*Application Report*
# Methods to Configure Current Regulation for Brushed and Stepper Motors

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## ABSTRACT

This document is provided as a supplement to the family of DRV88xx power stage device's data sheet. It details different methods which could be employed to provide an external analog voltage used as a reference voltage which in turn can be used to program a regulated current output.

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## 1 Introduction

Controlling current magnitude across an inductive load allows us to control the application's torque. In applications driving inductive loads such as brushed DC motors, it may be required to limit the current during startup or during stalling conditions. On applications involving stepper motors designed with a very low winding resistance, controlling current is of paramount importance during all segments of the motion control profile.

When driving a stepper motor, regulating the current can work to the user's advantage in two ways. If in full step commutation, controlling the maximum current level transfers into motor's shaft torque control. With this implementation, the system is tuned to use only the necessary amount of current, decreasing motor vibrations. However, by adding different current levels into a full step, by modulating the current regulation engine's input, micro steps can be induced. Such implementation reduces vibrations and audible noise further.

A good portion of the DRV88xx family of brushed DC and stepper motor drivers will contain a block offering current regulation which can be used to control the amount of current sourced into the aforementioned inductive loads. On this application note we detail some of the mechanisms available to program said current magnitude.

## 1.1 The Current Regulation Engine

There are two possible implementations for a current regulation engine on the DRV88xx family of power stage devices: Internal or External VREF. Figure 1-1 depicts the typical analog block utilized to sample current information and disable the H Bridge accordingly. User must refer to respective device's datasheet to learn whether the Analog Reference Voltage is internal or external to the device.
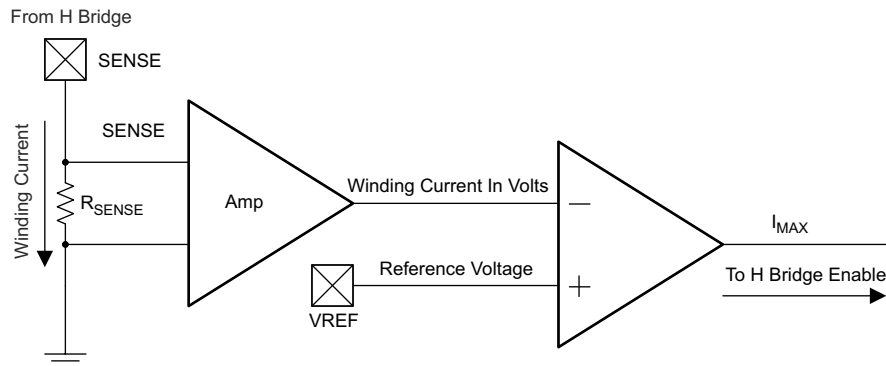
**Figure 1-1. Current Regulation Analog Block**

The Current Regulation Block is continuously monitoring motor winding current by sampling the voltage across the SENSE resistor. The SENSE resistor is in series with the H Bridge, so the current flowing through the inductive load will be the same as across the resistor. The SENSE resistor is chosen to be as small as possible in order to minimize power losses. This makes the voltage drop across it proportionally small.

In order for the SENSE voltage drop to be properly compared with the reference voltage, an amplifier is put in place. Typical gains for this amplifier stage are 5, 8, and so forth. User must refer to the respective device's datasheet to determine the amplifier's gain.

The amplified voltage is then compared against the reference voltage. When the amplified SENSE resistor voltage is greater than the reference voltage, this signifies winding current is larger than the target current. This event is referred to as an ITRIP event and when this happens, the device's logic disables the H Bridge and allows the current to decay through the internal structure. This process is repeated on a continuous basis thus obtaining a regulated current output.

**Note**

An ITRIP event will generate an immediate H Bridge disablement as long as the H Bridge has been enabled for longer than the TBLANK period. In order to filter out spurious noise at the SENSE resistor, caused by H Bridge enablement, a small delay is put in place. During this delay, the SENSE resistor voltage is not sampled.

## 1.2 Design Criteria

Before selecting the external analog reference voltage, it is customary to select the SENSE resistor. Since the application will define the range of currents the power stage will be dealing with, a SENSE resistor must be selected so that the allowable reference voltage be in the permissible range as specified by the respective device's datasheet.

