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System-On-Chip Architecture Raises Performance Of Microstepping Motor Driver Designs

by Enrico Poli, Vincenzo Marano, and Giovanni Frezza, STMicroelectronics, Agrate, Italy and Schaumburg, Ill.

In applications where stepper motors are used for positioning, the microstep technique offers several advantages. It enables the motor to be positioned with greater resolution, a reduction in mechanical noise and vibration, and smoother motion.

In this article, a unique motor-drive architecture for microstepping will be presented. This architecture includes a novel approach to driving stepper motors based on voltage-mode control and an advanced motion engine controlled through an SPI interface.

The novel voltage-mode approach removes the need for sensing the motor's phase currents and eliminates the special efforts normally required in classic phase-current control systems to reach acceptable performance. In the end, this control method allows high microstepping resolution with an extremely reduced torque ripple.

This control system has been integrated in a single-chip device, called dSPIN (model L6470), which also includes an advanced logic core that implements a set of positioning and speed commands, stall detection, as well as a complete set of protection features, making it suitable for high-performance and high-reliability applications [1]. The device offers high performance, system-architecture optimization, and cost-effective design, reducing the MCU resources needed in typical motor control applications (Fig. 1.)

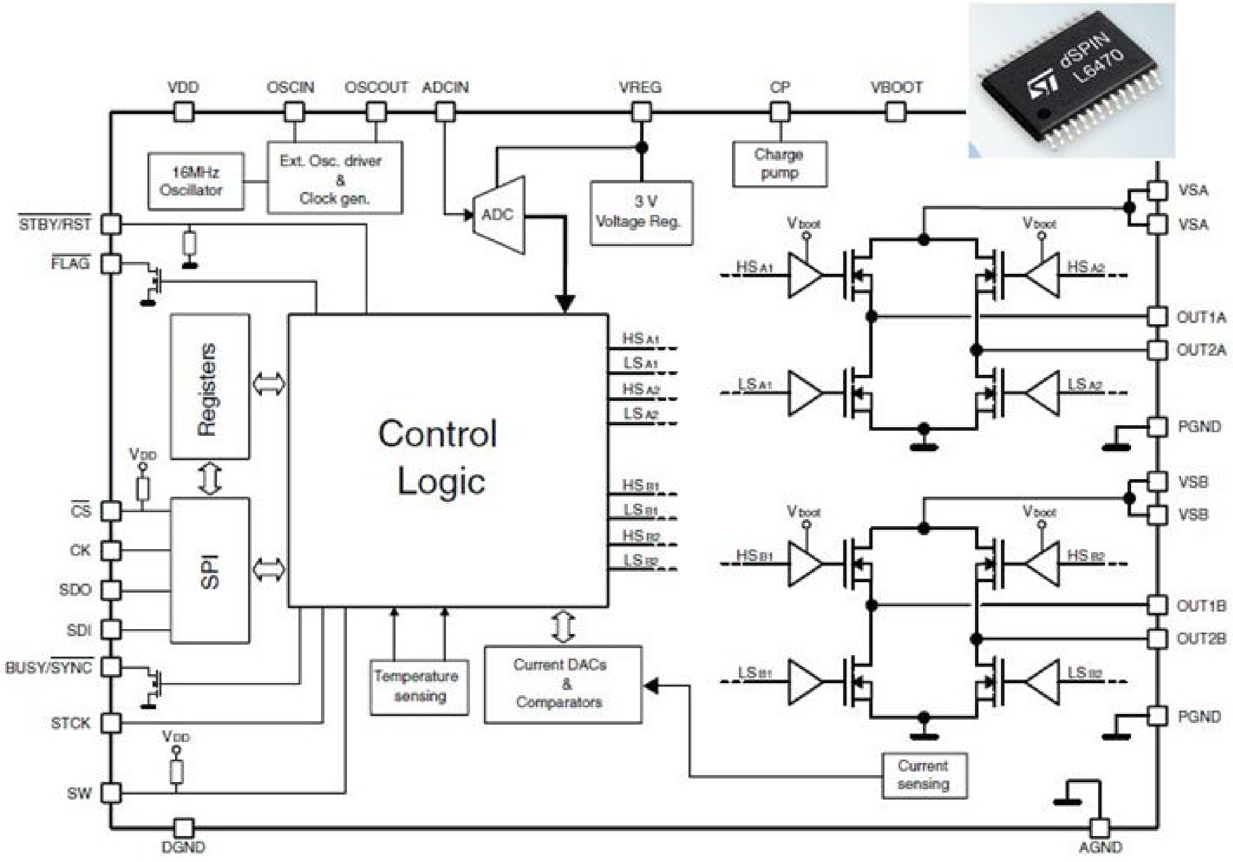


Fig. 1. Block diagram of the L6470 dSPIN fully integrated microstepping motor driver with motion engine and SPI. The L6470 is packaged in a 28-pin TSSOP, shown in the upper right hand corner of diagram.

