The H-bridge motor driver with a bridge to a wonderful heritage

Brushed DC motor control brought up to date

Introduction

Since the 1950s the semiconductor industry has grown from almost nothing into a mature and essential part of society. Today, the industry contributes more than $481 billion in revenue itself, while also enabling consumer electronics, power electronics, the tech industry as a whole, and e-commerce[1]. Trying to imagine our world without semiconductors is similar to attempting a world without plastics, the convenience of supermarkets, or air travel.

The industry is also now mature enough to have established products that can be considered defining: chips that most engineers will have interacted with either during their training, education, or career. The NE555, an 8-pin integrated circuit that simplified the construction of, amongst other things, monostable, bistable, and astable circuits, has formed the basis not only of chapters in books, but entire books as well[2]. The µA741 is considered the most popular operational-amplifier (op-amp) of all time, designed by the big names of the fledgling 1960s semiconductor industry[3]. And there cannot be a single engineer that hasn't built a 5 V power supply without turning to the 7805 in its, by today's standards, chunky TO-220 package.

However, all of this historical reflection originates from the North American semiconductor industry. Driving the miniaturisation of consumer products, Japanese businesses were utilising the high integration semiconductors were offering to deliver advancements in consumer technology. While the average western consumer of the 1960s and 1970s would have been largely unaware of the electronics inside the products changing their lives, they were perhaps more aware of the brands of the products themselves. The videocassette recorder (VCR), starting its life in television networks in the mid-1950s, made its way into homes by the 1970s and was based upon helical scan recording that had been developed by Toshiba[4].

Front-loading 'VHS' videocassette players demanded several motors to provide loading and unloading of cassettes, as well as careful control of the capstan and tape spool. Fundamental in this was the use of Toshiba's TA7291 H-bridge controller (figure 1). And, like its American counterparts, it too has attained a cult-like status. It now features in a wide range of books on Arduino and Raspberry Pi, being used to demonstrate to a new generation of engineers how the control of brushed DC motors can be implemented. This makes it another memorable integrated circuit that future generations will reflect upon as having kicked off their interest in electronics.

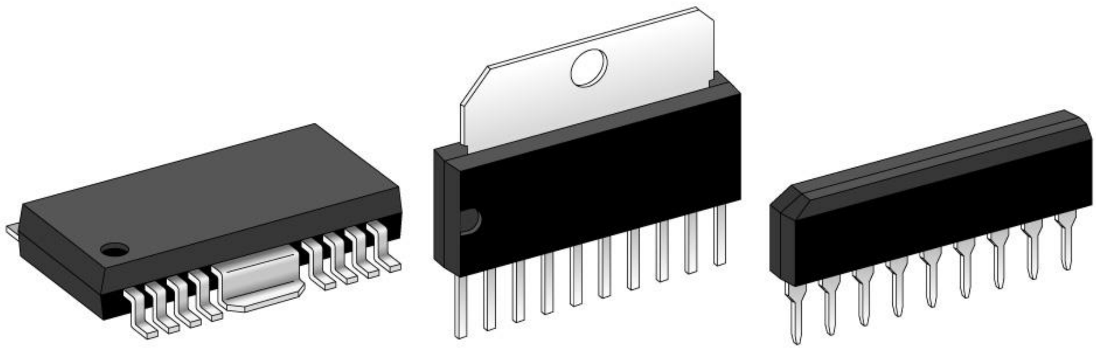

Figure 1: The TA7291 H-bridge motor controller was offered in three different package types supporting different upper current limits.

The basics of the H-bridge motor controller

Having understood that heavy loads, such as motors, cannot be powered directly from the pins of a microcontroller (MCU), the budding engineer learns about devices such as MOSFETs. First steps are undertaken to build circuits that allow a small output current from an MCU pin to control the large currents demanded by a brushed DC motor (figure 2). Of course, this limits control to on, off, or a variable speed if a pulse-width modulated (PWM) output is used. The next step of learning is how to additionally control the rotational direction of the motor.