The typical ITRIP equation is in the form of:

$$ITRIP = \frac{VREF}{AMP\_GAIN \times SENSER}$$

(1)

Where:

**ITRIP** is the current regulation set point
**VREF** is the analog reference voltage at the device's VREF input.
**AMP_GAIN** is the internal amplifier gain
**SENSER** is the SENSE resistor in Ohms

## 2 Resistive Network Voltage Divider Method

The simplest form to derive the external analog reference voltage is by dividing down a higher rail voltage. For example, the logic voltage could be set to be **VIN** equal to 3.3 V or 5 V and a voltage divider, as depicted on Figure 2-1(a), would step this rail down to the target reference voltage.
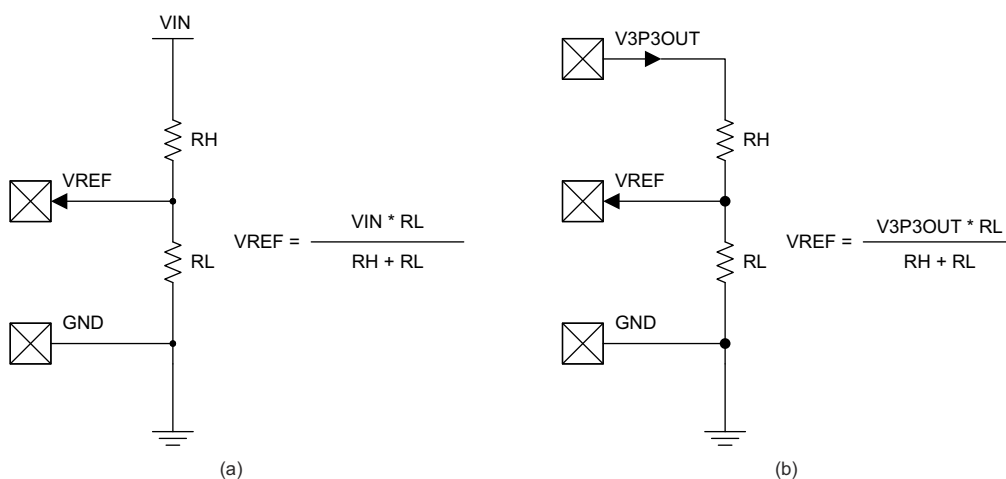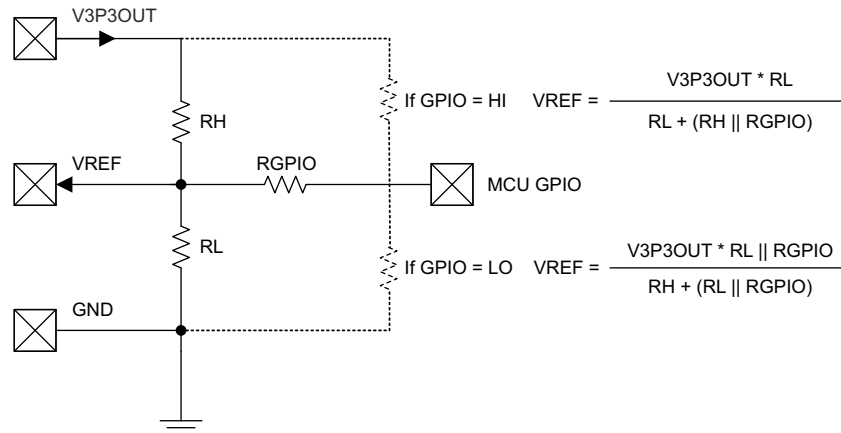


**Figure 2-1. A voltage divider can be used to set the VREF parameter.**

If the application requires manual current tuning, a potentiometer can be used instead of two fixed resistors. VREF is a high impedance input, so the total resistive value for the potentiometer is very flexible.

Figure 2-1(b) portrays how on some of the DRV88xx devices, a 3.3 V rail (V3P3OUT) is provided, which can be used as the voltage rail to drive the voltage divider and derive the target reference voltage. In these implementations, external device count is reduced as an external regulator is not required. User must refer to the respective device's datasheet to determine maximum available current from this output. Total resistance sourced from this output must be selected so maximum current drawn is not exceeded.

