

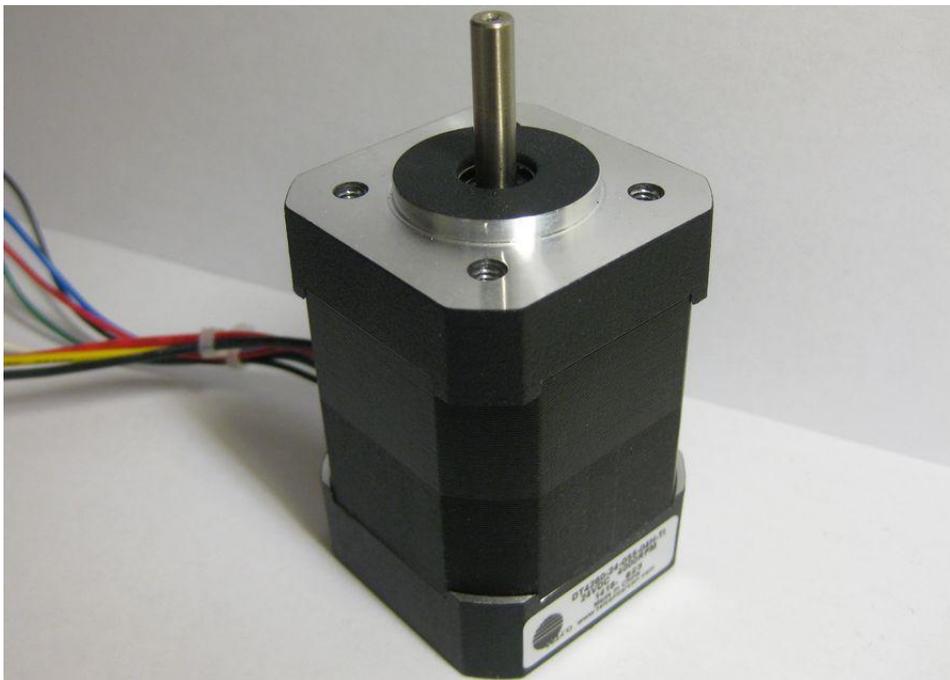
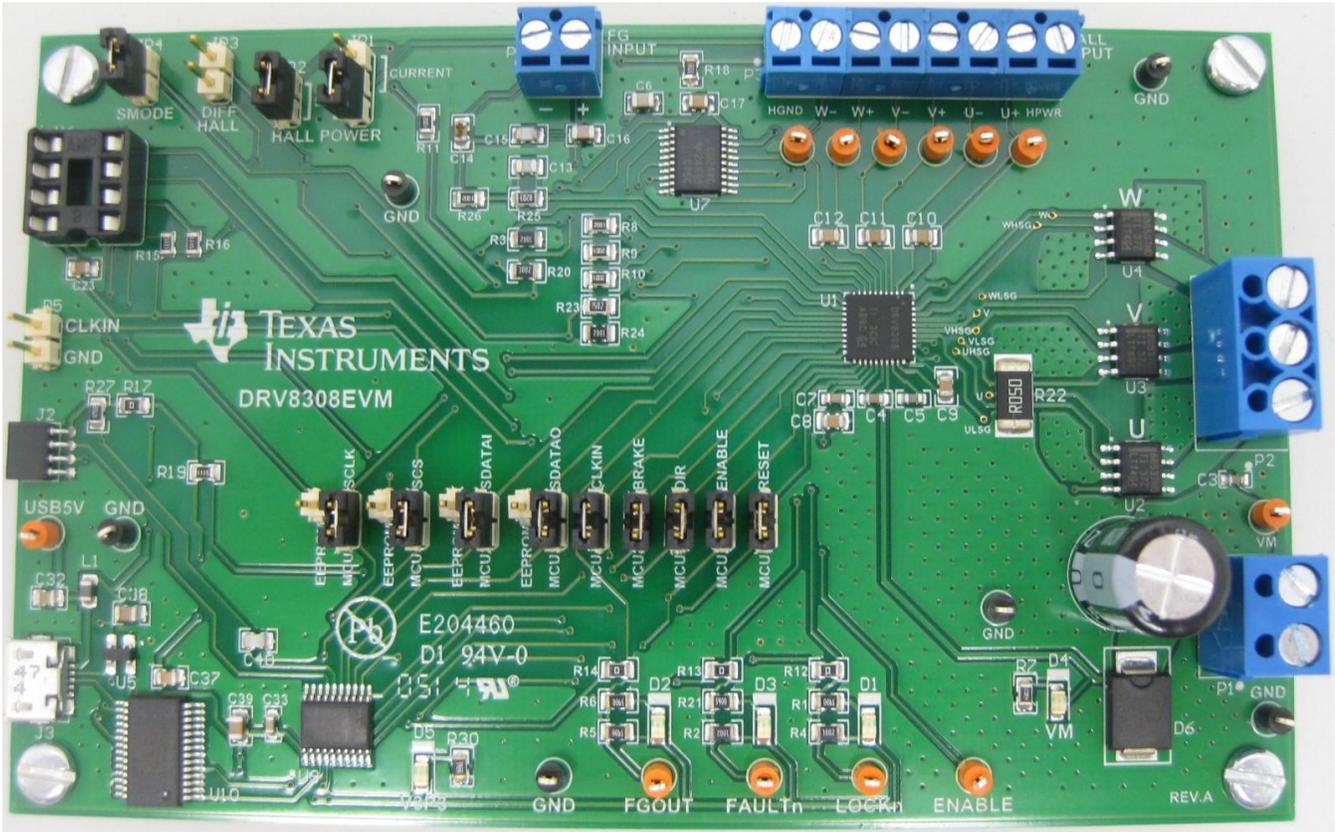
DRV8308 User's Guide

This document describes how to use the DRV8308EVM to spin sensored brushless DC motors, as well as a tuning process for the DRV8308 speed control system.