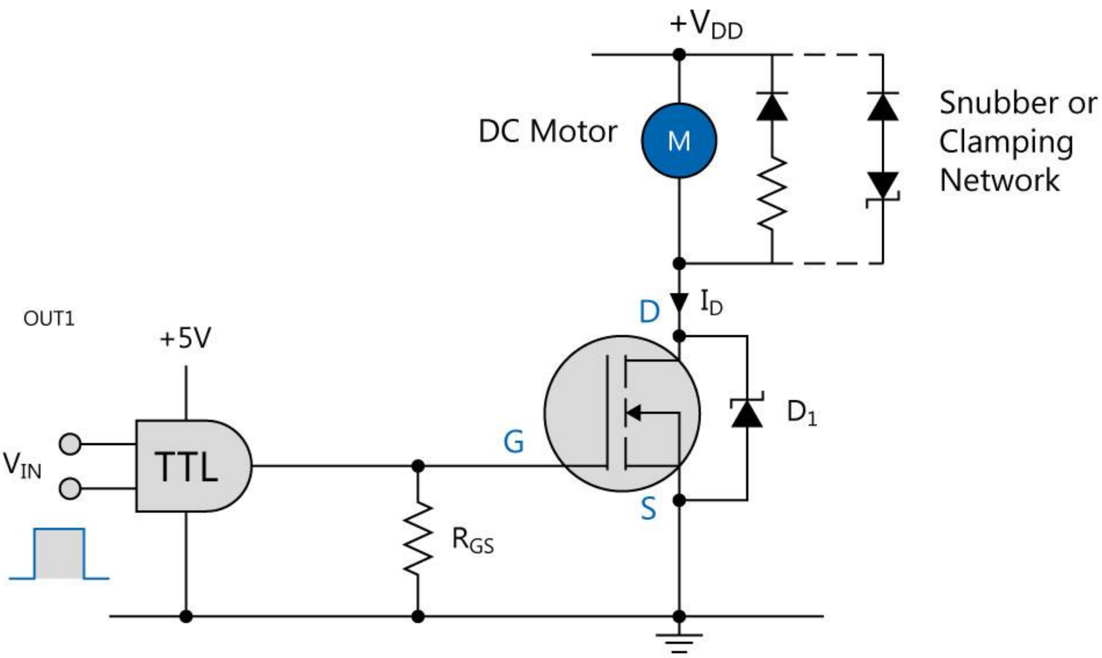

Figure 2: Basic uni-directional motor control can be implemented using a single switch.

The H-bridge is a simple concept that enables the polarity of the supply being applied to a brushed motor to be swapped. In combination with a PWM signal, the motor's rotational speed and direction can also be controlled. Due to inertia in the rotor and any attached load, the motor will continue to spin once power has been removed. However, a further capability of the H-bridge is its ability to short together the motor terminals, resulting in the back-electromotive force (back-EMF) being used to decelerate the rotor faster than leaving the terminals disconnected from one another. This capability is commonly termed 'braking' although it should be noted that it only slows the rotor speed and does not provide a hold function as would be expected of a mechanical brake.

The back-EMF issue raised is a serious problem that also needs to be dealt with by the H-bridge circuit. Once power has been removed from the motor, as long as the rotor continues to rotate, the motor will function as a generator. This obviously leads to a potential at the motor terminals which is also applied to the FETs that form the H-bridge. Without suitable protection, this potential can easily destroy the FETs due to the high voltages generated. Diodes in parallel to the switches, often termed freewheeling or flyback diodes, providing a path for this current to flow when the FETs are switched off and the rotor spins down. This completes the classic H-bridge design (figure 3).

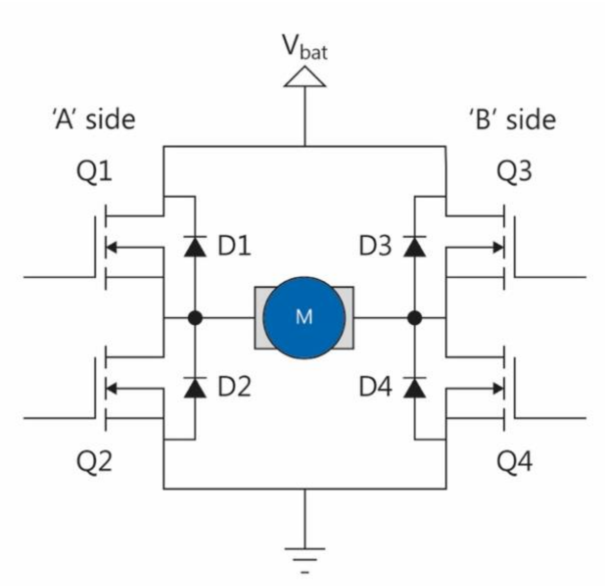

Figure 3: The basic H-bridge control circuit as implemented using discrete switches.