Introduction

In most stepper-motor applications, the system is composed of a controller, which generates the signal sequence that implements the target step sequence, and a motor driver that provides the power to the motor phases [2, 3]. The proposed single-chip device is not a simple integration of the two functions: it implements an innovative solution that offers, besides higher integration, better performance than a combination of controller and driver.

The novel phase-current control system combined with an advanced logic core makes the approach presented here a revolution in stepper motor drivers. The integration in a single die of power bridges and logic, along with a high thermal performance package, heavily reduces the need for external components, offering a smooth, silent and high performing control in a simple and effective implementation.

System Architecture Optimization: Advanced Motion Engine And Deep Diagnostics

The main objective in developing this integrated motor controller was to heavily reduce loading of the MCU by the motor positioning algorithm and to greatly simplify the implementation of architectures with multiple motors, allowing a single MCU to control several motor drivers at once. The device can communicate with a host MCU through a high-speed SPI interface with daisy chain capabilities. In this way, a single MCU is able to manage multiple devices, and then multiple stepper motors, using a single serial interface.

The motion engine embedded into the logic core is controlled via behavioral commands, e.g. absolute positioning requests, and drives the motor to perform the movement according to the programmed speed profile boundaries. A complete set of commands is available: relative and absolute positioning (reaching a target position), speed tracking (reaching and maintaining a target speed) and motor stop sequences. Specific commands for management of mechanical position sensors are also available.

A typical command for relative positioning is shown in Fig. 2: the motor starts the movement at a minimum speed, accelerates until maximum speed is reached and finally decelerates to minimum speed before stopping. All speed-profile parameters (minimum and maximum speed, acceleration and deceleration slopes) are independently programmable across a wide range of values. The number of steps needed for the deceleration phase is calculated in real time by the device's motion engine, so a trapezoidal (Fig. 1A) or triangular (Fig. 1B) profile is automatically chosen according to movement length.

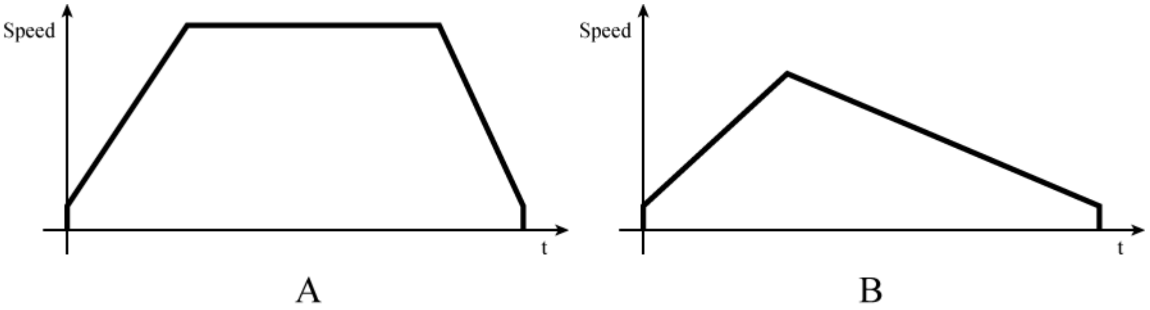


Fig. 2. Relative positioning

The dSPIN integrates a 22-bit absolute position register that keeps track of all movements performed—mapping the information on a circular axis in two's complement format as shown in Fig. 2. With a 200-step motor driven at 128 microsteps, the absolute position counter covers more than 160 motor revolutions; driving the same motor at 32 microsteps, the range increases to about 655 revolutions.

Using the information stored in this register, the device is also able reach a target absolute position by calculating the number of steps and the movement direction through a minimum-path algorithm (Fig. 3A-B). If a specific motor direction is preferred, the device can be forced to drive the motor in that way (Fig. 3C.)

