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Current Recirculation and Decay Modes

ABSTRACT

This document is provided as a supplement to the DRV88xx datasheets. Its goal is to explain current recirculation techniques, why it is important and how they are implemented throughout our decay mode circuitry.

Contents
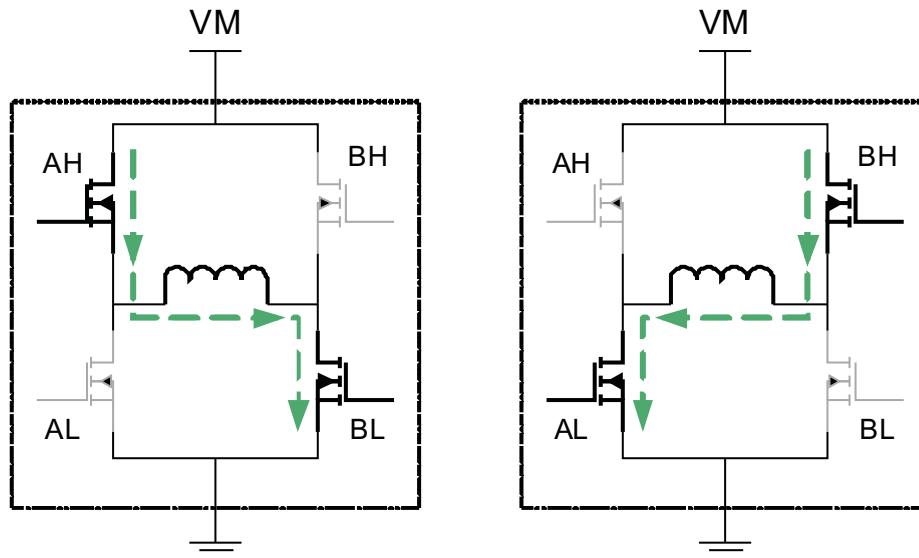
List of Figures

1   Introduction

An H Bridge allows the control of current on both directions through an inductive load such as a motor. Figure 1 shows how, by choosing which FET is enabled, current is made to flow in one direction or the other.
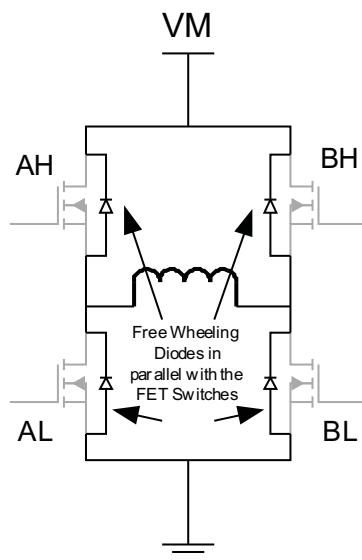

Figure 1. H Bridge

Due to the physical properties of inductive loads, once current is flowing in one direction, said direction must be maintained. This is also true when the H Bridge is disabled or when the opposing voltage polarity is applied (e.g. when the Direction command is switched).

Not giving a safe path for this current to flow, while it decays down to zero or switches to the new direction current, will result in damage to the H Bridge's power switches.

A proper path for this current decay is often offered as free wheeling diodes in parallel with the FET switch, which will start conducting as soon as the FET switches are disabled. A more efficient way to handle this current is to enable/disable FET switches in a sequence that carries the decaying current, but without causing shoot through.


Figure 2. Free Wheeling Diodes

These alternatives to control current flow until it decays are referred to as current recirculation methods. On this application note we will detail each style of current recirculation and decay modes.

1.1 Asynchronous Decay

When diodes are used to accept the current flow while it decays, this is referred to as asynchronous decay. It is asynchronous to the controller turning the FET switches ON and OFF. The timing of when the diodes will start conducting is not known, but it is highly recommended for this turn ON time to be as short as possible in order to avoid possible damage to the FET switches. Schottky diodes are often used for this purpose.

1.2 Synchronous Decay

Although FET switches often have a body diode associated with them, it is often much more efficient to utilize the FET ON resistance as a safe path for current decay. When the controller coordinates the turning ON and OFF of FET switches as a means to offer a safe path to current during decay, this is referred to as synchronous decay. The time of when the FETs are brought online to carry the current is known and fixed.