Of course, a discrete version of this circuit requires many individual components and, without further circuitry, risks shorting the power supply should the high-side and low-side switches be enabled simultaneously. Integration seems the obvious way to go in order attain a compact solution that also provides the necessary protection mechanisms.

The TA7291 was, for its time, a highly integrated solution for handling the challenges of motor control, integrating four bipolar transistors for the power switching along with the flyback diodes. It also included the necessary control circuitry, providing clockwise, counter-clockwise and braking control (figure 4). Once placed in STOP mode, the device would also drop into a respectable 50 µA low-power mode. There were also some protection features too, such as a thermal shutdown, overcurrent protection, and punch-through current restriction. Supporting average currents of up to 1.0 A, and peak currents of up to 2.0 A, the H-bridge was offered in both horizontal HSOP and vertical SIP/HSIP packages, providing space saving options for applications that required it. It is a testament to the device that it has been on the market for over 40 years and has been selling at roughly 10 million units per year.

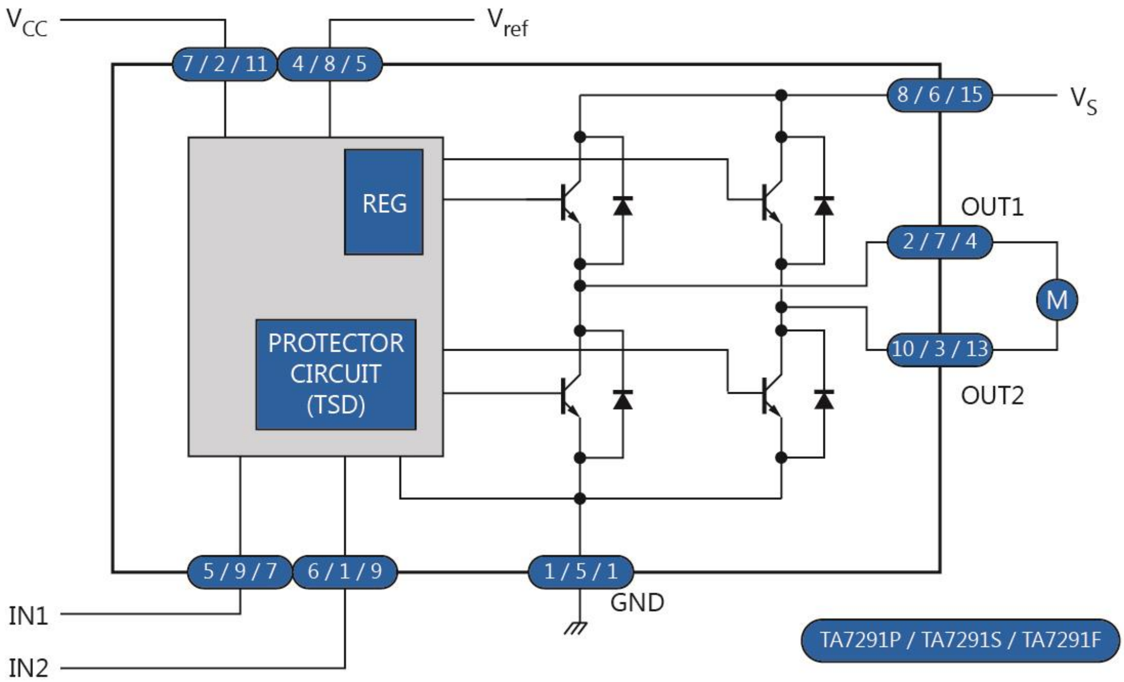

Figure 4: The TA7291 block diagram, featuring H-bridge and control circuitry.

In the last 40 years of course, much has changed with silicon technology, levels of integration, as well as the demands being placed on efficiency and manufacturability. The TA7291, with its on-resistance of 4.75 Ω, 25 V upper supply voltage, limited protection features, and large or through-hole packages, no longer meets the demands of today's applications.

Next generation H-bridge

Building upon the basis of its predecessor, Toshiba has introduced the TB67H450FNG and TB67H451FNG, utilising the latest generation of silicon processes, compact packaging, and the advances these technologies deliver. The core functionality of the TA7291 is retained, allowing the benefits of the BiCD silicon process to handle more current, higher voltages, and additional protection mechanisms (figure 5). They are also very compact, fitting into an SOP package with just 8 pins.

