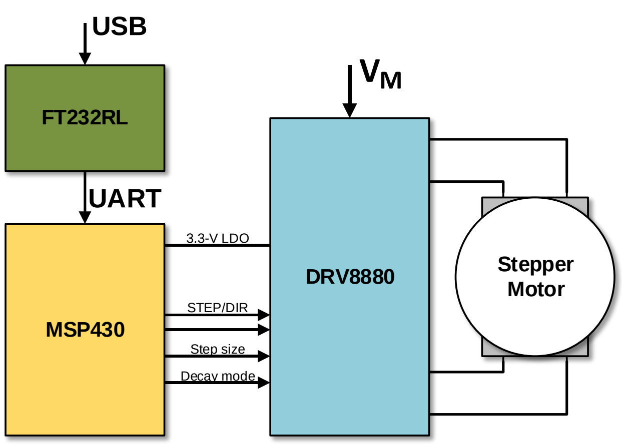
TIDA-00830 24V Stepper Motor Design with AutoTune™ TI Reference Design

Design Overview

TIDA-00830 is an application overview of TI's automatic stepper motor tuning feature known as AutoTune™. This design showcases how quickly AutoTune™ can adapt to changes in system inputs or motor characteristics without the user having to apply any type of parameter tuning. The hardware for this design is sourced from the DRV8880 Evaluation Module so the user has the ability to work with the entire feature set of this device.

Design Resources

TIDA-00830	Design Folder
DRV8880	Product Folder
MSP430F2617	Product Folder
FT232RL	Product Folder

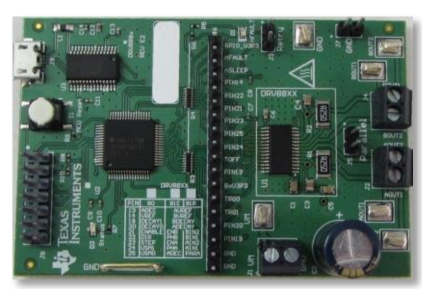


Design Features

- 6.5- to 45-V operation with up to 2.0-A full-scale (max drive current)
- Configurable PWM Off-Time of 10-, 20-, or 30-µs
- 3.3-V, 10-mA LDO Regulator supply
- AutoTune stepper motor tuning
- Simple GUI for driver input control and motor tuning
- Onboard USB communication for easy connectivity with external controller
- 100 mil header gives test probe access to all driver input controls

Featured Applications

- Automatic Teller and Money Handling Machines
- 3D Printers
- Factory Automation and Robotics
- Video Security Cameras



1. Introduction

For stepper motors, a common design problem is tuning. Tuning involves selecting the best decay mode to operate the stepper motor efficiently. A well-behaved current waveform makes for a well-behaved stepper. These steppers will run smoothly (less vibration), quietly (less noise) and efficiently (less power dissipation). Unfortunately, there are a lot of factors that can affect the waveform, such as supply voltage, motor parameters, motor speed and load. Finding a fixed decay mode to match these settings can sometimes be difficult, especially if these parameters shift during operation. Texas Instruments AutoTune offered in the DRV8880 makes this process much simpler by determining the proper decay mode and fast decay percentage based on individual motor characteristics and system inputs.

2. Current Limiting

In order to properly commutate a stepper motor, the controller device must continuously regulate the current through the motor coils at predetermined current values. An overview of the current regulation scheme found in the DRV8880 is shown in **Figure 1** below.