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1. The DRV8308EVM and motor



TelcoMotion DT4260-24-055-04H-TI

1.1 Overview

The DRV8308EVM makes it easy to evaluate the DRV8308 device with different BLDC motors. The kit includes the main PCB, a BLDC motor that uses DRV5013 Hall Effect sensors, a micro USB cable, and a downloadable Windows application that controls and monitors the DRV8308 with a graphical user interface (GUI).

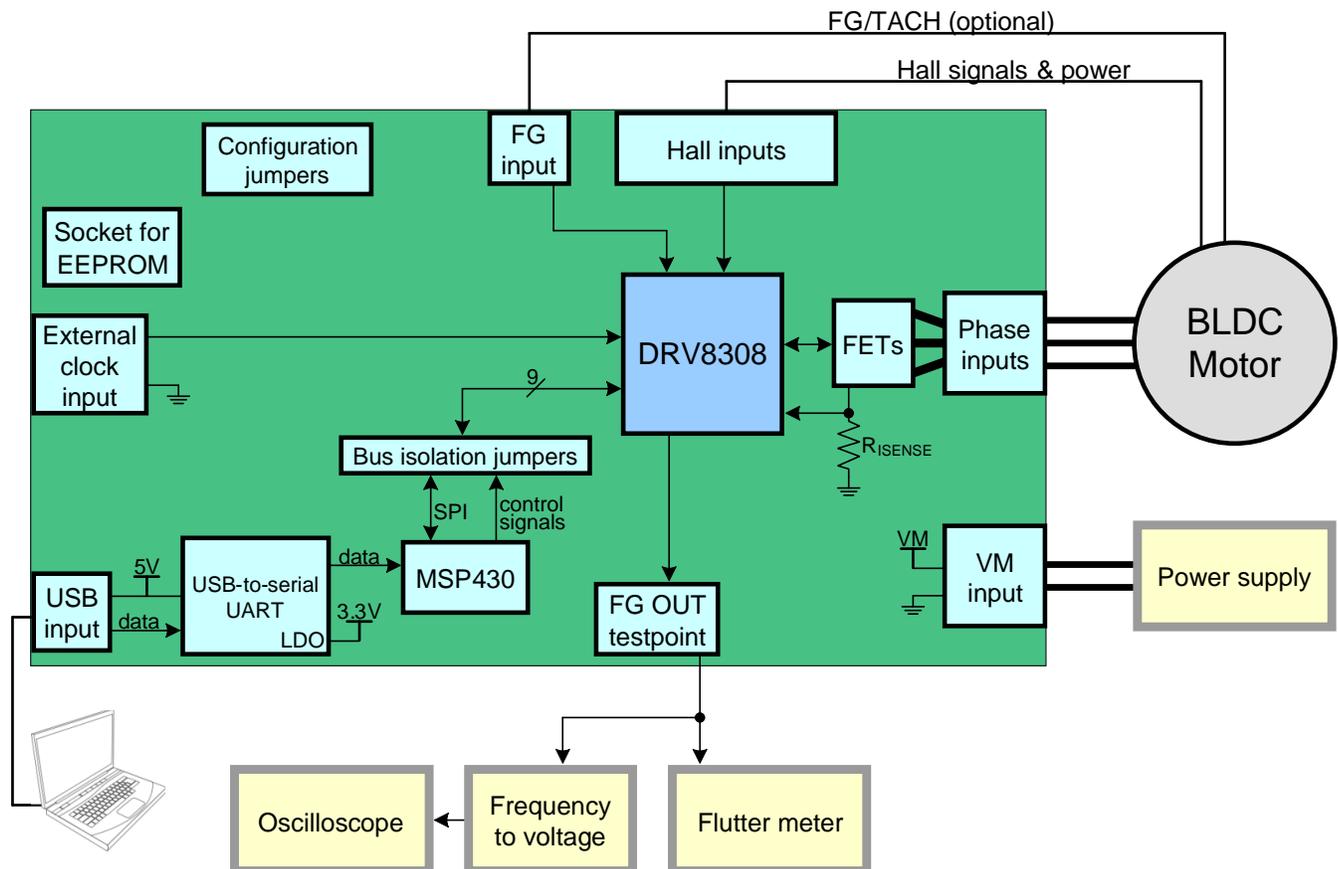


Figure 1. DRV8308EVM system diagram

1.2 External lab equipment

1. Power supply – The supply should be set to a voltage between 8.5V and 32V, and a current of at least 1A. A higher current setting is better, as that helps maintain a stable VM voltage, speeds spin-up time, and increases the torque capability. The DRV8308 will limit peak current to 5A on this board, since the sense resistor is sized at 0.05Ω , and $V_{LIMITER} = 0.25V$.
2. Flutter meter – When the motor rotates, it generates a periodic waveform on each Hall phase, and optionally on the FG line. The DRV8308 register “FGSEL” sets which input to use for the speed control loop and pass to FGOUT.

Flutter meters can analyze the FGOUT signal and calculate a jitter percentage. This jitter, or variation in edge timing, is a measure of motor speed consistency. Good flutter values are typically in the 0.03% to 0.5% range. Some causes of jitter are:

- a. Magnetic cogging force. Motors with high detent torque will have more speed variation when spinning.
- b. Non-ideal motor windings.
- c. Improperly-tuned DRV8308 register settings when in Clock Frequency Mode. The device's speed control loop has configurable pole and zero frequencies and gain values, and they significantly affect jitter performance.