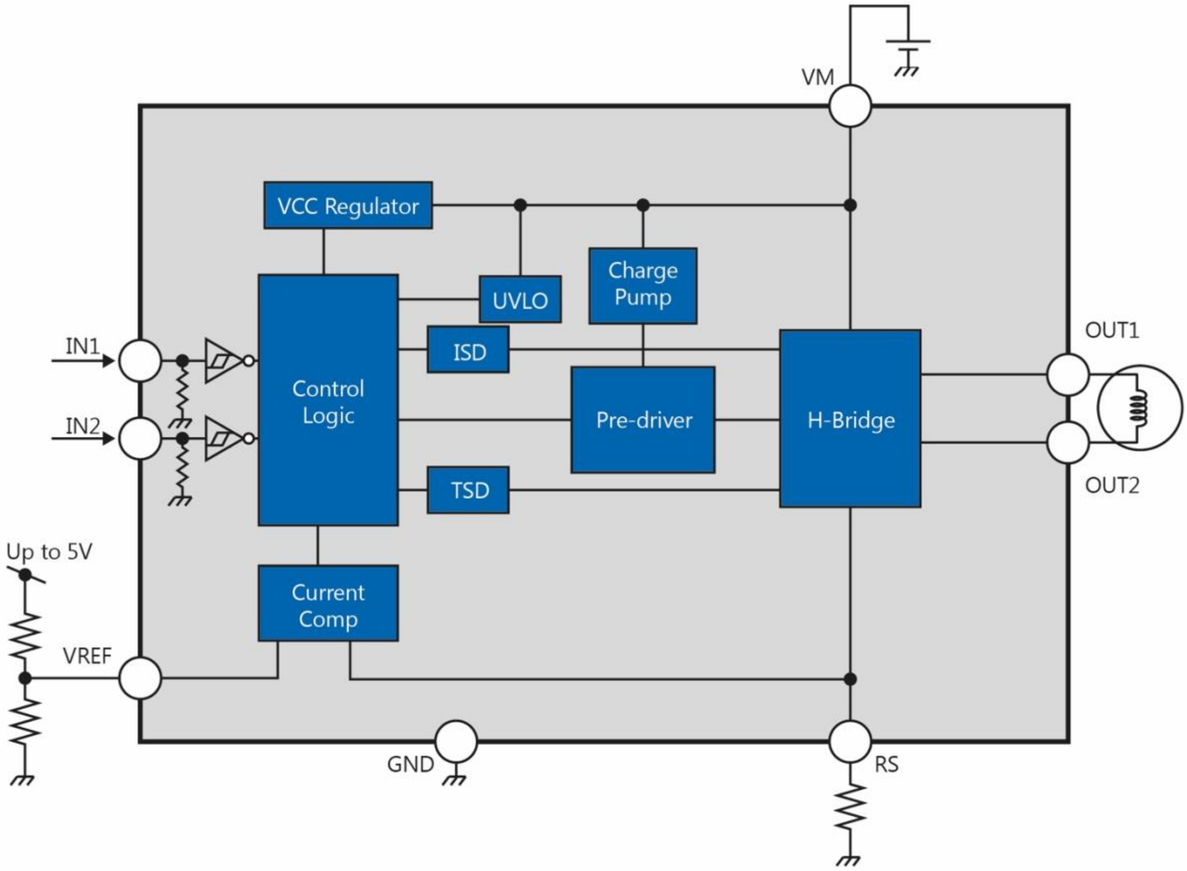

Figure 5: Featuring improved switches and control technology, the TB67H450FNG and TB67H451FNG provide significant benefits over the previous generation H-bridge motor controller.

The integrated bipolar transistors in the power stage have been replaced with MOSFETs that feature a typical on-resistance of just 0.6 Ω (high side plus low side). These are coupled with the necessary pre-driver stage and integrated charge pump. The devices also reduce the total number of pins required by integrating a voltage regulator for the control logic, meaning that the bridge can be powered via a single pin. These changes increase the upper operating limit of the H-bridge to 3.0 A, while also raising the upper operating voltage to 44.0 V.

