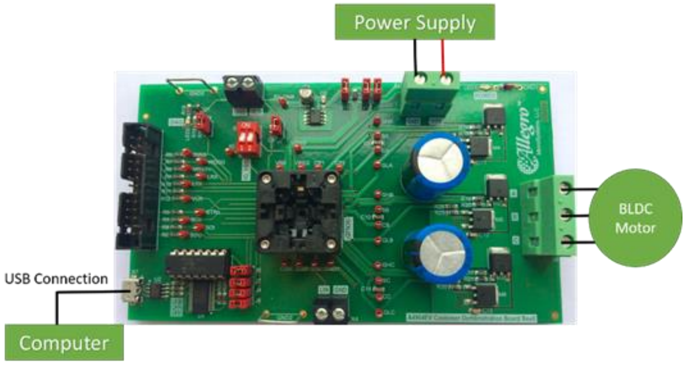


Figure 5: Connection Diagram to Interface the GUI

Software Installation

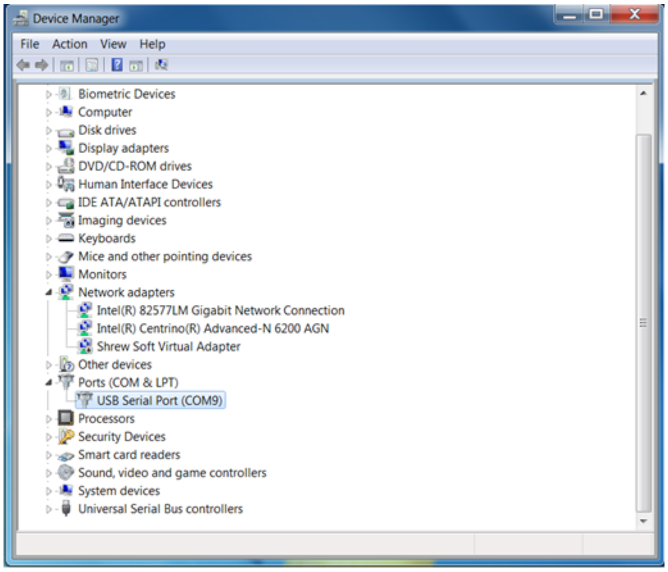
A USB cable is provided for users to operate the A4964 demo board from a Windows® based desktop or laptop PC using the A4964 Serial Control GUI. Hardware drivers must be installed for the USB cable before use. A driver installer can be downloaded for the correct Windows version from the drivers page 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 6.

Allegro also provides the A4964 Serial Control Graphical User Interface (GUI) which can be used to operate the demo board through the USB cable. The GUI is a standalone executable file, named A4964SerialVxpx.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 screen shot of the GUI when running is shown in figure 7.

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 demo board. Otherwise, if the cable is disconnected, or the driver has not been installed correctly, then the "SPI Status" window will display "False!".

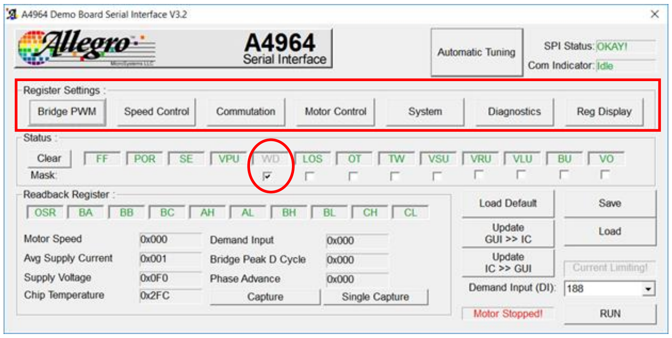


Biometric Devices
Computer
Disk drives
Display adapters
DVD/CD-ROM drives
Human Interface Devices
IDE ATA/ATAPI controllers
Imaging devices
Keyboards
Mice and other pointing devices
Monitors
Network adapters
Intel(R) 82577LM Gigabit Network Connection
Intel(R) Centrino(R) Advanced-N 6200 AGN
Shrew Soft 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 6: Windows Device Manager

General Overview of the GUI

The main window of the GUI is shown in figure 7.

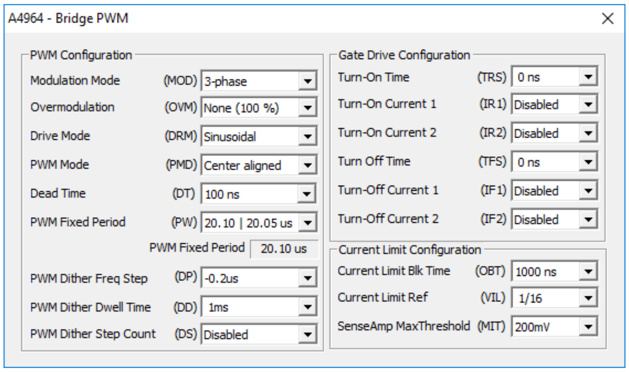


SPI Status: OKAY!
Com Indicator: Idle
Motor Speed 0x000
Avg Supply Current 0x001
Supply Voltage 0x0F0
Chip Temperature 0x2FC
Demand Input 0x000
Bridge Peak D Cycle 0x000
Phase Advance 0x000
Demand Input (DI): 188

Figure 7: GUI Main Window

Various settings such as type of control, fault detection, etc. can be configured in the GUI and based on their functionality, they are grouped in seven pop-up windows which are marked with red rectangle in figure 7. The summary of each of the configuration is provided in this application note, however, if the detailed explaination 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 8 will open. Then, if further information about "Modulation Mode" is requried, the title "Modulation Mode"can be searched in the A4964 datasheet in order to obtain full details about it.

Bridge PWM



A4964 - Bridge PWM

PWM Configuration

Modulation Mode (MOD) 3-phase

Overmodulation (OVM) None (100 %)

Drive Mode (DRM) Sinusoidal

PWM Mode (PMD) Center aligned

Dead Time (DT) 100 ns

PWM Fixed Period (PW) 20.10 | 20.05 us

PWM Fixed Period 20.10 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) 1000 ns

Current Limit Ref (VIL) 1/16

SenseAmp MaxThreshold (MIT) 200mV

Figure 8: GUI Bridge PWM Section

The first pop up window is the Bridge PWM which after clicking on it, should show the content shown in figure 8. “Modulation Mode”, defines the number of phases that are turned on at the same time. For 3-phase, all of the phases will be driven with PWM signal, whereas for the 2-phase, one of the phases is always driven low and two other phases are driven with PWM signal. The 2-phase modulation results in lower switching loss, however, with 3-phase modulation, the torque ripple reduces therefore resulting in less audiable noise at low power outputs. Both trapezoidal and sinusoidal driving mode are available in A4964 which can be selected in the “Drive Mode”. If higher driving capability than is available in sinusoidal mode is required, “Overmodulation” can be used.

The frequency of the applied PWM signal can be controlled in “PWM Fixed Period”, and the alignment of PWM signals in the three phases can be done by utilizing the “PWM Mode” option.

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” option.