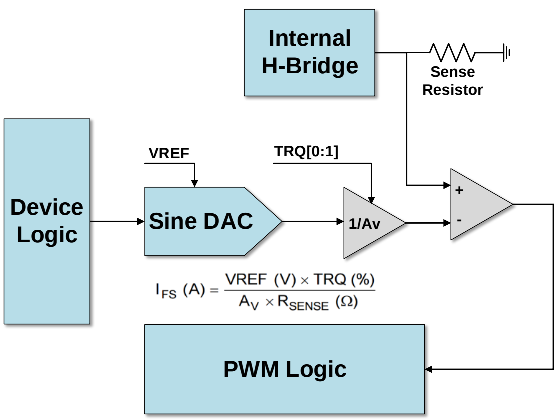


Figure 1. Single Phase Current Regulation Control Scheme

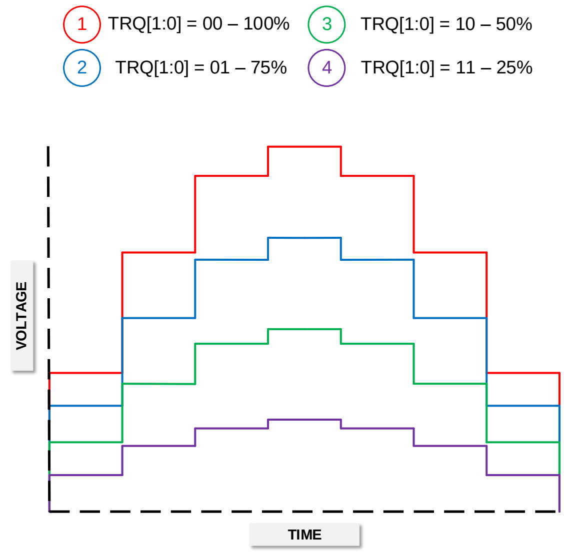


Figure 2. 1/4 Step Current Regulation Scaled by TRQ Percentage

The DRV8880 adjusts the current flowing through each phase of a stepper motor by internally comparing a reference voltage generated by the internal sine DAC to the voltage measured across an external sense resistor. This internal sine DAC is scaled based on the value of V_{REF} and has a preset table of voltage levels for each micro-stepping state. Current magnitude can be scaled using the percent torque inputs TRQ[1:0] as shown in **Figure 2** above. Adjusting the current magnitude using just the TRQ[1:0] bits simplifies the control process by not requiring a change in V_M or a change in V_{REF}. If the voltage across the sense resistor is larger than the internal comparison voltage, the device enters a different decay mode depending on the state of the decay mode setting pins and ATE pin. Depending on if the sine DAC table is increasing or decreasing steps will also affect the decay mode the device uses. All of these features included in the DRV8880s current regulation system allow the driver to have constant control over how much current is being supplied to the stepper motor.

3. Current Ripple

While the device is enforcing a specific current level during each step, there is a tradeoff between using slow or fast decay modes for current regulation. If the device uses too much fast decay then the level of current ripple in the power supply will increase and can result in unwanted noise and vibration in the stepper motor. However, if the device does not use enough fast decay then the current in the motor will gradually increase and result in the device not being able to effectively regulate current. This can damage the motor and create an uneven driving pattern. Some stepper motor drivers utilize a decay mode called mixed decay to operate while the device is lowering current through the motor windings. Mixed decay works by including a percentage of fast decay during t_{OFF} and then the remaining amount of t_{OFF} is held at slow decay. This allows the current to drop quickly during the fast decay interval and then slowly dissipate during the slow decay period, thus keeping the current ripple to a minimum. The downside to this form of current decay is that each t_{OFF} interval is often enforced regardless of how much fast decay is needed. An example of a motor tuning that utilizes too much fast decay at some steps is shown in **Figure 3** below. This results in a large amount of power supply decay current ripple.