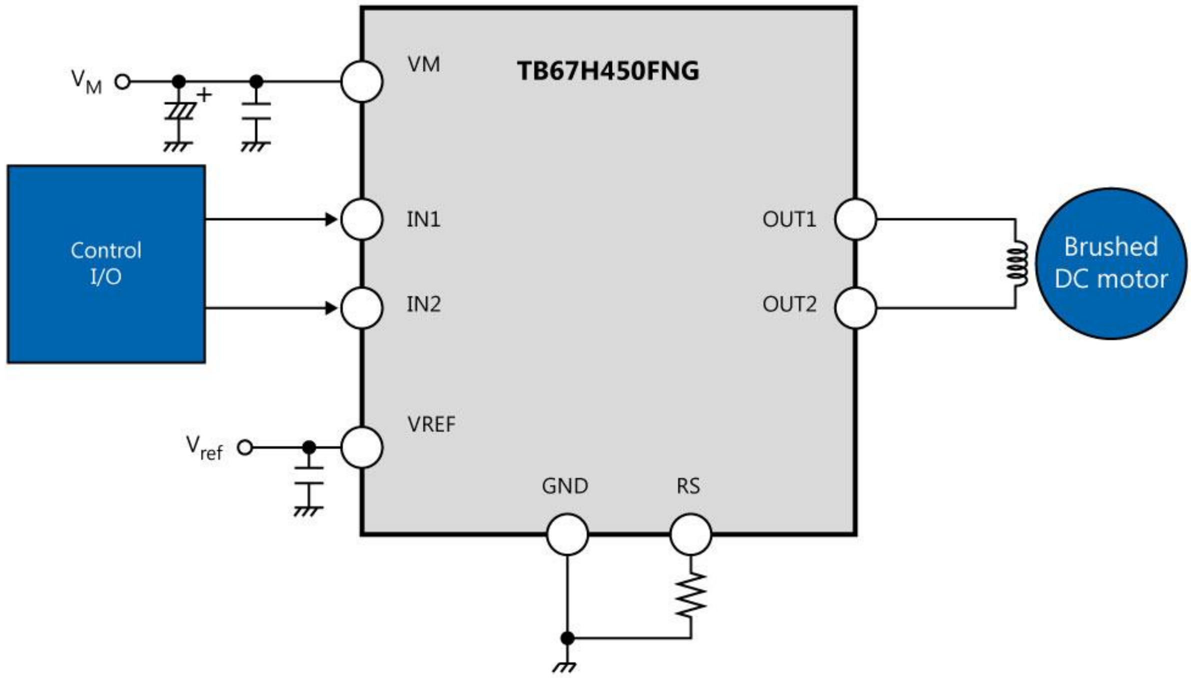

Figure 6: Basic brushed-DC motor control using the TB67H450FNG.

The supply voltage is also monitored thanks to an under-voltage lock-out (UVLO) block. Should the supply drop below 3.8 V, the outputs switches are turned off. This state is maintained until the supply rises again above 4.0 V. This makes it the ideal solution for controlling small motors in applications powered from a USB charger.

The current is monitored using a latched threshold measurement circuit in the TB67H450FNG. When the current drawn rises beyond a typical value of 4.9 A, the outputs are turned off until the device undergoes a power cycle or a high signal is applied to pins IN1 and IN2. This is implemented by setting the device into STOP (and standby) mode. The TB67H451FNG implements the same current protection but resets automatically once the overcurrent condition has been cleared.

Thermal runaway is kept in check, with the integrated protection circuitry halting operation once the temperature exceeds around 160°C. The thermal shutdown hysteresis has a typical value of 30°C.

Basic operation is provided, as in its predecessor, via two pins that define the rotational direction, apply braking, or stop the application of current to the motor. In this STOP mode the devices also revert to their low-power state after 1 ms drawing a maximum of 1 µA to save power. PWM control is achieved by controlling IN1 and IN2 and supports frequencies of up to 400 kHz with a minimum duty-cycle pulse width of 500 ns.

If desired, motor control can also be implemented in constant-current mode (figure 7). Through the implementation of a small resistor between the RS pin and ground, and by applying a suitable voltage via a voltage-divider to the VREF pin, the H-bridge operates in a mixed decay mode. This results in the device switching through a fast mode, feeding energy from the motor coil back into the power source, and a slow mode, where the current is circulated through the motor coil and low side switches, when the current limit is reached.