> **Note:** It is impossible to instantaneously offer a safe path for decaying current by turning opposing FETs, since this would cause shoot through. As a result, every controller employing a synchronous decay mechanism will, for a very small period of time, employ a form of asynchronous decay through the FET switches' body diodes.

2 Current Recirculation

On the upcoming definitions, the words "fast" and "slow" are meant to correlate to how fast the current decays down towards zero. They do not imply any form of speed of actuation on the inductive load.

2.1 Fast Decay

During a fast decay recirculation mode, current is said to decay towards zero as fast as possible. This is attained by disabling the energizing FET switches and then enabling the opposing FET switches (synchronous decay), or letting current flow through free wheeling diodes (asynchronous decay).
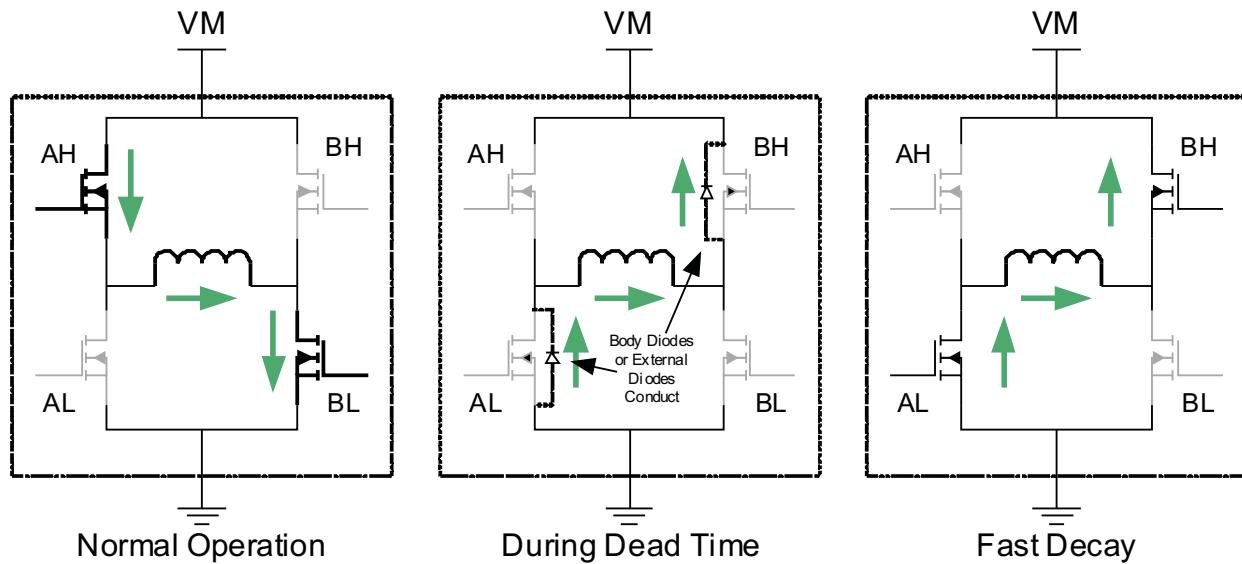
Current decays the fastest possible because a voltage of greater magnitude but opposing polarity is applied to the inductive load.

On synchronous decay, the proper technique to achieve fast decay mode is to employ a break before make mechanism in order to avoid shoot through. If the opposing FETs are enabled as soon as the energizing FET switches are disabled, there will be a short period of time in which all four FET switches will conduct. This is extremely hazardous to the device.