Some BLDC outrunner motors have a PCB mounted to the backside with a board trace antenna that senses magnetic reluctance. This "FG trace" is drawn like a square wave leading in a circle. When the motor spins, a low-level sinusoidal voltage is generated on the trace. The DRV8308 can use this signal to sense motor speed with FGSEL = 10b. Since implementations often cause about 30-60 FG cycles per physical revolution, and there often only 3-6 Hall U cycles per physical revolution, FG has an advantage of providing faster speed feedback, and that can improve jitter performance. For motors that lack FG, it is best to set FGSEL = 00b to use HALL U; this can achieve very similar performance as FG. Setting FGSEL = 01b for XOR has been generally seen to produce worse results.

3. Frequency-to-voltage converter and oscilloscope – It is useful to convert the FGOUT frequency to be represented by an analog voltage, and send the signal to a scope. This allows observing spin-up and spin-down profiles, and any overshoot. Some flutter meters have an integrated frequency to voltage converter.
4. Computer – The computer connects to the PCB with a USB cable, and the GUI controls the MSP430G2553 microcontroller (MCU). This MCU can generate a clock, set High and Low voltages on the control inputs, read the status outputs, and read/write DRV8308 registers using SPI. The *bus isolation jumpers* provide a simple way to disconnect the MCU from the DRV8308, if you want to use a different controller.
5. Function generator (not shown) – While the MCU can generate a clock with different duty cycles and frequencies, you can instead use an external clock source attached to connector P5. When doing this, be sure to disable the MCU clock to prevent contention. That can be done by removing the CLKIN bus isolation jumper, or selecting GUI option "External Signal" in the first two tabs, or unchecking "Enable MCU CLK" on third tab. While the MCU clock is not quite as accurate as a function generator, there's a negligible difference on flutter.

1.3 Configuration jumpers

The DRV8308EVM board has 3 groups of configuration jumpers.

| | Jumper | Description |
|------------|--------|---|
| HALL POWER | JP1 | Hall sensor power is "5V" or "current" |
| | JP2 | |
| DIFF HALL | JP3 | Differential or single-ended Hall sensors |
| SMODE | JP4 | SPI (GUI) or EEPROM mode |

Jumpers “HALL POWER”

Sensored BLDC motors typically use either Hall Effect *ICs* or *elements*. Most ICs can use 5V power, while elements typically have power pins that have an equivalent circuit of a resistor, and current must be limited to about 10mA.

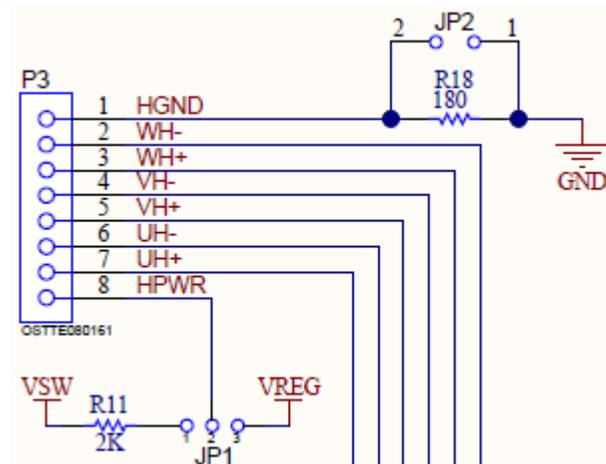


Figure 2. Hall PWR/GND circuits

“VREG” is a regulated 5V output from the DRV8308. By installing a jumper on JP1 pins 2-3, and JP2, 5V power is available on the P3 terminal block for powering Hall ICs. VREG is only powered when the DRV8308 is enabled, unless register VREG_EN is used.

“VSW” equals VM when the DRV8308 is enabled. By installing a jumper on JP1 pins 1-2, and removing JP2, this circuit is available for Hall elements:

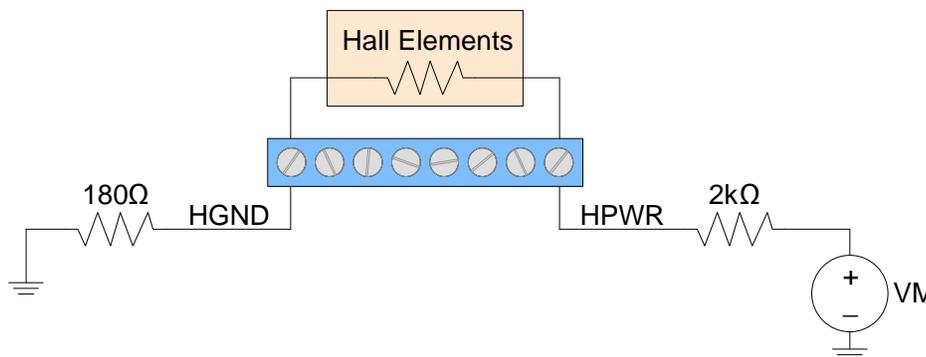


Figure 3. Circuit when setting Hall power to “current”

Here’s an example to calculate current: if $VM = 24V$, and 3 Hall elements that have a resistance of 400Ω are connected in parallel, 10.4mA will be supplied. Always refer to your Hall element specifications to understand the proper current. The purpose of the 180Ω resistor is to bias-up the common mode voltage of Hall element differential signals, since the DRV8308 requires V_{ICM} between 1.5V to 3.5V.

If you are unsure about whether to apply 5V or the current-limiting circuit, measure the resistance between the Hall power and ground wires. If it is $<250\Omega$, the current-limiting circuit should probably be used. Hall elements can be easily damaged if too much current is allowed.