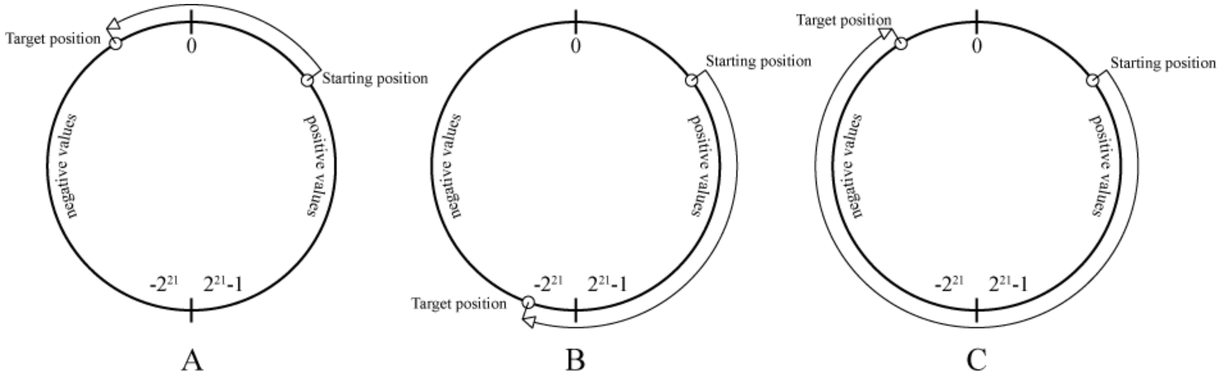


Fig.3. Absolute positioning.

Because the number of steps required for deceleration is calculated in real time, this command can be performed starting from a non-zero speed; the minimum path algorithm is also able to reverse the motor direction to reach a requested position (the number of steps needed to decelerate to zero speed is also accounted for in the calculation of path length.)

Speed-tracking commands can be used to drive the motor at a target speed. Target speed (value and direction) can be changed anytime, allowing the host MCU to perform complex movements (Fig. 4.) For example, an X-Y positioning system can be driven, making stepper motor speed proportional to the joystick input position. Even in this case, the loading of the MCU is minimum.

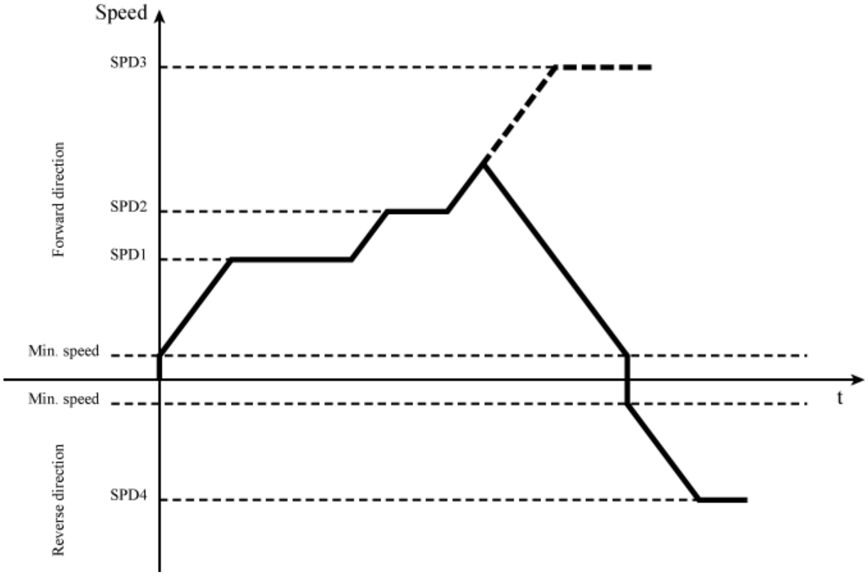
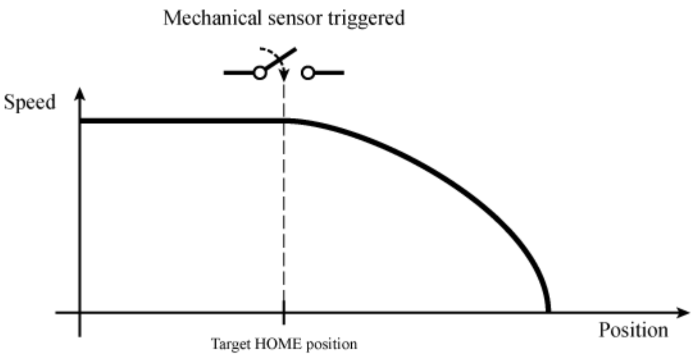