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 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” accrodingly. 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 controling the FET gate charge and discharge rate. In A4964 the slew rate control can be utilized 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 which are labelled IR1 and IR2. For the duration defined by the TR, the current defined by the 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 of the time, TR, ends, the current IR2 is sourced to the the gate of the FETs. IR2 is usually set lower than IR1 to increase duration of miller region which would therefore result in slower rise of the phase voltage. When the FET reaches 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 the 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 measured 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 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 would circulate through low side switches. This state is maintained untill the next PWM period starts. The V_{ILIM} can be calculated using the following equation:

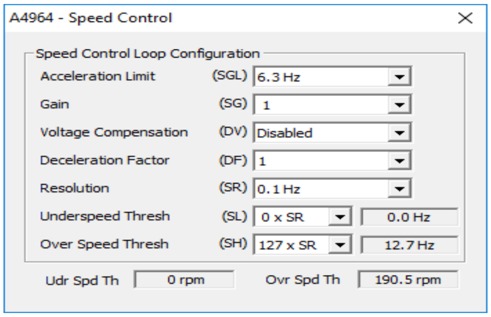
$$V_{ILIM} = V_{MIT} \times V_{ISC}$$

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

For example, if V_{MIT} is set to 200mV and V_{ISC} to 1/16, then the maximum allowed voltage across sense resisor is equal to 12.5mV. The current limit can be disabled by clicking on the System window and disabling DIL as shown in figure 13.

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)	1
Voltage Compensation	(DV)	Disabled
Deceleration Factor	(DF)	1
Resolution	(SR)	0.1 Hz
Underspeed Thresh	(SL)	0 x SR · 0.0 Hz
Over Speed Thresh	(SH)	127 x SR · 12.7 Hz

Udr Spd Th 0 rpm · Ovr Spd Th 190.5 rpm

Figure 9: GUI- Speed Control Section

The acceleration and deceleration profile that can be achieved with A4964 is shown in figure 10. The linear speed rise, or constant acceleration, is limited by the product of SGL and the gain SG. Once the motor reaches to the speed = reference speed – SGL , the acceleration will be limited by SG only. For deceleration, there is an additional variable limting 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 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 7-19V, the compensation should be set to 12V, and for voltage ranges between 14-38V, 24V compensation should be used. The 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 motor control section.

The minimum and maximum achieveable speed can be set by underspeed (SL) and overspeed (SH) threshold. If the motor speed is below underspeed threshold or above overspeed threshold, the loss of synchronization occurs and the fault , LOS, shown in the content of status register in figure 7 will flag and the motor will stop by shutting down the FETs M1-M6 in figure 2. More information about LOS can be found in the datasheet.

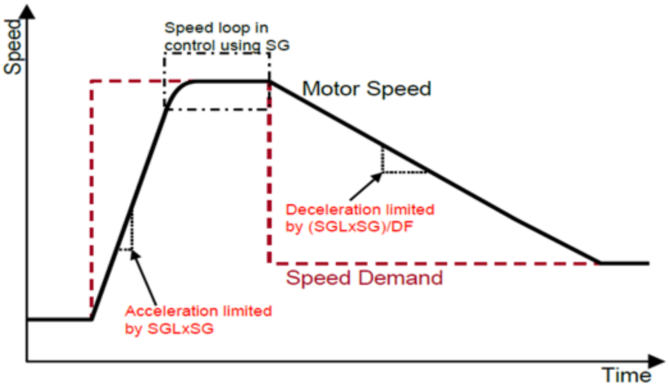
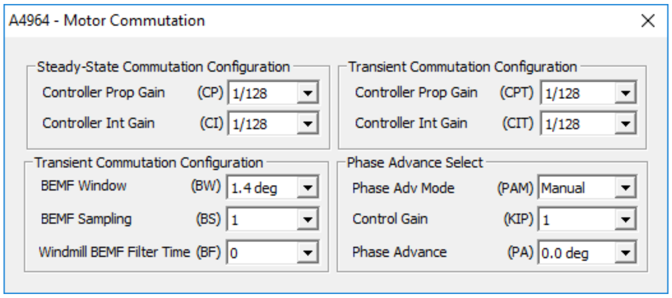

Speed
Speed loop in control using SG
Motor Speed
Deceleration limited by (SGLxSG)/DF
Speed Demand
Acceleration limited by SGLxSG
Time

Figure 10: Acceleration and Deceleration Profile

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

Commutation



A4964 - Motor Commutation

Steady-State Commutation Configuration

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

Transient Commutation Configuration

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

Transient Commutation Configuration

BEMF Window	(BW)	1.4 deg
BEMF Sampling	(BS)	1
Windmill BEMF Filter Time	(BF)	0

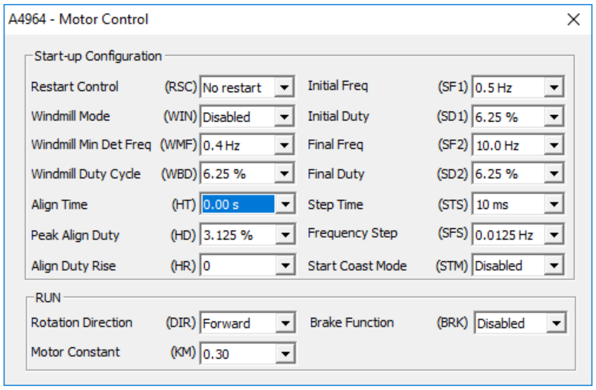
Phase Advance Select

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

Figure 11: GUI- Motor Commutation Section

The content of motor commutation pop-up window is shown in figure 11. The parameters in this section affect the closed loop control and need to be properly tuned in order to allow smooth operation of the motor. A4964 uses motor bemf for control purposes and therefore "BEMF Window" and "Sampling" are used to achieve the purpose. Also to allow motor operate beyond the base speed with the same supply voltage, field weakening needs to be performed. This can happen by tuning parameters in the "Phase Advance" section. Further information about the control gain adjustment, bemf sensing and phase advance are provided in this application note in section "Setting Up for First Time Use".

Motor Control



A4964 - Motor Control

Start-up Configuration

Restart Control	(RSC)	No restart	Initial Freq	(SF1)	0.5 Hz
Windmill Mode	(WIN)	Disabled	Initial Duty	(SD1)	6.25 %
Windmill Min Det Freq	(WMF)	0.4 Hz	Final Freq	(SF2)	10.0 Hz
Windmill Duty Cycle	(WBD)	6.25 %	Final Duty	(SD2)	6.25 %
Align Time	(HT)	0.00 s	Step Time	(STS)	10 ms
Peak Align Duty	(HD)	3.125 %	Frequency Step	(SFS)	0.0125 Hz
Align Duty Rise	(HR)	0	Start Coast Mode	(STM)	Disabled

RUN

Rotation Direction	(DIR)	Forward	Brake Function	(BRK)	Disabled
Motor Constant	(KM)	0.30			

Figure 12: GUI- Motor Control Section

This section of the GUI mainly focuses on the start-up 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 start up sequence which 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 start up sequences can be tuned and modified to achieve smooth and consistent start up. The start up sequence is discussed in details in the last section of this application note.

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

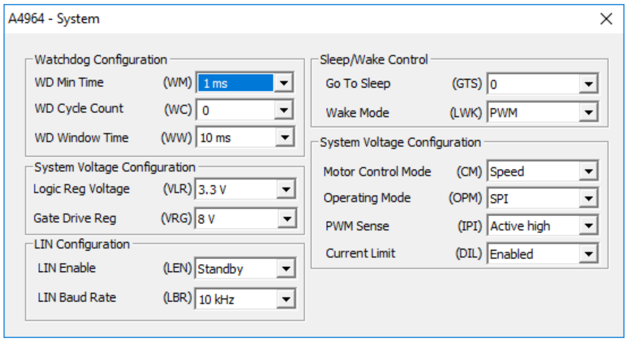
The motor rotation direction can also be controlled by modifying "Rotation Direction", DIR. If electromagnetic brake is required, the "Brake Function", BRK, can be used to enable all low side FETs and disable all high side FETs. By enabling all low side FETs, the current continues to flow within the phases due to back emf (bemf), creating a torque against the rotational directon of the motor and therefore force 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. The motor constant (KM) is related to the motor back-emf constant and can be calculated based on the following equations depending on the setting for the voltage compensation (DV).