## 2.1 GPIO Driven Voltage Divider

Utilizing a fixed voltage divider may work for limiting start and stall current on DC motors, but may result constrictive when dealing with most stepper applications in which a current level is required during run time and a different value during position/torque holding. A simple topology often utilized to derive a dual current level into the VREF pin is to use a conventional GPIO microcontroller terminal to drive a resistor into the VREF voltage divider.



**Figure 2-2. A MCU Controllable Voltage Divider**

If GPIO = HI

$$VREF = \frac{V3P3OUT * RL}{RL + (RH \parallel RGPIO)}$$

If GPIO = LO

$$VREF = \frac{V3P3OUT * RL \parallel RGPIO}{RH + (RL \parallel RGPIO)}$$

Figure 2-2 shows how the GPIO resistor is placed in parallel with the high side or the low side depending on whether the digital output is made HI or LO, respectively. It is also possible to make the GPIO an input, in which case the GPIO resistor becomes a high impedance path, offering a third current level setting. If the GPIO resource is configured as an input, RGPIO disappears from the system, and the equation is the same as depicted on Figure 2-1(b).

# 3 Digital-to-Analog Converter Method

In some applications it is required for the VREF input to be modified in real time. In this case, fixing the analog voltage through a voltage divider is detrimental to the application. The optimal solution is to employ a DAC function which can be programmed to a target value as the application requires. The DAC can be a function internal to a microcontroller, or a stand alone block driven by any processor.

The DAC output can be connected directly to the VREF input, as shown on Figure 3-1. A 1000 pf capacitor to GND is recommended to filter out any DAC transition noise.
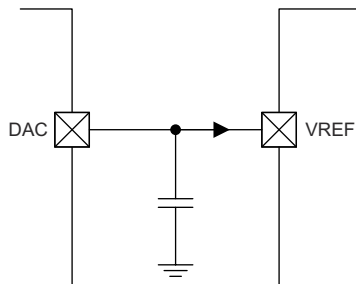


**Figure 3-1. A Microcontroller DAC Drives the DRV88xx VREF Input**

Typical implementations requiring a DAC function are brushed DC motor driving with torque control, steppers requiring a holding torque different than running torque, and steppers being commutated through a high resolution micro-stepping lookup table.

# 4 PWM to RC Filter Method

The DAC function solution may result prohibitive for some circumstances. For example, not every microcontroller will contain a DAC block. Also, the added cost of a stand alone DAC function may not be favorable for the end application. Timers, on the other hand, are much more common place on today's microcontroller offering.

A simple technique to fashion a DAC channel by utilizing a timer function is to have the timer operate as a PWM generator into an RC filter, as shown on Figure 4-1. By modulating the PWM's duty cycle, a directly proportional analog voltage can be obtained. The RC filter element must be configured so the output voltage has the least amount of ripple, as such variations may transfer into the regulated current output.
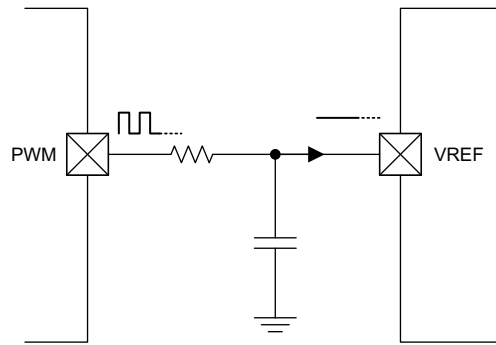


**Figure 4-1. PWM Timer and RC Filter Generates an Analog Voltage**

Typical implementations around an RC filter based DAC may be a brushed DC motor requiring torque control or a stepper motor requiring a current during run time and a different current for position holding torque. In order for this topology to work as a DAC function capable of generating high resolution micro-stepping, the PWM frequency would need to be higher than the stepping rate.

# 5 Changeable Holding Current Circuit

The circuit in Figure 5-1 can realize changeable holding current function by using the CD74HC123. The CD74HC123 is a dual, retriggerable, monostable multivibrator, with reset. In this application, the input STEP comes from the step signal of the motor driver ICs, such as DRV8818. The output $V_{REF}$ is applied to the $V_{REF}$ pin of the motor driver ICs to achieve changeable holding current.