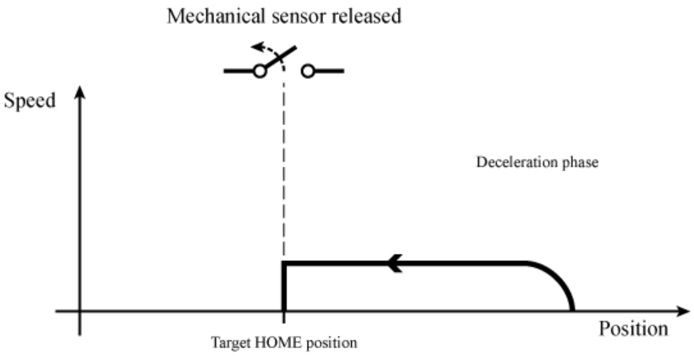
Fig. 4. Speed tracking

Stop commands interrupt the current motion and force the motor to stop. The device can stop the motor immediately (infinite deceleration) or using the programmed deceleration and minimum speed values.

The dSPIN makes position-initialization algorithms easier with external position sensor management commands and a dedicated input. The GoUntil command makes the motor run at a constant speed until the input is forced low (e.g. position sensor triggered); after that the device decelerates the motor to zero speed. The ReleaseSW command is complementary to the GoUntil one: it makes the motor run at low speed until the dedicated input is forced high; after that the motor is immediately stopped. After a GoUntil-ReleaseSW sequence, the mechanical position of the motor is exactly on the mechanical sensor triggering point (Fig. 5.)



GoUntil command execution



ReleaseSW command execution

Fig. 5. Position initialization.

Voltage-Mode Control: An Open-Loop Approach To Microstepping

The voltage-mode control is the core feature that makes the L6470 an innovation in stepper motor control. It has been invented and developed in order to control motors without sensing the phase currents and to considerably decrease the torque ripple and the motor vibrations caused by step changes.

The classic driving methods limit the phase current to a reference value using a comparator and a current sensor (usually an external resistor). This kind of control is the most intuitive but introduces some drawbacks: current ripple can be high and variable, introducing errors in the average current and harmonics that lead to uneven, rough motion. Keeping an acceptable control of the current can be challenging because of the back EMF on the motor. Current-control algorithms were made more and more complex, including techniques such as fast-decay and mixed-decay, in order to reduce the mentioned limitations.

With the introduction of microstepping, new limitations of current-control algorithms became evident: the analog circuitry and the control loop should be able to manage lower currents with higher resolution [4, 5], and those systems could only control the peak value of the motor current, making inevitable errors that result in positioning errors and poor smoothness.

To overcome all the issues of the traditional control systems, the voltage-mode approach directly controls the phase voltage in order to reach the desired current. This result can be obtained through the analysis of the stepper motor electrical model shown in Fig. 6.

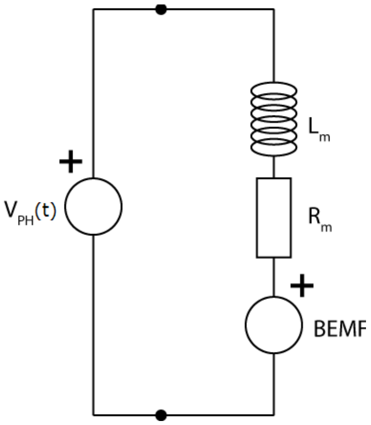


Fig. 6. Motor phase electrical model.

Applying the appropriate voltage sinewave to the motor phase, a current sinewave with constant amplitude is obtained without the need for sensing the current through a shunt resistor (Figs. 7-9.)

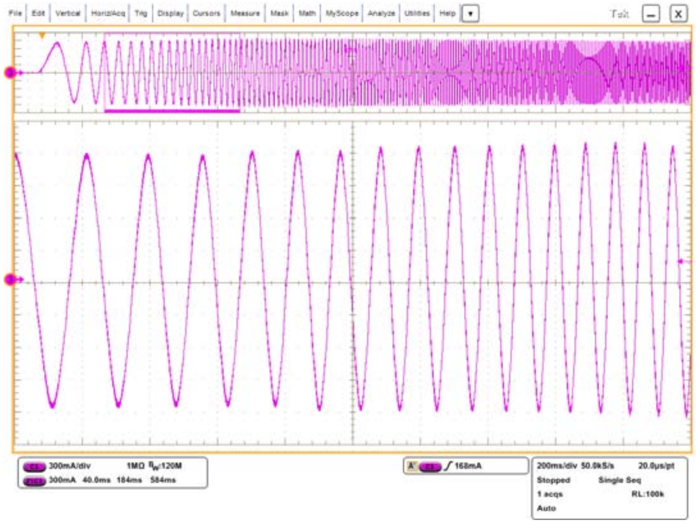


Fig. 7. BEMF compensation in voltage mode. The motor current amplitude is kept constant