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

Where K_{emf} is the motor back-emf constant in unit of $\frac{\boldsymbol{V.s}}{\boldsymbol{rad}}$. 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)	8 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)	Enabled

Figure 13: GUI- System Section

In this pop up window, several features of the device such as logic regulator and driver output voltage can be modified. Also 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 the adverse state.

When watchdog is enabled, the input waveform to the WDOG terminal needs to follow certain configuration which is explained in the datasheet. If the watchdog failure occurs, the MRSTn terminal output which is active low signal, can be used to disable or reset the microcontroller. The watchdog failure also disable 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 7.

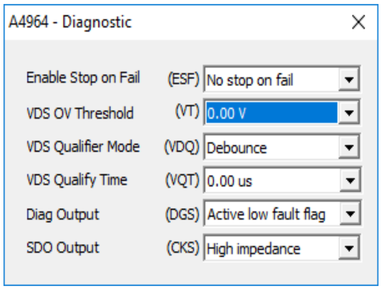
There are three control modes in A4964, closed loop speed control, closed loop current control and open loop voltage control mode, which can be set by defining the CM bit.

There are two ways to set the demand input (speed reference) in 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 7. In this case serial interface communication is used and therefore the "Operating Mode" OPM shown in figure 13 needs to be set to SPI. The other method is to apply duty cycle to the LIN input. In this case the OPM needs to be set to PWM (stand-alone 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, needs to be disabled. In this case the "Current Limiting!" status in the main window of the GUI , shown in figure 7, 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 to the limit and it will be grey 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 datasheet.

Diagnostics


A4964 - Diagnostic

Enable Stop on Fail	(ESF)	No stop on fail
VDS OV Threshold	(VT)	0.00 V
VDS Qualifier Mode	(VDQ)	Debounce
VDS Qualify Time	(VQT)	0.00 us
Diag Output	(DGS)	Active low fault flag
SDO Output	(CKS)	High impedance

Figure 14: GUI- Diagnostic

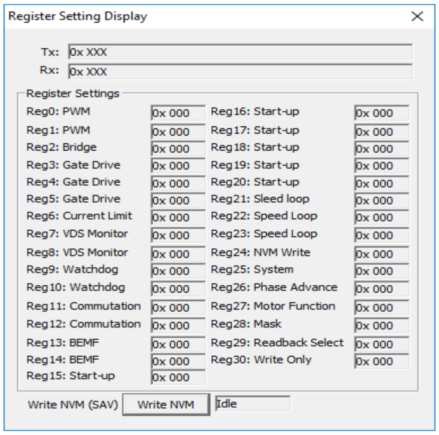
The setting in the diagnostic register should be adjusted properly in order to increase the reliability of the overall system and possible damage to the A4964 as well as other components such as FETs. The ESF bit, if set to "Stop on fail", will disable all the A4964 outputs in several conditions such as overtemperature, drain to source overvoltage and power supply voltage, VBB, 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 the drain to source voltage threshold VT provide 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 been persistent for the duration VQT. If VDQ is set to "Blank", the comparison of voltage across FET and overvoltage threshold VT is ignored once the output is turned on for the duration defined by VQT. When the VQT ends, if the voltage across 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 board can provide important information such as motor electircal 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 low signal in case any fault occurs. If it is set to FG, it will then output the motor speed and so on. To fully comprehend the different types of output waveforms depending on the setting of the DGS, refer to 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 transimmited (STRn=1). This generated waveform allow more precise calibration of the timing settings if required.

Register Display


Register Setting Display

Tx: 0x XXX
Rx: 0x XXX

Register Settings

Reg0: PWM	0x 000	Reg16: Start-up	0x 000
Reg1: PWM	0x 000	Reg17: Start-up	0x 000
Reg2: Bridge	0x 000	Reg18: Start-up	0x 000
Reg3: Gate Drive	0x 000	Reg19: Start-up	0x 000
Reg4: Gate Drive	0x 000	Reg20: Start-up	0x 000
Reg5: Gate Drive	0x 000	Reg21: Sleed loop	0x 000
Reg6: Current Limit	0x 000	Reg22: Speed Loop	0x 000
Reg7: VDS Monitor	0x 000	Reg23: Speed Loop	0x 000
Reg8: VDS Monitor	0x 000	Reg24: NVM Write	0x 000
Reg9: Watchdog	0x 000	Reg25: System	0x 000
Reg10: Watchdog	0x 000	Reg26: Phase Advance	0x 000
Reg11: Commutation	0x 000	Reg27: Motor Function	0x 000
Reg12: Commutation	0x 000	Reg28: Mask	0x 000
Reg13: BEMF	0x 000	Reg29: Readback Select	0x 000
Reg14: BEMF	0x 000	Reg30: Write Only	0x 000
Reg15: Start-up	0x 000		

Write NVM (SAV) Idle

Figure 15: GUI Register Display

The register display, shown in figure 15, 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 stand-alone mode with only a PWM control input.

To update write the present register values into the NVM the main supply should first be increased to at least 24V 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 the NVM. Click "Yes" or "No" and writing to the NVM will commence. If the NVM is updated successfully then the NVM write status box will display "success!". If there are any problems such that the NVM is not updated successfully then the NVM write status box will display "Failed!". If this occurs check that the supply voltage is above 24V 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 7. 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 a previously configured parameters into the GUI and as well update the A4964 with these new parameters. The previously configured parameter is a text file with the ".rst" extension. The 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 onto the GUI. Also if the GUI window is opened after 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 on to 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 the 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 subscript "`.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 needs to 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 R_{sense} is the sense resistor. In this case demand input sets V_{ILIM} as a ratio of maximum threshold of the V_{MIT}. V_{MIT} can be set by modifying the variable MIT which can be found in the "Bridge PWM" section of the GUI. For example when demand input is 256 and V_{MIT} is set to 200mV, V_{ILIM} will be 50mV.

Motor Status

Should there be any fault during operation of 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 over temperature, supply under voltage, regulator under voltage, etc. Once specific type of fault occurs, the associated fault will be marked with red colour and if there is no fault, it will be marked with green colour.

When A4964 is initially powered, the bits VLU, VRU, VSU, WD, SE, POR and FF will be shown with red colour. If watchdog is not used, WD bit needs to 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 the source of it needs to 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 the 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 the motor speed and average supply current, the number of pole pairs and sense resistor value need to be configured correctly. The information in the capture window is updated at approximately 700ms intervals, however, this severely depends on the operating system and also number of applications opened in the system background.

Setting up for First Time Use

Before operating the demo board for the first time, it should be set into a safe condition to avoid over current 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 the Supply Current to Minimum

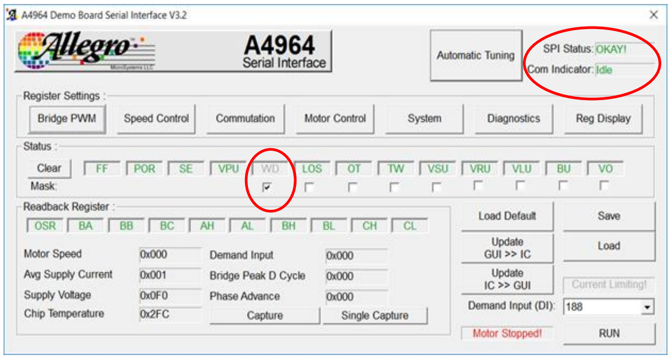
Before connecting the supply for the first time, ensure the supply current limit is set to a low value to avoid unexpected current caused by any component or load problems.
After connecting the power supply to VBB (connector X1), the power supply current should be approximately 15mA at 12V without any motor connected.