According to the principle of CD74HC123, when a pulse is applied to pin 1, there is a high output on pin 13, with a pulse width of 0.45 $R_X \times C_X$ starting at the falling edge of the signal on pin 1. When the signal frequency on pin 1 is bigger than 1 / (0.45 $R_X \times C_X$), the high level on pin 13 maintains all the time. Figure 5-2 shows that by this time, the voltage on pin 13 stays high (Vcc), through a potential-divider network, an R4 × Vcc / (R4 + R2 // R3) output voltage is applied to the $V_{REF}$ pin of the motor driver IC.

When the stepper motor is in holding state, there will be no pulse on the STEP, the level on pin 1 will be low so the output voltage on pin 13 will be driven low (GND), hence the VREF voltage becomes Vcc × (R2 // R4) / (R2 // R4 + R3), as shown in Figure 5-3. In this way, the holding current of the stepper motor can be set by choosing suitable resistors.

So the $V_{REF}$ can be automatically changed when the stepper motor enters into holding state. Note: to get a good performance of normal operation, adjust the value of RX and CX based on a target STEP signal to achieve a constant high level on pin 13 when the stepper motor is in normal operation. For example, if the frequency of the step signal is 1/15 Hz, that is, there are only four steps in one minute, then 1/15 > 1 / (0.45 RX × CX), so RX × CX must be larger than 33.3, so 10 M can be selected for RX, 10 μF can be selected for $C_X$.
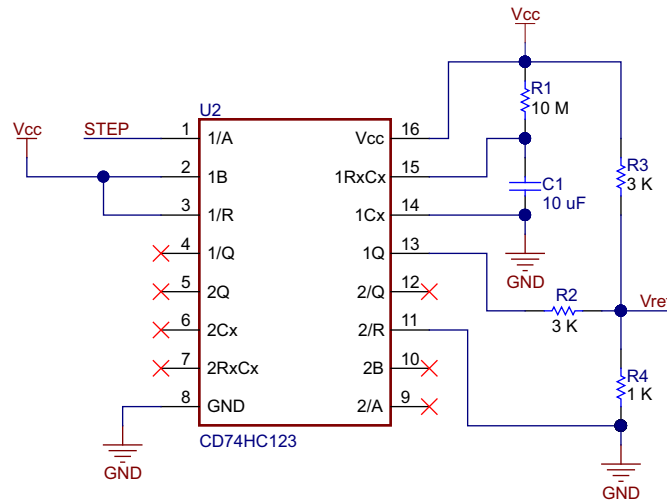
**Figure 5-1. Changeable Holding Current Circuit**
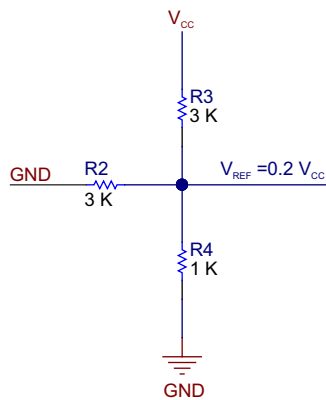
**Figure 5-2. Output of Normal Operation**
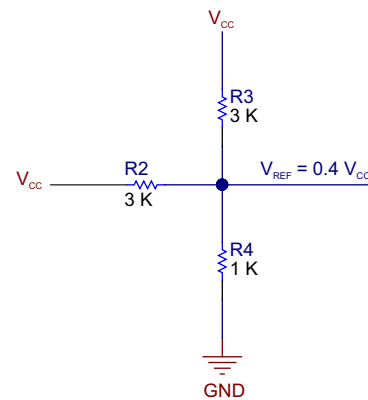
**Figure 5-3. Output of Holding State**

## 6 Devices With Internal Reference Voltage

Some devices are built with a low pin count design constraint. In this case, a reference voltage input falls outside the design scope. The reference voltage is internally configured with the only means to change the actual current regulation point by selecting a particular SENSE resistor. Users must refer to the respective device's datasheet to determine the internal reference voltage parameter.

## 7 Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

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