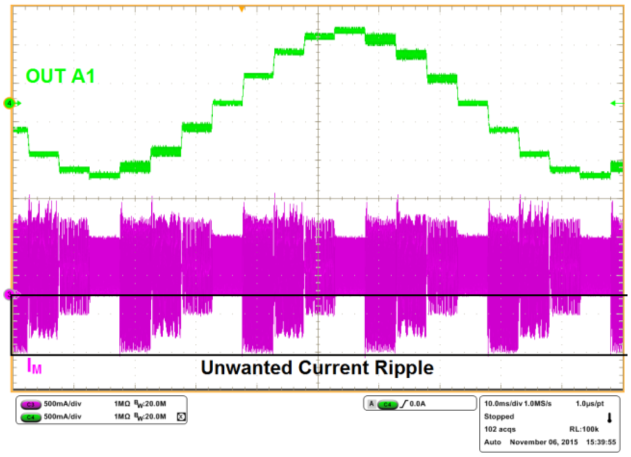


Figure 3. Supply Current Ripple Using Fast / Slow Decay

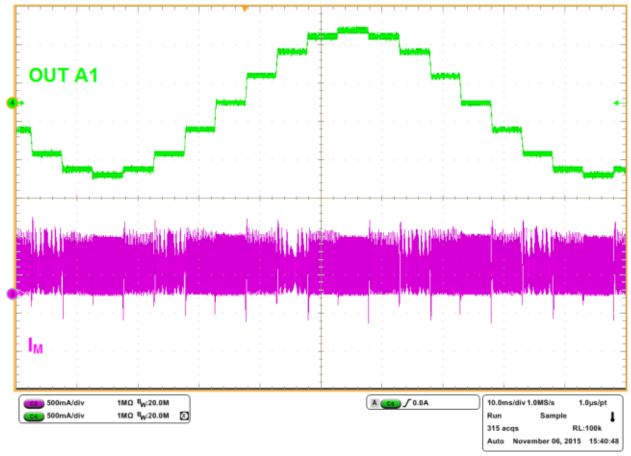


Figure 4. Supply Current Ripple Using AutoTune

To avoid this issue, the DRV8880 has an adaptive decay mode called AutoTune™ that automatically adjusts the amount of fast decay inserted during t_{OFF} to best suit the motor characteristics and load conditions at any instance in time. An example of AutoTune working is shown in **Figure 4** above.

4. AutoTune

By utilizing AutoTune™, the user can simply connect a motor and the driver will begin spinning it in the most effective way possible without requiring any other parameter tuning. AutoTune operates by actively calculating and adjusting the current decay. Each drive cycle has a mandatory t_{BLANK} interval to drive the motor. Once the t_{BLANK} interval has elapsed, the device can continue with the remainder of the t_{DRIVE} interval if it has not hit the current limit I_{TRIP}, or stop driving and begin decaying current if the current limit has been reached based on whichever decay setting AutoTune™ chooses.

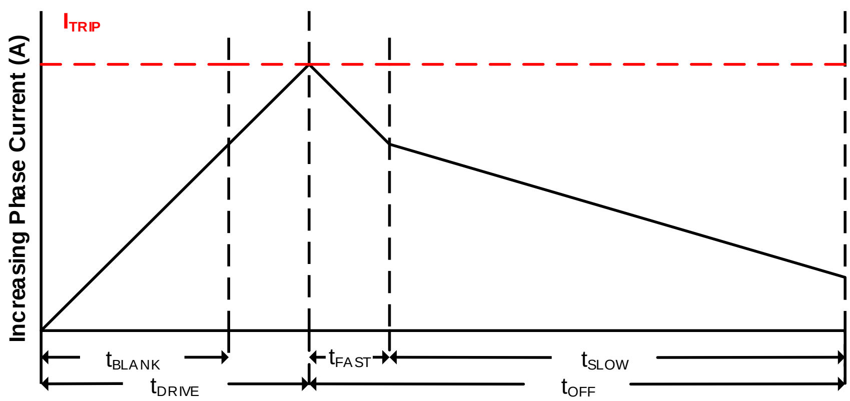


Figure 5. Mixed Decay Timing Profile

If AutoTune™ selects a mixed decay mode the driver actively inserts different percentages of fast decay during each t_{OFF} interval, and effectively lowers the current ripple while driving the motor in the most efficient way possible. An example of a mixed decay current profile is shown in **Figure 5** above. Since the driver is allowed to actively change the decay pattern it can also easily adapt to changing motor operation factors without requiring the user to retune any of the driver parameters. This is an especially relevant feature in applications where the motor will be run for long periods of time and aging effects need to be considered.