Interface the GUI

Table 1: Default jumper connections

Jumper	Terminal Detail	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 5V 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 USB driver as well as the GUI has already been discussed in section "Software Installation". The connection can be done by connecting one end of the provided micro USB to the PC and the other end to the demo board (connector X7). After connecting the two device together, open the GUI software. If the connection has been succesful, the "SPI status" window indicates 'OKAY!' as shown in figure 16, otherwise it will indiciate 'False!'. There is one more step needed before setting up the control parameters of the motor in the GUI and connect the motor to the board. Since watchdog is not utilized when interfacing the GUI, it needs to 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 check mark the "WD" bit as shown in figure 16. After doing so, press the "Clear" button. If the operation is done succesfully, 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 16. 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 V3.2

A4964 Serial Interface

SPI Status: OKAY!
Com Indicator: Idle

Register Settings :

Status :

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

Readback Register :

Motor Speed	0x000	Demand Input	0x000
Avg Supply Current	0x001	Bridge Peak D Cycle	0x000
Supply Voltage	0x0F0	Phase Advance	0x000
Chip Temperature	0x2FC		

Demand Input (DI): 188

Current Limiting!

Motor Stopped!

Figure 16: GUI- Main Window

Controlling the Motor with the GUI

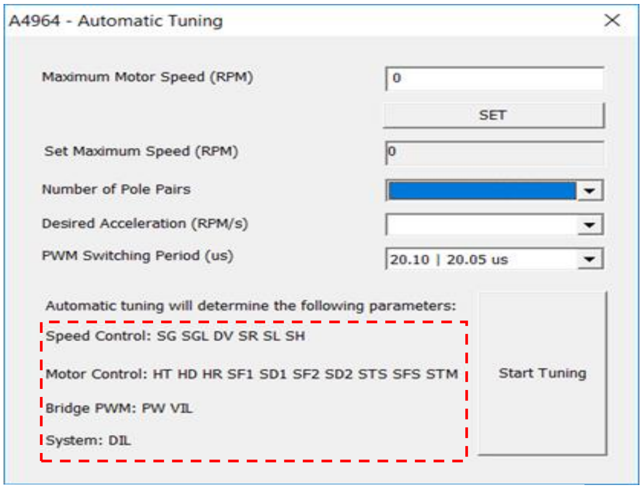
A number of example settings to run motors for different applications is provided in Appendix D. Once the desired setting is determined, open a blank text file (ie:notepad), copy and paste the determined setting into the file. Next, save the file with the ".rst" extension. In the main window of the GUI, click on the "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 on 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 start up problem, the guidelines provided in section "Tuning Parameters for Speed Control" can be followed and with minimum changes the motor should be able to run.

Automatic Tuning for Speed Control Mode

The A4964 GUI provides automatic tuning feature to adjust the gains for the closed loop speed control. To use automatic tuning feature, first ensure that the board is powered and the PC is connected to GUI via 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 16 if watchdog is not used. The parameters that are changed during automatic tuning is shown and marked in figure 17.

Once the default values are loaded in the GUI, click on the “Automatic Tuning” button. The pop-up window shown in figure 17 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): 20.10 | 20.05 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

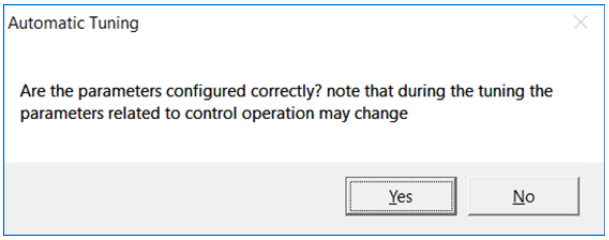
Bridge PWM: PW VIL

System: DIL

Figure 17: Automatic Tuning Window

In order to start tuning, two important parameters about the motor (rated speed (no load) and number of pole pairs) are required which can be easily found in the specific motor datasheet. The user then has to 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 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 “Set Maximum Speed” window is updated with the latest motor rated speed and then click on “Start Tuning” button. A new pop-up message will appear to confirm all the parameters are configured properly which is shown in figure 18. 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 18: Automatic Tuning Message

The only parameter that needs to be tuned in the “Auto Tuning” window is the desired acceleration. If the requested acceleration is too high and more than capability of the motor there can be start up problem. It is recommended to start with 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 at any of the provided acceleration profiles, small adjustment to the control gain settings will be necessary for which the guidelines provided in the next section can be utilised.

Tuning Parameters for Speed Control

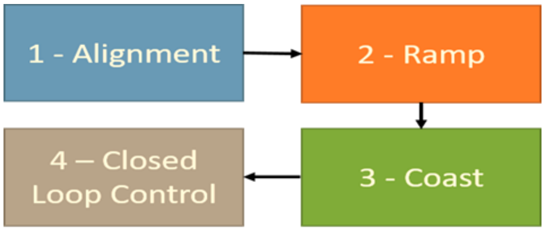


Figure 19: Start Up Sequence

The summary of start-up sequence is shown in figure 19. In order to achieve succesful start up of the motor, the parameters for each of the sequences need to 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 need to 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 very helpful for motor and loads with high inertia. Consider a simplfied drawing of typical BLDC as shown in figure 20. The winding of phase A is energized to form a magnetic pole shown with orange color in figure 20a. Considering the blue and orange colors indicate magnetic poles of different polarities, the rotor starts rotating clockwise as shown in figure 20a until the blue magnetic pole of the rotor is fully aligned with the stator which is demosntrated in figure 20b. At this point in order to further rotate the rotor, the phase B of the stator needs to be commutated. However, assume for the turn on duration of phase A, it is not possible for the rotor to fully align itself with the stator.due to its high inertia and it is placed at the location shown in figure 20c. At this point by commutating phase B, rather than moving clockwise, the rotor will try to rotate coutner clockwise causing disturbance in the motor performance. Therefore, the alignment function in the A4964 is used to place the rotor into a known position in order to achieve correct commutation sequence in the next start-up stage which is ramp.

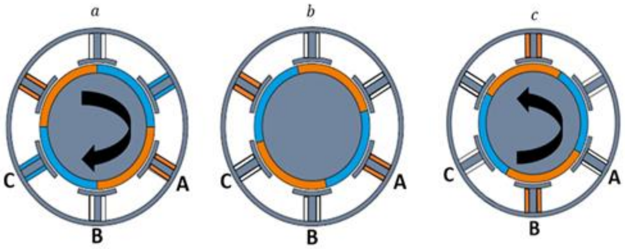


Figure 20: Illustration of rotor movement

The state flow diagram to tune the parameters for the alignment is shown in figure 21. Depending on the current position of the rotor and its inertia, the parameters relating to the alignment which are HT, HD, and HR need to be tuned. These parameters can be found in the “Motor Control” section of the GUI as shown in figure 12. For example, if the inertia is high and initial rotor position is far from the known position, the hold time, HT, needs to be increased to provide more time for the rotor to move to the desired position. Increasing the parameters align duty,HD, and reducing HR results in faster movement of the rotor to the known position which can be utilized if long hold time is not desired. It should be noted that during the alignment, once the motor reaches to the known position, it will remain in that position until the the hold time, HT, ends and the Ramp sequence begins.

If there are any problems with tuning of the parameters in this section, the motor starts vibrating and juddering at a certain position. For example, if HT is set to 3s and motor juddering is observed after 2s of running the motor, it means that the parameters in the alignment section needs to be tuned. Otherwise, if the motor viberation occurs after 3s, the problem is due to other untuned parameters in the next sequences of start up. The worst case condition is if the rotor is 180˚ far from the known position and motor inertia is high. In this case longer hold time , 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 start up. It should be noted that high value of HD can also result in motor vibration and so if the motor starts to vibrate this value needs to be reduced.