Jumper “DIFF HALL”

Hall sensors output either a differential signal pair, or a single-ended open-drain. You can tell which type your motor uses simply by counting the number of wires; a sensed BLDC typically has 3 phase wires, 2 Hall power wires, and 3 or 6 Hall signal wires. 8 total mean single-ended; 11 total mean differential (excluding optional FG or TACH wires).

The DRV8308 has differential comparators on the Hall inputs, and they can also accommodate single-ended signals with the use of a few passive components.

- When using differential Halls, directly connect the 6 Hall signals to the DRV8308 pins.
- When using single-ended Halls, they require pull-ups, and the DRV8308 comparator’s “-” pins should be biased with a middle voltage, so that a single-ended swing on the “+” pin is detected like a differential voltage.

Jumper JP3 controls U7, an 8-line FET switch, and it decides when to connect the pull-ups and middle voltage. **Install JP3 when using differential Halls. Uninstall JP3 when using single-ended Halls and connect wires to the “+” terminals of P3.**

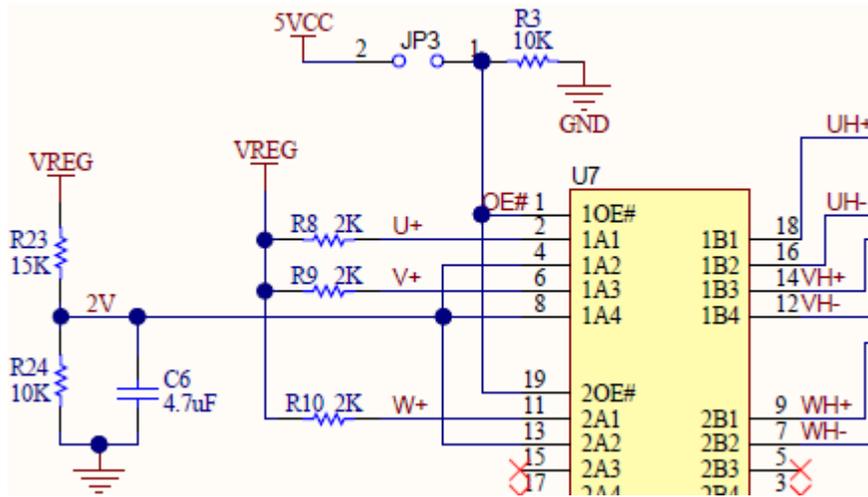


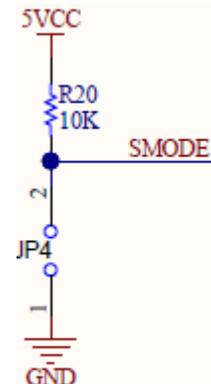
Figure 4. JP3 controls whether 6 connections are made

Jumper “SMODE”

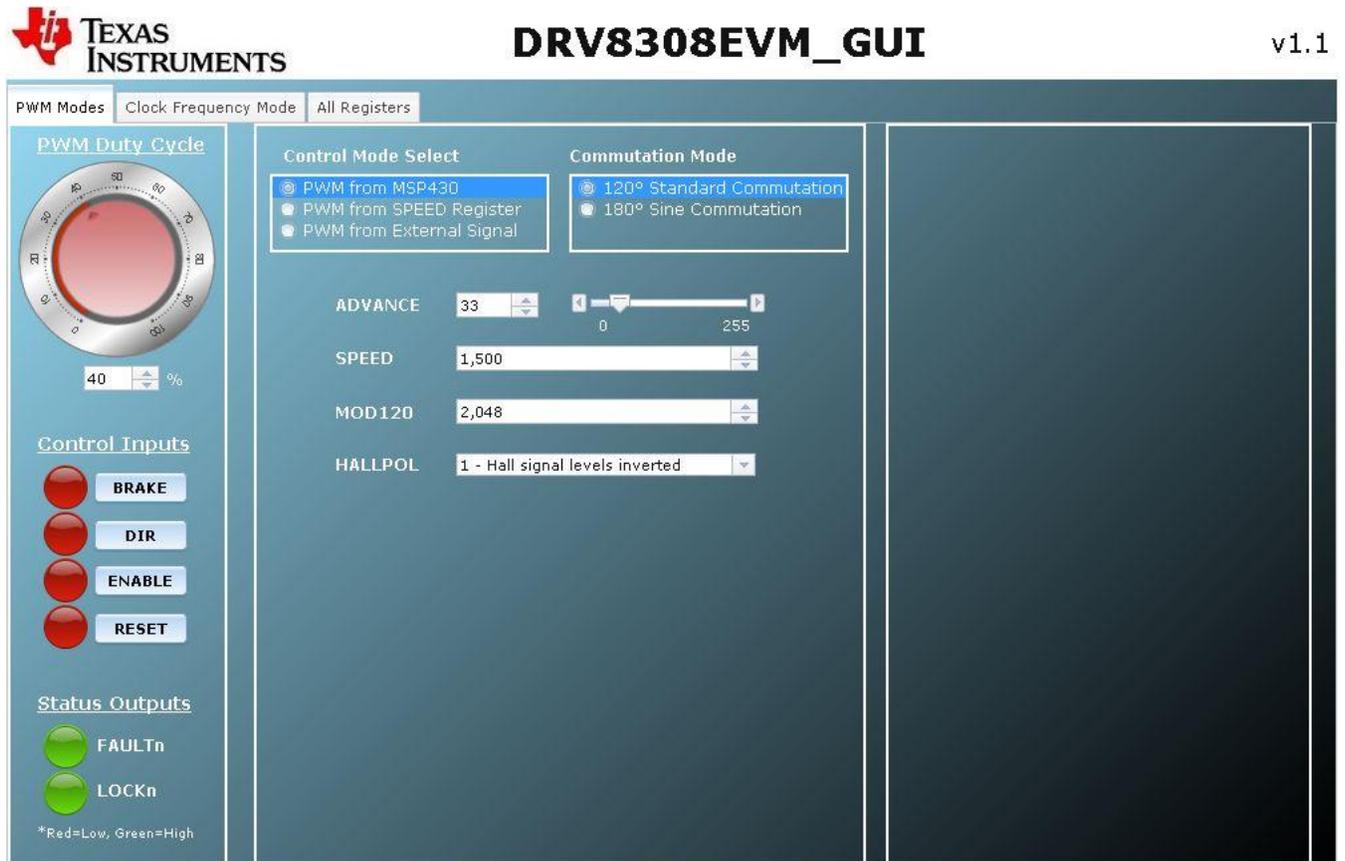
When the DRV8308 powers up, it checks if pin SMODE is High or Low to decide whether to load register data from an external EEPROM, or from the internal non-volatile One-Time Programmable memory (OTP). When the OTP method is used, the DRV8308 also accepts SPI commands to read and write registers.