The solution is to add a period of time in which all FET switches are off, called dead time. During this time, energizing FET switches are allowed to switch to their OFF state and inductive load existing current is carried by either body diodes or external Schotky diodes.
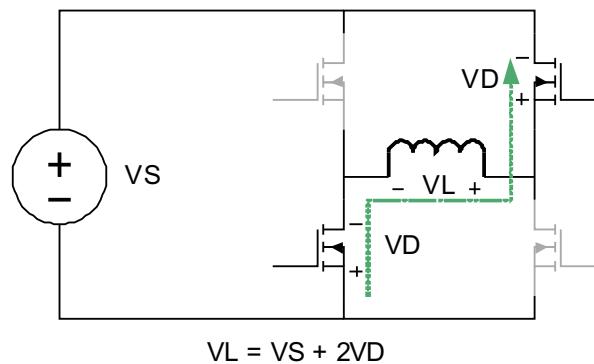
H Bridges employing asynchronous decay will let the diodes conduct the current while it decays. H Bridges employing synchronous decay will turn the opposing FET switches until current decays down to zero, or a fixed time off elapses.

Figure 3. Fast Decay Mode
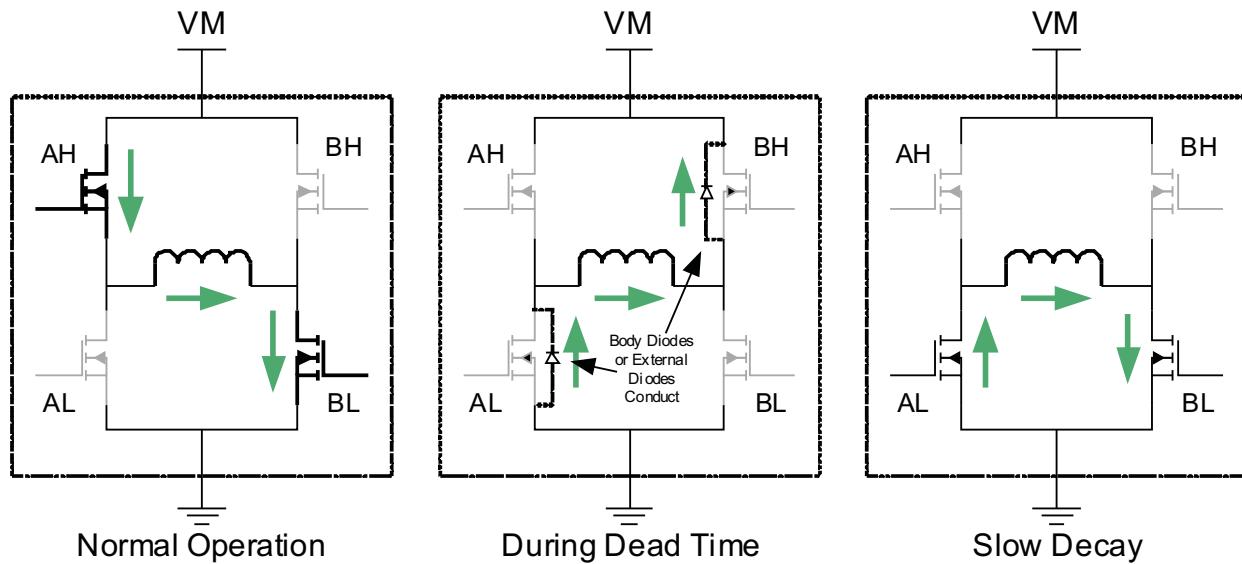
Note that the voltage applied to the inductive load is that of the source plus two diode forward voltage drops, or current multiplied by respective switch RDSon.


$$VL = VS + 2VD$$

Figure 4. Voltage Applied to the Inductive Load

2.2 Slow Decay

During a slow decay recirculation mode, current is said to decay towards zero on a slower than fast decay basis. Slow decay mode is attained by disabling the high side energizing FET switch and enabling the opposing low side FET switch.

Figure 5. Slow Decay Mode
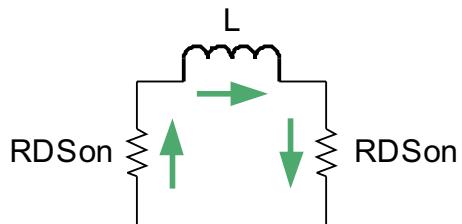
Note: Although slow decay is often portrayed as both low side FET switches turned ON with both high side FET switches turned OFF, the same phenomenon can be achieved by enabling both high side FET switches, while disabling both low side FET switches. Some DRV88xx devices will allow for either technique to be employed by properly configuring the device through respective MODE input signals.