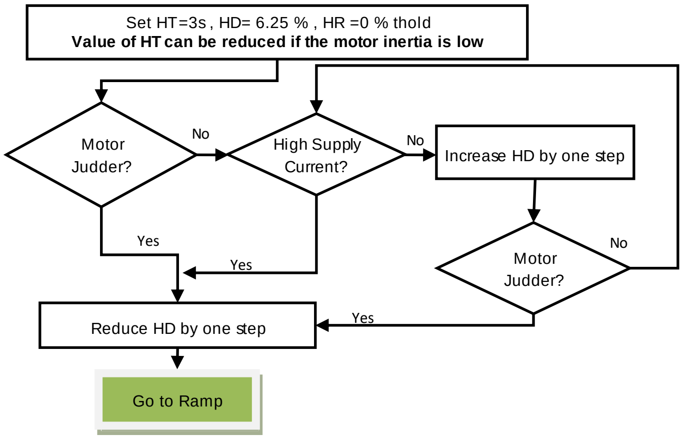


Figure 21: State Flow Diagram for Tuning Parameters for Alignment Sequence

Distinguishing Between the Untuned Parameters for the 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 the start-up this had occurred, the waveform of the signal FG have to 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. In order to ensure that it provides the 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 the FG. Measure the frequency of the signal FG on the oscilloscope. An example of frequency measurement is shown in figure 22. If the measured frequency is higher than the value defined by parameter SF2, it is confirmed that the Ramp sequence is implemented succesfully and the tuning needs to be done for the parameters of the Closed loop sequence. If the motor stops or judder before the frequency reaches to the value defined by the SF2, it indicates the parameters for the Ramp sequence are not well tuned . SF2 is among the parameters that needs to be tuned for the Ramp sequence and the importance of it is discussed in the next section.

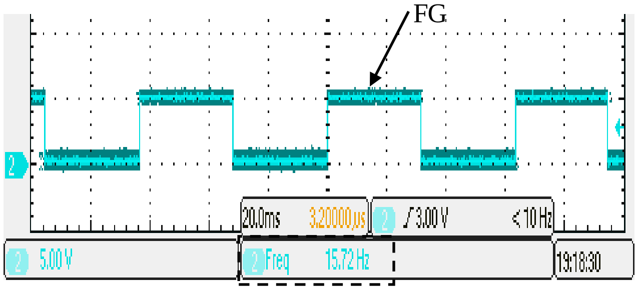


Figure 22: Demonstration of Frequency Measurement of the Signal FG

Ramp

The next important start-up 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 12. In order to implement sensorless closed loop control of the motor, the 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 the 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 rotating. The initial frequency of the waveforms and the peak applied duty cycle is determined by the parameters SF1 and SD1. For two phase modulation the peak applied duty cycle at zero degree positon 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 increase in each step is determined by SFS. Figure 23 illustares 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 to the value defined by SF2 after which the next sequence which is either Coast or closed loop control will initiate depending on the configuration which will be discussed later.

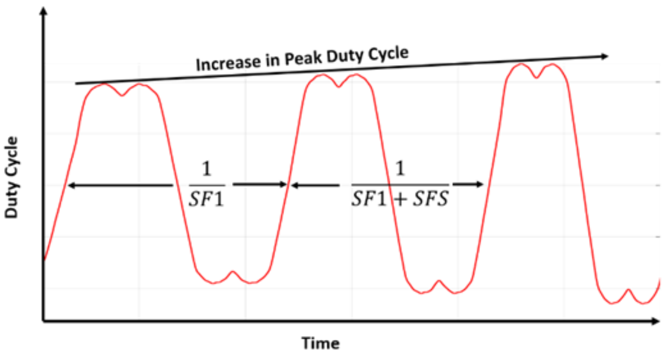


Figure 23: Ramp Sequence, Illustration of Duty Cycle with Respect to Time

Tuning the Parameters for the Ramp

The state flow diagram to tune parameters for the Ramp sequence is provided in figure 24. In order to tune parameters for the Ramp, one should realize the interdependency between the applied duty cycle and frequency. Consider figure 20 once again. If high frequency step is applied to the phases, it means the rotor also needs to 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 which 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 comparable to the applied frequency.

To tune, start with low value 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 the motor manufacturers provide the motor voltage (bemf) constant. If the motor has low voltage constant, higher value of SF2 is needed and vice versa. For motors with high inertia, SD2 needs to be high. If the inertia is low, SD2 needs to 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 start-up 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 the switches are turned off for very short duration which allows full measurement of bemf signal and detection of zero crossing point. This mode is useful for 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 the very low inertia motors, the Coast mode can completely stop the motor, therefore causing disturbance in the turn on sequence. It is recommended to enable the Coast mode if high inertia motor is used and disable it if the inertia is low. The Coast mode can be enabled or disabled by changing the bit STM in the "Motor Control" section in figure 12.

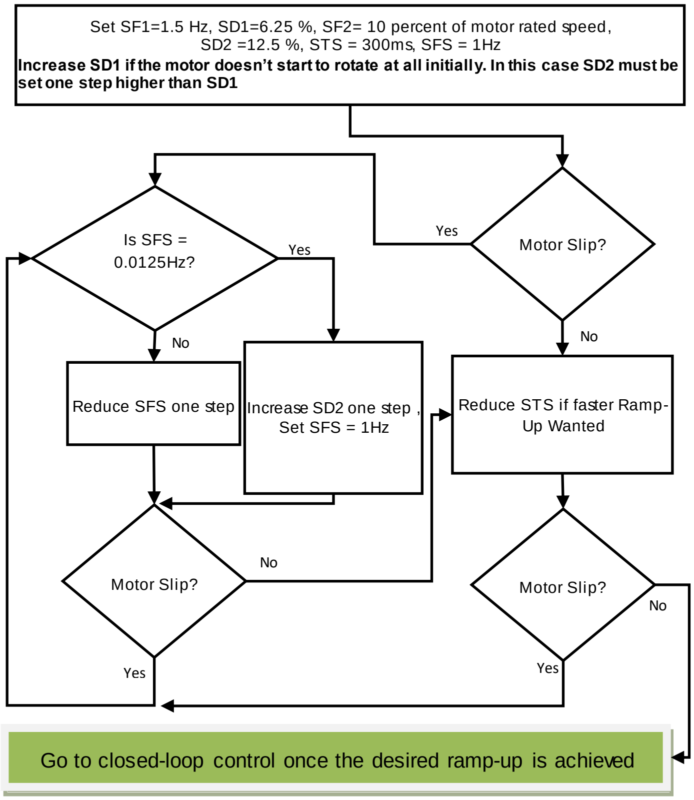

Set SF1=1.5 Hz, SD1=6.25 %, SF2= 10 percent of motor rated speed, SD2 =12.5 %, STS = 300ms, SFS = 1Hz
Increase SD1 if the motor doesn't start to rotate at all initially. In this case SD2 must be set one step higher than SD1
Is SFS = 0.0125Hz?
Yes
No
Motor Slip?
Yes
No
Reduce SFS one step
Increase SD2 one step , Set SFS = 1Hz
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 24: State Flow Diagram for Tuning Parameters for the Ramp Sequence

Closed Loop Control

The last important part for the start-up configuration is tuning the parameters for the closed loop speed control. The parameters that need to 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 25.