Install JP4 when using the GUI and SPI.

Uninstall JP4 when using an external EEPROM, and also install JP5a, JP6a, JP7a, JP8a, and a 93C46B-compatible EEPROM into the DIP socket (U6).



2. The GUI



2.1 Installation

Step 1: Download and install the latest version of [GUI Composer Runtime](#). You will need to register for a TI account if you don't already have one.

http://processors.wiki.ti.com/index.php/Category:GUI_Composer#GUI_Composer_Downloads

Step 2: Download and unzip the GUI: <http://www.ti.com/lit/zip/slvc552>.

Step 3: Install the USB driver by running: [USB driver\CDM v2.10.00 WHQL Certified.exe](#).

Step 4: Go to folder [\Application\](#) and move folder [DRV8308EVM_GUIv1.2](#) into directory [..\guicomposer\webapps\](#) (depending on where you installed GUI Composer during Step 1). If you installed GUI Composer to the default directory, the folder is: [C:\ti\guicomposer\webapps\](#).

Step 5: Create a shortcut for yourself to [..\guicomposer\webapps\DRV8308EVM_GUIv1.2\launcher.exe](#) by clicking and dragging the file while holding the Alt key.

Before running the GUI, you must first connect the USB cable between your computer and the DRV8308EVM. Then, after you run [launcher.exe](#), wait until the  and  [initializing...](#) icons disappear before doing anything else; if they don't disappear after a minute, it's sometimes necessary to close the GUI and re-run it.

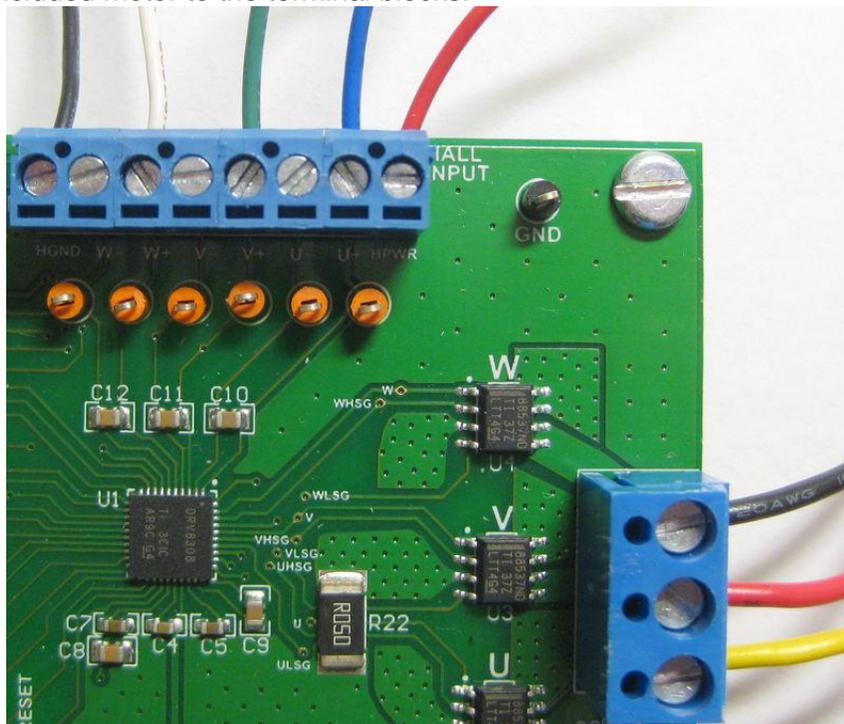
2.2 Quick guide to spin with open-loop PWM

Step 1: Set these jumpers:



Step 2: Connect the USB cable between the board and your computer, and run the GUI.

Step 3: Wire the included motor to the terminal blocks:



Step 4: Connect your power supply to the board VM and GND terminals. Set the supply to 24V with at least 1A (higher current is better).

Step 5: With the GUI loaded and no  symbols, set the PWM Duty Cycle to 40% and click ENABLE. The motor should spin!

Next,

- To change from counter-clockwise to clockwise, click DIR.
- To change speed, use the duty cycle knob.
- To apply sinusoidal commutation, first change MOD120 from 2048 to 3970, and then select 180° Sine Commutation. Note that when MOD120 = 3970, a 2.1x factor is applied to the input duty cycle, so a 40% duty cycle input is treated like 84%.
- To use no clock and command speed from a register, select "PWM from SPEED Register". Then the SPEED decimal value divided by 4095 is the input duty cycle.