5. AutoTune Adaptation

5.1. Torque DAC

In applications that require a driver to vary the amount of torque being supplied to the motor, the DRV8880 allows the user to dynamically adjust a torque register (TRQ[0:1]) to change the magnitude of current supplied to the motor. Once the torque register has changed, the device must change the motor current regulation pattern and actively adapt the level of current supplied to the motor as shown in **Figure 1** on page 2. The amount of time it takes for current in the motor windings to change is dependent on the decay patterns ability to adapt to this new current limit while also considering the inductance of the motor windings. **Figure 6** and **Figure 7** below show the interval where the torque value is changed from 100% to 25% torque using AutoTune and Slow / Fast decay modes. In **Figure 6**, AutoTune™ is being used to quickly adapt to the change in required torque and keep the regulation pattern constant. Minimal current ripple is observed during the lower current steps. **Figure 7** uses a fixed decay setting where the current decreases more slowly through the winding until it falls below the current limit.

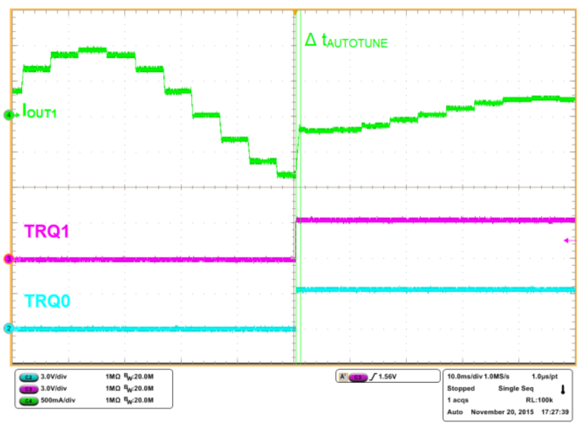


Figure 6. AutoTune 100% - 25% Torque Change

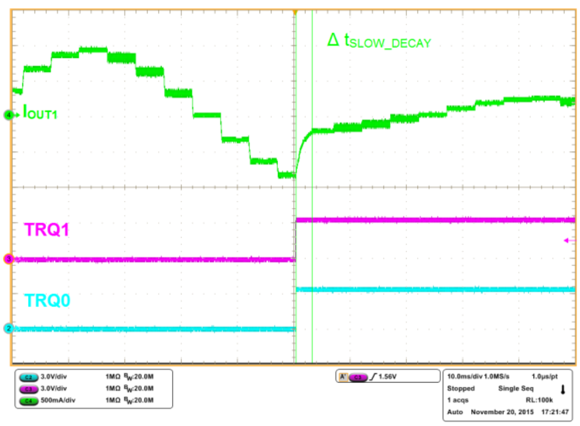


Figure 7. Slow / Fast Decay 100% - 25% Torque Change

5.2. Power Supply Variations

In a typical stepper motor power supply, there is the possibility for voltage variations caused by capacitance instability, conducted / inducted noise, and other system design issues. With a typical decay pattern and motor tuning, the driver may not be able to adapt to a sudden change in voltage supplied to the motor rail. An example of how the current ripple can vary as V_M (Motor Voltage) changes is shown in **Figure 9** below.