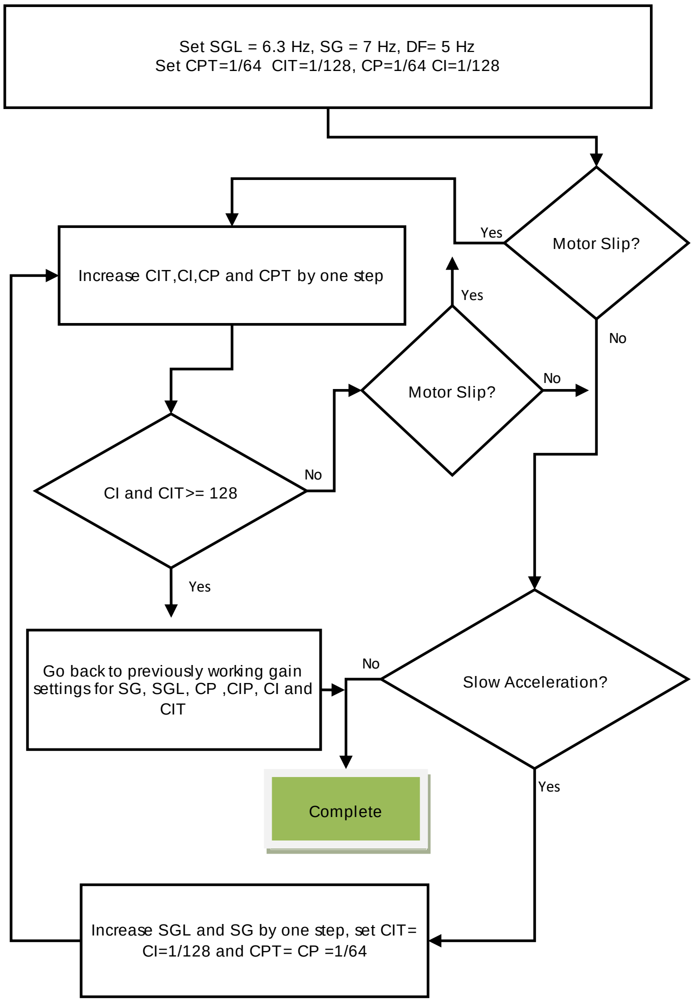

Set SGL = 6.3 Hz, SG = 7 Hz, DF= 5 Hz
Set CPT=1/64 CIT=1/128, CP=1/64 CI=1/128
Motor Slip?
Yes
No
Increase CIT,CI,CP and CPT by one step
Yes
Motor Slip?
No
CI and CIT>= 128
No
Yes
Go back to previously working gain settings for SG, SGL, CP ,CIP, CI and CIT
No
Slow Acceleration?
Yes
Complete
Increase SGL and SG by one step, set CIT= CI=1/128 and CPT= CP =1/64

Figure 25: State Flow Diagram for Tuning Parameters for the Closed- Loop

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 a slow deceleration is required, the deceleration factor can be increased.

Position Loop Gains

The transient phase controller gains, CP, CI, CPT and CIT, also need to be tuned properly for the 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. In contrary if high gains are used, the estimated motor position can be further ahead from the actual motor position, which can again result in disturabnce in the peroformance of the motor. Therefore, it is suggested to start the proportional gains CP and CPT at a low value such as 1/64 and then increase them until the desired performance is achieved. The integral gains CI and CIT should be usualy an order of two or four lower than proportional gains CP and CPT

Phase Advance

Phase advance can be used to serve two purposes. It can be used to improve the efficiency of the system. Also, it is utilized to allow the motor go beyond the base speed. The state flow diagram to tune the parameters for the phase advance is shown in figure 26.

The improvement in the efficiency by utlizing phase advance can be understoond by observing figure 27 and 28. In figure 27, the waveforms of phase current and voltage are shown without application of phase advance. It should be noted that phase voltage signal is averaged to make the impact of phase advance more clear. Due to inductance of the windings in the stator, when the phase voltage is applied, there is always going to be a short delay in the rise of the current. The bemf signal is synchronized with the signal , FG, as shown in figure 27 If at a point the bemf zero crossing occurs the current won’t be zero, there is going to be a sudden voltage 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 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 lead to harmonic losses and 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 28. By shifting the current waveform by 7 degree, it can be noticed at the point the bemf zero crossing occurs the current is zero. Therefore this results in less distorted current and voltage waveform leading to a more efficient system. To adjust the phase advance in manual mode, intially set PA to zero degree. 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.

There are also cases where even with the application of 100 % duty cycle, the desired speed can't be achieved. In these cases, the phase advance can be used to force the motor to go beyond the base speed. The back-emf of the motor depends on motor speed and the voltage constant. In the best case scenario back-emf 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 back-emf, a field created in the stator which opposes the permanent magnet field. This results in reduction of flux density and therefore reduction of voltage constant. Reduction of voltage constnat allows increase of the speed beyond the base value. However, it should be noted in this case due to weakening of the field, there is less torque avaiable and if the motor is heavily loaded, it can result in disturbance in the perforamcne of the motor.

Back-emf Sensing

The next important parameter to be tuned is the bemf window. In order to detect the 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 needs to be extended to allow detection of zero-crossing point which is used for the closed-loop speed control. The increase in the bemf window results in more reliable control perforamce at high speed at the expense of less sinusoidal waveform.The number of times the window is opened in each electrical cycle, depends on the 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, 1 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 the phases. The bemf filter time is used for windmill and it needs to be tuned only if windmill is used.

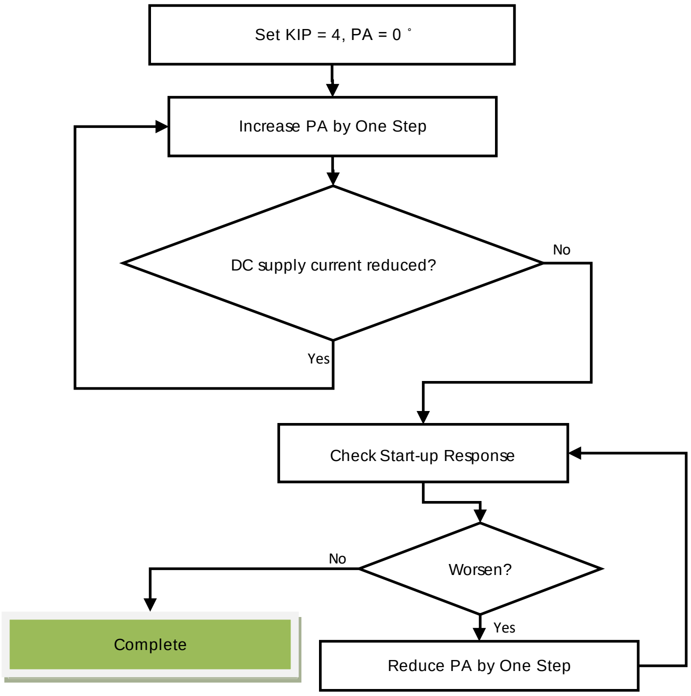


Figure 26: State Flow Diagram for Tuning Parameters for the Phase Advance

Tuning Parameters for Current Control and Open Loop Voltage Control

In both of the control modes, the first two sequence ,which are Alignment and Ramp, remains the same as the speed control. In open loop control mode, the DI defines the applied duty cycle to the system after the first two sequence. In current control mode, the error between measured current across the sense resistor and the reference current , defined by the DI, defines the duty cycle applied to the phases. For positive error, the duty cycle continues to increase until the the reference current is achieved and vice versa for the negative error. In both cases the position loop gains need to be adjusted properly using the same method as 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 need to be tuned. The desired control mode can be selected in the GUI by clicking on “System” and then modyifing “Motor Control Mode”, CM.