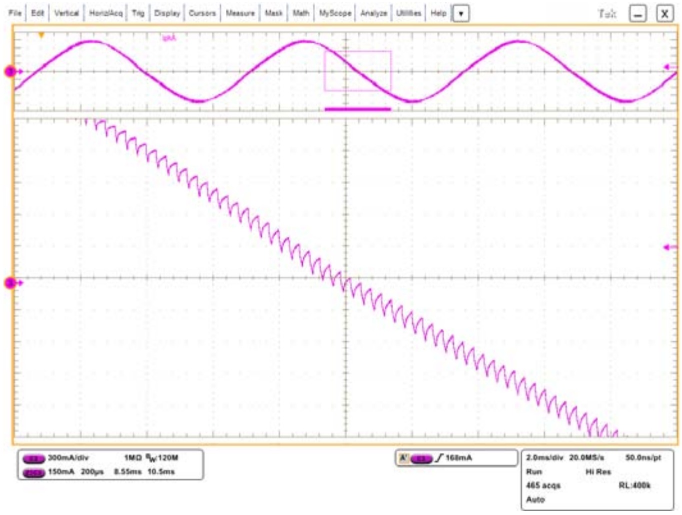


Fig. 8. Motor current with voltage-mode control. Detail of the zero-crossing region.

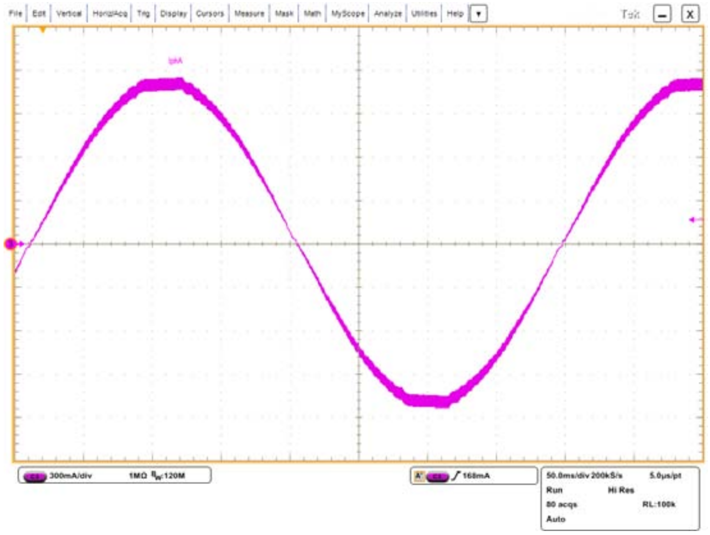


Fig. 9. Motor current with voltage-mode control at 10 steps per second.

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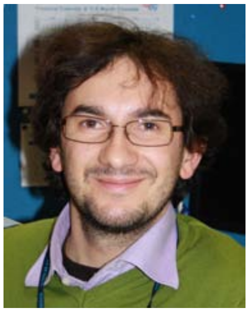
About The Authors



Enrico Poli is a senior application engineer for STMicroelectronics in Agrate Brianza, Italy. Since 2006 he has worked in the Industrial Business Unit, Motor Control Team, with a focus on monolithic solutions.

Vincenzo Marano is a system and application manager in the Industrial and Power Conversion Division, STMicroelectronics. He received a degree in electronic engineering from the Politecnico di Milano, Italy, in 2000 and then joined STMicroelectronics. His main focus is on motor drivers, MOS/IGBT drivers and industrial ICs. He is the author of papers and holds several patents on motor control ICs and architectures.

Giovanni Frezza joined STMicroelectronics in 1999 after he received a Master of Science Degree in physics from the University "La Sapienza" of Rome, Italy in 1998. After several years working on MEMS, advanced packaging and sensors as R&D team leader, he focused on industrial application-specific products in the Technical Marketing organization. Today, he is a technical marketing manager in the Americas region based in Schaumburg, Illinois, USA.