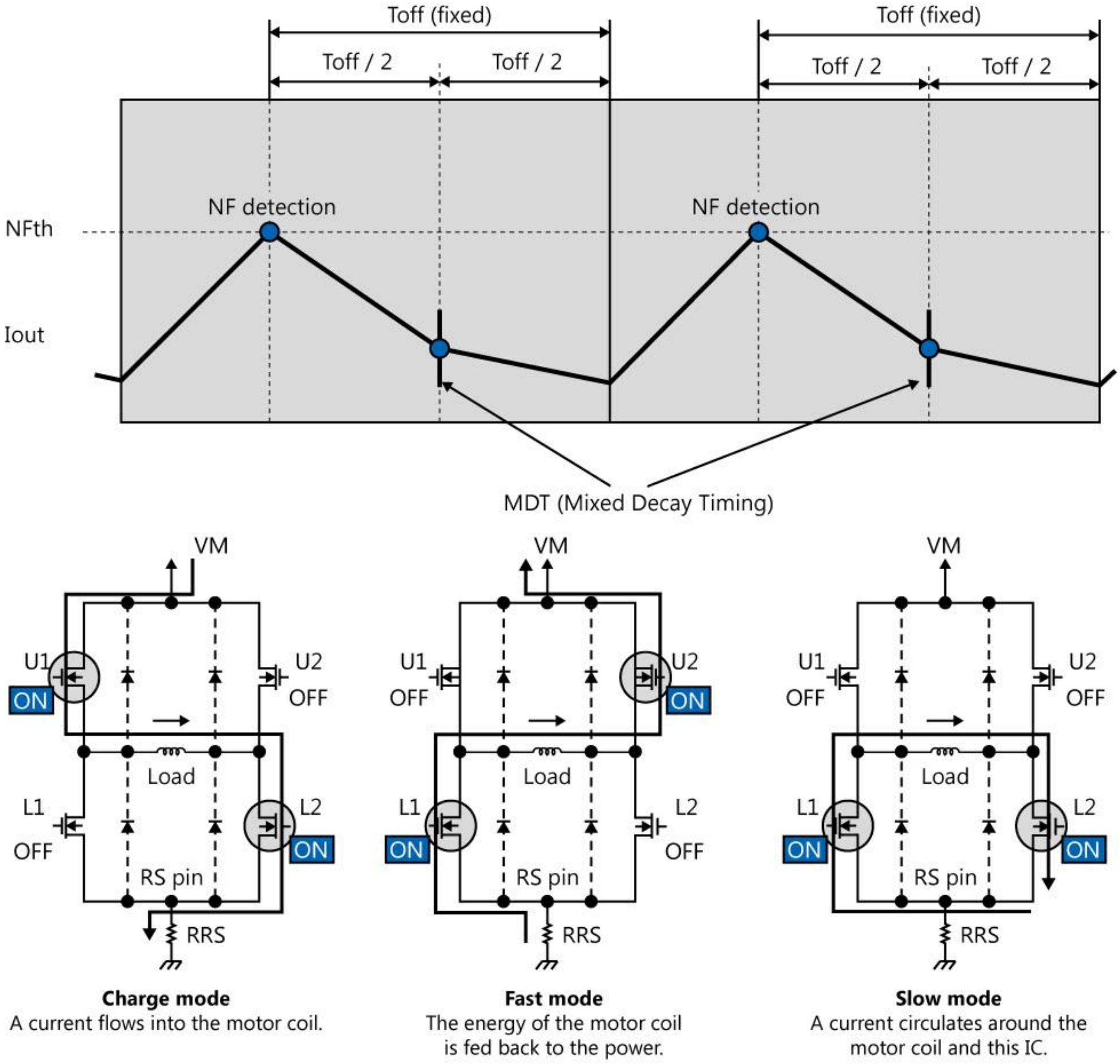

Figure 7: Mixed Decay Mode waveform and switch function in constant current control mode.

As well as being suitable for brushed DC motor control, two TB67H450FNG or TB67H451FNG devices can also be combined to implement the control of a stepper motor (figure 8).