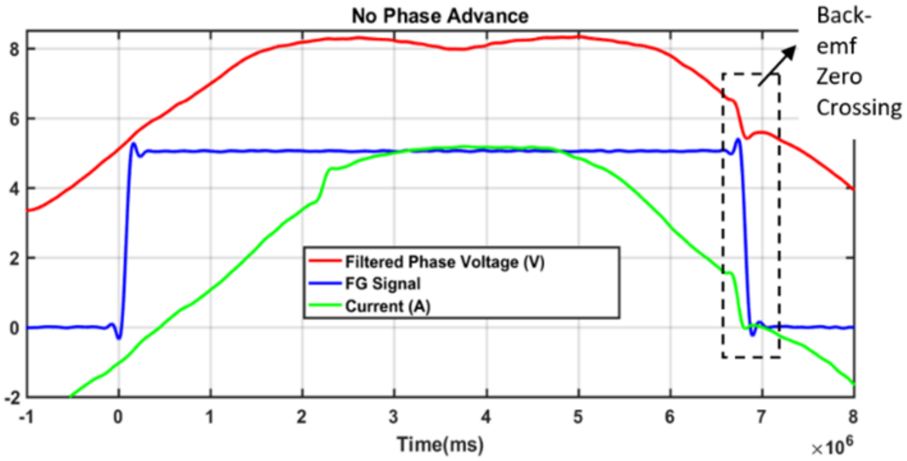


Figure 27: Phase Current and Voltage Waveform Illustration with no Phase Advance

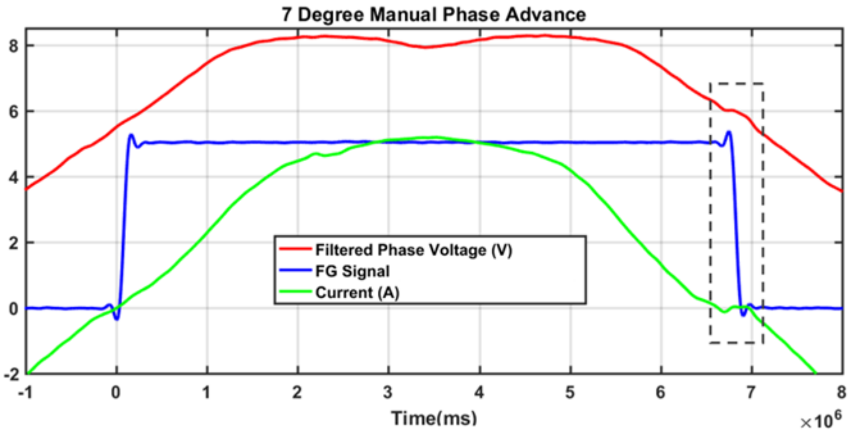


Figure 28: Phase Current and Voltage Waveform Illustration with 7 Degree Phase Advance