2.3 Quick guide to spin with speed control

The second GUI tab operates the DRV8308 in Clock Frequency Mode, utilizing the closed-loop speed control system. It's important to determine the right frequency for your desired RPM; for example:

- If you are using FGSEL = 00b (Hall U), and the motor's rotor has 8 magnet poles, there will be 4 Hall U cycles per revolution and $RPM = f_{CLKIN}/4 * 60$.
- If you are using FGSEL = 10b (FG), and there are 42 FG cycles per physical revolution, then $RPM = f_{CLKIN}/42 * 60$.

If you're unsure of your motor's number of Hall U cycles per revolution, you can test it by doing this: disconnect the 3 phase wires, enable the DRV8308 (to apply Hall power), probe the Hall U testpoint, and use your hand to rotate the motor 360° while counting the number of cycles.

The included TelcoMotion motor has 8 magnetic poles, and the below steps will involve a 100Hz f_{CLKIN} , so RPM will be 1500.

Step 1: Un-click ENABLE so the motor is stopped.

Step 2: Select the second GUI tab. Then:

- Set AG_SETPT to 5 - 95Hz
- Set LOOPGAIN to 200
- Set MOD120 to 3970
- Select CLK from MSP430

Step 3: Click ENABLE to spin at exactly 1500 RPM. Connecting a scope probe to FGOUT allows you to observe the Hall U frequency. If you load the motor with your fingers, you will see power supply current increase, but Hall U frequency stay the same since speed is locked. If you're able to stop the motor by squeezing hard enough, your power supply is probably set to 1A or less.

2.4 The third GUI tab

The last tab shows all the device registers, for the highest level of complexity and control. Changes made to this tab stay in effect when switching back to the first two tabs.

By default, the "Auto Write" checkbox is enabled, so changes you make are immediately written through SPI.

The button "Burn OTP Memory" permanently writes the DRV8308 non-volatile memory with the registers shown. ENABLE must be active for it to work. After writing the OTP, whenever the DRV8308 is powered up with SMODE = Low, the default registers will be what was programmed. Here's how you can verify the OTP was successfully written: uncheck Auto Write, cycle power to the EVM, type a random number into one of the register fields, click the Read All button, and verify the random number gets overwritten to the correct value.

2.5 If the GUI has slow performance

Some computers exhibit slow performance on the third GUI tab. 2 common causes are:

1. Too many Ports in Device Manager. Go there by accessing Start → Control Panel → System → Device Manager. Under Ports, the one for the EVM is named “USB Serial Port”. If there are others listed, try disabling them with a right-click Disable. Then restart the GUI.
2. A slow computer with many programs running in the background. Try closing all extra programs and disk scanners.

3. Tuning the speed control system

The DRV8308 Clock Frequency Mode for speed control performs best when the device registers are tuned for a particular system’s motor, inertia, speed, and load torque.

3.1 Key registers

This first set of registers must be set correctly:

- MOD120** – Always set this to 3970.
- SPEED** – This is the open-loop gain during spin-up, before LOCKn goes Low. It simply must be high enough in order to reach the commanded RPM.
- AUTOGAIN** – When enabled, the DRV8308 scales LOOPGAIN with RPM, because more gain is needed for more speed. This is a valuable feature and should generally be left enabled. Then $\text{ScaledGain} = \text{LOOPGAIN} * f_{\text{CLKIN}} / \text{AG_SETPT}$.
- AG_SETPT** – This setpoint effectively sets the range for AUTOGAIN. Simply use the setting that is closest to f_{CLKIN} (see the DRV8308 datasheet register descriptions).
- AUTOADV** – When enabled, the DRV8308 more aggressively scales ADVANCE with RPM: $\text{ScaledAdvance} = \text{ADVANCE} * f_{\text{HALLU}} / \text{AA_SETPT}$. Note that without this, ADVANCE by itself already scales with speed since each value shifts timing by 0.1% of the Hall U period. Disable AUTOADV initially; once a system is well-tuned, you can experiment with AUTOADV to potentially improve performance.
- AA_SETPT** – This only applies when AUTOADV is enabled. Use the setting closest to the frequency of Hall U.
- IDRIVE** – This sets the predriver output current and directly controls the external FET V_{GS} turn-on time. Unless high current FETs are used, lower values are generally better, to minimize switching noise.
- FGSEL** – If an FG Sense trace is not used, it is generally best to set FGSEL to 0 (HALL_U).

These next registers should be tuned for a particular system:

- ADVANCE** – This adjusts the timing shift between when the DRV8308 receives Hall signals and commutation. While a motor is running, ADVANCE can be modified in realtime (if AUTOADV is disabled), and you will instantly see the difference in power supply current. Lower current is generally better, but flutter performance can be a tradeoff.
- LOOPGAIN** – This gain primarily affects max RPM, max torque, and startup speed overshoot. If it's too low, the motor won't spin up to the commanded RPM, or the torque capability may be limited. If it's too high, motor speed will initially overshoot.
- SPDGAIN** – This gain affects how aggressively error is compensated. If it's too high, speed will oscillate around the target speed. If it's too low, flutter may be higher.
- FILK1** – Sets the Pole1 frequency.
- FILK2** – Sets the Zero1 frequency.
- COMK1** – Sets the Pole2 frequency.
- COMK2** – Sets the Zero2 frequency.

3.2 Tuning process

Tuning a motor system is a trial-and-error process. The following steps are a general guide. The GUI loads with default register values that attempt to have reasonable filter settings.

Step 1: Use the first tab to run in PWM mode. You might need to try different wire connections and HALLPOL to get your motor to consistently spin. After that, while spinning change ADVANCE and find the value that causes the lowest power supply current and audible motor noise. Then stop the motor by bringing ENABLE low.

Step 2: Determine the appropriate clock frequency, f_{CLKIN} (see [example](#)).

Select the third GUI tab, and:

- Set AG_SETPT closest to your f_{CLKIN} .
- Set MOD120 to 3970
- Set SPEED to 4000

Turn on the clock, and start the motor with ENABLE.