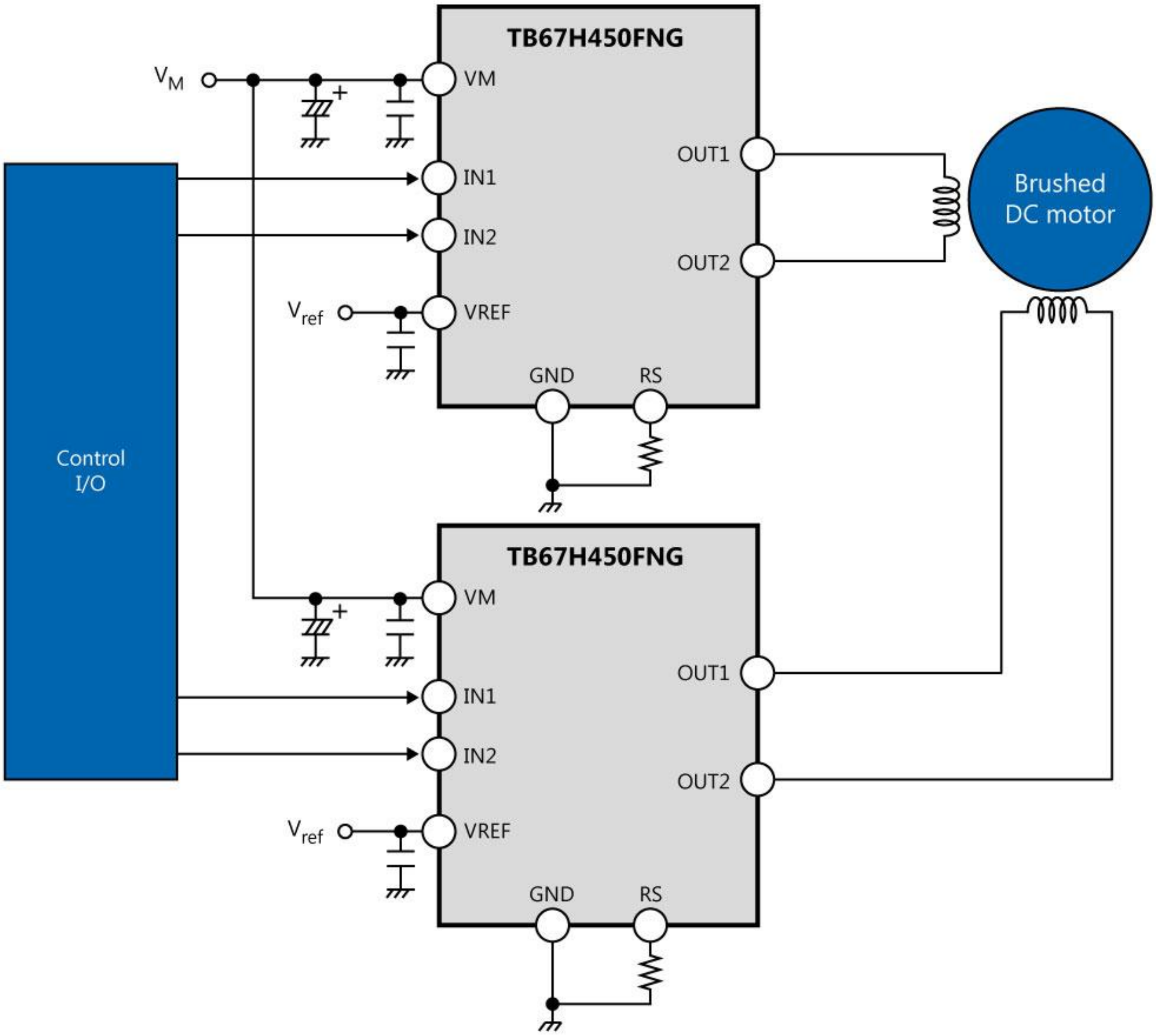

Figure 8: For the control of a stepper motor, two TB67H450FNG or TB67H451FNG can be combined to implemented the desired control.

Evaluation of both devices is simplified thanks to new development boards such as the DC Motor 14 Click from MikroElektronika (figure 9). Utilising the standardised pinning approach of their mikroBUS™ boards, they also offer a driver as part of their mikroSDK software package, allowing the device to be tested quickly and efficiently.

Figure 9: The H-bridge drivers can be quickly evaluated thanks to the DC Motor 14 Click board from MikroElektronika.

Summary

While technology seems to continuously move forward, the basics remain, with new integrated circuits replicating old classics making use of the advances offered. While the younger ‘Netflix’ generation may never have seen or used a VCR, the technology that made it possible remains as relevant today as it always was. The TA7291 must, sadly, be consigned to the history books. However, perhaps the TB67H450FNG and TB67H451FNG will take its place in all the text books and courses as the de facto H-bridge controller, introducing the next generation of engineers to the wonderful world of electronics and motor control.

Contact us to discuss incorporating our products and solutions into your design:
http://apps.toshiba.de/web/ContactUs/

toshiba.semicon-storage.com

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