Appendix A: Demo Board Schematic

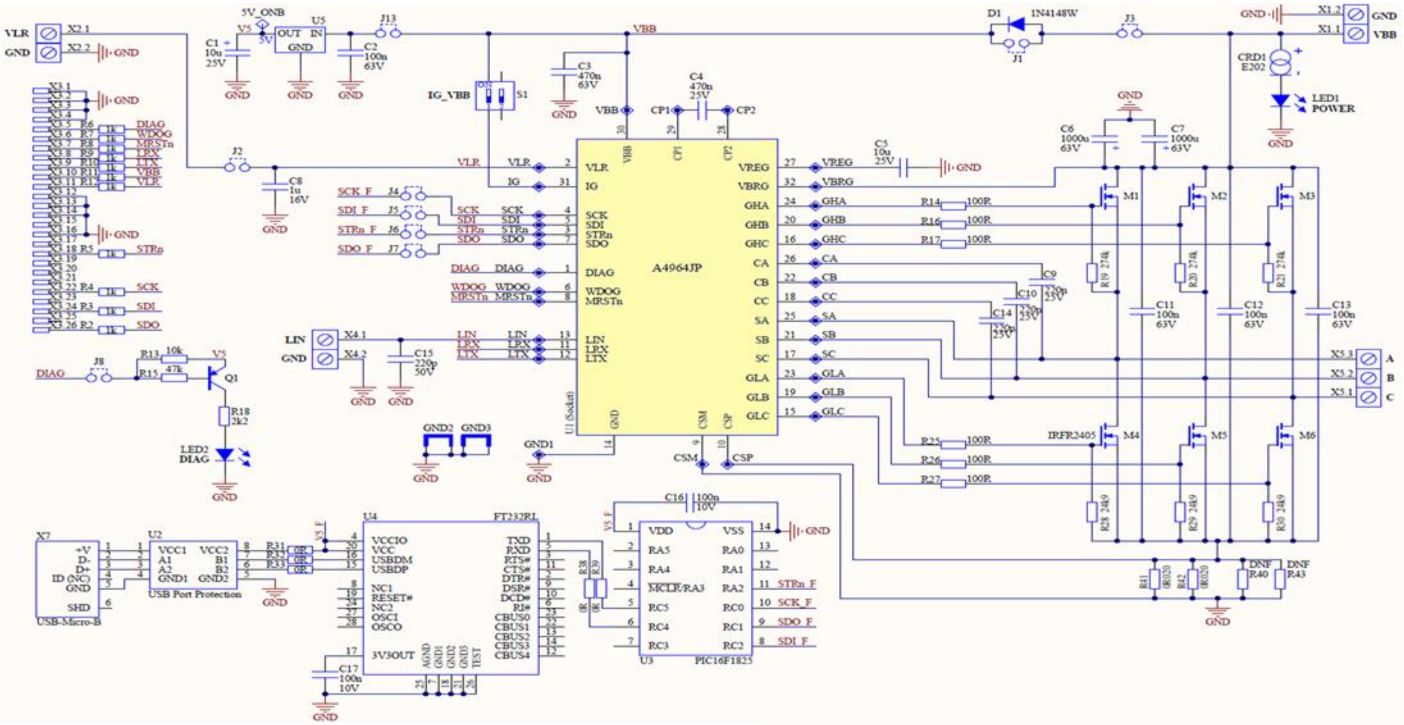


Figure 2: A4964 Demo Board Schematic

Appendix B: Demo Board Layout

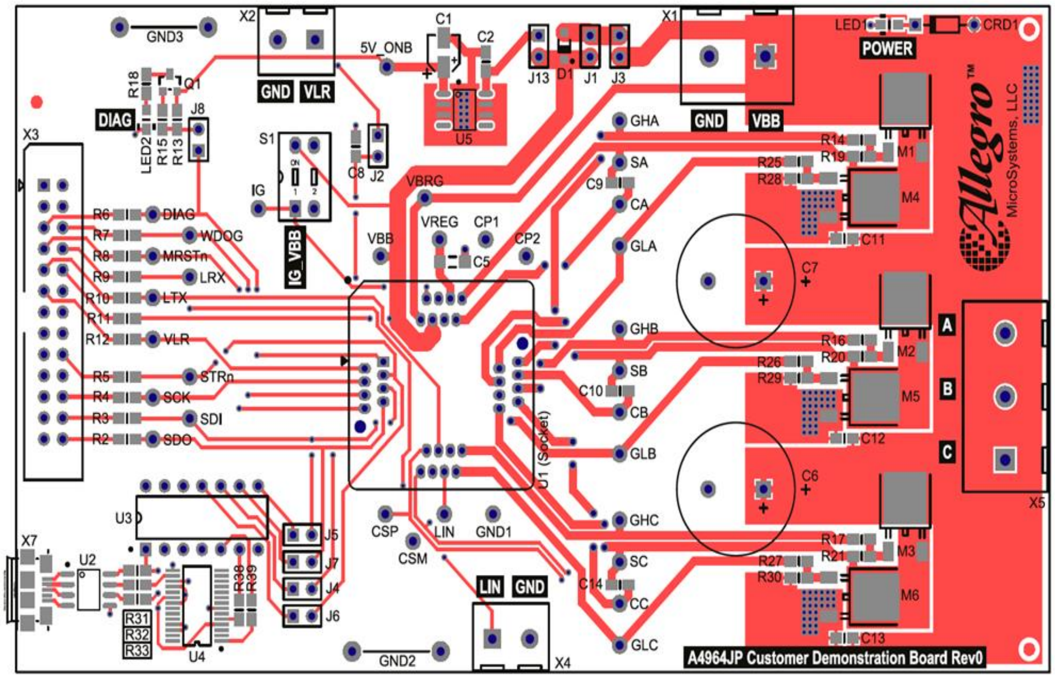


Figure 3: Board Layout - Top

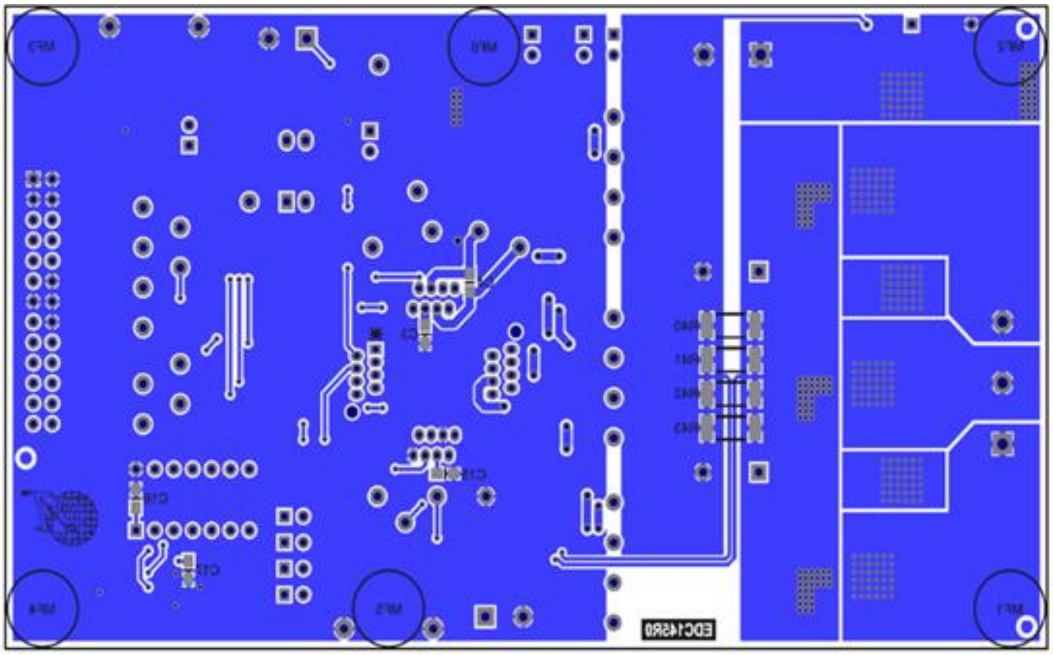


Figure 4: Board Layout - Bottom

Appendix C: Board Components

Table C1: Component function, specification and selection criteria

Component	Value	Type	Suggested part numbers
	Notes		
C1	10uF (25V)	X7R Ceramic Capacitor	
	Decoupling capacitor used for the 5V regulator Output. It is used to provide the in rush current for the LED used for the diagnostic.		
C2	100nF (63V)	X7R Ceramic Capacitor	
	Decoupling capacitor used for the 5V regulator input. It is used to provide the ripple current required by the regulator.		
C3	470nF (63V)	X7R Ceramic Capacitor	
	Local decoupling capacitors for the near VBB pin of the A4964 to provide high switching currents.		
C5	10uF (25V)	X7R Ceramic Capacitor	
	The output decoupling capacitor used for the VREG voltage. It is used to reduce the Vreg output voltage ripple.		
C6, C7	1000uF (63V)	Electrolytic Capacitor	
	Motor supply decoupling capacitor. Provides a local low impedance source to compensate for any supply wiring inductance. This capacitor provides the ripple current pulses to the motor phase. It is selected to be able to handle the maximum motor phase ripple current.		
C8	1uF	X7R Ceramic Capacitor	
	VLR output decoupling capacitor. Provides a local low impedance source to compensate for any supply wiring inductance. This capacitor provides the ripple current pulses to VCC. It is selected to be able to handle the maximum VCC load ripple current.		
C9,C10, C14	220nF (25V)	X7R Ceramic Capacitor	
	Bootstrap capacitors used to turn on high side FETs.		
C11,C12, C13	100nF (63V)	X7R Ceramic Capacitor	
	Local supply decoupling capacitors for the VBB supply pins. These capacitors provide the high frequency switching currents to the motor phase. These capacitors are mounted as close as possible to the VBB terminals on the A4964.		
C15	220pF 50V	X7R Ceramic Capacitor	
	Local decoupling capacitors for the LIN interface.		
D1	0.2A 60V	Diode	
	Provides an 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		

Component	Value	Type	Suggested part numbers
	Notes		
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 the default condition. R18 limits the current through this LED to about 2 mA		
R2, R3, R4, R5, R6, R7,R8,R9,R10,R11, R12	1kΩ	0805 Chip resistor	
	Logic signal current limit resistors. Provide some protection for the logic inputs of the A4964.		
R13	10kΩ	0805 Chip resistor	
	Current limit resistor. Prevent the current flow from 5V regulator to DIAG pin.		
R14,R16, R17,R25 R26,R27	100Ω	0805 Chip resistor	
	Filter resistors for the gate of the FETs.		
R15	47kΩ	0805 Chip resistor	
	Current limiting resistor. It is used to limit the current going flowing from DIAG pin to the base of transistor Q1.		
R18	2.2kΩ	0805 Chip resistor	
	Current limiting resistor for LED2.		
R19,R20,R21, R28,R29,R30	274kΩ	0805 Chip Resistor	
	Used a protection purpose to turn off the FETs in case the A4964 device is fully turned off.		
R31,R32,R33, R38,R39	0Ω	0805 Chip Resistor	
	Jumper resistors used to provide interface between communication devices		
R41,R42	20mΩ	2512 Chip Resistor	
	5V LDO on-board regulator for on-board parts.		
U2	USB port protection		
	Used to avoid flow of current back to USB port and limit the current from USB device.		
U3	PIC device		
	Microcontroller that provides the serial interface		

U4	FTDI Chip		
	-		

U5	LDO	LM2936HVMA-5.0	
	5V LDO on-board regulator for on-board parts.		

CRD1	E202		
	Current regulator to control the current going to the LED1.		

Appendix D.1: Default Setting

The default setting should be initially loaded into the GUI if none of the recommended settings provided in this appendix section works at all. In this case the register settings can be tuned using the guidelines provided in this application note.

To load the new settings into the GUI follow the instruction below:

1. Copy and paste the text provided in the table shown on the right side.
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 A4964 with these values.

```
The part number is: A4964
Config[0]  is: 0CC
Config[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 & Load

This setting is used for BLDC motors used with light resistive torque loads with low inertia. It works best for the motors with low inertia and max. power rating in the range of 20W to 100W. Some further tuning may be needed after applying these settings if the motor doesn't run smoothly for which the guideline provided in this applciation note can be utilized.

To load the new settings into the GUI follow the instruction below:

1. Copy and paste the text provided in the table shown on the right side.
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 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: 0CA
Config[12] is: 0CE
Config[13] is: 006
Config[14] is: 060
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

This setting is used for BLDC motors used for vehicle engine cooling fan application. It works best for the motors with high inertia fan loads and max. power rating in the range of 300W to 700W. Some further tuning may be needed after applying these settings if the motor doesn't run smoothly for which the guidelines provided in this applcation note can be utilized.

To load the new settings into the GUI follow the instruction below:

1. Copy and paste the text provided in the table shown on the right side.
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 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: 085
Config[13] is: 007
Config[14] is: 06A
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	Date	Change
0	4 May 17	Initial Release
1	10 May 17	Correct Ramp Section
2	8 Nov 17	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

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