If the motor spins very roughly,

- Try reducing or increasing f_{CLKIN} to find a working case as a baseline reference.
- Try changing the filters (FILK1/FILK2/COMK1/COMK2) with different combinations in increments of 150. Spend some time to find good values.
- Try increasing SPDGAIN and LOOPGAIN.

Step 3: By now, the motor should spin smoothly, but the frequency of the signal on FGOUT might not match f_{CLKIN} . If the two frequencies don't match, speed is not locked. Many times that can be fixed by increasing LOOPGAIN or SPEED.

Step 4: Now, the motor should be spinning with the FGOUT frequency matching f_{CLKIN} . If you load the motor using your hand, it should maintain the same RPM and FGOUT frequency. To increase the load capability, try increasing LOOPGAIN, or you may need to decrease the value of the R_{SENSE} resistor to allow more motor current.

It's useful to now determine the minimum "total gain" needed to reach your target RPM and torque drive. To do this, keep decreasing LOOPGAIN and toggling ENABLE, to find the LOOPGAIN that prevents f_{FGOUT} from reaching f_{CLKIN} . The filter registers of course affect pole and zero frequencies of the control system; they also affect gain in the same way as LOOPGAIN, where:

$$\text{Total gain} = \text{LOOPGAIN} * (2 * \text{FILK}_2 / \text{FILK}_1) * (0.5 * \text{COMK}_2 / \text{COMK}_1).$$

Inside the downloaded Board Files and Software, open this file: [\Application\Filter calculator.xls](#). Enter your filter values and LOOPGAIN into the green cells, and look at the "Total gain". This is the minimum gain your system needs to reach the commanded RPM.

In future trials, changing the filters (to improve flutter and dynamic performance) will also change total gain, and the calculator should be used to determine the right value for LOOPGAIN, in order to keep total gain at least 20% above the minimum. Being 1.5-3x above the minimum is often ok, and the primary consequence of having too much total gain is that startup speed can overshoot. Note that more gain is needed to drive more torque.

Step 5: To optimize flutter performance, vary ADVANCE, SPDGAIN, and many combinations of FILK1/FILK2/COMK1/COMK2. These filter settings can be changed in realtime while the motor is spinning, but the new "total gain" is only updated when the motor restarts (technically, it's when LOCKn transitions to Low if AUTOGAIN is enabled).

In many cases it works well to set Pole1 to a much higher frequency than the others, and set Zero2 to Pole2 to a frequency band between Zero1 and Pole1.

Try many combinations, and hopefully you will find good settings within a few hours. Good luck! Feel free to post any questions to the TI E2E Forum online.

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1. *Delivery:* TI delivers TI evaluation boards, kits, or modules, including any accompanying demonstration software, components, or documentation (collectively, an "EVM" or "EVMs") to the User ("User") in accordance with the terms and conditions set forth herein. Acceptance of the EVM is expressly subject to the following terms and conditions.
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 - 2.1 These terms and conditions do not apply to Software. The warranty, if any, for Software is covered in the applicable Software License Agreement.
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 - 2.3 If any EVM fails to conform to the warranty set forth above, TI's sole liability shall be at its option to repair or replace such EVM, or credit User's account for such EVM. TI's liability under this warranty shall be limited to EVMs that are returned during the warranty period to the address designated by TI and that are determined by TI not to conform to such warranty. If TI elects to repair or replace such EVM, TI shall have a reasonable time to repair such EVM or provide replacements. Repaired EVMs shall be warranted for the remainder of the original warranty period. Replaced EVMs shall be warranted for a new full ninety (90) day warranty period.
3. *Regulatory Notices:*
 - 3.1 *United States*
 - 3.1.1 *Notice applicable to EVMs not FCC-Approved:*

This kit is designed to allow product developers to evaluate electronic components, circuitry, or software associated with the kit to determine whether to incorporate such items in a finished product and software developers to write software applications for use with the end product. This kit is not a finished product and when assembled may not be resold or otherwise marketed unless all required FCC equipment authorizations are first obtained. Operation is subject to the condition that this product not cause harmful interference to licensed radio stations and that this product accept harmful interference. Unless the assembled kit is designed to operate under part 15, part 18 or part 95 of this chapter, the operator of the kit must operate under the authority of an FCC license holder or must secure an experimental authorization under part 5 of this chapter.
 - 3.1.2 *For EVMs annotated as FCC – FEDERAL COMMUNICATIONS COMMISSION Part 15 Compliant:*

CAUTION

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Changes or modifications not expressly approved by the party responsible for compliance could void the user's authority to operate the equipment.

FCC Interference Statement for Class A EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class A digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses, and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

FCC Interference Statement for Class B EVM devices

NOTE: This equipment has been tested and found to comply with the limits for a Class B digital device, pursuant to part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and receiver.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/TV technician for help.

3.2 Canada

3.2.1 For EVMs issued with an Industry Canada Certificate of Conformance to RSS-210

Concerning EVMs Including Radio Transmitters:

This device complies with Industry Canada license-exempt RSS standard(s). Operation is subject to the following two conditions: (1) this device may not cause interference, and (2) this device must accept any interference, including interference that may cause undesired operation of the device.

Concernant les EVMs avec appareils radio:

Le présent appareil est conforme aux CNR d'Industrie Canada applicables aux appareils radio exempts de licence. L'exploitation est autorisée aux deux conditions suivantes: (1) l'appareil ne doit pas produire de brouillage, et (2) l'utilisateur de l'appareil doit accepter tout brouillage radioélectrique subi, même si le brouillage est susceptible d'en compromettre le fonctionnement.