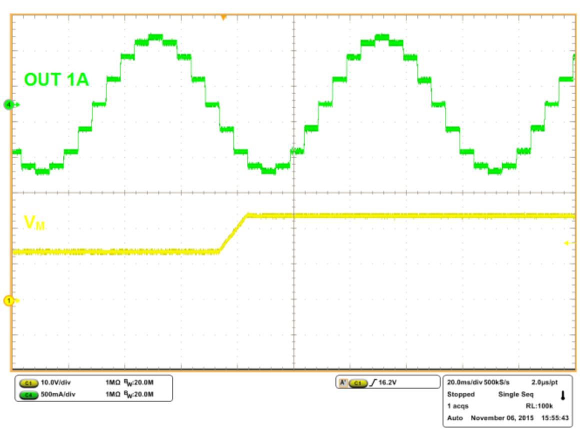


Figure 8. AutoTune Adaption to V_M Variation

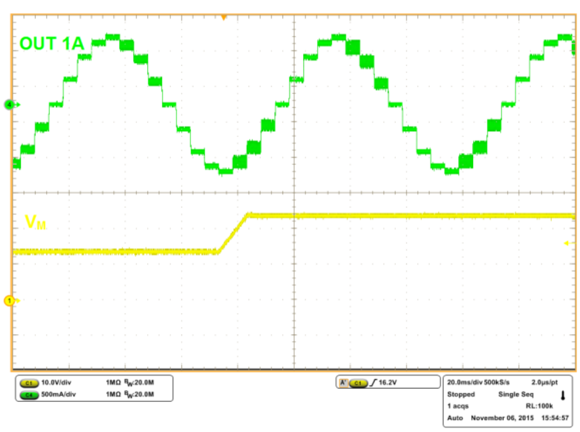


Figure 9. Slow / Fast Decay Adaptation to V_M Variation

This additional chopping is an effect of the device trying to regulate the large amount of current that is now present in the coils as compared to before. If the previous tune has a barely acceptable amount of current ripple, then the change in V_M will cause a larger amount of ripple. This can result in instability and other issues on devices sharing the V_M rail throughout the rest of the design. By utilizing AutoTune™ in the DRV8880, the device can quickly tune the stepper motor to run at this voltage and regulate the current accordingly as shown in **Figure 8** above.

5.3. Temperature Effects

A typical application may require the stepper motor to run at a continuous speed with a large load for a prolonged period of time, which can cause the stepper motor to significantly increase in temperature. This increase in temperature results in an increase in the motor resistance, causing the motor to start drawing less current from the power supply. If the motor were tuned at room temperature and without any load that same tuning may no longer be ideal once temperature increases. AutoTune™ can actively adapt to changes in motor resistance caused by the increase in temperature. Using a QSH 4218-41-10-035 stepper motor running at 1000 PPS under loaded conditions for 350 seconds at 1/8 micro-stepping the following temperature plot and current profile were captured in **Figure 10** and **11** below.

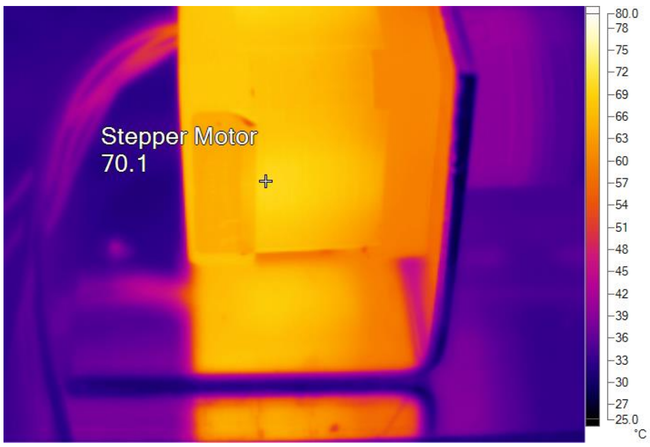


Figure 10. Stepper Motor Thermal Characteristics

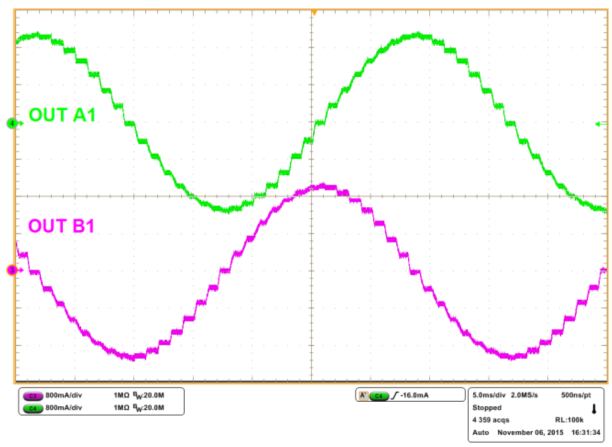


Figure 11. Stepper Motor Current Profile

6. Board Layout

This design is intended to allow the user to quickly test AutoTune's capabilities against a variety of different stepper motors without having to tune a lot of different motor parameters. This design also offers the full functionality of a Texas Instruments EVM, allowing the entire feature set of the device to be configurable via the supplied GUI and a 100 mil header located at the center of the board for the driver inputs. This board also includes an onboard USB – UART IC for quick interfacing with an MSP430 that controls fault handling and motor commutation.

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