There are certain special characteristics to the slow decay mode that the user must understand:

1. Current will decay as slow as the LR time constant, where L is the inductance on the inductive load and R is two times the low side switch RDSon.

Figure 6. Current Decay

2. On DC motors, where a Back EMF develops as the motor rotates, slow decay mode offers a short to the winding, which in turn shorts (collapses) the Back EMF. This results in a very quick rotor stop.
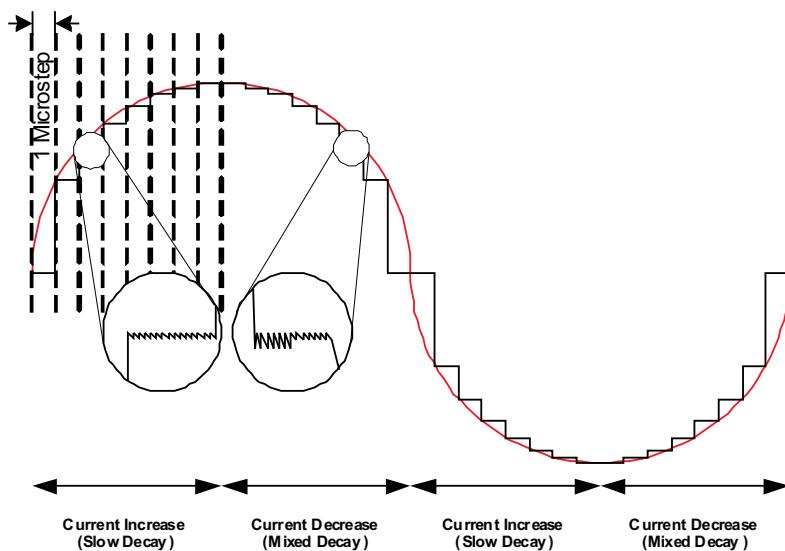
2.3 Mixed Decay

During a mixed decay recirculation mode, current is made to decay towards zero faster than on slow decay method but slower than the fast decay method. This technique is achieved by coordinating FET switch ON and OFF time so that fast decay mode is engaged for a fixed amount of time, subsequently engaging in slow decay mode for the remaining period of time. The ratio of how long the system will be maintained in fast decay versus slow decay is referred to as the mixed decay percentage.

Mixed decay is particularly meaningful to stepper motor driving, but most importantly, to microstep driving. When microstepping, a certain wave shape is to be maintained in order to obtain the best motion quality. For example, it is common to drive the stepper motor windings with a sine wave like current profile. Triangle shapes and rhomboid shapes can also be used to the same extent.

The faster the stepper motor is commanded to move, the harder it is to follow the desired wave shape. This is due to the fact that the motor inductance limits how fast the windings are bled out. Therefore, it is necessary to find a rate of current recirculation in between fast and slow decay modes to accommodate the different portions of the wave shape in question.

When current is increasing, as the microsteps are issued, preferred recirculation mode is slow decay. In essence, slow decay mode is ideal due to decreased EMI and increased efficiency during recirculation. During the increase of current stage on the superimposed waveform (first 90 electrical degrees), slow decay is enough to handle changes in current value as new microsteps are issued as shown in Figure 7.

Figure 7. Mixed Decay Mode

However, slow decay mode is not fast enough to bleed out the current on the inductor with the speed necessary to jump to the next microstep and still follow the wave shape when the current is decreasing. Fast decay would be too fast and would also account for warped wave shape. A safe point is found by selecting a reasonable mixed decay ratio.

2.3.1 Mixed Decay on DRV88XX Devices

There are two ways to handle mixed decay mode: fixed and adjustable.

Fixed Mixed Decay Mode: A percentage such as 75% or 67% is programmed into the core. Mixed decay mode will time multiplex fast to slow decay ratio to this percentage (e.g. 75% of the time on fast decay and 25% of remaining cycle time on slow decay).

Adjustable Mixed Decay Mode: An analog input is provided such that an analog voltage encodes the mixed decay ratio. Particular device datasheet offers the equation to correlate analog voltage input to mixed decay ratio.

IMPORTANT NOTICE