Concerning EVMs Including Detachable Antennas:

Under Industry Canada regulations, this radio transmitter may only operate using an antenna of a type and maximum (or lesser) gain approved for the transmitter by Industry Canada. To reduce potential radio interference to other users, the antenna type and its gain should be so chosen that the equivalent isotropically radiated power (e.i.r.p.) is not more than that necessary for successful communication. This radio transmitter has been approved by Industry Canada to operate with the antenna types listed in the user guide with the maximum permissible gain and required antenna impedance for each antenna type indicated. Antenna types not included in this list, having a gain greater than the maximum gain indicated for that type, are strictly prohibited for use with this device.

Concernant les EVMs avec antennes détachables

Conformément à la réglementation d'Industrie Canada, le présent émetteur radio peut fonctionner avec une antenne d'un type et d'un gain maximal (ou inférieur) approuvé pour l'émetteur par Industrie Canada. Dans le but de réduire les risques de brouillage radioélectrique à l'intention des autres utilisateurs, il faut choisir le type d'antenne et son gain de sorte que la puissance isotrope rayonnée équivalente (p.i.r.e.) ne dépasse pas l'intensité nécessaire à l'établissement d'une communication satisfaisante. Le présent émetteur radio a été approuvé par Industrie Canada pour fonctionner avec les types d'antenne énumérés dans le manuel d'usage et ayant un gain admissible maximal et l'impédance requise pour chaque type d'antenne. Les types d'antenne non inclus dans cette liste, ou dont le gain est supérieur au gain maximal indiqué, sont strictement interdits pour l'exploitation de l'émetteur.

3.3 Japan

3.3.1 *Notice for EVMs delivered in Japan:* Please see http://www.tij.co.jp/lstds/ti_ja/general/eStore/notice_01.page 日本国内に輸入される評価用キット、ボードについては、次のところをご覧ください。
http://www.tij.co.jp/lstds/ti_ja/general/eStore/notice_01.page

3.3.2 *Notice for Users of EVMs Considered "Radio Frequency Products" in Japan:* EVMs entering Japan are NOT certified by TI as conforming to Technical Regulations of Radio Law of Japan.

If User uses EVMs in Japan, User is required by Radio Law of Japan to follow the instructions below with respect to EVMs:

1. Use EVMs in a shielded room or any other test facility as defined in the notification #173 issued by Ministry of Internal Affairs and Communications on March 28, 2006, based on Sub-section 1.1 of Article 6 of the Ministry's Rule for Enforcement of Radio Law of Japan,
2. Use EVMs only after User obtains the license of Test Radio Station as provided in Radio Law of Japan with respect to EVMs, or
3. Use of EVMs only after User obtains the Technical Regulations Conformity Certification as provided in Radio Law of Japan with respect to EVMs. Also, do not transfer EVMs, unless User gives the same notice above to the transferee. Please note that if User does not follow the instructions above, User will be subject to penalties of Radio Law of Japan.

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本開発キットは技術基準適合証明を受けておりません。

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3.3.3 *Notice for EVMs for Power Line Communication:* Please see http://www.tij.co.jp/llds/ti_ja/general/eStore/notice_02.page

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4 *EVM Use Restrictions and Warnings:*

4.1 EVMS ARE NOT FOR USE IN FUNCTIONAL SAFETY AND/OR SAFETY CRITICAL EVALUATIONS, INCLUDING BUT NOT LIMITED TO EVALUATIONS OF LIFE SUPPORT APPLICATIONS.

4.2 User must read and apply the user guide and other available documentation provided by TI regarding the EVM prior to handling or using the EVM, including without limitation any warning or restriction notices. The notices contain important safety information related to, for example, temperatures and voltages.

4.3 *Safety-Related Warnings and Restrictions:*

4.3.1 User shall operate the EVM within TI's recommended specifications and environmental considerations stated in the user guide, other available documentation provided by TI, and any other applicable requirements and employ reasonable and customary safeguards. Exceeding the specified performance ratings and specifications (including but not limited to input and output voltage, current, power, and environmental ranges) for the EVM may cause personal injury or death, or property damage. If there are questions concerning performance ratings and specifications, User should contact a TI field representative prior to connecting interface electronics including input power and intended loads. Any loads applied outside of the specified output range may also result in unintended and/or inaccurate operation and/or possible permanent damage to the EVM and/or interface electronics. Please consult the EVM user guide prior to connecting any load to the EVM output. If there is uncertainty as to the load specification, please contact a TI field representative. During normal operation, even with the inputs and outputs kept within the specified allowable ranges, some circuit components may have elevated case temperatures. These components include but are not limited to linear regulators, switching transistors, pass transistors, current sense resistors, and heat sinks, which can be identified using the information in the associated documentation. When working with the EVM, please be aware that the EVM may become very warm.

4.3.2 EVMs are intended solely for use by technically qualified, professional electronics experts who are familiar with the dangers and application risks associated with handling electrical mechanical components, systems, and subsystems. User assumes all responsibility and liability for proper and safe handling and use of the EVM by User or its employees, affiliates, contractors or designees. User assumes all responsibility and liability to ensure that any interfaces (electronic and/or mechanical) between the EVM and any human body are designed with suitable isolation and means to safely limit accessible leakage currents to minimize the risk of electrical shock hazard. User assumes all responsibility and liability for any improper or unsafe handling or use of the EVM by User or its employees, affiliates, contractors or designees.

4.4 User assumes all responsibility and liability to determine whether the EVM is subject to any applicable international, federal, state, or local laws and regulations related to User's handling and use of the EVM and, if applicable, User assumes all responsibility and liability for compliance in all respects with such laws and regulations. User assumes all responsibility and liability for proper disposal and recycling of the EVM consistent with all applicable international, federal, state, and local requirements.

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